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A Sustainable Water Resources Management Assessment Framework (SWRM-AF) for Arid and Semi-Arid Regions—Part 1: Developing the Conceptual Framework

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Abstract: The evaluation of water resources management practices is essential for water usage decisions in regions with limited water resources. The literature provides numerous assessment frameworks, but many ignore the unique characteristics and conditions of some special arid and semi-arid regions, such as the Gulf Cooperation Council (GCC) countries, which lack any permanent rivers or lakes. Thus, this study, the first in a two-part series, seeks to develop a conceptual Sustainable Water Resources Management Assessment Framework (SWRM-AF). General and particular criteria explain how components and indicators were identified. The conceptual SWRM-AF provided here has four components (environment, economy, society, and infrastructure) and 24 indicators. Almost every indicator has been selected from the literature and is briefly explained and justified. This research presents, possibly for the first time, clear and straightforward directions for evaluating each indicator in colour-coded tables. To create a more holistic framework for arid and semi-arid regions, social indicators like "intervention acceptability" and environmental indicators for assessing the impacts of desalination treatment plants have been added to form a unique framework applicable to such regions. Therefore, the components and indicators of conceptual SWRM-AF could work collectively to aid the process of decision-making. The next phase is validating this framework using a participatory approach.

Keywords: water resources management; sustainable assessment; water sustainable framework; conceptual; arid; semi-arid; framework; indicator; indicator-based

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1. Introduction

The importance of water resources management (WRM) has increased during the last few decades due to rapid increases in global populations, not least in urban areas. Simply put, this means more supplies are required to cover the increasing demand for water from different end-users (and uses). However, water resources (WR) are finite, and in some regions, they are limited or scarce. Therefore, careful planning and the appropriate management of these resources are highly significant to avoid any future water crisis that might affect the current or future generation(s), including water shortages and deterioration in water quality.

This goal is similar to and parallel with the pursuit of sustainable development, where the satisfaction of the current generation's needs should not impact the life requirements of the next generation [1]. However, sustainability generally has a broad range of applications and many descriptions to be targeted as an overall goal. Meanwhile, the complex connection between culture and nature in terms of their spatial, temporal, and personal factors makes it challenging to have a single definition of sustainability that can handle particular environmental and social problems related to different contexts and local conditions [2]. Therefore, it would be more beneficial to individually treat specific fields (i.e., place-based) that share common features, such as WRM systems. This could be achieved by considering the sustainability assessment of such systems to be measurable or, more importantly, in the domain of specific, measurable, achievable, realistic/relevant, and tangible/time-bound (SMART) goals. Therefore, all elements of a SMART goal should be considered during the design stages of any practical sustainability assessment.

On the other hand, questions might arise about the meaning of "sustainability assessment" and why it should be used for WRM. Sustainability assessment is defined as ". . . a process to determine whether or not a particular proposal, initiative or activity is, or is not, sustainable" [3], and it should be used as "a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable" [4]. Thus, a WRM system includes several activities that need to be measured and evaluated to help water authorities and stakeholders choose the right actions and apply the best management methods to advocate sustainability.

While several Sustainable Development Goals (SDGs) are related, whether directly or indirectly, to the aspects of WRM, the purpose of this study is more aligned with SDG6, which aims to "ensure availability and sustainable management of water and sanitation for all" [5]. Hence, considering the sustainability assessment of WRM as a sustainable water resources management (SWRM) strategy is a must and would play a vital role in the flourishment of any society. Vice versa, ignoring such a strategy would cause numerous difficulties sooner or later and could exacerbate the WR situation year after year.

To develop and accomplish such a strategy, specific elements are required. One of these elements is an indicator—something that "helps you understand where you are, which way you are going and how far you are from where you want to be" [6]. Indicators help narrow down and sum up numerous data into one or few numbers and metrics that would be easier to follow by both stakeholders and decision-makers. Therein, metrics "give a unit of measurement to indicate progress against that criterion" [6]. Indeed, using indicators would help measure, assess, and inform the sustainability level of a complex system [7,8], such as SWRM, in a less complicated way. Nevertheless, in the case of a WRM system, indicators often represent different unrelated aspects of the system. Therefore, they would require a more extensive umbrella akin to a structured framework [9].

Moreover, developing a bespoke indicator-based water sustainability framework (IBWSF) can be helpful in the following:

1. Containing all elements of WRM that can assist in the improvement of WR [2,10–13];
2. Providing definitions for the variables included in the framework and drawing attention to significant connections between them [14];
3. Helping in identifying and understanding the most critical issues by both users [14] and decision-makers, which is vital for the process of prioritising tasks and identifying trade-offs [2,13];
4. Communicating the current status of WR to a bigger group of stakeholders [12,13];
5. Where applicable, setting benchmarks—where a benchmark is "a quantification that reflects a desired level of performance for an indicator" [6].

For the aforementioned condition and benefits, different IBWSFs have, in the past, been developed for several purposes related to WRM, not least as an evaluation tool. These indicators can be classified as measuring the conservation level of the environment [15–17], the socio-economic impact [18–20], or the effectiveness of the physical factor (i.e., infrastructure) [21–23]. Examples of indices that prioritise the environment are either those with a target of comparing the ecological health of the freshwater system(s) [24–27] or those that aim to quantify the environmental impacts of material inputs and outputs by using life cycle assessment methods [28–30].

Another preferred method that has been developed is to combine a range of indicators in one framework that aims to assess the overall level of sustainability of WR [2,31,32]. This method mainly considers the assessment of all three main pillars of sustainability (i.e., environment, economic, and social). This framework's purpose is similar to sustainable development's goal, in that it seeks to find the right balance between these three pillars [33,34];

it is the "triple bottom line" (TBL) concept, where equal significance should be given to the environmental, social, and economic aspects during the decision-making process [3]. Therefore, the framework provided here focusses on relating each indicator to one of the three pillars of sustainability, such as other previous frameworks plus the physical factor represented here by the infrastructure pillar, which is essential to any WRM system.

Conversely, one might question the necessity of developing a new sustainability framework for WRM, given the abundance of existing frameworks in the literature, such as those included and discussed previously [35]. The simple answer is that it is known that each place, region, or continent has both common and unique features related to the weather, geographic location, culture, economic condition, etc. Indeed, the mutual specifications of some particular regions can help use a previous assessment framework to some extent to obtain or improve their SWRM system. However, this approach may not be feasible for areas with markedly distinct and challenging conditions. Similarly, Juwana et al. [13] reported that the successful application of existing WRM indices does not mean they are highly applicable to be reused in a different place; therefore, developing a unique framework becomes necessary to fit with the natural and socio-economic characteristics of that region.

For example, some arid and semi-arid region (ASAR) are basically deserts in nature without any permanent rivers or lakes. The term arid is used for areas that receive an average rainfall < 100 mm/year and experience high temperatures [36], and the term semi-arid is used to describe the climate of regions that receive an average rainfall in the range of 250–500 mm/year [37]. Moreover, both regions are characterised by potential evapotranspiration that is higher than the precipitation [38], and they are subjected to frequent and severe droughts and infrequent but significant floods [39]. In addition, these regions are naturally considered to be the most water-stressed areas in the world, where groundwater (GW) is the primary water resource [40]. Hence, all these factors show the importance of designing a bespoke framework that can enhance and/or maintain the sustainability of WR among countries in these regions.

Aim and Objectives

This study aims to develop a Sustainable Water Resources Management Assessment Framework (SWRM-AF) for some ASAR with harsh climate conditions, such as the Gulf Cooperation Council (GCC) countries. To discover the importance of this aim, an illustration of the WRM situation in GCC countries is given first (see Section 2). Then, general and specific guidelines are required and would be explored and presented, as the first objective, to help in understanding the rules that govern such a process (see Section 3). The methodology used to reach this goal needs, in general, two stages:

- Stage One: searching the literature to identify appropriate components, as the second objective, and indicators, as the third objective, that suit the temporal and spatial conditions of the understudied region [11,13,41,42]. The suggested set of components/indicators that results from this stage is sometimes called the conceptual framework (see Section 4).
- Stage Two: presenting the conceptual framework with its selected indicators and metrics to the stakeholders who are in charge of evaluating (i.e., choosing between keeping, adding, removing, and changing) any of these indicators, distilling them down to an appropriate set as required [12,43–45]. This is the refinement stage and usually ends with the framework's final version.

To achieve the first stage, a selection process based on checking the literature review and data availability for components and indicators is required as a first step in the selection process (see Section 4.2). Then, a brief description with justification for each indicator is provided to explain the relevancy (see Section 4). The second stage is based on the participatory method that needs the opinions of both experts and stakeholders about the output of the first step. This stage would work as inclusion and exclusion criteria in parallel to assigning specific weights, and it is an essential part of the validation process.

This paper focusses on Stage 1—developing a novel and conceptual framework; Stage 2 is the focus of a forthcoming paper.

2. Water-Related Issues in Gulf Cooperation Council (GCC) Countries

The GCC countries are located on the southwest side of the Asian continent, which is considered as an ASAR. Moreover, based on the Köppen–Geiger climate classification, the prevailing climate of these countries is described as arid (B), desert (W), and hot (h) [46]. GCC countries belong to Arab countries, which are located in a hyperarid to arid region (<0.2 on the Aridity Index (AI)) with pockets of semi-arid areas (between 0.2 and 0.5 AI) [47]. Aridity is defined as "the degree to which a climate lacks adequate, life-promoting moisture" [48].

On the other hand, the GCC countries are part of what is known in the geopolitical area as the Middle East [49]. More specifically, they are located between latitudes 15° and 30° North and longitudes 35° and 59° East. The GCC countries constitute the biggest part of the Arabian Peninsula, which is known to be surrounded by seas from three directions. One of these seas is the Arabian or the Persian Gulf, to which the name (i.e., Gulf) of GCC countries refers because each has a direct coast. These six countries are the Kingdom of Saudi Arabia (KSA), United Arab Emirates (UAE), Oman, Qatar, Kuwait, and Bahrain. The map of GCC countries is shown in Figure 1.

Figure 1. Map of GCC countries and their capital cities [50].

The water situation in the GCC countries is overly critical since most of their lands are desert-based with limited conventional WR. This inconvenient situation can be seen by the small individual share of renewable water that does not surpass 500 m^3/year, while the rainfall is rare and irregular, with an average of around 100 mm/year [51,52]. Moreover, not only is the low rainfall rate an issue, but it combines with a high evaporation rate [53] exceeding 3000 mm/year, making the conditions of having a perennial surface water system impossible to take place [54]. Lastly, the per capita freshwater availability has dropped by almost 30% during the past two decades overall in the Middle East, causing a water scarcity situation [55]. Therefore, careful consideration for the planning and management of WR in GCC countries to ensure that they are sustainable is significant.

2.1. Water Supplies

The main conventional WR in GCC countries is GW, which is classified as non-renewable GW (NRGW) (or deep GW) and renewable GW (RGW) (or shallow GW). In addition, surface water (SW) is the second conventional WR that only provides a very low quantity in most GCC countries. Both types of GW represent the highest share (from 77.7% in 2017 to 70.5% in 2020) among WR in GCC states in supplying water for all purposes, while SW represents the lowest rate, which was 0.5% in 2017 and increased slightly to 0.8% in 2020 [56]. Moreover, the yearly rate of SW runoff is very rare or does not exist in three GCC nations (i.e., Kuwait, Qatar, and Bahrain), while the other three countries received considerable amounts starting from 150 to 3210 million cubic meters (MCM) per year (MCM/year) [57]. Thus, since the focus of this framework is on all GCC countries, less attention might be given to SW.

Furthermore, NRGW is fossil water that is exceedingly difficult to replenish under the current hydrological regime [58]. In general, NRGW provided the largest share (approximately 67%) of water supply in the period from 2012 to 2020 if we take five out of six GCC countries as one block region [57]. Oman is the exception by using more renewable water, SW and RGW, than NRGW [57]. Hence, the continued dependence and high use of NRGW can only ever be considered a temporary solution; moreover, it is far from sustainable for GCC countries. Furthermore, with the depletion rate (i.e., the ratio of conventional WR withdrawal to available WR) of GCC countries being so high in 2020, the remaining lifespans of available WR are assumed to be between 50 years for Oman and <9 years for UAE, Bahrain, and Kuwait [57]. Therefore, with the advent of climate change and further population growth, it will be difficult for GCC countries to withstand more extended periods, not least if they continue to rely only on conventional WR.

On the other hand, the discovery of oil under the land of GCC countries during the 1970s made these countries economically prosperous, which led to a momentous change in their lifestyle and living conditions. As a result, the total population of GCC countries increased dramatically between 1960 to 2020, from 5.34 million to 58.43 million [59], as seen in Figure 2. The increase rate in these 60 years was 994.5%, while the average yearly increase rate was 16.6%. This percentage of population growth is considered as one of the highest on a global scale [60]. Indeed, it was necessary during these years to deal wisely with the increased demand for WR to ensure that these countries could preserve their flourishment while their citizens could survive.

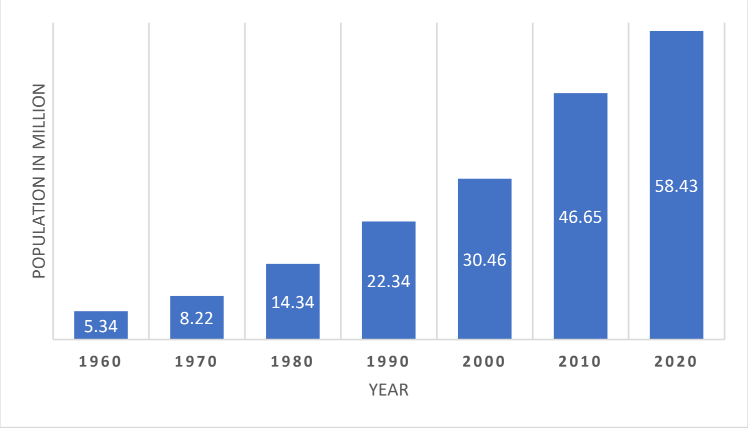


Figure 2. Total population of GCC countries between 1960 and 2020.

