Developing A Sustainable Water Resources Management Assessment Framework (SWRM-AF) for Arid and Semi-Arid Regions

By

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Abstract

The rapidly growing world population highlights the need for evaluation methods like indicator-based water sustainability frameworks (IBWSFs) to assess and improve water resources management (WRM) practices. This is particularly important in arid and semi-arid regions (ASAR) where water resources are scarce. Furthermore, a particular IBWSF that fully fits the context of ASAR could not be found in the literature. Therefore, a sustainable water resource management assessment framework (SWRM-AF) has been developed, specifically tailored to evaluate water use in the domestic sector of countries with similar water conditions to those of the Gulf Cooperation Council (GCC) countries.

The first step in the process of developing the SWRM-AF is to create a conceptual SWRM-AF, which consists of four components (i.e., three pillars of sustainability: environment, economy, and society plus infrastructure) underpinned with 24 selected indicators. These indicators were chosen rigorously through an extensive literature review. Each indicator is provided with a brief description and justification. One contribution of this research is that, for the first time, every indicator is presented with clear and straightforward instructions represented by coloured-code tables to explain how to evaluate each. In addition, social indicators such as the *'intervention acceptability*' and environmental indicators to tackle the impact of the desalination treatment plants have been included to form a more holistic framework applicable to GCC countries.

The second step is to utilise the Delphi technique as a participatory method to refine and validate the conceptual framework. This technique employs an iterative questionnaire to achieve consensus, through which 60 expert stakeholders from the GCC countries were invited to assess each indicator across four components and assign their respective weights. This process, through two rounds, resulted in a final version of SWRM-AF consisting of 4 equal-weight components and 17 indicators. Also, it was found that indicators within the social, economic, and infrastructure components should carry equal weights, while indicators within the environmental component should be assigned different weights.

Lastly, data about the water sector of the Kingdom of Saudi Arabia (KSA), which was selected as an example of GCC countries, were collected to give a comprehensive idea about the overall water situation. Then, an application of the final SWRM-AF to the WRM of the domestic sector of the KSA, focusing on its current practices and assumptions of possible future scenarios, is presented.

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Abbreviations & Notations

Abbreviations		Notations	
ADWI	Abu Dhabi Water Index	C_c	coefficient of agreement
AHP	Analytical Hierarchy Process	DSW_i	quantity of desalinated water
ASAR	Arid and Semi-Arid Regions	DT_{net}	net total water demand from all sectors
AWSI	Arab Water Sustainability Index	i	indicator (or component)
BOD_5	Biochemical Oxygen Demand	I	aggregated indicator (or component)
BW	Brackish Water	j	criteria
CO_2	Carbon Dioxide	N	total number of indicators
COD	Chemical Oxygen Demand	$NRGW_i$	abstraction quantity of the NRGW
CWR	Conventional Water Resources	$RUWi$	reusing quantity of TWW
CWSI	Canadian Water Sustainability Index	S	sub-index value
CVI	Climate Vulnerability Index	$SFWA_i$	availability of surface freshwater
DSR	Driving force, State, Response	V_n	number of experts disagreeing with the dominant direction
DPs	Desalination Plants	V_t	total number of experts
DW	Desalination Water	X_{max}	maximum threshold value
EPI	Environmental Performance Index	X_{min}	minimum threshold value
FC	Faecal Coliforms	Z	category
FHI	Freshwater Health Index		
GCC	Gulf Cooperation Council		
GCC UWS	Gulf Cooperation Council Unified Water Strategy		
GHG	Greenhouse Gasses		
GW	Groundwater		
GWSI	Global Water Security Index		
GWP	Global Water Partnership		
IBTs	Increasing Block Tariffs		
IBWSF	Indictor-Based Water Sustainable Framework		
IIWRM	Indicators of Integrated Water Resources Management		
IRBM	Integrated River Basin Management		
IWRM	Integrated Water Resources Management		
KSA	Kingdom of Saudi Arabia		
LCA	Life Cycle Assessment		
MCM	million cubic meters		
MED	Multi-Effect Distillation		
MEM	Municipal Environmental Management		
MIWABS	Malaysia Manufacturing Industry Water Benchmarking System		
MSF	Multi-Stage Flash		
NH_3-N	Ammoniacal nitrogen		
NO_3	Nitrates		
NRGW	Non-renewable Groundwater		
NRW	Non-revenue Water		
NTU	Nephelometric Turbidity Units		
NWR	Non-conventional Water Resources		
O&M	Operation and Maintenance		
PCA	Principal Components Analysis		
pH	Potential of Hydrogen		
PTT	Proximity-to-Target		
RBWSI	River Basin Water Sustainability Index		
RGW	Renewable Groundwater		
RO	Reverse Osmosis		
RW	Renwed Water		
RWH	Rainwater Harvesting		

RWSI	Rural Water Sustainability Index
SASO	Saudi Arabian Standards Organization
SDG	Sustainable Development Goal
SeW	Seawater
SI	Sustainability Index
SLR	Systematic Literature Review
SMART	Specific, Measurable, Achievable, Realistic/Relevant and Tangible/Time-bound
SW	Surface Water
SWM	Smart Water Meter
SWMM	Stormwater Management Model
SWRM	Sustainable Water Resources Management
SWRM-AF	Sustainable Water Resource Management Assessment Framework
SWWA	Swedish Water and Wastewater Association
TBL	Triple Bottom Line
TBL-MCDA	Hybrid Triple Bottom Line & Multicriteria Decision Analysis
TC	Total Coliforms
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TWW	Treated Wastewater
UAE	United Arab Emirates
UFW	Unaccounted For Water
WASSI	Water & Sanitation Sustainability Index
WEF nexus	Water–Energy–Food Nexus
WJWSI	West Java Water Sustainability Index
WNI	Water Needs Index
WRI	World Resources Institute
WRT	Water Rationalisation Tools
WPI	Water Poverty Index
WQI	Water Quality Index
WR	Water Resources
WRM	Water Resources Management
WSC	Water Sensitive Cities Index
WSI	Watershed Sustainability Index
WStI	Water Stress Indicator
WTP	Water Treatment Plant
WW	Wastewater
WWTPs	Wastewater Treatment Plants

1. Introduction

1.1. Background

Most of Earth's species have a greater need for water for survival than any other element. The Earth possesses a liveable environment primarily characterised by its moderate climate and, of greater significance, the existence of water, a crucial element that is either lacking or yet to be substantiated on any other planets (Kasting et al., 1988; Gonzalez et al., 2001). Water is a finite substance that covers over 71% of the world's surface, but 96.5% of it is saltwater in the seas, and only 3.5% is freshwater (Gleick, 1993). Although this quantity seems small, the availability of freshwater is still sufficient globally, but its distribution is uneven, leading to regions with inadequate water resources for various needs (Cosgrove and Loucks, 2015). Furthermore, there are several types of freshwater, or more broadly, water resources (WR), which are all of the earth's natural waters, whether they are in a vapour, liquid, or solid condition, and are capable of being used by humans (Britannica, 2021). Therefore, it would be essential to deal carefully with these precious WR to ensure the longevity of life on earth for all species.

Meanwhile, not only the small amount of available freshwater (i.e., 3.5%) as a natural resource compared to salty water is part of the dilemma, but the issue is that this amount should serve several competitors such as humans, animals, and plants. Among these users, humans have seen global population growth in the last decades, especially after World War II, which has nearly tripled from 2.7 billion to 7.5 billion (UNDESA, 2019) within a span of seventy years. The observed rise in population and alterations in societal patterns, such as dietary choices, have resulted in a notable strain on several essential natural resources, including but not limited to water, that are crucial for meeting human needs. The requirements mentioned above are classified into three distinct categories, namely basic, psychological, and self-fulfilment needs, in accordance with Maslow's hierarchy of needs (Maslow, 1943, 1954). This study generally concentrates on water, which is often regarded as the first and fundamental basic need for humans to survive.

However, the demand for this resource has experienced an unprecedented surge in recent decades (Falkenmark et al., 1989; Strayer and Dudgeon, 2010; Mekonnen and Hoekstra, 2016) caused by the increase of anthropogenic activities, which includes agricultural and industrial advancements that require more and more water. This might not be a big issue or threat for the rich and developed countries with plenty of WR. Nevertheless, many developing countries suffering from exceptional population growth and increased urbanization (Gain et al., 2016) can end with extreme water demand and stress.

Therefore, adequate planning and management for WR are required to meet these countries' increasing demands and secure their resources in the long term. Prior to delving deeper, it is advisable first to comprehend the meaning of the term 'planning and management of water resources'. Loucks et al. (1981) define the previous phrase as follows:

a) Suitable allocation of water to all users at different locations and times ensures fairness in space and time.
b) Enhancing water systems and strategies to safeguard against water crises such as floods and droughts, primarily focusing on safety and preventive measures.
c) Ensuring the preservation of water quality criteria.

The key points above can be summarised as guaranteeing fair water distribution in terms of space and time, improving safety measures, and assuring water quality. Therefore, it is crucial to consider these factors when developing present and future strategies and regulations concerning water resources in order to ensure their sustainability. Moreover, by appropriately implementing these principles, humanity could protect itself from numerous calamities stemming from the mishandling of WR, including drought, famine, desertification, and erosion.

However, a prevalent issue was observed that many countries around the world, particularly developing nations, lack effective water resources management (WRM) (Tuncok et al., 1999; Björklund, 2001; UNFPA, 2003; Foster and Ait-Kadi, 2012; Mujumdar, 2013). Consequently, many people residing in these countries had experience and/or are likely to encounter significant challenges in the foreseeable future if they are left without obtaining suitable policies, strategic plans, and effective execution strategies that fit with the principles of appropriate WRM.

To overcome such possible obstacles, the Integrated Water Resources Management (IWRM) principle was established in 1992 through considerable collaboration and debates with numerous experts from 100 nations (Hassing, 2009). The Global Water Partnership (GWP) (2000) defined IWRM as "*a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*". According to this definition, an effective WRM system should carefully address three factors: (a) maximising the economic benefits of water, land-use, and associated resources through ensuring the development of the WRM system; (b) ensuring the social well-being and equitable distribution of water among various users; (c) avoiding any harm to the sustainability of ecosystems during the whole process. Thus, considering these factors can assist decision-makers in specific areas or regions in selecting the most suitable option to improve the longevity of their WR and ecosystems. On the other hand, a recent report showed that 185 countries endeavoured for the implementation of IWRM, with 47% of these countries still below average in this trend, while 53% are above average (UNEP, 2021).

In order to achieve the right execution of IWRM, a series of stages towards development objectives have to be followed, as shown in Figure 1-1. Assigning these stages should be planned or done by any country or city's associated governmental body responsible for WRM. To begin, it is necessary to allocate the necessary development targets that would lead to the attainment of the national goals established by the government. The second stage involves assessing the current situation of WR with their management, problems, and circumstances, whereas the third stage entails formulating appropriate policies and strategies to address WR, informed by the findings of the preceding step. Next, the fourth stage involves creating a plan that integrates the fundamental concepts of IWRM with the recommended methods from stage three. This plan should be tailored to suit the specific circumstances of the country or city undergoing the process. Next, the plan's implementation actions would be carried out, and they should comprise the four components inside the middle box of Figure 1-1 when implementing the plan.

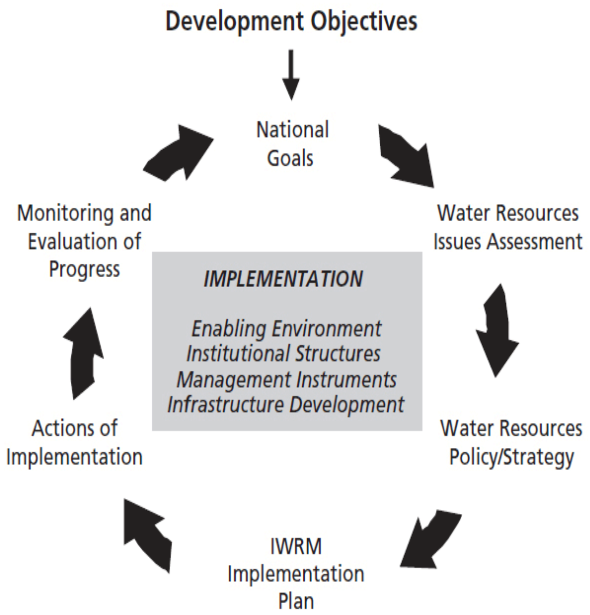


Figure 1-1 Stages required for the planning and implementation of IWRM (UNDESA, 2014)

Ultimately, the final stage towards ensuring the successful completion of national objectives is to closely monitor and analyse the progress in order to align it with the set goals. Nevertheless, due to the limited scope of this research, it will only concentrate first on the second stage in Figure 1-1 (i.e., WR issues assessment), which could arguably considered as the base of the IWRM process. Of course, this stage should align first with the national or global goals that can be set as starting points and targets as well to complete the implementation cycle. Then, the principle of the final stage in Figure 1-1 (i.e., monitoring and evaluation of progress) would be considered to monitor and assess the current practices of the WRM in the domestic sector of ASAR and then compare the result of this assessment with the national goals. This tactic would be based on the notion that it would be challenging to arrive at your destination (or your aims) if you did not know where you are at this moment and which way you are headed. As a result, decision-makers can benefit from the output of this process by providing and designing proper policies and strategies based on solid foundations that can aid in the planning and managing of WR and their systems.

On the other hand, the consequences of global warming and climate change exert additional pressure on WR worldwide (Vörösmarty et al., 2000; Lobell et al., 2008; Mujumdar, 2013). These effects would impact the traditional planning of WR in one way or another. For example, it can potentially cause changes in the quantity and duration of rainfall events, sea level rise, water demands (Frederick and Major, 1997), rising water temperatures, shorter periods of ice cover, severity of floods and droughts, and water-supply shortages (Strayer and Dudgeon, 2010). Hence, it would be wise enough to prepare for such possible changes by taking care of the current practices of WRM and improving any aspect that might be impacted sooner rather than later.

Not only is this the issue, but the circumstances of climate change above have the potential to significantly worsen the situation in Arid and Semi-Arid Regions (ASAR), which are already characterized by a scarcity of natural WR. Arid refers to the climate of places characterised by extremely high temperatures and an annual rainfall of less than 100 mm (Şen et al., 2017). On the other hand, semi-arid refers to locations characterised by annual rainfall ranging from 250 to 500 mm/year (Cirilo, 2008) and hot temperatures but lower than in arid regions. A map of the global distribution of ASAR is presented in Figure 1-2, which shows that they exist on every continent. Both types of regions have greater evapotranspiration rates than precipitation rates (Tyler, 2020), with more possibility of frequent severe droughts and uncommon but significant floods (Jolly et al., 2008). Moreover, these regions are internationally recognised as the most water-stressed places, where the groundwater (GW) stored in aquifers, serves as the main water supply (Almazroui et al., 2017). Nevertheless, since some ASAR exhibit low precipitation levels, and given that rain is crucial for the speed and replenishment period of aquifers, the utilisation of GW is not very sustainable (Shomar et al., 2014; Odhiambo, 2017). In addition, a significant reliance on GW coupled with extensive pumping renders it susceptible to contamination, such as salinity intrusion (Alyamani, 1999; Kinzelbach et al., 2010). Hence, novel solutions and methods are necessary for both the demand and supply aspects, which are essential for any WRM.

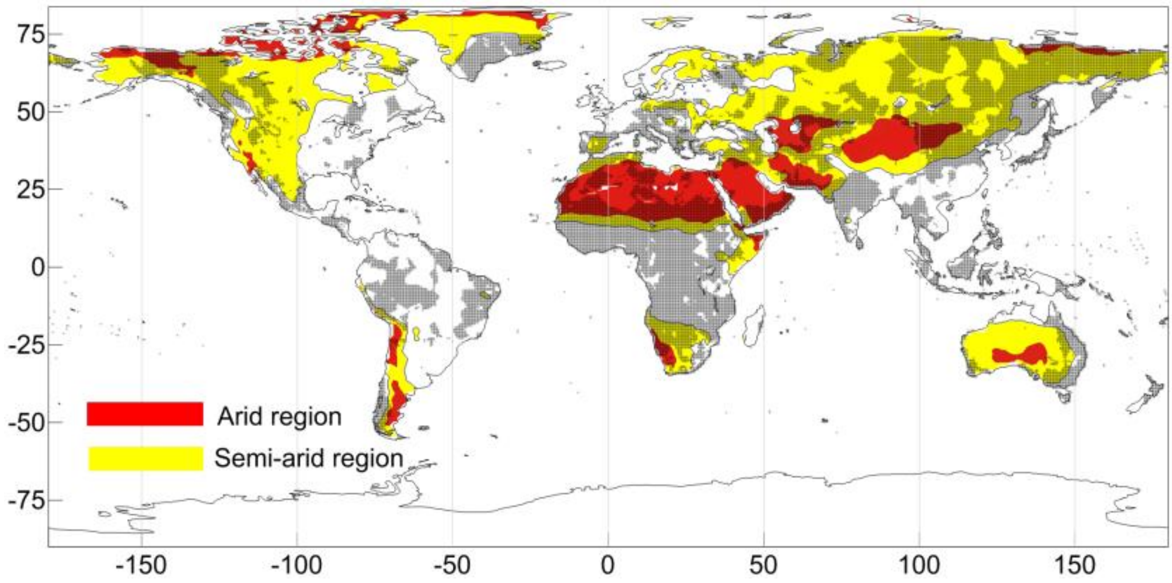


Figure 1-2 Map of the locations of ASAR in the world (Ma and Yang, 2015)

In contrast, many countries in ASAR realised that it is challenging to depend mainly on this conventional resource alone (i.e., GW), and the necessity for developing their existing WR or establishing new ones is crucial. This process is part of what is called water supply management, where there is an inclination to address water constraint issues by increasing the water supply (Cosgrove and Loucks, 2015). On the other hand, conventional WR (CWR) refers to the water sources that are part of the natural hydrological cycle, including rivers, streams, lakes, rainfall, and GW from aquifers (Chen et al., 2021). In contrast, unconventional or non-conventional WR (NWR) is defined as those WR that used to be considered unsuitable or inaccessible, such as seawater, wastewater, and hard-to-reach WR (Brewster and Buros, 1985) and require specific treatment or comparable procedures before use (Indelicato et al., 1993; Karimidastenaei et al., 2022). Therefore, several nations in ASAR either started or should begin soon to use a combination of CWR and NWR to provide new and efficient water supplies that can meet the increasing water demand.

An example of nations that have already started using NWR as main WR and have no other option but to continue is the Gulf Cooperation Council (GCC) countries. This is because the common feature of these countries is that their nature is basically desert without any permanent rivers or lakes, meaning they have generally small amounts of freshwater. Also, these nations are located on the southwest side of the Asian continent, which commonly experiences lengthy periods of drought (Sherif et al., 2023) and is categorized as ASAR. GCC countries consist of six countries: The Kingdom of Saudi Arabia (KSA), United Arab Emirates (UAE), Oman, Qatar, Kuwait, and Bahrain. The map of GCC countries and their capital cities can be shown in Figure 1-3.

Figure 1-3 Map of GCC countries and their capital cities (Encyclopædia Britannica, n.d.)

The main issue with GCC countries, which the research tries to observe, is whether or not their practices related to WRM are sustainable. Historically, much dependence was on GW, as any other ASAR, to cover the domestic and other sectors' needs (Al-Zubari, 2003; Saif et al., 2014; Dawoud, 2017). The overconsumption of this resource has caused different problems, such as aquifer depletion (Shomar et al., 2014), a decline in the water table (Tariq et al., 2022), quality degradation (World Bank, 2005), seawater intrusion (Alyamani, 1999; Al-Zubari, 2003), which makes the whole process unsustainable (Sherif et al., 2023). In addition, the other problem is that since the evaporation rate is high, the recharge rate of the aquifers that contained GW was not ideal (Sherif et al., 2017, 2023).

On the other hand, the discovery of oil beneath GCC nations in the 1970s made GCC countries monetarily affluent and changed their lifestyle and living circumstances. Thus, GCC population rose from 5.34 million to 58.43 million between 1960 and 2020 (World Bank, 2023b). These conditions pushed these countries to find a solution for this dilemma between little supply and huge demand for water. To fill the water supply-demand mismatch, GCC nations find themselves pushed to use NWR like desalination water (DW), which appears now to be one of the most important options. Much of the world in the past could not afford or avoid DW because of its huge economic expenses, but this was not a problem for GCC nations. However, the sustainability of DW, in addition to the other NWR, still needs to be assessed to see whether these solutions have caused another problem or not.

Thus, the importance of developing assessment methods or tools that can tackle the issues of sustainable WRM (SWRM) comes from the fact that it can show how good or bad the situation is based on the number of problems that any WRM system in general is facing. Moreover, these tools can directly or indirectly measure each issue's impact size, which would help prioritise them to be treated and/or improved. This would follow the philosophy that suggested that “what cannot be measured, cannot reliably be improved”, and that science and engineering flourished with the advent of measurement (or evaluating) tools (Kott and Linkov, 2021). Therefore, proper planning with necessary changes and new regulations for the future by relying on such tools is needed and could result in better SWRM for GCC countries.

One of these tools that has been commonly applied during the last two or three decades is the indicator-based water sustainable frameworks (IBWSFs) or indexes. However, even though there might be various frameworks for assessing sustainability, it is unclear whether these tools are appropriate for the context and local characteristics of ASAR. To explain, Alshuwaikhat and Mohammed (2017) argued that a technique (or framework) that is appropriate for one nation may not be effectively applied to another due to the distinct circumstances present in each particular country. For instance, the challenges faced in a region rich in their WR vary significantly from those in a country with a water scarcity situation. Therefore, a special investigation is conducted in this research to make sure that no previous IBWSF have appropriately been done to evaluate the sustainability of WRM in ASAR while considering all their conditions. Then, if this hypothesis is correct, the novelty of this study lies in developing a bespoke IBWSF or a sustainable water resources management assessment framework (SWRM-AF) that is designed especially for ASAR while taking into account all current issues. Of course, SWRM-AF should aim to help measure the required distance of any WRM system toward sustainability.

1.2. Aim and Objectives

This research aim is

'*To develop an indicator-based framework that can assess the current level of sustainability of the WRM system in the domestic sector of some ASAR such as GCC, which could contribute to enhancing the level of sustainability in the near future*'.

In order to achieve this aim, this study will pursue the following six objectives in Table 1-1.

Table 1-1 Objectives, methodologies, and outputs of the research

No.	Objective	Methodology	Research outputs	Chapter
1	To critically review the current SWRM-AFs and evaluate their applicability for special ASAR such as GCC	Review the existing literature in a systematic way	A gap of knowledge in the existing literature	2
2	To develop a new conceptual SWRM-AF for some ASAR, such as KSA	Select the appropriate components and indicators that have been used in the literature and fit the context	A preliminary version of SWRM-AF	3
3	To validate the selected components and indicators that constitute the conceptual SWRM-AF and its application through consulting experts and general stakeholders	Doing a survey by distributing a questionnaire among experts from different backgrounds	Feedback about the SWRM-AF design based on its components, indicators, and their weights	4
4	To refine the SWRM-AF with its final components and indicators and their weights based on analysing the results of the previous objective	Revising the preliminary version of SWRM-AF by treating the results of the questionnaire through the Delphi technique method	A final version of SWRM-AF	4
5	To collect data about the WRM issues of KSA, as an example for some ASAR and GCC, in terms of supply and demand	Review the existing literature and official reports	Required data to apply the SWRM-AF to evaluate the WRM of KSA	5
6	To apply the final version of SWRM-AF to a case study from ASAR (KSA particularly)	Applying the output of Objective 5 to the output of Objective 4	An actual application of SWRM-AF that could illustrate its mechanism to other researchers and water authorities in other countries	5

1.3. Contributions of this Study

The research possesses commendable qualities and makes useful contributions to the current body of literature. To summarise, the following points highlight its merits:

1. The study introduces a framework called SWRM-AF, which can be applied to any current WRM system in ASAR to evaluate the level of sustainability. It is important to mention that this specific and applicable framework is not currently available for ASAR, and particularly GCC countries. Additionally,
2. It outlines the initial framework in these regions, which is based on the three main pillars of sustainability as well as the infrastructure, and includes the impact of using NCW and different issues that are not common in other previous IBWSFs designed

for regions with different conditions; and

3. This framework probably is the first in the GCC region to take into account the expert opinions and their consensus to evaluate all its components, indicators, and their weights prior to producing the final version.

1.4. Organization of the Thesis

The thesis is structured into six chapters. Below is a concise overview of the subject matter covered in each chapter. Table 1-1, previously shown, illustrates the correlation between the study's objectives, research inquiries, chosen methodologies, and the corresponding chapters.

Chapter 1. Introduction. This chapter describes the background of the study, presenting an overview of the principle and stages of IWRM, challenges and concerns related to ASAR, the current situation of water use in GCC countries, the importance of having an appropriate IBWSF that can aid the decision-makers to pursue sustainability. It then outlines the study's aim and objectives and briefly illustrates the methodology steps and outcomes.

Chapter 2. Literature Review. This chapter provides a general overview of sustainability and particularly SWRM. It then illustrates the main elements and guidelines that need to be included and followed in developing any IBWSF. Finally, a systematic literature review (SLR) is provided to check whether the previous studies have provided any replicable (or reusable) IBWSF that can help evaluate sustainability in ASAR, followed by a comparative analysis. All of this was done in order to determine the knowledge gap about the importance of developing a framework that helps in the assessment of SWRM for ASAR in the literature.

Chapter 3. Methodology. This chapter begins with an overview of WRM in the GCC countries in order to clarify what kind of issues they have, and to select appropriate indicators based on that. Then, the methodological stages used to develop the conceptual framework (see Figure 3-4) are explained. Lastly, the suggested components and indicators, which have been collected from the literature based on specific criteria and together form the conceptual SWRM-AF, are illustrated with justifications and explanations for what they should evaluate and how (A coloured code table is presented to help evaluate each indicator).

Chapter 4. Development of the final framework (SWRM-AF). This chapter contains the validation process of SWRM-AF by using Delphi technique as a participatory method, outlining how the two questionnaires were designed within two rounds and how consensus was achieved. The first-round questionnaire was longer since it comprised brief explanations of the framework and each of the 24 indicators. In addition, other introductory, check the understanding, and feedback questions were included. The second-round questionnaire was shorter and focused mainly on areas that did not get enough consensus. Then, the final SWRM-AF, which is based on the expert opinions of the GCC countries as stakeholders, is presented with four components and 17 indicators and their weights.

Chapter 5. Framework Application. This chapter presents and discusses the study findings after applying the WRM system of the domestic sector of the KSA as a case study to SWRM-AF; it also provides different future scenarios to suggest alternative solutions within the case study. It discusses the outcomes of the baseline year and other future scenarios. Finally, it presents the influence of the application of SWRM-AF in helping stakeholders and decision-makers understand the water situation and what affects its sustainability to adopt appropriate solutions that can improve its sustainability level.

Chapter 6. Conclusions The last chapter provides a summary of the PhD research, evaluating the goals and methodological processes outlined in Chapters 2, 3, and 4 that were employed to create the SWRM-AF. Furthermore, it provides an account of the contribution that this research makes to the existing knowledge gap identified in Chapter 2. Furthermore, it delineates the constraints of the study, namely regarding the extent of coverage (or comprehensiveness) of the SWRM-AF. Finally, it presents suggestions for future implementation.

Many parts of this chapter are published in the *Journal of Sustainability* under this title: *Sustainable Water Resources Management Assessment Frameworks (SWRM-AF) for Arid and Semi-Arid Regions: A Systematic Review*

2. Literature Review

This chapter reviews the following concepts from the literature:

2.1. Sustainability concepts and its three pillars;

2.2. Sustainable Water Resources Management (SWRM);

2.3. Assessment frameworks for SWRM;

2.4. Main elements of an indicator-based assessment framework;

2.5. Systematic literature review;

2.6. Summary and Conclusions.

The review examines the principles of sustainability in combination with WRM, as well as their implementation through frameworks and guidelines. In addition, an explanation for the main elements that together represent any IBWSF is presented. Another objective of this review was to identify strengths, deficiencies, similarities, and differences in the existing literature regarding several IBWSFs. The main purpose of this review is to evaluate their utilisation for ASAR specifically. Through a systematic assessment, studies examining SWRM frameworks in the context of ASAR were identified and analysed. Please refer to Section 2.5 for more details.

2.1. Sustainability Concepts and its Three Pillars

The water cycle and its influence on interconnected ecosystems exemplify a long-standing, sustainable process that has endured for millions of years. Nevertheless, the present water requirements and worldwide climatic alterations are affecting its capacity to sustain this status (Ni et al., 2012; Castro et al., 2017). The use of the terms "sustainability" and "sustainable development" has become ever more popular since Brundtland's (1987) definition: *"The ability of the present generation to meet their needs without endangering or compromising the ability of future generations to meet their own needs"*. This is particularly crucial for SWRM in ASAR, as the depletion of GW is increasingly affecting the capacity of future generations to get water and fulfil their requirements, which, due to population growth, will be greater than the present.

Elkington (1997) proposed a breakdown for the definition or idea of sustainability and expressed it as follows: "Sustainability *aims to ensure that the range of economic, social, and environmental options would stay open and not limited for the future generations because they were not hindered by the current human actions*". The previous definition has coined the principle of the *'triple bottom line'* (TBL) concept, where equal significance should be given to environmental, social, and economic aspects during the decision-making process (Pope et al., 2004). Therefore, the concept of sustainability became commonly acknowledged to be based on three fundamental pillars or dimensions: the environment, the economy, and the society (Basiago, 1998; Stirling, 1999; Lehtonen, 2004; Gibson, 2006; Kuhlman and Farrington, 2010). In other words, to achieve a sustainable system, it is crucial to safeguard its environment, ensure economic viability, and prioritise social equality and acceptance to the greatest extent possible.

However, there are different theories behind these pillars and how they should be connected or interact, as seen in Figure 2-1. The three intersecting circles form, which can be seen on the left side of Figure 2-1**,** is found in several shapes in the academic and grey literature as a visual representation of sustainability (Purvis et al., 2019). The second form, which is the nested concentric circles, describes how each pillar is contained by another pillar or dimension, where it seems that the combination of them would represent sustainability. These circles might imply that the environment, which includes anything surrounding us, such as the air, land, water, and creatures, is the base, while society, which lives in and needs to trade, comes next, followed by the economy. Lastly, the third shape illustrates that sustainability stands on three foundations or legs, where the lack of consideration of any of them in any system would not make it sustainable.

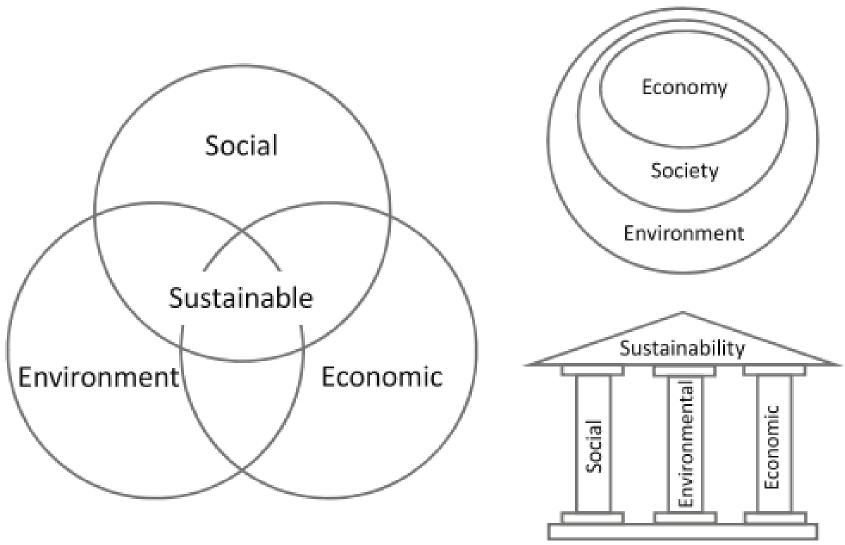


Figure 2-1 Three shapes to describe the relation between pillars of sustainability (Purvis et al., 2019)

Concurrently, the significance of attaining equilibrium (as opposed to a compromise or trade-off) among these aspects of sustainability has sparked extensive deliberation (Purvis et al., 2019; UN, 1997b; Moldan et al., 2012; Maiolo and Pantusa, 2019). For instance, the sale of water in plastic bottles is advantageous for companies in terms of profitability and fulfils the social demands of numerous individuals. Nevertheless, if the bottles are not recycled, this company has a detrimental impact on the environment. Thus, in order to optimise the sustainability of any given system, it is imperative that all three pillars are maintained in equilibrium.

2.2. Sustainable Water Resources Management (SWRM)

2.2.1. Overview

There is urgent and great importance for considering the enhancement of sustainability level as a target for WRM systems (or SWRM) in ASAR, where GW is becoming depleted, negatively impacting the ability of future generations to draw down water and meet their needs—which due to growing populations, will be greater than today. In general, efforts to appreciate the positive impact of sustainability have paved the way for the introduction of 17 sustainable development goals (SDGs), the sixth (SDG6) of which is to "*ensure availability and sustainable management of water and sanitation for all*" (United Nations, 2015). Therefore, it can be said that this study is of immense value and driven by a global objective, and it has never been more relevant in ASAR.

SDG6 became more significant after the global impact of climate change on WR. Over the past few decades, the scientific community has organised numerous meetings and performed extensive studies to examine the repercussions of this pattern (GWP-TAC, 2000; Hanjra and Qureshi, 2010; Allouche, 2011; Vörösmarty et al., 2013; Cuthbert et al., 2019). One of the early attempts to deal with this issue was in 1992 during the International Conference on Water and the Environment (ICWE, 1992), which ended with the declaration of the four Dublin principles, summarised as follows:

1. "Fresh water is a finite and vulnerable resource, essential to sustain life",
2. Water in general "has an economic value… and should be recognised as an economic good" where,
3. Any "development and management" for water "should be based on a participatory approach … at all levels" without ignoring that,
4. "Women play a central part in the provision, management and safeguarding of water".

While all these principles are essential, the focus of this research will be on the third one.

This is because it informed one of the main strategies to enhance WRM and ensure the continuity of WR (i.e., participation of stakeholders).

2.2.2. Definitions

Although sustainability was defined in Section 2.1, it is crucial to provide more precise definitions for terms used in this study, particularly WRM. WR encompass all forms of natural water found on Earth, including atmospheric water vapour, surface water (SW) bodies like oceans and rivers, and GW reserves. These water sources have the capacity to be utilised by humans (Britannica, 2021). Furthermore, management can be briefly described as the process of effectively overseeing and controlling a particular entity or activity. Regarding WRM, these concepts specifically relate to the supply and demand for water, as well as any associated issues.

Moreover, the definition of WR encompasses both freshwater and saltwater ecosystems that are influenced by the hydrological cycle and the activities of other species. Humans have the ability to influence the well-being of natural resources through their use, but what exactly does it entail to ensure the sustainability of this process?

Gleick et al. (1995) defined sustainable water use as: "*the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it*." (Gleick et al., 1995) (p. 24).

Nevertheless, it is the actions of humans that have the most profound influence on the ecosystem as a whole, and specifically on WR (Vörösmarty et al., 2000; Cosgrove and Loucks, 2015; Ivanova et al., 2016). The anticipated consequences on WR are projected to amplify in the future, leading to heightened unpredictability in terms of water availability, increased occurrence of severe weather events such as droughts and floods, and accelerated evaporation of SW resources (Cosgrove and Loucks, 2015). Therefore, it is crucial to thoroughly plan for these potential risks before or when they escalate in order to enhance the SWRM systems.

Consequently, by merging the three definitions for the three terms (i.e., sustainability, water resources, and management), we may offer a potential explanation for SWRM. The purpose of this definition is to facilitate comprehension of the aim by stakeholders with diverse backgrounds, hence enhancing the communication process and fostering trust and cooperation. This possibly has been done by the definition of IWRM (See Section 1.1), and it is generally recognised and universally acknowledged by the scientific community. However, the primary objective of IWRM's definition is to optimise the advantages for the economy and society while ensuring the preservation of the ecosystem and environment. Meanwhile, one may contend that the objective of sustainability differs slightly, as it focuses on achieving the most favourable outcome (i.e., optimising) for all three dimensions (i.e., economy, society, and environment) in a harmonious manner. Thus, the proposed definition for SWRM employed in this research is *"to ensure that the current management of water resources meets the need of the present generation in a way that balances between social, economic, and environmental factors, avoiding negatively impacting future generations' capability to meet their water needs"*. It is worth noting that while acknowledging the difficulty of identifying future demands, it is important to utilise several types of foresight to forecast them accurately. This definition necessitates a dissection into multiple objectives or components that underlay with indicators and sub-indicators, which all together can form an IBWSF, for assessing the performance of SWRM.

2.3. Assessment Frameworks for SWRM

To improve the sustainability of any WRM system, it is crucial to have an appropriate amount of different related indicators (i.e., quantitative and qualitative), metrics, and benchmarks contained within an assessment framework or index in order to help decision-makers and concerned stakeholders determine the current level (or performance) of their SWRM and improve it accordingly, should it be underperforming (Juwana et al., 2012; Bertule et al., 2017). (N.B. The terms framework or index are used interchangeably within the literature; however, in this research, they are considered to be one and the same.) An indicator is something that '*helps you understand where you are, which way you are going and how far you are from where you want to be'* (Hunt et al., 2008). The function of indicators is to help narrow down and sum up numerous data into one or few numbers and metrics that would be easier for both stakeholders and decision-makers to follow. Therein, metrics *'give a unit of measurement to indicate progress against that criterion*' (Hunt et al., 2008).

Given the diverse applications and various interpretations of sustainability as a goal, Iribarnegaray et al. (2012) contend that the intricate relationship between culture and nature, considering their spatial, temporal, and personal aspects, poses a challenge in formulating a singular definition of sustainability that can effectively address specific environmental and social issues within different contexts. Hence, it would be more advantageous to treat each distinct domain that exhibits shared characteristics, such as WRM systems, on an individual basis. This can be accomplished by evaluating sustainability in such systems as quantifiable or, more significantly, within the realm of specific, measurable, achievable, realistic/relevant, and tangible/time-bound (SMART) goals. Hence, it is imperative to consider all components of a SMART goal when constructing the practical sustainability assessment framework.

Conversely, there may be inquiries regarding the definition of 'sustainability assessment' and its relevance to WRM. Sustainability assessment is: *"...a process to determine whether or not a particular proposal, initiative or activity is, or is not, sustainable"*(Pope et al., 2004, p. 607). Also, sustainability assessment frameworks 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.*"(Devuyst et al., 2001, p.9). Hence, the WRM system encompasses several operations that necessitate measurement and evaluation. This aids water authorities and stakeholders in selecting appropriate actions and implementing effective management techniques to promote sustainability. Moreover, it is essential to consider the sustainability assessment of WRM as a strategy to promote any community's growth and development. In contrast, disregarding such a strategy would lead to many challenges in the near future and could worsen the WR situation annually.

On the other hand, since there are several global threats to SWRM, such as climate change and population growth, some studies emphasized the need to incorporate resilience into any SWRM assessment framework (Hashimoto et al., 1982; Butler et al., 2017). Simply, resilience can be defined or described as: "*the degree to which the system minimises level of service failure magnitude and duration over its design life when subject to exceptional conditions*" (Butler et al., 2014). Therefore, including this principle, whether implicitly or explicitly, could strengthen these frameworks and prepare their users to handle a variety of different situations.

Moreover, since the target of this research is to develop an IBWSF for the WRM in ASAR, a question might be given about what indicator means and what its function is to guide the process. Indicators present data about the case of a phenomenon (Guy and Kibert, 1998), used mainly to measure/assess progress toward sustainability (Hiremath et al., 2013). Furthermore, the benefit of creating an indicator-based framework is its capability to evaluate and clarify multidimensional aspects or ideas that cannot be easily quantified (Sullivan, 2002) and cannot be understood by only one component or indicator (Nardo et al., 2005). Hence, complicated systems like WRM, which has several aspects and impacts, require this type of tool (i.e., IBWSF) to be evaluated.

While these definitions and instructions can help give a general perspective on any framework, it is still important to know what the main elements are that can constitute the IBWSF. These details are provided in the next section.

2.4. Main Elements of An Indicator-based Assessment Framework

Prior to constructing or developing any evaluation framework, it is crucial to acknowledge and identify its fundamental elements. This method would guarantee that the framework or index is built with utmost clarity and a solid underlying basis. Hence, the indicator-based assessment framework encompasses seven key features, which are delineated succinctly below and drawn upon by the examination of relevant literature.

First of all, it can be said that any sustainability framework (or index) is constituted of several key parts: (1) a set of headline categories (components), (2) a set of underpinning indicators for each component, and (3) a set of second-order and possibly third-order sub-indicators (Juwana et al., 2012). To explain, a visual illustration is presented in Figure 2-2, where the components are represented by the blue boxes, the indicators by the green ones, and the sub-indicators by the orange boxes. It can be observed that the framework is in a hierarchy shape, where the aggregating (or calculations in the red arrow in Figure 2-2) direction is a bottom-up process. A particular calculation method (i.e., normalization) to have an equivalent value for each indicator and sub-indicator would be applied. This is because some indicators and sub-indicators have different metrics or units, and they need special treatment or processes to be calculated, such as normalization. Then, the aggregation and the weight of the output value of each sub-indicator would produce the indicator value. The same process is applicable for the resultant values of indicators and components in obtaining the final value of the framework (i.e., the top yellow box in Figure 2-2). More details about each element in Figure 2-2 will be presented in the next sections.

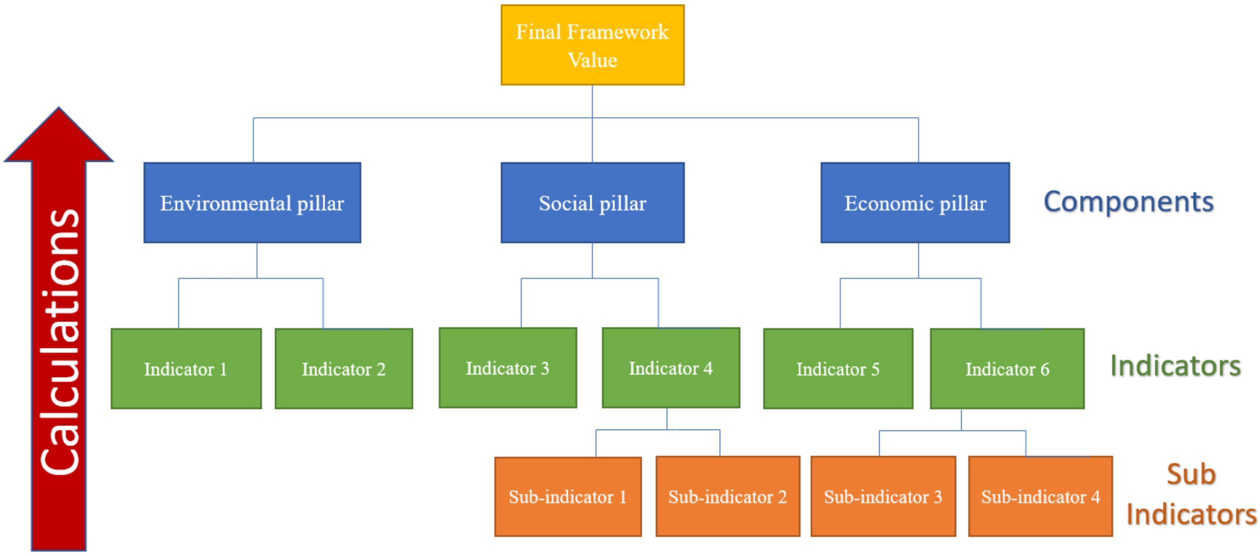


Figure 2-2 Visual illustration of an IBWSF

2.4.1. Indicator

The first element in forming an assessment framework or index is the indicator itself, which has the feature of being able to:

- combine with other indicator(s) to produce a component, and/or
- split to create more sections related to the same indicator, with each branch called a sub-indicator.

Indicators and sub-indicators are often objective and quantitative—representing a quantity or change based on metrics (e.g., water leakage rate [%], litres of water per person [l/p]). They may also include other aspects, such as area (e.g., [l/m^2]) or time periods [l/p/d] [l/p/yr]). On the other hand, they can be qualitative and subjective—dealing with cases that cannot be measured by a number, such as opinions, which differ from one person to another (Bertule et al., 2017). For example, they may be elicited by such questions as "How happy are you with your water provider (5 being very happy and 1 being very unhappy)"? However, in several SWRM frameworks in the literature, the value of a qualitative indicator or sub-indicator is converted into a number based on pre-defined conditions or criteria to simplify the aggregation process, enabling the calculation of a final equivalent score for each component (Chaves and Alipaz, 2007; Juwana et al., 2016a; Silva et al., 2020b). In general, combining the two types or classifications of indicators in the SWRM frameworks is not uncommon (Juwana, 2012), although using only one or the other is more popular (Chaves and Alipaz, 2007; Juwana et al., 2016a; Silva et al., 2020a)..

2.4.2. Benchmark

The second element of the indicator-based assessment framework is the benchmark or target (i.e., an aspired level of performance) with which any indicator and sub-indicator is usually measured or compared (Liverman et al., 1988; Policy Research Initiative, 2007; Bertule et al., 2017). For example, if the current domestic potable water consumption of a country is 160 L/capita/day, a baseline and specific range (i.e., roadmap and timeline) of values can be developed from any related benchmark to achieve the end goal, which might be to reach 120 L/capita/day by 2025 and 80 L/capita/day by 2040. This process is considered helpful for stakeholders and decision-makers to gain more comprehensive knowledge about the output of these indicators and enhance their contributions to moving towards, rather than away from, such an end goal.

2.4.3. Application Scale

Another vital element of the indicator-based assessment framework that needs to be carefully dealt with is the application scale. The scales assigned in the literature for SWRM indices in descending order are usually global, national, territorial (or regional), local, and community scales, in addition to river basins. Indeed, it is important to understand that the application of each scale might require different criteria and specific guidelines for the selection process of indicators that would form a suitable framework. For example, the Water Poverty Index (WPI) (Lawrence et al., 2002) has two different versions/values of the same indicator because of the scale change. In other words, the original version was on a global scale with specific indicators of commonly available data among countries that can serve for this scale (Lawrence et al., 2002), while the second version was on a community scale, adding and removing some indicators to fit with the requirements of the case studies (Sullivan et al., 2003). Therefore, knowing the appropriate application scale is essential to select the right indicators and to collect the appropriate data.

2.4.4. Normalization Method

The fourth element of the indicator-based framework is the method of calculating sub-index values, or the normalization method (i.e., obtaining equivalent component values for each set of indicators and their following sub-indicators if applicable, as shown above in Figure 2-2). Before going further, it is essential to note that many indicators under the same index or framework would have different unit values. To illustrate, the water coverage or access indicator, which is common to numerous sustainable water indices, is usually measured as a percentage (%) of people who already have (or are connected to) the water service. On the other hand, the water quality indicator, which is also popular, is typically quantified by a unique summation of different sub-indicators. For instance, water turbidity, which refers to the solution's spectral light absorbance property, or "transparency", and is measured in nephelometric turbidity units (NTU), while another sub-indicator is the concentration of total suspended solids (TSS), measured in (mg/l) (Parnian et al., 2021). Furthermore, if these indicators (i.e., water coverage and water quality) are categorized under one component with different unit values, they cannot be aggregated or compared directly. Therefore, a particular method to combine and compare their values as a normalization process should be chosen based on the features of the data and the goal of creating such a framework (Juwana et al., 2012; Nardo et al., 2005). There are two widely used normalization methods in the literature for sustainable water indices addressing the issue of calculating the sub-index values:

(a) continued re-scaling (Lawrence et al., 2002; Policy Research Initiative, 2007), and

(b) categorical scaling (Chaves and Alipaz, 2007; Silva et al., 2020b).

The first method is also referred to as empirical normalization (Shilling, 2013). This method is proposed to re-scale the actual values of indicators by converting them mathematically into comparable numbers belonging to an identical interval of numbers ranging from either 0 to 1 or 0 to 100, based on the Equations (1) and (2), respectively (Juwana et al., 2012):

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \times 100 \quad (2)$$

Where S_i is the component value for indicator *i*, X_i is the actual value for indicator *i*, and X_{min} and X_{max} are the minimum and maximum threshold values of the indicator, respectively, or in some cases, it can be said that X_{min} is the least preferred value and the X_{max} is the most preferred value, which means that to be able to use this method, the threshold values including the minimum and maximum should be identified for each indicator (Juwana et al., 2012). The advantage of this method is that it is easy and efficient in comparing the initial state of the indicator with alternatives (Shilling, 2013). Overall, this method might be more applicable when the assessment framework has a majority of quantitative indicators in terms of their data.

