Chapter 4
Water Security in Saudi Arabia

Khalid G. Biro Turk and Faisal I. Zeineldin

Abstract Water is critical for economic and social development in Saudi Arabia (KSA). It is essential to meet basic human needs, manage the environment, and sustain economic growth. However, despite the water scarcity and importance, the KSA faces severe challenges due to the unsustainable use of water resources. This chapter aims to comprehensively analyse water status in KSA concerning water resources, uses, security, policies, regulations, technologies, and prospects. The collected data used in this study were mainly from the published reports by the KSA Ministry of Environment, Water and Agriculture (MEWA). Also, the study analysis benefits from the most recent literature covering different water sector disciplines in KSA and similar regions. Based on the current status of water resources in KSA, the study suggested a conceptual framework which can be used to implement the water sector strategy established by the MEWA. The framework can set the problems, aims, procedures, services, action plans, and system monitoring for the water sector in KSA.

Keywords Policies and regulations · Saudi Arabia · Sustainability · Water sector · Water uses · Water security

1 Introduction

Water is vital for agriculture but also for industrial and tourism, social life, and nature conservation (Hussain et al. 2019). Water resource management in the twenty-first century faces complex problems as it is the most crucial resource for producing food

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and represents the essential central resource for humankind throughout human history (Ma and Gourbesville 2022). However, in arid and semi-arid regions, the management of water resources gets worse due to water scarcity, accessibility, irregular rainfall patterns, and high evaporation rates. Also, climate change can affect water availability in these regions through changes in the natural water resources process (Rajmohan et al. 2019).

The KSA covers a land area of ~ 2.25 million km^2 (Fig. 1), and the population increased from 25 million in 2007 to about 33 million in 2018, with an average annual growth rate of 3%. (Mumtaz et al. 2019; Alkhudhiri et al. 2019). The economy of the KSA depends mainly on oil, which covers ~ 90% of foreign export earnings and accelerates comprehensive development coupled with population growth and living standards (Chowdhury and Al-Zahrani 2015).

The major part of the KSA is arid, while the coastal strip along the Red Sea is a semi-arid climate. The rainfall in the southwestern part of the country is around 300 mm year^{-1} due to the southwest monsoon. However, the annual rainfall in the rest of the country is about 100 mm year^{-1} (Chandrasekharam et al. 2017). The dominant arid climatic conditions in the KSA make water resources management rather difficult. However, managing and developing water resources in the KSA are essential for sustaining population growth and growing the country's agricultural, industrial, and tourism sectors (Fallatah 2020). Groundwater is the KSA's primary water source for agriculture and human activities (Algaydi et al. 2019). Nevertheless,

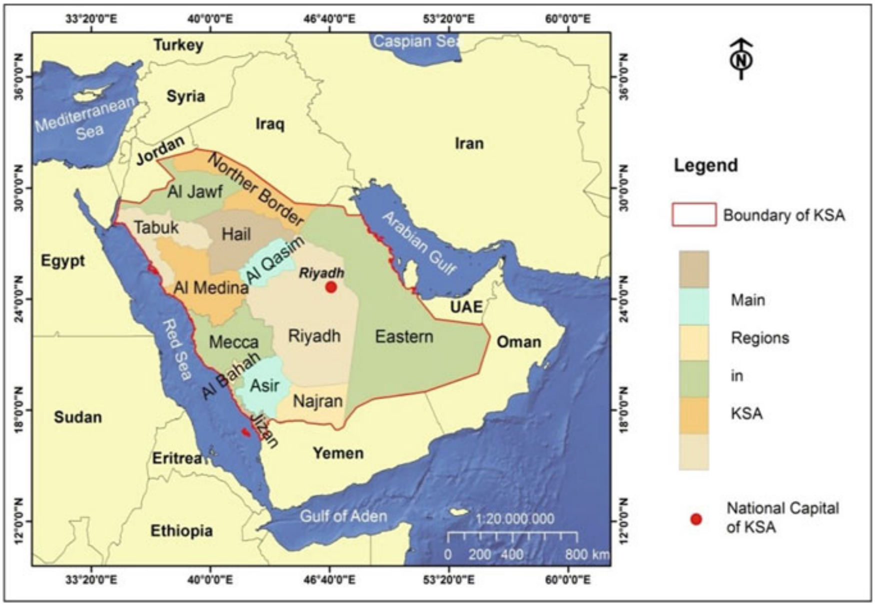

Fig. 1 Geopolitical location of Saudi Arabia. *Source* The map production was by the Water studies Center, KFU, in 2020

the over-exploitation of its current usage could be more sustainable and increases the potential threat to groundwater quality (Fallatah 2020).

In this chapter, we comprehensively analyse the water status in KSA, including water resources and uses, irrigation methods and techniques, water security, policies and legislation to water use in agriculture and current technologies for improving water utilisation. Also, an attempt was made to analyse the prospects of the water situation concerning use and scarcity.

2 Water Resources

The KSA water resources are categorised into conventional (surface water, renewable and non-renewable groundwater) and non-conventional (desalinated seawater and reclaimed urban water).

2.1 Conventional Water Resources

Water is vital to basic human needs, environmental management, and economic growth. However, conventional water resources in the KSA are limited and challenged by deficient precipitation, i.e. the annual average rainfall is 59 mm; harsh climactic conditions, i.e. in summer, the temperature can reach 55 °C; population growth; and extensive uses of the agricultural sector (Ghanim 2019). These challenges have affected the sustainability of water resources and degraded renewable and non-renewable freshwater resources. In addition, it can negatively impact the country's environment and economy. Therefore, the vision of 2030 has provided opportunities to enhance water use efficiency in the agricultural sector and reduce the annual extraction from non-renewable water resources. For instance, due to the implementation of the National Water Strategy, the annual extraction of non-renewable groundwater dropped to 15.5 BCM in 2019 and to 13.8 BCM in 2020 (MEWA 2020).