Therefore, the need for extra water supplies was necessary for GCC countries to cover the gap between the supply and demand of water. Thus, the establishment and use of non-conventional WR, such as desalination water (DW), was one of the very crucial solutions for such a situation. Globally, many countries cannot afford or try to avoid DW since it comes with high economic costs, but this has, thus far, not been an issue for the

GCC countries. Historically, the first brand-new desalination facilities were built in Saudi Arabia, Kuwait, Bahrain, and Qatar in the 1950s [61]. Nowadays, the six GCC countries together are one of the world's leading producers of DW in terms of quantity, as we know that more than 60% of the world's total desalination production capacity is contributed by the GCC nations [62]. However, while the social aspect has been satisfied by this WR, some economic and environmental impacts [63–66] require special attention to achieve the balance between all three pillars of sustainability.

The second non-conventional WR is treated wastewater (TWW) or, as some GCC countries refer to it, "Renewed Water" (RW). Sometimes, this resource is difficult to use directly for the domestic sector from society's point of view by looking at its origin [67]. However, it is still one of the strategic solutions in regions with limited WR, like ASAR and GCC countries [68]. Not only this, but using TWW can benefit all three pillars of sustainability. This is because it costs less, which is better for the economy, and contributes positively to preserving the environment from the discharge of polluted water [69], and more importantly, in terms of WRM, it can help save other conventional WR for society. The use of TWW in GCC countries is designated for several reuse applications such as landscaping, recreation, recharging depleted aquifers, and irrigation of parks and plants [57,62] that mainly are not producing any edible fruits or crops. This type of irrigation is called restricted irrigation.

In summary, it can be said that there are five main water supplies in the GCC countries. Three are conventional WR (i.e., NRGW, RGW, SW), while two are non-conventional WR (DW, RW). Although the consideration of these resources is significant, very few IBWSFs in the literature have taken them into account in their indicators.

2.2. Water Demand

GCC countries are classified globally by the World Resources Institute (WRI) as among the most stressed in terms of WR [70]. Moreover, the high population growth in these countries, which means bigger demand, made them consume vast amounts of water that are not proportional to their water provision capability. The total water consumption between 1980 and 2020 is shown in Figure 3, where the biggest share was from Saudi Arabia, UAE, and Oman. This is understandable since these countries have the largest area and population compared to other countries, with the exception of Kuwait, the population of which was higher than that of Oman in two periods (i.e., 1980 and 2010). However, Oman still consumed more water in all periods because its agricultural and industrial water use is bigger [71]. Overall, it should be noted that the GCC countries' primary water consumers or sectors are agriculture, domestic, and industrial.

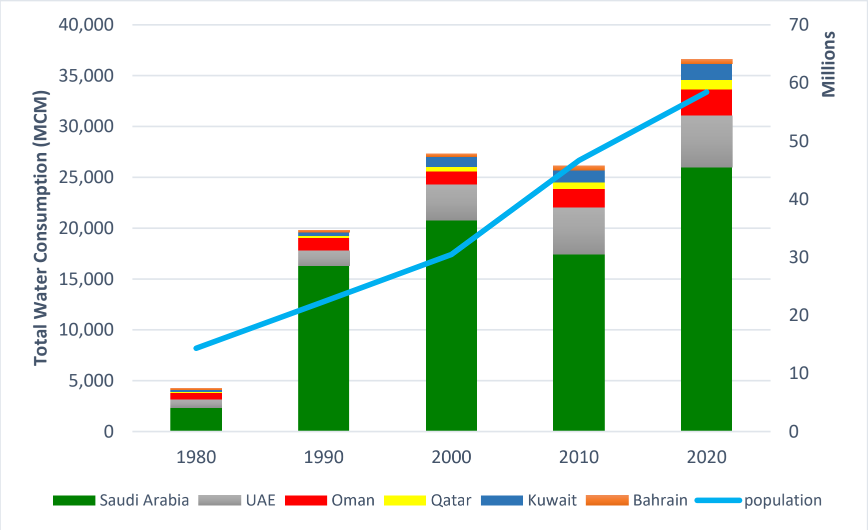


Figure 3. Total water consumption and population in GCC countries from 1980 to 2020 [54,72,73].

The agriculture sector has the largest share of the water demand in GCC nations, with an average percentage of 70% [74], similar to the global trend of 70% for agricultural water use [75]. The vast water consumption by the agriculture sector is because some of these countries had policies to strengthen food security [74], while others, such as Saudi Arabia, sought, by using their lands and natural resources, food self-sufficiency as a key strategy [76,77], However, little consideration was given to the long-term impact of these policies and strategies on water availability and security. Hence, enormous quantities of NRGW and RGW, which were and still are the major water supplies in some GCC countries for matching this sector's demand, were consumed. Figure 3 above indicates the effects of these policies and strategies on water consumption compared to the population growth between 1990 and 2000.

For example, several programmes for letting the agriculture sector flourish were introduced during the 1980s in Saudi Arabia. At the time ground surveys estimated that there were 500 billion m^3 of GW reserves, mostly non-renewable [78]. Following this trend, it was estimated that the extraction of GW between 1980–1999 in Saudi Arabia to support agricultural activities was 300 billion m^3 [78], with wheat being exported abroad [79]. Thus, it was not only a mismanagement issue of WR in a region with limited resources to cover the internal need for food security, but also it was going beyond to sell the product of this scarce WR to other countries. This promoted a review of farming policies between 2000 to 2004 because of severe impacts on WR, such as the depletion of GW [80], which led to a decree to gradually phase out wheat production yearly (by 12.5%) starting from 2008 [81].

The other primary water user is the consumption of the domestic sector, where many of the GCC countries, surprisingly and contrary to their limited conventional WR, are among the highest in the world. This fact can be proven by checking the daily water consumption per capita and comparing it to other countries. An estimation of the average annual per capita water use of GCC countries was 560 L/capita/day, which is far away from the global average of 180 L/capita/day [62,82]. Recently, the dominant water supply for domestic or municipal demand has been DW [54], which, as previously stated, is known to be expensive and lacking environmental credentials, not least with current technologies/processes used. This high dependence affects the three pillars of sustainability and needs careful consideration and attention.

The industrial sector is the third and last water user in the GCC countries with the lowest percentage or share (i.e., >10%) among all water sectors or users, as can be seen in Figure 4 below. This might be because the industrial sector in general is not that big in most GCC countries. Another observation that can be realised in Figure 4 is that the consumption of water by the agriculture sector has been fluctuating and overall declining over the last 25 years, while the municipal (or domestic) sector has continued to increase. Meanwhile, the main focus of the conceptual framework provided here is on the assessment of the sustainability of WRM within the domestic sector. Whilst the agricultural sector and industrial sector are important, they are beyond the scope of this research.

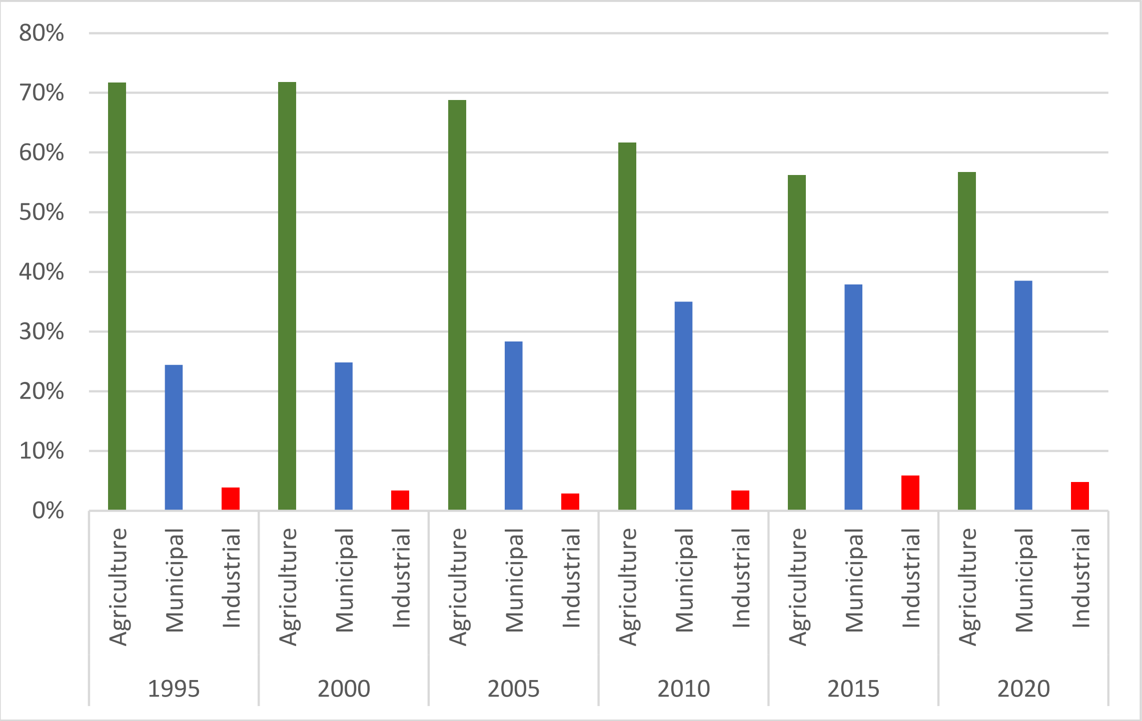


Figure 4. The total share of each water sector in GCC countries from 1995 to 2020 [83].

3. Guidelines for Developing the SWRM-AF

Having illustrated the water issues of the GCC countries, a case has been made for the development of a unique indicator-based framework to assess the sustainability of their WRM. From here on, this will be referred to as the SWRM-AF.

Firstly, this research follows the idea that the development of SWRM-AF should be based on combining and integrating existing information, including WRM theories, principles, and guidelines [84]. Thus, considering the existing scientific base is essential to ensure the framework's reliable foundation and keep the knowledge wheel moving forward. Meanwhile, such a study's uniqueness (or novelty) comes from considering a new area, field, or region where a framework should be appropriate and fit its context. Not only this, but the second contribution of this study is to provide a framework that can be easily replicated in order to be used in different areas and case studies because it was built in a clear and understandable way.

3.1. General Guidelines for Developing an Indicator-Based Framework

Before going further, it would be better to know that this framework should generally follow guidelines that experts previously introduced and have found to be effective.

Initially, it is essential to take into account and link the three dimensions of sustainability (i.e., environmental, economic, and social) [85] that are common to a host of water-related frameworks [86–88]. Adding the technical side [89,90] or more precisely infrastructure aspect [91] either explicitly [2,12,44,92,93] or implicitly [41,94–96] to these three pillars is no less common. Although it is essential to evaluate the whole sustainability of the WRM system, an effective SWRM-AF would ensure integration and perhaps equal treatment among the above three main pillars of sustainability in addition to the infrastructure that can be considered as the main connection between the supply and demand sides of these delicately balanced scales. This combination is shown in Figure 5, where having infrastructure as a component would play a vital role in checking water utilities' overall management and continuity ability.

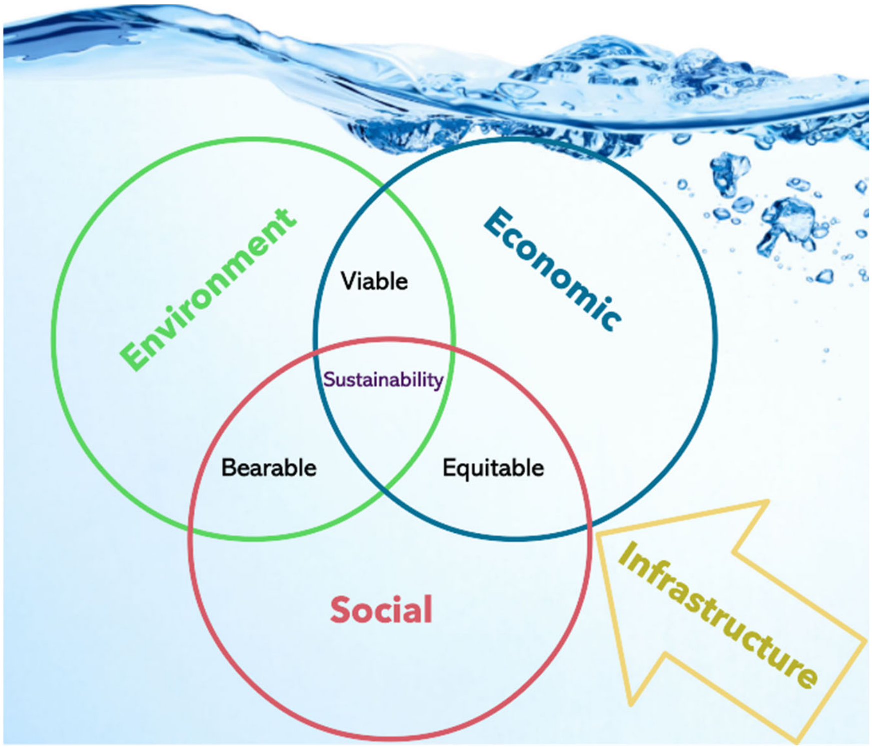


Figure 5. Intersection of pillars of sustainability plus infrastructure for WRM.