The second method to obtain equivalent indicator values is categorical scaling, where the values of indicators are categorised and assigned based on pre-defined criteria (Juwana et al., 2012). These categories can be numbers, such as from 1 to 5, or descriptions and opinions, such as "low", "medium", or "high".

The general Equation (3) for using this method is presented below (Juwana et al., 2012):

$$S_i = \begin{cases} Z_j & \text{if } X_i \text{ meets criteria 1} \\ Z_j & \text{if } X_i \text{ meets criteria 2} \\ \dots & \dots \\ Z_n & \text{if } X_i \text{ meets criteria } n \end{cases} \qquad (3)$$

Where S_i is the component value for indicator i, X_i is the actual value for indicator i, Z_j *is* the category for X_i that meets criteria j, and n is the number of categories. Overall, this method has the advantage of being able to work on both quantitative and qualitative data. For instance, because of the diversity of scales and units in their indicator-based system, Silva et al. (2020) used a quali-quantitative scale working as a normalization step to aggregate and compare contrasting model elements.

2.4.5. Weighting Scheme

The fifth element of the indicator-based framework is the weighting scheme that should be considered before doing any aggregation for the product of the previous element (i.e., the normalization method). The weighting scheme is a process of multiplying each part of the indicator-based framework or index by a value representing its importance or weight during each calculation stage to get the final index number. These weighting techniques are classified in general, according to Nardo et al. (2005), into two broad categories: a) statistical-based methods, where weights are given based on the analysis of the indicators' data (e.g., (Hashimoto et al., 1982; Loucks, 1997; McMahon et al., 2006; Sandoval-Solis et al., 2011)), and b) participatory-based methods, where weights are assigned based on the preference of expert decision-makers or stakeholders (Moglia et al., 2012; Criollo et al., 2019; Crispim et al., 2021).

However, since the first approach is not used in most frameworks covered in this study, it is considered out of the scope of this current research. In addition, the participatory-based methods are preferred to be used in SWRM because they match the Dublin principles' requirements and the definition of the IWRM. Moreover, participatory processes in these assessment types proved valuable and tended to lead to system change through cooperation (Rijke et al., 2013; Rogers et al., 2020). Nevertheless, it is mandatory prior to using the participatory-based methods to consider providing appropriate justifications for the type of experts or people who have been selected. Not least, since this process might involve subjective judgment (Juwana et al., 2012) and bias.

Furthermore, the weighting distribution scheme can be classified based on the literature of sustainable water indices, particularly in the participatory-based methods, into two schemes:

a) Equal weights scheme and

b) Non-equal weights scheme.

According to Nardo et al. (2005), most of the composite indicators, in general, have historically relied on equal weighting, and this also applies to some WR sustainable indices (Chaves and Alipaz, 2007; Silva et al., 2020b; Lawrence et al., 2002; Policy Research Initiative, 2007). Indeed, it might be argued that a truly sustainable assessment system should equally balance sustainability's main pillars without giving lower attention or introducing bias toward one aspect. For example, the economic cost and return of WRM and their environmental impacts might be better to be treated equally.

2.4.6. Aggregation Technique

The sixth element of the indicator-based framework is the aggregating methods for the values of sub-indicators, indicators, and components. There are two common aggregating techniques, which are usually linked to the weighting schemes. The first one is the arithmetic (or linear) method, where all the output values of the indicators (or sub-indicators) would be summed and then divided by their numbers to get an equivalent value for each component (or indicator). This method is commonly called the mean or the average, which has the advantage of being simple, and the disadvantage of being sensitive to outlier values. The general expression for this method is shown in Equation (4) (Swamee and Tyagi, 2000):

$$I = \sum_{i=1}^{N} w_i \, S_i \tag{4}$$

Where I is the aggregated component (or indicator), N is the total number of indicators (or sub-indicators) that needs to be calculated, S_i is the sub-index for the indicator i and w_i is the weight of indicator i. Another feature of this method is that it can ensure perfect substitutability and compensability among sub-index values (Nardo et al., 2005). However, this method was criticised since it might hide or compensate for the poor (or low) indicator quality if combined with a high-quality one (Swamee and Tyagi, 2000; Juwana et al., 2012).

The second method is the geometric aggregation method, where all the weighted sub-index values are multiplied instead of being summed as in the athematic. Then, the result is powered by the inverse of their total numbers. Moreover, the geometric aggregation method does not have the feature of creating perfect substitutability and compensability among the sub-index values (Juwana et al., 2012). The Equation (5) for using this method is (Swamee and Tyagi, 2000):

$$I = \prod_{i=1}^{N} S_i^{w_i} \tag{5}$$

Where the symbols for Eq. (4) are the same for the ones in Eq. (5), meanwhile, the weights (w_i) in both equations reflect the relative significance of S_i, and the summation of these weights should always equal one (Swamee and Tyagi, 2000).

2.4.7. Final Framework Value

The seventh element of the indicator-based framework is the final index value, which is the final goal of having an index. This element is usually represented by one number, and it is the final score of the standardised procedures of the fourth, fifth, and sixth elements of the indicator-based framework (i.e. normalisation method, weighting scheme, and aggregation technique, respectively) (Bahar et al., 2020). This number is most likely to be from 0 to 100 or 0 to 1. The benefit of having such a number is to make the result of the whole framework easy to understand, not least by a range of different stakeholders, without the need for a more detailed assessment.

To sum up, it can be said that there are seven main elements of any practical indicator-based assessment framework that should be considered during the process of making composite indicators in general or sustainability index in specific. The first and the most significant element is the indicator itself which can be combined with another or split into different sections under a common factor or category. The second element is the benchmark or the thresholds that set the boundaries for the re-calculation of the indicator. The third element is the application scale, which can differ from global or national to local with special requirements for each type. The fourth element is the method of getting the sub-index values or the normalisation process, where a particular function is selected and applied to produce equivalent values that can be easily compared and aggregated. The fifth and sixth elements are the way of calculating the index value cumulatively based on the weighting scheme, which is given based on the relative importance of sub-index and can be equal or non-equal and the aggregating methods, which can be arithmetic or geometric. The last element is the final index value, which is one of the primary purposes of creating an indicator-based framework. All these elements with their descriptions and functions are summarised and presented in Table 2-1.

Table 2-1 Summary of the description and function of the seven main elements of the indicator-based framework

	Element	Description/function
1	Indicator	• Indicates the measurement of something • Used to present data (quantitative or qualitative), • Can be combined to represent the same component or category, also can be split into sub-indicators.
2	Benchmark	• The threshold or interval needed to measure the performance of 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: 1) continued re-scaling (usually better with quantitative data), 2) categorical scaling (better with qualitative, but can serve both)
5	Weighting scheme	• 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 one
6	Aggregation technique	• It reflects how the summation of the product of indicators and their weights should be done • 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 • Represent the final and most important output of any framework

		• Usually it is a number from 0 to 1 or 100

2.5. Systematic Literature Review

After the previous brief exploration and explanation of the main elements of the indicator-based assessment framework, it would be helpful to conduct a SLR to any existing IBWSF. The main purpose of this SLR is to check whether these frameworks are applicable or not to arid and semi-arid regions. This section is vital to find any limitation or knowledge gap(s) in their application and whether they would be suitable to be used in other case studies with different local contexts and conditions. For this reason, a specific search in the literature is conducted in this study for every IBWSF available since the year 2000 up to the end of 2021. Key objectives in the form of questions for the research include:

- Since the turn of the century, what indicator-based frameworks and/or indices have been used to assess the sustainability of WRM?
- What similarities and differences exist amongst indicator-based sustainability assessment frameworks of WRM, such as the number of components (and indicators) and the scaling, aggregating, and weighting methods?
- How effective are the current water resource indices or frameworks in assessing the sustainability of WRM in ASAR?

By answering these questions, it would be possible to ascertain whether a bespoke SWRM framework were needed within the context of ASAR.

2.5.1. Methodology

To answer the previous questions posed in the previous section (i.e., Section 0), a systematic literature search using the two well-known databases Scopus and Engineering Village was conducted to check relevant studies. In the first stage, a group of pertinent keywords were identified and used to search databases using the title/abstract/keywords included in the papers. The first step required a filter, since the area of sustainability is extensive within the literature. Moreover, looking through a confined yet credible quantity for a literature review paper is crucial. Before starting the initial automatic search, inclusion and exclusion criteria needed as screening stage to be assigned and followed generally. Therefore, the scope of this search was exclusive to peer-reviewed articles and peer-reviewed conference papers. Additionally, the search had two conditions for all included documents: (a) documents should have been produced in the period from 2000 to 2021 and (b) documents should be written in the English language only. This period was selected because several frameworks for assessing the WRM system were produced after 2000. Furthermore, the inclusion and exclusion criteria are consistent with the method applied by other authors, such as Topal et al. (2020). This method uses a four-step clustering algorithm (i.e., Scope, Target Group, Subject Domain, and Methods) to narrow the research area. This narrowing process would mean excluding, to some degree, any unrelated studies by using the OR operator within each category's keywords and the AND operator within each cluster. The idea of this process is straightforward, requiring all studies covered in this review to be included in the intersection area of all four clusters.

2.5.1.1. ***Keyword Selection***

In the Scope cluster, many terms mainly related to sustainability and WRM were used to define the largest frame with which the search should start. These specific terms and their derivatives were *"#water resources management", "#water management", "#water shortage", "#water assessment", "#SWRM", "#sustainable assessment", "#sustainable measurement", "#water sustainable index", "#sustainability principles", "#sustainable development"*.

The Target Group of this study concerned the primary sectors that received water or were affected by any decisions related to its supply and demand. The main terms used for the Target Group cluster were: *"domestic water", "municipal", and "stakeholder"*.

The Subject Domain keywords were specific for the required method and its main parts that could evaluate the combination of the Scope and the Target Group and the geographic areas that needed to be investigated. The terms used in this search for these purposes were *"indicator", "indicator-based", "framework", "criteria", "index", "component", "arid", and "semi-arid"*. It is worth mentioning that this category (i.e., Subject Domain) was used twice in the exact search. The first one included all required fields (i.e., Subject/Title/Abstract in the Engineering Village database, and Title/Abstract/Keywords in the Scopus database). The second one was only in the title, that is, one of the keywords needed to be in the article's title. This action was essential to reduce the enormous number of unrelated studies.

The fourth group, the methods of data collection or treatment based on the participatory approach, was assigned. The terms included in this cluster were *"survey", "interview", "questionnaire", and "participatory"*.

2.5.1.2. ***Database Search***

The search through the Scopus and Engineering Village databases was undertaken on the 14th of October 2021 and returned with 1428 and 1316 articles, respectively. However, the Engineering Village database was a combination of three databases: (1) Compendex, (2) GEOBASE, and (3) Inspec. For this reason, many of the 1316 articles were duplicated in the search output. Fortunately, the search engine had a feature to remove these duplications, and the number was subsequently reduced to 721 articles. This result, plus that from Scopus (i.e., 2149 articles) were merged in EndNote Library, which also has the advantage of automatically removing duplications, reducing the total number to 1627 articles in this identification stage. Among these papers, 174 were conference papers, while the remaining were peer-reviewed articles. Then, the screening stage is required to keep only relevant research. This includes other inclusion and exclusion criteria. Under these criteria, any articles unrelated to the main scope (i.e., both WRM and sustainability), whether directly or indirectly, would be excluded right away. For example, many articles related mainly to the medical, education, and energy sectors were removed. In addition, if this criterion were applicable, another specific check was required to ensure that these studies had considered a framework or index by mentioning that clearly in either the title or the keywords. Consequently, both conditions were applied in the first screening stage by checking each title and all keywords of the 1627 papers. This stage resulted in a reduction in the number of articles to 400. In the second round, abstracts were investigated concerning the target group and main elements of the subject domain (i.e., indicator, indicator-based, and component). The results dropped to 45, where most of these articles seemed to be eligible. Furthermore, this round was supposed to be the last round, but after checking some articles among the 45, it appeared they lacked an applicable framework or index that included specific indicators. Therefore, a final round was added to skim-read each of the 45 papers and ensure that they contained these essential elements to be included in the full-text review. Consequently, 23 studies were selected to be included in the analysis. All these screening and assessing stages were summarized and illustrated below in Figure 2-3.

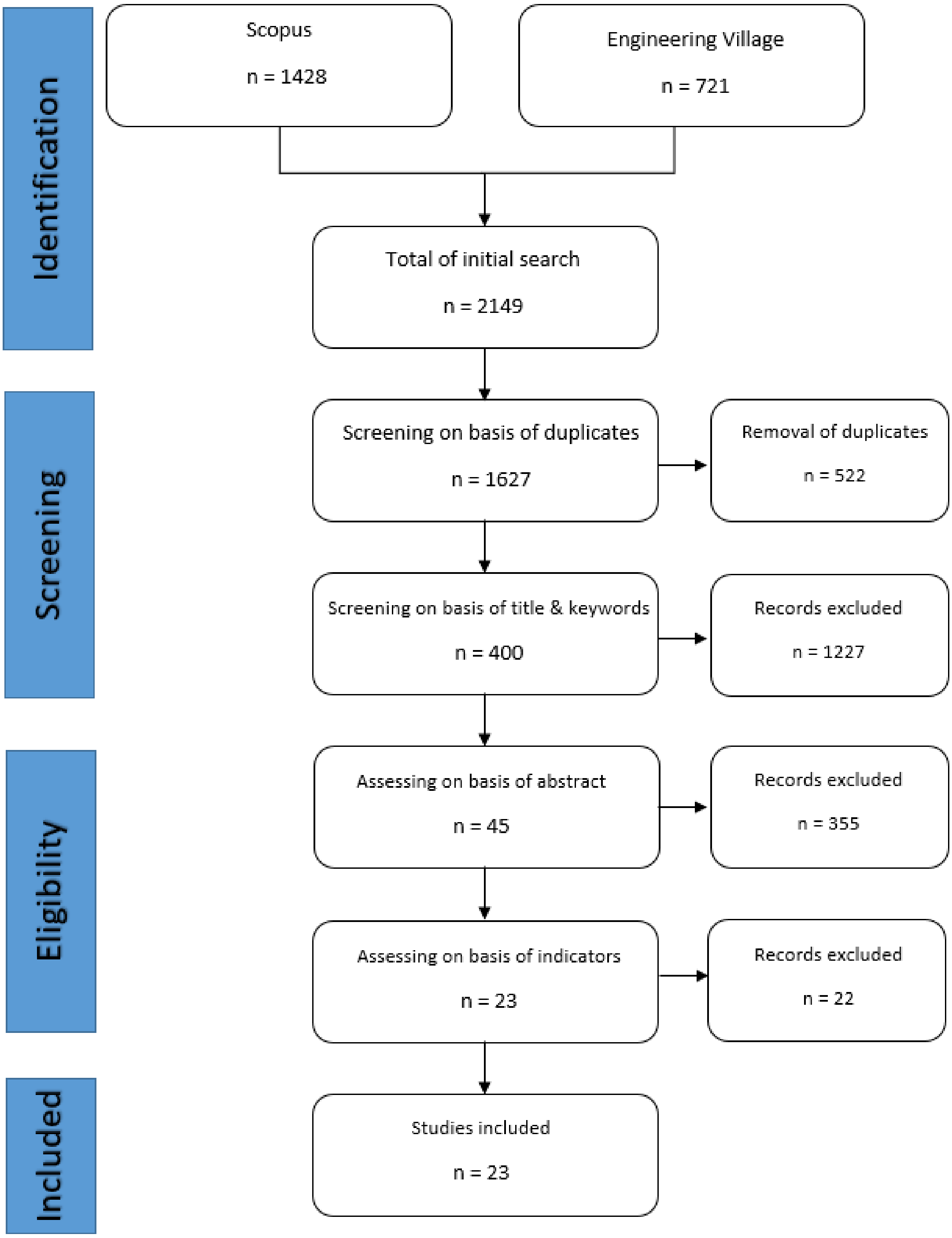


Figure 2-3 Flow diagram of the selection process for articles

2.5.2. Results

As illustrated above in Figure 2-3 and discussed in Section 2.5.1.2, the final number of studies that matched the systematic review requirements from the two databases was narrowed in the final stages to only 23 studies. Of these 23 studies, which were supposed to be taken to the full review stage, 17 original frameworks were identified. Inevitably, each of these frameworks has different purposes, uses different assessment techniques, and was made for a specific application at different scales and within diverse local contexts and conditions. Nevertheless, each of them was presented as a supportive tool to either measure or improve the level of sustainability of the WRM system, individually or collectively.

The other six studies were excluded for several reasons. One of these is that they applied one of the other 17 frameworks but with only minor changes. For example, by varying only the case study, which happened with a journal article (Castro et al., 2017) that applied the same Watershed Sustainability Index (WSI) (Chaves and Alipaz, 2007) to a different region. Therefore, it was decided to only include the paper that introduced the original index in this review. In addition, a conference paper that suggested the application of the Canadian Water Sustainable Index (CWSI) to evaluate a specific case study had very few details about the index itself (Attari and Mojahedi, 2009). This was consequently replaced by the original framework published in a previous report (Policy Research Initiative, 2007). Likewise, a conference paper (Moglia et al., 2013) about some procedures used in developing the Water Needs Index (WNI) was excluded because the same index was provided in full detail in another paper (Moglia et al., 2012) that was included in the review.

Another reason for excluding other papers was when their research served either as guidance on how to make indicators and frameworks with examples (Lundie et al., 2006), or as criticism of the indicators assigned for the SDG6 (Guppy et al., 2019).

The last reason for not including some studies in the final comparison, even though they had a framework and indicators, was that their purpose and indicators were not sufficiently focused on improving/assessing the sustainability of WRM. The first study of this type was a conference paper focused on evaluating the United States' infrastructure performance related to the water sector, without careful consideration of other dimensions of sustainability (Lee et al., 2019). Similarly, to some degree, another study concentrated to some degree on evaluating the already existing performance indicators related to the water supply network that targeted the issue of water losses (Kanakoudis et al., 2013). There were three main issues with the previous study: (1) the final product was not compatible with the definition of an index/framework; (2) it had too much technical detail in its indicators that were not all specifically related to sustainability, and (3) the final number of performance indicators reached 117, which did not comply with the guidance with regard to having a simple sustainable framework. Thus, this study was excluded.

The remaining studies, ordered from the oldest to newest, are shown in Table 2-2 and Table 2-3. Further comparative analysis among all frameworks included in both tables is provided in Section 2.5.3.

Table 2-2 Summary and comparison of main elements of existing SWRM-AFs

SWRM-AF name	Acronym	Author(s), Year	Number of indicators: Component	Number of indicators: Indicator	Number of indicators: Sub-indicator	Benchmark	Scale [Location]	Normalization method	Weighting scheme	Aggregation tech.	Final index value
Water Poverty Index	WPI	(Lawrence et al., 2002)	5	17	15	yes	Global	Continuous rescaling	Equal	Arithmetic	0 - 100
Canadian Water Sustainability Index	CWSI	(Policy Research Initiative, 2007)	5	15	×	yes	Community [2] [Canada]	Continuous rescaling	Equal	Arithmetic	0 - 100
Watershed Sustainability Index	WSI	(Chaves and Alipaz, 2007)	4	15	×	yes	Local & Regional[2] [Brazil]	Categorical rescaling	Equal	Arithmetic	0 - 1
West Java Water Sustainability Index	WJWSI	(Juwana et al., 2010b, 2010a)	3	9	6	yes	Territorial (Regional) [2] [Indonesia]	Continuous + Categorical rescaling	Equal + Non-equal	Geometric	0 - 100
Water Needs Index	WNI	(Moglia et al., 2012)	6	9	×	yes	Local (Ward & District) [Vietnam]	Continuous rescaling	Non-equal (user defined)	Arithmetic	0 - 100
Water & Sanitation Sustainability Index	WASSI	(Iribarnegaray et al., 2015)	9	15	2	yes	Local (urban & peri-urban) [Argentina]	Continuous + Categorical rescaling	Equal	Arithmetic	0 - 100
Global Water Security Index	GWSI	(Gain et al., 2016)	4	10	×	yes	Global	Continuous rescaling	Non-equal (authors defined)	Arithmetic	0 - 1
Hybrid Triple Bottom Line & Multi-criteria Decision Analysis	*TBL-MCDA* [1]	(Cole et al., 2018)	3	44	×	yes	Local & Community [USA]	Categorical rescaling	Equal	Arithmetic	1 - 5 [3]
Freshwater Health Index	FHI	(Vollmer et al., 2018)	3	11	31	yes	Local & Regional [2]	Continuous + Categorical rescaling	Equal + Non-equal	Geometric+ Arithmetic	0 - 100 [3]

							[China]				
Assessing Water Security & Water–Energy–Food Nexus	*WEF nexus* [1]	(Marttunen et al., 2019)	4	17	×	yes	National [Finland]	Categorical rescaling	×	×	×
Municipal Environmental Management	MEM	(Criollo et al., 2019)	4	40	×	yes	Local & Regional [Colombia]	Continuous rescaling	Non-equal (user defined)	Arithmetic	0 - 1
River Basin Water Sustainability Index	RBWSI	(Silva et al., 2020b)	3	8	19 (54)	yes	Territorial Regional [2] [N/A]	Categorical rescaling	Equal	Arithmetic	0 - 1
Water Sensitive Cities Index	WSC	(Rogers et al., 2020)	7	34	×	yes	Local (metropolitan/ municipal) [Australia]	Categorical rescaling	×	Arithmetic	1 - 5 [3]
Malaysia Manufacturing Industry Water Benchmarking System	MIWABS	(Bahar et al., 2020)	4	9	×	yes	Factories level [Malaysia]	Proximity-to-Target + Categorical rescaling	Non-equal (user defined)	Arithmetic	0 - 100
Indicators of Integrated Water Resources Management	*IIWRM* [1]	(Ben-Daoud et al., 2021)	4	12	×	yes	Local [2] [Morocco]	Categorical rescaling	Equal	Arithmetic	1 - 5
Sustainability Index	SI	(Najar and Persson, 2021)	3	14	82	yes	Local [Sweden]	Survey (Categorical rescaling)	Equal	Arithmetic	0 - 2
Rural Water Sustainability Index	RWSI	(Crispim et al., 2021)	5	21	58	yes	Rural & Community [Brazil]	Categorical rescaling	Non-equal (user defined)	Arithmetic	0 - 10
		Average	4.5	17.6	30.3						

[1]indicates a suggested acronym; [2]designed for river basin scale; [3]Does not have a final index value but a final value for each component only.

Table 2-3 Summary of why and how the existing SWRM-AFs have been developed with pros and cons

Acronym (Reference)	**Purpose**	**Selection process for indicators**	**Stakeholders involved**	**Advantage**	**Disadvantage**
WPI (Lawrence et al., 2002)	To find the relation between the water availability or scarcity impacts on the welfare level of human populations among 147 countries	Literature review then Stakeholder opinion	Physical & Social Experts, Academics, Practitioners, Others	Good range of stakeholders, Helpful for general comparisons	General nature (or base) of indicators can neglect internal important issues related to the context of specific regions
CWSI (Policy Research Initiative, 2007)	To evaluate water sustainability and well-being in Canadian communities concerning freshwater	Literature review then Stakeholder workshop	Government Officials, Academics, Consultants	Participatory Method with stakeholders in refining the selected indicators	Developed only for communities that depend on River Basins
WSI (Chaves and Alipaz, 2007)	To combine the treatment of the three pillars of sustainability within an integrated and dynamic process	Literature review	None	Equal Weighting of indicators to ensure mutual respect among all sectors	No Stakeholder engagement, Developed only for River Basins
WJWSI (Juwana et al., 2010b, 2010a)	To identify main factors help improving WR, to assist in prioritise issues of WRM, and to communicate current condition of WR to community	Literature review then Conceptual framework, then Delphi application & stakeholders' interview	Academics, Consultants, Government Officials, Community Representatives	Participatory Method with stakeholders in refining the selected indicators, Good range of stakeholders	Developed for River Basins particularly in Indonesia, Unclear way of combination of normalization methods
WNI (Moglia et al., 2012)	To pinpoint persistent water problems and hotspots that local water authorities should address	Literature review then Stakeholder workshop	Academics, Government Officials	Participatory Method with stakeholders in refining the selected indicators & assigning weights for components only	Indicator weightings assigned by researchers alone, Component of aquatic ecosystems is specific for surface water

WASSI (Iribarnegaray et al., 2015)	Developed as a tool to support governance procedures for more SWRM, applied to four cities in northern Argentina	Developed in collaboration with the provincial water company	Government officials, Water Company	Helpful in comparing level of SWRM among cities, New information / Data easily uploaded to web-interface	Website in Spanish, Only one stakeholder group involved in the indicator selection process
GWSI (Gain et al., 2016)	To integrate physical and socio-economic aspects of security within a SWRM index	Literature review	None	Helpful for general comparisons, Water Security evaluation maps are well developed	General nature (or base) of indicators because of global scale, No Stakeholder engagement
TBL-MCDA (Cole et al., 2018)	To evaluate the pillars (lenses) of sustainability related to using alternative water supply strategies versus maintaining the conventional system.	Developed in collaboration with Technical experts & Stakeholders	Technical experts, City departments, Non-profit organization	Good range of stakeholders, Performance indicators used with stakeholder preferences to support decision-making	Unclear if literature review used, Indicator number too large to be implemented in practical way, No final Index value calculated.
FHI (Vollmer et al., 2018)	To integrate the multiple social, ecological, and governance dimensions toward the sustainability of freshwater management.	Literature review then Scientific workshops & Stakeholder opinion	Scientific experts, Local stakeholders	Stakeholder engagement – include for indicator selection and partially in weightings	No final Index value calculated. Developed for River Basins
WEF nexus (Marttunen et al., 2019)	To evaluate water security and its trends in the future through a participatory process, and to analyse connections with water, energy, and food security in Finland	Literature review then Stakeholder workshop	Academics, Government officials, Security organizations	Stakeholder engagement, High-level interviews, Excel tool with different sheets	Highly qualitative, Missed three main elements, Difficult to use in other contexts / settings
MEM (Criollo et al., 2019)	To create, as a bottom-up approach, a WRM that can measure local government administrations' dedication to sustainability	Literature review & Stakeholder opinion then Interviews and online surveys	Academics, Government & Municipal officials, Social organizations	Participatory Method with stakeholders in refining the selected indicators and weights, Results published in a website	Environmental focus, Large number of indicators that needed aggregation
RBWSI (Silva et al., 2020b)	To evaluate and guide the decision-making process in promoting water sustainability as part of Integrated River Basin Management (IRBM)	Literature interrogation	None	Literature reviewed using an inductive approach	No Stakeholder engagement, Large number of sub-indicators that needed aggregation, Developed for River Basins
WSC (Rogers et al., 2020)	To evaluate a city's water sensitivity, create aspirational goals, and guide management actions to enhance water-sensitive processes	Literature review then Consultation with stakeholders	Industry experts, Academics	Participatory method for developing indicators and scoring system	High number of indicators, Weightings seem ambiguous, No Final Index value

MIWABS (Bahar et al., 2020)	To evaluate the industrial sector's water performance within a factory-level scale in Malaysia	Literature review then Stakeholder workshop to screen & filter	Industry Experts, Academics	Weighting used Analytical Hierarchy Process (AHP) applied to questionnaire output	Method for aggregation not reported, Scale applicable to Factory alone
IIWRM (Ben-Daoud et al., 2021)	To produce an indicator-based framework to evaluate the application of IWRM within Meknes city, Morocco	Literature review then Survey of Stakeholder via questionnaires	Government officials (water sector actors), Practitioners	Easy to interpret radar diagram used for displaying results	No evidence / justification for calculations or weighting scheme provided
SI (Najar and Persson, 2021)	To evaluate and guide Sweden's municipal water and wastewater sectors to be more sustainable	Swedish Water and Wastewater Association (SWWA) developed framework	Members of SWWA, Water Utilities of the municipalities	Annual survey – rigorously developed and well-written, simply to use / understand, Results published in a web-based database	High number of sub-indicators, Yearly application would have huge time, resource implications
RWSI (Crispim et al., 2021)	To help decision-makers in the process of finding and prioritizing rural communities that need state intervention with regard to water provision	Literature review then Delphi method via questionnaires to stakeholders	Policymakers, Technicians, Experts, Others	Participatory Method with stakeholders in refining the selected indicators and weights	High number of indicators, Mostly applicable to rural communities

2.5.3. *Comparative Analysis of Existing SWRM-AFs*

After the brief illustration of all the frameworks obtained from the SLR (see Table 2-2 and Table 2-3), a comparative analysis is performed in order to collectively get valuable observations and insights. The comparative analysis is undertaken using the aspects previously detailed in Section 2.4 and the key headings shown in Table 2-2 and Table 2-3.

2.5.3.1. *Number and Type of Components*

The first observation was in regard to the number of components (Figure 2-4), where their total number of components in all IBWSFs included in the SLR was 76, with an average number of 4.5 components. Moreover, 13 frameworks (76.5% of the total) opted for 3 to 5 components, with 4 being the most widely adopted featuring within 6 studies (35.3% of the total). Whilst 3 and 5 components are featured in four and three frameworks (i.e., 29.4% and 17.6% of total), respectively. The other frameworks adopted 6, 7, or 9 components (23.5% of total). The highest number of components (9) was found in WASSI (Iribarnegaray et al., 2015) and likewise the least number of components (3) was found in RBWSI (Silva et al., 2020b), FHI (Vollmer et al., 2018), TBL-MCDA (Cole et al., 2018) and WJWSI (Juwana et al., 2010a, 2010b). Based on this observation, it can be suggested for any new SWRM-AF being developed, the number of components is preferred to stay within the threshold of 3 to 5 with a preference of 4 since it was the most repeated number.

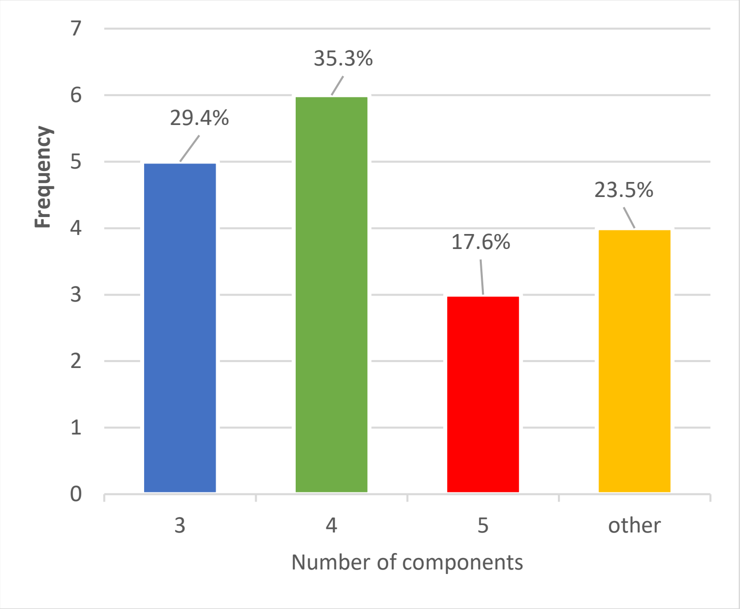


Figure 2-4 Total number of components used in each framework

Regarding the type of components, a thematic analysis was conducted to categorise them in two steps. The first step was to check the common words in the title of the components that were repeated based on their numbers. A criterion was suggested to eliminate any word repeated less than three times. Therefore, only 63 components distributed among 14 main words were included in this analysis, as seen in Figure 2-5. The most repeated words are resource and water (i.e., seven times for each), followed by environment and access, which were mentioned six times. In contrast, capacity, social, infrastructure, quality, and service were the less repeated words, with only three times for each.

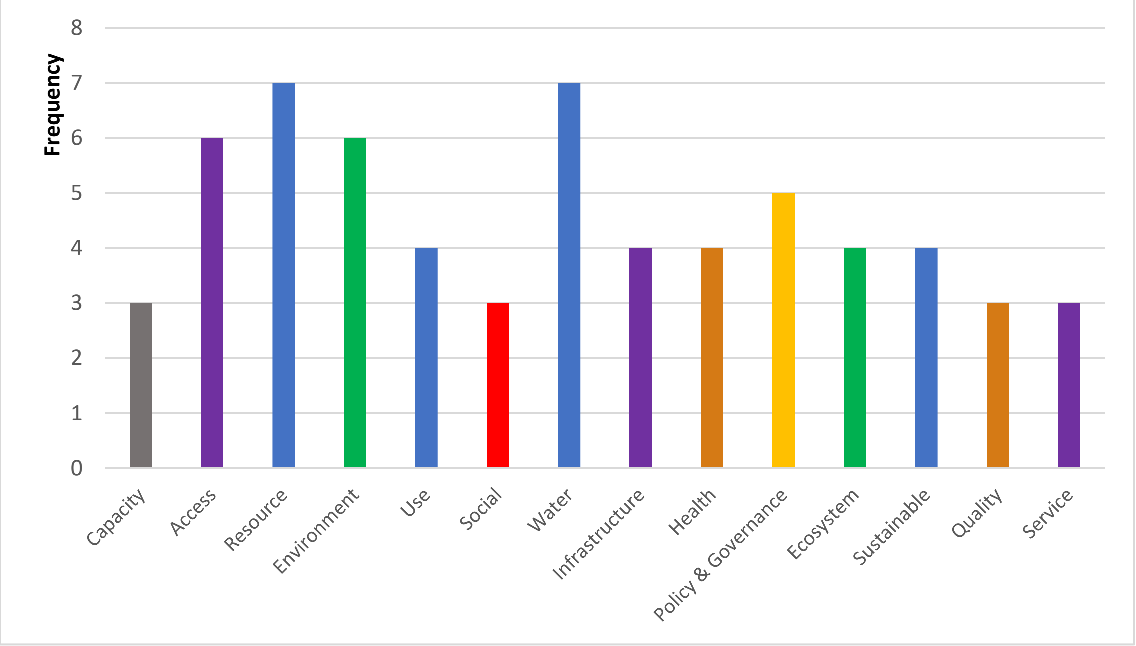


Figure 2-5 Number of the most repeated words in the title of components

Further investigation, which is the second step, highlighted that thematic categorization is possible by combining these categories in Figure 2-5 that serve the same theme, as shown below in Figure 2-6. Overall, it can be seen that the infrastructure, environmental, and socio-environmental components are critical in any SWRM-AF since they have the biggest share, respectively. Thus, the developers of any new framework shall pay attention and consider such components carefully to see the importance of including them or not.

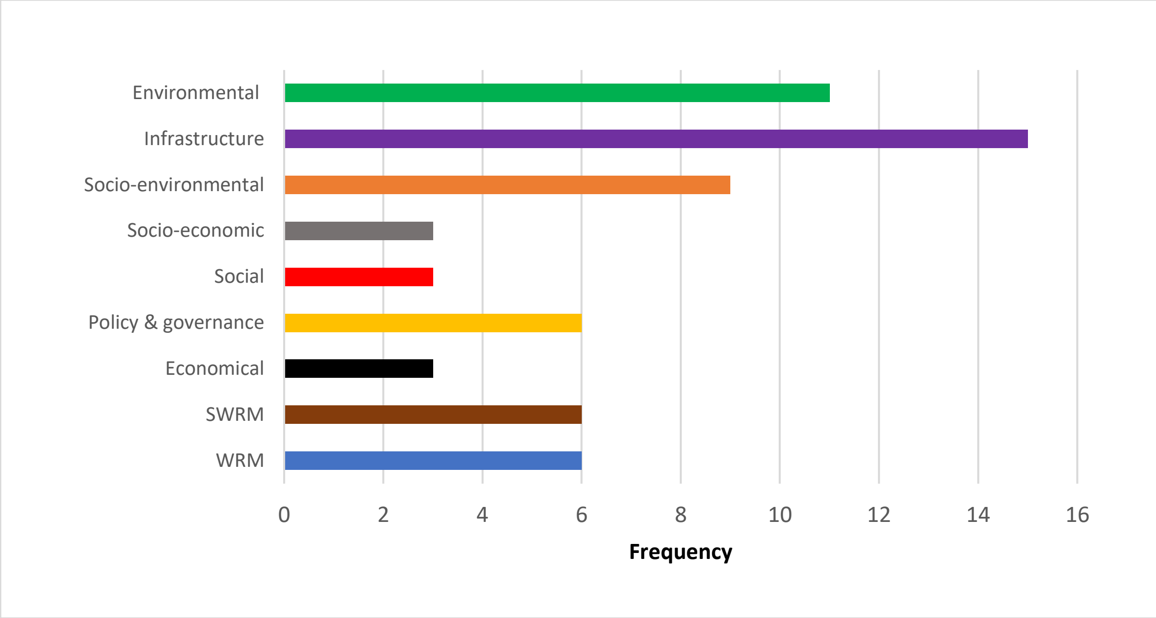


Figure 2-6 Main themes of components based on their repeated number

2.5.3.2. *Number of Indicators*

The second observation concerns the number of indicators. From the interrogation of Table 2-2, the average number of indicators in all included frameworks is 17.6 indicators. However, it can also be noticed that most frameworks (twelve - 70.6% of total) have a total number of indicators ranging between 9 (Juwana et al., 2010a; Moglia et al., 2012; Bahar et al., 2020) to 17 (Marttunen et al., 2019; Lawrence et al., 2002)(inclusive), leading to an average of 12.75 in this discrete group. The most repeated number of indicators therein was 9 (Bahar et al., 2020; Moglia et al., 2012; Juwana et al., 2010a) and 15 (Iribarnegaray et al., 2015; Chaves and Alipaz, 2007; Policy Research Initiative, 2007), where each of these numbers was found in three of the seventeen frameworks . Four of the remaining frameworks (i.e., 23.5% of total) had a higher number of indicators, 21 in RWSI (Crispim et al., 2021), 34 in WSC (Rogers et al., 2020), 40 in MEM (Criollo et al., 2019), and 44 in TBL-MCDA (Cole et al., 2018), respectively, while only one study (i.e., RBWSI (Silva et al., 2020b)) had a lower number with eight indicators. The lower number is not typical; however, this framework has a unique design with two orders of sub-indicators.

2.5.3.3. *Number of Sub-Indicators and Benchmarks*

In terms of sub-indicators, Table 2-2 shows that they are not always used. In other words, only seven frameworks (41.1% of total) included them. The average number was 30.3 sub-indicators with a minimum of 2 in WASSI (Iribarnegaray et al., 2015) and a maximum of 82 in

SI (Najar and Persson, 2021). In terms of benchmarking, all frameworks reviewed contained these (see Table 2-2).

2.5.3.4. *Scale of Application*

Various scales can be noticed within the frameworks reviewed (Figure 2-7). The global scale appeared only twice in WPI (Lawrence et al., 2002) and GWSI (Gain et al., 2016), likely because the amount of time, effort and required data are extensive. The scale with the most significant share (9 studies or 52.9%) tends toward the local (mainly city) scale. The remaining six studies were evenly split between the community scale (Policy Research Initiative, 2007; Cole et al., 2018) and territorial (regional) scale (Chaves and Alipaz, 2007; Criollo et al., 2019), which refers to large areas, such as those with several cities. The last of these is the 'other' category with two frameworks, which include national and factory scales (Bahar et al., 2020; Najar and Persson, 2021). It is worth noting also that six studies (i.e., 35.3% of total) considered areas with river basins (Chaves and Alipaz, 2007; Silva et al., 2020b; Policy Research Initiative, 2007; Juwana et al., 2010b; Vollmer et al., 2018; Ben-Daoud et al., 2021).

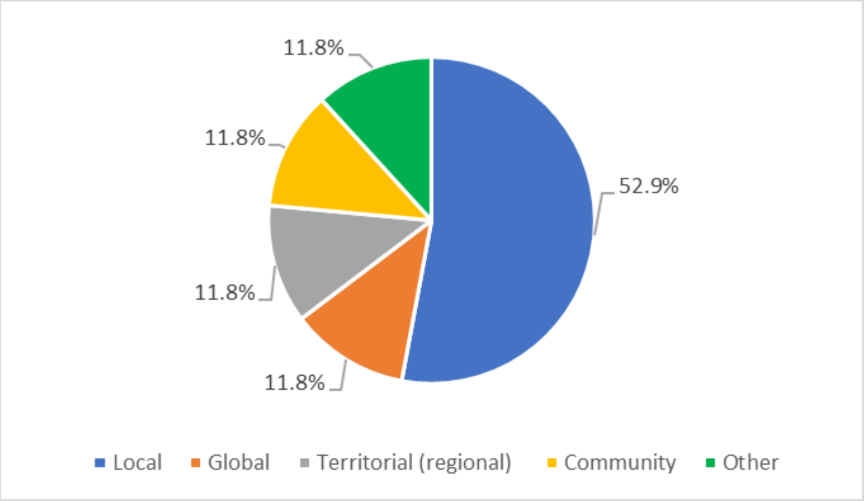


Figure 2-7 Scale of Application

2.5.3.5. *Normalization Process*

All percentages for the process of normalization are shown in Figure 2-8. Eight studies used categorical rescaling (Marttunen et al., 2019; Chaves and Alipaz, 2007; Silva et al., 2020b; Rogers et al., 2020; Cole et al., 2018; Ben-Daoud et al., 2021; Najar and Persson, 2021; Crispim et al., 2021), and five studies used continuous rescaling (Gain et al., 2016; Lawrence et al., 2002; Policy Research Initiative, 2007; Moglia et al., 2012; Criollo et al., 2019) with 47.1% and 29.4% of the total share, respectively. Three studies (17.6% of total) used a combination of both (Juwana et al., 2010b; Iribarnegaray et al., 2015; Vollmer et al., 2018). This option is not common because this task would be confusing for non-expert stakeholders. On the other hand, only one framework (i.e., MIWABS (Bahar et al., 2020)) used a different approach, the Proximity-to-Target (Bahar et al., 2020), which happens to be a very close match to continuous rescaling, albeit with subtle, nuanced differences.

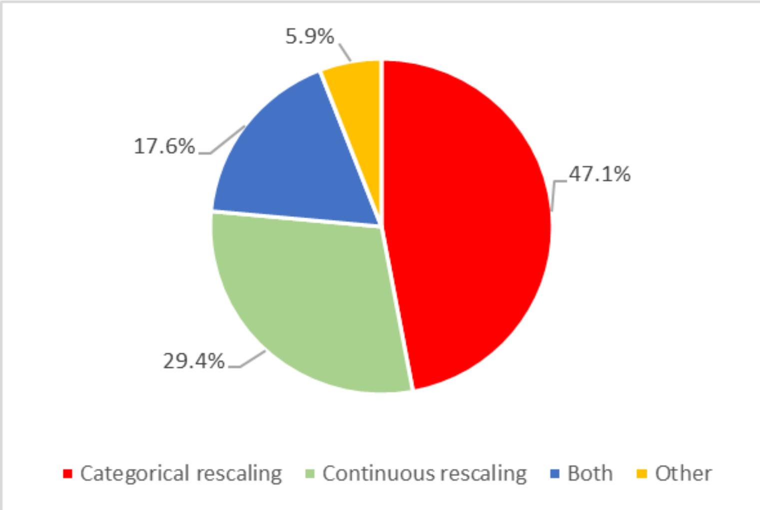


Figure 2-8 Percentage of Normalization Methods

2.5.3.6. *Weighting Process*

The process of weighting indicators and components was seen in 15 of the 17 (90%) frameworks reviewed (Figure 2-9). Out of all the frameworks reviewed, the preference to allocate equal weights was dominant in 8 studies (Iribarnegaray et al., 2015; Chaves and Alipaz, 2007; Silva et al., 2020b; Lawrence et al., 2002; Policy Research Initiative, 2007; Cole et al., 2018; Ben-Daoud et al., 2021; Najar and Persson, 2021) with a percentage of 47.1%. This aligns with the ethos of sustainability, which is very much about balancing, rather than trading off, respective pillars, while the indicator weighting might be different. Moreover, five studies (Gain et al., 2016; Bahar et al., 2020; Moglia et al., 2012; Criollo et al., 2019; Crispim et al., 2021) considered the non-equal weights (user-defined) with a percentage of 29.4% of the total. Only two frameworks (Juwana et al., 2010b; Vollmer et al., 2018)(11.8% of total) adopted a combination of both approaches.

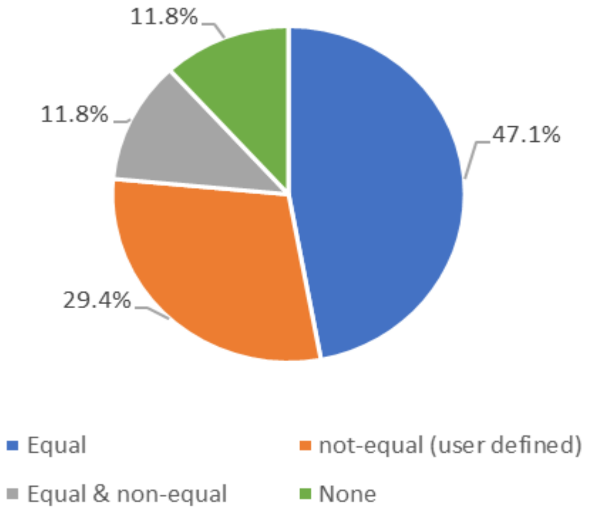


Figure 2-9 Percentage of Weighting Schemes

2.5.3.7. *Aggregation Technique and Final Framework Value*

The next element is the aggregation technique which is used in combination with the weighting scheme in order to reach a final framework value. Most frameworks (Gain et al., 2016; Iribarnegaray et al., 2015; Chaves and Alipaz, 2007; Lawrence et al., 2002; Policy Research Initiative, 2007; Rogers et al., 2020; Bahar et al., 2020; Moglia et al., 2012; Cole et al., 2018; Criollo et al., 2019; Ben-Daoud et al., 2021; Najar and Persson, 2021; Crispim et al., 2021, 2021)(i.e., 14 or 82.35%) have relied on the arithmetic technique - calculating the average rescaling value of indicators. The geometric technique was used twice: one time alone (Juwana et al., 2010b) and the other in combination with the arithmetic technique (Vollmer et al., 2018). In contrast, the WEF nexus framework (Marttunen et al., 2019) has used neither aggregation technique nor final framework value.

In Figure 2-10, it can be seen that the most widely adopted interval for the final framework value (with 41.2% of total) was 0 and 100 (Iribarnegaray et al., 2015; Lawrence et al., 2002; Policy Research Initiative, 2007; Bahar et al., 2020; Moglia et al., 2012; Juwana et al., 2010b; Vollmer et al., 2018). Therefore, it can be suggested that this interval is the most preferred choice for both experts and stakeholders within the frameworks reviewed. The second most widely adopted interval for final framework value (with 23.5% of total) was 0 and 1 (Gain et al., 2016; Chaves and Alipaz, 2007; Silva et al., 2020b; Criollo et al., 2019). The third place most widely adopted interval for final framework value (with 17.6% of total) was 1 to 5 (Rogers et al., 2020; Cole et al., 2018; Ben-Daoud et al., 2021). A category called ‘other’ was used to combine any final framework value with a unique range that appeared once in the frameworks reviewed. This happened only in two indices (Najar and Persson, 2021; Crispim et al., 2021) (11.8% of total).

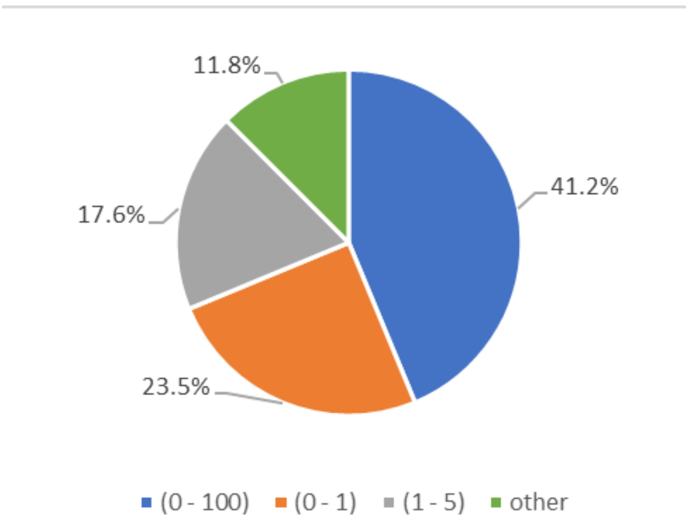


Figure 2-10 Intervals of Final Framework Value

2.5.4. SWRM-AF for ASAR

After going through the systematic literature review, it was clear that no dedicated SWRM-AF has explicitly been made for or applied to ASAR – these areas explicitly lack any permanent rivers or river basins. That said, the frameworks reviewed in Section 2.5.2 have considerable use in being developed (in whole or part) for such purposes.

By furthering the scope of the review to the grey literature outside the two databases that were checked previously, another two additional frameworks were identified, namely the Arab Water Sustainability Index (AWSI) (Ali, 2009) and Abu Dhabi Water Index (ADWI) (Alsalmi et al., 2013). Thus, an overview and brief analysis are provided in the following sections to check their effectiveness.