2.1.1 Surface Water

The KSA is devoid of natural permanent rivers or lakes. The surface water represents the torrents and floods resulting from rainfall and what go from it in reefs and valleys. Surface water runoff into valleys and down streams occurs whenever a powerful storm occurs in upper stream drainage basins. Most of the torrents and rainwater are in KSA's western and southwestern regions. A study of rainfall data over 64 years indicated that the average annual rainfall in KSA ranged from 4 to 300 mm (Amin et al. 2016). The western and southwestern regions had the highest mean annual rainfall, 300 mm year^{-1}, while the north-western and south-eastern parts had the

Fig. 2 King Fahad Dam in Wadi Bisha of Jizan region built in1997. *Source* Water studies Center, KFU in 2003

lowest, 4–50 mm year^{-1}. The occurrence of rainfall in KSA is scarce and highly varied from year to year. In Al-Qasim, in the country's central region, the rain was 37.2 mm in 2017, while it was 292 mm in 2018 (MEWA 2017; MEWA 2018). The flash in the southwestern mountainous regions is infrequent (Abu-Rizaiza and Allam 1989).

The total number of constructed dams in 2020 in the KSA reached 532 (MEWA 2020), of which 51% have been located in the western and southwestern regions of (Mecca, Asir, Jizan, Al Bahah and Najran) with a total storage capacity of about 2.0 billion cubic meters (BCM). The primary purposes of the dams are to harness surface water, control floodwater, provide drinking water for cities and divert water for agriculture (Baig et al. 2020). For example, the King Fahad dam (Bisha dam), as shown in Fig. 2, is a big dam in the Kingdom with a storage capacity of 325 MCM (FAO 2009). Its primary purposes are flood control, municipal water supply, irrigation, and groundwater supply recharge.

2.1.2 Renewable Groundwater

The Renewable Groundwater represents floods and surface runoff that naturally replenish sediments of valleys and discoveries and eventually recharge shallow alluvial aquifers in KSA. The alluvial aquifers are unconfined aquifers of a thickness that infrequently surpasses 100 m, with an average width of about 1 to 2 km and a length that could run up to 10 kms (Omar and Mohamed 1989; Fallatah 2020). Their mean annual recharge is 900 Mm^3. About 80% of it occurs in alluvial aquifers of the western and southwestern regions, representing 10% of the country area. The mean annual surface runoff was estimated to be about 2000 Mm^3, 30% redirected for agriculture, 45% infiltrated for recharging the groundwater aquifers, and 25% lost by evaporation (Omar and Mohamed 1989; Fallatah 2020). The alluvial renewable groundwater resources usually are used for municipal and agricultural purposes.

2.1.3 Non-Renewable Groundwater

The non-renewable groundwater characterizes a humongous amount of fossil water formed thousands of years ago in deep confined aquifers at depths of 150–1500 m (FAO 2009). Numerous studies indicated that the fossil groundwater in KSA is stored in seven major consolidated sedimentary old-age aquifers: Saq, Wajid, Minjur, Dhruma, Wasia, Umm Er-Radhuma, and Dammam (Abdulrazzak 1995; FAO, 2009; Chowdhury and Al-Zahrani 2015). Most deep confined aquifers are located in KSA's eastern and central regions. The water reserves estimate of the non-renewable groundwater aquifers of the KSA were shown to be 259–761 BCM, with a limited effective annual recharge rate of 2.4 BCM (Chowdhury and Al-Zahrani 2015; Fallatah 2020). However, the FAO (2009) indicated that the reserve estimate in the KSA is 253 BCM as a proven resource, 405 BCM as a probable resource, and 705 BCM as a possible resource. This is because the agricultural and industrial activities in KSA mainly depend on the fossil water of the deep aquifers. Table 1 shows details of the deep confined aquifers in the country.

2.2 Non-Conventional Water Resources

2.2.1 Desalinated Seawater

The KSA leads the world in producing desalinated seawater for public use. Its production capacity is 51% compared with Arabian Peninsula countries and 19% with global countries (Abdulrazzak 1995). However, the KSA's natural water resources are limited and cannot meet the urban water demand (Ouda et al. 2018). By 2020, the Saline Water Conversion Corporation (SWCC, 2023) reported 32 desalination production systems on the eastern and western coasts. In 2020, the total freshwater production reached 1.9 BCM, of the daily production of 5.9 MCM of desalinated water. The eastern coast plants were set to supply desalinated water to Riyadh and Al-Qasim cities. In contrast, the western coast plants were to supply holy Mecca, Jeddah, Al-Medina, Tabuk, Abha, Asir and Jizan regions (SWCC 2014). The SWCC annual report of 2016 showed that 58.4% of the desalination seawater diverted to the KSA cities comes from the east coast while 41.6% from the west coast. As

Table 1 Deep fossil aquifers in the KSA

Aquifer	Location	Proven reserve (BCM)	Probable reserve (BCM)	Possible reserve (BCM)	Depth (m)	Water quality (ppm)	Yield (l/s)
Saq	Tabuk	65	100	200	2000	< 1000	Tabouk (9–28), Hail (13–19), Al-Qasim (10–110)
Wajid	Najran	30	50	100		< 1000	Wadi Aldawasir (10–100)
Minjur Dhruma	Riyadh	17.5	35	85	1200–1500	1200–15,000	
Wasia	Riyadh	120	180	290		15,000	
Umm Er-Radhuma	Hraad	16	40	75	240–700		4–32
Dammam	Salwa	5	5	5	80	< 1000	

BCM = billion cubic meter; ppm = part per million or mg per liters; l/s = liter per second
Source Water Atlas (1995) and Chowdhury and Al-Zahrani (2015)

shown in Fig. 3, the annual productivity of desalination seawater increases annually with a variable rate of 5.8–13.3% to meet the demand increase for freshwater in the country's growing cities. The production of desalination seawater developed from 997 MCM in 2012 to 1.4 BCM in 2016 (SWCC 2016). All the freshwater produced by the SWCC is directed to municipal uses, representing 63% of total demand and 37% from renewable and non-renewable groundwater (MEWA 2018).

2.2.2 Reclaimed Urban Water

Treated sewage water (TSW) is an essential alternative water resource for reuse in the agriculture sector in KSA. Also, it can alleviate the pressures of pumping groundwater for irrigation purposes.