Regarding the structure of SWRM-AF, Alsaeed et al. [35] found that many IBWSFs in the literature have seven important mutual elements that make them clear and easily reusable. These elements, with their descriptions and functions, are summarised in Table 1. The first three elements are essential to know what this framework represents within its clearly defined boundaries. The next three elements can be categorised under the umbrella of the calculation process. The last element can be considered as the aim of making a framework, which is to provide a value that is easy to understand by different stakeholders and represents the overall situation (i.e., level of sustainability) or performance of the system.

Therefore, having these seven elements identified clearly would be helpful for other researchers and decision-makers to reuse or apply the framework in additional and different cases. The first element (i.e., indicator) in Table 1 is considered the cornerstone or base of many sustainable water frameworks. One of the guidelines within the literature stated that a sustainable framework should consist of simple and straightforward indicators that work together as a set, which includes enough data that could be helpful in the decision-making process [97].

Another guideline suggested that the total number of main indicators should not be small, which could result in wrong conclusions being drawn and misleading policies and/or decisions being made [14]. Vice versa, a large number of indicators is not preferred either since it could lead to the following:

- The complexity of the entire process of application and interpretation [98,99];
- Making gathering and preserving data more administratively expensive [14].

Therefore, it is worth knowing the right number of indicators that should be in place during the development stage to avoid the above obstacles. One of the suggested methods is to check the number of indicators included in the previous frameworks. This work was performed in an earlier study, which found that an appropriate number of indicators should be between 17 and 18 [35]. However, since this paper is about developing the conceptual framework, the number of indicators suggested here is higher. Stage 2 (forthcoming paper) is used to thin these down to a more appropriate number. A brief overview of the process and the philosophy behind it is captured below:

The thinning process in Stage 2 accords with an important guideline, referred to as the third Dublin principle [100], which emphasises the significance of a participatory approach for any development for WR. Similarly, having a framework to enhance the sustainability of any form of WRM, which is one of the crucial goals of integrated water resources management (IWRM), requires the participation of stakeholders in such a process [101–104]. As a result, stakeholders' participation in water management processes has been promoted by several institutions to aid in decision-making [105]. The advantage of a participatory approach is that it can create formalised and shared representations of reality through a deliberate learning activity that draws on stakeholders' implicit and explicit knowledge [106]. Thus, it would be essential to consider the involvement of stakeholders in the designing process of this SWRM-AF to at least gain their trust that their thoughts are appreciated.

Table 1. Description and function of the seven main elements of the indicator-based framework.

No.	Element	Description/Function
1	Indicator	• Indicate the measurement of something; • Used to present data (quantitative or qualitative); • Can be combined to represent the same component or category and can also be split into sub-indicators.
2	Benchmark	• The threshold or interval needed to measure the performance of an indicator; • Can be either maximum and minimum value, or baseline and target.
3	Application scale	• To know to which extent the framework can be reused or reapplied; • Whether it is for community, local, regional, national, or global scale; • Usually, each scale would require different data for the indicators.
4	Normalisation method	• To obtain equivalent component values, which can be aggregated or compared, for each set of indicators even with different unit values; • Most used methods based on data type of indicators are as follows: (1) Continuous re-scaling (usually better with quantitative data); (2) Categorical scaling (better with qualitative, but can serve both).
5	Weighting scheme	• A weight is a value that represents the importance of each indicator; • Can be equal or non-equal based on different criteria; • Usually, it is a fraction, where all weights under the same category should be equal to 1.
6	Aggregation technique	• It reflects how the summation of the product of indicators and their weights should be performed; • Can be arithmetic (most common) or geometric base.
7	Final index value	• Significant to make the result of the whole framework easy to understand by a range of different stakeholders; • Represents the final and most important output of any framework; • Usually, it is a number from 0 to 1 or 100.

Nevertheless, the initial output of this study, which is the conceptual framework, does not include or require stakeholders' participation [13], since this occurs in Stage 2 [43]. The second stage is refinement, where the stakeholders can add, remove, and modify indicators forming the conceptual framework. Not only this, but the stakeholders can be involved in assigning weights for each component and indicator; this stage is out of the scope of the current article.

While these guidelines can help shape or form a practical framework, they are still general. Therefore, other guidelines regarding the needed criteria for selecting indicators, and more precisely in the context of ASAR, should be included.

3.2. Specific Guidelines for the Selection of Indicators in ASAR

While the characteristics of indicators that should be examined before integrating them in a sustainability assessment framework are presented in Table 2, it is not anticipated that each indicator will satisfy all of these requirements as their goals may vary depending on the context and scope of use [107]. Thus, wherever possible, it is pertinent to take these guidelines and characteristics into account in the process of indicator selection.

Table 2. Desired characteristics of global sustainability indicators.

Desirable Characteristic	Description
Sensitive to change over time	To investigate the critical variations and trends of an indicator, its data over different time intervals should be available for collection and analysis
Sensitive to change across space or within groups	To observe the reality of socio-economic situation by indicators over a geographic region or within a population, the distribution of conditions among different places or groups should be reasonably considered
Predictive or anticipatory	The ability of the indicator to forecast unsustainable risks is helpful to eliminate their effects and to deal with their signs or warnings as early as possible
Availability of reference or threshold values	To evaluate the level of performance of sustainability indicators, it is critical to have threshold or benchmark values working as a reference for these indicators
Unbiased	To avoid any misrepresentation of results occurring because of the selection of biased measures. While developing fully unbiased indicators within different contexts is difficult, considering universal standards, such as life expectancy, would be better.
Appropriate data transformation	To compare values, raw data alone cannot be helpful sometimes, but converting them to rates or ratios based on appropriate relations would give more insight and meaning to the value
Integrative	Different indicators under one component shall have a common linkage to integrate various measures that can smoothly assess sustainability to form a logic index
Relative ease of collection and use	The collection process of indicators' data should not require excessive time, effort, and cost, while the interpretation and presentation should be clear and straightforward for decision-makers

On the other hand, specific criteria should be considered to select indicators that belong to the SWRM-AF for ASAR, such as GCC countries. While many indicators can be selected from the literature, it is vital to check whether they are applicable to the context of ASAR lands that are desert in nature without permanent rivers or lakes. This is because several frameworks were designed mainly to deal with river basins [11,12,42,45,95,108], and even if river basins are located within ASAR, their conditions are different to some extent. Hence, it would not be meaningful to consider many of their indicators during the selection stage. Likewise, the final version of the SWRM-AF is suggested to be flexible and applicable in many aspects for reuse with any city, region, or country in ASAR with similar conditions to GCC countries. Definitely, some changes would be required; not least, the benchmarks of the framework would need to be changed to match the targets or specifications of these new areas.

Another essential criterion is that the selection stage should give special attention to the common water scarcity situation in these regions by having specific measures. For example, measuring the pressure of water users (i.e., water stress) on WR, where any increase in the water demand usually leads to the water scarcity situation being worsened, needs to be considered. This includes any other factor that might affect the already limited WR such as water leakage, which exaggerates water scarcity.

The last specific criterion is that the indicators shall be comprehensive by including all WR, whether from renewable, non-renewable, conventional, or non-conventional sources. This is because several frameworks mainly focussed on renewable and conventional WR [12,45,95], without considering other sources of supply. However, the case is different within some ASAR that depend on all WR to satisfy the overall demand, which requires special treatment and consideration during the evaluation process. Not only this, but the impact of using non-conventional sources, whether positive or harmful to the SWRM, needs to be measured within these indicators. Thus, a clear insight into the level of sustainability of the WRM system can be evaluated and observed.

4. Developing the Conceptual SWRM-AF for ASAR

4.1. Brief Description of the Mechanism of the Framework

It would be meaningful to explain or describe briefly first what the IBWSF is. A visual illustration of how the final IBWSF should look with the direction of the process of calculations is presented in Figure 6. In general, it may be said that the process of obtaining the final framework indicator value is made up of three essential parts:

1. A set of headline categories (components);
2. A set of supporting indicators for each component;
3. A set of second-order and possibly third-order sub-indicators [35,109]. [Sub-indicators do not exist in all frameworks; they only exist when some indicators are not sufficient alone because of a diverse set of measures and available data.]

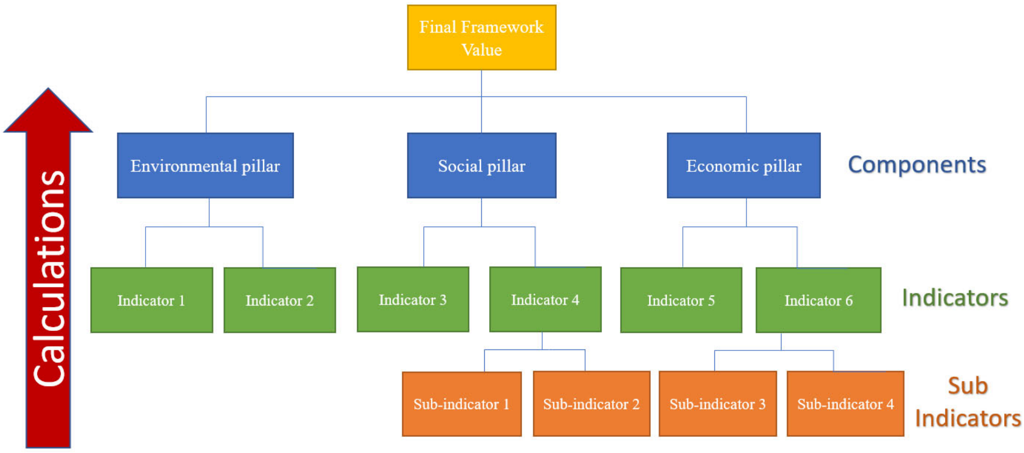


Figure 6. Visual illustration of an IBWSF.

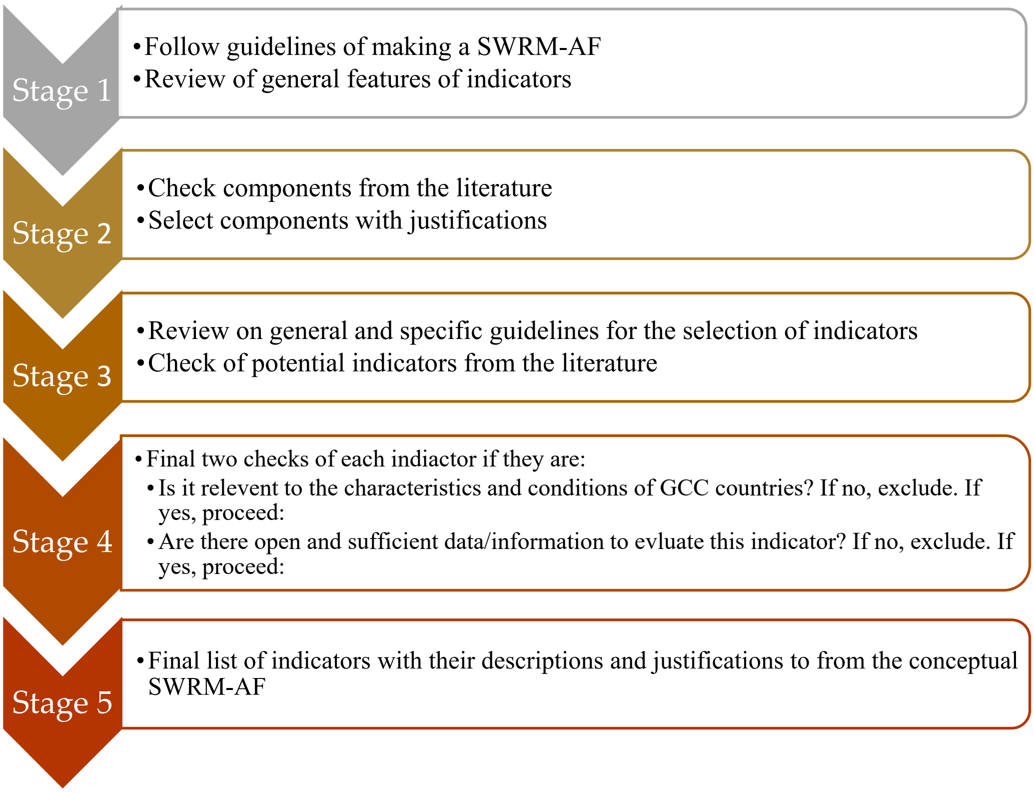
Also, as seen in Figure 6, the framework is organised hierarchically. At the same time, the calculation direction is a bottom-up approach following the red arrow to obtain the final framework value (i.e., level of sustainability). Initially, sub-indicators should be normalised, weighted, combined, and averaged to reach a value for the above indicator. Then, the exact process is repeated for indicators that belong to the same category (i.e., component). Finally, the average of all components times their weights will present the final framework value. As a result, the sustainability level of this framework can be measured theoretically and hence improved by knowing the system's weak points and working on enhancing them. Regarding the other selected main elements from Table 1 for our framework, these include the consideration of the following:

- Application scale: national scale (i.e., specific for GCC countries);
- Normalisation method: continuous rescaling for indicators with quantitative data and categorical scaling for indicators with qualitative data;
- Aggregation technique: arithmetic (i.e., average);
- Final index (or framework) value: from 0 to 100.