2.5.4.1. ***Arab Water Sustainability Index (AWSI)***

The AWSI is presented as a monitoring tool to address the water sustainability state relative to a base condition or period (Ali, 2009). The scale of its application could be considered a national scale. In this index, 22 Arab countries, where 82.2% of their weather is either arid or semi-arid, were evaluated through four main components that were divided into only eight indicators. These components can be classified by checking their indicators and main themes or categories from Figure 2-6 as follows:

1. Water crowding (related to WRM category);
2. Water dependency (related to SWRM category);

3. Water scarcity (related to SWRM category);
4. Environmental sustainability (related to socio-environmental category).

Based on our comparative analysis above, it can be said that four components are an adequate number; however, the number of indicators (8 only) is lower than the average number of indicators, found to be approximately 18. Other main elements of indicator-based framework were used, such as the benchmark, aggregation technique (i.e., arithmetic), and the final index value ranging between 0 to 100%. The normalization method of AWSI is based on a statistical method (i.e., Principal Components Analysis (PCA)), which was also used to assign weights, which were not equal, for each component and indicator. A unique advantage of AWSI is the consideration of conventional and non-conventional WR (e.g., GW and DW, respectively), which is crucial for ASAR.

Meanwhile, the continuous rescaling method as a normalization method was mentioned, but whether that was for application or just information was unclear. Overall, even though the pillars of sustainability were considered, the stakeholders' participation in all phases did not exist in AWSI, which does not match the general guidance in developing such a framework. Therefore, to avoid such limitations, it is still required to have a more helpful framework that can gain public trust and cooperation.

2.5.4.2. *Abu Dhabi Water Index (ADWI)*

The other framework is the ADWI which was developed through the adoption of the cause-effect approach (DSR – Driving force, State, Response) to deal with the challenging context of WRM of the United Arab Emirates (UAE) (i.e., very much at a local scale) (Alsalmi et al., 2013). The selection of indicators was based on a review of the literature, followed by checking the availability of their data and if they are relevant to the UAE environment. This process ended with four categories (i.e., components), 19 indicators, and 12 sub-indicators. Then, the benchmark for most of the indicators was obtained from the literature. These components with our main themes or categories from Figure 2-6 are as follows:

1. Water availability (related to WRM category);
2. Water quality (related to socio-environmental category);
3. Water use efficiency (related to SWRM category);
4. Policy and governance (related to policy & governance category).

Overall, the methodology for building ADWI was well-organized and systematically illustrated. In addition, taking the conventional and non-conventional WR into account is essential for the context of ASAR, which is another advantage similar to AWSI.

On the other hand, while considering all sustainability pillars in any SWRM-AF as significant, little attention was given to the economic pillar. Also, ADWI seems to lack any stakeholders' participation or involvement. However, an indicator to measure public participation in water activities existed, but it was based only on the researchers' evaluation. Moreover, the normalization method seems to be categorical rescaling. Still, the scoring criteria were not entirely clear (i.e., all scores are either good represented by a happy face or poorly represented by a sad face, while only one seems neutral).

Furthermore, each of the weighting scheme, aggregation technique, and final index value did not exist, except for the calculation of sub-indicators. Therefore, it can be said that ADWI was an attempt to develop a particular framework for ASAR, but with many limitations. Hence, it is significant to build or develop an SWRM-AF that could avoid these flaws and is suitable to fit the main requirements and contexts of ASAR by considering stakeholders' participation. A summary of the main elements that form the above two SWRM-AFs is presented in Table 2-4 to make the process of comparing them simpler.

Table 2-4 Summary and comparison of existing SWRM-AFs for ASAR

SWRM-AF	Number of indicators			Benchmark	Scale [Location]	Normalization	Weighting scheme	Aggregation tech.	Final index value
	Component	Indicator	S. indicator						
AWSI	4	8	×	yes	National [Arab countries]	Principal Components Analysis	Non-equal	Arithmetic	0 - 100
ADWI	4	19	12	yes	Local [UAE]	Categorical rescaling	×	×	×

2.5.5. Discussion

This SLR sought to identify whether any existing SWRM-AF would be suitable for application in arid or semi-arid regions; by way of Section 2.5.5.1, this is explored further. Section 2.5.5.2 identifies the shortfalls of this research before determining the possible next steps of research.

2.5.5.1. ***Existing SWRM-AFs and their Applicability for ASAR***

The review has helped identify six key requirements that a framework would need in order for it to be considered appropriate for application in ASAR. In other words, they should:

1. Adopt a participatory approach (i.e., stakeholder engagement) during the selection

process of indicators and assigning weights;

2. Have appropriate numbers of indicators;
3. Include all seven primary elements of the indicator-based framework (Section 2.4.1 to 2.4.7);
4. Include Water Scarcity as a key theme;
5. Consider all WR – conventional and non-conventional;
6. Fit with an ASAR context.

With this in mind, Table 2-5 provides a synthesis of the analysis to evaluate (by way of grading) the 19 frameworks, including those from the systematic review and the previous two SWRM-AFs found in the grey literature. The total checking aspects are based on the six requirements mentioned above. The first three aspects (i.e., 1 to 3) are considered general but essential for inclusion in any SWRM-AF. The last three aspects (i.e., 4 to 6) are specific and considered vital to any SWRM-AF for ASAR. In Table 2-5, one point was assigned for each aspect included - based on its existence, except for the participatory approach, where a point was equally divided between the selection and weighting. Also, half of the maximum point was given if the aspect was either partially fulfilled or partially existed. This meant a maximum value of 6 could be achieved where a framework met all six criteria fully.

Table 2-5 Evaluation of the applicability of each SWRM-AF for ASAR

SWRM-AF	**Participatory approach**		**Number of indicators**	**7 main elements**	**Water Scarcity**	**All WR**	**Fit ASAR**	**Total**
	selection	weighting						
WPI	0.5	0	1	1	1	0	0.5	**4**
CWSI	0.5	0	1	1	1	0	0	**3.5**
WSI	0	0	1	1	0	0	0	**2**
WJWSI	0.5	0	1	1	1	0	0	**3.5**
WNI	0.5	0.25	1	1	0	0	0	**2.75**
WASSI	0.5	0	1	1	1	0	0	**3.5**
GWSI	0	0.25	1	1	1	0	0.5	**3.75**
TBL-MCDA	0.5	0.25	0	0.5	0	0	0	**1.25**
FHI	0.5	0.25	1	0.5	0	0	0	**2.25**
WEF nexus	0.5	0	1	0	0	0	0	**1.5**
MEM	0.5	0.5	0	1	0	0	0	**2**
RBWSI	0	0	0	1	1	0	0	**2**
WSC	0.5	0.25	0	0.5	0	0	0.5	**1.75**
MIWABS	0.5	0.5	1	1	0	0	0	**3**
IIWRM	0.5	0	1	1	0	0	0	**2.5**
SI	0.5	0	1	1	0	0	0.5	**3**
RWSI	0.5	0.5	0	1	1	0	0.5	**3.5**

AWSI	0	0	0	1	1	1	1	**4**
ADWI	0	0	1	0	1	1	1	**4**

Table 2-5 shows that the highest total points is 4 out of 6, found in three frameworks (i.e., WPI, AWSI, and ADWI). While two of these frameworks are developed mainly for ASAR (i.e., AWSI and ADWI), some general requirements are missing and identifiable by a zero in the respective columns. Therefore, they are hard to be replicable. Regarding WPI, it obtained this high evaluation since its scale is global and should fit any context for comparison purposes. Similarly, GWSI got the second highest point (i.e., 3.75) since it was developed for the global comparison. However, both frameworks have general indicators that cannot tackle some specific issues of ASAR, such as counting the non-conventional WR, which might present a big difference in the output. On the other hand, the other frameworks had a total of 3.5 points or less, which indicates less applicability for ASAR. In other words, this SLR has shown that no SWRM-AF could be considered fully fit-for-purpose for application in ASAR. Hence, steps should be taken to address this gap in knowledge.

2.5.5.2. *Shortfalls of this SLR*

This SLR has gone some way towards filling the knowledge gap with respect to identifying whether a SWRM-AF for ASAR exists. However, it should be noted that the review was restricted to two well-known academic databases (i.e., Scopus and Engineering Village) in addition to the search terms and filtering process adopted herein. Broadening the review to other databases (e.g., Google Scholar and Research Gate) may have identified more literature (including grey literature) beyond the two most applicable papers found. In addition, this research was very much focused on the derivation of the frameworks themselves and not on the detailing (and usefulness) of individual indicators or the data availability to be able actually to measure their values. Hence, whilst the need for a new framework has been identified by this review, more stages of research are required during its derivation.

2.6. Summary and Conclusions

The sustainability of the water supply to match the proper demand is crucial for any future planning for the WRM system. This strategy became more significant in areas with limited WR and located in ASAR with challenging water conditions. During the last few decades, many scientific meetings and recommendations were conducted and presented to tackle the WRM issues, such as the Brundtland's definition, Dublin principles, and the IWRM definition and principles. These efforts were the foundation for introducing guidance and criteria that led to the creation of several SWRM-AFs, such as those manifested above. However, it is essential to remember that sustainability does not mean only focusing on one pillar. Meanwhile, getting the balance between the three pillars (i.e., environmental, social, economic) would generate the best results. This opinion shall be counted during the development process of any tool that aims to improve and monitor sustainability progress. One of these tools is the indicator-based framework to assess sustainability. Therefore, having specific and clear SWRM-AF to measure the level of SWRM would undoubtedly help improve the longevity of such vital resources.

While many SWRM-AFs, such as those described briefly in this review, were developed for this purpose in the past, it has been shown that they are insufficient to assess some ASAR. Moreover, even where frameworks have been developed specifically for ASAR many shortfalls exist. That said, this review helps recognise the primary elements required to establish this type of framework. Moreover, detailed investigation and comparison among SWRM-AFs have helped identify similarities, differences, and limitations/knowledge gaps. As such, several recommendations are suggested based on the results of this review:

- Having all seven standard main elements of SWRM-AF clearly defined and justified during both the development and application stages will make the SWRM-AF less challenging to reapply in ASAR. This includes its adoption by the scientific community and water authorities in regions with similar conditions. In contrast, ignoring some of these elements could reduce the whole benefit of the framework and make it obsolescent. For example, if it is too complicated to reuse or has been developed without stakeholder buy-in.
- For any new SWRM-AF, it would be preferred to select elements and normalization methods with a higher application rate, such as those highlighted in Section 2.5.3. For example, while the application of local scale (52.9%) and the final index value of [0 – 100] (41.2%) seem more popular in many frameworks, categorical rescaling (47.1%), equal weighting (47.1%), and the arithmetic technique (82.35%) are the most used normalization methods. Thus, choosing them might ensure more confidence of both decision-makers and the public in the output of such a framework.
- Finally, it was found that the SWRM-AF for ASAR for particular countries without any permanent rivers or lakes is needed since water shortage conditions highly threaten them, and little or inadequate research has been conducted to develop such a tool.

Therefore, a specific SWRM-AF for ASAR is recommended to tackle this issue, and its development is currently underway in the next chapter. The main mission will seek to develop a SWRM-AF for ASAR that satisfies all six aspects outlined in Section 2.5.5.1. In order to ensure it is both practical and meaningful for application, this development will involve some key steps:

- Providing a detailed map of all components, indicators and sub-indicators;
- Developing the methodology for selecting important indicators for each component;
- Justifying (by way of stakeholder engagement) indicators and weights adopted;
- Refining SWRM-AF based on the consensus of expert stakeholders;
- Applying the framework to case studies (KSA as an example of GCC countries).

Many parts of this chapter are submitted to the *Journal of Sustainability* under this title: *A Sustainable Water Resources Management Framework for Arid and Semi-arid Regions – Part 1: Developing the Conceptual Framework*

3. Methodology

The results of the SLR indicated the absence of existing frameworks that fit the context of ASAR and enable the evaluation of the SWRM in GCC countries. The methodology outlined in this chapter seeks to create a conceptual framework that will address this knowledge gap.

This chapter comprises six primary sections:

3.1. Introduction.

3.2. Overview of water-related issues in GCC countries

3.3. Guidelines to develop a conceptual SWRM-AF.

3.4. Development stages of the conceptual SWRM-AF

3.5. Suggested components and indicators that form the conceptual SWRM-AF

3.6. Summary and Conclusion

3.1. Introduction

The importance of WRM has increased during the last 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, WR are finite, and they are limited or scarce in some regions. Therefore, careful planning and the appropriate management of these resources are highly significant in avoiding any future water crisis that might affect the current or future generation(s), including water shortages and deterioration in water quality. Hence, considering the sustainability assessment of WRM as a 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 the indicators. Indicators help narrow down and sum up numerous data into one or few numbers and metrics that would be easier for both stakeholders and decision-makers to follow. Therein metrics *'give a unit of measurement to indicate progress against that criterion'* (Hunt et al., 2008). Indeed, using indicators would help measure, assess, and inform the sustainability level of a complex system (Ness et al., 2007; Kajikawa, 2008), 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 (Jenkins et al., 2003).

Moreover, developing a bespoke IBWSF can be helpful in the following:

1) To contain all elements of WRM that can assist in the improvement of WR (Sullivan, 2002; Chaves and Alipaz, 2007; Policy Research Initiative, 2007; Juwana et al., 2010b; Iribarnegaray et al., 2012);
2) To provide definitions for the variables included in the framework and draws attention to significant connections between them (Bertule et al., 2017).
3) To help in identifying and understanding the most critical issues by both users (Bertule et al., 2017) and decision-makers, which is vital for the process of prioritising tasks and identifying tread-offs (Juwana et al., 2010b; Iribarnegaray et al., 2012);
4) To communicate the current status of WR to a bigger group of stakeholders (Policy Research Initiative, 2007; Juwana et al., 2010b);
5) Where applicable, to set benchmarks - where a benchmark is *'a quantification that reflects a desired level of performance for an indicator'* (Hunt et al., 2008).

On the other hand, a question might be presented about the feasibility of developing a new sustainability framework for WRM if there are many in the literature. 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 would not be applicable to areas with significant differences and both special and harsh conditions. Similarly, Juwana et al. (2010) reported that the successful application of existing WRM indices does not mean they are highly applicable to be re-used in a different place; therefore, developing a unique framework becomes necessary to fit with the natural and socio-economic characteristics of that region. Hence, this could show the importance of developing a bespoke framework that can enhance and/or maintain the sustainability of WR among regions that lack efficient frameworks.

This study aims to develop a conceptual SWRM-AF for some ASAR with harsh climate conditions, such as the GCC countries. The methodology used to reach this goal needs, in general, two stages:

- Stage One (building or development stage): Searching the literature to identify appropriate components and indicators that suit the temporal and spatial conditions of the understudied region (Chaves and Alipaz, 2007; Juwana et al., 2010b; Gain et al., 2016; Silva et al., 2020b). The suggested set of components/indicators that results from this stage is sometimes called the conceptual framework.

- Stage Two (refinement or validation stage): Present 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, as required distilling down to an appropriate set (Policy Research Initiative, 2007; Juwana et al., 2010a; Moglia et al., 2012; Vollmer et al., 2018). 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. Then, a justification for each component and indicator is provided to explain the relevancy. 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 an inclusion and exclusion criteria, and it is essential to be part of the validation process.

This chapter focuses only on Stage 1 – to develop a novel and conceptual framework. Stage 2 is the focus of the next chapter. On the other hand, an overview of the water situation of GCC countries is presented first in the next section to understand the reasons behind selecting indicators that would represent the conceptual SWRM-AF.

3.2. Overview of Water-related Issues in Gulf Cooperation Council (GCC) Countries

Based on the Köppen-Geiger climate classification, the prevailing climate of GCC countries is described as arid (B), desert (W), and hot (h) (Peel et al., 2007). 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) (Erian, 2013). Aridity is defined as *"the degree to which a climate lacks adequate, life-promoting moisture"* (Glickman, 2000).

On the other hand, the GCC countries are part of what is known in the geopolitical area as the Middle East (Beaumont et al., 1988). 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 surrounded by seas from three directions. One of these seas is the Arabian or the Persian Gulf, where the name (i.e., Gulf) of GCC countries is referred to because each has a direct coast (See Figure 1-3).

The water situation in the GCC countries is 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 (Water Resources Committee, 2014; Akkad, 1989). Moreover, not only is the low rainfall rate the issue, but it combines with a high evaporation rate (Sahour et al., 2020) exceeding 3,000 mm/year, making the conditions of having a perennial SW system impossible to take place (Al-Zubari et al., 2017). Lastly, the per-capita freshwater availability has dropped by almost 30% during the past two decades overall in the Middle East, which caused a water scarcity situation (UN Habitat and WHO, 2021). Therefore, careful consideration is necessary for the planning and management of WR in GCC to ensure that they are sustainable.

3.2.1. Water Supplies

The main CWR in GCC is GW, which is classified as non-renewable GW (NRGW) (or deep GW), and renewable GW (RGW) (or shallow GW). In addition, SW is the second CWR that only provides very low quantity in most GCC countries. Both types of GW represent the highest share (between 77.7% in 2017 to 70.5% in 2020) among WR in GCC states to supply water for all purposes, while SW represents the lowest rate, which was 0.5% in 2017 and increased slightly to be 0.8% in 2020 (GCC-STAT, 2022). 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 other three countries received considerable amounts starting from 150 to 3210 million cubic meters per year (MCM/year) (Al Rashed et al., 2023). Thus, since the focus of this framework is on all GCC countries, less attention might be given to the SW.

On the other hand, NRGW is fossil water that is exceedingly difficult to replenish under the current hydrological regime (Al-Sheikh, 1995). In general, NRGW provided the largest share (approximately 67%) of the water supply in the period from 2012 to 2020 if we take 5 out of 6 GCC countries as one block region (Al Rashed et al., 2023). Oman is the exception because it uses more renewable water, SW and RGW, than NRGW (Al Rashed et al., 2023). Hence, the continued dependence and high use of NRGW can only ever be considered a temporary solution, and it is far from being sustainable for GCC countries. Furthermore, with the depletion rate (i.e., the ratio of CWR 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 (Al Rashed et al., 2023). 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 CWR.

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 increased dramatically between 1960 to 2020, from 5.34 million to 58.43 million (World Bank, 2023b), as seen in Figure 3-1. 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 one of the highest on a global scale (Odhiambo, 2017). 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.

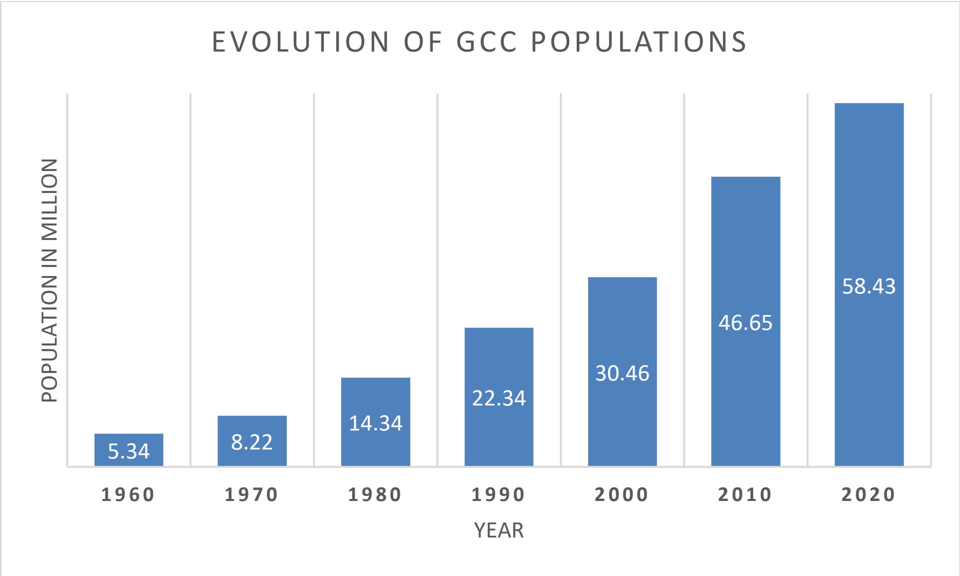


Figure 3-1 Total population of GCC countries between 1960 and 2020

Therefore, extra water supplies were necessary for GCC countries to cover the gap between the supply and demand for water. Thus, the establishment and use of NWR, such as DW, was one of the very crucial solutions for such a situation. Historically, the first brand-new desalination facilities were built in Saudi Arabia, Kuwait, Bahrain, and Qatar in the 1950s (Angelakis et al., 2021). Nowadays, the six GCC countries together are one of the world's leading producers of DW in terms of quantity, with more than 60% of the world's total desalination production capacity being contributed by the GCC nations (Qureshi, 2020). However, while the social aspect has been satisfied by this WR, some economic and environmental impacts (Höpner and Windelberg, 1997; Sadhwani et al., 2005; Napoli and Rioux, 2016; Moossa et al., 2022) require special attention to achieve the balance between all three pillars of sustainability.

The second NWR is the 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, especially when looking at its origin (Sebastian, 1974). However, it is still one of the strategic solutions in regions with limited WR, like ASAR and GCC countries (Al-Jasser, 2011). Not only this, but using RW 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 (Zhao et al., 2022), and more importantly, in terms of WRM, it can help save other conventional WR for society. The use of RW in GCC is designated for several reuse applications such as landscaping, recreation, recharging depleted aquifers, and irrigation of parks and plants (Qureshi, 2020; Al Rashed et al., 2023) that mainly do not produce any edible fruits or crops. This type of irrigation is called restricted irrigation.

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

3.2.2. Water Demand

GCC countries are classified globally by the World Resources Institute (WRI) among the most stressed in terms of WR (Hofste et al., 2019). Moreover, the high population growth in these countries, which means bigger demand, made them consume vast amounts of water that is not proportional to their water provision capability. The total water consumption between 1980 and 2020 can be shown in Figure 3-2, where the biggest share was from Saudi Arabia, UAE, and Oman, respectively. This can be understandable since these countries have the largest area and population compared to other countries, with an exemption from Kuwait that their population was higher than 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 was bigger (World Bank, 2023c). Overall, it should be noted that the primary water consumers or sectors of the GCC countries are agriculture, domestic, and industrial.

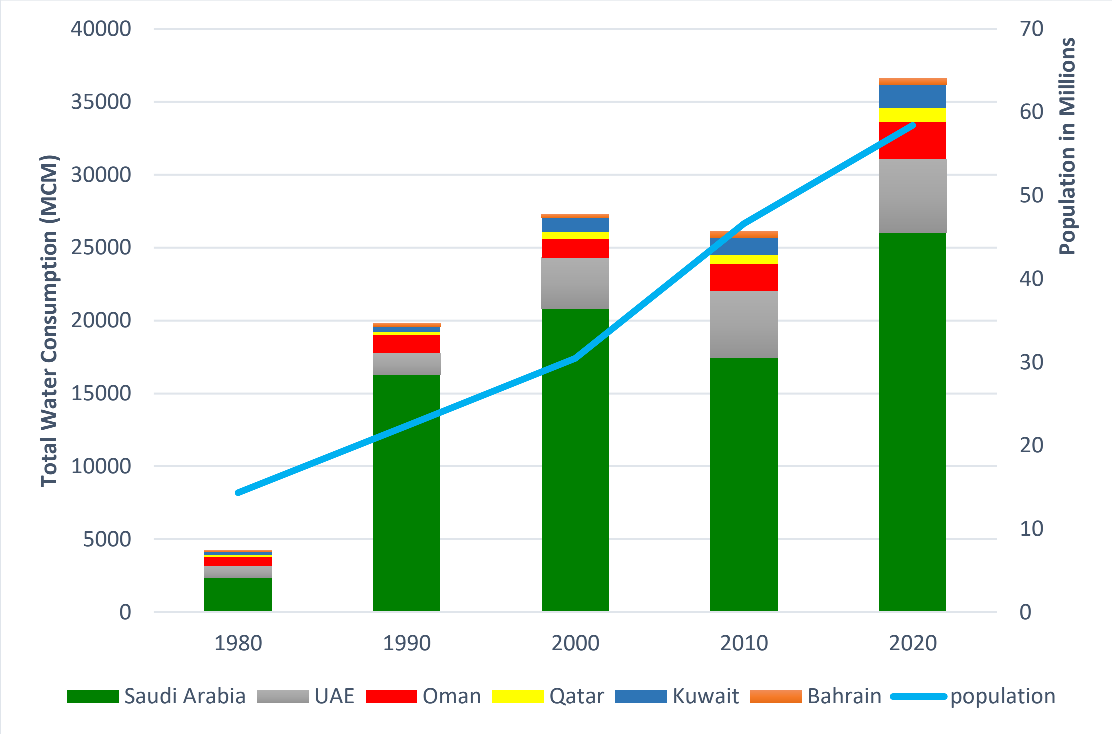


Figure 3-2 Total water consumption and population in GCC countries from 1980 to 2020 (Abdulrazzak, 1994; Al-Zubari et al., 2017; Sherif et al., 2023)

The agriculture sector has the largest share of the water demand in GCC nations, with an average percentage of 70% (Parmigiani, 2015), similar to the global trend of 70% for agricultural water use (Boretti and Rosa, 2019). The vast water consumption by the agriculture sector is because some of these countries had policies to strengthen food security (Parmigiani, 2015), while others, such as Saudi Arabia, sought, by using their lands and natural resources, food self-sufficiency as a key strategy (Baig and Straquadine, 2014; Alturki, 2015). 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 to match this sector's demand, were consumed. Figure 3-2 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 to help the agricultural 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 (Shah, 2023). 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 (Shah, 2023), with wheat being exported abroad (Al-Zahrani, 2009). 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 it was also going beyond to sell the product of this scarce WR to other countries. This promoted a review of farming policies between 2000 and 2004 because of severe impacts on WR, such as the depletion of GW (AL-Subaiee et al., 2005), which led to a decree to gradually phase out wheat production yearly (by 12.5%) starting from 2008 (USDA, 2016).

The other primary water user is the consumption of the domestic sector, where many of the GCC countries, surprisingly and contrary to its limited conventional WR, are among the highest in the world. This fact can be proven by checking daily water consumption per capita and comparing it to that of other countries. An estimation of the average annual per capita water use of GCC countries was 560 l/cap/d, which is far away from the global average of 180 l/cap/d (Qureshi, 2020; Al Bannay and Takizawa, 2022). Recently, the dominant water supply for domestic or municipal demand is the DW (Al-Zubari et al., 2017), 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 3-3 below. This might be because that the industrial sector in general is not that big in most GCC countries. Another observation can be realized in Figure 3-3 that the consumption of water by agriculture sector is fluctuating and overall declining over the last 25 years, while the municipal (or domestic) sector is keep increasing. 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.

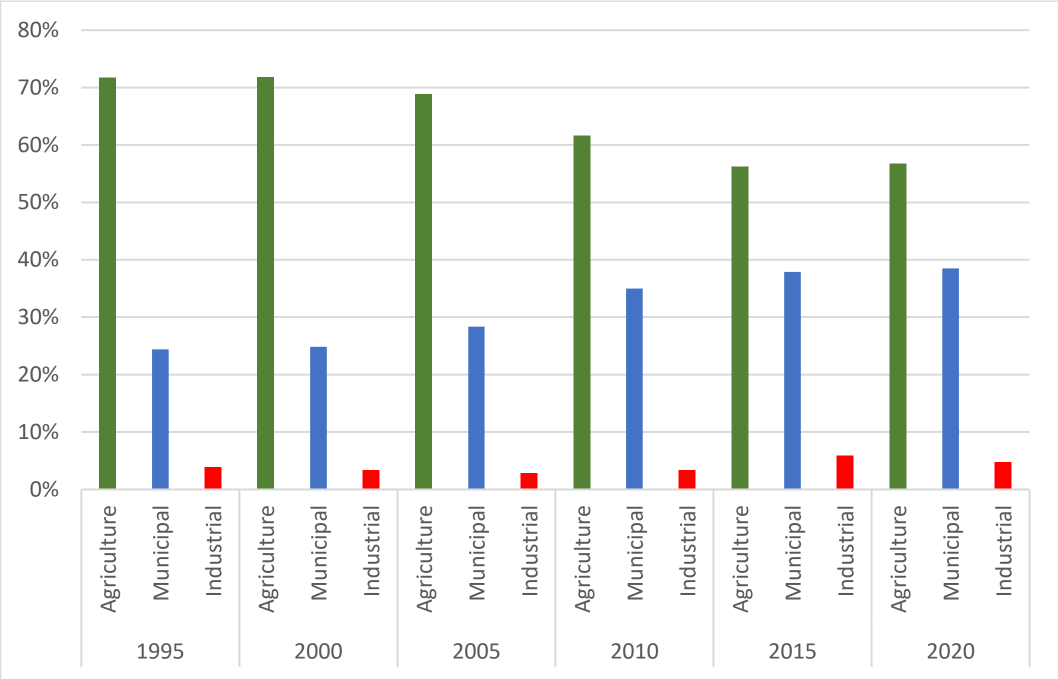


Figure 3-3 The total share of each water sector in GCC from 1995 to 2020 (AQUASTAT, 2021)

3.3. Guidelines to Develop A Conceptual 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. As was stated before, this will be referred to as the conceptual SWRM-AF.

Firstly, this chapter follows the idea that development of SWRM-AF should be based on combining and integrating existing information, including WRM theories, principles, and guidelines (Thornton et al., 2006). 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 on a clear and understandable way. General guidelines need to be followed before and through the developing stage and will be illustrated in the next section.

3.3.1. 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.

In general, diverse interpretations of sustainability frameworks and associated indicators are possible and desirable, contingent upon the viewpoint, circumstances, and local environment in which they are employed. Frameworks designated for buildings or businesses in general, for instance, would differ from those prescribed for WRM. In fact, each domain should have unique standards and requirements for every recommended indicator that fits inside that sector (Joumard and Nicolas, 2010; Bertule et al., 2017). Therefore, it is essential to consider only previous frameworks and their indicators while developing new ones, where all of them should be related to the WRM system, whether directly or indirectly.

On the other hand, several IBWSFs have already been developed for various objectives associated with WRM, particularly as an assessment tool. The main classification for developing these frameworks was to measure either the conservation level of the environment (Xu et al., 2018; McGarigal et al., 2018; Xu et al., 2019), the socio-economic impact (Abel et al., 2003; Smajgl et al., 2010; Dodds et al., 2013), or the effectiveness of the physical factor (i.e., infrastructure) (Bos, 1997; Sara and Katz, 1997; Stampini et al., 2012). Frameworks that prioritise the environment include those that aim to assess and compare the ecological well-being of freshwater system(s) (Xu et al., 2005; Lacouture et al., 2006; Brooks et al., 2009; Korbel and Hose, 2011), or those who seek to measure the environmental effects of material inputs and outputs by employing the life-cycle assessment methods (Lundin and Morrison, 2002; van Leeuwen et al., 2012; Carden and Armitage, 2013).

An alternative approach that has been devised involves integrating multiple indicators into a single framework with the goal of evaluating the overall sustainability of WR (Iribarnegaray et al., 2012; Shilling, 2013; Juwana et al., 2016a). This method primarily focuses on assessing the three main pillars of sustainability, namely the environment, economy, and society. Indeed, having a balanced linkage between these three pillars could be the aim of sustainability, as suggested by sustainable community frameworks (Guy and Kibert, 1998). This suggested role is common to a host of water-related frameworks (Cole et al., 2018; Bahar et al., 2020; Crispim et al., 2021).

Meanwhile, the objective of this research is akin to the aim of sustainable development, as it endeavours to achieve an optimal equilibrium among these common three fundamental aspects (Barton, 2000; Giddings et al., 2002). In addition, adding the physical (or technical) factor (Loucks and Gladwell, 1999; Foxon et al., 2002) or more precisely infrastructure aspect (Mays, 2006) either explicitly (Policy Research Initiative, 2007; Moglia et al., 2012; Iribarnegaray et al., 2012; Criollo et al., 2019; Rogers et al., 2020) or implicitly (Lawrence et al., 2002; Juwana et al., 2011; Gain et al., 2016; Marttunen et al., 2019) to these three pillars is no less common.

This is because including the technical side is essential to handle the complexity and uncertainty of water-related issues in any WRM system (Loucks and Gladwell, 1999). Indeed, having infrastructure as a component would play a vital role in checking water utilities' overall management and ability to continuity. Therefore, this research would follow this approach (and consider it the first guideline) because it seems suitable for evaluating the sustainability through its three main pillars in addition to the infrastructure since it is considered as the main connection between the water supply and demand, which makes it a basic part of any WRM related to the domestic sector.

Regarding the structure of SWRM-AF, it was found that many IBWSFs in the literature have seven important mutual elements (See Section 2.4) to make them clear and easily reusable. These elements, with their descriptions and functions, were summarised previously in Table 2-1. 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.

Furthermore, it is both beneficial and necessary to build any indicator-based framework based on a wide array of indicators (Moldan et al., 2012) that have been widely vetted and endorsed and that can guide the assessment and improvement of the sustainability credentials for WRM systems (Iribarnegaray et al., 2015). Another guideline suggested that the total number of main indicators of any framework should not be small, which could result in wrong conclusions being drawn and misleading policies and/or decisions being made (Bertule et al., 2017). Vice versa, the large number of indicators is not preferred either since it could lead to:

- the complexity of the entire process of application and interpretation (Lundie et al., 2006; United Nations, 2007),
- make gathering and preserving data more administratively expensive (Bertule et al., 2017).

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 average number of indicators included in the previous frameworks.

The thinning process in Stage 2 accords to an important guideline, referred to as the third Dublin principle (See Section 2.2.1), which emphasises the significance of a participatory approach for any development for WR. Similarly, having a framework to enhance the sustainability of any WRM, which is one of the crucial goals of integrated water resources management (IWRM), requires the participation of stakeholders in such a process (GWP-TAC, 2000; Mostert et al., 2008; Basco-Carrera et al., 2017; Badham et al., 2019). Moreover, participatory method is considered as a critical process recommended by the principles of IWRM (Xie, 2006), where it is emphasized that stakeholders should be involved in the planning and implementation process (Mostert et al., 2008). However, in reality, the application of IWRM in general has faced different issues ranging between the complexity in measuring its effects and the difficulty in applying prescriptive ideals to the decision-making process (Giordano and Shah, 2014). Thus, considering that any indicator-based framework relies on a participatory technique would overcome the flaws of the application of IWRM.

Similarly, stakeholders' participation in water management processes has been promoted by several institutions to aid in decision-making (Vogel et al., 2015). 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 (Voinov et al., 2018). Thus, it would be essential to consider the involvement of stakeholders in the designing process of any SWRM-AF to at least gain their trust that their thoughts are appreciated. Lastly, the adoption of this approach would likely ensure the cooperation of stakeholders with any developed future plans and interventions after assessing their WRM system's sustainability.

Nevertheless, the initial output of this chapter, which is the conceptual framework, does not include or require stakeholders' participation (Juwana et al., 2010b), since this occurs in Stage 2 (Juwana et al., 2010a). 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.

3.3.2. *Specific Guidelines for the Selection of Indicators in ASAR*

While the characteristics of indicators that should be examined before integrating them into a sustainability assessment framework are presented in Table 3-1, 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 (Liverman et al., 1988). Thus, wherever possible it is pertinent to take these guidelines and characteristics into account in the process of indicator selection.

Table 3-1 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 to collect and analyse
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 pretty considered
Predictive or Anticipatory	The ability of the indicator to forecast the 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 occurred 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 rate or ratio based on appropriate relations would give more insight and meaning for 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 to decision-makers.

On the other hand, specific criteria should be considered to select indicators that belong to 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; that their lands are desert in nature without permanent rivers or lakes. This is because several frameworks were designed mainly to deal with river basins (Policy Research Initiative, 2007; Chaves and Alipaz, 2007; Juwana et al., 2011; Vollmer et al., 2018; Silva et al., 2020b; Ben-Daoud et al., 2021), which even if they 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 to reuse with any city, region, or country in ASAR with similar conditions of GCC countries. Definitely, some changes would be required, not least the benchmarks of the framework 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 the WR, which any increase in the water demand usually leads to worsening the water scarcity situation, 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 focused on renewable and CWR (Policy Research Initiative, 2007; Juwana et al., 2011; Vollmer et al., 2018), 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 to the level of sustainability of the WRM system can be evaluated and observed.

3.4. Development Stages of the Conceptual SWRM-AF

Similar to the methodology of developing previous conceptual frameworks (Juwana et al., 2010b; Alsalmi et al., 2013), the development of the SWRM-AF will follow the steps manifested in Figure 3-4 below.

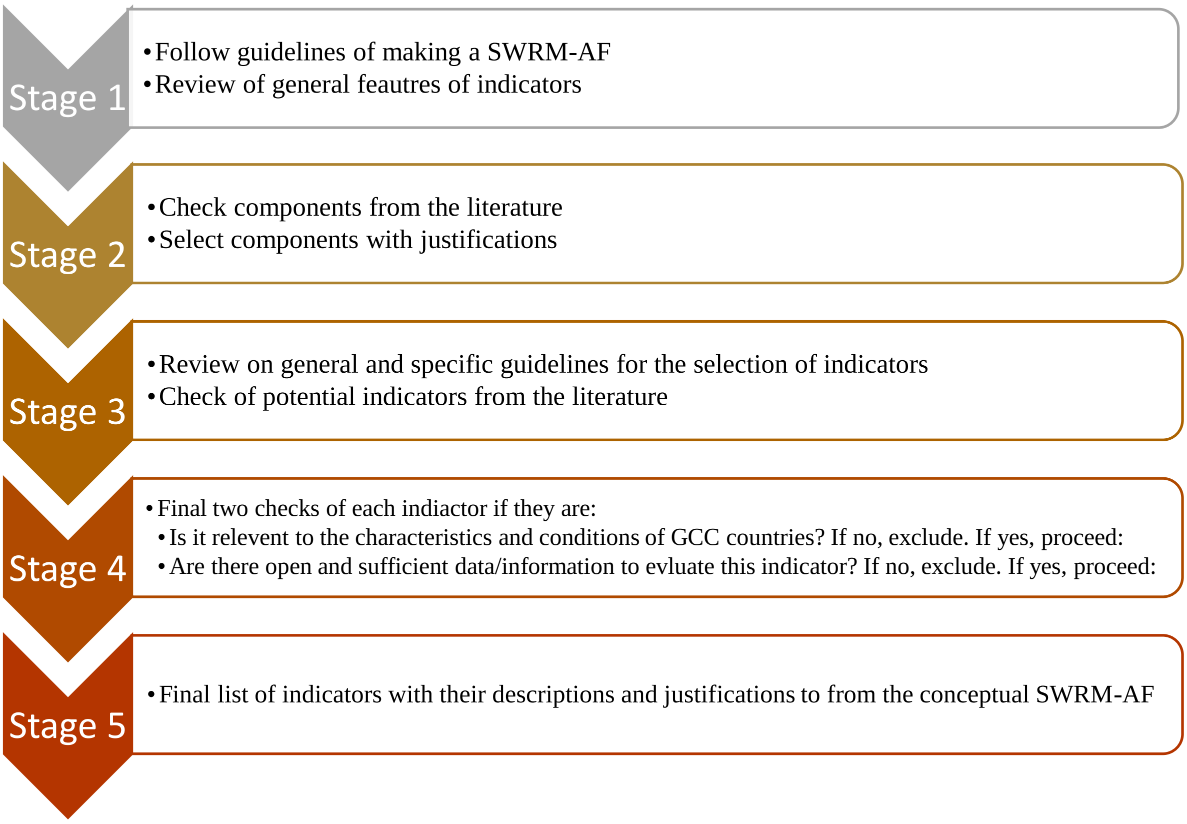


Figure 3-4 Flowchart for the development of the conceptual framework for ASAR

The details of the first stage, which is the review of guidelines and features of indicators, were covered in Sections 3.3.1. and 3.3.2. The second stage is to select appropriate components, which was facilitated by investigating several IBWSFs (for further details, see Section 2.5.3.1).

Indeed, since the framework is designed to evaluate the SWRM, the main components have consisted 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 in building upon where the others have ended and benefiting 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 or not (Pires et al., 2017). See Table B1 in Appendix B for the whole list.
- Indicators belong to the SDG6 (United Nations, 2015), with more focus on those related to water use and management in general (UN-Water, 2021). See Table B2 in Appendix

B for the whole list.

- Indicators and targets are shown in the GCC Unified Water Strategy (GCC UWS) (Al-Zubari et al., 2017). See Table B3 in Appendix B for the complete list.

Meanwhile, several other indicators were also checked from other sources, such as those belong to seventeen plus two frameworks included in the SLR (see Section 2.5.5.1), 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 on which their regions depend. However, this type of indicators 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 evaluating 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 normalization 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 would be 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-annual) of performance results. Therefore, only the indicator 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 3-4, provides the final list of components and indicators that comprise the conceptual framework (See Section 3.5). Therein, each indicator should be accompanied by a brief description that explains 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 reference(s) from other frameworks that have used the same indicator are presented to make the selection process more credible and strengthen the justification.

3.5. Suggested Components and Indicators that Form the Conceptual SWRM-AF

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 3-4. This list ended with 24 selected indicators representing the previously selected four components of the conceptual SWRM-AF for ASAR, as shown in Figure 3-5. Each component has six indicators to give equal attention to each component, and to follow the rule that emphasizes that the total number of indicators should be neither too many (Lundie et al., 2006; United Nations, 2007) or too few (Bertule et al., 2017). In addition, reference, a brief description, and justification for each indicator are provided below.

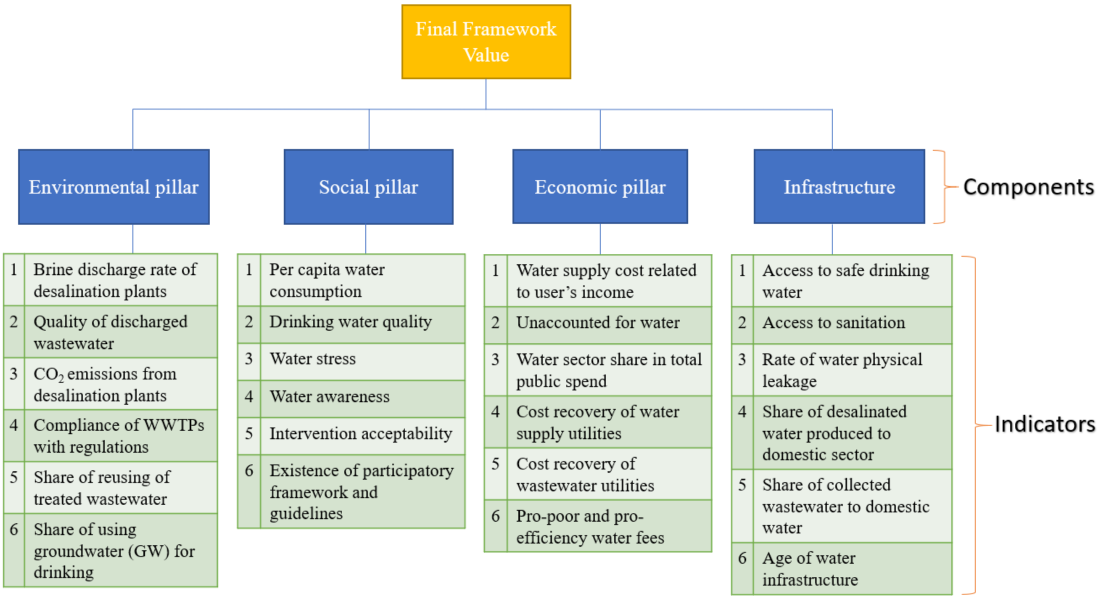


Figure 3-5 Conceptual SWRM-AF for ASAR

The four components (i.e. Environmental, Social, Economic and Infrastructure) and their underpinning indicators with associated metrics and benchmarks (where applicable) will be further discussed in Sections 3.5.1 to 3.5.4, respectively.

3.5.1. Environmental Indicators

If the pillars of sustainability were considered as a series of concentric circles, the environment could be considered the bigger circle that contains both the social and economic pillars (See Figure 2-1). 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, along with their types and references.

Table 3-2 Environmental indicators of the conceptual SWRM-AF with their types and supporting references

Environmental Indicator	Data type	References
1) Brine discharge rate of desalination plants (See Section 3.5.1.1)	Quantitative	(Muñoz and Fernández-Alba, 2008; Gil-Trujillo and Sadhwani Alonso, 2023)
2) Quality of discharged wastewater (See Section 3.5.1.2)	Quantitative	(Pires et al., 2017; United Nations, 2015; Ramkumar et al., 2022; United Nations, 2015; Marttunen et al., 2019)
3) Carbon dioxide emissions from desalination (See Section 3.5.1.3)	Quantitative	(United Nations, 2015; Afgan et al., 1999; Rogers et al., 2020; Gil-Trujillo and Sadhwani Alonso, 2023)
4) Compliance of wastewater treatment plants with regulations (See Section 3.5.1.4)	Qualitative	(Pires et al., 2017; OECD, 2022; Iribarnegaray et al., 2015; Najar and Persson, 2021)
5) Share of reusing of treated wastewater (See Section 3.5.1.5)	Quantitative	(Al-Zubari et al., 2017; Criollo et al., 2019; United Nations, 2015)
6) Share of using groundwater for drinking (See Section 3.5.1.6)	Quantitative	(Pires et al., 2017; Iribarnegaray et al., 2015)

3.5.1.1. *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 the process of extracting pure water from saline water (Nair and Kumar, 2013), whether from the sea or stored in aquifers. The output of this process became known as DW, which requires desalination plants (DPs) to be treated and produced.

The process produces freshwater, and concentrated brine, a wastewater that includes elevated levels of salt and other chemicals (Ahmed et al., 2001; Djuma et al., 2016; Wenten et al., 2017). Unfortunately, unregulated discharges of this untreated wastewater into the sea can harm the ecosystem therein (Amy et al., 2017). In addition, DPs close to the coast frequently release untreated brine into salty SW bodies, such as oceans and seas (Arnal et al., 2005), while inappropriate surface disposal of other DPs could pollute GW resources (Ahmed et al., 2001). Therefore, identifying the rate and composition of brine discharges is significant. According to Xu et al. (2013), the estimation of the brine production rate depends on two factors:

1) Salinity level of feedwater (e.g., seawater (SeW) or brackish water (BW)) that is used as an input at the beginning of the process;
2) Type of desalination technology (e.g., Reverse Osmosis (RO), Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED)) that is used to get desalted water.

To illustrate, 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., called recovery ratio (Harvey, 2008)) while using brackish water (BW) with RO would have 65%, the remaining percentage (i.e., 78% and 35% respectively) in both cases would be brine (Jones et al., 2019). 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 DW production and 55% of the total brine (Jones et al., 2019). 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. (2019) presented several assumptions about the water recovery ratios resulting from the combinations of feedwater-technology, where the important ones related to this study can be shown in Table 3-3. While these technologies and types of feedwaters in Table 3-3 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. (2022) collected information about the daily DW production in 2020 and the rate of technology used, as shown in Table 3-4. Therefore, by knowing these data plus the water recovery ratio for each technology combined with the type of feedwater, which is presented in Table 3-3, the average quantity of brine discharge can be estimated for each GCC country. Then, this quantity can be considered as a baseline of the previous specific year (e.g., in our case, it can be 2020) and can be monitored and compared with future years. A suggested criterion to evaluate this indicator is presented in Table 3-5.

Table 3-3 Water recovery ratios resulted from the combinations of feedwater and technology (Jones et al., 2019)

Technology / Feedwater type	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 3-4 DW daily production and the share of using each desalination technology in GCC (Moossa et al., 2022)

Country	**Desalinated water production data of 2020** (million m^3/day)	**Desalination technology**	**Country-wise share based on technology** (%)
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 3-5 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) have increased or equal to the baseline year	0
High	Brine discharge rate (or quantity) is ≤ 5% of the baseline year	1
Medium	Brine discharge rate (or quantity) is ≤ 15% of the baseline year	2
Below	Brine discharge rate (or quantity) is ≤ 25% of the baseline year	3
Low	Brine discharge rate (or quantity) is ≤ 35% of the baseline year	4
Very low	Brine discharge rate (or quantity) is ≤ 45% of the baseline year	5

3.5.1.2. *Quality of Discharged Wastewater*

The quality of wastewater (WW), whether treated or untreated, should be monitored before it is discharged. This action would be more significant when it is known that 44% of household wastewater globally was not safely treated in 2020 (UN-Water, 2021). Thus, checking the quality of WW would help eliminate many environmental issues by ensuring that they are at least unharmful before they are 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 would be treated as sub-indicators here, which 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 (FC). The quality limit of each parameter based on the type of WW is shown in Table 3-6.

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, Tertiary TWW, which can be known for example by the standard given in Table 3-6. Then, this average will be taken to Table 3-7 to be compared and given an appropriate score.