Due to the limitation of water resources, many countries across the Globe resumed reusing TSW for agriculture; landscaping and industrial cooling purposes (FAO 2009). Although the Kingdom has a high capacity of TSW, a fraction of it is being diverted for reuse in the agriculture or industry sectors. The rest of the sewage water is dumped into the Red Sea or Arabian Gulf (Chowdhury and Al-Zahrani 2015). Ministry of Economic and Planning (MOEP) reported that the production of TSW in KSA increased with an annual rate of 9.3% from 2004 to 2008, while the reclaimed quantity in 2008 was 730 MCM (MOEP 2010). However, the statistical book of the Ministry of Environment, Water and Agriculture (MEWA 2018) reported that the Kingdom established 91 sewage-treated plants across the country with a yearly

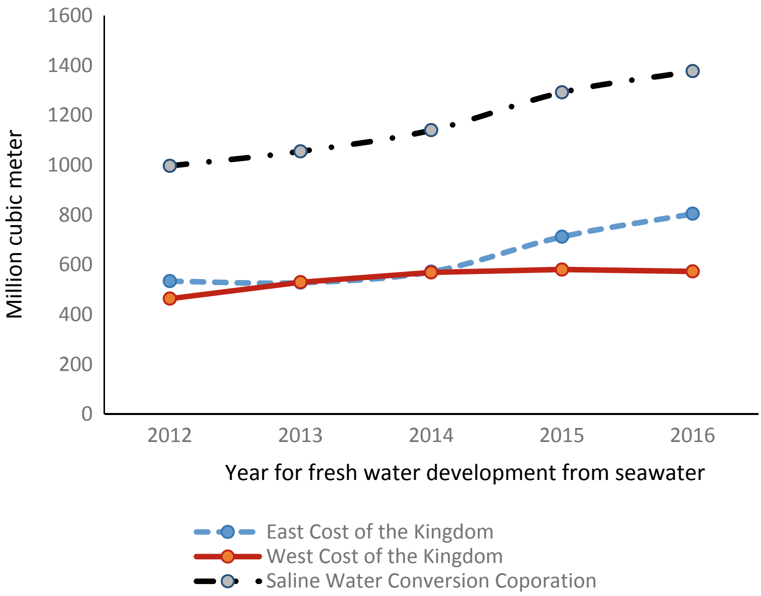

Fig. 3 Development of desalination seawater production in KSA (2012–2016). *Source* SWCC (2016)

production of 1.7 BCM. The highest producer regions in the KSA for TSW, respectively, were Riyadh (480.1 MCM), holy Mecca (431.3 MCM), Eastern (404.3 MCM) and Al Medina (128 MCM).

3 Water Uses

The total water demand in the KSA rapidly increased from 17,447 MCM in 2010 to more than 25,990 MCM in 2018 (Fig. 4). However, information on water use between 2010 and 2018 shows high demand in the agricultural sector compared to municipal and industrial sectors (Table 2).

Based on data shown in Table 2, the annual agricultural water demand was 6 times higher than the municipal one during 2010–2018 since there was an embargo on water consumption by the agricultural sector (Chandrasekharam et al. 2017).

Irrigated agriculture utilises almost 82–83% of the demanded water in KSA between 2010 and 2018. The water consumption for the different agricultural products in 2016 (Fig. 5) indicated that alfalfa and dates are the dominant water users in the KSA (Baig et al. 2020).

The municipal water quantities show spatial disparities in KSA, ranging from a minimum of 31 MCM in Najran to a maximum of 1027 MCM in Riyadh (Fig. 6). About 85% of municipal water was consumed domestically, while the remaining

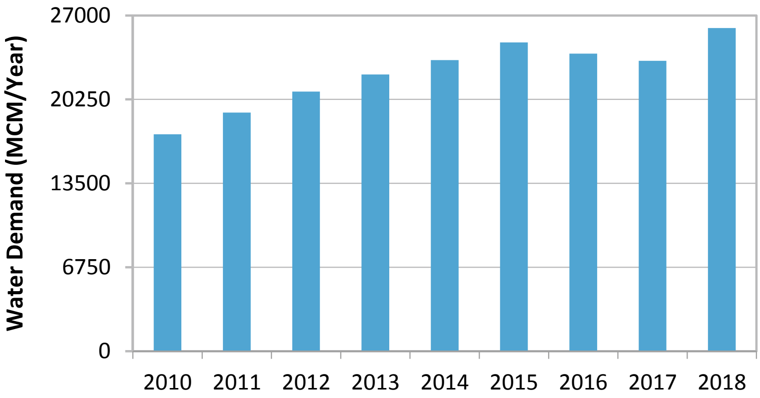

Fig. 4 Total water demand in KSA during 2010–2018. *Source* MEWA (2018)

Table 2 Annual water demand for the main sector in KSA (MCM)

Sector	Years								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Municipal	2284	2423	2527	2731	2874	3025	3130	3150	3392
Industrial	753	800	843	890	930	977	1015	1000	1400
Agricultural	14,410	15,970	17,514	18,639	19,612	20,831	19,789	19,200	21,200
Total	17,447	19,193	20,884	22,260	23,416	24,833	23,934	23,350	25,992

Source MEWA (2018)

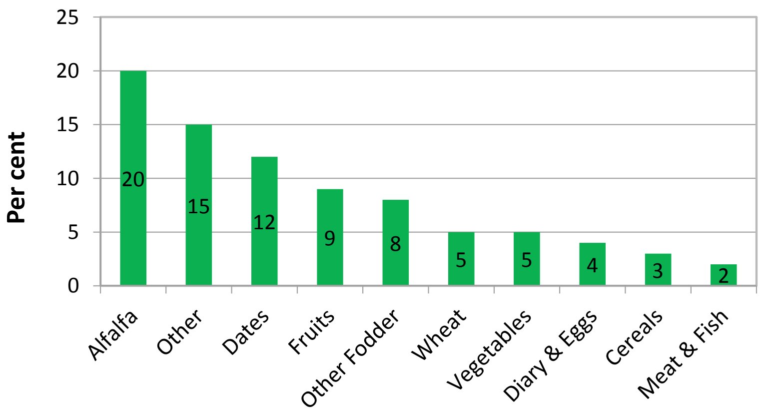

Fig. 5 Agricultural water use in 2016. (Adapted from Baig et al. 2020). Dates were excluded from fruits and wheat from cereals. Other uses indicate pesticide and fertilizers applications and the leaching requirements

15% was commercially used. Baig et al. (2020) estimated the average per capita water use at 97 m^3 $year^{-1}$ in 2017 in KSA.

Industrial water uses have increased from 753 to 1400 MCM between 2010 and 2018, an increase of 7.5% (Table 2). Also, KSA consumes over 1600 million m^3 $year^{-1}$ of water for producing crude oil (Sakhel et al. 2013). Moreover, industrial water use is projected to increase by 50% in the coming 15 years (Baig et al. 2020) due to the rapid growth of intensive industrial water uses like petrochemicals, fertilisers, mining, cement, steel, and food production (Ouda 2014b).