The last two elements (i.e., benchmark and weighting scheme) will be based on the participatory approach that will validate the framework and be presented in the second part of this research. The benchmark for indicators with quantitative data will be given for only the final list of indicators to save the time and effort required to find them. This is because some selected indicators in this version of the framework (i.e., the conceptual version) will be eliminated based on the evaluation of experts in Stage 2. Similarly, those experts will decide whether the weight of components and indicators should be equal or non-equal.

4.2. Stages of Development

Similar to the methodology of developing previous conceptual frameworks [13,110], the development of the SWRM-AF will follow the steps manifested in Figure 7 below.



- Follow guidelines of making a SWRM-AF
- Review of general features of indicators

- Check components from the literature
- Select components with justifications

- Review on general and specific guidelines for the selection of indicators
- Check of potential indicators from the literature

- Final two checks of each indiactor if they are:
  - Is it relevent to the characteristics and conditions of GCC countries? If no, exclude. If yes, proceed:
  - Are there open and sufficient data/information to evluate this indicator? If no, exclude. If yes, proceed:

- Final list of indicators with their descriptions and justifications to from the conceptual SWRM-AF

Figure 7. Flowchart for the development of the conceptual framework for ASAR.

The details of the first stage, which is the review of guidelines and features of indicators, were covered in Section 3.1. The second stage is to select appropriate components and was facilitated by investigating several indicator-based frameworks (for further details, see [35]). Indeed, since the framework is designed to evaluate the SWRM, the main components consist of the three pillars of sustainability plus the infrastructure.

The third stage reviewed the guidelines needed to select appropriate indicators for the SWRM-AF and required an intensive literature search of the many indicators that already exist. This process is helpful to build upon where the others have ended and benefit from the cumulative knowledge created. Nevertheless, the majority of potential indicators to be checked were mainly from three sources:

- A collection of 170 indicators related to water use and management that international experts have evaluated to see whether they fulfil the three pillars of sustainability in addition to the institutional component [111].
- Indicators belonging to the SDGs [5], with more focus on those related to water use and management in general (i.e., SDG6).
- Indicators and targets shown in the GCC Unified Water Strategy (GCC UWS) [54].

Meanwhile, several other indicators were also checked from other sources, such as those belonging to the seventeen plus two frameworks included in the previous article [35], to cover many aspects of ASAR in general and GCC countries in particular. This study aims to manifest all references for all the suggested indicators that would be included to give the selection process more credibility and traceability and to avoid any bias or arbitrary choices as much as possible.

Stage 4 is critical as a filtration process to ensure that the outputs of the previous stage (i.e., potential indicators) are applicable to be included in the final list of indicators if they fulfil two conditions. To pass the first condition or filtration step, each indicator must fit the context of ASAR and GCC countries. Of course, this would include whether these indicators consider both the typical characteristics of the WRM system of GCC countries and the conditions of their WR. If no, then this indicator shall be excluded. If yes, then the indicator can proceed to the second filtration step. To explain, indicators of several IBWSFs were chosen to tackle the issues of the SW that their regions depend on. However, this type of indicator is not effective in frameworks designed for some ASAR whose major WR is different (e.g., GW), and SW might be rare. Hence, indicators that cannot help evaluate sustainability because of their spatial features must be excluded.

The second condition of stage 4 is that the data of each indicator should be sufficient to do the calculations and also with data that is readily available and obtainable. Of course, the adequate data here include the thresholds or benchmarks of every indicator needed during the normalisation process to gain an equivalent value that can be aggregated and compared with other indicator units. In addition, if the data of any indicator are hidden or need special permissions to be collected every time, then it might not be easy and time-consuming to complete the results of the framework. This issue can be more prominent if this kind of framework supports periodic publication (e.g., yearly or bi-annually) of performance results. Therefore, only indicators with both enough data to be measured or evaluated and open-source information can be kept in the final list of indicators. On the contrary, missing both or one of these criteria or checks will lead to excluding this or that indicator and making it inapplicable to qualify for the next stage.

Stage 5, the last stage presented in Figure 7, provides the final list of components and indicators that comprise the conceptual framework (see Section 4.3). Therein, each indicator should be accompanied by a brief description explaining its purpose and ideology for both expert and non-expert users and stakeholders. Moreover, a brief justification is provided to show the importance of such an indicator. Finally, the references from other frameworks that have used the same indicator are presented to make the selection process more credible and strengthen the justification.

4.3. Results

This section presents the output of Stage 5 as the final list of indicators that came after following the instructions of the flowchart in Figure 7. This list ended with 24 selected indicators representing the previous four components of the conceptual SWRM-AF for ASAR, as shown in Figure 8. Each component has six indicators, to give equal attention to each component and to follow the rule that emphasises that the total number of indicators should be neither too many [98,99] nor too few [14,35]. In addition, a reference, a brief description, and a justification for each indicator are provided below.

The respective four components (i.e., environmental, social, economic, and infrastructure) and underpinning indicators with associated metrics and benchmarks (where applicable) will be further discussed in the next sections. Meanwhile, tables containing actual statistics from GCC countries for some indicators will be presented in Appendix A to guide framework users on the specific information they need to seek during the application or implementation phase.

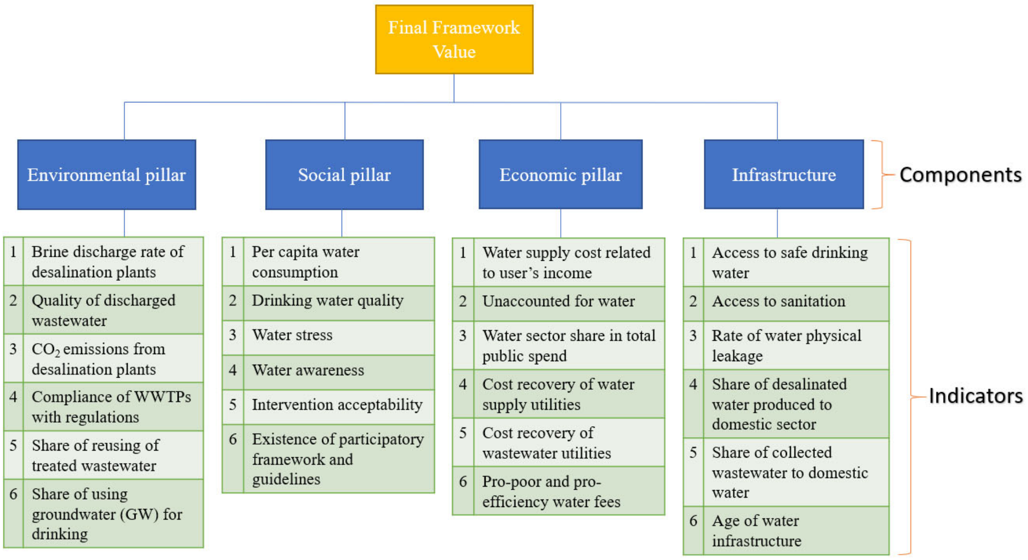


Figure 8. Conceptual SWRM-AF for ASAR.

4.3.1. Environmental Indicators

If the pillars of sustainability are considered as a series of concentric circles, the environment can be considered the bigger circle that contains both the social and economic pillars. This is because if the environment is not well maintained and protected, the impact of this careless act would greatly influence all other aspects of sustainability and life overall. Hence, in the development of this framework, the environment is placed first in this research.

A list of all environmental indicators included in the SWRM-AF is provided in Table 3 with their types and references.

Table 3. Environmental indicators of the conceptual SWRM-AF with their types and references.

No.	Environmental Indicator	Data Type	References
1	Brine discharge rate of desalination plants	Quantitative	[112,113]
2	Quality of discharged wastewater	Quantitative	[5,96,111,114]
3	Carbon dioxide emissions from desalination	Quantitative	[5,93,113,114]
4	Compliance of wastewater treatment plants with regulations	Qualitative	[111,115–117]
5	Share of reusing of treated wastewater	Quantitative	[54,92]
6	Share of using groundwater for drinking	Quantitative	[111,116]

No. 1. Brine Discharge Rate of Desalination Plants

Since WR are commonly scarce in ASAR, alternatives are necessary to reduce the gap between water supply and demand. One of these alternatives that countries now rely upon is the process of extracting pure water from saline water [118], whether from the sea or stored in aquifers. The output of this process became known as desalination water (DW), which requires desalination plants (DPs) to be treated and produced.

The process produces freshwater, and concentrated brine, a wastewater (WW) that includes elevated levels of salt and other chemicals [119–121]. Unfortunately, unregulated discharges of this untreated WW to the sea can harm the ecosystem therein [122]. In addition, DPs close to the coast frequently release untreated brine into salty surface water bodies such as oceans and seas [123], while inappropriate surface disposal of other DPs could pollute GW resources [119]. Therefore, identifying the rate and composition of brine discharges is significant. According to Xu et al. [124], the estimation of the brine production rate depends on two factors:

1. Type of desalination technology (e.g., reverse osmosis (RO), multi-stage flash (MSF), and multi-effect distillation (MED));
2. Salinity level of feedwater (e.g., seawater or brackish water) that is used as an input.

To illustrate the point, it was previously estimated that using seawater (SeW) as feedwater with MSF as a technology would produce desalted water with an average rate of 22% (i.e., recovery ratio [125]), while using brackish water (BW) with RO would result in a rate of 65%; the remaining percentage (i.e., 78% and 35%, respectively) in both cases would be brine [126]. Therefore, it is significant to work on reducing brine disposal directly into nature to maintain the environment of that region by having a specific indicator that can measure the brine production rate. In contrast, ignoring this process by at least not having an indicator would affect the environment directly and people's health indirectly.

Globally, it is worth noting that four nations of the GCC (i.e., KSA, UAE, Kuwait, and Qatar) are responsible for 32% of desalination water production and 55% of the total brine [126]. Hence, to deal with this vast brine discharge rate, some changes for the current practices (i.e., the two factors above) are needed, if not with existing DPs, then at least for any future ones. Jones et al. [126] presented several assumptions about the water recovery ratios resulting from the combinations of feedwater technology, and the important ones related to this study are shown in Table 4. While these technologies and types of feedwaters in Table 4 dominate in GCC countries, an estimation for the average rate or quantity of brine discharge among GCC countries can be calculated if the right data are available. Furthermore, Moossa et al. [66] collected information about the daily DW production in 2020 and the rate of technology used as shown in Table A1. Therefore, by knowing these data plus the water recovery ratio for each technology combined with the type of feedwater, as presented in Table 4, the average quantity of brine discharge can be estimated for each GCC country. Then, this quantity can be considered as the baseline of a previous specific year (e.g., in our case, it can be 2020) and can be monitored and compared with future years. A suggested criterion for evaluating this indicator is presented in Table 5.

Table 4. Water recovery ratios resulting from combinations of feedwater and technology [126].

Technology **Feedwater**	**Reverse Osmosis (RO)**	**Multi-Stage Flash (MSF)**	**Multi-Effect Distillation (MED)**
Seawater (SeW)	0.42	0.22	0.25
Brackish (BW)	0.65	0.33	0.34

Table 5. Scores and their descriptions assigned for evaluating the brine discharge rate.

Brine Discharge Rate Level	**Qualitative Description**	**Score**
Very high	Brine discharge rate (or quantity) has increased or is equal to the baseline year	0
High	Brine discharge rate (or quantity) is ≤5% compared to the baseline year	1
Medium	Brine discharge rate (or quantity) is ≤15% compared to the baseline year	2
Below average	Brine discharge rate (or quantity) is ≤25% compared to the baseline year	3
Low	Brine discharge rate (or quantity) is ≤35% compared to the baseline year	4
Very low	Brine discharge rate (or quantity) is ≤45% or more than the baseline year	5

No. 2. Quality of Discharged Wastewater

The quality of WW, whether treated or untreated, should be monitored before it is discharged. This action increases in significance when considering that 44% of household WW globally was not safely treated in 2020 [127]. Thus, checking the quality of WW would help eliminate many environmental issues by ensuring that it is at least unharmful before it is released for any purpose. Moreover, deciding whether this indicator should be under the environmental or social pillar was far from straightforward. However, since its impact is more comprehensive than being confined only to humans alone, the choice was to keep it under the environmental pillar.

For example, regulations in KSA stated that several physical, chemical, and microbiological parameters of WW and TWW need to be checked and monitored regularly (e.g., weekly or bi-weekly). These parameters are treated as sub-indicators here and include biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), potential of hydrogen (pH), ammoniacal nitrogen (NH_3-N), nitrates (NO_3) and faecal coliforms (FCs). The quality limit of each parameter based on the type of WW is shown in Table A2. The evaluation of this indicator will be based on the average quality of discharged WW in a country by checking the total quantity and its quality produced from sources of WW and TWW and the type of treatment. This includes whether the quality of discharged WW is untreated WW, secondary TWW, or tertiary TWW, which can be known for example by the standard given in Table 6. Then, this average will be taken to Table 6 to be compared and given an appropriate score.

Table 6. Scores and their descriptions assigned for evaluating the quality of discharged wastewater.

Quality of Discharged Wastewater	Qualitative Description	Score
Very low	Average quality of discharged WW is less than the standard quality of WW	0
Low	Average quality of discharged WW is equal to the standard quality of WW	1
Below average	Average quality of discharged WW is lower than the standard quality of secondary TWW	2
Medium	Average quality of discharged WW is equal to the standard quality of secondary TWW	3
High	Average quality of discharged WW is lower than the standard quality of tertiary TWW	4
Very high	Average quality of discharged WW is equal to the standard quality of tertiary TWW	5

No. 3. Carbon Dioxide Emissions from the Desalination Sector

It is known that the desalination technology in its current procedures requires much energy to produce potable water. This energy requirement imposes an environmental effect mainly represented by the carbon dioxide (CO_2) emissions that depend on the type of technology and fuel used. Moreover, CO_2 can be considered as a proxy to represent the issue of greenhouse gasses (GHGs) [128,129] to shed light on the issue of traditional and renewable energy within the desalination sector. Meanwhile, CO_2 is chosen alone here because its produced quantity from DPs is found to be the largest among other gasses [114].