Table 3-6 Standard quality parameters and their limits of WW and TWW in KSA (MOWE, 2000)

Parameter (Unit) / Water Supply	Biochemical Oxygen Demand (BOD_5) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Suspended Solids (TSS) (mg/l)	Total Dissolved Solids (TDS) (ppm)	pH (mg/l)	Ammoniacal nitrogen (NH_3-N) (mg/l)	Nitrates (NO_3) . (mg/l)	Faecal Coliforms (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 3-7 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 lower than the standard quality of WW	0
Low	Average quality of discharged WW is equal to the limit of 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 limit of standard quality of secondary	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 limit of standard quality of tertiary TWW	5

3.5.1.3. *Carbon Dioxide Emissions from the Desalination Sector*

H 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 (GHG) (Liu et al., 2015; Saleh and Mezher, 2021), while the reason to choose it alone is because its produced quantity from DPs found to be the largest among other gasses (Afgan et al., 1999).

For example, some DPs use thermal plants that rely on burning fuels to produce electrical energy, which is required to operate these plants (Sadhwani et al., 2005; Tokui et al., 2014). On the other hand, RO technology requires less energy (Soliman et al., 2021), meaning lower CO_2 emissions (Hamieh et al., 2022). In addition, using renewable energies instead of conventional energy sources is very promising in mitigating and reducing the negative emissions (i.e., CO_2) of DPs (Al-Karaghouli and Kazmerski, 2013). 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"* (United Nations, 2015). Not only this, but also this type of indicator was similarly used somehow in other SWRM frameworks such as WSC Index (Rogers et al., 2020), TBL-MCDA (Cole et al., 2018).

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) (Hamieh et al., 2022). In addition, the average apparent emission factor of desalination in 2016 was 21.4 kg CO_2/m^3 of desalinated water, reduced to 15.2 kg CO_2/m^3 in 2019 due to technological improvements (Hamieh et al., 2022). 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 to evaluate this indicator are either similar to the one provided in the previous paragraph by Hamieh et al. (2022) or by considering the number of DPs in each country, their type of technology, and their yearly actual production. Then, this data should be aggregated and multiplied by the estimated CO_2 emissions of each technology, which is presented in Table 3-8. The final output of this process should be compared to a previous year (e.g., 2 or 5 years before), when its data are available and accurate, as a baseline of that country.

A suggested criterion to evaluate this indicator is presented in Table 3-9.

Table 3-8 CO_2 emissions per m^3 of produced water for different desalination technologies (Cornejo et al., 2014)

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 3-9 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% than the baseline year	1
Medium	CO_2 emissions are $\leq$ 40% than the baseline year	2
Below average	CO_2 emissions are $\leq$ 60% than the baseline year	3
Low	CO_2 emissions are $\leq$ 80% than the baseline year	4
Very low	CO_2 emissions are $\leq$ 100% than 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.

3.5.1.4. *Compliance of Wastewater Treatment Plants 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 (1) type of treatment used, whether primary, secondary, or tertiary; (2) plants' age; and (3) actual production, compared to design capacity, thereby checking the plants' performance. The values of this indicator are qualitative based on the previous three criteria and are illustrated in Table 3-10.

Table 3-10 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

3.5.1.5. *Share of Reusing of Treated Wastewater*

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 for using RW is that the environment is protected from the effluents that might otherwise be discharged into the environment with small or inadequate treatment (Baig et al., 2020). 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 re-used the 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 (Al-Zubari et al., 2017). Thus, these countries are required to make non-inconsiderable concerted efforts to reach this target within the next few years. Meanwhile, RW can have different uses, such as urban area landscaping and municipal park irrigation (Ouda, 2014), which help reduce the pressure on other WR. The values of this indicator can be qualitative, as shown in Table 3-11.

Table 3-11 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

3.5.1.6. ***Share of Using Groundwater for Drinking***

Since GW is one of the major WR in GCC, ensuring that this resource is not overused is still significant. Continuing decline in the water table (Baig et al., 2020) or, worse still, salinity intrusion (Alyamani, 1999; Kinzelbach et al., 2010), are both environmentally unsustainable. Hence, monitoring this via a specific indicator is required. GW in the GCC countries are divided into types (Al-Zubari et al., 2017):

1) GW in shallow aquifers, which is considered the only renewable water source, and
2) fossil GW in deep aquifers, which is considered non-renewable GW.

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 (Al Rashed et al., 2023), which is possible only with type 1.

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 (Al-Zubari et al., 2017). Nevertheless, some GCC countries have a small reserve of the above types of GW (e.g., Qatar and Bahrain) (Al-Zubari et al., 2017), 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 million cubic meters (MCM), the yearly withdrawn from this reserve is 58 and 19,460 MCM, respectively (Al Rashed et al., 2023). If we assume that the recharge rate of these reserves, which holds 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 GW (especially the NGW) 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 3-12.

Table 3-12 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 GW for drinking is > 80%	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

3.5.2. Social Indicators

While protecting the environment of the SWRM system is significant to 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. As such, this process needs a number of different steps to be adopted, such as illustrating how individual use in parallel to the degree of awareness (Hunt and Shahab, 2021) 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 drinking water quality 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 3-13.

Table 3-13 Social indicators of the conceptual SWRM-AF with their types and supporting references

Social Indicator	Data type	References
1) Per capita water consumption (See Section 3.5.2.1)	Quantitative	(Pires et al., 2017; Al-Zubari et al., 2017; Lawrence et al., 2002; Silva et al., 2020b; Criollo et al., 2019; Crispim et al., 2021; Muñoz and Fernández-Alba, 2008; Gil-Trujillo and Sadhwani Alonso, 2023)
2) Drinking Water Quality (See Section 3.5.2.2)	Quantitative	(Pires et al., 2017; Policy Research Initiative, 2007; Juwana et al., 2011; Silva et al., 2020b; Cole et al., 2018; Criollo et al., 2019; Crispim et al., 2021; Gain et al., 2016; Iribarnegaray et al., 2015; Marttunen et al., 2019; Najar and Persson, 2021; Moglia et al., 2012)
3) Water Stress (See Section 3.5.2.3)	Quantitative	(Pires et al., 2017; United Nations, 2015; Lawrence et al., 2002; Policy Research Initiative, 2007; Silva et al., 2020b; Gain et al., 2016; Juwana et al., 2011)
4) Water Awareness (See Section 3.5.2.4)	Qualitative	(Pires et al., 2017; Lawrence et al., 2002; Policy Research Initiative, 2007; Juwana et al., 2010b; Silva et al., 2020b; Chaves and Alipaz, 2007; Ben-Daoud et al., 2021; Crispim et al., 2021; Rogers et al., 2020)
5) Intervention Acceptability (See Section 3.5.2.5)	Qualitative	(Foxon et al., 2002; Cole et al., 2018; Najar and Persson, 2021)
6) Existence of participatory framework & guidelines (See Section 3.5.2.6)	Qualitative	(Pires et al., 2017; United Nations, 2015; Juwana et al., 2011; Silva et al., 2020b; Ben-Daoud et al., 2021; Iribarnegaray et al., 2015; Rogers et al., 2020; Vollmer et al., 2018)

3.5.2.1. ***Per capita water consumption (Domestic Sector)***

This indicator has a graded scale from high to low consumption. It 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 problematic 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 (UN, 1997a).

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 over, 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 suffers 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, most GCC countries figured out that their average water consumption is high (e.g., KSA = 278 L/capita/day in 2018 (GASTAT, 2018a), Bahrain = 320, Kuwait = 500, Qatar = 512, and UAE = 520 L/capita/day, while Oman is exception with only 140 L/capita/day (Al-Zubari et al., 2017)). These high levels of most GCC nations let experts decide to set a target in the GCC UWS to reach at least 250 L/capita/day by 2035 (Al-Zubari et al., 2017). This target aligns with the recommendations that emphasise demand management by motivating the enhancement of consumption behaviour better than focusing on supply management. The adoption of water-efficient appliances and changes in user behaviour are fundamental to achieving these targets (Hunt and Rogers, 2014; Hunt and Shahab, 2021).

Therefore, while this target (i.e., 250 L/capita/day) is considered in Table 3-14, more targets are added to push the boundaries of reducing consumption, where achieving them would benefit the water sector greatly. Moreover, water consumption that does not match the assigned numbers in Table 3-14 should rounded to the nearest number in the table. For example, if the average use of the country is 190 L/cap/day, which is close to 200 L/cap/day, then the consumption level should be considered Low, and its score is 4.

Table 3-14 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

3.5.2.2. *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 the fact that it helps ensure the health and well-being of society - by maintaining a decent quality of drinking water. Otherwise, water diseases (e.g., cholera, typhoid), which occur after drinking polluted or low-quality water, can happen. Moreover, the importance of this indicator would increase 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 to consume 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 to calculate this indicator is to use scores of overall drinking water quality from other indexes, such as the Environmental Performance Index (EPI) (Wolf et al., 2022). Otherwise, most parameters that were used in many water quality indexes 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 3-15 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).

Table 3-15 Standard quality parameters of drinking water (Al-Omran et al., 2015)

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

Another way to measure the value of this indicator in order to be consistent with previous indicators is provided in Table 3-16. In this table, categorical scaling is used to consider the issues 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. Measuring the water quality level of this indicator in Table 3-16 can be done by estimating the size of the areas that have drinkable water that matches the standard quality in Table 3-15.

Table 3-16 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)

3.5.2.3. *Water Stress*

This indicator was introduced by Falkenmark et al. (1989) 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)(Cosgrove and Rijsberman, 2014). The renewable supply in this context means the annual amount of conventional WR only (i.e., average yearly stream flow and/or the sustainable GW yield) on a per capita basis (Policy Research Initiative, 2007). Water stress in any specific region starts when there is less than 1700 m^3/cap/year, and it becomes severe when it is less than 1000 m^3/cap/year (Cosgrove and Rijsberman, 2014), while less than 500 m^3/cap/year could represent that water availability is a main constraint to have a normal life (Policy Research Initiative, 2007; UNCTAD, 2021). 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 is not considering these resources since they are categorised as non-renewable or need excessive cost or technology to be treated. Meanwhile, a new indicator that follow the same previous categorization and combined the conventional, which includes NRGW, and non-conventional WR is suggested to reflect the real water stress in countries like the GCC. The equation needed to calculate the water stress (or scarcity) indicator (WStI) is as follows (Al Rashed et al., 2023):

$$WSI_i = \left(\frac{DT_{net\ i} - (NRGW_i + DSW_i + RUW_i)}{SFWA_i}\right) \times 100 \qquad (6)$$

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 Eq. (6) 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 SW (Al Rashed et al., 2023). Then, the water stress level can be indicated by referring to Table 3-17.

Table 3-17 Scores and their descriptions assigned for evaluating water stress (UN, 1997a; Falkenmark, 1997)

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

3.5.2.4. *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 (Corral-Verdugo et al., 2003; Fan et al., 2014). 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 (Fan et al., 2014; Hunt and Shahab, 2021), 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. (2017) 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 that water authorities produce water awareness campaigns on different media. Finally, this indicator is presented on a qualitative measure, as seen in Table 3-18, starting from 0 to 5, with a specific description given to each evaluation since it is hard to measure quantitively.

Table 3-18 Scores and their descriptions assigned for evaluating water awareness

Efforts Level	Qualitative Description	Score
No efforts at all	The advocating for water awareness is missing by all means.	0
Small	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	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

3.5.2.5. ***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 (WRT)) and making its use mandatory. Other examples include the smart water meter (SWM), greywater system, 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 to evaluate 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 IBWSF. Like the previous indicator, each description with its score is presented in Table 3-19.

Table 3-19 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 (WRT) 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 is subsidised).	2
Moderately acceptable	At maximum, three interventions are accepted, but one of them is better to be free (e.g., WRT), and the others (e.g., greywater and RWH systems) could be afforded by 50% of their cost	3
Highly acceptable	Any interventions are accepted and could be afforded by 75% of their cost	4
Fully acceptable	Any number of interventions are accepted at any cost.	5

3.5.2.6. *Existence of Participatory Framework and Guidelines*

According to the Dublin principles (ICWE, 1992), 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:

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 agreed plan and achieving key objectives.
4) To let them convey 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 to fill the institutional gap. In addition to the existence of such a framework and its guidelines, the main criterion for evaluating 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 to check this is suggested here, along 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 3-20.

Table 3-20 Scores and their descriptions assigned for evaluating the existence of participatory framework indicator

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 & framework about the roles of stakeholders exist on paper but without activation or actual application.	2
Exist for limited groups but without application	Participatory framework & guidelines about the roles 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 & guidelines about the roles 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 & guidelines about the roles of stakeholders exist with the involvement of the majority of stakeholders' groups with a real contribution in making decisions.	5

3.5.3. *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 rationalize their water use and hence reduce their water bills. Therefore, it is vital to create and investigate the 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 suggest 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 3-21.

Table 3-21 Economic indicators of the conceptual SWRM-AF with their types and supporting references

Economic Indicator	**Data type**	**References**
1) Water supply cost related to users' income (See Section 3.5.3.1)	Quantitative	(Pires et al., 2017; Rogers et al., 2020; Iribarnegaray et al., 2015; Crispim et al., 2021; Criollo et al., 2019; Cole et al., 2018)
2) Unaccounted for water (water losses) (See Section 3.5.3.2)	Quantitative	(Pires et al., 2017; Cole et al., 2018; Liemberger and Farley, 2004; AWWA WLCC, 2020)
3) Water sector share in total public spend (See Section 3.5.3.3)	Qualitative	(Pires et al., 2017; Criollo et al., 2019; Rogers et al., 2020)
4) Cost recovery of water supply utilities (See Section 3.5.3.4)	Quantitative	(Pires et al., 2017; Al-Zubari et al., 2017; Cole et al., 2018)
5) Cost recovery of wastewater utilities (See Section 3.5.3.5)	Quantitative	(Pires et al., 2017; Al-Zubari et al., 2017; Criollo et al., 2019)
6) Pro-poor and pro-efficiency water fees (See Section 3.5.3.6)	Qualitative	(Pires et al., 2017; Chaves and Alipaz, 2007; Rogers et al., 2020; Silva et al., 2020b)

3.5.3.1. ***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 (Andres et al., 2019). Moreover, most low- and middle-income countries have water tariffs that cannot cover water providers' daily costs unless financial authorities would give compensation (Andres et al., 2019). On the other hand, unaffordable and increased water tariffs can result in a lot of bills that cannot be paid by customers, which prevents expected revenues from being collected on time (Colton, 2005). 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 they are affordable and could generate revenues.

To calculate this, the average number of people (or households) who lived in the same house 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) shall 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 to discover this relationship between monthly income and the water bill are presented in Table 3-22.

Table 3-22 Examples of required data to calculate the relation between average user income and the water cost*

Country	Average Household (Year)	Average yearly Income [d] (US dollars)	Average monthly Income (US dollars)	Average daily water consumption (L/cap/d)	Average monthly water consumption (m^3/house/Month)	Average water tariff (US $/$m^3$)
Saudi Arabia	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](UNDESA, 2017), [b](UNDESA, 2022), [c](Esri, 2022), [d](World Bank, 2023d), [e](GASTAT, 2018a), [f](Al-Zubari et al., 2017), [g](Andres et al., 2021), [h](GWI, 2023) , [i](Al Khoury et al., 2023; KAHRAMAA, 2023), [j](ADDC, 2023), [k](EWA, n.d.), [l] (Alazmi et al., n.d.), * water tariff is different in these countries since some of them charge variable tariffs based on specific ranges of water consumption, while some give discounted rates (e.g., UAE) or free of charge (e.g., Qatar) for their citizens, while non-citizens should pay higher amounts.

After doing this calculation, the cost level can be known by taking the output of this process to Table 3-23, which can tell whether it is high for the final user or not. Most of these levels assigned to the average income are based on a global study of water affordability presented by Smets (2009), where any water tariff surpassing 5% of the user income is considered high.

Table 3-23 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% to 8% of the average user income	1
Above Average	Average water tariff is between 4% to 5% of the average user income	2
Average	Average water tariff is between 3% to 4% of the average user income	3
Low	Average water tariff is between 2% to 3% of the average user income	4
Very Low	Average water tariff is ≤ 2% of the average user income	5

3.5.3.2. *Unaccounted for Water (Water Losses)*

Unaccounted-for water (UFW) is the difference between the water amount produced and entered the water supply system and the amount that is billed or consumed (Motiee et al., 2007). 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 (Liemberger and Farley, 2004). However, this indicator is responsible for measuring these losses that came mainly from leaking from an economic point of 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 $14.6 billion USD (Rashid et al., 2014). 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 (Ayala–Cabrera et al., 2013; Laspidou, 2014). On the other hand, many GCC countries had issues in the municipal distribution network with water leakage that caused a high economic loss (Al-Zubari et al., 2017). 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 meter of water would be calculated (e.g., 2 US$/m^3). Then, the average leakage rate from the water pipes network (e.g., 35%) is multiplied by the total amount of water produced during a specific period (e.g., 2000 million m^3 (MCM)/year). Therefore, if the water leakage is 700 MCM, the total economic loss based on the unit cost of 2 US$/m^3 is 1,400 million US$/year. This vast monetary loss could burden the whole economic system and might be paid by the final user who did not receive this water, reflecting an injustice. Therefore, having such an indicator to measure and evaluate these losses would help shed light on the magnitude of this problem and work on decreasing it. Table 3-24 below shows the different levels of these economic losses, along with their criteria.

Table 3-24 Scores and their descriptions assigned for evaluating the losses of unaccounted-for water

Level of UFW	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

3.5.3.3. *Water Sector Share in Total Public Spend*

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 3-25.

Table 3-25 Scores and their descriptions assigned for evaluating the water sector share in total public spend

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., spend ≤ 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% < spend ≤ 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% < spend ≤ 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% < spend ≤ 80% of the needs of the water sector)	4
Excellent	A Very high percentage is given to cover the basic requirements of the water sector (e.g., 80% < spend ≤ 100% of the needs of the water sector)	5

3.5.3.4. *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 capital costs through their own spending and charge customers only O&M costs to make water prices reasonable within society (Barraqué, 2020). 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)(World Bank, 2005). 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, GCC countries seek in the GCC UWS to recover 100% of O&M costs by 2025 as a first target and 100% of total costs by 2035 as a second goal (Al-Zubari et al., 2017). 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 overall be sustainable in the long term for the economy (Aljamal et al., 2020). Therefore, data from 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 3-26, with the average cost recovery being calculated.

It can be seen that Kuwait's cost recovery rate is the lowest, while three other countries are charging their population water tariff that is lower than the actual 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 3-26 might need to be revised and updated since many possible changes to the cost occurred recently as a result for the research and development of the used technology and energy. A specific evaluation is provided in Table 3-27 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 3-26 Examples of average water costs, tariffs, and cost recovery ratio in GCC

Country	Average Costs of water supply (US$/m^3)	Average water tariff (US $/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](Ouda et al., 2018), [b](World Bank, 2005), [c](Saif et al., 2014), [d](Tariq et al., 2022), [e](Andres et al., 2021), [f](GWI, 2023) , [g](Al Khoury et al., 2023; KAHRAMAA, 2023), [h](ADDC, 2023), [i](EWA, n.d.), [j](Alazmi et al., n.d.)

Table 3-27 Scores and their descriptions assigned for evaluating the cost recovery ratio

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

3.5.3.5. *Cost Recovery of Wastewater Utilities*

Similar to the previous indicator, a comparison is required here between the unit cost of treated wastewater 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 off 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 flourish the economy and protect the environment by reducing the discharge of untreated WW rate. Not only this but wastewater treatment and reuse are increasingly necessary to support the water supply in the GCC countries, considering the high expenses linked to desalinated water production (Aleisa and Al-Zubari, 2017). On the other hand, this indicator can shed light on the feasibility of current economic practices and help fix any flaws. Therefore, similar data were needed to give an estimation for the cost recovery in the previous indicator (See Section 3.5.3.4) is required here but for the costs and tariffs of wastewater. Then, the level of cost recovery would follow the same descriptions and scores in Table 3-27.

3.5.3.6. *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 this global recommendation by the United Nations where:

"*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.*" (CESCR, 2003; 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, applying the Increasing Block Tariffs (IBTs) system, which means the water would have a varying price or tariff based on the monthly total consumed amount, where low cumulative amount would have a lower unit cost than high consumption (Pinto and Marques, 2015; Boakye-Ansah et al., 2019). To explain, the monthly unit cost of low consumption, for example, with a block cap of 20 m^3 /month, is \$0.5/m^3, while the monthly unit cost would increase if the customer exceeded the previous cap to \$1/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 3-28.

Table 3-28 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 measure(s) for either pro-poor nor pro-efficiency water fees	0
Minimum	The water tariff system includes specific and ineffective measure(s) for either pro-poor or pro-efficiency water fees.	1
Below average	The water tariff system includes specific and partially effective measure(s) for either pro-poor or pro-efficiency water fees.	2
Medium	The water tariff system includes specific and effective measure(s) for either pro-poor or pro-efficiency water fees.	3
Good	The water tariff system includes specific and partially effective measure(s) for both pro-poor and pro-efficiency water fees.	4
Excellent	The water tariff system includes specific and highly effective measure(s) for both pro-poor and pro-efficiency water fees.	5

3.5.4. Infrastructure Indicators

As previously discussed, while infrastructure may not be a primary focus of sustainability, it remains a crucial piece of the SWRM puzzle. This is due to the infrastructure's significant role in measuring the quality of life for those living in urban areas. This level of life quality encompasses evaluating the quality of water services, which relies on the availability of widespread infrastructure for citizens in a given region or country. Additionally, it is necessary to identify and address common obstacles that may hinder or reduce the benefits of water infrastructure. Therefore, specific indicators are needed to assess infrastructure performance 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 3-29.

Table 3-29 Infrastructure indicators of the conceptual SWRM-AF with their types and supporting references

Infrastructure Indicator	**Data type**	**References**
1) Access to safe drinking water (See Section 3.5.4.1)	Quantitative	(United Nations, 2015; Pires et al., 2017; Lawrence et al., 2002; Policy Research Initiative, 2007; Juwana et al., 2011; Silva et al., 2020b; Criollo et al., 2019; Crispim et al., 2021; Gain et al., 2016; Marttunen et al., 2019; Rogers et al., 2020; Moglia et al., 2012)
2) Access to sanitation (See Section 3.5.4.2)	Quantitative	(United Nations, 2015; Pires et al., 2017; Lawrence et al., 2002; Policy Research Initiative, 2007; Juwana et al., 2011; Silva et al., 2020b; Criollo et al., 2019; Gain et al., 2016; Iribarnegaray et al., 2015; Marttunen et al., 2019; Rogers et al., 2020; Moglia et al., 2012)
3) Rate of water physical leakage (See Section 3.5.4.3)	Quantitative	(Pires et al., 2017; Al-Zubari et al., 2017; Policy Research Initiative, 2007; Juwana et al., 2011; Alsalmi et al., 2013)
4) Share of desalinated water produced to domestic sector (See Section 3.5.4.4)	Quantitative	(Pires et al., 2017; Saleh and Mezher, 2021)
5) Share of collected wastewater to domestic water (See Section 3.5.4.5)	Quantitative	(United Nations, 2015; Al-Zubari et al., 2017; Marttunen et al., 2019; Criollo et al., 2019)
6) Age of water infrastructure (See Section 3.5.4.6)	Quantitative	(Cole et al., 2018; Iribarnegaray et al., 2015; Kaur et al., 2021)

3.5.4.1. *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 (UN-Water, 2021) 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 3-30. These estimations in Table 3-30 are based on the updated data for the world coverage of water for each country, where some countries that located in ASAR have low access ratio (e.g., Ethiopia with 52%) (World Bank, 2023a).

Table 3-30 Scores and their descriptions assigned to evaluate the rate of the access to safe drinking water

Access to drinking water Level	Qualitative Description	Score
Very Low	Access ratio is ≤ 50%	0
Low	Access ratio is ≤ 60%	1
Below Average	Access ratio is ≤ 70%	2
Average	Access ratio is ≤ 80%	3
High	Access ratio is ≤ 90%	4
Very High	Access ratio is ≤ 100%	5

3.5.4.2. *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 (Bartram and Cairncross, 2010). 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 (UN-Water, 2021). 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 this city or place is to reaching national or global targets, such as the one provided by the SDGs (UN-Water, 2021). Table 3-31, which is based on comparison criteria suggested by the UN (UN Habitat and WHO, 2021), is provided below to measure the level of access to sanitation in any country.

Table 3-31 Scores and their descriptions assigned to evaluate the rate of access to sanitation

Access to Sanitation Level	Qualitative Description	Score
Low	Access ratio is ≤ 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

3.5.4.3. *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. Not only does this problem impact the infrastructure, but 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 (Liemberger and Wyatt, 2019). Therefore, it is highly recommended to specify an indicator to monitor 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 (Al-Zubari et al., 2017). 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 3-32.

Table 3-32 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

3.5.4.4. ***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. Meanwhile, this technology needs either an appropriate existing infrastructure or to develop 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 using DW 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, DW share in half of the GCC countries is equal to or more than 90% (Al-Zubari et al., 2017). 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 3-33.

Table 3-33 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 to 19%	1
Below Average	Share of desalinated water produced to domestic sector is between 20 to 39%	2
Average	Share of desalinated water produced to domestic sector is between 40 to 59%	3
High	Share of desalinated water produced to domestic sector is between 60 to 89%	4
Very High	Share of desalinated water produced to domestic sector is ≥ 90%	5

3.5.4.5. *Share of Collected Wastewater to Domestic Water*

The collection of wastewaters can occur if the infrastructure includes a specific network for such a purpose. Otherwise, this wastewater 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 wastewater. This indicator can be measured by comparing the share of collected wastewater to domestic water. Hence, infrastructure capacity can be scrutinised, and the environment can be saved. Not only this but if the increase of wastewater collection would increase the TWW and its use, this will enhance the sustainability of the entire system. In some GCC countries with available data, the average amount of collected wastewater was below 50% of the total volume of water provided to the domestic sector in 2010 (Al-Zubari et al., 2017). This share is aimed to be 60% by 2030 in the GCC UWS (Al-Zubari et al., 2017), which can be considered as the average target or range for our indicator. Other levels and their descriptions are provided in Table 3-34.

Table 3-34 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 produced to domestic water is ≥ 81%	5

3.5.4.6. *Age of Water Infrastructure*

It is well known that most engineering design has a suggested lifetime or age that must be aware of for regular maintenance, extensive rehabilitation, or replacement required before its function could deteriorate. Water infrastructure includes reservoirs, storages, distribution systems represented by pipe networks, and WTPs. On the other hand, ignoring the proper action to monitor and deal with the issue of the 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 (Iribarnegaray et al., 2012; Cole et al., 2018), which can be a good sign of its importance.

Table 3-35 is provided below to give an evaluation for each age or lifetime. The higher age in this table was according to Chohan et al. (2023) who found that the typical 50-year lifespan of pipeline networks was considered in multiple life cycle assessment (LCA) studies.

Table 3-35 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

3.6. Summary and Conclusion

Several IBWSFs had, at least in theory, great emphasis on fostering the sustainability of WRM, but some 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 one of the most water-stressed areas in the world without any permanent rivers or lakes. As a result, this chapter is the first step to developing 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. Before setting up or developing a SWRM-AF, it is important to think about and follow the unique rules and requirements for having one. If not, the result of this process would not be useful and strict enough.

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 guidelines have been introduced and applied to select individually and collectively the right indicators in order to end with a practical framework.

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 to understand humans' motivations and barriers to behaving or receiving these new changes to either convince them or adjust based on that. 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 the 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.

Additionally, a color-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 the 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.

The main output of this SWRM-AF is a final value that represents the level of sustainability of the WRM of that region or country. Therefore, the simplicity of this output can be valuable for decision-makers and stakeholders to let them both get a hint about the situation of their WRM. By informing the two groups, 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.

That being said, this chapter (and stage) still lacks one of the most important criteria to develop an IBWSF: the participatory approach. This is because this chapter 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 get the final version of SWRM-AF, but this is out of the scope of this chapter. 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 next chapter will produce more details about the calculation (or aggregation process) since it should end with the final version of SWRM-AF based on the opinions of the expert stakeholders.

Many parts of this chapter are submitted to the *Journal of Sustainability* under this title: *A Sustainable Water Resources Management Framework for Arid and Semi-arid Regions – Part 2: refining the conceptual framework using Delphi technique*

4. Development of the Final Framework (SWRM-AF)

4.1. Introduction

The final results of the SLR (See Section 2.5.2) showed that some sustainable frameworks developed for water were solely based on searching the literature to find appropriate components and indicators (Chaves and Alipaz, 2007; Gain et al., 2016; Silva et al., 2020b) as the first stage, whilst many, either for creation or validation purposes, sought stakeholder opinion (Sullivan et al., 2003; Policy Research Initiative, 2007; Juwana et al., 2010a; Rogers et al., 2020; Bahar et al., 2020; Ben-Daoud et al., 2021).

Whilst selecting components and indicators from the literature is a crucial initial part of developing a water sustainability framework, the final set requires scrutiny and verification by appropriate stakeholders. These stakeholders, who are experts within the field (in this case with respect to water), are used for screening, filtering, and validating the choices made initially by the researcher(s) (Juwana et al., 2010a; Crispim et al., 2021). This study aims to use the same processes to help refine the conceptual SWRM-AF for ASAR. While there are different approaches for the stakeholders' engagement, such as the Bayesian Belief networks, that can be used to incorporate stakeholder understandings of how a system works (Singto et al., 2020), the Delphi technique will be applied here to seek consensus since it fits better. A simple and general definition and purpose of the Delphi technique states that it is:

"… *a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.*"(Linstone and Turoff, 1975)(p. 3)

Likewise, WRM and its sustainability measurement can be considered a complex problem requiring the participatory approach, as stated by the Dublin principles (ICWE, 1992), to deal with and develop.

Initially, this technique aims to reach a consensus through multiple rounds of questionnaire surveys (Hanafin, 2004) as an alternative to face-to-face meetings allowing opinions to be sorted and anonymity to be protected (McMillan et al., 2016). This approach avoids peer pressure and allows opinions to be provided purely based on opinion and prior knowledge, particularly in the first round. Another advantage of this technique is that it can assist in obtaining expert opinions without having them gather at a pre-determined time and location (Juwana et al., 2010a). Consequently, using this method will allow many experts from different backgrounds to make the SWRM-AF both reliable and usable for decision-makers and the public as a whole.

In this chapter, the Delphi technique (See Section 4.2) is used to assist in reaching consensus on the identification of final sets of both components and indicators and assign their weights accordingly. Such an approach has previously been used successfully in a variety of domains (e.g., (Lee et al., 2013; de Brito et al., 2017; Ahmad et al., 2018; Casanovas-Rubio and Armengou, 2018)), including refining the indicators of a water sustainability index or framework (Juwana et al., 2010a; Crispim et al., 2021). In this chapter, due consideration is required for:

- the Delphi technique (Section 4.2)
- Identification of the selection of stakeholders (Section 4.2.2)
- the design of the questionnaires (Section 4.2.3),
- the distribution and collection of questionnaires (Section 4.2.4),

All of these aspects are further discussed in Section 4.2.

4.2. Application of Delphi Technique

To check whether the selected sets of components and indicators, which form the conceptual SWRM-AF, could match with locally conceived and context-specific demands, the participatory approach was chosen to assess these sets. Not only this but the weights of each elected indicator and component shall be assigned during this process. One of these approaches that can fulfil the two objectives is the Delphi technique. In short, the Delphi technique is a survey method used to help isolated respondents make decisions (Cantrill et al., 1996), or sometimes, like in our case, validate the SWRM-AF. The following section will present more about this method and how it would be applied in our case.

4.2.1. The Delphi Technique

4.2.1.1. *Overview*

The first use of this technique was by Rand Corporation during the 1950s to forecast the consequences of nuclear war in the USA (Cantrill et al., 1996). This project was named "Project Delphi", and its details were released a decade later for security reasons, where experts were asked to answer questionnaires and provide feedback to arrive at a reliable consensus. (Dalkey and Helmer, 1963). This approach replaces direct debate with a well-crafted programme of successive individual interrogations (best done through questionnaires) and information and opinion feedback derived from computed consensus from the program's earlier sections (Helmer and Rescher, 1959).

Since then, many studies have adopted this technique to achieve the same target: consensus among experts regarding a complex issue. Nonetheless, obtaining and incorporating knowledge from various specialists with diverse viewpoints is not easy (Hwang et al., 2006). Still, few applications, such as Delphi, can overcome this difficulty (Hugé et al., 2010). The philosophy behind this technique is that getting an accurate and trustworthy assessment is ideal by consulting a panel of experts, whose consensus should be accepted as the best estimate of the answer (Campbell and Cantrill, 2008). This includes setting priorities, such as for planning purposes, which can be aided by applying this method (Uhl, 1983).

Hence, this technique has been shown to be effective in handling many issues and reaching consensus in different scientific areas if we can measure that by the number of studies that have applied it since it was introduced. To find the answer, a simple search was done through the Scopus database to show the number of research within its Title/Abstract/Keywords with the word “Delphi” between 1969 and 2022. The results show that 34,007 research started from only 14 in 1969 and ended with 4,110 in 2022. The main subject area was medicine, with 15,924 studies, followed by social sciences, engineering, business and management, and computer science, respectively. Hence, this variety of subjects can indicate that this technique is helpful for both qualitative and quantitative research. The previous remark was also noticed by Faulkner and Valerio (1995), who argued that the strength of this method resides in its capacity to simultaneously provide a framework for consultation while allowing for the evaluation of both qualitative and quantitative elements.

Similarly, another search was undertaken on the 13th of October 2023 through the Scopus database to show the number of studies that within its Title/Abstract/Keywords combined between only two words: “Delphi” and “Sustainab*”, where the star simple referred to both sustainable and sustainability. Results of this search manifest that there was 2,031 research in total, with an increased trend in the number starting from less than 10 studies in 2005 and ending with more than 300 research in the last two years (i.e., 365 in 2022 and 327 in 2023) as shown in Figure 4-1. Another trend can be realized in Figure 4-1 after 2015, when the number of studies surpassed 100, and that could be because of the declaration of the SDGs in 2015 (United Nations, 2015). Therefore, adopting this technique in this study is not something new or out of the ordinary, but it is meaningful and rationalized based on this trend.

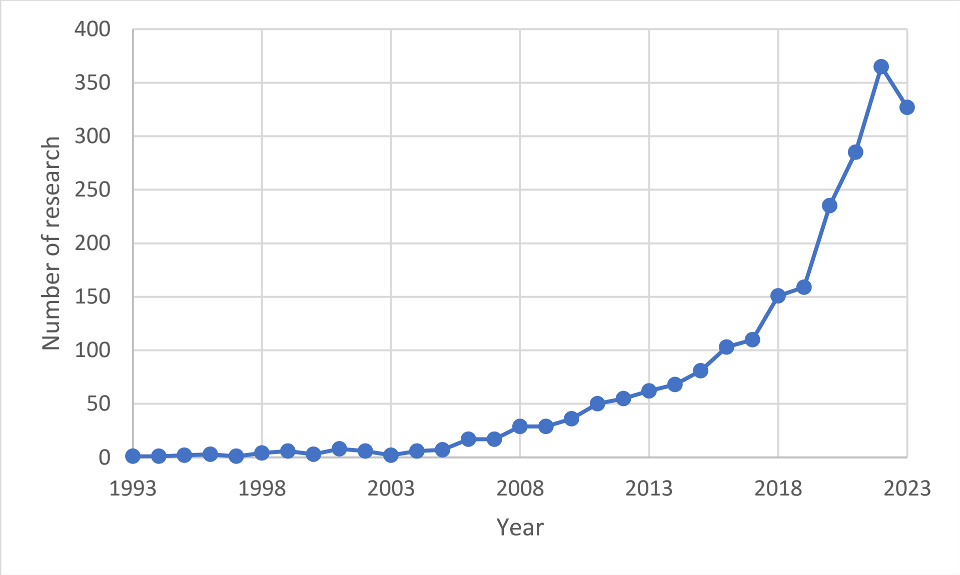


Figure 4-1 Trend of studies that combined sustainability and Delphi technique (1993-2023)

Another question might arise about when we can use this technique. There are two possible main conditions or justifications behind using this technique (Linstone and Turoff, 1975):

1- When accurate data does not exist or is expensive to get or
2- Subjective inputs are necessary for evaluation models to the extent that they become the primary parameters.

Thus, consulting specialists in that industry could save time and effort in discovering exact data that may be unavailable or need to be replaced by subjective thoughts. Because gathering specialists from many nations at one time and place is difficult, this method is also used. Regarding the mechanism of this technique, preparing the initial questionnaire statements often starts with thoroughly examining the literature review (Cantrill et al., 1996; Campbell and Cantrill, 2008) as the first step. The first stage involves delivering questionnaires to specialists to complete with their ideas and comments within a certain deadline. After collecting and analysing first-round questionnaire replies, the new round's questionnaire is created. Following the last round's results, the next questionnaire should ask more questions regarding points where responses or ratings are disputed. Therefore, respondents can reconsider their choice or judgement depending on having an idea about the majority's opinion and then decide to keep their original thought or to change. This would be continued until a consensus is reached, which can vary by research method and percentage.

There are several features and advantages to using the Delphi technique. One of these advantages is that this technique is considered a powerful tool that enables individuals to think about problems in more sophisticated ways than they often would (Pollard and Tomlin, 1995). Another advantage is that all participants can freely give their opinions (Franklin and Hart, 2007), which helps lessen the impact of some psychological elements, including the bandwagon effect of majority opinion, fraudulent persuasion, and the unwillingness to renounce publicly declared ideas (Helmer and Rescher, 1959). In addition, Delphi advocates contend that group decisions are of greater reliability than those made by a single person (Murry Jr and Hammons, 1995) and are more objective when experts and their intuitive perspectives are sought after on a specific topic (Lang, 1995). Consequently, reliability and objectivity in the outputs of this technique can be ensured since it depends on the collective opinion of experts.

Moreover, the questionnaires of this technique used to be distributed by mail, but more lately, the so-called e-Delphi Technique has been conducted by email (Avery et al., 2005), which might be the norm for the future application (McMillan et al., 2016). Thus, it would be more convenient for expert stakeholders to participate anytime and anywhere that suits them, which can be an extra motivator. Not only this, but it would save time, money, and effort for the researchers to conduct their studies while using this technique. Therefore, it was feasible and possible in this study to access the knowledge of respondents located at different geographic distances, such as those found in the GCC countries, affordably.

Despite these advantages, the Delphi technique has some concerns. One drawback is that the respondents' extreme viewpoints are frequently ignored (Bardecki, 1984), and sometimes also the minority since the main goal is the consensus by the majority. However, some researchers suggested that minority views should not be omitted but be discussed (Uhl, 1983; Juwana et al., 2010a). Others suggested that if a point was raised several times by different participants during a specific round, it should be presented in the next round to ensure whether it needs to be considered. Thus, such a compromise for the minority can be provided if their new or adjusted ideas or opinions have been repeated. This is especially important if we remember that the whole process is based on the participants' anonymity, which reduces the bias and the influence of others to adopt the same thoughts. Meanwhile, this may allow the majority to have a new view of that particular point or subject from different angles.

Another critique argued that it is challenging to evaluate the correctness and dependability of a procedure based on judgment and opinion (Woudenberg, 1991). Likewise, it was observed that this method's output quality is not always accurate since the practices of selecting the expert panel sometimes might not be taken carefully (Harrison, 1999). However, it can be said that the confronting argument for these critiques is that choosing the Delphi panel should be based on both subject-matter competence and ensuring that panellists come from a variety of backgrounds with experience in the area being studied (Masser and Foley, 1987; Rowe et al., 1991; Briedenhann and Butts, 2006). As a result, the outputs of this method could be more accurate and trustworthy if clear and sound criteria were assigned and applied correctly.

4.2.1.2. ***Application approach***

To be able to apply the Delphi technique in the questionnaires of this study, Likert scales were used to evaluate identified components, indicators, and their weights. While different point system formats represent the possible responses, 5- or 7-point formats are considered the most used (Malhotra and Peterson, 2006). Also, modelling experiments and empirical investigations have agreed that utilizing 5- to 7-point scales rather than coarser ones (i.e., those with fewer scale points such as 3-point scales) improves reliability and validity (Dawes, 2008). Hence, it was decided to use the 5-point scale in rating the questionnaires of this study while applying the Delphi technique. Meanwhile, it will be more convenient and less complicated for participants to give evaluations. For example, the scale of 1 to 5 ranges from “Not important” to “Very important”, with 3 being neutral was used.

The previous rule applies to 73% of the questions in the questionnaires of this study except those regarding the weight of both components and indicators. The remaining questions start with a yes or no answer about whether the participants either agreed to consider assigning equal weighting or not, in which case the Likert scale was used to assign these accordingly.

Furthermore, since consensus among experts is the target of conducting the Delphi technique, it is essential to have clear criteria and know when and how this has been achieved. This is important for the robustness of the SWRM-AF and its adoption by stakeholders. While different statistical methods with other criteria have been assigned to measure and obtain the consensus in some studies (Casanovas-Rubio and Armengou, 2018; de Brito et al., 2018), using simple methods might be better to ensure the understanding of several stakeholders and gain their cooperation and trust. For example, a coefficient of agreement (C_c) was used to determine the level of consensus (i.e., the vote of the majority of participants) (Santos, 2001; Santiago and Dias, 2012; Crispim et al., 2021). This level can be estimated by Equation (7) (Santos, 2001):

$$C_c = \left(1 - \frac{V_n}{V_t}\right) \times 100 \tag{7}$$

Where: C_c is the coefficient of agreement presented as a percentage; V_n is the number of experts disagreeing with the dominant direction; V_t is the total number of experts. Regarding the acceptable level of consensus in general, there were different opinions in the previous studies. For instance, Salmond (1994) conducted a brief literature survey and revealed that consensus levels can range from 50% to 80%. Moreover, some studies decided that consensus can be achieved when participants have at least two-thirds or a percentage equal to or bigger than (i.e., ≥) 67% towards one option (Alexandrov et al., 1996; Juwana et al., 2010a). Others preferred ≥ 50% to get a consensus level (Santiago and Dias, 2012; Crispim et al., 2021), which can be understandable if the selection is among multi-options (i.e., more than two). However, in this study, the percentage suggested by Santos (2001) to obtain a consensus level was followed, which is ≥ 60%, as a cut-off. This is because this level can work with two types of questions (i.e., those with two-options and multi-options).

4.2.2. Identification of Water-related Stakeholders

The identification of water-related stakeholders is one of the crucial tasks in the application of the Delphi method. A criterion was assigned to select this study's experts' stakeholders:

- their work or expertise should belong to the water sector and/or sustainability.
- this experience should be related to the GCC countries as the target
- application of expertise should be in ASAR.

On the other hand, this study identified the stakeholders from six categories:

- academics,
- consultants,
- government officials,
- practitioners or engineers,
- technical experts, and
- community or non-profit organizations.

Unfortunately, the response rate from the last category was very low. As a collective, these categories aim to have stakeholders from diverse backgrounds with genuine interests in WRM and its sustainability. During round one, about 60 stakeholders were targeted from all six categories.

4.2.3. Design of the Questionnaires

Whilst it was assumed that multiple rounds of questionnaires could be required to reach a consensus on the selected indicators and the weight of components and selected indicators, this was achieved in two.

A first draft of the questionnaire was prepared and passed ethical review from the University of Birmingham ethics team (Approval code: ERN_0969-Apr2023). The questionnaire was refined following a pilot study. This involved 12 specifically chosen post-graduate researchers and alumni from the University of Birmingham who have worked in the field of sustainability, WRM, or GCC countries to get their early feedback on the overall design and the questions' clarity. This pilot study also allowed measurement of the average time participants would need to finish the whole questionnaire. Subsequently, questions were either revised, removed, or added based on their valuable feedback. The estimated time to finish the questionnaire (25 to 35 minutes) was noted in the invitation sent to the main participants.

It is worth mentioning that the traditional application of Delphi during round one typically starts with open-ended questions to collect information in the initial round (Hsu and Sandford, 2007). However, the modified method adopted herein features close-ended questions and is considered a more appropriate option if the information related to the targeted field exists (Kerlinger, 1973). Using close-ended questions has several advantages, such as saving time for both the creator (i.e., researcher) and respondents, encouraging more people to participate and complete all rounds, ensuring important statements are included and not ignored (McCampbell and Stewart, 1992; Hsu and Sandford, 2007), and reduces the confusion and randomness that comes with an open-ended discussion (Franklin and Hart, 2007).

Hence, most questions were close ended since the conceptual framework is already available. The majority of questions are based on a 5-point (or level) Likert scale, while the minority are simply yes or no questions. Very few questions are open-ended. Regarding the Likert scale, respondents are considered to support or give high importance if they selected 4 or 5 on the Likert scale and are deemed not to support or give low priority if they picked 1 or 2 on the Likert scale. The answer of 3 on the Likert scale is regarded as a neutral response.

In the first round, the questionnaire was divided into seven main sections, as summarised in Figure 4-2 below.

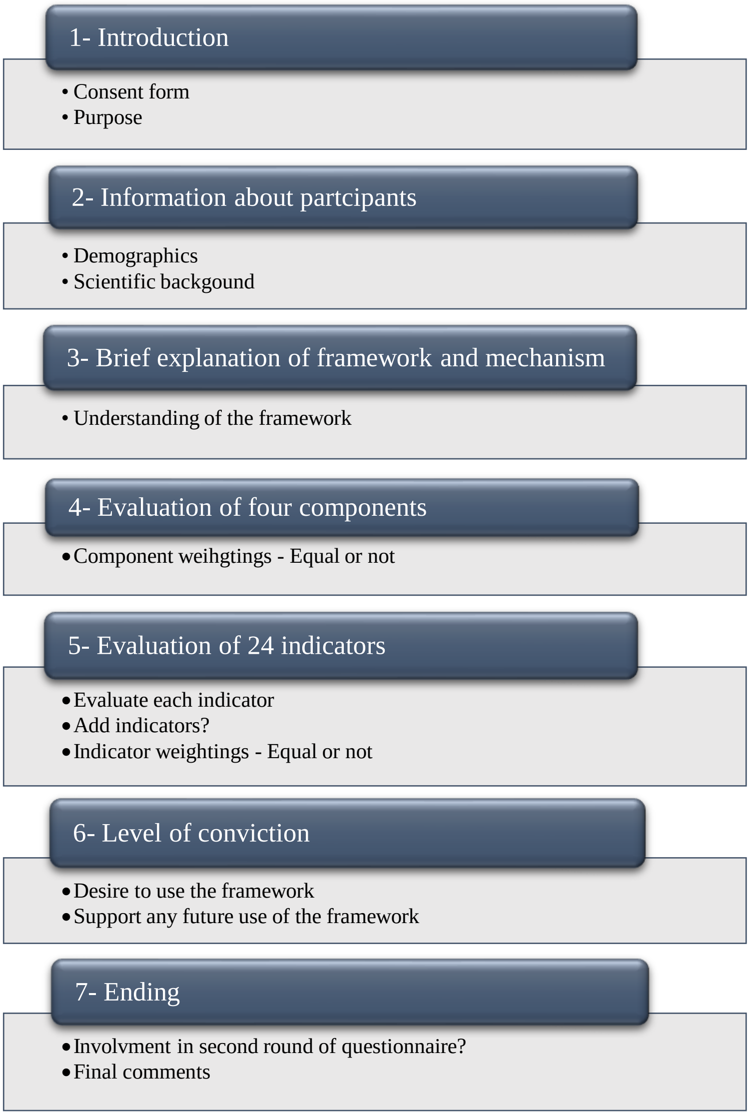


Figure 4-2 Seven main sections that constitute the questionnaire of the first round

The details of each section in Figure 4-2 are as follows:

1. Introduction (including consent form in English and Arabic) and outline of the purpose of the questionnaire. If the participants are willing to continue at this stage, they need to provide their approval to the consent form to let them move to the next section.
2. Participants' background includes 5 questions about their demographics (See Section 4.2.2) and 4 questions about their general scientific background with relation to Sustainability, Assessment tools, and WRM.
3. A brief explanation is presented for the framework and its mechanism, followed by a question on a five-level Likert scale to see to which degree the provided

explanation was clear to the participants.