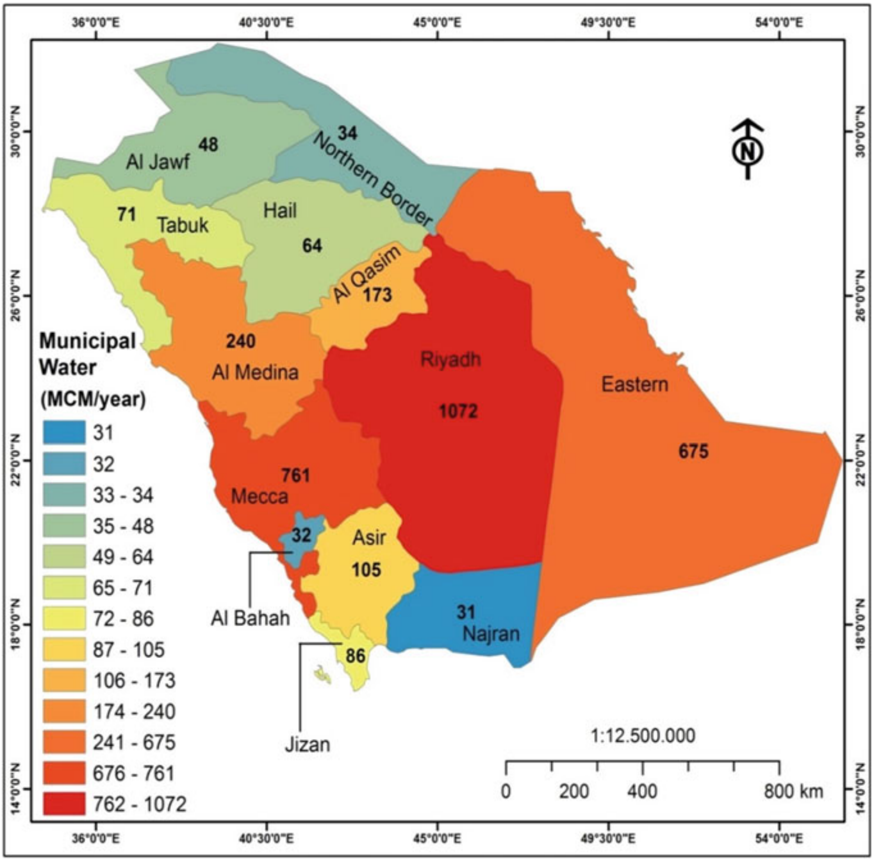

Fig. 6 Municipal water demand for the different regions in KSA during 2018. *Source* MEWA (2018). The map production was by the Water Studies Center, KFU, in 2020

4 Irrigation Methods and Techniques

4.1 Conventional Irrigation Methods

In the early 1900s, most irrigation methods were surface irrigation, done by flooding the land with water. The driving force of the water flow is gravity; henceforth, gravity flooding was used as an alternative term (Hart et al. 1980). Water was initially allowed to spill over rivers or artesian springs to flood the adjacent land; the method was called uncontrolled flooding. In the eastern region of the KSA, before the 1950s, uncontrolled flooding was practised nearby the hot springs (Euons) of Al-Ahsa oasis (Fig. 7). Later, the uncontrolled flooding methods evolved into controlled flooding methods such as basin, border and furrow surface irrigation. In the Kingdom, flooding methods have been used to irrigate date palm trees, citrus trees, vegetables and cereals crops. However, due to inadequate management of irrigation water using flooding methods has resulted in excessive water losses and tail-water runoff (Turbak and Morel-Seytoux 1988). Since sandy soils of high infiltration rates dominate most of the irrigated agricultural regions of the KSA, flooding methods with current severe water scarcity status are not recommended.

4.1.1 Uncontrolled Flood Irrigation Method

It was a kind of surface irrigation in which croplands were irrigated regardless of the low water use efficiency or uniformity (Walker 1989). It irrigated low crop value or land for grazing or recreation. A field irrigated by uncontrolled flood irrigation method (UFI) is mostly flooded with water that soaked into the soil to supply soil water for the roots of plants or trees. The UFI has prevailed in regions where water supplies were ample. For example, in the KSA, the UFI method was used in the eastern region et Al-Ahsa Oasis, where spring waters were plenty and easy to divert onto the nearby farms and orchards.

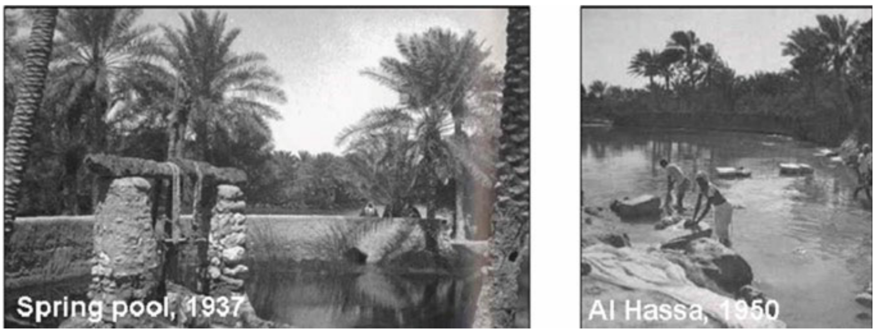

Fig. 7 Historical hot springs in Al-Ahsa Oasis. *Source* Al-Tokhais and Rausch (2008)

Table 3 Suggested basin areas for different soil types and rates of water flow

Soil type			
Sand	Sandy loam	Clay loam	Clay
Unit areas (ha/100 l/s)			
0.067	0.2	0.4	0.67

Source Adapted from Booher (1974)

4.1.2 Basin Irrigation Method

Basin irrigation is the simplest surface irrigation method constructed by hand. Basin sizes for various soil textures and inflow rates were empirically suggested by a method by Booher (1974), as shown in Table 3. Basin shapes are square but can also exist in irregular and rectangular configurations. An opening in the perimeter dike of a basin was set to supply water from an adjacent ditch. Inside the basin, the inflow of water is undirected and uncontrolled. The basin irrigation method has been used in most of the agricultural regions of the Kingdom, particularly in areas with small field layouts. However, due to the prevailing sandy soils in most of the Kingdom's agricultural regions, the authorities do not recommend the adoption of basin irrigation.