For example, some DPs use thermal plants that rely on burning fuels to produce electrical energy, which is required to operate these plants [64,130]. On the other hand, RO technology requires less energy [131], meaning lower CO_2 emissions [132]. In addition, using renewable energies instead of conventional energy sources is very promising for mitigating and reducing the negative emissions (i.e., CO_2) of DPs [133]. Therefore, such an indicator should be included in the assessment of SWRM in regions or countries using this WR, such as ASAR, to stimulate the desire to deal positively with one of the main reasons for the climate change issue. Meanwhile, the target of this indicator would be in line with one of the Sustainable Development Goals (i.e., SDG13) to “take urgent action to combat climate change and its impacts” [5]. Not only this, but also this type of indicator was similarly used somehow in other SWRM frameworks such as the Water Sensitive Cities Index [93], triple bottom line, and multicriteria decision analysis [86].

Moreover, GCC countries, which rely heavily on desalinated water to deal with their limited WR and high population growth, must carefully account for this technology’s environmental impact. For example, it was found in 2019 that the desalination sector in the KSA is in third place among industries for producing CO_2 emissions, with a percentage of 13% representing 75 million metric tons per year (mt/year) [132]. In addition, the average apparent emission factor of desalination in 2016 was 21.4 kg CO_2/m^3 of desalinated water, which was reduced to 15.2 kg CO_2/m^3 in 2019 due to technological improvements [132]. Therefore, each GCC nation needs to monitor the carbon footprint of its DPs and work toward reducing it to save the environment and decrease the process of climate change.

The required data for evaluating this indicator are the number of DPs in each country, their type of technology, and their yearly actual production. Then, these data should be aggregated and multiplied by the estimated CO_2 emissions of each technology, as presented in Table A3. The final output of this process should be compared to a previous year (e.g., 2 or 5 years before), in which its data are available and accurate, as a baseline for that country. A suggested criterion for evaluating this indicator is presented in Table 7.

Table 7. Scores and their descriptions assigned for evaluating the CO_2 emissions from the desalination sector.

CO_2 Emissions Level	**Qualitative Description**	**Score**
Very high	CO_2 emissions have increased or equal to the baseline year	0
High	CO_2 emissions are $\leq$20% compared to the baseline year	1
Medium	CO_2 emissions are $\leq$40% compared to the baseline year	2
Below average	CO_2 emissions are $\leq$60% compared to the baseline year	3
Low	CO_2 emissions are $\leq$80% compared to the baseline year	4
Very low	CO_2 emissions are $\leq$100% compared to the baseline year to achieve net zero carbon *	5

* While the aim of net zero carbon (CO_{2e}) includes all GHG emissions, CO_2 is used here as a proxy.

No. 4. Compliance of Wastewater Treatment Plants (WWTPs) with Regulations

Since wastewater treatment plants (WWTPs) have a critical role in dealing with the used and polluted water, it would be essential to ensure that these plants follow up-to-date regulations to avoid any negative environmental impact and achieve maximum benefit. This would include identifying the (1) type of treatment used, whether primary, secondary, or tertiary; (2) the plant's age; and (3) the actual production, compared to design capacity, thereby checking the plant's performance. The values of this indicator are qualitative, based on the previous three criteria, and are illustrated in Table 8.

Table 8. Scores and their descriptions assigned for evaluating the compliance level of WWTPs.

Compliance Level	**Qualitative Description**	**Score**
None	No public WWTPs are available at all.	0
Small	Most WWTPs produce primary treatment, in old age, and far away from matching the designed capacity.	1
Below average	Most WWTPs are producing secondary treatment, in old age, and not matching the designed capacity.	2
Medium	Most WWTPs produce both secondary and tertiary treatments, not in old age, but not matching the designed capacity.	3
Good	Most WWTPs produce both secondary and tertiary treatments, not in old age, and match the designed capacity.	4
Excellent	Most WWTPs produce tertiary treatments, not in old age, and match the designed capacity.	5

No. 5. Share of Reusing of Treated Wastewater (TWW)

ASAR are well known to have limited WR, which emphasises the importance of considering/adopting additional non-conventional supplies to reduce the gap between the low supply and high demand of water, which includes, for example, TWW that can be used or RW. The additional benefit of using RW is that the environment is protected from the effluents that might otherwise be discharged into the environment with small or inadequate treatment [134]. Thus, having an indicator that measures the ratio of RW to the total TWW of a region or country would show stakeholders and decision-makers how far their WRM system is from being more sustainable. For instance, KSA and Kuwait have reused TWW with a percentage of 16% and 61%, respectively, in 2010, while the suggested GCC UWS aims to achieve at least 90% by 2035 for all GCC countries [54]. Thus, non-inconsiderable concerted efforts are required by these countries to reach this target within the next few years. Meanwhile, RW can have different uses such as urban area landscaping and municipal park irrigation [135], which help reduce the pressure on other WR. The values of this indicator can be qualitative, as shown in Table 9.

Table 9. Scores and their descriptions assigned for evaluating the share of reusing of TWW.

Reusing Level	Qualitative Description	Score
None	Treated wastewater (TWW) is not used at all	0
Small	The percentage of using RW to total TWW is ≤20%	1
Below average	The percentage of using RW to total TWW is ≤40%	2
Medium	The percentage of using RW to total TWW is ≤60%	3
Good	The percentage of using RW to total TWW is ≤80%	4
Excellent	The percentage of using RW to total TWW is ≤100%	5

No. 6. Share of Using Groundwater (GW) for Drinking

Since GW is one of the major WR in GCC countries, ensuring this resource is not overused is still significant. A continuing decline in the water table [134] and, worse still, salinity intrusion [136,137] are both environmentally unsustainable. Hence, monitoring this via a specific indicator is required. GW in the GCC countries is divided into types [54]:

1. GW (or RGW) in shallow aquifers, which is considered the only renewable water source;
2. Fossil GW in deep aquifers, which is considered as NRGW.

The issue with both types is that the water recharge rate to the aquifers that contain them should be higher than or at least equal to the drawdown rate [57], which is possible only with type 1. Therefore, the aim of this indicator is to focus on the consumption of the NRGW.

Moreover, all the GCC countries have assigned for their domestic sectors a specific policy that aims to reduce the use of GW in favour of desalination [54]. Nevertheless, some GCC countries have a small reserve of the above types of GW (e.g., Qatar and Bahrain) [54], so using other water supply alternatives based on their conditions is important and should be included in the SWRM-AF. In contrast, while the estimation of the quantity of NRGW in Bahrain and Saudi Arabia is 155 and 400,148 MCM, the yearly withdrawn from this reserve is 58 and 19,460 MCM, respectively [57]. If we assume that the recharge rate of these reserves, which hold this NRGW, is almost zero, then this would mean this natural and strategic storage of water could be depleted within approximately 3 to 20 years.

Therefore, the aim of having such an indicator is to show the importance of reducing the reliance on NRGW in the domestic sector in GCC countries to sustain it and to avoid negative environmental impacts resulting from overconsumption. The values of this indicator can be qualitative, as shown in Table 10.

Table 10. Scores and their descriptions assigned for evaluating the share of using groundwater (GW) for drinking.

GW Using Level	Qualitative Description	Score
Very high	Share of using groundwater (GW) for drinking is ≤100%	0
High	Share of using GW for drinking is ≤80%	1
Medium	Share of using GW for drinking is ≤60%	2
Below average	Share of using GW for drinking is ≤40%	3
Low	Share of using GW for drinking is ≤20%	4
Very low	Share of using GW for drinking is ≤0%	5

4.3.2. Social Indicators

While protecting the environment of the SWRM system is significant for the welfare of the planet, taking care of the satisfaction of society is equally important. The advantages and the procedures of having a widely accepted sustainable approach herein are no less powerful. Therefore, this process needs a number of different steps to be adopted, such as illustrating how individual use in parallel to the degree of awareness [138] could directly or indirectly affect the SWRM system. This is more important in regions such as ASAR, which often suffer from water stress, and overcoming the barrier to public acceptance of some interventions is key to ensuring that WR can withstand challenging conditions. Furthermore, the quality of drinking water strongly impacts the health and well-being of society. In addition, all these previous measures work better if stakeholders from the community have a clear role in the regulatory decision-making process. Therefore, an effective SWRM system requires social indicators to be strongly evaluated and not overlooked.

A list of all social indicators included in the SWRM-AF with their types and supporting references is presented in Table 11.

Table 11. Social indicators of the conceptual SWRM-AF with their types and supporting references.

No.	Social Indicator	Data Type	References
1	Per capita water consumption	Quantitative	[42,54,88,92,94,111–113]
2	Drinking water quality	Quantitative	[12,41,42,44,86,88,92,95,96,111,116,117]
3	Water stress	Quantitative	[5,12,41,42,94,95,111]
4	Water awareness	Qualitative	[11–13,42,88,93,94,108,111]
5	Intervention acceptability	Qualitative	[86,90,117]
6	Existence of participatory framework and guidelines	Qualitative	[5,42,45,93,95,108,111,116]

No. 1. Per Capita Water Consumption (Domestic Sector)

This indicator has a graded scale from high to low consumption and reflects the demands of the domestic sector, particularly by focusing on the behaviour of using water or the average consumption of individuals forming that sector. Having such an indicator is essential to avoid being in a difficult water scarcity situation. Water scarcity occurs when the amount of water withdrawn from natural WR (i.e., conventional) is massive and still cannot fulfil all people or ecosystem requirements, which leads to high competition among water users [139].

The main inputs of this indicator are the total domestic water consumption of a city, region, or country, which is usually counted per year, and its population. The output can be simply calculated by dividing the total yearly water consumption by the population and converting the time unit to a day. Thus, this rate can show clearly which rank the people of that region belong to, whether to high, normal, or low water consumption compared to other regions. Then, stakeholders and decision-makers in that area should be aware of their general behaviour in dealing with water and whether they need to carry on or fix it. This measure is more critical in ASAR, which already suffer from limited water resources.

In contrast, the use of non-conventional WR with relatively extremely low water tariffs and high government subsidies until recently made many countries, in our case, among the highest water consumers, which is unsustainable for the short and long run. Hence, a plan with a target to reduce this consumption is required to ensure the longevity of such WR. For instance, GCC countries figured out that their average water consumption is high (e.g., KSA = 278 L/capita/day in 2018 [140], Bahrain = 320, Kuwait = 500, Qatar = 512, Oman = 140, and UAE = 520 L/capita/day [54]). These high levels of most GCC nations let experts decide to put a target in the GCC UWS to reach at least 250 L/capita/day by 2035 [54]. This target aligns with the recommendations that emphasise demand management by motivating the enhancement of consumption behaviour rather than focusing on supply management. The adoption of water-efficient appliances and changes in user behaviour are fundamental to achieving these targets [138,141]. Therefore, while this target (i.e., 250 L/capita/day) is still high, it is still considered in Table 12 with a middle score to match the GCC UWS and to be a benchmark for other GCC countries with huge consumption. Meanwhile, more targets are added in Table 12 to match the global trend and push the boundaries of reducing consumption; achieving them would benefit the water sector greatly.

Table 12. Scores and their descriptions assigned for evaluating the per capita water consumption.

Consumption Level	Qualitative Description	L/Capita/Day	Score
Very High	Consumption is 60% above the target for the region	>400	0
High	Consumption is 40% above the target for the region	350	1
Above Average	Consumption is 20% above the target for the region	300	2
Average	Consumption is equal to the target for the region	250	3
Low	Consumption is 20% below the target for the region	200	4
Very Low	Consumption is 40% below the target for the region	<150	5

No. 2. Drinking Water Quality

This should be considered as a pass (5 marks)/fail (0 marks) indicator. Generally, this indicator is among the most significant to be included in any SWRM framework or index. The evidence found in the literature shows that many if not all IBWSFs have included it. Its significance comes from it helping ensure the health and well-being of society by maintaining a decent quality of drinking water. Otherwise, water diseases (e.g., cholera, typhoid) that occur after drinking polluted or low-quality water can take place. Moreover, the importance of this indicator increases in some ASAR, where using non-conventional resources such as DW is essential.

Since the water supplies of any country or region are most likely different, sub-indicators might be essential to distinguish between the quality of each water resource and ensure that they would meet the standards to be appropriate for consumption or discharge. However, since the output (i.e., quality of drinking water) of this treatment process is the target, all these WR are combined here under one category called “water supply”. Meanwhile, the most important parameters would be checked to reduce the complexity, time, and money resources needed for applying the framework.

In this framework, the first option for calculating this indicator is to use scores of overall drinking water quality from other indices, such as the Environmental Performance Index (EPI) [142]. Otherwise, most parameters that were used in many water quality indices (WQIs) are selected to be checked on a timely basis. These parameters and their permitted values based on the Saudi Arabian Standards Organization (SASO) are shown in Table A4 and classified into three main groups:

1. The physical parameters (total dissolved solids, turbidity);
2. The chemical parameters (pH, free chloride);
3. The microbiological parameters (total coliforms).

Another way to measure the value of this indicator in order to be consistent with previous indicators is provided in Table 13. In this table, categorical scaling is used by considering the issue of both urban and rural areas since it fits the context of both ASAR and GCC countries, where some and/or few groups of people still live far away from cities and towns.