4. Evaluation of the four components with one mandatory question about whether their weight should be equal. If not, another question based on a four-level Likert scale was provided to evaluate the relative importance of each component.
5. As the main section, there is a brief description defining the chosen six indicators under each respective component (i.e. environmental, economic, social, and infrastructure). Participants are subsequently allowed to evaluate them. based on a five-level Likert scale. The scale of 1 to 5 ranges from “Not important at all” to “Very important”, with 3 “Moderately important” being neutral. In the description of the evaluation question of each indicator, it was mentioned to participants that indicator(s) with low evaluation are likely to be excluded in the final version of the framework. Next, a ‘yes’ or ‘no’ question is presented to see if the participant suggests adding any indicator(s). If yes, then an open-ended question is given. This section's last question is whether each set of indicators under each respective component should carry equal weight. If the answer to the previous question by the majority was “No”, then the weight would be based on their prior evaluation of the remaining indicators (i.e., the ones that have high evaluation, so they are not excluded).
6. Participants are asked for feedback by way of two questions based on a five-level Likert scale regarding the use or support of the policy or decision-maker(s) to use any SWRM-AF in the future after going through this questionnaire. The scale of 1 to 5 ranges from “Very unlikely” to “Very likely”, with 3 being neutral with the phrase “Neither likely nor unlikely”. The purpose is to check the level of convection of each participant of having or applying such a tool.
7. In this final section, participants are asked two questions. The first one is about whether they are willing to participate in a second round of questionnaires. If the response is yes, then they are asked to send an email to confirm. The purpose of not only asking the participant to give their personal information in the questionnaire itself in case they are willing to participate in a second round is to keep their identity unknown during the analysis of results. In case the answer is no, then this would not affect the results of the first round, and the contribution of this participant is still valid to be considered while preparing the results of the first round to make

new questions for the second round. The second question of this category (i.e., Ending section) concerns the final or additional comment(s) that participants want to add before submitting the answers to the questionnaire.

Based on the outcomes of the first round, the questionnaire for round two was created. This second questionnaire first provides a summary of the first round. Secondly, any (yes or no) question regarding the weight that did not achieve a consensus by 60% in the first round was asked again while showing the collective result and the majority's opinion of the first round. The purpose of doing this is to let the experts now consider the majority's opinion and make sure that they would keep or change their opinion to achieve the targeted consensus. Finally, a specific rule to sort the suggestions that were given by experts in open-ended questions was applied. This rule emphasized that any comments or indicators that had been repeated at least three times should be given as a question in the second round to the participants to decide whether to consider them or not.

The design of the questionnaires in the second round started with another pilot study. The draft was distributed among the same but smaller number of participants from the first round. The feedback indicated that all questions in this round were clear and straightforward. Moreover, the estimated time to finish the questionnaire of the second round was much less than the first, at a time range from 5 to 10 minutes.

4.2.4. Distribution and Receiving of Completed Questionnaires

The first step in this process was to send an invitation with brief information about the questionnaire and its purpose to each expert stakeholder. A question was included if they were willing to participate and asked them what method they would prefer to send the questionnaire link. Different techniques were used to send this invitation, such as emails, ResearchGate, WhatsApp and social media accounts such as Twitter (now X) and LinkedIn. This starting step aligns with the preferred procedures to apply in general surveys (Salant and Dillman, 1994) and in Delphi technique, in particular (Hsu and Sandford, 2007).

The first invitations were sent on the 14th of June, 2023. After receiving the acceptance of the experts to participate, the link to the questionnaire was sent to them based on their answers to the invitation letter through their preferred method (i.e., Email, LinkedIn, ResearchGate, and WhatsApp, respectively). All questionnaires in this study were designed via Google Forms because of its simplicity and popularity among users.

The total number of respondents was 40 out of 60, and they were interested in filling out the questionnaire. However, some of them asked to send a reminder to them on or after a specific date because they were busy during the time of the invitation.

The estimated time to receive the completed questionnaire was one month, which was broadly similar to the second round. Except for one participant who submitted late because of his special conditions. Notwithstanding, only 33 out of 40 experts actually completed and submitted the first questionnaire; thus, the return rate for this stage was 82.5% for those who accepted the invitation and 55% for all experts who received the invitations. This first-round response rate is higher than that of other research that used the Delphi approach, which frequently ranges from 30% to 50% (Wright and Giovinazzo, 2000) of the people who received invitations to participate. Similarly, McMillan et al. (2016) conducted a literature review on several previous studies to show the number of experts who agreed and completed the questionnaire later. The calculated results showed that the average response rate of experts who agreed and then completed the questionnaire was 70.76%. Therefore, it can be said that having an 82.5% response rate in the first round is higher than other studies, which could indicate an efficient application of this technique.

The participants in the first round can be categorized as 13 academics, 9 consultants, 6 technical experts, 3 government officials, and 2 practitioners or engineers. It should be noted that a higher proportion of academic stakeholders (39.4%) could lead to analysis biases, such as the dominance of their viewpoint over that of other stakeholders. However, this can also be an advantage because academic stakeholders are well-known for having an in-depth understanding of water resource challenges in GCC countries, and some of them have participated in community-based water resource projects.

Regarding the gender of participants in the first round, 29 were males, 2 were females, and 1 chose not to say. From the responding cohort, it might be noted or suggested that fewer females (i.e., since only 6% participated) than males work or have experience in the water sector of the GCC countries. Whilst more female stakeholders were invited to take part, response rates still were low.

In terms of education level, 23 respondents (69.7%) held PhD degrees, 5 held Master's degrees, and 5 held Bachelor's degrees. Hence, it can be concluded that all participants are very well-educated, which should give more credibility to the final results of this technique. The breakdown of countries the respondents were from is as follows: 24 from Saudi Arabia, 4 from Kuwait, 2 from Bahrain, 1 from each of UAE, Oman, and Canada, respectively. Although asked, unfortunately, nobody from Qatar participated.

Regarding the experience, 11 respondents (33.3%) have (more than 20 years) experience, 8 (24.2%) with (6 to 10 years), 5 (15.2%) with (16 to 20 years), 5 (15.2%) with (1 to 5 years), and 4 (12.1%) with (11 to 15 years). Hence, it can be seen that most of the participating experts (i.e., 84.8%) had a high experience that surpassed 5 years in the field, which gave their evaluation more credibility.

In the second round, questionnaires were sent to only 20 experts. The decreased number of participants for different reasons between rounds is not rare (Green and Hunter, 1992; Pan et al., 1996; Dean et al., 2000; Juwana et al., 2010a; Crispim et al., 2021). Pan et al., (1996) promoted the idea that the sample size needs to be as large as possible to account for subsequent drop-outs during new rounds while still being sufficiently small to guarantee that the participants are all specialists in their areas. Thus, the number of participants who expressed their desire to participate in the second round of this study (i.e., 20) can be considered sufficient since the drop-outs are expected, and they represent 60% of the participants in the first round.

However, only 19 participants out of 20 actually completed and submitted the second questionnaire. If we calculate the response rate based on the agreed experts from the first round, the return rate becomes high (i.e., 95%). A flow chart illustrating the procedure of distributing invites and receiving completed questionnaires is presented in Figure 4-3. Still, if the calculation is based on the first round participants (i.e., 33), the return rate becomes low (i.e., 57.6%). Moreover, the number of participants in each category is 12 academics, 4 consultants, 2 technical experts, and 1 government official. It can be seen that the academics are only missing one person from the first round, maybe because they understand the importance of surveys and their results to contribute knowledge. On the other hand, 89.5% of experts in this round were males, and 10.5% were females, while the education level was PhD for 78.9%, Master for 5.3% and 15.8% for Bachelor’s degree. The country the participant is working in now, or at least has good experience with, was Saudi Arabia (12 participants), Kuwait (4 participants), and 1 participant for each of UAE, Oman, and Bahrain respectively. Regarding the experience, 7 have (more than 20 years) experience, 7 have (6 to 10 years), 2 have (16 to 20 years), 2 have (11 to 15 years), and 1 had (1 to 5 years). Therefore, the participant group was made of highly educated professional with a high level of experience.

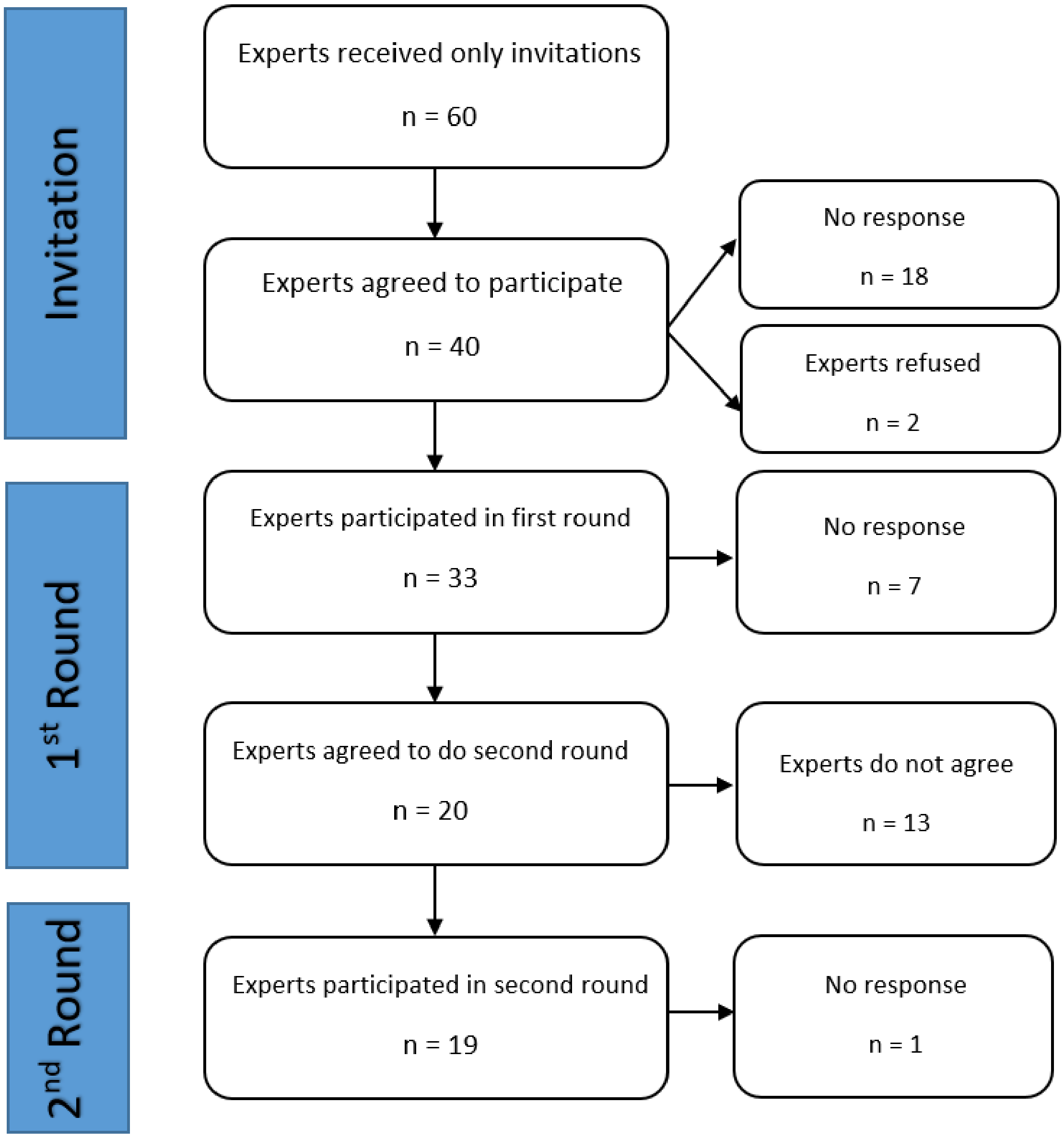


Figure 4-3 Questionnaire distribution and completion flow chart

4.3. Results and Analysis

4.3.1. Round One

As stated previously, the primary purpose of this questionnaire was to let experts evaluate the initially selected set of components and indicators and their weights. In addition, experts were asked to suggest any crucial indicators that were not included under any components and to give pertinent feedback regarding the conceptual framework. This conceptual framework was presented in the previous chapter of this two-part stage on the development of SWRM-AF for ASAR (See Section 3.5).

Below is a summary of the responses for the remaining sections of the first questionnaire.

4.3.1.1. *Introductory questions – Participants background*

Before moving to the main questions, introductory questions were posed to assess participants' general knowledge about sustainability, assessment tools, and WRM. These questions and the type of answers are illustrated in Table 4-1. The answers' rate and their distribution are shown in Figure 4-4.

Table 4-1 A brief survey about the scientific background of participants

#	Question	Type of Answer
a	How familiar are you with sustainability and its three primary pillars?	five-level Likert scale (Not familiar to Extremely familiar)
b	How frequently do you use any sustainability assessment tools?	five-level Likert scale (Never to Every time)
c	How would you rate your knowledge of sustainability in the field of Water Resources Management (WRM)?	five-level Likert scale (Very poor to Excellent)
d	Are you currently using any Sustainable Water Resources Management Assessment Frameworks (SWRM-AFs)?	Yes or No

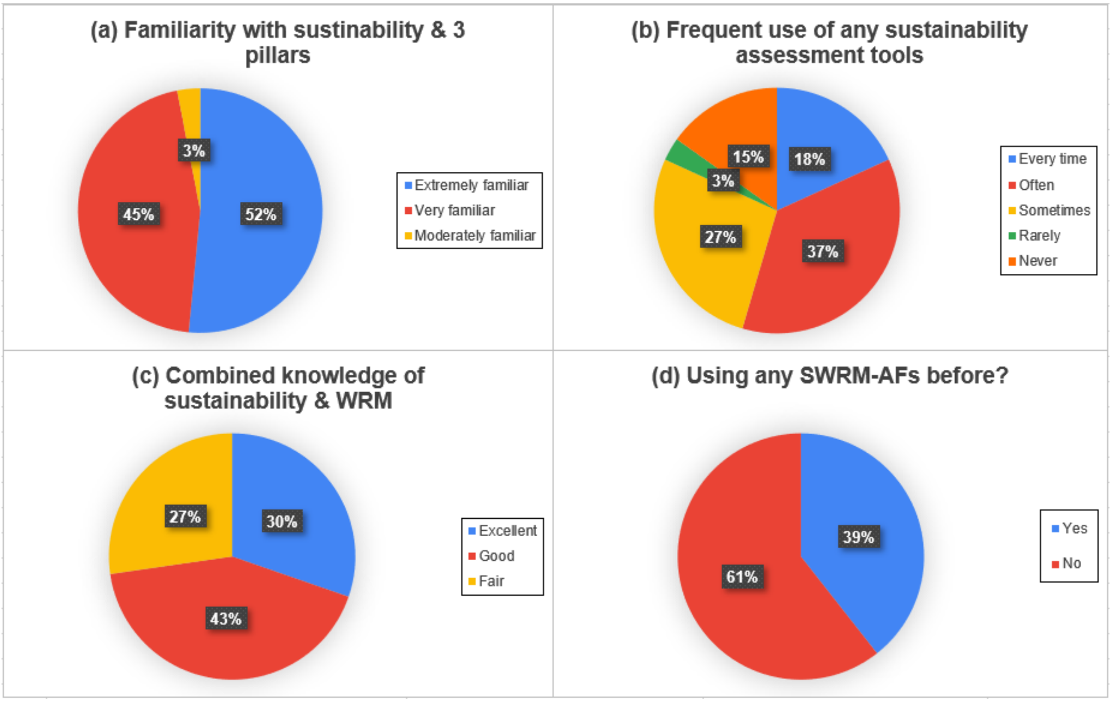


Figure 4-4 Distribution of answers to questions about the scientific background of participants

From the answers to Question a (Figure 4-4a), it can be said that most (i.e. 97%) participants are either "Extremely familiar" or "Very familiar" with the principle of sustainability and its three pillars. In addition, 3% are moderately familiar, meaning no participants were either "Slightly familiar" or "Not familiar". Similarly, Figure 4-4b shows that at least 82% have either Sometimes, "often", or "frequently" used a sustainability assessment tool. In parallel, Figure 4-4c indicates that 73% have either good or excellent knowledge of sustainability and WRM, while only 27% have acceptable levels (i.e., fair knowledge). The last two levels, "Poor" and "Very poor", were once again not selected for this question. Hence, these results strongly suggest that most of the participants had, in one way or another, some experience with (and therefore would be suitable for) helping achieve the aim of this study (i.e., to refine the SWRM-AF).

The last question in Table 4-1, a (yes or no) question was provided to check for any previous use of SWRM-AFs. This question can be split into two questions depending on the answer. If the answer is no, no further inquiry is required, while if the answer is yes, another question appears about the name of this SWRM-AF. Figure 4-4d shows that 61% of respondents had never used any SWRM-AFs before, while 39% claimed they had used them. Participants suggested SWRM-AF can be:

- the national water strategy of KSA,
- the use of greywater, which can be classified as a sustainable intervention,
- the importance of GW management,
- the supply and demand management,
- The sustainability of the non-conventional water resources.

Whilst many of these suggestions cannot individually represent a whole framework, they can collectively be considered essential to developing an SWRM-AF.

Additionally, the following water-related indices or tools were also stated:

- Water Quality Index (WQI) treats the issue of water quality in particular.
- Stormwater Management Model (SWMM) for sustainable urban drainage systems is a type of SWRM-AF, but it is more of an evaluation tool to improve stormwater infrastructure.
- IWRM, which is broader than an assessment tool.

Lastly, a minority of experts provided a range of actual SWRM-AF's (e.g., WPI, AWSI, and ADWI). One water expert was involved in developing a framework to help achieve sustainable development, but its name was not given since it was still in the conceptual stage. One water expert mentioned Mostadam and LEED, which are assessment frameworks but more about green building principles – that said they do include several key indicators on water. Hence, it appears that not all experts knew precisely the existence (or have used) of SWRM-AFs, which tallies previous findings. This also supports the importance and the premise of this research, which is the rare existence of any known and suitable SWRM-AF for ASAR.

4.3.1.2. *Check the understanding of the SWRM-AF*

In the third section of the questionnaire (See Figure 4-2),), a concise overview of the framework and its mechanism was presented. This overview included a visual example of the key parts forming indicator-based frameworks and the calculation direction. This explanation was crucial in ensuring that participants evaluated subsequent sections containing the most important components and indicators effectively.

Participants were subsequently asked to rate their understanding of a SWRM-AF, and the question was: is the brief explanation provided clear to you? The answers were on a five-level Likert scale, which starts from the lowest "Strongly disagree" to the highest "Strongly agree".

Of all the participants, 42.4% strongly agreed that the explanation was clear and 48.5% agreed. Only one person found the explanation unclear, while two others (9.1% combined) chose the neutral answer. Based on this, it can be concluded that most participants (i.e. 90.9%, or 30 people) found the explanation clear and sufficient.

4.3.1.3. *Evaluation of components*

While the main pillars of sustainability shall be included in any IBWSF, some doubts can arise about adding more components. However, it can be argued that based on what should researchers add any of these components? Thus, it was found that the infrastructure is a crucial component if this framework is developed to assist in evaluating the sustainability of WRM (See Section 2.5.3.1 and Figure 2-6), as it is in this study. Therefore, infrastructure was added as the fourth main category or component of the SWRM-AF.

Regarding how this is related to the questionnaire, a statement was given to the experts to inform them about the selection of the three pillars of sustainability and the addition of the infrastructure. This statement ended with a "Yes" or "No" question to check whether these four components should carry the same weight during the calculation process. Now, let's assume that the infrastructure should not be included; then, the apparent answer by the majority should be "No" since the infrastructure is not that important. In this case, another question would be given to let the experts evaluate the importance of each component per se based on a four-level

Likert scale that started from "Slightly important" to "Very important". This process can give an indirect sign to measure the acceptability of adding this component. However, almost the majority (i.e., 54.5%) voted that all four components should carry the same weight.

In contrast, 13 out of 15 (i.e., 45.5%) who disagreed with this rated the infrastructure as "Very important" by 5 experts and "Important" by 8. Therefore, these results could indirectly prove that having the infrastructure is essential. On the other hand, since the rate of both results is not equal to or more than 60%, which was selected as a cut-off to gain the consensus, this question needs to be repeated with its results to the experts in the second round to see whether some of them are willing to change their opinion.

4.3.1.4. *Evaluation of Indicators*

In the questionnaire, all participants were once again asked to provide an evaluation based on a five-level Likert scale (from "Not important at all" to "Very important") for each suggested indicator. The researcher assigned a point rating system to convert all these evaluations to a specific number, as seen in Table 4-2. Then, a yes or no question was given to see if any indicator(s) were missing and the experts would like to add. If yes, another open-ended question would appear to let the participant add this indicator(s) and give it a rate from 1 to 5 based on the previous scale. Finally, a similar question to the one related to the weight of the components was asked to see whether these indicators under the same component should carry equal weight or not. If the answer is yes (by 60% of the participants), then nothing should be done by the researcher. If the answer is no, then the weight assigned to each indicator would be determined by their previous evaluation based on the point rating system (i.e., Table 4-2), and that would include only those not excluded. However, if both answers did not achieve a consensus rate of 60%, this question should be asked again in the second round with a summary of the results of the first round. This is because some experts might not be 100% sure about their previous answers.

Table 4-2 Point rating system for indicators

rate	Meaning or description	Equivalent points
1	Not important at all	-2
2	Slightly important	-1
3	Moderately important	0
4	Important	1
5	Very important	2

4.3.1.4.1 *Environmental Indicators*

All the six environmental indicators in the conceptual SWRM-AF and their abbreviations are shown in Table 4-3. The summation of the points and the final evaluations are provided in Figure 4-5. It can be seen that Env.Ind.1 and Env.Ind.3 got the lowest evaluations. Therefore, they were colour-coded, highlighting the second lowest (pink) and lowest points (orange), respectively, and earmarked for exclusion from the final version of SWRM-AF.

Table 4-3 Environmental indicators and their abbreviations

#	Type of environmental indicator	Abbreviation
1	Brine discharge rate of desalination plants	Env.Ind.1
2	Quality of discharged wastewater	Env.Ind.2
3	Carbon dioxide emissions from the desalination sector	Env.Ind.3
4	Compliance of wastewater treatment plants with regulations	Env.Ind.4
5	Share of reusing of treated wastewater	Env.Ind.5
6	Share of using groundwater for drinking	Env.Ind.6

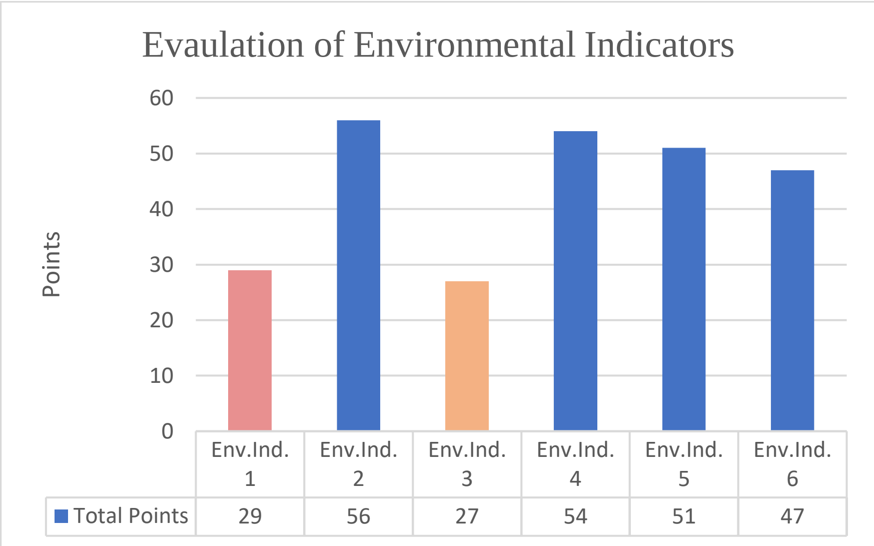


Figure 4-5 Collective evaluation of environmental indicators

Regarding adding any environmental indicator(s), 51.5% said yes, while 48.5% said No. Those who selected yes were asked to add their suggested indicators accordingly. Some of these proposed indicators were related to the agriculture sector, while the targeted sector is the domestic sector, as was mentioned in the questionnaire introduction.

Others mentioned other indicators already included under another component, such as water quality and water stress, which is included under the social component. Similarly, three experts suggested rainwater harvesting. However, this was already incorporated as a part of the “Intervention acceptability” indicator under the social component. The main reason for these requests was probably that the specific details of this indicator were not given in the question to reduce the time needed to finish the questionnaire. Thus, participants were not aware that these suggestions were already included.

Lastly, different views were given about greenhouse gasses (GHG) emissions and their impacts on climate change. Three experts indicated this view explicitly, while others talked about energy consumption, electricity production, and the use of clean energy, which together could represent the same case. Furthermore, all these issues were represented by the third environmental indicator in Table 4-3

In the last inquiry, the topic at hand was whether or not the environmental indicators should be given equal weight in the calculation process. Experts' opinions were divided; ultimately, a slim majority (51.5%) voted in favour of providing different weights, while 48.5% voted in opposition to choosing equal weights. However, since neither answer achieved a 60% consensus rate, the question was asked again in round two with a summary of first-round results.

4.3.1.4.2 Social Indicators

The six social indicators and their abbreviations are shown in Table 4-4, and the summation of the point and the final evaluation for each indicator is provided in Figure 4-6. It is clear that Soc.Ind.3 and Soc.Ind.6 received the lowest evaluations and were colour-coded, highlighting the lowest points (in pink) and second lowest points (in orange), which means they are excluded from the final version of SWRM-AF.

Table 4-4 Social indicators and their abbreviations

#	Type of social indicator	Abbreviation
1	Per capita water consumption	Soc.Ind.1
2	Drinking water quality	Soc.Ind.2
3	Water stress	Soc.Ind.3
4	Water awareness	Soc.Ind.4
5	Intervention acceptability	Soc.Ind.5
6	Existence of participatory framework and guidelines	Soc.Ind.6

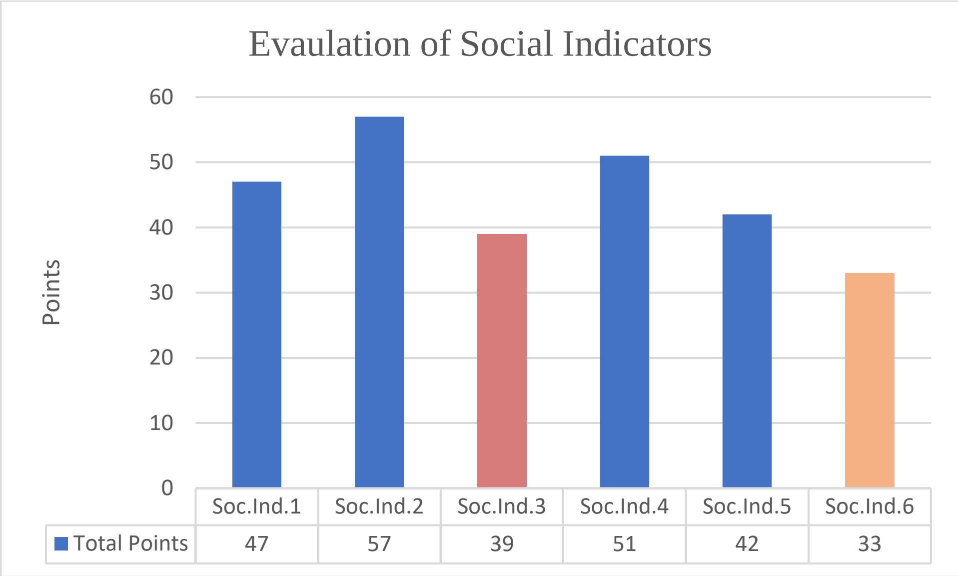


Figure 4-6 Collective evaluation of social indicators

In contrast, the majority of the experts (78.8%) voted against adding any additional social indicators, implying that the current list is sufficient. However, the question of whether to assign equal weight to the indicators or not did not reach a consensus in the first round of voting. Out of the experts who voted, 57.6% favoured assigning equal weight, while 42.4% were against it. Therefore, this question must be re-evaluated in the second round of voting.

4.3.1.4.3 Economic Indicators

While the six economic indicators and their abbreviations are shown in Table 4-5, the summation of the points and the final evaluations are provided in Figure 4-7. It is evident that Eco.Ind.4 and Eco.Ind.5 received the lowest evaluations. Therefore, they were color-coded, highlighting the lowest points (in pink) and second lowest points (in orange), and excluded from the final version of SWRM-AF.

Table 4-5 Economic indicators and their abbreviations

#	**Type of economic indicator**	**Abbreviation**
1	Water supply cost related to user's income	Eco.Ind.1
2	Unaccounted for water (water losses)	Eco.Ind.2
3	Water sector share in total public spend	Eco.Ind.3
4	Cost recovery of water supply utilities	Eco.Ind.4
5	Cost recovery of wastewater utilities	Eco.Ind.5
6	Pro-poor and pro-efficiency water fees	Eco.Ind.6

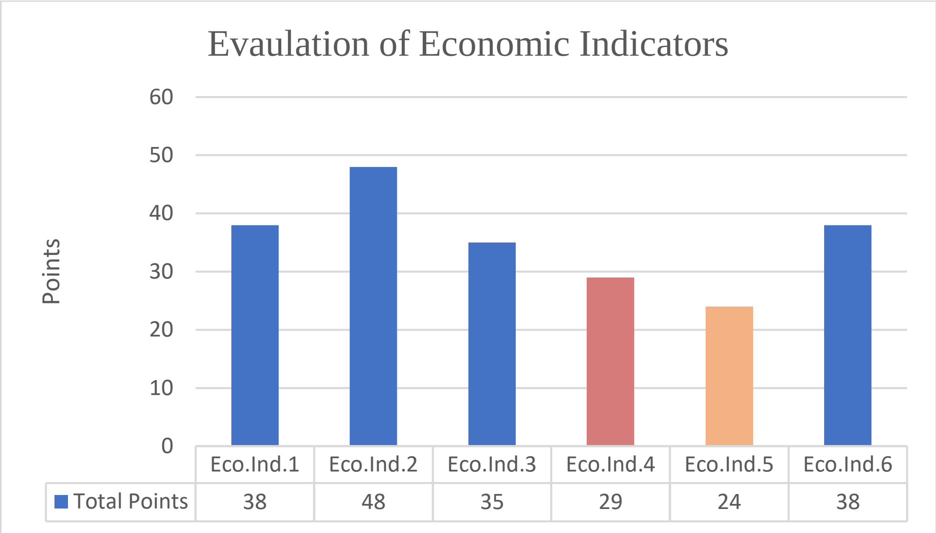


Figure 4-7 Collective evaluation of economic indicators

The results for the following two questions showed that 66.7% of the voters chose not to add any more economic indicators, which indicates that the current indicators are sufficient. Additionally, 63.6% voted to give equal weight to all economic indicators. This means both questions were resolved in the first round, and no further questions are needed in the second round.

4.3.1.4.4 Infrastructure Indicators

Table 4-6 shows the six infrastructure indicators and their abbreviations, while Figure 4-8 shows the results of their collective evaluations. It is evident that Inf.Ind.4 and Inf.Ind.5 were colour-coded, highlighting lowest points (in pink) and second lowest points (in orange), as they received the lowest evaluations and were excluded from the final SWRM-AF version.

Table 4-6 Infrastructure indicators and their abbreviations

#	Type of infrastructure indicator	Abbreviation
1	Access to safe drinking water	Inf.Ind.1
2	Access to sanitation	Inf.Ind.2
3	Rate of water physical leakage	Inf.Ind.3
4	Share of desalinated water produced to domestic sector	Inf.Ind.4
5	Share of collected wastewater to domestic water	Inf.Ind.5
6	Age of water infrastructure	Inf.Ind.6

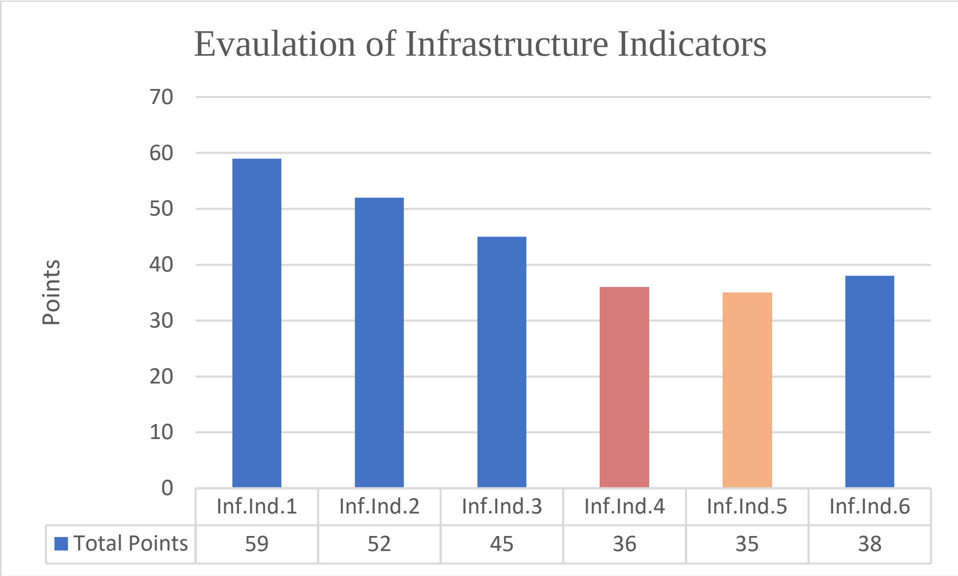


Figure 4-8 Collective evaluation of infrastructure indicators

It was discovered in the following question that the majority of experts (75.8%) did not want to add any more infrastructure indicators, indicating that the current list is sufficient. However, there was no consensus in the first round of voting on whether the indicators should be given equal weight or not. The results were similar to the previous category (i.e., social indicators). Of those who voted, 57.6% favoured giving equal weight, while 42.4% were against it. Therefore, this question must also be presented again in the second round of voting.

4.3.1.5. ***Level of conviction***

Before the final section of the questionnaire, two questions were asked to determine the extent to which participants were convinced or willing to support the use of SWRM-AFs. Both questions began with the phrase, "After participating in our questionnaire, how likely will you...". The two questions are based on a five-level Likert scale from 1 to 5, ranging from (very unlikely) to (very likely) with 3 being neutral. The first question focused on the participants' own adoption of SWRM-AFs, while the second question was about supporting the decision-makers in their area in using any SWRM-AFs. As illustrated in Figure 4-9a, an overwhelming 97% of experts expressed they would likely (36%) or very likely (61%) implement the use of SWRM-AF, with 100% stating they would support decision makers to do the same: 21% likely and 79% very likely (Figure 4-9b). These results demonstrate either a high level of conviction among experts regarding the benefits of using SWRM-AF by themselves or decision-makers in their area or that they are being polite.

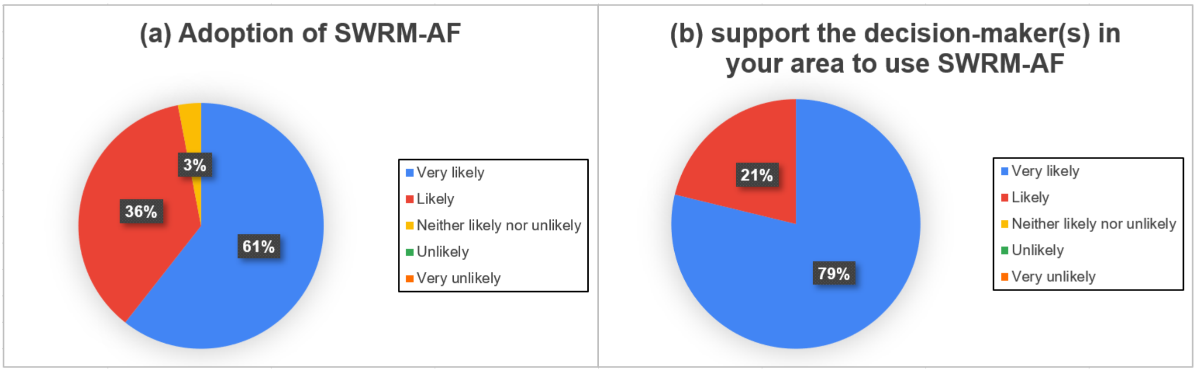


Figure 4-9 Level of conviction by experts (a) to use, or (b) to support the use of SWRM-AF

4.3.1.6. *Ending and final comments on Round One*

In the last section of the questionnaire, there were two final questions. The first question asked participants if they were willing to participate in a second round if needed. Of all the respondents, 60.6% expressed their desire to participate in the second round, while 39.4% said they were uninterested. Then, another optional question was asked if the expert wanted to provide additional comments before submitting the first round questionnaire. Many participants were thankful and grateful for being involved in this process.

On the other hand, some experts added their feedback regarding the process or the idea behind the questionnaire itself. One respondent suggested the questionnaire took too much time and effort to translate from English to Arabic to make the answer as accurate as possible. Another said that if there was another full Arabic version of the questionnaire, that would attract more professionals who have experience, but the language is a barrier. One expert thought most of the questions were very deep and needed explanation and may not be helpful if answered by someone who does not understand them. This is true if the participant is not an expert in the field. However, the respondents to this questionnaire had good expertise that was appropriate for participating in the questionnaire. The last critical comment was from an expert who suggested that the framework should be flexible, allowing modification according to the country and region where it will be applied. This point is under consideration by the researcher for future applications.

4.3.2. Round Two

As stated previously, the primary objective of the second questionnaire was to inform experts about the results of the first round and to let them reconsider the questions that did not achieve a consensus rate of 60% or higher. Meanwhile, it is important in this round to see the experts' opinions about adding any indicators suggested by different experts at least three times in the first round. Once all the issues have been resolved, the refinement stage will be considered complete, and the final version of SWRM-AF will be produced as an output of this process.

4.3.2.1. ***Evaluation of components***

After informing the participants about the results of the first round regarding the evaluation of components (refer to Section 4.3.1.3), they were first asked if they agreed with the majority's opinion from that round (i.e., an equal weight for all components, voted for by 54.5% of the participants). In this second round, 63.2% of the participants agreed, indicating that the required consensus rate had been achieved.

4.3.2.2. ***Evaluation of indicators***

4.3.2.2.1 Environmental indicators

The four environmental indicators that got the highest evaluation in the first round were subsequently presented to participants. The only suggested indicator that shall be considered is the addition of a GHG emissions indicator since it was suggested explicitly by three experts and implicitly by another three. Before the question, a short explanation was provided about how large the CO_2 emissions generated by the desalination plants in the GCC countries are. An inquiry was raised about whether to include carbon dioxide emissions from desalination as a fifth environmental indicator. The majority of respondents (78.9%) voted in favour, while the minority (i.e. 21.1%) voted against. As a result, a consensus was reached, and the decision was made to add this 5^{th} indicator under the Environmental Component.

The next task involved considering and allocating weights since the first round did not achieve the consensus rate for equal or non-equal ratings. The answer in this round was clear, with the majority (i.e. 84.2%) supporting non-equal weighting. Hence, the consensus rate was achieved, and environmental indicators should not be treated equally.

As a result, participants were asked to rate each indicator to know their weights. This was based on a five-level Likert scale ranging from “Slightly important” to “Extremely important”. The final list of environmental indicators and respective weights can be seen in Table 4-7. Therein, it can be seen that the central theme for indicators with higher weights is wastewater, and lower weights are given for the use of GW and GHG emissions. This might be because wastewater has had a visible and palpable impact on the environment for many years in the GCC countries, which made this issue require particular attention and fast treatments. On the other hand, the small weight of the added indicator reflects that several experts still think that it is not that significant, or it came as the last environmental concern.

Table 4-7 Final list of the environmental indicators and their weights (in hierarchy ordering)

Type of environmental indicator	**Weight**
Compliance of wastewater treatment plants with regulations	24.2%
Quality of discharged wastewater	23.8%
Share of reusing of treated wastewater	19.6%
Share of using groundwater for drinking	18.1%
Carbon dioxide emissions from the desalination sector	14.3%

4.3.2.2.2 Weight of social and infrastructure indicators

The last two close-ended questions in the round two questionnaire were regarding the weight of the social and infrastructure indicators since several opinions during the first round did not achieve the targeted consensus rate of 60%. Using the same approach as in the previous section, a question was provided to see whether the participants would agree with the first round's collective result, where most experts agreed for equal weight but without reaching 60%.

In the current round, 63.2% of the experts agreed to give equal weight to the social indicators, while 68.4% voted for equal weight to the infrastructure indicators. Both these percentages are higher than the targeted consensus rate. Therefore, it can be said that the weighting issue for all indicators that form the SWRM-AF is resolved, where all indicators under three components, including the economic, require equal weights. In contrast, only environmental indicators should have different weights, as illustrated in Table 4-7 above. The final weightings of the Economic, Infrastructure and Social indicators are shown in Table 4-8.

Table 4-8 The final weightings of the Economic, Infrastructure and Social indicators

#	Component in (CAPS) and indicators	Weighting
ECONOMIC INDICATORS		
1	Water supply cost related to user's income	25%
2	Unaccounted for water (water losses)	25%
3	Water sector share in total public spend	25%
4	Pro-poor and pro-efficiency water fees	25%
SOCIAL INDICATORS		
1	Per capita water consumption	25%
2	Drinking water quality	25%
3	Water awareness	25%
4	Intervention acceptability	25%
INFRASTRUCTURE INDICATORS		
1	Access to safe drinking water	25%
2	Access to sanitation	25%
3	Rate of water physical leakage	25%
4	Age of water infrastructure	25%

4.3.2.3. *Ending and final comments*

In the last section of the second questionnaire, an open-ended question was given to gather additional feedback. The majority of comments were, in general, supportive of the developed SWRM-AF, while two comments highlighted were either highly critical ((a) below) or provided good insight ((b) below):

a) One participant suggested the selection of indicators can be linked to each other (i.e. as cause and effect), for example, the issue of the age of the infrastructure and water leakage. Thus, inadvertently, the framework would be weighted more towards these two (although they are related) than the other two.

b) Weight flexibility should be considered since the SWRM-AF is developed for different countries with different local contexts and local priorities within several time sets or terms.

While the first comment above could be significant, it might not always be true that the two indicators are related. Water leakage can happen because of other factors and problems such as the material and diameter of the pipes (Saghi and Aval, 2015), high pressure (Marunga et al., 2006; Pérez et al., 2011), improper fixing of pipelines, heavy traffic, and roots of trees (Ali and

Choi, 2019). On the other hand, the ageing of water infrastructure can cause different problems to the whole process other than the leakage, such as the impact on the water quality (Clark et al., 1995; Al-Jasser, 2007; Cooper et al., 2019) and decreased water supply reliability (Ugarelli and Di Federico, 2012; Kerwin and Adey, 2020). The second comment above is reasonable and makes sense. However, the final say here was by the experts, while some features of the SWRM-AF can be user-defined in future iterations of the SWRM-AF.

4.3.3. The Refined SWRM-AF

After going through the results of the questionnaires during the two rounds above, it can be said that the refinement stage is completed, and the final SWRM-AF can be introduced. The output of this stage was controlled and proceeded via the Delphi technique. Moreover, the final version of SWRM-AF includes 4 components that should be treated equally during the calculation process and 17 indicators, as shown in Figure 4-10. Indicators under the economic, social, and infrastructure components will have equal weights (Table 4-8), while only environmental indicators will have different weights, as illustrated above in Table 4-7.

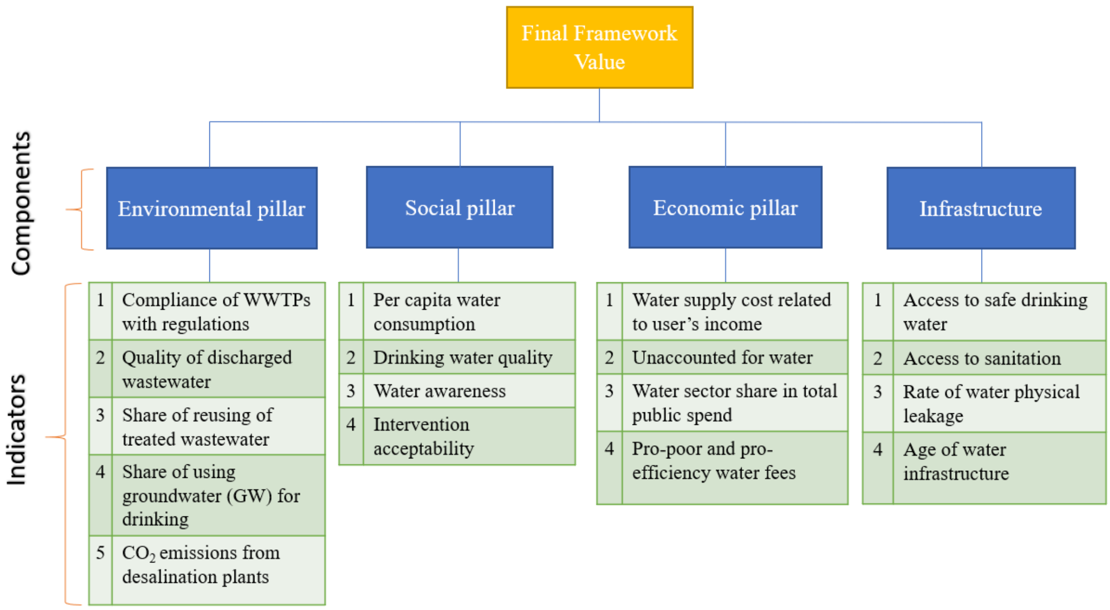


Figure 4-10 The final version of SWRM-AF after the application of the Delphi technique

It is assumed that the application scale for the SWRM-AF for ASAR and particularly GCC countries (i.e., national scale). Other scales could be applied but with several modifications, especially to some indicators, to fit the context of that scale and area. The normalization method, which is another main element to form an IBWSF (See Table 2-1), is mainly the categorical scaling method, while few indicators require the continued re-scaling method. While the weighting scheme is mixed between equal and non-equal based on stakeholders' opinions, the aggregation technique used here to make the summation among components and indicators is the arithmetic technique. Finally, the final framework (or index) value is a number or percentage from 0 to 100.

Moreover, since the direction of required calculations is a bottom-up process (See section 2.4), the aggregation procedures include taking each of the equivalent values of each indicator and multiplying it with the specific weight of that indicator. Then, the arithmetic or (the average) of the output of the previous step would be aggregated for each group of indicators. The previous process will give a value for each component, which also has a specific weight to be multiplied with (in our case, the weights of all components are equal). Finally, the final evaluation for each group of indicators under one component and the final framework value that all of them result from the final normalisation and aggregation process are what the user of SWRM-AF is expected to see as an output. These results are presented in a radar chart.

The initial design for the SWRM-AF as a tool is produced using an Excel spreadsheet. At the same time, the user must enter a specific whole number, which can be any number from 0 to 5 only. These numbers have particular colours similar to the traffic light system (red to amber to green) and are called scores, representing specific evaluations or levels of each indicator. While the indicator with an evaluation value of 0 or 1 usually means the worst option and is located in the red area, the evaluation value of 5 is the best level and is located in the green area. Also, an equivalent value from 0 to 100 is given for each score during the calculation process, where zero is 0, 1 is equivalent to 20, 2 is equivalent to 40, 3 is equivalent to 60, 4 is equivalent to 80, and 5 is equivalent to 100.

Then, the final evaluation for each group of indicators under one component and the final framework value that all of them result from the final normalisation and aggregation process are what the user of SWRM-AF is expected to see as an output. These results are presented in a radar chart. Examples of these outputs of each group of indicators and all components are shown in Figure 4-11 and Figure 4-12. Finally, it can be seen in Figure 4-11 that the final framework value is equal to 66.46 (out of 100), which represents the sustainability level of the domestic sector of the SWRM system based on the included indicators and components.