4.1.3 Border Irrigation Method

It is a surface irrigation method subdividing a field into graded strips by installing parallel dikes or border ridges. It suits soils with moderately low to reasonably high intake rates (USDA-SCS 1974). Border or strip irrigation is a modification of the conventional flood irrigation method. It conserves water by using the strip borders along each side of a tree line, thus limiting irrigation to half or less of the date palms floor area. Due to the slope's effects, the stream size per unit width must be significant following a tillage operation but smaller than basins. The accuracy of the field topography is also critical; nonetheless, the extended lengths enable better levelling using farm machinery. In the KSA, regarding border irrigation, water is applied to diked rectangular strips of length varied from 10.0 to 20.0 m, a width from 3.0 to 4.0 m, and spacing between centerlines of the strips of ~ 7.0 m. Irrigation occurs by allowing the flow to advance and infiltrate along the strip from a head ditch. However, larger inflow rates are engaged when the field slope is tiny.

In the Kingdom, the strip irrigation method is commonly used for young date palms. Besides, other crops like alfalfa, vegetables and citrus trees are intercropped between the young date trees. Therefore, to achieve high efficiencies, farmers must monitor the progress of water flow over the field, and sound judgment is required to terminate the inflow at the appropriate time. However, poor design and judgment may lead to reduced efficiency.

4.1.4 Furrow Irrigation Method

Furrow irrigation is a surface irrigation method that requires accurate field grading. It has small shallow channels installed evenly spaced down the slope of the field. Furrows vary in shape and size; they have parabolical cross-sections, flat bottoms, or about a 2–1 side slope (USDA 1979). Furrow grades should be 1.0% or less, but in an arid region like the KSA, furrow grades can be as much as 3.0%, where soil erosion from rainfall is not a hazard. Water flowed in at the high end and conveyed in the small channels to the locality of plants growing in or on beds between the channels. Water flowed in at the high end and conveyed in the small channels to the places of plants growing in or on beds between the channels. The application of enough irrigation water is aiming to achieve lateral penetration. Most vegetable and cereal crops in the KSA can be irrigated with furrow irrigation except fruit trees or crops are grown in ponded water, such as rice. The Furrow irrigation method is suited most to the medium and moderately fine-textured soil of relatively high available water holding capacity and conductivities, allowing water movement in horizontal and vertical directions. The movement of applied water by the furrow irrigation method on coarse-textured sandy soils is downward and has slight lateral penetration.

4.2 Improved Surface Irrigation Methods

4.2.1 Raised Bed Planting (Altadwees)

Raised beds of 0.20–0.40 m height are formed around the trunk of mature palm trees with a width of 2.00–3.0 m, and water flows in the wide depressed areas on the beds' sides, as shown in Fig. 8a (Al-Taher 2015). Losses due to evaporation are thus reduced when irrigation water flows alternately on each side of the raised beds. Furthermore, the method is suitable for irrigating mature palm trees with no intercropping as the canopies of the palms prevent such practice. Therefore, the technique is among the improved surface irrigation methods that Saudi Irrigation Organization (SIO) encouraged for water savings.

Fig. 8 Improved surface irrigation methods. **a** Raised bed planting; **b** Circular depression; **c** Strip irrigation. *Source* Water Studies Center, KFU, 2010

4.2.2 Circle Irrigation (Circular Depression)

Circle irrigation creates circular depressions around date palm tree trunks with a diameter varying between 1.0 m for the young trees and 3.0 m for the mature trees. The circular depressions are connected to concrete or an earth ditch or fed from the head ditch or a pipe (Fig. 8b). Then irrigation water is delivered to the individual circles through small checks from the head ditch or pipeline network. This method received more acceptance than raising bed planting in date palm irrigation because it subjects less surface area to water losses via evaporation.

4.2.3 Date Strip Irrigation (Albwaki)

In this method, the field is subdivided into rectangular strips set with different lengths and widths ranging from 4 to 6 m. Then, a strip is planted with young date palm trees in regular dimensional rows, and the adjacent strip is left without planting (Fig. 8c). Therefore, due to this method, the irrigated area was reduced by 50% (Al-Taher 2015) and consequently, the loss of irrigation water by evaporation was minimized.

4.3 Modern Pressurized Irrigation Systems

In the KSA, using scarce water resources is vital for agricultural development and sustainability (Al-Omran et al. 2021). Thus, adopting modern pressurized micro-irrigation systems and improving the physical properties of sandy soils are necessary for enhancing crop water use efficiency and economic return. Drip, sprinkler, and bubbler irrigation systems are water conservation techniques that reduce excessive on-farm applied water; therefore, they are important for water and food security in the KSA (Al-Ghobari and Mohammad 2011). Sprinkler irrigation saves about 42% compared to conventional surface irrigation methods, while drip irrigation saves about 70% (Al-Ibrahim 1990; Kaur et al. 2020). Accordingly, the irrigation application efficiency of the micro-irrigation systems ranged from 90 to 95%. It was about 70% for the sprinkler, and the surface irrigation method ranged from 45 to 60% (Phocaides 2000; Attri et al. 2022).

4.4 Micro-Irrigation

Micro-irrigation has advantages over traditional irrigation by automating and applying the needed irrigation water and fertilizer at the crop's root zone, decreasing weed and pest infestation, and lowering the operation cost (Madramootoo and Morrison 2013). Micro-irrigation methods include drip, spray, bubbles, and hose-basin application techniques (Kaur et al. 2020). Micro-irrigation is a pressurized irrigation system that utilizes pumps to deliver water under low pressure ranging between 10 and 3 bars. It can be done by sets of mains, sub mains and lateral lines directly to an individual plant or a tree where the water is distributed through an emitter for a plant or more emitters for a tree. However, clogging and mitigation of emitters can encounter their operation related to quality (Capra and Sciolone 2001). Hence, irrigators favour large-sized emitters to avoid clogging.

4.4.1 Sprinkler Irrigation System

Ten major sprinkler irrigation types can be grouped into fixed and portable sprinkler irrigation systems. A centre-pivot system has a moving lateral fixed at one end, and from sprinklers, sprinkles water to irrigate a large circular area. The centre-pivot system is the most adopted sprinkler irrigation type in the KSA. In the past thirty years, vast areas of the KSA desert land have been converted into productive irrigated farms (Al-Ghobari 2014). For example, in 1995, the Kingdom imported about 20,028 centre-pivot systems to irrigate wheat and forage crops. Such large numbers of pivots enhanced the intensive extraction of non-renewable fossil water for forage and wheat irrigation with almost zero recharge.