Table 13. Scores and their descriptions assigned for evaluating drinking water quality.

Water Quality Level	Qualitative Description	Score
Very Low	Water quality is not drinkable	0
Low	Water quality in many (≤25%) areas * is not drinkable	1
Below Average	Water quality in some (≤50%) areas is not drinkable	2
Average	Water quality in many (≤75%) areas is drinkable	3
Good	Water quality in most (≤90%) areas is drinkable	4
Excellent	Water quality in all (>90%) areas is drinkable	5

* It should be noted that areas include urban (e.g., cities and towns) and rural (e.g., villages).

No. 3. Water Stress

This indicator was introduced by Falkenmark et al. [143] to measure the population’s pressure on the renewable water supply of a specific city, region, or country. The stress here includes the needs of all major sectors (i.e., domestic, industrial, agricultural, and natural ecosystems) [144]. The renewable supply in this context means the annual amount of conventional WR only (i.e., average yearly stream flow and/or the sustainable groundwater yield) on a per capita basis [12]. Water stress in any specific region starts when there is less than 1700 m^3/cap/year, and it becomes severe when there is less than 1000 m^3/cap/year [144], while less than 500 m^3/cap/year could represent that water availability is a main constraint for having a normal life [12,145]. The renewable water supply of GCC countries is most likely below 500 m^3/cap/year, which made them adopt non-conventional WR to reduce the gap between water supply and demand. However, this indicator does not consider these resources since they are categorised as non-renewable or need excessive cost or technology to be treated. Meanwhile, a new indicator that follows the same previous categorisation and combines conventional, including NRGW, and non-conventional WR is suggested to reflect the real water stress in countries like the GCC countries. The equation needed to calculate the water stress (or scarcity) indicator (WSI) is as follows [57]:

$$WSI_i = \left(\frac{DT_{net\ i} - (NRGW_i + DSW_i + \ RUW_i}{SFWA\ _i} \right) \times 100 \tag{1}$$

where $DT_{net\ i}$ is the net total water demand from all sectors in each country (i) in the GCC. While $NRGW_i$ stands for the abstraction quantity of the NRGW, DSW_i is the quantity of desalinated water, RUW_i represents the reusing quantity of TWW, and $SFWA_i$ is the availability of surface freshwater (or SW) availability of that country (i). Moreover, the expression "$SFWA_i$" in the denominator of Equation (1) can be changed to "total recharge from all sources excluding return flow + total runoff volume from all catchments" since GCC nations do not have perennial surface water [57]. Then, the water stress level can be indicated by referring to Table 14.

Table 14. Scores and their descriptions assigned for evaluating water stress [139,146].

Water Stress Level	Qualitative Description	Score
Critical	Water stress/scarcity indicator (WSI) is >100%	1
High	WSI is from 40 to 100%	2
Medium-high	WSI is from 20 to 40%	3
Moderate	WSI is from 10 to 20%	4
Low	WSI is <10%	5

No. 4. Water Awareness

Raising the community's awareness about their region's water situation is significant. Doing this via different methods would let society understand the size of the problem and, more importantly, tackle it by changing consumption behaviour. In addition, disseminating knowledge about water scarcity would make the public cooperate with any initiation or regulation that would rationalise using this precious resource [147,148]. For that reason, it is essential not to ignore this side and to have this type of social indicator that would measure to which extent efforts are provided to increase the water awareness of the society of that region. This is because different studies have stated that some people used to underestimate their actual consumption by thinking they were consuming less water [138,148], which cannot help them reduce their water consumption.

One way to do this is to check the school curriculum and whether it includes information about the water issue with advice. To prove the importance of such an action, Pires et al. [111] found that the "water topics in school curriculum" indicator is one of the 24 indicators among many others found in the literature that can fulfil the majority of sustainability criteria based on different experts' opinions. Another way is to ensure the water authorities have produced water awareness campaigns in different media. Finally, this indicator would be evaluated as a qualitative measure, as seen in Table 15.

Table 15. Scores and their descriptions assigned for evaluating water awareness.

Efforts Level	Qualitative Description	Score
None	advocating for water awareness by any means is missing	0
Small efforts	providing little information to a limited group of people, such as only on the water bill which could benefit only the person who pays the bill	1
Below average	by providing information in only two and neither very popular nor interactive means such as water bills and newspapers	2
Medium	providing information to the public through three different means; one of them should be favoured in that region and interactive such as social media	3
Good	providing information to different public groups, including children in their school curriculum and university students, and organising awareness campaigns through four means; at least one should be popular and interactive	4
Excellent	providing information to different public groups, including children in their school curriculum and university students, and organising awareness campaigns and competitions periodically through five means; at least two should be popular and interactive	5

No. 5. Intervention Acceptability

Adopting new technical tools or methods that could reduce domestic water consumption is more critical in areas like ASAR—for example, providing tools that can be attached to water taps to reduce water consumption (i.e., water rationalisation tools (WRTs)) and making their use mandatory. Other examples include smart water meters (SWMs), greywater systems, and rainwater harvesting (RWH) systems.

However, this kind of intervention would require acceptance by the public, who might doubt the benefit of that process and then not react positively to it. Moreover, social resistance might occur if these novel changes need new or extra-economic costs, which some people either cannot afford or are unwilling to pay. Hence, it is crucial to propose such an indicator for evaluating the primary stakeholders' acceptance of these new interventions before introducing them. In addition, it is worth mentioning that the level of acceptance is qualitative and would correlate with the level of awareness. Therefore, it is suggested that both indicators need special preparation and consideration in any SWRM-AF. Like the previous indicator, each description with its score is presented in Table 16.

Table 16. Scores and their descriptions assigned for evaluating intervention acceptability indicator.

Acceptable Level	Qualitative Description	Score
Not acceptable	Society does not accept any new interventions.	0
Slightly acceptable	Some doubts exist, but at least one free, new, easy-to-install intervention, such as water rationalisation tools (WRTs) or smart water meter (SWM), could be welcomed.	1
Partially acceptable	At maximum, two interventions are accepted, but one of them should be free (e.g., WRT or SWM), and the other (e.g., greywater or RWH systems) should be within a highly subsidised cost (i.e., the cost paid by stakeholders is 20% to 40% of the actual cost, the remaining being subsidised).	2
Moderately acceptable	At maximum, three interventions are accepted, but it is better for one of them to be free (e.g., WRT), and the others (e.g., greywater and RWH systems) could be afforded at 50% of their cost.	3
Highly acceptable	Any interventions are accepted and could be afforded at 75% of their cost.	4
Fully acceptable	Any number of interventions are accepted at any cost.	5

No. 6. Existence of Participatory Framework and Guidelines

According to the Dublin principles [100], stakeholders should be involved in the decision-making process of any WRM plan based on a participatory approach. There are different important reasons for such a principle, such as the following:

1. To increase stakeholders' awareness about the water situation and its real problems.
2. To motivate them to provide or select appropriate objectives or solutions after giving them a chance to understand the main challenges.
3. To ensure their cooperation in applying the approved plan and achieving key objectives.
4. To let them convey the strategies and convince their close social circles about the importance of such strategies.

Thus, the existence of such a framework with specific guidelines that include regulations and the method of application is essential for any SWRM. Moreover, such an indicator could help countries and regions that applied this framework recognise the importance of the participatory approach and fill the institutional gap. In addition to the existence of such a framework and its guidelines, the main criterion for developing this indicator is that most stakeholder groups are represented and have a real contribution to the decision-making process. These groups include, for example, profit and non-profit organisations.

An indicator for checking this is suggested here with different measures to match the Dublin and IWRM principles. The values of this indicator would be from 0 to 5 based on qualitative descriptions or criteria, as shown in Table 17.

Table 17. Scores and their descriptions assigned for the indicator evaluating the existence of a participatory framework.

Application Level	Qualitative Description	Score
Nothing	Neither participatory framework nor guidelines are available.	0
Only guidelines	Guidelines about the participation of stakeholders exist on paper but without activation or actual application.	1
Exist without activation	Participatory guidelines and framework about the rules of stakeholders exist on paper but without activation or actual application.	2
Exist for limited groups but without application	Participatory framework and guidelines about the rules of stakeholders exist with the involvement of a minority of stakeholders' groups without a real contribution in making decisions.	3
Exist for several groups but without application	Participatory framework and guidelines about the rules of stakeholders exist with the involvement of the majority of stakeholders' groups without a real contribution in making decisions.	4
Exist with real application	Participatory framework and guidelines about the rules of stakeholders exist with the involvement of the majority of stakeholders' groups with a real contribution in making decisions.	5

4.3.3. Economic Indicators

Like many systems worldwide, the cost and benefit of WRM for the domestic sector shall be assessed to ensure its affordability and feasibility. This would include, for example, figuring out whether the average income of people in a specific region or country is proportional to the water cost they are paying. In addition, the cost recovery of the operation and maintenance of water services is crucial for companies that are already providing or would provide these services to survive. Otherwise, governments and municipalities will face difficulties treating, delivering, and maintaining water by their spending alone without the private sector, whose net-benefit matter is usually their primary goal. Nevertheless, since water is a fundamental element of life, it is necessary to support either special rates for people experiencing poverty and/or provide efficient tools to help them rationalise their water use and hence reduce their water bills. Therefore, it is vital to create and investigate economic indicators related to the WRM system to complete the evaluation of the three pillars of sustainability. Meanwhile, treating this pillar (i.e., economic) with other previous pillars in a balanced way is recommended to prove that they are all equally essential for sustainability.

A list of all economic indicators included in the SWRM-AF with their types and supporting references is presented below in Table 18.

Table 18. Economic indicators of the conceptual SWRM-AF with their types and supporting references.

No.	Economic Indicator	Data Type	References
1	Water supply cost related to users' income	Quantitative	[86,88,92,93,111,116]
2	Unaccounted-for water (water losses)	Quantitative	[86,111,149,150]
3	Water sector share in total public spending	Qualitative	[92,93,111]
4	Cost recovery of water supply utilities	Quantitative	[54,86,111]
5	Cost recovery of wastewater utilities	Quantitative	[54,92,111]
6	Pro-poor and pro-efficiency water fees	Qualitative	[11,42,93,111]

No. 1. Water Supply Cost Related to Users' Income

It would be tremendous and economically sustainable if the water supply cost is fully recovered by users or customers who have paid to obtain or buy water. Furthermore, this process would be better if it would bring profits to the provider, whether a company or the government. However, since water is one of the basic needs for humans to survive, many governments and/or municipalities have maintained heavily subsidised water to ensure that everyone can afford to buy water [151]. Moreover, most low- and middle-income countries have water tariffs that cannot cover water providers' daily costs unless financial authorities give compensation [151]. On the other hand, having unaffordable and increased water tariffs can end with a lot of bills that cannot be paid by customers, which prevents expected revenues from being collected on time [152]. This would lead to a loss for water providers either in the short or long run. Hence, monitoring this cost and comparing it to the water users' income by a particular indicator could assist in reviewing water tariffs to ensure it is affordable and also could generate revenues.

To calculate this, the average number of people living in the same house (or household) would be considered for each GCC country (e.g., 5 people). Then, the country's average daily water consumption per person (e.g., 260 L/cap/day) would be converted to m^3/house/month by considering the average household in the calculation. After that, the monthly unit cost of that amount of water (e.g., 2 USD/m^3) would be multiplied by the average monthly consumption per house, and the product of this process would be compared to the average monthly income. Finally, this cost would be calculated yearly to be compared to the average total annual income of people in that country. Examples of required data for discovering this relation between monthly income and the water bill are presented in Table A5.

After this calculation is performed, the cost level can be known by taking the output of this process to Table 19, which can tell whether the cost level is high for the final user or not. Most of these levels assigned to the average income are based on a global study for the water affordability presented by Smets [153], where any water tariff surpasses 5% of the user income is considered high.

Table 19. Scores and their descriptions assigned for evaluating the water supply cost related to users' income.

Cost Level	Qualitative Description	Score
Very High	Average water tariff is >8% of the average user income	0
High	Average water tariff is between 5% and 8% of the average user income	1
Above Average	Average water tariff is between 4% and 5% of the average user income	2
Average	Average water tariff is between 3% and 4% of the average user income	3
Low	Average water tariff is between 2% and 3% of the average user income	4
Very Low	Average water tariff is ≤2% of the average user income	5

No. 2. Unaccounted-for Water (Water Losses)

Unaccounted-for water (UFW) is the difference between the water amount produced and entering the water supply system and the amount that is billed or consumed [154]. Water leakage or physical losses from pipes and networks is one of the main components of UFW, and it is a big issue not only for the economy but also for the environment and infrastructure. In addition, the global non-revenue water (NRW) rate is estimated to be 39%, which means that around 39% of the water produced by water utilities around the world is lost before it reaches the end-users due to various reasons such as leaks, theft, and metering inaccuracies [149]. However, this indicator is responsible for measuring these losses that come mainly from leaking from an economic view.

Moreover, according to estimates from the World Bank, distribution systems lose over 48.6 billion cubic metres of provided water yearly, costing the global economy more than USD 14.6 billion [155]. Indeed, the impact of this issue can be considered double or triple in countries or regions suffering from water scarcity, such as in ASAR. Meanwhile, the focus on leakage reduction preserves the money and energy invested in those resources in addition to the WR [156,157]. On the other hand, many GCC countries had issues in the municipal distribution network with water leakage that caused a high economic loss [54]. Therefore, counting for this loss in a specific indicator could convince decision-makers to pay more attention to this issue and prioritise it.