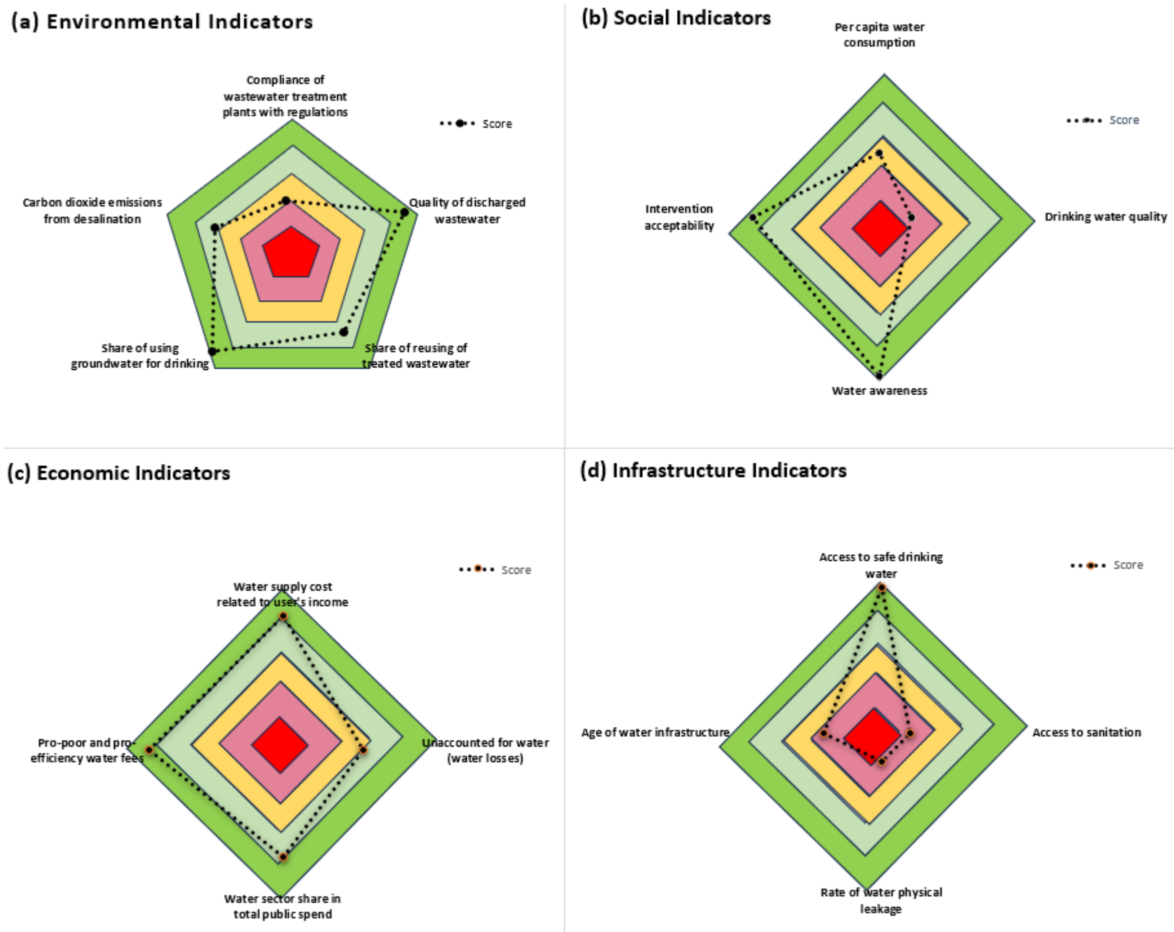


Figure 4-11 Example for the visual output of SWRM-AF for each group of indicators

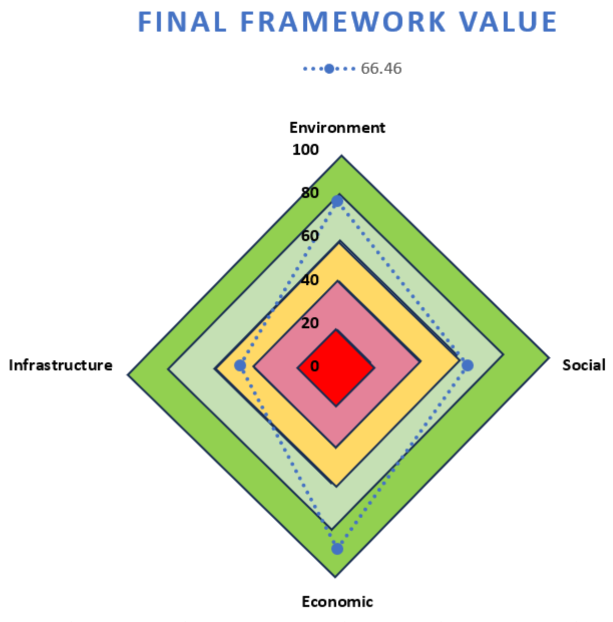


Figure 4-12 Example for the final visual output of SWRM-AF for all components

4.4. Discussion

This research sought to refine the conceptual SWRM-AF by applying a participatory method represented by the Delphi technique. A further discussion about this method, the reason for selecting this technique, and the design philosophy of the questionnaires is provided in Section 4.4.1. Section 4.4.2 illustrates the possible shortfalls of this research.

4.4.1. Reasons behind Selection and Design

The first idea that needs to be discussed here is whether the participatory approach, which is the base of this study, is mandatory and significant or optional and unnecessary. One method to find the answer is to look back at the previous indicator-based water sustainable framework. A comparison between 19 frameworks in the literature conducted in this study (See Section 2.5) can be used here. Among the researchers who developed these frameworks, 78.9% have made a connection with several stakeholders in one way or another to assist in one or both main missions that include indicators' selection and/or assigning weights for them. The majority (i.e., 73.7%) have been involved in the selection process of indicators, while only 42.1% have a leading role in giving or assigning specific weights to indicators and/or components. This low percentage in assigning weights was because most other researchers decided to use equal weighting as their primary assumption for all indicators and components. It is not inappropriate to assume that the reason behind this is likely that assigning specific weights can be administratively expensive. Nevertheless, this overall high percentage (i.e., 78.9%) in adopting the participatory approach to develop these frameworks can indicate its importance in accomplishing such a mission.

Another question might be posed about how the Delphi technique can serve the validity of the SWRM-AF. The simple answer is that it can be divided into two parts.

Firstly, it includes the opinion of experts from different backgrounds, who are simultaneously stakeholders with a genuine interest in seeking and pursuing the sustainability of WRM. Therefore, the Delphi technique can ease the way to share and combine their pure scientific opinions without any pressure since their identities are anonymous to each other. Then, their consensus should represent a quantum leap in the field for ASAR, which can provide a realistic method of measurement striving towards improved sustainability credentials.

Secondly, using this technique as a validation method or tool has a proven track record in a range of areas. For example, this includes, but is not limited to, the manufacturing industry (McLean et al., 2023), the role of advanced practice nursing (Chang et al., 2010), web engineering field (Torrecilla-Salinas et al., 2019), digital competence in higher education (Mengual-Andrés et al., 2016), construction and project complexity indicators (Kermanshachi et al., 2016), and ecological models (MacMillan and Marshall, 2006). In their studies, each of the previous examples emphasized the role of the Delphi technique in the validation stage and as a validation tool. Moreover, it was found in a study about the sustainable building criteria, which applies multiple consensus methods, that the results of the Delphi method are more significant in validating the gathered and reviewed data (Chan, 2022). Therefore, the adoption of this technique to validate the conceptual SWRM-AF can be justified based on all these scientific findings and views.

Another aspect that warrants further discussion concerns the questionnaires' overall design philosophy. The preliminary design of the first questionnaire, followed by the initial draft, was much longer. This is because there was a need to cover every aspect with a specific and direct question. In other words, there was a desire to make the questionnaire as comprehensive as possible as the first objective. On the other hand, the second objective was to not exceed 40 questions, following the assumption that each question would require one minute to be read and answered. However, some criticism was given regarding the length issue of the questionnaire during the first pilot test. This issue might increase the risk of receiving few responses with less engagement if significant reductions were not considered. Therefore, several questions were subsequently merged with each other to decrease the required time to complete the questionnaire.

Regarding the timing, some studies claimed that the ideal time to finish a questionnaire should not surpass 10 minutes to gain the maximum response rate (Cape and Phillips, 2015) and to reduce drop-out rates and the effects of tiredness (Revilla and Ochoa, 2017; Hunt and Shahab, 2021). However, while this aim is suitable for short surveys, adhering to this rule with a lengthy nature questionnaire became unrealistic. Therefore, based on the results of the first pilot test, the time suggested for completing the first questionnaire was between 25 and 35 minutes, and that was introduced to each participant before they started the questionnaire. This timing was somehow in line with a study about the average time to complete a lengthy questionnaire, which was found to be between 24 and 33 minutes (Cape and Phillips, 2015).

4.4.2. Shortfalls of this Chapter

This paper depends solely on the Delphi technique to refine and validate the framework. However, some researchers argued that since this technique was criticized because of a few weaknesses, such as its subjectivity and time-consuming nature (Pill, 1971), it is better to be combined with another method or theory, such as the fuzzy theory (Tseng et al., 2023; Huang et al., 2020), and AHP method (Shen et al., 2019; Nguyen et al., 2023). Hence, while using another method might enhance the final output, this did not apply to this study.

On the other hand, this study was conducted with a particular emphasis on measuring the SWRM of the ASAR. As a result, it is unclear how the framework might be applied to other regions. Meanwhile, despite being validated through multiple research rounds, the framework must still be tested and used in real-world scenarios. This (i.e., SWRM-AF application) will happen in the next chapter.

4.5. Summary and Conclusions

The Delphi technique was applied since a suitable participatory approach was recommended to complete the development of the conceptual SWRM-AF. Involving stakeholders in the development of SWRM-AF is important because it helps us figure out their main concerns so we can address them successfully. They can be involved in both the selection and weighting of those indicators. This means that bias in the results of SWRM-AF can be removed or at least lessened, and stakeholders would be more motivated and aware of SWRM. It's more important that this involvement, especially from expert stakeholders, could help to validate the SWRM-AF and make it more trustworthy.

The Delphi method's purpose was to contribute to refining and validating the initial framework designed for ASAR, particularly in the GCC countries. Hence, this paper illustrates the details of the application of the Delphi technique for bringing chosen experts (and stakeholders) to a consensus rate of 60% on the previously determined components, indicators, and their weights. This process consists of two rounds of survey questionnaires and allows the expert stakeholders to provide their opinions by evaluating, adding, or removing mainly the selected indicators. The first round included 33 participants, while only 19 completed the second round. The main results after the end of the Delphi questionnaire application are as follows:

- All four components (i.e., environmental, social, economic, and infrastructure) shall carry the same or equal weight;
- Reduce the previously determined indicators from 24 to 17 indicators;
- Three sets of sub-indicators (i.e., for social, economic, and infrastructure components) shall carry the same or equal weight. In contrast, only the set of environmental indicators

is assigned different weights.

Thus, it can be concluded that the final version of SWRM-AF is ready to be used on the national scale. The next step, the SWRM-AF, will now be applied to different case studies in the domestic sector of the GCC countries, serving as the foundation for suggestions to water authorities and decision-makers for appropriate plans for managing water resources in each country.

Overall, it appears that the experience of the Delphi technique is practical as a validation tool. Not only this, but it could help get consensus among experts, which can contribute to the widespread actual application of the subject of the study. This was noticed during the answers to questions about the level of conviction when the majority supported the adoption of this new framework, and all participants said they would like to see the decision-makers using it. Hence, this can indicate that GCC countries, represented by their experts, are eager to strive for the sustainability of their WRM.

5. Framework Application

This chapter presents the application of SWRM-AF on a case study and its results, with future scenarios and their discussion, which are covered in four sections. Section 5.1 describes the case study, which is the overall WRM of the Kingdom of Saudi Arabia (KSA). Then, the outcome of the application of SWRM-AF with discussion is presented in Section 5.2 and considered as a baseline for future comparisons. Three future scenarios are assumed to check the effects of changing or improving the current practices of the domestic sector's WRM on the sustainability level of the system. These scenarios and their discussions are presented in Section 5.3. Also, applying the SWRM-AF to these scenarios would clarify and contribute to selecting the most appropriate strategies to meet the goal and requirements of raising the level of SWRM.

5.1. KSA as a Case Study

This section presents an overview of the WRM system of the KSA, which is among the 11 countries classified as the most water-stressed regions on Earth (Hofste et al., 2019). Additionally, KSA is known for being one of the driest and hottest countries in the world, with summer temperatures regularly exceeding 45 degrees Celsius, while the average annual rainfall in KSA ranges from a mere 80 mm to 140 mm (Alkolibi, 2002). Meanwhile, not only the low rainfall rate is the problem, but KSA has a high evaporation rate of about 2200 mm (Dawoud et al., 2022), while some sources suggested that it is between 2500 to 3000 mm (Elsebaie et al., 2017). Saudi Arabia experiences an arid climate with minimal rainfall in most areas, except for the mountainous southwestern region, which receives an annual average of around 600 mm of rainfall (Subyani, 2004) and is classified as semi-arid (Ahmed, 1997). Therefore, KSA is one of the countries combining ASAR's features.

KSA is situated in the southwestern region of Asia, namely on the Arabian Peninsula. It is the largest country on the peninsula, covering a vast area of 2,150,000 km^2. In addition, this nation lacks any permanent rivers or lakes, and infrequent yet occasionally heavy rainfall occurrences often replenish its SW. Consequently, if we consider solely the fresh SW and GW, known as blue water, KSA finds itself in a highly precarious state regarding water resources, which means that its population would experience severe water scarcity during the entire year (Mekonnen and Hoekstra, 2016). Therefore, the need for alternative solutions was and remains substantial. As an illustration, Saudi Arabia extensively depends on the production of DW to meet a continuously growing need for water in its domestic and industrial sectors (Caldera et al., 2017). However, this technology requires substantial financial inputs and, up to near time, is not environmentally viable due to its existing form and procedures (Al-Mutaz, 1991; Al-Sahlawi, 1999; Roberts et al., 2010; Ghaffour et al., 2013), raising doubts about its long-term feasibility and sustainability.

Moreover, KSA faces severe constraints on its WR due to its arid desert environment and climate, exacerbated by rapid population expansion. As an illustration, the population of Saudi Arabia was 7.7 million in 1970 (MFNE, 2004), but it increased to 34 million in 2019 (CIA, 2020). Additionally, the projected population in 2050 is anticipated to be 43 million under the assumption of constant mortality and 46 million if the current growth rate remains unchanged (UNDESA, 2019). The persistent rise of the population and lifestyle improvement would exacerbate the strain on the already limited WR. Meanwhile, the country's domestic consumption rate in 2009 was 227 litres per capita (or person) per day (L/cap/day) (GASTAT, 2018a). Then, despite various efforts and research emphasising the significance of rationalising water usage, the per capita consumption rose to 278 L/cap/day in 2018 (GASTAT, 2018a), while it was in the most recent update 278 L/cap/day in 2021, which is considered among the highest water consumptions in the world.

Hence, the confluence of substantial demand and restricted resources underscores the formidable challenge of WRM in Saudi Arabia. Consequently, this circumstance should motivate water policymakers to develop comprehensive strategies and establish stringent regulations to improve the sustainability of this crucial resource. Moreover, while the aim and the focus of this research are about enhancing the SWRM of the domestic sector, it would be essential to provide this overview of all sectors to let readers know about the bigger context. Indeed, since other sectors, such as agriculture and industry, have their water consumption quota, they would directly or indirectly affect the domestic sector's water consumption. For example, since some areas in KSA are poor in the sources of GW and SW, new voices recently suggest using the DW, which is mainly for the domestic sector, to support the agriculture sector.

The next section will provide a comprehensive analysis of the critical components of the WRM system in Saudi Arabia, including the demand, supply, and governance (or the role of the government of KSA in the WRM).

5.1.1. Water Demand in KSA

Like several nations globally, Saudi Arabia has three primary sectors that contribute to its water needs. The sectors encompassed are agriculture, domestic, and industry. In 2009, the water consumption rates were 83.5%, 12.6%, and 3.9%, respectively, with a total water amount of 18,507 million m^3 (MEP, 2010). Likewise, similar percentages were observed in 2016 across all industries, but the overall water consumption did rise to 23,934 million m^3 (MEWA, 2019). The agriculture sector remains the primary consumer of water, which should be noted well. Several factors contribute to this situation, primarily because most users in this industry are agricultural companies and farmers who own their farms. These users typically rely on private wells to irrigate their plants using GW. Until recently, no water meters or governmental restrictions were in place to limit their water usage, except for specific regulations related to the type of crops being grown. This has exacerbated the water resource difficulties over the years despite the ineffectiveness of policies and actions aimed at altering or halting the cultivation of water-intensive crops.

Furthermore, Figure 5-1 below is a concise overview of the water consumption (or demand) in the KSA during the period from 1994 to 2018 (i.e., 25 years). The data includes usage in the three primary sectors: agriculture, domestic usage, and industrial usage. The agriculture sector has consistently had the highest proportion. The water allocation for this area exhibited minor fluctuations between 1994 and 2009, but more recently, it has been consistently growing. Conversely, there has been a gradual decline in the overall proportion of users, from 90.1% in 1994 to 81.6% in 2018, due to state regulations that provide subsidies or gradually eliminate some crops. More details about these fluctuations will be illustrated in Section 5.1.1.1.

Lastly, in Figure 5-1, the domestic sector is the second most significant consumer of water, with the industrial sector closely behind. Both industries have exhibited essentially linear growth throughout the course of these 25 years. More details about each sector will be provided in the next sections.

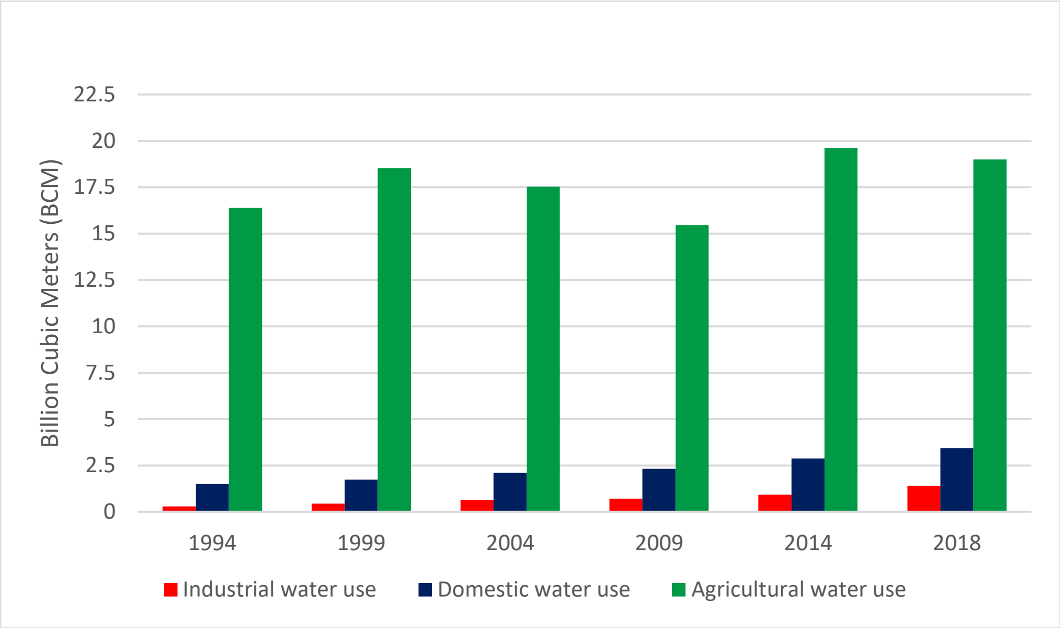


Figure 5-1 History of Water consumption among main sectors of KSA (1994-2018) (MEP, 1995, 2000, 2010; MEWA, 2019)

5.1.1.1. *Agricultural Sector*

Given that Figure 5-1 is insufficient to depict the complete narrative of the agriculture sector, obtaining a comprehensive perspective on the historical utilisation of water in agriculture is advisable, as portrayed in Figure 5-2. This will facilitate a thorough comprehension of the overall situation. Prior to 1985, the agricultural sector had significantly lower levels of consumption in comparison to the subsequent years. The primary factors contributing to this were the sector's low profitability and the absence of efficient water extraction and irrigation technology. Both of these challenges were costly and beyond the means of ordinary farmers. Due to the substantial increase in oil prices after 1980, the government of KSA has chosen to achieve food self-sufficiency. This choice encompasses the allocation of favourable loans, subsidies, and permits to farmers to drill wells and acquire modern irrigation equipment. Additionally, the government purchases these crops from farmers at a comparatively elevated price. During this period, the primary agricultural product was wheat, and its price exceeded the cost of importing the same crop. Nevertheless, the outcomes of this choice proved to be impractical in the long term, particularly due to the country's meteorological characteristics and insufficiently addressed water supplies. The primary repercussion was the decline in the water table due to excessive water use, which resulted from the flawed perception of achieving food self-sufficiency. This led farmers to export their products from a desert region without recognising the implications of implicit virtual water.

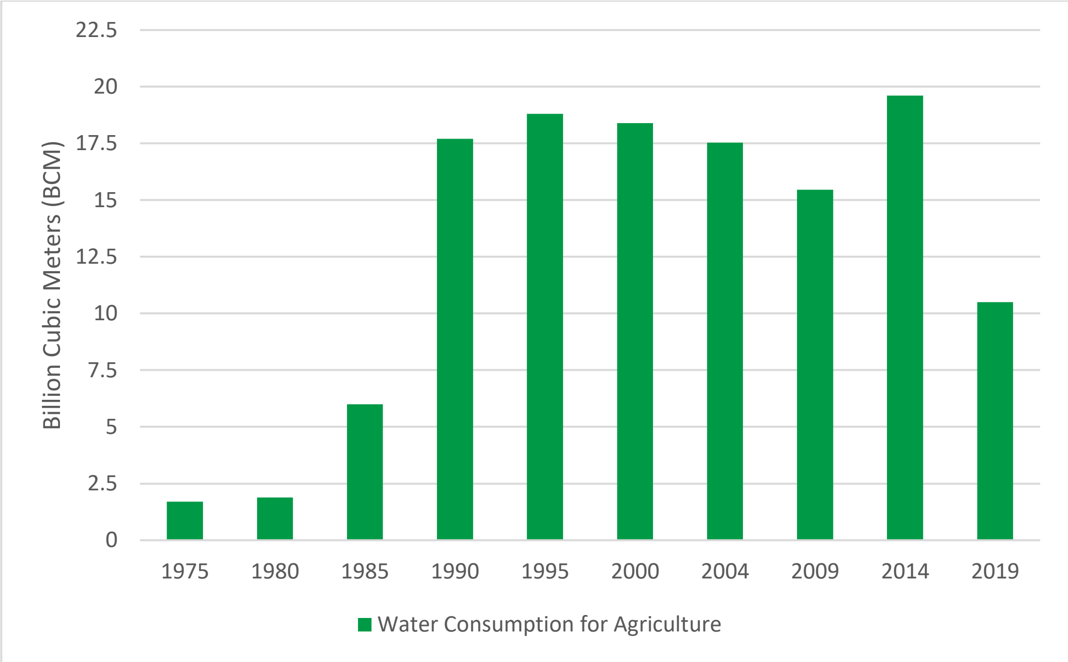


Figure 5-2 Agricultural water consumption in KSA between 1975 and 2019 (MEP, 2005, 2010; MEWA, 2019, 2022)

Moreover, Figure 5-2 can be summarised by identifying three primary factors that influenced the shift in water usage within the agriculture sector:

1) The commencement of achieving food self-sufficiency in the 1980s, which led to the rapid increase as described earlier,
2) The prohibition of wheat exports in 1993 and the discontinuation of subsidies given to local farmers for this particular crop were followed by a gradual reduction in wheat production through consecutive stages starting in 2008, with a yearly decrease of 12.5% until its complete cessation in 2016. This resulted in a slight decline in water usage in the agricultural sector from 1995 to 2009.
3) In 2016, there was a prohibition on cultivating forage crops in locations where the primary source of irrigation was NRGW, and the cultivated fields exceeded 50 hectares. This ban was implemented because many farmers had started growing forage crops instead of wheat crops. Nevertheless, small farmers are granted exemptions for cultivating forbidden crops such as wheat and alfalfa, provided that the size of their farms does not exceed 50 hectares. The objective of this decision is to address the fundamental requirements of the agricultural regions.

Meanwhile, the high decrease in water consumption in 2019 is a significant improvement. In addition to the previous point, this can be because the Saudi Arabian government has implemented a programme in the agricultural sector to cease the cultivation of fodder crops, commencing in 2019, to mitigate the consequences of farmers transitioning to forage crops. This has perhaps supported the opinion and concerns regarding the issues of the agricultural sector in KSA, which emphasizes that it is a policy and regulation issue. Therefore, the political well represented by the Ministry of Environment, Water and Agriculture (MEWA) is responsible for coping with this sector's critical issues by providing effective policies and regulations.

5.1.1.2. *Domestic Sector*

The historical domestic water uses by the population from 1994 to 2019 are demonstrated in Figure 5-3. The rise in water consumption in this sector exhibits a somewhat linear pattern, which can be attributed to the corresponding linear growth in the population. The population of the KSA experienced significant growth, rising from 18.2 million in 1994 to 30.1 million in 2019. During the same period, domestic consumption also underwent a notable change, increasing from 1500 million cubic metres (MCM) to 3493 MCM. In Figure 5-3, the average annual growth rate for the population throughout the entire time is 2.2%, whereas for domestic water usage, it is 3.9%.

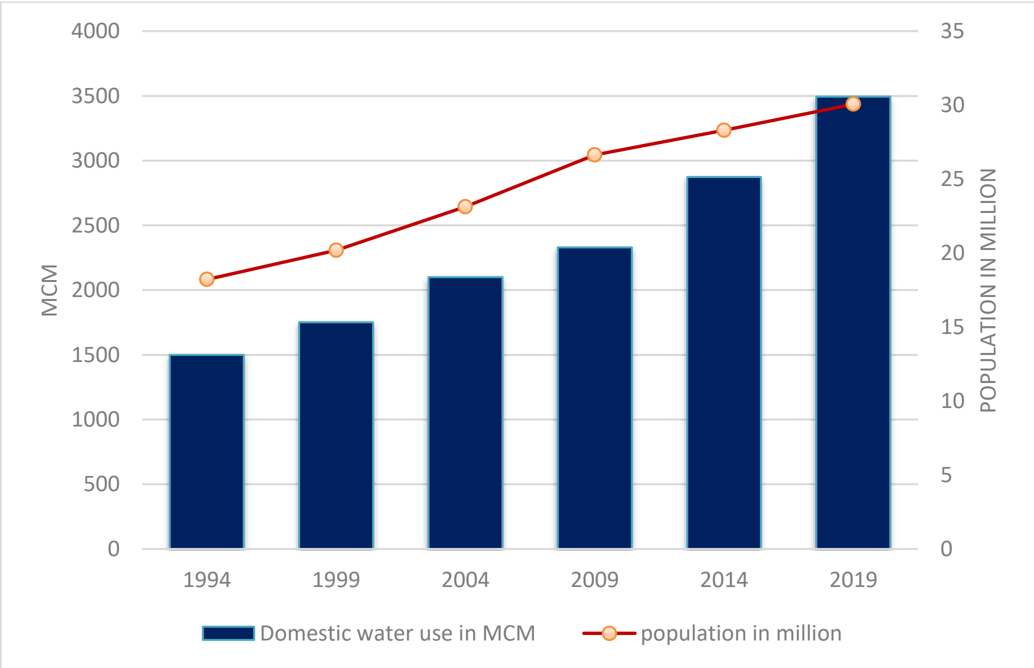


Figure 5-3 Historical domestic water consumption to the population in Saudi Arabia (1994-2019) (MEP, 2005, 2010; MEWA, 2019, 2022; GASTAT, 2023)

It is important to note that the overview in Figure 5-3 encompasses two water tariff regimes. As depicted in Table 5-1, the initial and original products received significant government subsidies, resulting in a considerably lower price than the overall cost. However, there has been a transition since 2016 to a new system, as depicted in Table 5-2. This system not only includes increased pricing for each block of consumption over 15 m^3, but also incorporates a new tariff for wastewater. Both systems were designed to decrease domestic water consumption by incentivizing individuals to optimise their water usage in exchange for lower costs. The two systems are represented by two currencies, which are the Saudi Arabian Riyal (SAR) and the United States Dollar (USD). This is due to the fact that the exchange rate between the USD and SAR is fixed at 1 USD = 3.75 SAR.

Table 5-1 Old Water Tariff System in Saudi Arabia (before 2016) (Adapted from McIlwaine and Ouda, 2020)

Block range based on water quantity	**Potable water**		**Maximum Invoice for each block**		**Cumulative Invoice**	
	SAR	US $/$m^3$	SAR	USD	SAR	USD
less than 50 m^3	0.1	0.027	5	1.33	5	1.33
51-100 m^3	0.15	0.04	7.5	2.00	12.5	3.33
101 – 200 m^3	2	0.53	200	53.33	212.5	56.67
201 – 300 m^3	4	1.07	400	106.67	612.5	163.33
Above 300 m^3	6	1.60	6/m^3	1.6/m^3	+612.5	+163.33

Table 5-2 Current Water Tariff System in Saudi Arabia (started in 2016) (Adapted from McIlwaine and Ouda, 2020)

Block range based on water quantity	**Potable water (PW)**		**Waste Water (WW)**		**Total cost/m^3 of PW + WW**		**Maximum Invoice for each block**	
	SAR	USD	SAR	USD	SAR	USD	SAR	USD
less than 15 m^3	0.1	0.027	0.05	0.013	0.15	0.04	2.25	1
15-30 m^3	1	0.27	0.5	0.13	1.5	0.40	22.5	6
31 - 45 m^3	3	0.80	1.5	0.40	4.5	1.20	67.5	18
46 - 60 m^3	4	1.07	2	0.53	6	1.60	90	24
Above 60 m^3	6	1.60	3	0.80	9	2.40	9/m^3	2.4/m^3

However, there was a significant rise in home consumption compared to previous times, as seen in Figure 5-3 by the reduced difference between the total amount of municipal water and the population. One view is that the yearly growth rates in 2014 for both the population and consumption were the great est rates, with 3.2% and 4.7%, respectively. An interesting observation is that in 2018, the population experienced a modest growth rate of 2.3%, although the consumption rate was the second highest at 4.5%. This increase is incompatible with the new water tariff introduced in 2016, which is costlier than the previous block rate structure. Further investigations are necessary to ascertain the underlying factors contributing to this rise.

On the other hand, the average water usage for the household sector consistently grew throughout the years, as seen in Table 5-3. The rise is substantial, starting at 227 L/cap/day in 2009 and reaching 274 L/cap/day in 2021, with an average of 263.1 L/capita/day during the period from 2009 to 2021. The average rate remains significantly high, particularly when compared to other countries that possess abundant CWR, as seen in Figure 5-4. Additionally, despite the ongoing increase in population, the yearly growth rate has declined from 3.01% in 2010 to 1.81% in 2018. During the whole time, the average annual growth rate for both the population and consumption from 2009 to 2021 was slightly different, with rates of 2.46% and 1.86%, respectively. However, determining the correlation between population growth rate and consumption rate is challenging. Furthermore, the reason behind the transitory impact of the water tariff alteration on the average water consumption rate, which amounted to a decrease of 1.85% in 2017, remains unclear.

Table 5-3 Population of KSA plus the average daily water consumption per person for the domestic sector (2009-2021) (Adapted from GASTAT, 2018; MEWA, 2021; GASTAT, 2023)

Year	Population (millions)	Population Annual Growth Rate	Average Water Consumption (L/cap/day)	Average Water Consumption Growth Rate
2009	23.1*	----	227	-
2010	23.98	3.01%	231	1.76%
2011	25.1	3.28%	235	1.73%
2012	26.17	3.00%	238	1.28%
2013	27.62	3.09%	249	4.62%
2014	28.31	2.83%	253	1.61%
2015	29.82	2.59%	263	3.95%
2016	30.95	2.21%	270	2.66%
2017	30.97	2.16%	265	-1.85%
2018	30.2	1.81%	278	4.91%
2019	30.06	-0.46%	318*	14.39%
2020	31.55	4.96%	315*	-0.94%
2021	30.78	-2.44%	278	-11.75%
Average	----	2.46%	263.1	1.86%

*Not official but estimations based on the population from the General Authority for Statistics (GASTAT, 2023) and the total domestic water consumption (MEWA, 2022)

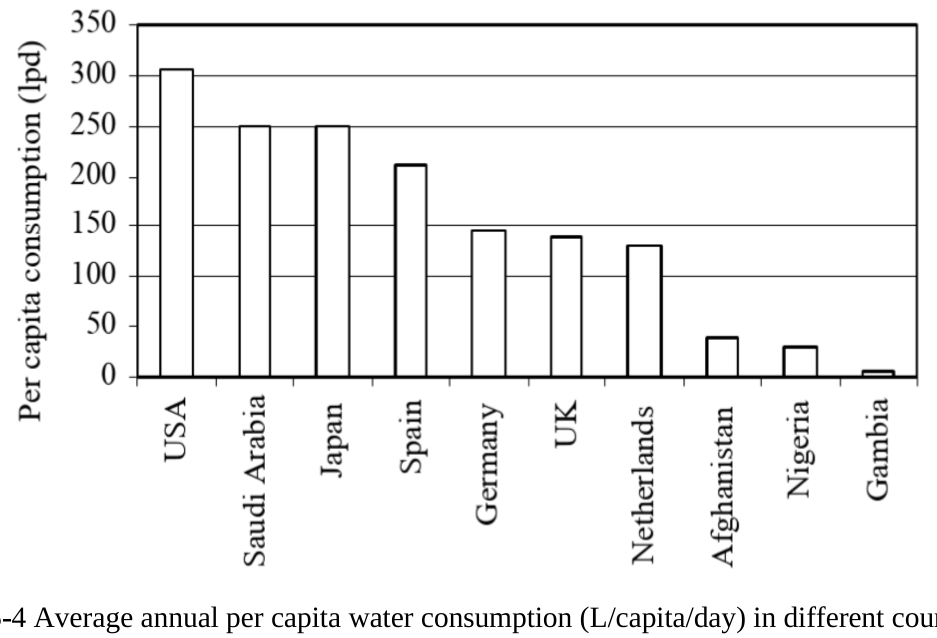


Figure 5-4 Average annual per capita water consumption (L/capita/day) in different countries (Butler and Memon, 2005)

5.1.1.3. *Industrial Sector*

The industrial sector is the last water consumer in terms of quantity in KSA. The amount of water between 1994 and 2019, illustrated in Figure 5-5, increased almost linearly until 2014. The average annual growth rate for the whole period was 7.9%, while from 2014 to 2019, the annual growth rate was the highest rate at 12.6%. This represents 1.4 billion cubic metres per year (BCM/year). This is most likely because of the government's new orientation to diversify the economy's revenues, which was announced in 2016 as Saudi Arabia’s Vision 2030 (SAV2030). The purpose of this goal is to lower the dependency of the economy of KSA on oil exports, especially after the high fluctuation in their price over the last decade. The initiatives to support various activities related to the industry, such as mining and defence industries, are one of many strategic goals to meet the targets of SAV2030. Therefore, these activities would play an important role in increasing water consumption by the industrial sector, which is expected to continue growing.

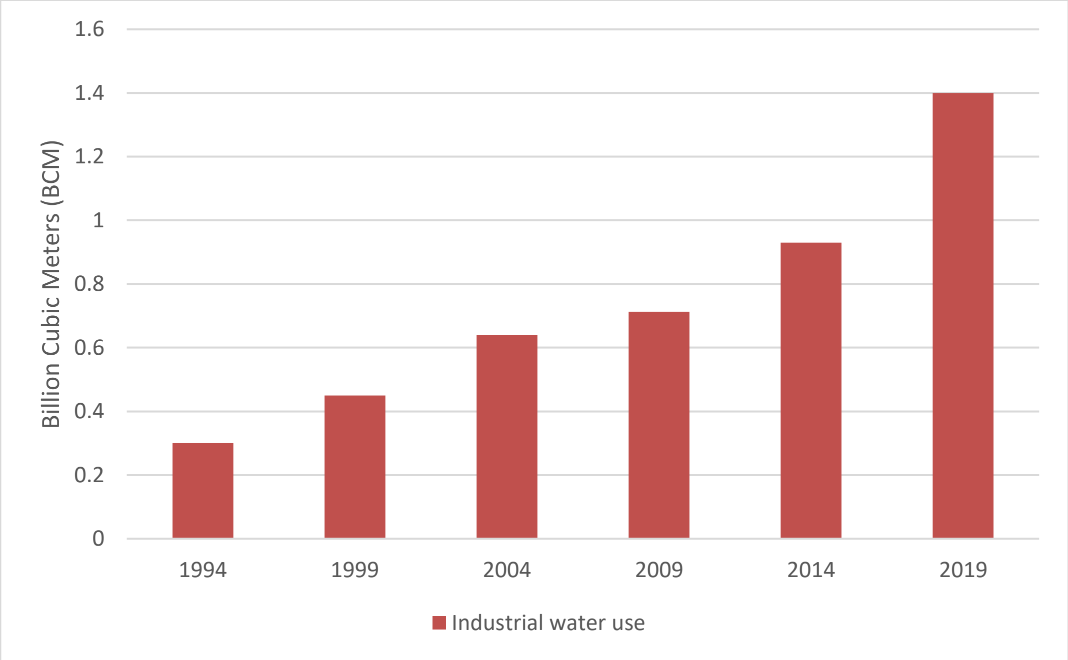


Figure 5-5 Industrial water consumption in Saudi Arabia (1994-2019)
(MEP, 2005, 2010; MEWA, 2019, 2022)

5.1.1.4. ***Recent water demands of all sectors***

Overall, Figure 5-6 sheds light on the most up-to-date data on the water demand among primary users from 2010 to 2021 in KSA, which can clearly reflect the continuity of the agriculture sector to dominate the ups and downs of the total water demand. Moreover, the entire water quantity has increased slightly until 2015. Then, a slight decrease took place in 2016 and 2017. Two decisions are the possible interpretations for this decrease:

1) the gradual decrease in the planting of wheat crops that were supposed to stop

completely by 2016,

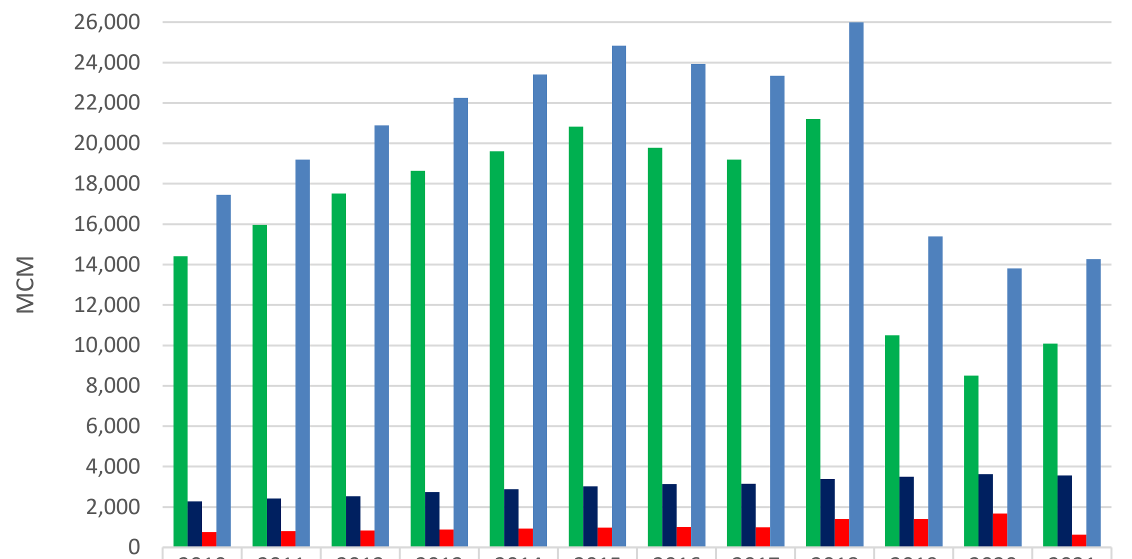
2) the implementation of the new water tariff for the domestic and industrial sectors.

However, the total water demand reached a new record in 2018, with almost 26,000 MCM. Again, there are two possible interpretations for such an increase:

1) The farmers shifted their products from wheat crops to forage crops, which consumed water for the whole year instead of only one season during the year for the wheat,
2) The high increase in water use by the industrial sector from 1000 MCM in 2017 to 1400 MCM in 2018, as illustrated in Figure 5-6, represents a 40% increase. The main reason for this change is to achieve one of the main goals of SAV2030: to vary the economic revenues by having more industrial factories and products. As a result, more water would be required to support these factories, affecting the total water demand entirely in the future.

Then, a significant decrease in total water consumption occurred in 2019, followed by 2020. There are two potential interpretations for this drop:

1) The government of KSA initiated a program for the agriculture sector to stop the cultivation of forage crops starting in 2019 to decrease the impact of the farmers' shift to this type of crops (MEWA, 2022; MEP, 2023),
2) The possible impact of COVID-19, especially in 2020, when the lockdown has taken place, and many governments globally forced many workers and students to do their jobs remotely (i.e., online) to avoid the chances of spreading the virus. This change may have affected water consumption in the agriculture sector in 2020. This is because many workers in the farms are foreigners who either stopped working because of these conditions, were on vacation in their countries just before the pandemic and could not come back because of the travel ban, or flew back to their countries to stay with their families when the international flights opened gradually. This interpretation can be supported by the water consumption of 2021, which is very close to 2019, when most of the restrictions of COVID-19 have been removed, and life went back somehow to its previous normal condition. Still, a question mark about the reduction of water use in the industrial sector in 2021 is presented without a clear answer.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Agriculture	14,410	15,970	17,514	18,639	19,612	20,831	19,789	19,200	21,200	10,500	8500	10080
Domestic	2,284	2,423	2,527	2,731	2,874	3,025	3,130	3,150	3,392	3,493	3629	3556
Indusrty	753	800	843	890	930	977	1,015	1,000	1,400	1,400	1680	628
Total	17,447	19,193	20,884	22,260	23,416	24,833	23,934	23,350	25,992	15,393	13809	14264

Figure 5-6 Water demand among main users in KSA (2010-2021)
(MWE, 2014; MEWA, 2019, 2022)

Regarding the share of each sector, the data presented in Table 5-4 indicates that the percentage distribution of each sector remained relatively stable from 2010 to 2018, with no significant changes observed for most industries and years. The agriculture sector has an average share percentage of 83.1%, while the household and industrial sectors have shares of 12.7% and 4.3%, respectively. However, the total water demand and the share of each sector have changed dramatically since 2019. The share of agriculture in 2019 decreased by around 13%, resulting in a nearly twofold increase in the share of other sectors despite their quantity remaining unchanged. Once again, this can be attributed to the alteration of legislation and policies within the agriculture sector. Consequently, this implies that the KSA increasingly depends on food imports. However, this reliance has potential risks, as it is vulnerable to political conflicts or health pandemics, such as COVID-19, in the country or region from which it imports.

On the other hand, the gradual increase in water consumption in the domestic sector indicates that this sector might need more consideration and methods to reduce it. The main problem is that even though KSA is one of the most stressed countries in terms of the availability of CWR, as in the other GCC countries, the per capita water consumption is still high. The continuity in this path is undoubtedly unsustainable. Therefore, the adoption of tools such as SWRM-AF and its indicators can help reflect the actual situation of the WR to both stakeholders and decision-makers. Hence, the result of such a tool can ensure the cooperation of both previous teams and could be the base for making the necessary changes to improve the sustainablility level of the WRM for the domestic sector.

Table 5-4 Quantity and Percentage of water consumption by each sector in KSA (2010-2021) (MWE, 2014; MEWA, 2019, 2022)

Users	**Year**											
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Agriculture (MCM)	14,410	15,970	17,514	18,639	19,612	20,831	19,789	19,200	21,200	10,500	8,500	10,080
Share (%)	82.6	83.2	83.9	83.7	83.8	83.9	82.7	82.2	81.6	68.2	61.6	70.7
Domestic (MCM)	2,284	2,423	2,527	2,731	2,874	3,025	3,130	3,150	3,392	3,493	3,629	3,556
Share (%)	13.1	12.6	12.1	12.3	12.3	12.2	13.1	13.5	13.1	22.7	26.3	24.9
Industry (MCM)	753	800	843	890	930	977	1,015	1,000	1,400	1,400	1,680	628
Share (%)	4.3	4.2	4.0	4.0	4.0	3.9	4.2	4.3	5.4	9.1	12.2	4.4
Total (MCM)	17,447	19,193	20,884	22,260	23,416	24,833	23,934	23,350	25,992	15,393	13,809	14,264

5.1.2. Water Supply in KSA

Like most GCC countries, the main water supplies in KSA are GW, SW, DW, and RW. As mentioned before, official documents classified GW into two types, NRGW and RGW and used to combine RGW and SW (MEP, 1995, 2010; MEWA, 2019). Regrettably, the primary source of water consumption for most of the past four decades has been NRGW. As a result of this improper use, there has been a decline in the availability of this valuable resource (Mekonnen and Hoekstra, 2016), and this reduction will persist unless robust measures or prudent regulations are implemented. Given the significant uncertainties surrounding its residual amount, it is crucial to conduct a thorough and accurate assessment of the quantity of NRGW. Moreover, in conjunction with these problems above, numerous studies have cautioned the nation about the repercussions of global warming and climate change on the WR of KSA (Alkolibi, 2002; Amin et al., 2013; Chowdhury and Al-Zahrani, 2013; DeNicola et al., 2015; Tarawneh and Chowdhury, 2018). Therefore, more precautions and preparations should be taken to tackle these issues before the water supply conditions worsen.

Figure 5-7 below presents a chronological summary of the quantity of each water supply in KSA during the recent period of 25 years, where data is available from 1998 to 2018 concerning the history of the water supply. It is important to note that the reclaimed agricultural water, stated in the old official reports, and RWW have been consolidated into a single category known as reclaimed water in the new government publications. This study will also refer to reclaimed water as "*Renewed Water*" (RW) sometimes since it is used in most new governmental documents to increase social acceptance.

In general, the water resources of Saudi Arabia can be divided into two categories based on how they are obtained and treated: CWR and NWR. The conventional resources consist of non-renewable groundwater (NRGW) and renewable groundwater and surface water (RGWSW), with renewable groundwater (RGW) being the largest component in this category. On the other hand, the NWR are DW and RW.

It is evident that NRGW has consistently been the most abundant source. NRGW refers to water stored in deep aquifers with a minimal recharge rate, requiring an extensive period of time on a human time scale to replenish; therefore, using NRGW is considered unsustainable (Maliva and Missimer, 2012).

The volume and proportion of this water supply gradually declined from 1994 to 2009, as seen in Figure 5-7 and

Table 5-5. Nevertheless, there has been a significant surge in 2014 and 2018 as compared to 2009, without any discernible cause or explanation. One interpretation is that due to the agriculture sector's predominant usage of this resource, many farmers opted to substitute the cultivation of wheat, which required a substantial amount of water but only for a single season, with the cultivation of feed crops that could be grown throughout the year. Another possible explanation for a significant increase in NRGW between 2014 and 2018 is the improved accuracy of data on the second most extensive water resource, RGWSW. The previous two periods exhibited an unexplained decline in the quantity of RGWSW, coinciding with the rise of NRGW. This raises worries about the possibility of reclassifying groundwater stored in the Continental Shelf from a renewable to a non-renewable condition.

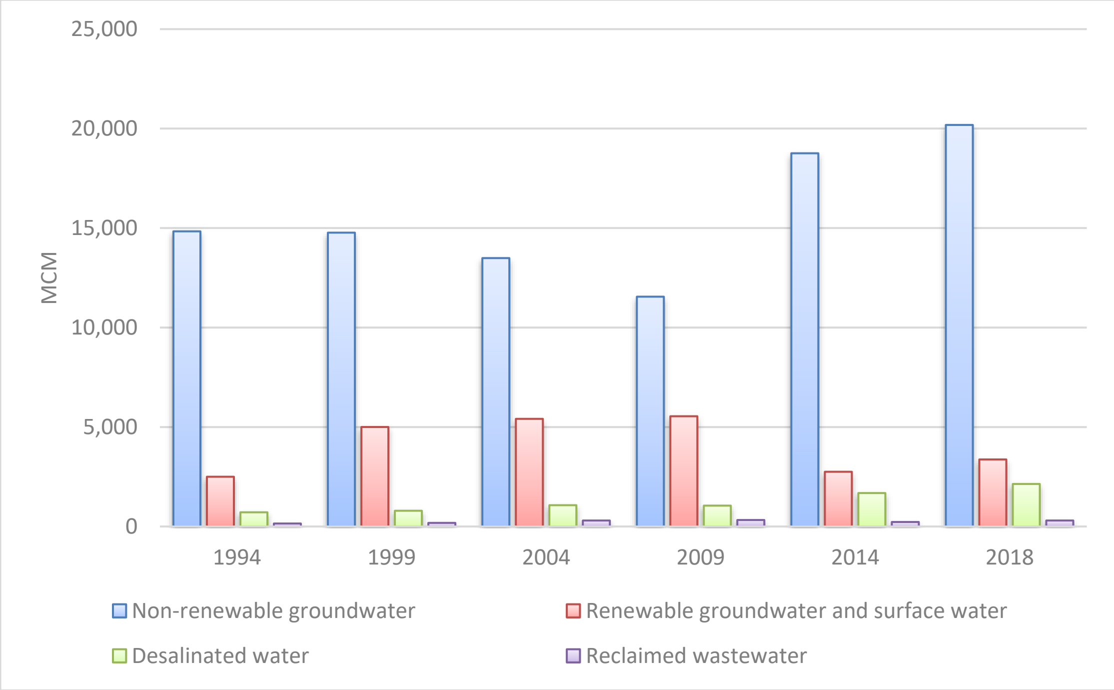


Figure 5-7 History of the quantity of water supplies from 1994 to 2018 (MEP, 1995, 2000, 2010; MEWA, 2019)

Table 5-5. History of the share of water supplies in KSA from 1994 to 2018 (MEP, 1995, 2000, 2010; MEWA, 2019)

Water Resource	1994		1999		2004		2009		2014		2018	
	Quantity	Share	Quantity	Share	Quantity	Share	Quantity	Share	Quantity	Share	Quantity	Share
	MCM	%	MCM	%	MCM	%	MCM	%	MCM	%	MCM	%
Non-renewable groundwater	14,836	81.5%	14,769	71.2%	13,490	66.6%	11,551	62.6%	18,760	80.1%	20,184	77.7%
Renewable groundwater and surface water	2,500	13.7%	5,000	24.1%	5,410	26.7%	5,541	30.0%	2,750	11.7%	3,370	13.0%
Desalinated water	714	3.9%	791	3.8%	1,070	5.3%	1,048	5.7%	1,680	7.2%	2,137	8.2%
Reclaimed wastewater	150	0.8%	180	0.9%	300	1.5%	325	1.8%	226	1.0%	301	1.2%
Total	18,200	100%	20,740	100%	20,270	100%	18,465	100%	23,416	100%	25,992	100%

A more recent look at the WR and their supply in KSA is provided in Table 5-6. The data in this table consists of actual amounts for DW and RW the whole time. However, the availability of NRGW data is limited to 2013 to 2018. Thus, the quantity of NRGW is approximated for the preceding years due to the unavailability of precise data. Similarly, the water requirements for RGWSW are matched using a straightforward method. This method involves deducting the total annual water amount (found in the last row of Table 5-6) from the sum of NRGW, DW, and RW. Meanwhile, the yearly anticipated volume of RGWSW is 4400 MCM, of which a portion is lost through evaporation or released into the oceans.