Consequently, the groundwater levels of principal confined aquifers in the KSA decreased annually by 1–2 m (MEWA 2020). However, in 2016, the authorities banned wheat production and restricted areas for green forage production. Henceforth, most centre-pivot systems were diverted to irrigate vegetable crops such as melons and potatoes. Compared to the conventional methods of irrigation, centre pivot irrigation uses less labour, reduces soil tillage, and lessens runoff and soil erosion.

4.4.2 Bubbler Irrigation System

Each bubbler of the bubbler irrigation system has a high discharge flow rate of about 7.6 L per minute; therefore, it is used to irrigate trees (Fig. 9a). This high discharge allows for shorter irrigation duration. The MEWA recommends using bubblers in date palm orchards and encourages the adoption of pressurized irrigation systems in place of traditional surface irrigation methods. The area irrigated by the bubbler irrigation method is a fraction of that irrigated by the conventional method. Thus it reduces the intensity of water losses caused by evaporation and deep percolation. However, bubblers are sensitive to debris in irrigation water but much less susceptible than the emitters of drip irrigation systems.

4.4.3 Free Flow Pipe Irrigation System

It is a simple irrigation method to supply water around a tree trunk. The SIO developed this tailor-made emission device that consists of a PE tube of 13 mm diameter ending

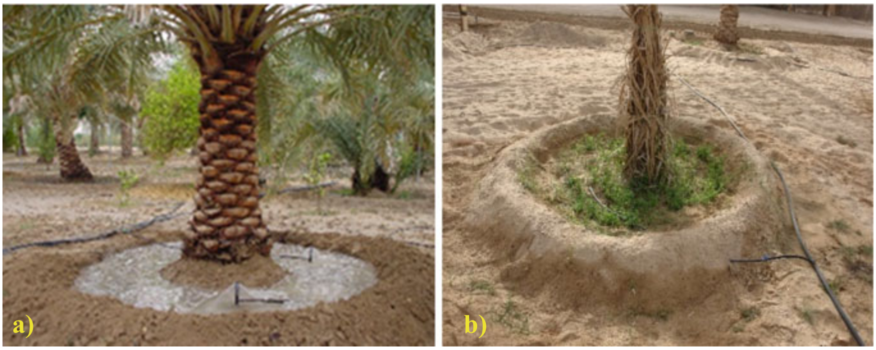

Fig. 9 Micro-irrigation systems. **a** Bubblers irrigation; **b** Free flow pipe irrigation. *Source* Water Studies Center, KFU, 2010

with a gate valve, as shown in Fig. 9b. This method can mitigate clogging when using drippers and bubblers and reduce the need for an expensive filtration module. The gate valve adjusts the flow required for a tree to achieve a high level of distribution uniformity. MEWA recommends such kind of irrigation method for both young and mature palm trees.

4.4.4 Drip Irrigation System

Sandy soils prevailed in most of the cultivated areas of the KSA. Therefore drip irrigation is an appropriate method of irrigation. There are two methods of drip irrigation, surface and subsurface, as shown in Fig. 10a, b. Drip irrigation methods, if designed and implanted properly, farmers could efficiently use water resources and enhance the water productivity of crops (Locascio 2005). Subsurface drip irrigation (SDI) is the most advanced method that applies water and nutrients 15–30 cm under the soil surface near plants' root zone for maximum crop benefits (Mali et al. 2017). Therefore, the SDI can maintain higher soil water content in the crop root zone and provide favourable conditions for improving plant growth. In addition, the SDI can reduce deep percolation and surface evaporation losses and minimize seasonal water usage (Montazar et al. 2017). The SDI has several significant advantages over the surface drip irrigation (DI) method, such as increased yield, reduced applied water and improved water productivity (Zeineldin and Al-Molhim 2021; Ayars et al. 2015). Drip irrigation methods use around 35% of the water consumed by surface irrigation methods. This was based on an on-farm evaluation, giving high water use efficiency (Maisiri et al. 2005).

Fig. 10 Drip irrigation systems. **a** Surface drip irrigation; **b** Subsurface drip irrigation. *Source* Water Studies Center, KFU, 2021

4.4.5 Traditional Irrigation Systems

Modern irrigation methods such as water-saving techniques, improvement of soil properties, and deficit irrigation are viable options for increasing water use efficiency and conserving scarce water resources of the KSA compared to traditional surface irrigation methods (Al-Zaidi et al. 2014; Al-Omran et al. 2021). Modern irrigation technology focuses on controlling water to reach the best use of water and labour and mitigate the dangers of waterlogging or salting. The gradual shift towards improved surface irrigation methods and then to modern pressurized irrigation systems was observed all over the agricultural regions of the KSA. For example, a study at Tabuk in the northwest region of the KSA indicated the positive attitudes of farmers toward adopting modern irrigation instead of traditional surface irrigation methods (Al-Zaidi et al. 2014). Based on the Aquastat survey of 2008, the FAO showed modern irrigation methods in the Kingdom covered about 66%, while conventional irrigation methods were employed in the remaining 34% of the irrigated area (FAO 2009). Table 4 shows the distribution per cent of traditional and modern irrigation across the thirteen agricultural regions of the KSA. The survey revealed that the largest irrigated areas are in Riyadh, Al-Qasim, Jizan, Hail, Eastern, and Al Jawf. In the Al-Qasim area, the central part of the KSA, more than one-third of the farmers (38.3%) employed traditional flood irrigation methods (Al-Subaiee et al. 2013) in date palm irrigation.

4.5 Water Security

The water and food security in the Middle East region is generally affected by climate change, water deficit, population increase, urbanisation development, and political problems (Hameed et al. 2019). Therefore, to fill gaps in the water supply, extensive

Table 4 Regional irrigated areas by traditional and modern irrigation methods

	Traditional irrigation		Modern irrigation		Total	
Region	Area (ha)	%	Area (ha)	%	Area (ha)	%
Riyadh	43,010	15	243,275	85	286,285	24
Mecca	43,924	98	1032	2	44,956	4
Al-Medina	26,618	93	2020	7	28,638	2
Al-Qasim	15,541	7	208,712	93	224,253	19
Eastern	16,081	15	92,987	85	109,068	9
Asir	22,232	99	296	1	22,528	2
Tabuk	5113	11	42,057	89	47,170	4
Hail	12,368	10	116,139	90	128,507	11
Northern	19	14	114	86	133	0
Jizan	177,375	99	1995	1	179,370	15
Najran	8811	68	4008	31	12,819	1
Al Bahah	2658	98	55	2	2713	0
Al Jawf	11,688	11	93,224	89	104,912	9
Total	385,438	32	805,913	68	1,191,351	100

Source FAO (2008)

energy is consumed for water desalination and wastewater recycling in the KSA (McDonnell 2014).