To estimate these losses, and since the region or country might have different WR with varying costs for each, the average cost of producing one cubic metre of water is calculated (e.g., 2 USD/m^3). Then, the average leakage rate from the water pipes network (e.g., 35%) is multiplied by the total amount of water produced during a specific period (e.g., 2000 million m^3 (MCM)/year). Therefore, if the water leakage is 700 MCM, the total economic loss based on the unit cost of 2 USD/m^3 is 1400 million USD/year. This vast monetary loss could burden the whole economic system and might be paid by final users who did not receive this water, reflecting an injustice. Therefore, having such an indicator for measuring and evaluating these losses would help shed light on the magnitude of this problem and work on decreasing it. Table 20 below gives different levels of these economic losses with their criteria.

Table 20. Scores and their descriptions assigned for evaluating the losses of unaccounted-for water.

Level of Unaccounted-for Water	Qualitative Description	Score
Very High	Losses are equivalent to a physical leakage that is >40%	1
High	Losses are equivalent to a physical leakage that is ≤40%	2
Above Average	Losses are equivalent to a physical leakage that is ≤30%	3
Average	Losses are equivalent to a physical leakage that is ≤20%	4
Low	Losses are equivalent to a physical leakage that is ≤10%	5

No. 3. Water Sector Share in Total Public Spending

In some countries and regions, this type of information requires transparency and might not be easy to obtain. However, it would be economically significant to know whether the decision-makers who allocated the financial budget gave the water sector their fair share to provide and maintain an acceptable quality of water services. The difficulty of including such an indicator is knowing the range of justified share quantitatively in the framework since it can vary based on the time and place. Thus, using qualitative scores would be more meaningful. The evaluation of this indicator would be from 0 to 5 based on qualitative descriptions or criteria, as shown below in Table 21.

Table 21. Scores and their descriptions assigned for evaluating the water sector share in total public spending.

Spending Level	Qualitative Description	Score
Nothing	The budget does not include any specific spending for the water sector	0
Minimum	A tiny percentage of the budget is given to cover the basic requirements of the water sector (e.g., spending ≤ 20% of the needs of the water sector)	1
Below average	A small percentage is given to cover the basic requirements of the water sector (e.g., 20% < spending ≤ 40% of the needs of the water sector)	2
Medium	A medium percentage is given to cover the basic requirements of the water sector (e.g., 40% < spending ≤ 60% of the needs of the water sector)	3
Good	A high percentage is given to cover the basic requirements of the water sector (e.g., 60% < spending ≤ 80% of the needs of the water sector)	4
Excellent	A high percentage is given to cover the basic requirements of the water sector (e.g., 80% < spending ≤ 100% of the needs of the water sector)	5

No. 4. Cost Recovery of Water Supply Utilities

It is suggested that any system can be economically sustainable if the revenues cover its continued costs. Regarding SWRM, this should include the capital cost during the establishment stage of any type of water treatment plant (WTP) and water networks in addition to the operation and maintenance (O&M) costs. However, many developing countries tend to take care of the capital cost through their own spending and charge the customers only O&M costs to make water prices reasonable within the society [158]. Moreover, the cost of water treatment would be different based on the used technology (e.g., RO or MSF) and the type of water and its salinity level (e.g., SeW or BW) [159]. Therefore, this indicator would follow a strategy to compare the average water tariff with the average water costs. This indicator aims to show how far the water prices are from being sustainable by covering at least the O&M costs.

Along the same lines, in the GCC UWS, GCC countries seek to recover 100% of O&M costs by 2025 as a first target and 100% of total costs by 2035 as a second goal [54]. However, the focus for this indicator would be only on the first target since it is more realistic and still far from being applicable. Moreover, having such an indicator is significant. This is because some GCC countries heavily subsidise this cost to their citizens, such as Kuwait with a coverage of 92% of production cost, which cannot be sustainable overall in the long term for the economy [160]. Therefore, data for two main elements are required to proceed with this indicator: the average cost (in case there are different WR with variable costs) and the average water tariff in GCC countries. These data are collected and illustrated in Table A6, with the average cost recovery calculated.

It can be seen that Kuwait's cost recovery rate is the lowest, while three other countries are charging their population a water tariff that is lower than the real cost. The exception is for Bahrain and Oman with 15.1% and 6.72% higher water tariffs than the real cost, respectively. However, the data for average water costs in Table A6 might need to be revised and updated since many possible changes to the cost occurred recently as a result of the research and development of the used technology and energy. A specific evaluation is provided in Table 22 to find the level of cost recovery for any other country or in the case of different or future data for the GCC countries.

Table 22. Scores and their descriptions assigned for evaluating the cost recovery ratio.

Cost Recovery Level	Qualitative Description	Score
Very Low	cost recovery ratio is $\leq$5%	0
Low	cost recovery ratio is $\leq$25%	1
Below Average	cost recovery ratio is $\leq$50%	2
Average	cost recovery ratio is $\leq$75%	3
Good	cost recovery ratio is $\leq$100%	4
Excellent	cost recovery ratio is >100%	5

No. 5. Cost Recovery of Wastewater Utilities

Similar to the previous indicator, a comparison is required here between the unit cost of TWW and the tariff paid by the end user. If there are some profits, this will encourage the private sector to manage WWTPs if they are not already available, which takes this burden from the government entities. Hence, more WWTPs could be established either by governments of GCC countries or the private sector or both, which would cause the economy to flourish and protect the environment by reducing the discharge of untreated WW rate. Not only this, but WW treatment and reuse are increasingly necessary to support the water supply in the GCC countries, considering the high expenses linked to desalinated water production [161].

On the other hand, this indicator can shed light on the feasibility of current economic practices and help fix any flaws. Therefore, similar data that were needed to give an estimation for the cost recovery in the previous indicator are required here but for the costs and tariffs of WW. Then, the level of cost recovery would follow the same descriptions and scores in Table 22.

No. 6. Pro-Poor and Pro-Efficiency Water Fees

While the cost recovery through the water tariff is vital for the economy, considering special rates or incentives in the pricing system to use less water can be a win–win deal, especially for poor people. Not only this, but considering this socio-economic indicator would follow part of the global recommendation by the United Nations:

> *"Any payment for water services has to be based on the principle of equity, ensuring that these services, whether privately or publicly provided, are affordable for all, including socially disadvantaged groups. Equity demands that poorer households should not be disproportionately burdened with water expenses as compared to richer households."* ([162], paragraph 27).

This indicator matters because it would help and encourage low-income people to consume lesser amounts of water that meet their basic needs, and its price fits their budget. For instance, the Increasing Block Tariffs (IBTs) system could be applied, which means the water would have a varying price or tariff based on the monthly total consumed amount, where a low cumulative amount would have a lower unit cost than high consumption [163,164]. To explain, the monthly unit cost of low consumption, for example, with a block cap of 20 m^3/month, is 0.5 USD/m^3, while the monthly unit cost would increase if the customer exceeded the previous cap to 1 USD/m^3 up to the next block cap, and so on.

In addition, using less water in low-income areas would directly or indirectly reduce the O&M costs, which decrease the pressure on the WRM system. Therefore, a particular indicator is suggested here to assess the water tariff system in favour of both poor people and efficient use. The scores of this indicator would be from 0 to 5 based on qualitative descriptions, as shown in Table 23.

Table 23. Scores and their descriptions assigned to evaluate whether the water tariff system is pro-poor and pro-efficiency.

Consideration Level	Qualitative Description	Score
None	The water tariff system does not include any specific measures for either pro-poor or pro-efficiency water fees.	0
Minimum	The water tariff system includes specific and ineffective measures for either pro-poor or pro-efficiency water fees.	1
Below average	The water tariff system includes specific and partially effective measures for either pro-poor or pro-efficiency water fees.	2
Medium	The water tariff system includes specific and effective measures for either pro-poor or pro-efficiency water fees.	3
Good	The water tariff system includes specific and partially effective measures for both pro-poor and pro-efficiency water fees.	4
Excellent	The water tariff system includes specific and highly effective measures for both pro-poor and pro-efficiency water fees.	5

4.3.4. Infrastructure Indicators

As explained before, while infrastructure is not one of the main pillars of sustainability, it is still essential for completing the puzzle of SWRM. This is because of the key role of infrastructure in measuring the quality of living in urban areas. This degree of life quality would include checking the water services, which depend on the wide spread of infrastructure, provided to citizens of a particular region or country. Not only this, but the assessment of the common problems facing water infrastructure that could hinder or lessen its benefit is required. Hence, it would be significant to have particular indicators to evaluate the performance of infrastructure in supporting SWRM for the domestic sector.

A list of all infrastructure indicators included in the SWRM-AF with their types and supporting references is presented below in Table 24.

Table 24. Infrastructure indicators of the conceptual SWRM-AF with their types and supporting references.

No.	Infrastructure Indicator	Data Type	References
1	Access to safe drinking water	Quantitative	[5,12,41,42,44,88,92–96,111]
2	Access to sanitation	Quantitative	[5,12,41,42,44,92–96,111,116]
3	Rate of water physical leakage	Quantitative	[12,54,95,110,111]
4	Share of desalinated water produced to domestic sector	Quantitative	[111,129]
5	Share of collected wastewater to domestic water	Quantitative	[5,54,92,96]
6	Age of water infrastructure	Quantitative	[86,116,165]

No. 1. Access to Safe Drinking Water

Providing access to safe drinking water can be considered one of the most important basic services that any government or municipality should take care of, and any human should have. However, around 26% of the world's population (i.e., approximately 2 billion people) in 2020 lacked this access [127] for several reasons. The situation could be more difficult for people in ASAR who are already struggling with the harsh weather most of the year. Therefore, it would be vital to keep tracking this indicator in any region to ensure that the coverage of this access is sufficient and to resolve any reduction. Meanwhile, GCC countries already have a high access rate to safe drinking water, so the target here is to achieve a coverage of 100%, while the lower rates and their equivalent evaluations are presented in Table 25. These estimations are based on the updated data for the world coverage of water for each country, where some countries that are located in ASAR have low access ratio (e.g., Ethiopia with 52%) [166].

Table 25. Scores and their descriptions assigned to evaluate the rate of access to safe drinking water.

Access to Drinking Water Level	Qualitative Description	Score
Very Low	Access ratio is $\leq$50%	0
Low	Access ratio is $\leq$60%	1
Below Average	Access ratio is $\leq$70%	2
Average	Access ratio is $\leq$80%	3
High	Access ratio is $\leq$90%	4
Very High	Access ratio is $\leq$100%	5

No. 2. Access to Sanitation

Many health problems and diseases in the past were due to a lack of proper hygiene after the need to use toilets that might not exist [167]. This issue is still there since approximately 46% of the world's population (i.e., around 3.6 billion people) in 2020 lacked access to safely managed sanitation services [127]. Hence, it is significant to provide this service to the domestic sector and consider it one of the priorities for any government or municipality when planning its infrastructure. Moreover, this indicator is quite common in many IBWSFs and is responsible for providing a clear picture of the ability of the infrastructure of a region or country to handle this matter. Also, this type of indicator can measure how far or close a city or place is to reaching national or global targets, such as the one provided by the SDGs [127]. Table 26, which is based on comparison criteria suggested by the UN [55], is provided below to measure the level of access to sanitation in any country.

Table 26. Scores and their descriptions assigned to evaluate the rate of access to sanitation.

Access to Sanitation Level	Qualitative Description	Score
Low	Access ratio is $\leq$25%	1
Below Average	Access ratio is from 26 to 50%	2
Average	Access ratio is from 51 to 75%	3
High	Access ratio is from 76 to 90%	4
Very High	Access ratio is >90%	5

No. 3. Rate of Water Physical Leakage

One of the most essential elements of any infrastructure is the water network. This is because it can ensure that the water can be easily delivered to different users and places through buried pipes or mains. However, water leakage could occur if these mains are not well maintained and monitored or if they are in a deteriorated state. This issue with its effects is fundamental to be considered when the talk is about SWRM. This problem impacts not only the infrastructure, but also all the other three pillars, whether directly or indirectly. Moreover, if the global NRW volume were decreased by just 33%, the resulting savings would be enough to provide water to 800 million individuals, assuming each person consumes 150 litres per day [168]. Therefore, it is highly recommended to specify an indicator for monitoring the level of water leakage to reduce it.

On the other hand, all GCC countries suffered from water leakage in their municipal distribution network, so they aimed in the GCC UWS to reduce it to 10% by 2035 [54]. The previous percentage will be assigned as a target for this indicator, while the baseline will be 40%, which probably represents the highest rate among GCC countries as estimated in KSA. More levels of leakage with their scores are illustrated in Table 27.

Table 27. Scores and their descriptions assigned to evaluate the rate of water physical leakage.

Level of Leakage	Qualitative Description	Score
Very High	water physical leakage is >40%	1
High	water physical leakage is ≤40%	2
Above Average	water physical leakage is ≤30%	3
Average	water physical leakage is ≤20%	4
Low	water physical leakage is ≤10%	5

No. 4. Share of Desalinated Water Produced to Domestic Sector

Since most GCC countries are not rich in their conventional WR, using DW became necessary to match the growing water demand in the domestic sector and ensure the continuity of water supply. Meanwhile, this technology needs either an appropriate existing infrastructure or the development of a new one that could assist in water transportation from the primary source to the final user. Hence, this indicator would indirectly measure any country's ability and its infrastructure to depend on DW for the domestic sector. This can be done by knowing the percentage of DW used for municipal use in that region or country. Another benefit of having this indicator, especially for ASAR is that using this non-conventional WR (i.e., DW) can reduce the stress on the non-renewable WR (e.g., NRGW).