Table 5-6 Quantity of each water supply in KSA (2010-2018) (MWE, 2014; GASTAT, 2018b, 2018c, 2018d; MEWA, 2019)

Type of Water Resource	Quantity in Years (MCM/year)								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Non-Renewable Groundwater (NRGW)	13,608*	15,067*	16,498*	17,841	18,760	19,831	18,909	18,206	20,184
Desalinated Water (DW)	1258	1476	1545	1,594	1,680	1,833	1,947	2,175	2,137
Renewed Water (RW)	219	225	194	181	226	223	216	255	301
Renewable Groundwater and Surface Water (RGWSW) *	2,361*	2,425*	2,647*	2,644*	2,750*	2,953*	2,822*	2,668*	1,970*
Total Water Supplies	17,446	19,193	20,884	22,260	23,416	24,833	23,933	23,350	25,992

*Estimated

The number of dams in the Kingdom of Saudi Arabia (KSA) used to store rainfall water and manage floods is presented in Table 5-7. The number of dams, which was 351 with a combined storage capacity of 1644.75 MCM in 2010, has risen to 524, with a storage capacity of 2,327.56 MCM in 2018. The average yearly growth rates for dams' quantity and size from 2010 to 2018 are nearly identical, at 5.2% and 4.54%, respectively. Nevertheless, the cumulative amount of water these dams receive remains very little compared to their storage capacity and depends mainly on the yearly rainfall rate. These rainfalls usually occur in the mountainous southwest, categorised as semi-arid (Ahmed, 1997) and receives an average of about 600 mm of rainfall annually (Subyani, 2004). Conversely, increasing the number of dams with their new locations on the amount obtained is beneficial. From 2015 to 2018, the number of dams exceeded 500, reaching new record levels. This development caused the reserved quantity behind the dams in parallel, possibly to the increase in rainfall rate to surpass 1100 MCM in 2018 and 2020.

Table 5-7 Total number of dams, their storage capacity, and received quantity (2010-2018) (MWE, 2014; MEWA, 2019, 2022)

Year	Number of Dams	Storage Capacity (MCM)	Received Quantity (MCM/year)
2010	351	1644.75	n/a
2011	349	1926.9	n/a
2012	422	1967.4	n/a
2013	449	2016.9	486
2014	482	2083.9	358
2015	502	2167.2	450
2016	502*	2167*	720
2017	508	2250	561
2018	524	2327	1200
2019	534	2361	970
2020	543	2445.4	1297
2021	544	2445.8	955

*Estimated

Furthermore, with an average of 80%, Table 5-8 displayed the high share percentage of the NRGW across all water sources from 2013 to 2018. This percentage is expected to drop soon as WR and renewable energy sources become more important to increase the WRM system's sustainability level. Table 5-9, where the desalination water amount grew annually apart from the final year, clearly illustrates the increase in the NWR. Additionally, it is evident how the DW rose to prominence in the KSA's WRM system under its average share of other WR, which is currently 8% and is predicted to increase shortly.

Table 5-8 Comparison between the Quantity of NRGW to total quantity of water (2013-2018) (GASTAT, 2018c)

WR & Relation	Years					
	2013	2014	2015	2016	2017	2018
Quantity of Non-Renewable Groundwater (NRGW) in MCM	17,841	18,760	19,831	18,909	18,206	20,184
Total quantity of Water (ToW) in MCM	22,260	23,416	24,833	23,933	23,350	24,592
Percentage of NRGW to ToW (%)	80%	80%	80%	79%	78%	82%

Table 5-9 Comparison between quantities of desalinated water to the total quantity of water (2010-2018) (GASTAT, 2018b)

Water Resource & Relation	Years								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Quantity of DW in MCM	1258	1476	1545	1,594	1,680	1,833	1,947	2,175	2,137
Total quantity of Water (ToW) in MCM	17,446	19,193	20,884	22,260	23,416	24,833	23,933	23,350	24,592
Percentage of DW to ToW (%)	7%	8%	7%	7%	7%	7%	8%	9%	9%

Reclaimed water, or what the water authorities have started to refer to as "Renewed water," is the other NWR and the final component of the WR in KSA. The new name was chosen in an effort to obtain societal acceptance. This material is essential to the nation's efforts to increase the WRM system's sustainability. All quantities of total domestic water (TDoW), TWW, and RW from 2010 to 2021 can be shown in Figure 5-8. This figure indicates that the number or the capacity of WWTPs in KSA is either small or their production does not match the actual treatment capacity. This can be realized by knowing that the average rate of TWW to TDoW is 49%.

Likewise, Table 5-10 manifested that the ratios of RW to both TWW and TDoW were low, where their average is 17% and 9%, respectively, even if their ratios between 2010 and 2021 had fluctuated and then grown recently. However, targets have been assigned to increase this rate by involving the private sector in establishing and operating new WWTPs. Meanwhile, the RW can be sold based on the new regulations introduced in 2020 to support the national water strategy. One of these targets is that water authorities aim for the TWW to be more than 5 BCM by 2050 (Dawoud et al., 2022).

Moreover, some estimations suggest that just 60% of the domestic sector is covered by wastewater networks and that 40% of the population does not yet have access to wastewater services. This can be a major contributing factor to the current situation. However, by 2030, this coverage is expected to rise to more than 75% and up to 95 to 100% (Dawoud et al., 2022). To lessen the strain on the non-renewable WR, this approach would successfully help produce additional TWW, which should be utilised as RW.

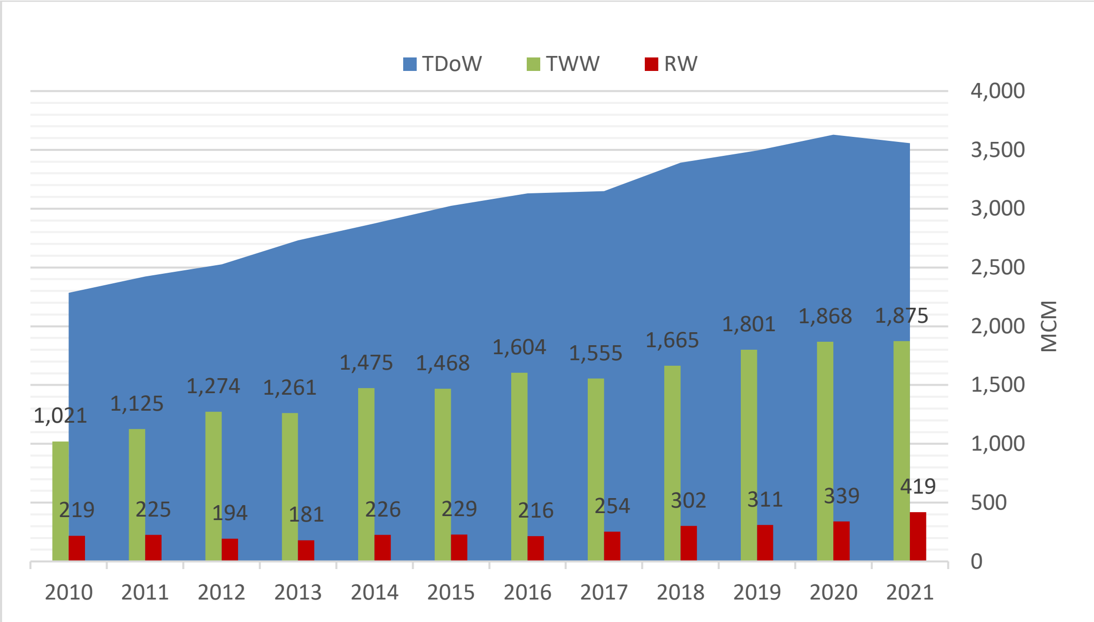


Figure 5-8 Quantities of TWW, and RW from the Total of Domestic Water (TDoW) (2010 to 2021) (MWE, 2014; GASTAT, 2018d; MEWA, 2019, 2022)

Table 5-10. Comparison between total quantities of domestic water to the total quantity of wastewater and renewed water (2010-2021) (adapted from MWE, 2014; GAS, 2018c; MEWA, 2019, 2021; Statista Research Department, 2023)

WR & Relation	Years											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
TDoW in MCM	2,284	2,423	2,527	2,731	2,874	3,025	3,129	3,150	3,392	3,493	3,629	3,556
Number of WWTPs	65*	76*	81	81	81	81	82*	91*	91	99	116	133
Designed Capacity	3500	4300	4700	4700	4700	4700	4984	5300	5300	5300	5300	5300
TWW to TDoW	45%	46%	50%	46%	51%	49%	51%	49%	49%	52%	51%	53%
RW to TWW	21%	20%	15%	14%	15%	16%	13%	16%	18%	17%	18%	22%
RW to TDoW	10%	9%	8%	7%	8%	8%	7%	8%	9%	9%	9%	12%

*Estimated

5.1.3. Relation Between Water Supply and Demand in KSA

Following an illustration of the amounts and distributions of the primary water resources and users in KSA over the previous 25 years, it is crucial to understand how these supplies relate to each sector. Figure 5-9 summarises this relationship using a unique order. Water resources are represented by the first row, arranged from left to right based on their current rates, from highest to lowest. Water sectors are represented by the vertical columns arranged from top to bottom to show the largest to smallest water consumers.

The household sector is using the CWR faster than the agriculture sector. Furthermore, the government pays very little for the NRGW and RGW utilised by the agricultural sector because the farmers who own their wells bear the obligation for the costs associated with drilling, delivering, and/or pumping. Due to legislative action in the past, the largest consumer of NRGW consumed enormous amounts of it without carefully considering the long-term effects.

Conversely, the domestic and industrial sectors account for most of the NWR consumers for DW and RW, respectively. This would make sense, given that the high standards of these resources mean that their delivery and treatment costs are higher than those of CWR. Furthermore, payment is required from users of NWR to use them, which would ensure some reimbursement to the government for operating expenses.

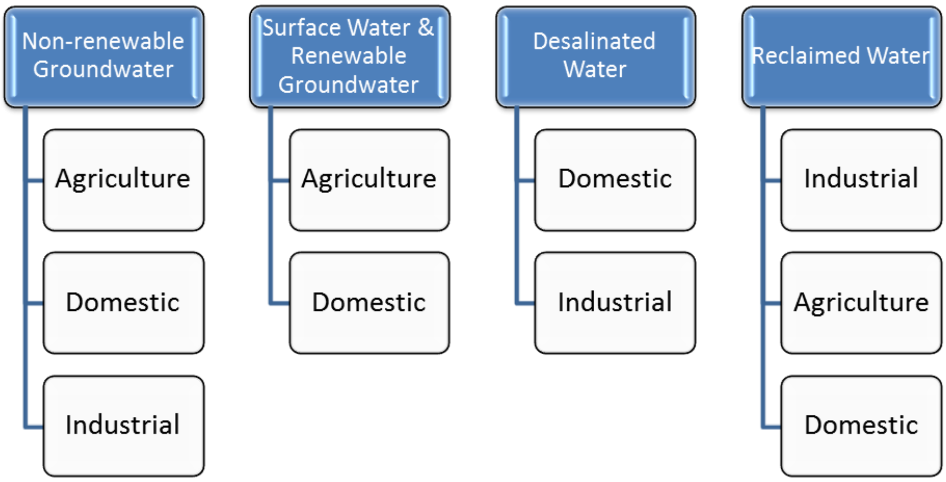


Figure 5-9 Relation between main water resources and users in Saudi Arabia

A water allocation flow chart depending on treatment type is shown in Figure 5-10 to illustrate the connections and relationships between WR elements. The household sector in RO plants is the sole setting in which NGW and RGWSW are treated; in most cases, the industrial and agricultural sectors do not require treatment. Three distinct technologies—RO, MSF, and MED—are employed in desalination facilities to process seawater, and both the industrial and residential sectors utilise the resultant desalinated water. Wastewater treatment facilities, or WWTPs, collect and treat all of the water leftovers produced by the three sectors. All three sectors use a small portion of the treated wastewater as RW, with the remaining wastewater being discharged in various ways. The new direction for this water allocation chart, shown by the red arrow in Figure 5-10, is the use of DW for agricultural purposes as a new trend for innovative or modern types of planting or irrigating. This step is still in the early stages, and more investigations about its feasibility are required.

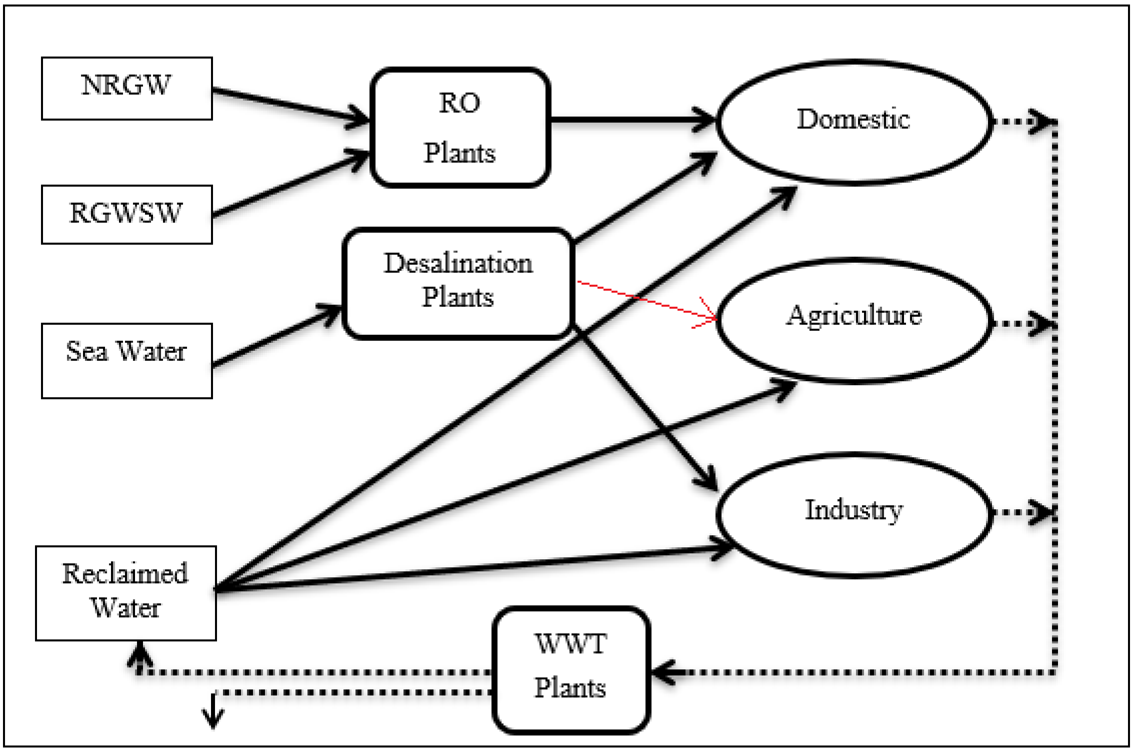


Figure 5-10 Water allocation flow chart in KSA according to treatment type

Concerning water distribution to the residential sector, Table 5-11 illustrates the amount and percentage of DW and GW in general (i.e., NRGW and RGW) that feed the residential sector between 2007 and 2018. The good news is that the domestic sector's burden on the GW is lessened because the DW has doubled and is predicted to continue growing in production. Before moving further, decision-makers should carefully weigh the trade-offs between the objectives of preserving conventional WR, shielding the environment from the harmful effects of current desalination technologies, and saving the economy from the high cost of such a technology.

Table 5-11 Quantity and percentage of main WR used by the domestic sector (adapted from GASTAT, 2018a, 2018b; MEWA, 2019)

Year	Water Quantity (MCM/year)			Annual Growth Rate (%)	Percentage (%)	
	GW	DW	Total		GW	DW
2007	910	1,067	1,977	-	46	54
2008	942	1,063	2,005	1	47	53
2009	978	1,145	2,123	6	46	54
2010	1,025	1,258	2,283	8	45	55
2011	947	1,476	2,423	6	39	61
2012	981	1,546	2,527	4	39	61
2013	1,137	1,594	2,731	8	42	58
2014	1,189	1,685	2,874	5	41	59
2015	1,190	1,835	3,025	5	39	61
2016	1,182	1,947	3,129	3	38	62
2017	975	2,175	3,150	1	31	69
2018	1,255	2,137	3,392	8	37	63

5.1.4. Governance of WR in Saudi Arabia

What role does the government of KSA play in handling the WR issue? This question may come up based on past data and projections. The Ministry of Environment, Water, and Agriculture (MEWA) was established in 2016 by the Saudi Arabian government as a single ministry to oversee matters related to the environment, water, and agriculture. The goal of this ministry is to conserve the nation's natural resources, like water, and promote the sustainability of the environment and food sources in order to improve Saudi Arabia's standard of living (MEWA, 2019). Applying the concepts of IWRM to all WR that support Saudi Arabia's broad spectrum of consumers is one of the primary ways to realise this ambition. Therefore, a thorough understanding of IWRM concepts and procedures (See Section 1.1) is necessary for successful implementation, which raises the WRM system's effectiveness and sustainability.

Hence, KSA, represented by MEWA, presented the National Water Strategy 2030 (NWS2030) in 2018 (MEWA, 2018), which would lead to the goals of the SAV2030. This strategy is founded on the ideas of IWRM, a restructuring initiative that seeks to make the water sector more efficient and sustainable. For example, one of these targets is to increase the percentage of RW to 80% of the entire amount of TWW by 2030 (MEP, 2023). In this NWS2030, the assessment of the water sector, in general, was based on the five main strategic dimensions: the abundance of water, the ability to afford costs, the overall quality, and the environmental and economic sustainability. Not only this, but a new “water law” was prepared and introduced in 2020 to provide a legal framework that governs the use, distribution, and preservation of water resources in order to guarantee their responsible use (MEP, 2023). Therefore, it can be said that KSA is on the right path to resolving several complex issues related to its WRM with the guidance of the IWRM. Meanwhile, this study is another attempt to contribute to this process by developing the SWRM-AF that can assess the current situation of WRM, particularly the domestic sector. Then, future scenarios will be presented and evaluated using the same tool to see how SWRM-AF can set future targets that would enhance the sustainability level of the system.

5.2. SWRM-AF Application for Evaluating WRM of KSA

5.2.1. Introduction

As stated before, the refined and final version of SWRM-AF consists of 4 components and 17 indicators (See section 4.3.3), while each of these indicators has its colour-coded table that presents different criteria to evaluate those indicators (See section 3.5). It is required to assess each indicator based on its related data from the country in ASAR, which is the KSA in our case. Meanwhile, it is preferred to choose one specific year of that country where all (or most) of its WRM data are available to apply the SWRM-AF and produce the baseline year that any future comparison should be with to measure the progress toward having or achieving a SWRM. In some cases, it might be alright to combine two years after each other if the data of one of them is missing or hard to find. Therefore, based on the data found and included in this research, the base year for applying the SWRM-AF on KSA would be 2018 and/or 2019.

5.2.2. Evaluation of Environmental Indicators and Component

In this section, the evaluation will be about the five environmental indicators. The first one is about the compliance of WWTPs with suggested regulations (See Section 3.5.1.4) to give an idea about their performance. Three factors need to be in hand to properly assess this indicator: type of treatment, age, and both designed and actual capacity (See Table 3-10). By checking Table 5-10, it can be seen that the number of WWTPs has increased by 42 new WWTPs just between 2018 and 2021. This can indicate that many WWTPs have recently established and entered the service so the age can be considered not old.

Regarding the treatment type, most WWTPs rely on secondary and tertiary treatment. At the same time, for many of them, the actual production is either higher (few) or lower (many) than the designed capacity of these plants (Official government, 2023). Therefore, most WWTPs do not match the designed capacity. By referring to Table 3-10, the compliance level indicator can be estimated as **Medium** whose equivalent score is 3.

The second indicator is about the average quality of discharged wastewater (See Section 3.5.1.2). The average quality of discharged WW is below the secondary treatment (Official government, 2023). Therefore, by referring to Table 3-7, the rate of this indicator can be classified as **Below average** which its equivalent score is 2.

The third indicator is related to the share of using RW (See Section 3.5.1.5). This information is given in Table 5-10. If only 2018 and 2019 are considered, then the average rate is 17.5%, which is regarded in Table 3-11 as **Small** level. Therefore, the equivalent score for this indicator is 1.

The fourth indicator is the share of using GW for drinking (or domestic sector) (See Section 3.5.1.6). The data to evaluate the level of this indicator is available in Table 5-11, where the most updated one is 37% in 2018. However, another official source showed that this rate has decreased in 2021 to 34% (MEWA, 2022). Meanwhile, the data for 2019 and 2020 could not be found. Anyhow, any rate below 40% is considered in Table 3-12 as **Below average** level. Hence, the equivalent score for this indicator is 3.

The last environmental indicator is about evaluating CO_2 emissions from the desalination sector (See Section 3.5.1.3). The data in this study is taken away from Hamieh et al. (2022) by comparing the emissions unit in 2016, which was 21.4 kg CO_2/m^3 of desalinated water, to that in 2019, which was 15.2 kg CO_2/m^3. This reduction is 29%, and by checking Table 3-9, the level of these emissions is considered **Medium.** Thus, the equivalent score for this indicator is 2.

All these evaluations with their equivalent values and weights illustrated in Table 5-12 should be available to do the calculations. Then, after entering the values into the Excel spreadsheet (See Section 4.3.3), the output will be shown in Figure 5-11. What is needed to do now is to multiply the equivalent values by their weights and then take the average of the output of the five indicators together to get a specific value that can represent the component of the environmental pillar.

Table 5-12 Evaluations and weights of Environmental Indicators (Baseline years)

Environmental Indicators	Score	Equivalent Value	Weights
Compliance of wastewater treatment plants with regulations	3	60	24.2%
Quality of discharged wastewater	2	40	23.8%
Share of reusing of treated wastewater	1	20	19.6%
Share of using groundwater for drinking	3	60	18.1%
Carbon dioxide emissions from desalination	2	40	14.3%

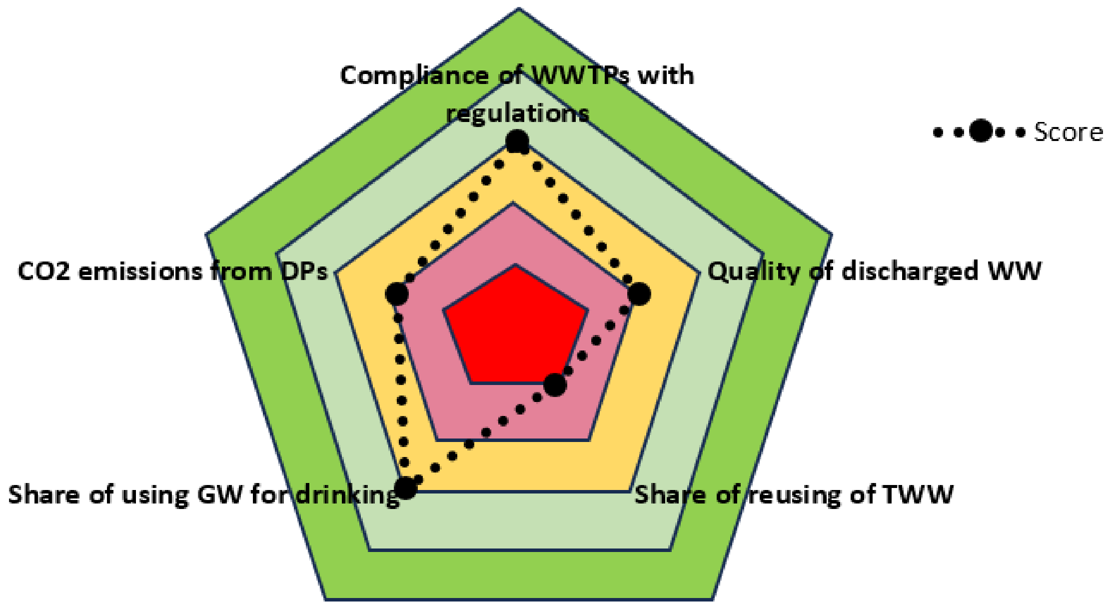


Figure 5-11 Radar chart of the Evaluations of Environmental Indicators (Baseline years)

Thus, by applying the previous calculations, the final value of the first component (i.e., environmental pillar) is 44.54, which is considered low and surely will have an effect in decreasing the final framework value or the sustainability level of the WRM of the domestic sector in the KSA. Therefore, more attention should be given to reaching the green zone in Figure 5-11, which enhances the environmental pillar and sustainability.

5.2.3. Evaluation of Social Indicators and Component

The first social indicator to be evaluated is the per capita water consumption (See Section 3.5.2.1). The data that can be used is presented previously in Table 5-3, where the average daily water consumption per person in 2018 was 278 L/cap/day, and was estimated in 2019 to be 318 L/cap/day. Therefore, the average of these two numbers can be considered here, which is 298 L/cap/day. This value should be taken to Table 3-14, which shows that the evaluation of the consumption level is **Above average** since the value is very close to 300 L/cap/day. Thus, the equivalent score for this indicator is 2.

The second indicator in this group is related to the drinking water quality (See Section 3.5.2.2). The water quality in KSA overall is that few regions receive high water quality and can drink tap water, like Riyadh, the capital city. In contrast, others received lower quality, such as the eastern region, where tap water is salty. Therefore, by checking Table 3-16, the water quality level can be considered as **Below average** since the water quality in some (≤ 50%) areas is not drinkable. This is somehow close to the evaluations provided, but the EPI (Wolf et al., 2022), which gave KSA a score of 51%. Hence, the equivalent score for this indicator is 2.

The third indicator is about water awareness and the number of methods used to increase it (See Section 3.5.2.4). The level of awareness is measured by the number of means and the targeted group age of the people who lived in that country or region, as explained in Table 3-18. KSA has considered the awareness level in several ways. The school curriculums always included different topics about the water situation and rationalization. Also, the universities in KSA used to and are still executing campaigns for the same purpose. Not only this, one of the newest initiatives to encourage water conservation in the commercial and residential sectors is called Qatrah, which translates to "droplet" in Arabic (Alodah, 2023). This program is provided with interactive content through social media, such as the platforms X, Instagram, and YouTube. Also, the newspaper and the television presented some facts and advice about how to use water effectively. Finally, the government of KSA established in 2021 the National Water Efficiency and Conservation Centre and called it MAEE, which translates to "my water" in Arabic. This centre became the official hand for the government to raise water awareness by different means and with a specific budget. Therefore, by referring to Table 3-18, the rate of this indicator can be classified as **Excellent efforts** with its equivalent score of 5.

The intervention acceptability is the fourth and last social indicator in the SWRM-AF (See Section 3.5.2.5). This indicator can be measured by the level of interventions that already exist and how people interact with it. In the past, water rationalisation tools (WRT) were provided to many people living in KSA for free to install in every tap water of the residential sector. However, most people did not keep them for a long time before they removed them. There are two possible reasons; the first one is that these tools reduced water pressure, which many users disliked, leading to non-usage. The second reason is that the water tariff was highly subsidised by the government at that time (See Table 5-1), and even some people have never paid for the water service since no specific punishment is assigned in the laws for this case. On the other hand, the water bill kept accumulating with very low tariffs, which were estimated to cover only 5% of the total actual cost, while 95% was subsidised (Ouda, 2013). Therefore, the behaviour of consuming water was not motivated to be lowered by such a tariff system, and people felt there was no need for such WRT.

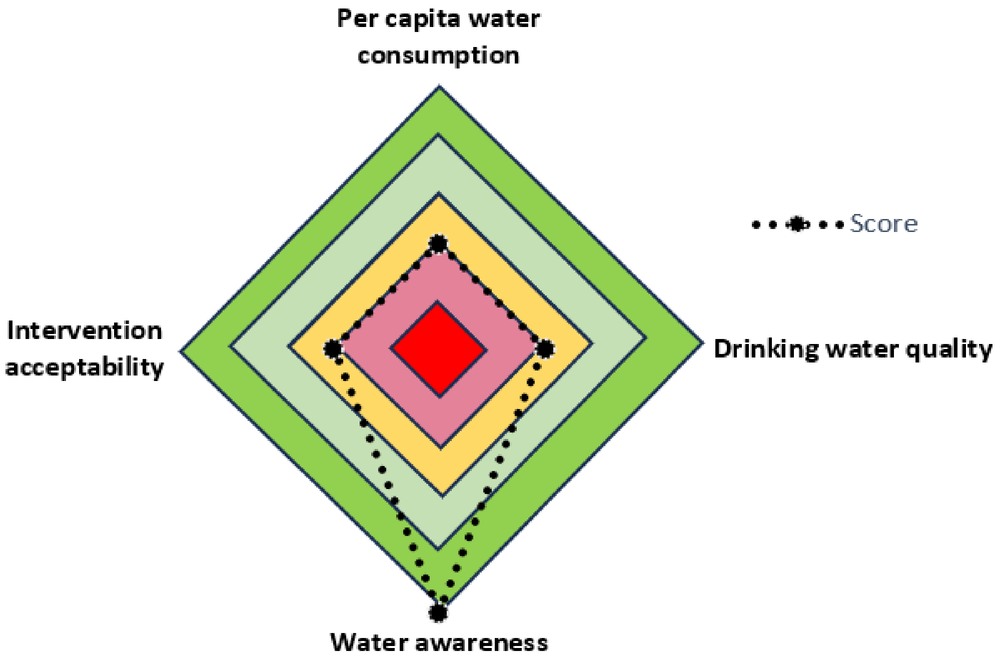
However, the situation has changed since introducing the new water tariff system (See Table 5-2). Also, some regulations were introduced to chastise those who do not pay their bills by stopping their governmental services (and sometimes their bank accounts) until they pay their water bills. Therefore, the people started to complain about the water bills and claimed that they were inaccurate, which was true for some cases after investigation by water authorities. Meanwhile, this issue was possibly the reason for the social acceptance of introducing the smart water meter (SWM) to every house and most of the domestic sector. The positive point here is that this intervention was free, lessening social resistance.

On the other hand, the domestic sector still needs more interventions, such as the greywater and RWH systems, because the average consumption is still high. The cost of introducing or installing these systems might be increased in the short term. Nevertheless, it would benefit the whole country in the long term by reducing consumption and saving water for the next generations. Hence, by referring to Table 3-19, the rate of this indicator can be classified as **Partially acceptable** and its equivalent score is 2. This is because two strategies in the past were introduced and have been partially accepted.

Therefore, based on the calculations for the values and weights in Table 5-13, the social pillar or the second component has a final value of 55, indicating an above average level (i.e., > 50%). Meanwhile, this result might not reflect the three social indicators with slightly below-average values, as can be seen in Figure 5-12, which need special efforts to be made to increase their levels and evaluations.

Table 5-13 Evaluations and weights of Social Indicators (Baseline years)

Social Indicators	Score	Equivalent Value	Weights
Per capita water consumption	2	40	25%
Drinking water quality	2	40	25%
Water awareness	5	100	25%
Intervention acceptability	2	40	25%



3.5.2.5

Figure 5-12 Radar chart of the Evaluations of Social Indicators (Baseline years)

5.2.4. Evaluation of Economic Indicators and Component

The first economic indicator measures the proportion between the average income and the water supply cost. Following the instructions that were given in Section 3.5.3.1 to calculate the value of this indicator, and by considering the data presented in Table 3-22, the average water supply cost of KSA is estimated to be 2.2% of the average monthly income. Therefore, this cost level is considered **Low** according to Table 3-23, and the equivalent score is 4.

The second indicator here is about the UFW caused by the leaking or loss in general in one way or another (See Section 3.5.3.2). Based on personal communications, the UFW rate in KSA is estimated to be around 40% (Official government, 2023), which is far away from the GCC UWS target (i.e., 10%) by 2035. Hence, in Table 3-24, the level of UFW is **High**, and its equivalent score is 2. This issue is critical, and more efforts should be spent towards minimizing it.

The third indicator concerns the water sector's share in total public spend (See Section 3.5.3.3). The average spent on water projects in 2018 and 2019 was estimated from the Ministry of Finance (MF) reports to be 6.4%, which is equivalent to around 133 billion SAR of the total budget (MF, 2019, 2020). Several projects were included, while others were planned to be given to the private sector. Therefore, by checking Table 3-25, the spending level is suggested to be

Medium; its equivalent score is 3.

The last economic indicator is about supporting people experiencing poverty by any method, such as special discounts and rewarding the efficient use of water with lower fees (See Section 3.5.3.6). In KSA, the government designed in 2017 a special program called the citizen account, where special financial welfare provided in cash would be given to each family based on the evaluation of the income of the whole family who lived in the same house. This program is effective to some extent. Also, as illustrated previously in Table 5-2, the IBT system is used in the country and several poor (and also middle-class) people tend to reduce their consumption to avoid paying a high amount of money. Thus, by referring to Table 3-28, the rate of this indicator can be classified as **Good** which its equivalent score is 4.

Based on the calculations for the values and weights in Table 5-14, the economic pillar or the third component has a final value of 65, indicating an **Above Average** level. The visual result can be observed in Figure 5-13.

Table 5-14 Evaluations and weights of Economic Indicators (Baseline years)

Economic Indicators	Score	Equivalent Value	Weights
Water supply cost related to user's income	4	80	25%
Unaccounted for Water (UFW)	2	40	25%
Water sector share in total public spend	3	60	25%
Pro-poor and pro-efficiency water fees	4	80	25%

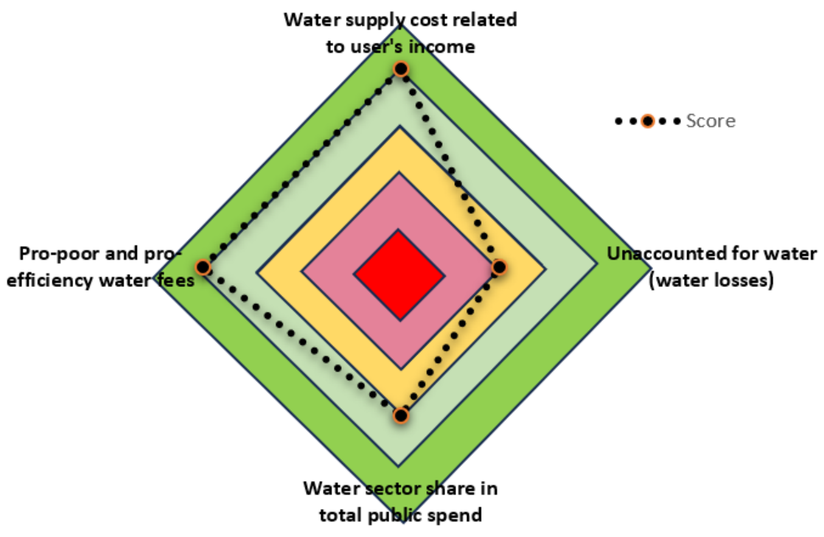


Figure 5-13 Radar chart of the Evaluations of Economic Indicators (Baseline years)

5.2.5. Evaluation of Infrastructure Indicators and Component

The final set of indicators pertains to the water infrastructure. The first indicator concerns the availability of potable water (See Section 3.5.3.6). The general water network coverage is high in KSA and is estimated to be above 99% between 2016 and 2020 (MEP, 2023). As clarified before, the water quality provided in some regions might need filters connected to the taps to be drinkable. However, it is delivered and still acceptable to be used in every house for all other purposes. Hence, by referring to Table 3-30, the rate of this indicator can be classified as **Very High** which its equivalent score is 5.

Regarding the second indicator, the focus is on the coverage of the sanitation services or network. While some research and reports estimated different rates of coverage that are between 50 to 100% (Dawoud et al., 2022; MEP, 2023), while another report that is more specific suggested that 59.7% of the coverage is connected to piped sewers and another 20% is collected from septic tanks (WHO and UN Habitat, 2020). However, since this indicator is under the infrastructure category, 59.7% is the correct number to be taken to Table 3-31. Thus, the access to sanitation level is **Average** which its equivalent score is 3. This rate can be considered low for a wealthy country such as KSA. Nevertheless, according to different sources, this rate is expected to be 80% in the coming few years.

The third indicator is the rate of water physical leakage (See Section 3.5.4.3). While several reports indicated that this rate is around 40%, there is confusion in this estimation since it was found through an interview with a government manager that this leakage includes technical (i.e., real leakage) and billing issues (Official government, 2023). He stated that the actual rate of physical leakage in KSA is estimated at 21% (Official government, 2023). Therefore, by looking at Table 3-32, this leakage level is considered **Above average** which its equivalent score is 3.

The last indicator under this component is the age of water infrastructure (See Section 3.5.4.6). Based on personal communications, the estimation for the average age of the water infrastructure is approximately 30 years (Official government, 2023). Thus, this age is considered **Average** by checking Table 3-35, whose equivalent score is 3.

According to the calculations using the values and weights in Table 5-15, the infrastructure pillar, which is the fourth component, has a final value of 70, indicating the best result among all other components. The visual outcome is seen in Figure 5-14.

Table 5-15 Evaluations and weights of Infrastructure Indicators (Baseline years)

Infrastructure Indicators	Score	Equivalent Value	Weights
Access to safe drinking water	5	100	25%
Access to sanitation	3	60	25%
Rate of water physical leakage	3	60	25%
Age of water infrastructure	3	60	25%

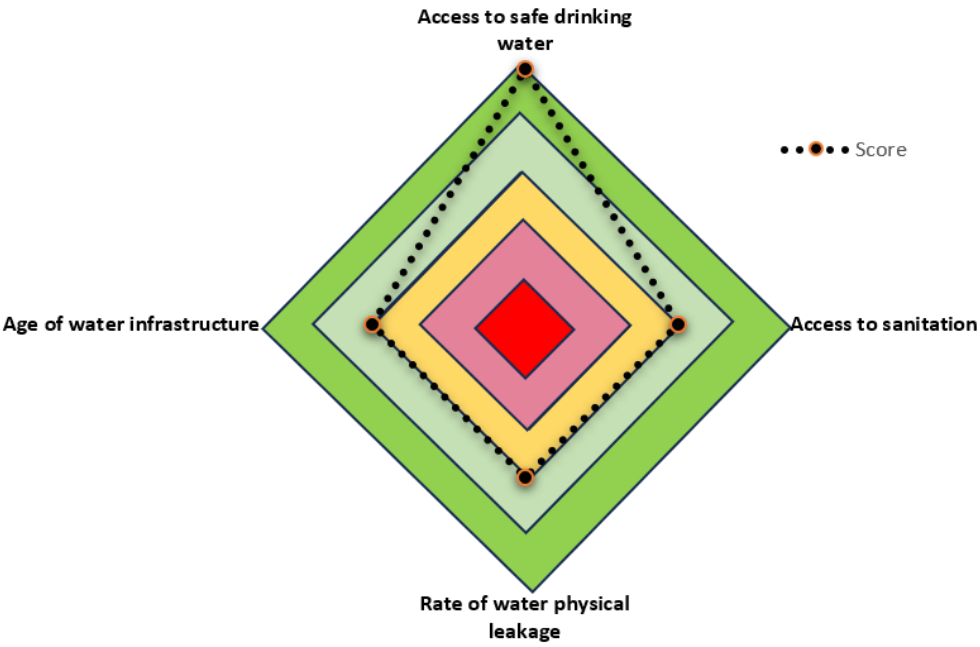


Figure 5-14 Radar chart of the Infrastructure Indicators (Baseline years)

5.2.6. Outcome of SWRM-AF

After knowing the evaluation and score of each indicator, which has produced the value of each component, now is the time to aggregate the values of the components together to find the final framework value. The value and weight of each component required to do this calculation is presented in Table 5-16. After doing these calculations, the output and the final framework value is 58.64, as shown in Figure 5-15.

Table 5-16 Evaluations and weights of each component (Baseline years)

Components	Aggregated Value	Weights
Environmental pillar	44.54	25%
Social pillar	55	25%
Economic pillar	65	25%
Infrastructure	70	25%

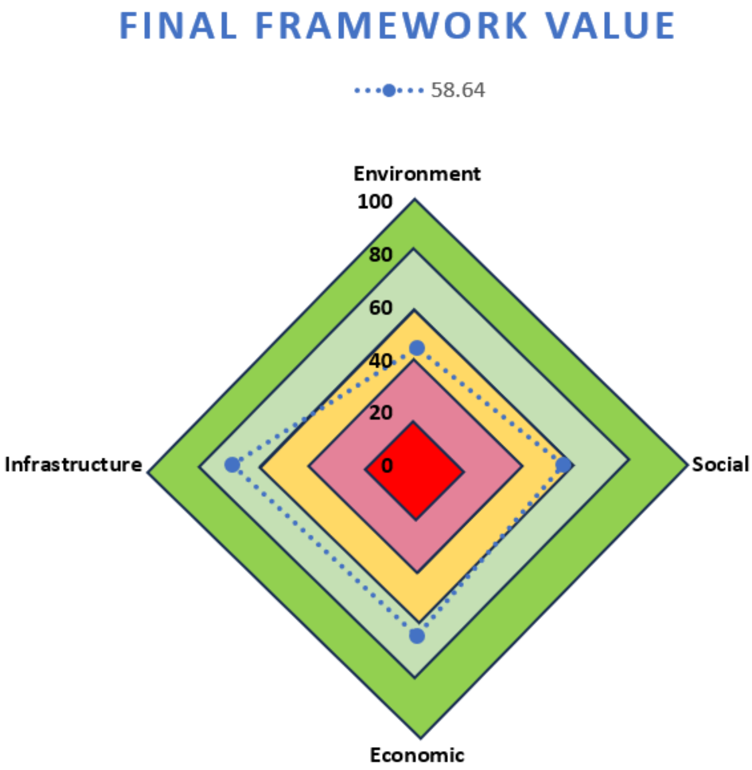


Figure 5-15 Radar chart of the components and final output of the SWRM-AF (Baseline years)

Hence, the current water resource management (WRM) level of the KSA's domestic sector may be above average, namely over 50%. Consequently, further efforts are required to improve this level. To begin, it is advisable to prioritise the environmental pillar and related indicators, as they now have the lowest overall value. Then, the focus should be on enhancing the social and economic aspects, in that order, because of their low rates. The infrastructure pillar and associated metrics yield the most favourable outcomes, which is promising considering the substantial investment required for improvement. However, it is essential to note that the establishment phase of infrastructure projects, such as road closures, might potentially pose challenges for society in the short term.

Moreover, this evaluation reflects the SWRM level of the current practices in KSA. More future scenarios can be provided and analysed to see how they can affect the whole system's sustainability level.

5.3. Future Scenarios and Application of SWRM-AF

In this section, two future scenarios based on specific changes to the WRM system of KSA will be assumed and then evaluated by the tool (i.e., SWRM-AF) developed in this study. Before going further, it should be noted that future scenarios represent possible outcomes, are not intended as forecasts or predictions, and explicitly exclude trend analysis (Hunt et al., 2010).

The first scenario will include maintaining the status quo without altering current practices. This state is called the business as usual (BAU) scenario in this research (See Section 5.3.1). The second scenario assumes the achievement of multiple targets of the GCC UWS and SDGs, presenting an optimistic outlook (See Section 5.3.2).

Moreover, the context of WRM systems encompasses various aspects and restrictions that must be considered, including population expansion, water supply capacity and infrastructure, as well as environmental, economic, and social implications. Furthermore, the population growth of all GCC countries is projected to persist due to their strong economic conditions. However, the rate of this expansion may vary depending on numerous circumstances, making it challenging to provide a precise number. Therefore, it is recommended for any user of SWRM-AF to take into account the average growth rate of the most recent census data from the past decade (or any available and most up-to-date 10 years) for research purposes. Subsequently, the population's growth rate for upcoming years would be presumed to be constant. Thus, the population of any future year can be counted as the first step in checking the circumstances of any scenario. The second step is estimating the water demand required to supply the domestic sector. This quantity can be forecasted using the same method that was used to estimate the population for research purposes.

Since the case study here is about the KSA, the projected increase in their population is based on the average annual growth rate that was calculated in Table 5-3, which is 2.46%. Meanwhile, the average yearly growth rate of domestic water use can be calculated by going back to Table 5-4, which is equal to 4.1%. Therefore, the projections for future population and domestic water use are presented in Table 5-17.

Table 5-17 Estimations for future population and total domestic water use in KSA

Year	Population (Million)	TDoW (MCM)
2021 (Base year)	30.78	3556
2030	37.60	4657
2035	42.23	5619
2040	45.17	6063
2050	52.75	7469

Now, all scenarios will be presented, followed by the application of SWRM-AF to measure the impacts of each one.

5.3.1. Business as Usual Scenario

It is possible that when decision-makers thought that everything in the WRM system was right, they were reluctant to make any changes to the system. As a result, a BAU scenario became the dominant state. Thus, the level of any helpful practice could remain the same or be reduced with time, while the harmful practice can accumulate until it reaches a point where it would be hard or very costly to improve or adjust. However, presenting such a scenario is significant since it can evaluate and show the results for keeping the same practices without any change to both stakeholders and decision-makers.

In this scenario, water demand and populations would increase while the level of all services, costs, number of WWTPs, etc, would be the same as the baseline years. Therefore, the effect of such a scenario on WRM's sustainability must be assessed.

Regarding the environmental indicators, the increase in water demand would put more pressure on the WWTPs, which would turn out to be old after 2030. Therefore, the level of the first environmental indicator will be **Below Average,** with a score of **2**. For the quality of discharged WW, since most WWTPs would be old, it is highly possible that their actual production will be lower than the design capacity, and it might lose different features to accommodate this situation. Thus, the quality level is supposed to decrease to a **Low** level with a score of **1**. Meanwhile, the share of reusing of TWW would be the same as the baseline year since it will stay less than 20% but not zero. Hence, its level would remain **Small** with a score of **1**. Then, the share of using GW for domestic purposes would increase since all other CWR would remain the same in the baseline years, and thus, they cannot cover the increase in demand. However, the level of using GW might be **Medium** (i.e., ≤ 60%) with a score of **2** in 2030 and 2040 only, while 2050 can be High. The last environmental indicator is the CO_2 produced by DPs. This indicator would likely be the same or less than the baseline years since no new DPs will be established. Therefore, the CO_2 emissions level will be **Medium**, with a score of **2**.

For the social indicators, the per capita water consumption would remain the same in the baseline years (i.e., **Above Average**), and its score is **2**. The drinking water quality would possibly decrease since some WTPs would be out of service or unable to function fully. Hence, the quality level is supposed to be **Low**, with a score of **1**. The effect of the water awareness campaigns might be lower since their methods have become outdated and need to be improved to match the interests of the new generations. Therefore, the evaluation for the effort level to raise the water awareness is assumed to be **Below Average,** with a score of **2**. The assessment of the final social indicator (i.e., Intervention acceptability) would remain the same (i.e., **Partially acceptable**) with a score of **2** since the two previous interventions are still applicable.

Regarding the economic indicators, the first one is about the relation between user income and water cost, which should be the same based on our suggested scenario. Therefore, the cost level here remains **Average,** with a score of **3**. The second indicator is about the UFW. Here, the leakage and technical issues in water billing are supposed to increase because of the increase in water consumption. In parallel, the same level of service might not continue in the same situation, but it is supposed to deteriorate. As a result, the water losses in the water network are expected to increase, and their level will become **Very High**, with a score of **1**. The next indicator is about the share of the water sector in the yearly governmental budget. The evaluation of this indicator is expected to decrease since more and/or new supplies will be needed to cover the increasing demand, but they are out of sight. Hence, the spending level is expected to be **Below Average,** with a score of **2**. Finally, the pro-poor and pro-efficiency water fees indicator shall be the same as the baseline years, with a score of **4**, whose level is **Good**.