KSA highly depends on the groundwater resources found in the different aquifer formations that serve for crop production and domestic and industrial usage (Oumar et al. 2015). While the country is endowed with 2360 BCM of nonrenewable groundwater; however, only 1180 BCM is extractable, 50% (MEWA 2018). The over-extraction, especially for agricultural activity, and the negligible recharge rates have initialised severe concerns towards the KSA water security (National Water Strategy 2016).

Thus, water security faces fundamental challenges, including declining freshwater, water quality deterioration, climate change, non-beneficial water losses and poor water use efficiency in the KSA (Hameed et al. 2019).

The Kingdom's population rapidly increased, from around 4 million in 1960 to 32.5 million in 2018, and is projected to grow by 77% by the year 2050 (Baig et al. 2020; Rambo et al. 2017). This situation made the country incapable of meeting its agricultural water demands and investing heavily in desalination to meet the potable water-increasing needs (Baig et al. 2020; Palanichamy et al. 2018). As a result, water consumption rates in KSA's agricultural and urban sectors are considered wasteful (MEWA 2018). Furthermore, the lack of a tariff policy on extracted water from wells for agricultural purposes resulted in quantitative depletion and qualitative deterioration of groundwater, which have jeopardised water and food security in the KSA (Baig et al. 2020).

Despite the rapid population increase in urbanised areas and improving living quality, the KSA ensures its long-term water security for potable water by desalination (Lovelle 2015). Furthermore, seawater desalination is suggested as a sustainable solution for water scarcity in Saudi Arabia by employing renewable energy (Gujral et al. 2018).

However, if urbanisation growth outpaces the sustainable growth rate, the KSA will undergo a heightened threat to water and food security. Therefore, managing the demand and supply of water with the unprecedented population growth is a critical challenge for the KSA water security in the future. Therefore, there is a crucial need for behaviour changes to encourage water conservation and efficient water practices in agricultural, municipal and industrial usage sectors.

4.6 Policies and Legislation to Water Use in Agriculture

Water conservation and sustainability are the most critical components for overcoming water scarcity in KSA. However, according to the MEWA report of 2018, the rate of water consumption in the urban and agricultural sectors could have been more economically reasonable.

The KSA has started to formulate policies and strategies that regulate water use. The KSA started an agricultural policy for food self-sufficiency in the 1970s and achieved food self-sufficiency in many crops. Unfortunately, this policy resulted in the rapid depletion of groundwater. Later on, in 2008, the KSA introduced a new agricultural policy (Ouda 2014a). Accordingly, efforts were made to develop extensive, but efficient water conveys systems (Baig et al. 2020). Hence, the KSA's new policies restrict planting crops of high water consumption like wheat, barley and fodder. Also, the new policies encourage farmers to grow vegetable crops in greenhouses using water-saving technologies (Baig et al. 2017). As a result, the new policy has resulted in a noticeable reduction in irrigation water demand and the cultivated area of cereal crops. However, it needed to support the sustainable utilisation of groundwater resources (Ouda 2014a). The new policy has increased the importation of food crops to satisfy the country's demand (Multsch et al. 2017). However, this virtual water-dependent policy will save more water (Antonelli and Tamea 2015). Therefore, the virtual water trade is suggested to preserve water resources in KSA (Grindle et al. 2015). Trade-in virtual water can reduce water requirements in the agricultural and industrial sectors, allowing the exporters to achieve higher water productivity than importers (Odhiambo 2017).

The ministries council has approved the new water system act of the KSA, and it has been acting since the end of the year 2020 (MEWA 2020). It is a comprehensive new system that contains 77 articles. The system aims at preserving, developing, and protecting water resources, ensuring their sustainability and management. Also, it aims to regulate the water resources affairs, the rights related to them, and their uses, enhance the private sector's participation in the water system's activities, and strengthen effective governance. The act gave the MEWA the right to install meters to measure the water flow from wells located in non-renewable aquifers. Moreover, the new water policy aims to control and regulate the amount of water consumption and rationalise its use. Also, the MEWA may consider charging a fee if water consumption exceeds a given water rationing.

Permit-based groundwater systems (PBGS) have become more dominant; because more powerful pumps, population increase, and economic development have driven demand for groundwater that often oversupply. The PBGS enable the water administration to allocate water to different uses ranging from domestic, agricultural, and industrial uses to environmental ones, such as sustaining wetlands and the base flow of rivers (Mechlem 2016). However, implementing the PBGS is not cost-effective, administratively challenging, and time-consuming, especially in countries with many small-scale users. Moreover, introducing the PBGS will likely only succeed if it is well-designed and tailored to the local context and administrative capacity (Mechlem 2016). Hence, water policies and strategies in KSA should address the allocation of agricultural water demand with crop market values and water conservation aspects (Odhiambo 2017).

4.7 Technologies for Improving Water Utilisation

Adopting modern irrigation technologies in KSA reached 66%, while traditional surface irrigation was 34% (Baig et al. 2020). Nevertheless, the irrigation efficiency is only 50% (Al-Omran et al. 2021). Hence, improving irrigation technology and implementing on-farm water management can enhance irrigation efficiency. Al-Ghobari and Dewidar (2018) reported that integrating deficit irrigation strategies into surface and subsurface drip irrigation can save water in KSA. They found that the most significant irrigation water use efficiencies were obtained from the subsurface and surface drip at 0.6 of the total irrigation supply compared to 1.0 and 0.8. They conclude that deficit irrigation strategies show specific advantages to irrigation water management with minimum effects on crop production and quality. Also, the subsurface irrigation (SSI) system positively impacted irrigation efficiency and enhanced fruit yield and quality of the date palms in the eastern region of KSA (Mohammed et al. 2020). Moreover, the SSI was combined with the smart irrigation scheduling system in the arid region of KSA by Al-Ghobari et al. (2016). They indicated that the smart water controllers significantly reduced the amount of applied water and increased crop yield.