Based on data from 2010, the DW share in half of the GCC countries is equal to or more than 90% [54]. Therefore, this percentage (i.e., 90%) can be suggested as a target for other countries to evaluate the preparedness of their infrastructure to accommodate this water supply. More assigned levels of using DW in the domestic sector with their scores are shown in Table 28.

Table 28. Scores and their descriptions assigned to evaluate the share of desalinated water produced to domestic sector.

Share Level of Using Desalinated Water	Qualitative Description	Score
Very Low	There is no desalinated water produced to domestic sector (i.e., 0%)	0
Low	Share of desalinated water produced to domestic sector is between 1 and 19%	1
Below Average	Share of desalinated water produced to domestic sector is between 20 and 39%	2
Average	Share of desalinated water produced to domestic sector is between 40 and 59%	3
High	Share of desalinated water produced to domestic sector is between 60 and 89%	4
Very High	Share of desalinated water produced to domestic sector is ≥90%	5

No. 5. Share of Collected Wastewater to Domestic Water

The collection of wastewater can occur if the infrastructure includes a specific network for such a purpose. Otherwise, this WW can be discharged into the environment or kept in special underground tanks without any treatment. To avoid this harmful act, it would be necessary for any country or municipality to enhance its infrastructure to receive more WW. This indicator can be measured by comparing the share of collected WW to domestic water. Hence, infrastructure capacity can be scrutinised, and the environment can be saved. Not only this, but if the increase in WW collection would increase the TWW and its use, this would enhance the sustainability of the entire system. In some GCC countries with available data, the average amount of collected WW was below 50% of the total volume of water provided to the domestic sector in 2010 [54]. This share is aimed to be 60% by 2030 in the GCC UWS [54], which can be considered as the average target or range for our indicator. Other levels and their descriptions are provided in Table 29.

Table 29. Scores and their descriptions assigned to evaluate the share of collected wastewater to domestic water.

Share Level of Collected Wastewater	Qualitative Description	Score
Very Low	Share of collected wastewater to domestic water is ≤20%	0
Low	Share of collected wastewater to domestic water is ≤35%	1
Below Average	Share of collected wastewater to domestic water is ≤50%	2
Average	Share of collected wastewater to domestic water is ≤65%	3
High	Share of collected wastewater to domestic water is ≤80%	4
Very High	Share of collected wastewater to domestic water is ≥81%	5

No. 6. Age of Water Infrastructure

It is well known that most engineering design has a suggested lifetime or age that must be considered for regular maintenance, extensive rehabilitation, or replacement required before its function deteriorates. Water infrastructure includes reservoirs, storages, distribution systems represented by pipe networks, and WTPs. On the other hand, ignoring the proper action for monitoring and dealing with the issue of old infrastructure age could cause social, economic, and environmental problems. Therefore, it is suggested here to have a specific indicator that can measure the average age or life cycles of pipes, which could be a proxy for the need to rehabilitate or replace water infrastructure. This type of indicator was applied in other frameworks [2,86], which can be a good sign of its importance.

Table 30 is provided below to give an evaluation for each age or lifetime. The lower age in this table was according to Chohan et al. [169], who found that the typical 50-year lifespan of pipeline networks was considered in multiple life cycle assessment (LCA) studies.

Table 30. Scores and their descriptions assigned to evaluate the age of water infrastructure.

Age Level of Water Infrastructure	Qualitative Description	Score
Very Old	Average age of water infrastructure is ≥50 years	0
Old	Average age of water infrastructure is <50 years	1
Below Average	Average age of water infrastructure is ≤40 years	2
Average	Average age of water infrastructure is ≤30 years	3
Above Average	Average age of water infrastructure is ≤20 years	4
Good	Average age of water infrastructure is ≤10 years	5

5. Conclusions, Limitations, and Future Research

Several IBWSFs had, at least in theory, great emphasis on fostering the sustainability of WRM, but a few seem to fall short in evaluating the water sustainability of some ASAR with different conditions. Consequently, the main focus of this study is the GCC countries, which are not only located in ASAR, but are also some of the most water-stressed areas in the world, without any permanent rivers or lakes. As a result, this paper is the first in the series of two articles to develop a new conceptual indicator-based framework (i.e., SWRM-AF) for assessing the SWRM of the domestic sector of GCC countries. Such a framework can contribute to the discussion on what this kind of assessment should cover and act as a more thorough and reliable water sustainability assessment tool than what is now available.

On the other hand, this study is the main result of following specific guidelines and the extensive literature review described here to identify components and indicators that form the conceptual SWRM-AF. Moreover, this framework consists of four components: the environment, economy, and society (i.e., three pillars of sustainability), in addition to the infrastructure, representing the main headings of the framework's structure. Each component is underlaid with six suggested indicators collected from the literature, exemplifying the most critical issues related to the WRM of the domestic sector in the GCC countries. Furthermore, general and specific conditions have been introduced and applied to select individually and collectively the right indicators in order to end with a practical framework.

Probably for the first time, key indicators have been mixed into a single framework for assessing water sustainability. For instance, the intervention acceptability in the social indicators reflects how people can interact with introducing new tools that can reduce water consumption. This type of indicator is important for understanding humans' motivations and barriers to receiving these new changes to either convince them or adjust the changes based on that understanding. In addition, the environmental impact of the desalination treatment plants has been included in two indicators: the discharge rate of brine and the carbon dioxide emissions. Many other IBWSFs did not consider these indicators since they did not have DW as a significant part of their WR. Therefore, the new assessment framework was created to enable a comprehensive analysis of water ecosystems within the context of ASAR.

The main output of this SWRM-AF is a final value that represents the level of sustainability of the WRM of the considered region or country. Therefore, the simplicity of this output can be valuable for decision-makers and stakeholders to let them both obtain a hint about the situation of their WRM. As a result of the two groups being informed, decision-makers can build strategies toward reinforcing indicators performing well and fixing any indicators with flaws hindering the SWRM process. Meanwhile, decision-makers could ensure stakeholders would likely support their recommendations and cooperate to make them successful.

Additionally, a colour-coded table was provided for each indicator, which might aid in giving a clear image of the subject matter of the evaluation. These kinds of tables are useful in enabling decision-makers, users, and representatives of water authorities from any nation in ASAR to easily and reproducibly use the SWRM-AF. Because of its simplicity and reusability, this research can therefore be considered a true contribution to the field of SWRM.

That being said, this research still lacks one of the most important criteria for developing an IBWSF: the participatory approach. This is because this study aimed to introduce the initial version of SWRM-AF for GCC countries based on searching the literature to select appropriate components and indicators. Then, expert stakeholders will be involved in evaluating this selection with their valuable feedback to obtain the final version of SWRM-AF, but this is out of the scope of this paper. In addition, another limitation of this framework is that few indicators were about GW, although it is one of the main WR in the GCC countries. This is because the accurate data were difficult to find during the filtration stage; therefore, some indicators were excluded. Finally, the calculation (or aggregation process) was not explained thoroughly here because of the descriptive nature of this paper. However, the second paper in this series will produce more details since it should end with the final version of SWRM-AF based on the opinions of the expert stakeholders.

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Abbreviations and Notations

Abbreviations

ASAR	Arid and Semi-Arid Regions
BOD_5	Biochemical Oxygen Demand
BW	Brackish Water
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
DW	Desalination Water
DPs	Desalination Plants
EPI	Environmental Performance Index
FC	Faecal Coliform
GCC	Gulf Cooperation Council
GCC UWS	Gulf Cooperation Council Unified Water Strategy
GHG	Greenhouse Gas
GW	Groundwater
IBTs	Increasing Block Tariffs
IBWSF	Indicator-Based Water Sustainability Framework
IWRM	Integrated Water Resources Management
KSA	Kingdom of Saudi Arabia
LCA	Life Cycle Assessment
MCM	Million Cubic Meters
MED	Multi-Effect Distillation
MSF	Multi-Stage Flash
NH_3-N	Ammoniacal Nitrogen
NO_3	Nitrates
NRGW	Non-Renewable Groundwater
NRW	Non-revenue Water
O&M	Operation and Maintenance
pH	Potential of Hydrogen
RGW	Renewable Groundwater
RO	Reverse Osmosis
RW	Renewed Water
RWH	Rainwater Harvesting
SASO	Saudi Arabian Standards Organization
SDG	Sustainable Development Goal
SeW	Seawater
SMART	Specific, Measurable, Achievable, Realistic/Relevant, and Tangible/Time-Bound

Notations

DSW_i	quantity of desalinated water in country (*i*)
$DT_{net\ i}$	net total water demand from all sectors in country (*i*)
$NRGW_i$	abstraction quantity of the NRGW in country (*i*)
RUW_i	reusing quantity of TWW in country (*i*)
$SFWA_i$	availability of surface freshwater in country (*i*)

SW	Surface Water
SWM	Smart Water Meter
SWRM	Sustainable Water Resources Management
SWRM-AF	Sustainable Water Resources Management Assessment Framework
TBL	Triple Bottom Line
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TWW	Treated Wastewater
UAE	United Arab Emirates
UFW	Unaccounted-for Water
WQI	Water Quality Index
WR	Water Resources
WRI	World Resources Institute
WRM	Water Resources Management

Appendix A

All real data belonging to GCC countries will be provided here in tables to let the users of the framework know what type of information they should look for during the application or implementation stage. These tables are presented as follows:

Table A1. DW daily production and the share of using each desalination technology in GCC countries.

Country	**Desalinated Water Production Data of 2020**	**Desalination Technology**	**Country-Wise Share Based on Technology**
	(Million m^3/day)		**(%)**
Saudi Arabia	5.9	MSF	38.2
		RO	51.5
		MED	8.3
Oman	1.18	MSF	19.4
		RO	75.7
		MED	4.9
Qatar	2.16	MSF	63.8
		RO	22.4
		MED	12.5
UAE	7.21	MSF	61.6
		RO	22.8
		MED	15.6
Bahrain	0.82	MSF	26.8
		RO	41.6
		MED	29.5
Kuwait	1.89	MSF	57.7
		RO	29.7
		MED	12.6

Table A2. Standard quality parameters of WW and TWW in KSA [170].

Parameter (Unit) Water Type	BOD$_5$ (Mg/L)	COD (Mg/L)	TSS (Mg/L)	TDS (ppm)	pH (Mg/L)	NH$_3$-N (Mg/L)	NO$_3$ (Mg/L)	FC (Cells/100 mL)
WW	≤500	≤1000	≤600	-	6–9	≤80	-	-
Secondary TWW	≤40	-	≤40	≤2500	6–8.4	≤5	≤10	≤1000
Tertiary TWW	≤10	-	≤10	≤2500	6–8.4	≤5	≤10	≤2.2

Table A3. CO$_2$ emissions per m^3 of produced water for different desalination technologies [171].

Technology	Reverse Osmosis (RO)	Multi-Stage Flash (MSF)	Multi-Effect Distillation (MED)
CO$_2$ emissions (kg CO$_2$/m^3)	0.08–4.3	0.3–34.7	0.3–26.9

Table A4. Standard quality parameters of drinking water [172].

Parameter (Unit)	Turbidity (NTU)	Total Dissolved Solids (TDS) (Mg/L)	Free Cl$_2$ (Mg/L)	pH	Total Coliforms (TC) (Counts/100 mL)
Water supply	<5	<700	0.2–0.5	6.5–8.5	0

Table A5. Examples of required data to calculate the relation between average user income and the water cost *.

Country	Average Household (Year)	Average Yearly Income [d] (USD)	Average Monthly Income (USD)	Average Daily Water Consumption (L/capita/day)	Average Monthly Water Consumption (m^3/House/Month)	Average Water Tariff (USD/m^3)
KSA	5.6 (2010) [a]	27,590	2299.17	278 [e]	46.7	1.07 [g]
Oman	8.0 (2003) [b]	20,150	1679.17	140 [f]	33.6	1.43 [h]
Qatar	4.7 (2012) [b]	70,500	5875.00	512 [f]	72.2	1.51 [i]
UAE	4.9 (2022) [c]	48,950	4079.17	520 [f]	76.4	1.35 [j]
Bahrain	5.9 (2010) [a]	27,180	2265.00	320 [f]	56.6	2.21 [k]
Kuwait	5.8 (2011) [a]	39,570	3297.50	500 [f]	87.0	0.58 [l]

[a] [173], [b] [174], [c] [175], [d] [176], [e] [140], [f] [54], [g] [177], [h] [178], [i] [179,180], [j] [181], [k] [182], [l] [183], * water tariff is different in these countries since some of them charged variable tariff based on specific ranges of water consumption, while some give discounted rate (e.g., UAE) or free of charge (e.g., Qatar) for their citizens, while non-citizens should pay higher amounts.

Table A6. Examples for average water costs, tariffs, cost recovery ratio in GCC countries.

Country	Average Costs of Water Supply (USD/m^3)	Average Water Tariff (USD/m^3)	Average Cost Recovery (%)
Saudi Arabia	2 [a]	1.07 [e]	53.50%
Oman	1.34 [b]	1.43 [f]	106.72%
Qatar	2.74 [c]	1.51 [g]	55.11%
UAE	2.48 [c]	1.35 [h]	54.44%
Bahrain	1.92 [c]	2.21 [i]	115.10%
Kuwait	2.42 [d]	0.58 [j]	23.97%

[a] [184], [b] [159], [c] [185], [d] [186], [e] [177], [f] [178], [g] [179,180], [h] [181], [i] [182], [j] [183].

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