The last group of indicators is about the infrastructure, where no expansion to any part is expected. There might be a gap between water supply and demand since domestic water would increase without any further increase in water mains. Thus, the evaluation for the level of the first infrastructure indicator, which is access to safe drinking water, can reduce and become **High** in 2030 to **Average** in 2040 and 2050, with a score of **3**. Likewise, the rate of access to sanitation might decrease to **Below Average** level and a score of **2**, where the overall access ratio would be ≤ 50%. The rate of Water physical leakage will probably be like the baseline years, where its level is **Above Average** with a score of **3**. Lastly, the infrastructure age will be older than the baseline years. The age would become 39, 49, and 59 for 2030, 2040, and 2050, respectively. Therefore, the age level can be classified as **Old** and has a score of **1**.

Consequently, the output of the application of SWRM-AF on the BAU scenario with the result of each indicator and component is shown in Table 5-18. It can be seen that the evaluation of the economic component and its indicators produced the highest results in this scenario, while the environmental gave the worst results. This result is because the minimum cost is required to maintain the operation of the WRM system since no projects are on the horizon.

Meanwhile, the environmental pillar can deteriorate if the not environmentally friendly practices continue at the same rate without any mitigation plan. The sustainability level of the BAU scenario is below average at **40.33**. Thus, it would not be wise enough to keep things in the future as they were in the past. Improvement of the system is a cornerstone of raising the sustainability level of any system.

Table 5-18 Results of the Evaluation of BAU Scenario by using SWRM-AF

Indicators	Score	Equivalent to	Weight (%)	Value of Component	Final Framework Value
Environmental Indicators					
Compliance of WWTPs with regulations	2	40	24.2	31.32	40.33
Quality of discharged WW	1	20	23.8		
Share of reusing of TWW	1	20	19.6		
Share of using GW for drinking	2	40	18.1		
CO_2 emissions from DPs	2	40	14.3		
Social Indicators					
Per capita water consumption	2	40	25	35	
Drinking water quality	1	20	25		
Water awareness	2	40	25		
Intervention acceptability	2	40	25		
Economic Indicators					
Water supply cost related to user's income	3	60	25	50	
Unaccounted for water (water losses)	1	20	25		
Water sector share in total public spend	2	40	25		
Pro-poor and pro-efficiency water fees	4	80	25		
Infrastructure Indicators					
Access to safe drinking water	3	60	25	45	
Access to sanitation	2	40	25		
Rate of water physical leakage	3	60	25		
Age of water infrastructure	1	20	25		

5.3.2. Optimistic Scenario

In this scenario, several targets would be assumed that it would be achieved. These targets include the objectives of indicators of SDGs and GCC UWS. While the timeframe to accomplish many SDGs indicators is set to be by 2030 (UN, 2023), many indicators of the GCC UWS are expected to meet their targets by 2035 (Al-Zubari et al., 2017). The expectations for each group of indicators in the optimistic scenario are as follows:

The first environmental indicator is expected to flourish since one of the GCC UWS targets increasing the rate of using the RW to TWW to 90% by 2035. This rate required high standards of new WWTPs and relied more on tertiary treatment. Therefore, the compliance level is **Excellent,** with a score of **5.** As a result of the high trend of using the tertiary treatment in the previous indicator, and also since another target of the GCC UWS is to increase the collected WW to TDoW to be 60% (i.e., above average), the second indicator can achieve High to Very High levels of the quality of discharged WW. Therefore, the score would be given to **4** (i.e., **High** level) since a lot of TWW would be reused based on evaluating the previous indicator. Again, the evaluation of the third indicator would be affected by the effective targets of GCC UWS mentioned previously, such as the rate of RW to TWW, which should be 90%. Based on the ambition of this scenario, the reusing level of TWW can be classified as **Excellent**, with a score of **5**. Regarding the share of GW used in the domestic sector, KSA aims to reduce and compensate for it by extending the DW supplies. This trend can be realized in Table 5-11, while the up-to-date rate of using GW and DW was 35.1% and 64.9% in 2020 (Official government, 2023). Therefore, the efforts would continue to decrease GW, and it can reach 20% or below based on the new projects to build new DPs. Thus, the GW using level can be **low** at least by 2040, with a score equivalent to **4**. The last indicator of this group is the CO_2 emissions of the DPs. KSA aims to reduce these emissions by 62% in 2025 compared to 2018 (SWCC, 2023). Therefore, if this aim is achieved, then the future emissions level of this scenario could be **Low** with a score of **4**.

For the social indicators, the target of the GCC UWS is to reduce it to 250 L/cap/day by 2035. Therefore, this scenario will assume that this consumption has been achieved. Thus, the consumption level is **Average**, with a score of **3**. The drinking water quality would most likely increase in this scenario since more dependence would be on the DW, whose quality is high. Hence, the quality level can be classified as **High**, with a score equivalent to **4**. In this scenario, all efforts would be given to enhance the sustainability level of the WRM. Therefore, water awareness will continue in KSA, and it is expected to be **Excellent,** with a score of **5**. The last social indicator is intervention acceptability. The issue for most people is the cost of applying some of these interventions. So, they are either to be provided for free to be accepted, or some of these interventions can be made mandatory by including them in the building codes and requirements for the new buildings. In this case, the acceptable level could be increased to **Highly acceptable**, with a score of **4**.

Regarding the economic indicators, the first indicator is not expected to change in KSA.

Therefore, the cost level would still be considered **Low** with a score of **4**. Then, the level of UFW presumably would decrease since one of the targets of the GCC UWS is to make it only 10% by 2035. Therefore, following this scenario would mean that the level of UFW will be **Low**, with a score of **5**. Similarly, the spending level is assumed to be **Excellent**, with a score of **5**, since new projects would be required in this scenario and would improve the overall water sector. The level of the last economic indicator is expected to be **Excellent**, with a score of **5,** since more focus and effort would be given to reducing water per capita consumption. This would include providing pro-efficiency tools and/or equipment to help society decrease its current high-water consumption.

The final group here is related to the infrastructure. The first and the second indicators can match the targets of the SDGs, and both could be considered **Very High**, where their scores are **5**. The water leakage rate through water pipes is deemed to match the target of GCC UWS. The strategy aims to reduce the physical leakage in all GCC countries to 10% or less. Therefore, this leaking level is considered **Low,** with a score of **5**. Finally, the age of water infrastructure in this scenario is anticipated to be higher. The age level can be considered **Above Average,** with a score of **4**.

Applying SWRM-AF on the optimistic scenario yields the output, including the outcome of each indicator and component. This information is presented in Table 5-19. The assessment of the economic and infrastructure aspects and their indicators generated the most favourable outcomes in this situation, but the social aspect yielded the least good evaluations. The main reason for this low evaluation is the result of the first social indicator (i.e., Per capita water consumption), which is still lower than other world targets. The reason for assigning this target was because some GCC countries have very high-water consumption use, and 250 L/cap/day might be a massive achievement for them. Therefore, it might be better for KSA to consider and pursue another advanced target with lower water consumption to increase the sustainability level of their WRM system.

On the other hand, the environmental component and indicators performed excellently in this scenario. Lastly, the sustainability level of the optimistic scenario is outstanding, namely at **89.63**. Hence, it would be realistic to start work based on the targets of this scenario to enhance the WR and ensure the sustainability level of any system is elevated.

Table 5-19 Results of the evaluation of optimistic scenario by using SWRM-AF

Indicators	Score	Equivalent to	Weight (%)	Value of Component	Final Framework Value
Environmental Indicators					
Compliance of WWTPs with regulations	5	100	24.2	88.76	89.69
Quality of discharged WW	4	80	23.8		
Share of reusing of TWW	5	100	19.6		
Share of using GW for drinking	4	80	18.1		
CO_2 emissions from DPs	4	80	14.3		
Social Indicators					
Per capita water consumption	3	60	25	80	
Drinking water quality	4	80	25		
Water awareness	5	100	25		
Intervention acceptability	4	80	25		
Economic Indicators					
Water supply cost related to user's income	4	80	25	95	
Unaccounted for water (water losses)	5	100	25		
Water sector share in total public spend	5	100	25		
Pro-poor and pro-efficiency water fees	5	100	25		
Infrastructure Indicators					
Access to safe drinking water	5	100	25	95	
Access to sanitation	5	100	25		
Rate of water physical leakage	5	100	25		
Age of water infrastructure	4	80	25		

6. Conclusions

6.1. Introduction

This chapter serves as the finalisation of the research project. Section 1 provides a concise overview of the research study, aligning it with the initial aim and objectives and outlining the methodology phases that were carried out to accomplish these goals. Section 6.3 discusses the significance of the study and how it contributes to filling the identified knowledge gap. The study's limitations are detailed in Section 6.4, namely on the scope of the SWRM-AF. Section 6.5 offers guidance to relevant parties and proposes areas of further research within the framework of SWRM-AF.

6.2. Summary of the Study

This study demonstrates a comprehensive approach to evaluating the decision-making process of WRM for the domestic sector, explicitly emphasising the ASAR aspect. More specifically, this tool is primarily designed for use in countries with special conditions, such as the GCC nations. Nevertheless, it could be feasible through certain modifications (such as altering indicators and weights) to potentially apply SWRM-AF to other countries. SWRM-AF offers a notable benefit compared to current IBWSFs since it allows for the implementation of durable improvements through an iterative approach. To explain, the validity, relevance, and refinement of the conceptual version of the framework tool were assessed by subjecting SWRM-AF to pressure testing with a user group through several rounds. Similarly, the same steps can be repeated for any new version or enhancement of SWRM-AF, which makes it supple.

This study was derived from the objectives outlined in Section 1.2. These objectives have been attained, although, as is the case with any research, there is always additional work that may be accomplished if sufficient time and resources are available. Concisely, the research has accomplished the following:

- Objective 1: A comprehensive and systematic assessment of previous studies has been conducted to identify the existing knowledge gap regarding whether an appropriate assessment framework for the SWRM of the domestic sector in ASAR is available or not;
- Objective 2: The conceptual SWRM-AF framework was developed to evaluate the various indicators, which belong mainly to the three pillars of sustainability plus the infrastructure (together represent the four components), utilised in GCC countries.

Furthermore, the data referred to and an explanation with justification for each indicator were presented. Most of these indicators had international or regional targets. Therefore, specific evaluation criteria were given to each indicator to ease the mission of users to reuse the framework at any time;

- Objectives 3 and 4: The SWRM-AF’s indicators and weights have undergone rigorous refinement stages by various field experts using the Delphi technique. Its utility and validity, specifically in the context of GCC countries, have been verified. These stages have produced the final version of SWRM-AF, and facilitated the attainment of user acceptance. An essential component in achieving the adoption and utilisation of the tool in GCC countries is a prerequisite for making significant advancements in revolutionising the sustainability level.
- Objectives 5 and 6: The SWRM-AF tool was applied to evaluate and enhance the sustainability level of the KSA's WRM. This includes illustrating the whole situation of the WRM of KSA, with more focus on areas that need to be improved. This allows for the evaluation of current practices and future scenarios to see how far they are from being sustainable based on the specific local conditions and context.

On the other hand, the study presents the following main findings:

➢ A detailed review of recent studies reveals substantial challenges in creating a universally accepted evaluation tool for WRM sustainability in ASAR. Each unique assessment framework quantifies sustainability using different methods. This process uses many global, national, and local indicators, metrics, and benchmarks. According to this study, a framework adapted to the GCC context is needed to depict its distinct local or regional characteristics effectively. It was also found necessary to prioritise water shortage, availability, and demand, both present and future. It's also essential to understand how to construct an IBWSF by inspecting and explaining the seven basic elements.

➢ Before constructing or developing a SWRM-AF, it is crucial to consider and adhere to the precise principles and requirements for its implementation. Otherwise, the outcome of this procedure would lack practicality and rigour.

➢ To establish a practical framework, general and specialist criteria must be used to choose indicators carefully, individually, and together. The conceptual SWRM-AF was developed, and its main components are infrastructure, the environment, the economy, and society. Six literature-based indicators support each component and highlight the most pressing household WRM concerns in GCC nations.

- A colour-coded table for each indicator may help clarify the evaluation topic. These tables let decision-makers, users, and water authorities from any ASAR nation use the SWRM-AF easily and reproducibly. Thus, this research contributes to SWRM due to its simplicity and reusability.
- Involving stakeholders in SWRM-AF development is vital for identifying and addressing their major issues. They can choose indicators, weigh them, or both. Thus, removing or reducing bias in SWRM-AF output helps motivate and educate stakeholders about SWRM. Importantly, competent stakeholders, especially experts, can validate the SWRM-AF, boosting its credibility.
- While the Delphi experience looks useful for validation, it may also help specialists reach consensus, which could lead to widespread application of the study's topic. In response to questions concerning conviction, the majority approved this new framework, and all participants wanted decision-makers to use it. This suggests that GCC countries, represented by their specialists, want to strive for the sustainability of their WRM.
- After the Delphi questionnaire application, the key outcomes are:
    - All four components (environmental, social, economic, and infrastructure) should carry equal weight;
    - Reduce indicators from 24 to 17;
    - Three groups of indicators (social, economic, and infrastructure) receive equal weight, while environmental indicators receive different weights.
    - The final version of SWRM-AF is ready for national use.
- The application of SWRM-AF on WRM of KSA showed that the sustainability of current practices is below average, which needs careful attention. Two scenarios were presented; the first one is BAU, which shows that the sustainability level will be lower in the future if no improvements are initiated to solve this problem and improve the current practices. On the other hand, the second scenario demonstrated that achieving global and regional targets could quickly increase the sustainability level.

6.3. Value of the Study

The following research study benefits the field:

- Research indicates that despite their existence, most IBWSFs may not be appropriate for ASAR like GCC countries. The lack of assessment frameworks for the NWR and other water scarcity factors in GCC for the rapidly growing supply and demand of the building sector is due to factors such as the unique nature of geographical location, cultural and climatic conditions, ineffective management, poor implementation, and lack of public awareness.
- Using the Excel-based SWRM-AF application to assess WRM help both decision-makers and stakeholders see the reality of their water system simply and quantitatively and lets them differentiate between effective and ineffective practices. This would contribute to making the right decisions to enhance the system's sustainability and ensure society's high potential to cooperate to save the balance among pillars of sustainability and infrastructure.
- SWRM-AF is a practical tool for GCC practitioners, such as water authorities, water companies, and contractors. The assessment framework tool, which considers the early impact of such decisions related to the water sector, is not yet available in the region with these features:
    - Adopt simple calculations,
    - Allow data updates as information changes,
    - Present the sustainability level of the whole system.
- Achieving sustainability requires the water sector to adapt to changing conditions, such as the possible consequences of climate change. The SWRM-AF can be adaptable to address other performance concerns and knowledge gaps, which might require additional study. Thus, the framework can be improved, rectified, and evolved.
- The SWRM-AF's benefits are advantageous for the community, as it specifically focuses on the domestic sector. Indeed, the successful execution will have a beneficial impact on nearly all individuals inside the GCC. This aligns closely with SDGs and GCC UWS, prioritising a much-enhanced sustainability strategy. Of course, the policy implications of the framework implementation could improve the current WRM practices if the water authorities consider its output.

6.4. Limitations of the Research Study

While the development of the SWRM-AF has several advantages to the WRM field, some shortfalls still exist, as follows:

- Besides the SLR search criteria and filtering technique, the evaluation was limited to two well-known academic databases, Scopus and Engineering Village. Beyond the two most relevant publications, searching other databases like Google Scholar and Web of Science may have found further literature (including grey literature). Also, a new updated SLR might be required since the one included in this research was conducted at the end of 2021.
- Considering the application of SWRM-AF on the national scale might hinder or hide the display of important and unique factors related and specific to each region or city of that country. For example, depending on the nature or the geography of each city, such as those located on the coastal side and others situated in high elevations, their WR can be different. Of course, this would mean that their WRM is not going to be the same. Hence, it might be better to change the application to be either local-scale or multi-scale.
- The Delphi technique is used exclusively to refine and validate the framework in this study. Some researchers argue that since this technique was criticized for its subjectivity and time-consuming nature (Pill, 1971), it might be combined with another method or theory, such as fuzzy theory (Tseng et al., 2023; Huang et al., 2020) or AHP. On the contrary, this study did not benefit from employing additional methods to follow the previous recommendation.
- This research focused on using SWRM-AF with ASAR and particularly GCC countries. However, how the framework could be adapted to other regions might be unclear.
- Some users might find the indicators of the conceptual SWRM-AF, which were removed after the application of the Delphi technique, helpful. Therefore, the fixability of using and applying such a framework should be considered if a realistic justification for any change is provided with the consultation of other experts in that region.
- The number of presented scenarios was limited, and having others (Hunt et al., 2012) could improve the application and vision of users.

- Addressing uncertainty through sensitivity analysis is needed to assess the impact of different thresholds or benchmarks on evaluating indicators and final framework values (Juwana et al., 2016b). However, the limited scope of this research could not afford this process.

6.5. Recommendations and Further Work for this Study

To make the output of this study practical, it is hoped that different practitioners can use SWRM-AF to discover its benefits, become more familiar with it, spot missing parts, and develop further. The SWRM-AF proposed in the PhD thesis aims to enhance the sustainability level of ASAR's WRM with a long-term impact by improving the four components in a balanced way. Meanwhile, this framework presents a potential approach for developing legislation and guidelines for creating SWRM for the domestic sector inside the GCC countries. Several recommendations need to be sent to relevant researchers and stakeholders to pursue in future projects:

- While this framework followed the guidance that the total number of indicators should be neither too small nor too big, some crucial indicators might be missing either during the selection process (i.e., the conceptual SWRM-AF) or the refinement stage (i.e., the final SWRM-AF). However, the initial selection was in line with the purpose of this study (i.e., to develop an IBWSF that can enhance the level of sustainability of WRM). Therefore, it is worth considering replacing or adding different indicators to the SWRM-AF if its purpose or criteria differ. Nevertheless, following the same significant development steps applied here is still recommended to provide justifications and ensure stakeholders' participation. These steps can be summarized into:
    - having a conceptual framework first based on particular criteria and extensive search through the literature;
    - To refine the framework with the participation of the right stakeholders.
- While the SWRM-AF include all three pillars of sustainability, it would be better to incorporate resilience explicitly in any new development. This is because of the variety of threats that surrounded the WRM in general and of the domestic sector in particular as a consequence of climate change. This can be addressed by adding a specific indicator under each component that can measure the preparedness of this pillar to mitigate the impact of service failure magnitude and duration.

- Consider the limitations of this research mentioned previously (See Section 6.4), such as having more scenarios for each case study to widen the view of how to change the current practices and the expected results. Also, it is essential to address the uncertainty through sensitivity analysis even for the output of this research. This might see the light in a future publication.
- Converting the SWRM-AF into a digital platform, such as a website, is a viable approach to enhance and widen its application in the future. This concept can potentially advance the adoption of SWRM-AF within the water sector. Additionally, having a website can help produce different versions of SWRM-AF based on the application scale, which can be global, national, local, and community (or neighbourhood) scale. This idea can also help generate helpful feedback from users, which definitely would contribute to improving SWRM-AF. Keeping SWRM-AF open-source would be a logical and practical approach in this scenario.
- Combining another software with SWRM-AF can help provide a comprehensive view of the WRM. For example, integrating a Geographic Information System (GIS) could be valuable in presenting the results in more visual ways.

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Appendix A. List of Publications

1. Alsaeed, B. S., Hunt, D. V., & Sharifi, S. (2022). Sustainable Water Resources Management Assessment Frameworks (SWRM-AF) for Arid and Semi-Arid Regions: A Systematic Review. *Sustainability*, 14(22), 15293. Available at: https://www.mdpi.com/2071-1050/14/22/15293

Submitted but not published yet:

2. Alsaeed, B. S., Hunt, D. V., & Sharifi, S. (202X). A Sustainable Water Resources Management Framework (SWRM-AF) for Arid and Semi-arid Regions – Part 1: Developing the Conceptual Framework. *Sustainability*
3. Alsaeed, B. S., Hunt, D. V., & Sharifi, S. (202X). A Sustainable Water Resources Management Framework (SWRM-AF) for Arid and Semi-arid Regions – Part 2: refining the conceptual framework using the Delphi technique. *Sustainability*

Appendix B. List of Indicators in the Literature

Table B1. Collection of 170 indicators related to water use and management (Pires et al., 2017)

Indicator	Description
Water Poverty Index	Provides a better understanding of the relationship among the physical extent of water availability, its ease of abstraction and the level of community welfare. Evaluates 5 strategic elements: resource, access, management capacity, uses, and environment.
Climate Vulnerability Index	Links water resources with human vulnerability assessments, considering the following aspects: geographical vulnerability of the location, water resources available, access to water, how effectively water is used, capacity to manage water, and environmental impacts.
Water shortages	Represents the number of people and countries affected by water shortages, the number of countries unable to supply minimum drinking water.
Fraction of the burden of ill-health from nutritional deficiencies	Accounts for the percentage of the burden of ill-health resulting from nutritional deficiencies, attributable to water scarcity effects on food supply.
Water Reuse Index	Considers consecutive water withdrawals for domestic, industrial, and agricultural water use along a river network relative to available water supplies. A measure of upstream competition and potential ecosystem and human health impacts.
Water Footprint	The sum of water directly used and virtual water. Represents the amount of water required to produce the resources needed by one person, based on lifestyle and consumption.
Incidence of worms, scabies, trachoma, diarrhea	Represents the number of countries that have presented incidence of worms, scabies, trachoma, and diarrhea above predefined limits. Considers health problems in urban populations linked to contaminated water, lack of water supply, and sanitation.
Performance Index of Water Utilities	Accounts for the performance of water service providers in urban areas assessed in terms of affordability, quality of water supplied, accessibility to service, quantity of water supplied, and reliability. The level of performance of these utilities dictates how well the cities are being served.
Access to Improved Sanitation	Represents the proportion of the population (total, urban, and rural) with access to an improved sanitation facility (for defecating)
Proportion of Urban Population Living in Slums	Provides a measure for identifying the percentage of the urban population living in slums based on an assessment of the following several conditions: access to safe water, access to sanitation, secure tenure, durability of housing, and sufficient living area.
Social and Economic Impacts from Drought	Considers water-related disasters: number of drought and the socioeconomic losses associated with them
Incidence of cholera	Represents the number of cholera cases per region. The disease is linked to contaminated water and food and occurs more frequently where access to safe drinking water and basic sanitation cannot be ensured.
Causes of food emergencies Considers the causes of food emergencies:	Considers the causes of food emergencies: comparison between number of countries affected vs. human-induced disasters and number of countries affected vs. natural disasters.
Ecological footprint	The amount of land required to produce the resources needed by one person, based on land type (arable, pasture, forest, fossil energy land, built-up area, and water area) and consumption (food, housing, transportation, goods, services. and waste).
Progress towards achieving IWRM target	Categorizes countries into three groups based on ten specific criteria of Integrated Water Resources Management: 1) good progress and being on the road towards meeting the target; 2) only some progress; 3) hardly any progress made.
Water Provision Resilience	Provides a means of approximating the ability of a city or water provider to maintain or increase the portion of the population with access to safe water. Assesses six aspects: supply, finances, infrastructure, service provision, water quality, and governance.
Major drought events and their consequences	List of major drought events and their associated loss of life and economic losses in the last 100 years.
Relative Water Stress Index	Domestic, Industrial, and Agricultural water demand per available water supply. This indicator is also known as Relative Water Demand (RWD). RWSI = DIA / Q

Index of Non-sustainable Water Use	It is the result of renewable available freshwater resources (Q) minus geospatially distributed human water demand for Domestic, Industrial, and Agricultural (DIA). INSWU = Q - DIA
Water sector share in total public spending	Represents the percentage of the national budget spent in the water sector for expanding access to water supplies and improving water resources management and governance.
Country's dependence ratio	The relation between the surface and ground water that inflows from neighbouring countries (or other given geographic divisions) and the total amount of water available at annual bases.
Pro-poor and pro-efficiency water fees	Assesses the application of economic and financial tools in water allocation (fees and charges) favoring the poor (pro-poor policy) and efficient water use.
Water topics in school curriculum	Represents the number of countries (or other geographic division) that have introduced water-related content into school curricula.
Total water storage capacity	The total water storage capacity in artificial storage structures above a minimum size (e.g. 5000 m3)
Existence of legislation advocating Dublin principles for water (1992)	Existence of legislation in issues related to water sustainability and management, participatory approach, gender and economic value (is the baseline for IWRM)
Access to safe drinking water	The proportion of the population (total, urban and rural) with access to an improved drinking water source as their main source of drinking water.
Water use by sector	Water withdrawal by sector as a percentage of total water withdrawal
Burden of water-associated diseases (expressed in DALYs) with Comparative Risk Assessment	Total amount of DALYs related to water-associated diseases. In the poorest regions of the world, unsafe water, sanitation and hygiene are major contributors to loss of healthy life, expressed in DALYs (Disability Adjusted Life Years). The sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability. The Comparative Risk Assessment (CRA), aims to assess risk factors in an unified framework. It provides a vision of potential gains in population health by reducing exposure to a risk factor or a group of risk factors.
Risk reduction and preparedness action plans formulated	Existence of Risk Reduction Plans and preparedness actions implanted to face uncontrolled water-related climatic events (drought, floods, etc.).
Basin Water Dependency	Relation between the number of people that depend exclusively on internal renewable water resources and the total number of habitants.
Disaster Risk Index	Compares the average population exposed to water-related hazards with average annual deaths caused by these hazards. Risk is modelled using socio-economical parameters. Multiparameter equation.
Cooperation and conflict on Shared basins / aquifers	The number of events related to conflicts or cooperation in shared basins / aquifers. The WWDR, 2003 proposed to classify each event in a 15 levels scale that varies from the conflict side (formal war, extensive military acts, etc) to the cooperation side (water treaties, unification, etc)
Demand changes (sectoral) and distribution	Changes over time in the demand of water by sector (industrial, agricultural and domestic), expressed in annual growing.
Human Poverty Index: 5 indicators	HDI consists of three main components; longevity, knowledge and standard of living, and assesses these components as development.
Number of surface and groundwater users licensed according to the regulations	Number of licenses issued. May be further divided by total number of user.
Industrial use of water per capita	Annual amount of water used by the industrial sector divided by the number of inhabitants at a given region
Child mortality rates: deaths per 1,000 live births	Number of children (presented in relation to 1,000 live births) that died due to causes related to water provision, sanitation, drainage, waste removal and healthcare system (i.e. diarrhoea diseases, etc.).
Land cover profile	Distribution of the land cover in a given region according to categories such as: forest, cropland (irrigated and no-irrigated), grassland, wetland, urban area, etc.
Investment in debugging (cleaning up)	Annual budget for water quality programs, including proceedings in treatment and management of public water.
Groundwater development indicator	Indicates the groundwater abstraction as a percent of the groundwater recharge component (GAR) of the Total Actual Renewable Water Resources (TARWR). The quantity of groundwater resource used by major sectors (municipal, agricultural, industrial) depends on the groundwater recharge component (GAR) of TARWR.

Overharvesting – fisheries catch	Overharvesting and exploitation of depletes living resources in relation to the natural restore rate of the fish specie: impacts on biodiversity loss and ecosystem functions. Collapse of fisheries or dramatic decline
Budget allocation for water risk mitigation	Total amount of money allocated by public (and private sector, in some cases) each year to deal with water risk mitigation – compared to the total budget of the institutions.
Land converted to agriculture	Total forest are a per year converted to agricultural use. As forest land is changed to agriculture use, the products and services provided by that ecosystem (such as timber, water, wildlife, carbon storage, aesthetic beauty, etc.) are reduced/lost.
Knowledge Index (KI)	Average of the rankings of the performance of a country or region in three areas: education, innovation, and information and communications technology.
Metals in groundwater	Indicates the presence of hazardous substances in groundwater. Includes metals and metalloids: Arsenic, Cadmium, Lead and Mercury, naturally occurring and / or as result of human activities. It is an indicator of water quality for human consumption.
Population density	Number of people living per square Kilometre of the basin.
Water source distance from demand centre: > 8 km	Percent of the total population of a given area that its water supply comes from a source over 8 km far from the demand centre.
Water supply cost related to users I income	Annual cost of water supply paid by user divided by the total annual income of the user (applied to urban, industrial and agriculture uses).
Great natural catastrophes	List of major natural catastrophes: number of occurrences of floods, windstorms, earthquakes and volcanic eruption. NB, that lead to considerable human deaths and significant economic losses.
Water Policy accounts and statements	Existence of water policies-setting goals for water use, protection and conservation.
Pesticides in groundwater	Pesticide active substances, including metabolites and degradation and reaction products that are relevant. Indicator of pollution by agricultural activities
Average per capita food consumption	Per capita food consumption at global and developing country levels, and other specific regions. The indicator shows a global food security situation, and is used as the indicator of food intake.
Dependence of agricultural population on water	The Proportion of total population of a region using water irrigation technics (both traditional and modern) to enhance the productivity of agriculture or livestock enterprise.
Status of surface water bodies (in risk)	The indicator measures the risk level of not achieving the environmental objectives proposed by the institutions responsible for the management surface water bodies The indicator is calculated as the ratio of number of surface water bodies located in each of the four risk levels considered and the total number of surface water bodies in each river basin district or the national average.
Population exposed polluted water	Percentage of population exposed to several kind of pollutants (coliforms, industrial substances, acid, heavy metals, ammonia, nitrates, pesticides, sediments, salinization). Poor water quality affects both human health and ecosystem health.
Emissions of water pollutants by sector	Indicates the Biological Oxygen Demand (BOD) loads to waterways by sector (agriculture, house, hold, and, industry) as well as the nitrogen loads to waterways due to agriculture.
Groundwater as a percentage of total use of drinking water	The indicator expresses the present state and trends of surface water and groundwater use for drinking purposes.
Food production trends	Trends in food production: increase in annual production. It is relevant to remember that the amount of water involved in food production is significant.
Investment in water management	Annual budget for management actions and water infrastructure.
Ratio of actual to desired level of public investment in water supply	Ratio of actual to desired level of public investment in water supply.
Access to electricity rural and urban coverage for the whole world	Rural and urban households with access to electricity for each country. Access to electricity is a prerequisite for economic and social development and in some case to access water (pumps, etc).
Percentage of Health Impact Assessments (HIA) of water resources development and compliance with HIA recommendations	Definition – HIA is a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population

Productivity in terms of jobs per m^3	Number of jobs generated in irrigated agriculture and industry by each m3 of water abstraction.
Ammonium in groundwater	Indicates the amounts of ammonium ions present as a result of human activities. It is an indicator of water quality for human consumption.
Existence of participatory framework and operational guidelines	Existence of participatory framework for the management of water including operational guidelines to its implementation and follow-up.
Amount of underwater or wetland area placed into protected management, including the establishment of no fishing zones	Amount of underwater or wetland area placed into protected management, including the establishment of no fishing zones.
Existence of water quality standards, for effluent discharges, minimum river water quality targets	Indicates the existence of water quantity and quality standards
Mining waste pools	This indicator estimates the influence of mining waste pools that contamine water depending on the productive sector (PS), potential storage (PS), permeability (P) and water table depth (WTD). The pressure is significant if the indicator presents values greater than 5.
Percentage of compliance of the wastewater treatment plant with current regulations	The indicator is calculated by the ratio of the number of wastewater treatment plants that meet compliance criteria established by the legislation (pollution load expressed in population equivalents) and the total number of wastewater treatment plants existing.
Naturally occurring inorganic contaminants fluor and arsenic	Percentage or contaminated water sources and number or people exposed through drinking water supply by naturally occurring inorganic pollutants (Fluor and arsenic) as a critical determinant of chemical contamination of drinking water.
Intensive crop area	Total agricultural area for the production of crops considered intensive due to their higher water needs. Cropping intensity is estimated as total crop area divided by total cultivated area.
Restoration schemes	Existence of restoration schemes/projects focused on freshwater and coastal ecosystems degradation issues.
Nutrition productivity	Total generation of food products generated by agriculture (calculated in calories or other nutritional indicator) divided by the total abstraction of water for irrigation.
Total investment (private, state, development agencies) in irrigation and drainage	Total investment (private, state, development agencies) in irrigation and drainage, expressed in millions dollars.
Water availability per capita	Percentage of the world's water resources that a region has divided by the world's population (in %) living in that region.
Uptake of strategies/legislation for environmental protection	Use of adequate strategies/legislation for environmental protection.
Crop Area	Agricultural area used for crop production or pasture.
Proportion of water pollution permit holders complying with permit conditions.	Number of monitoring visits with water quality samples not complying with established conditions divided by the total number of visits.
Crop-Water Productive Index	Amount of water required per unit of yield. It is a vital parameter to assess the performance of irrigated and rainfed agriculture. Crop water productivity will vary greatly according to the specific conditions under which the crop is grown.
Fish consumption (marine, inland and aquaculture)	Average consumption of fish from different sources (marine, inland and aquaculture).
Water used for irrigation	Annual amount of water used in irrigation systems. It can bee classified by source (groundwater and surface), by system type (surface irrigation, spate irrigation, sprinkler irrigation, drip irrigation, local water harvesting, etc), among others classifications.
Consumption of livestock food products	Consumption of food from livestock including meat (beef, pork, poultry), vegetables, crops, dairy products, eggs, milk, etc.
Density hydrological monitoring stations	Number of hydrological observing/monitoring stations in a given region / country.

Index of groundwater explotation	Percentage of extracted groundwater per year in relation to the total volume of the aquifer. Pressure is considered significant when the total groundwater extraction exceeds 20% of resources allocated.
Urban Water and Sanitation Governance Index	It is a combination of the fowling 4 indicators. Percentage of departments establishing programme monitoring water and sanitation coverage. Percentage of councils that provide for external audit of the departments. Percentage of departments meeting water quality standards. Percentage of departments with improved public quality control of the service provided.
Groundwater depletion	Is calculated as the total area with groundwater depletion problem (means the area in which regional level decline is observed resulting from excessive exploitation of groundwater) divided per the total area of studied aquifer.
Groundwater usability with respect to treatment requirements	Usability of abstracted groundwater that is publicly distributed with respect to treatment requirements.
Wetlands: % threatened	Percent of threatened wetlands due to pressures from agriculture, settlements, urbanization and other land uses.
Reduced releases of pollution to groundwater recharge zones	Reduction of the amount of pollutants discharged to groundwater recharge zones.
Index of groundwater abstraction	Evaluates the recharge-discharge aquifer balance and therefore the sustainability of exploitation. The threshold considered is Ind abs > 40%.
Nitrate in aquifers	The indicator measures the concentration of nitrate in groundwater in mg/l. It is an indicator related to the pressure from farming activities and the chemical status of groundwater. High concentrations of nitrates in surface water and groundwater may affect its fitness for potable uses.
Renewable groundwater resources per capita	Total amount of groundwater resources (m3 per year) per capita at a national, regional or natural (aquifer, basin) level that comes from a renewable source.
Groundwater vulnerability	The concept of groundwater vulnerability is based on the assumption that the physical environment (the soil properties, lithology and thickness of the unsaturated zone and groundwater level) provides some degree of protection to groundwater against natural influences and human impacts.
Percentage of undernourished people	Percentage of people not having access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.
Disability-Adjusted-Life Year (DALY)	Is a summary measure of population health, integrating mortality with morbidity and disability information in a single unit. Is an indicator of the time lived with a disability and the time lost due to premature mortality.
Area of wetland drained	Transformations of wetlands due to human uses: area of wetland drained
Trends in freshwater habitat protection	The percentage of area of different types of freshwater habitat set aside for protection.
Food imports/exports between regions	Amount of food imports/exports for individual countries and between regions The indicator shows the difference between production and consumption and also the virtual water flow between regions.
Groundwater quality	This indicator can be applied to both natural and anthropogenic contamination, as presented below: A) For natural quality contamination: Relation between the total area of aquifers with groundwater natural-quality problem divided by the total area of studied aquifers; B) for anthropogenic contamination: Relation between the total area with increment of concentration for specific parameter divided by the total area of studied aquifers.
Non-point source pollution programs implemented (area treated with best management practices; kg reduced)	Area treated with best management practices as a result of implemented nonpoint source pollution programs The goal of these programs is to minimize nonpoint source pollution from new land use activities and to reduce pollution from existing activities.
Number of dams in basin and in main stem of river	Number of large and major dams in each basin.
Discharges to groundwater	Includes waste water and cooling water discharge in aquifers. Moreover, landfill underground pollution: storage of CO2 and brine. Direct discharges are a important source of point pollution of groundwater.
Water table	The steady decline of water table (in free water aquifers) or the level of groundwater in confined aquifers, are the main impact indicator of excessive water extraction.
Runoff: % used by humans	Relation between the total annual abstraction of water and the total annual runoff at a given basin.

State Hydrological index	This indicator provides information on hydrological drought resulting from the rainfall deficits. The hydrological drought may lead to periods of scarcity.
Mentions of water in international agenda,CC, WB, GEF, WSSD	Number of times that water issues appears in the main international agenda – i.e. Climate Change negotiation, UN initiatives, GEF projects, World Bank activities, World Summit on Sustainable Development, etc.
Loss of original forest	Indicates the difference between the original forest extent and the current forest extent.
Total Actual Renewable Water Resources (TARWR)	TARWR = (External inflows + Surface water runoff + Groundwater Recharge) (Overlap +Treaty obligations).
Increased stakeholder awareness and documented stakeholder involvement in water use decisions	Evaluates how is the stakeholders awareness and documented involvement in water uses decisions.
Agricultural water use (by country)	Annual amount of water (including irrigation and green water – rainfall, snowfall, etc) used by the agricultural sector. It is usually compared to industrial and domestic use (expressed in %).
Water lending for irrigation and drainage	Annual amount of water lending for irrigation and drainage and costs associated.
Formation and empowerment of regulatory or other institutions	Formation/creation and empowerment of regulatory institutions to control / monitor the use of water resources and the protection of the ecosystems.
Existence of institutions responsible for water management, that are independent of sectorial water users.	Existence of institutions (water resources authorities) responsible for water management (including issuing abstraction and discharge licenses), that are independent of sectorial water users (irrigators associations, etc.).
Private sector involvement and stakeholders responsibility established and implemented	Existence of legal framework and local capacity to promote / regulate the involvement of private sector and stakeholders responsibility in the management of water resources.
Asset ownership properly defined	Existence of legal framework to asset ownership in order to have water rights properly defined.
Unaccounted for Water (Water Losses)	Unaccounted-for-Water (UfW) is the difference between the water delivered to the distribution system and the water sold. It has two basic components: physical losses, such as water lost from pipes and overflows from tanks, and commercial losses, which include water used but not paid for.
Water Productivity	Economic value generated per cubic metre of water withdrawn by sector / user
Existence of law for judicious distribution of water	Existence of laws for determining equitable allocation of water – defining the rules needed to achieve policies and goals.
Water Availability index (WAI)	This index is used to forecast water availability in the short term (i.e., days). It combines water quantity and quality data, evapotranspiration, soil moisture, and surface water and ground water flux information into no parameterized variables in mathematical formulations. Water quality is based on the calculation of another index called Potential Use Index, which enables one to classify the water in terms of its measured quality and to determine its suitability for a defined use.
Price of water charged to farmers for irrigation	Cost of using irrigation water to farmers compared with their incomes.
Sources of Contemporary Nitrogen Loading	Total and inorganic nitrogen loads as deposition, fixation, fertilizer, livestock loads, human loads and total distributed nitrogen to the land and aquatic system.
Salinization in groundwater	The conductivity is used as a parameter indicative of saline and is an indicator of total dissolved ions. The increase in salinity often indicates the presence of discharges, overexploitation of the aquifer or seawater intrusion or inland saline aquifers, due to changes in flow by exploitation.
Percentage of poor people living in rural areas	Number of poor people living in rural areas (RPP) / Total population (TP).
Prevalence of underweight children under five years of age	Percentage of children under five years old whose weight-for-age is below minus two standard deviations from the median of the NCHS/WHO reference population.

Withdrawals: % of total annual renewable freshwater	Relation of the total annual abstraction of water and the total annual renewable freshwater (both superficial and groundwater).
Area of arable land (whole world)	Amount (expressed in million hectares) of arable land in the world in relation to population (arable land per person or hectares per 100 inhabitants).
Rate of recovery	Measures water fees actually collected as percent of the total collectable charges billed by the water utility.
No. of water resource scientists	Number of scientists that develop research on water related themes.
Biological water quality (based on community response)	Biological water quality indicators provide a complementary measure to chemical water quality and are useful in assessing intermittent pollution or impacts of unknown contaminants.
Prevalence of stunting among children under five years of age	Percentage of children under five years old whose height-for-age is below minus two standard deviations from the median of the NCHS/WHO reference population.
Artificial induced recharge	Volume of resources available artificially introduced into aquifers by irrigation returns or by reversing the flow (of the river to the aquifer) due to intensive exploitation of groundwater.
Capability for hydropower generation	Gross theoretical capability of hydropower generation, technically exploitable capability and economically exploitable capability.
Mortality rate of children under-five years of age	Probability of dying between birth and exactly five years of age expressed per 1000 live births.
Volume of desalinated water produced	Volume of desalinated water produced per year
Mechanisms for sharing within country (allocations/priorities) both routinely and at times of resource shortage	Existence of legal / institutional mechanisms for sharing water within country (allocations / priorities) both routinely and at times of resource shortage.
Extent of land salinized by irrigation	Area of soil salinized by irrigation as a percentage of total irrigated land.
Compliance with water quality standards for key pollutants	Number of rivers / aquifers that meet water quality standards for key pollutants.
Drinking Water Quality	Share of samples failing drinking water quality standards in the total number of drinking water samples.
Fragmentation and flow regulation of rivers	A complex calculation of the negative impact on ecosystems of altering waterways by dams, water transfers and ca
Ecological Flow	Percent of actual flow of a river in relation to the estimated ecological flow.
Biological assessment (perturbation from reference condition)	In biological assessment, reference conditions are established by identifying least impaired reference sites, characterizing the biological condition of the reference sites, and setting threes holds for scoring the measurements. The basic procedural steps for biological assessment are as follows: 1. Sample the biological groups (assemblages) selected by the program; 2. Calculate chosen metrics using relative abundance and other measurements; 3. Compare each to its expected value under reference conditions and assign a numeric score; 4. Sum the scores of all metrics of an assemblage to derive a total score for the assemblage; 5. Compare the total score to the biological criterion based in part on the expected total score under reference conditions.
Compliance with environmental objectives. Status of groundwater bodies	According to the pressure and impact analysis, this indicator evaluates the risk of ground water bodies failing to achieve the environmental objectives in a specified period.
Institutional strengthening and reform (post-1992)	Existence of institutional strengthening and reform of national / regional water management model for the implementation of IWRM and Dublin principles.
Percent of protected area	Percentage of protected area divided by the total of a given area.
Per capita food consumption (and its broken down into cereals, oil crops, livestock and fish)	Average per capita food consumption per year (and its breakdown into categories: cereals, oil crops, livestock, fish, etc.).
Defined roles of government (central and local)	Existence of legal framework that defines with clarity the roles of central and local governments to manage water resources.

Irrigated land as percentage of cultivated land	Area under irrigation as a proportion of total cultivated land.
Relative importance of agriculture in the economy	The share of the country's GDP derived from agriculture.
Trends in ISO 14001 certification	Number of companies receiving ISO 14001 certification per the total number of companies
Access to information, participation and justice	Proportion of countries with strong, intermediate or weak access to information, participation and justice. (to water related themes).
Organic pollutants load	Concentrations of the follow organic pollutants: COD: chemical oxygen demand; NH4N: ammonium; PAH: polycyclic aromatic hydrocarbons; DEHP: diethylhexylphthalate; EE2: ethinylestradiol; E2: estradiol; EDTA: ethy-lenediamine tetraacetic acid.
Climate Moisture Index (coefficient of variation)	CMI is a statistical measure of variability in the ratio of plant water demand to precipitation. It is useful for identifying regions with highly variable climates as potentially vulnerable to periodic water stress and/or scarcity.
Importance of groundwater for irrigation	Percentage of land under irrigation relying on groundwater
Seawater intrusion in groundwater	The indicator measures the concentration of chloride in mg / l in groundwater. It is a status indicator that measures the degree of salinization of coastal groundwater bodies due to seawater intrusion and its suitability for different uses such as drinking or irrigation water.
Area equipped for irrigation vs. total arable land	Percent of the arable land that is equipped for irrigation (by country or geographical division).
Biological contaminants (E. coli/thermotolerant coliform)	Presence of biological contaminants in water (E. coli/thermotolerant coliform) Escherichia coli and thermotolerant coliforms are of major importance as indicators of fecal contamination of water.
Proportion of water allocation permit holders complying with permit conditions	Number of monitoring visits not complying with conditions divided by the total number of visits.
Organic pollution emissions (BOD) by the industrial sector	Proportion of organic water pollution (calculated in BOD), generated by industrial sector.
Numbers or presence/absence of non-native (alien) species	Is an indicator that evaluates the ecosystem condition by measuring the number of introduced species, focusing on aquatic species (e.g. fish, molluscs, benthic organisms, plants).
Number of endemic fish	Total number of fish endemic species in a river basin. This indicator should be taken as general indicator of fish diversity.
Areas covered or half covered in water	Percentage groundwater mass: area covered by humid, swampy, or intertidal zones, lakes, lagoons, reservoirs, coastal lagoons, estuaries, seas and oceans.
Impact of Sediment Trapping by Large Dams and Reservoirs	This indicator evaluates the residence time of water held in large reservoirs, sediment trapping efficiency of large reservoirs and determinates how many years takes to full-fill a reservoir with water transported sediment.
Freshwater species population trends index	A measure of change and trends in the populations of freshwater species.
Head of cattle	Number of head of cattle (cattle, sheep, swine and goats).
Use of water in thermal towers and competition with other uses	Total annual amount of water used in thermal towers. It is usually compared with others industrial uses (presented in percent).
Number of Amphibian Species	Number of Amphibian Species in each basin. Amphibians are a sensitive biological indicator of environmental quality.
Ministerial statements mentioning water	Number of ministerial statements that mention water.
Nivale reserve	Volume of water stored as snow.
Biological oxygen demand (BOD)	Biological oxygen demand (BOD)
Water impounding reservoirs (dams): supply volume m3 per year	Water impounding reservoirs (dams): supply volume m3 per year

Table B2. Global indicators belong to SDG6 (UN-Water, 2021)

Indicator number	Description
6.1.1	Proportion of population using safely managed drinking water services
6.2.1a	Proportion of population using safely managed sanitation services
6.2.1b	Proportion of population with a handwashing facility with soap and water available at home
6.3.1a	Proportion of household wastewater flow safely treated
6.3.1b	Proportion of industrial wastewater flow safely treated
6.3.2	Proportion of bodies of water with good ambient water quality
6.4.1	Change in water-use efficiency over time
6.4.2	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5.1	Degree of integrated water resources management implementation (0–100%)
6.5.2	Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6.1	Proportion of river basins showing high surface water extent changes
6.a.1	Amount of water- and sanitation-related official development assistance (ODA) received
6.b.1	Number of counties (or areas) with a high level of participation by users/ communities, across sectors

Table B3. Main Key Performance Indicators and Targets of the GCC UWS (Al-Zubari et al., 2017)

No.	Description	Target
1	Desalination capacity manufactured/owned locally to total desalination capacity in GCC countries	10% by 2035
2	Share of renewable energies in the water sector in each GCC country (based on set targets by GCC countries for renewable energy; COP21, SDGs)	10% at least by 2035
3	Collected wastewater to municipal water supply in each GCC country	60% by 2030
4	Reused treated wastewater to total treated in each GCC country	90% by 2035
5	Physical leakage in the municipal distribution network in each GCC country (weighted average of all regional utilities in the country)	10% maximum by 2035
6	Per capita water consumption it the municipal water sector (calculated after deducting the physical leakage)	250 L/capita/d maximum by 2035
7	Average irrigation efficiency in each GCC country	60% minimum by 2035
8	Development of national integrated emergency preparedness plan in each GCC country	By 2020
9	Establishment of a joint GCC water grid committee under the umbrella of the GCC General Secretariat	By 2017
10	Implementation of bilateral gridding between neighboring countries based on the results of comprehensive studies	By 2025
11	Conducting project study for the "General GCC Water Grid"	By 2030
12	Existence of a unified tariff framework and guideline for water sources and uses in the GCC countries	By 2018
13	Cost recovery of water supply utilities	100% of operation and maintenance costs by 2025, and 100% of total costs by 2035