The farmers can easily adopt auto-steer machinery and centre-pivot irrigation systems since it requires little training and skills. However, adoption is often limited to technologies that require further investment in learning, hiring external services and data analysis, like soil and plant moisture sensors and related software (García et al. 2020).

The role of remote sensing technology (RST) is increasing rapidly as a complementary source of information for water resources assessment and monitoring. It can, directly and indirectly, measure nearly all hydrological cycle components (Sheffield et al. 2018). Therefore, satellite remote sensing can play a vital role in filling the gaps and enhancing water resources management (WRM) in KSA. The applications of the RST for WRM include crop water use and stress, evapotranspiration, precipitation, waterlogging, reservoir mapping and infrastructure evaluation (Mahmoud and Alazba 2016; Madugundu et al. 2017; Elhag and Bahrawi 2017; Allbed et al. 2018; Turk et al. 2021).

Desalinated water technology (DWT) can grow many crops under KSA's greenhouse conditions. In addition, using solar desalination reduces the energy cost of producing low-salt concentration water (Hussain et al. 2019). As a result, KSA is one of the leading in the Arab world in DWT, producing more than 1.6 billion m^3 of desalinated water each year (Awaad et al. 2020).

Information and Communications Technologies (ICT) have recently been linked with the Internet of Things (IoT) to improve water management globally. Also, they are used to make the operations of water resources, distribution, and quality more efficient (Alshattnawi and Jordan 2017).

4.8 Water Prospects in Saudi Arabia

Water is vital to human needs and development in the Arabian Peninsula. However, Mazzoni et al. (2018) reported that by 2050 the Arabian Peninsula would experience severe water shortages that can reach 20% in Saudi Arabia to almost 190% in Yemen based on their current water budgets. Furthermore, the water resources availability and quality can affect the environment and economy of these states at local and regional scales (Drewes et al. 2012). Therefore, the KSA must establish water management plans integrating water-resource development and management (Odhiambo 2017).

Currently, the KSA water prospects are significantly reducing the annual extraction and instead reusing treated sewage water in the agriculture sector. Based on vision 2030, the country's water strategies have proposed an objective to reduce the annual extraction from 22 to 12 BCM and reuse treated sewage wastewater for irrigation (MEWA 2018). The national strategic water plan of the KSA is to conserve the groundwater of confined aquifers for municipal and industrial usage and achieve water security, in turn, food security. Moreover, the MEWA for achieving development and suitability in the agricultural sector has proposed new crop structures for the agricultural regions, excluding extensive water-demanding crops like alfalfa. Also, MEWA encourages farmers to adopt modern irrigation systems and edge new irrigation technologies like hydroponic and aquaculture production systems.

MEWA formulated and developed a unified framework for the water sector in KSA. The framework includes a comprehensive water strategy that links trends and directions, policies, regulations and practices in the water sector at the national level of the KSA. Also, the framework sets the principal objective of directing the key challenges and restructuring the water sector (MEWA 2020). The MEWA framework has several parts: stakeholder engagement, assessment of the current situation, water

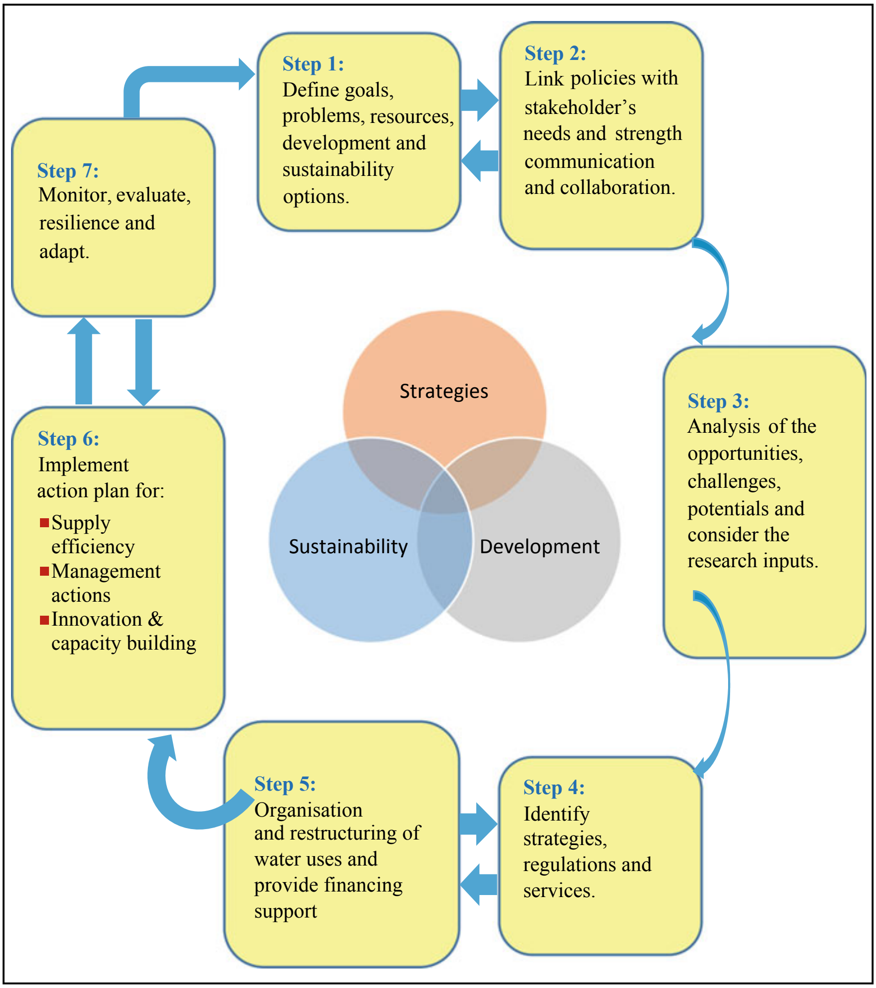

Fig. 11 A conceptual framework for water resources management in KSA. Adapted from MEWA (2020)

resources, sector operations, and facilities. Therefore, to make the MEWA framework more operational, a conceptual framework is suggested in this chapter to adjust the implementation process and consider future changes (Fig. 11).

The suggested conceptual framework can function as a tool that matches the MEWA strategies and policies with developing sustainable water resources. Hence, it defines the problems, aims, procedures, services, action plans, system monitoring, and adaption.

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