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Review

Water Resources in Jordan: A Review of Current Challenges and Future Opportunities

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Abstract: Jordan is facing significant challenges related to water scarcity, including overexploitation of groundwater, increasing demand, and wasteful practices. Despite efforts to manage water resources, inadequate planning has resulted in ongoing water security concerns and deteriorating water quantity and quality. To address water stress, Jordan has implemented measures such as desalination, dam construction, and water conservation initiatives. However, water stress remains high, necessitating a comprehensive strategy that includes short-term demand-side interventions and long-term supply-side reforms. Financial and governance challenges hinder the implementation of these measures, requiring private investment and coordination among stakeholders. This paper provides a comprehensive review of Jordan's water resources, analyzing current trends, challenges, and opportunities. The aim is to offer insight into the current situation and propose sustainable management approaches. The findings will be valuable for policymakers, researchers, and stakeholders working towards addressing Jordan's complex water challenges and securing a sustainable water future for its citizens.

Keywords: water resources; management; challenges; opportunities; wastewater; desalination; conventional; nonconventional; harvesting; water sustainability

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1. Introduction

Acute limitation of freshwater resources emerges as a foremost challenge in the 21st century. This dearth of water resources is anticipated to intensify in the coming years due to various factors, notably the anticipated adverse consequences of climate change. Projections indicate that by the year 2030, approximately 40% of the global populace will experience the ramifications of water scarcity [1,2]. Unfortunately, less than 3% of the global water resources are fresh water, i.e., water with an acceptable salinity level. Less than 1% of the available freshwater can be used directly for industrial, agricultural, and drinking applications [3], as the remaining freshwater is ice, which is a sad fact given that the majority of the water on Earth is saline water from oceans, seas, and deep groundwater [4,5]. Due to population growth, urbanization, industrialization, and improved life quality around the world, especially in the Middle East and North Africa (MENA) region, the demand for freshwater is both undeniable and increasingly unsustainable. The availability of freshwater in MENA is very limited due to low precipitation and high evaporation rates [5]. On the other hand, even though the reduction in water supplies is directly attributed to the low precipitation and high evaporation rates, the reasons behind the increase in water demand are also responsible for the overexploitation of aquifers and the contamination of water supplies, which eventually reduce the available water resources [6].

Jordan, a country in the Middle East region, is one of the countries with the scarcest renewable water resources per capita in the world; it was the second-poorest country in 2017 with only 100 m^3 per capita per year, which could reach almost 80 m^3 in the year 2020 [7]. Jordan has an area of 89,210 km^2, and despite its relatively compact size, its diverse topography and landscape rival those typically found in much larger countries [8]. Based on a physiographic standpoint, the country can be divided into four districts: (1) the ghors (marshes), (2) the highlands, (3) the plains, and (4) the desert. The ghors in the west of the country are further divided into three zones: the Jordan Valley, which starts at Lake Tiberius in the north; the swamps around the Dead Sea; and the Wadi Araba, which stretches southward to the northern shores of the Red Sea (total area: 5000 km^2). The Ghor regions were all discovered to be below sea level. The highlands extend from the north to the south at an elevation of between 600 m and 1600 m above sea level (total area: 5510 km^2). The plains extend from the north to the south along the western borders of the desert (Badiah) (total area: 10,000 km^2). And finally, the desert region (Badiah), an extension of the Middle Eastern desert (total area: 68,700 km^2), is located in the east [8,9]. Jordan's climate is characterized by long, hot, and dry summers and wet, cold winters. The temperature increases towards the south, with the exception of a few southern highlands. Precipitation shifts impressively in the area, primarily due to the country's topography [8,10]. In the Jordan Rift region, the annual mean temperature typically falls within the range of 22 to 25 °C, while in Badia, it fluctuates between 18 and 21 °C. The highlands, in contrast, maintain an average temperature spanning from 14 to 18 °C [11]. Precipitation patterns are notably variable, with the concentration of occurrences during the winter and early spring. More than 93% of the nation receives less than 200 mm of precipitation annually, ranging from 700 mm in the northwest to under 20 mm in the southeastern deserts, as illustrated in Figure 1 [12]. The annual volume of precipitation in Jordan has shown concerning deviations from long-term averages, primarily because of climate change and periods of drought, as detailed in Figure 2. The third national communication report to the UNFCCC anticipates a warmer and drier climate in Jordan by 2100, with potential increases in air temperature ranging from +2.1 °C to +4 °C and potential reductions in annual rainfall between 15% and 35% [13]. The long-term average annual precipitation volume is approximately 8217 million cubic meters. Over a 50-year record, rainfall rates have varied between less than 100 mm and 520 mm. Notably, evaporation accounts for a substantial portion of the total rainfall, ranging from 88% to 93%, while infiltration rates have been observed at approximately 4% to 10% [7,14].

In addition to the previously mentioned reasons for the global water shortage, Jordan, in particular, has experienced the following circumstances: (a) Since 1948, there have been significant influxes of refugees, including more than 1.4 million Syrians since 2010 [15]. (b) Jordan shares 26% of its water resources with neighboring countries [12]. (c) It has a significant amount (roughly 50%) of non-revenue water, of which 70% is a result of illegal use [16]. All these circumstances have combined to put a tremendous amount of pressure on water resources and prevent the implementation of workable management plans.

Water stress is an actual problem in Jordan. Groundwater resources have been over-exploited for decades, and the country's groundwater is estimated to be being used up twice as fast as it can be replenished. Jordan suffers from serious supply shortages, but rapidly increasing demand and a significant increase in waste have been the main causes of exacerbating water shortages in recent years. Due to the interaction of many factors, there is no standalone fix. Jordan is taking steps to reduce its water stress, including attempts to increase water supply through desalination and dam construction and decrease water usage through strengthened public water networks. Despite these efforts, water stress remains at an all-time high. To find a lasting solution to the challenges Jordan faces and ensure a more sustainable water future, both short-term demand-side strategies to decrease and improve water usage efficiency and long-term supply-side reforms to increase water availability are necessary. However, a comprehensive solution to meet all water demands has yet to be found.

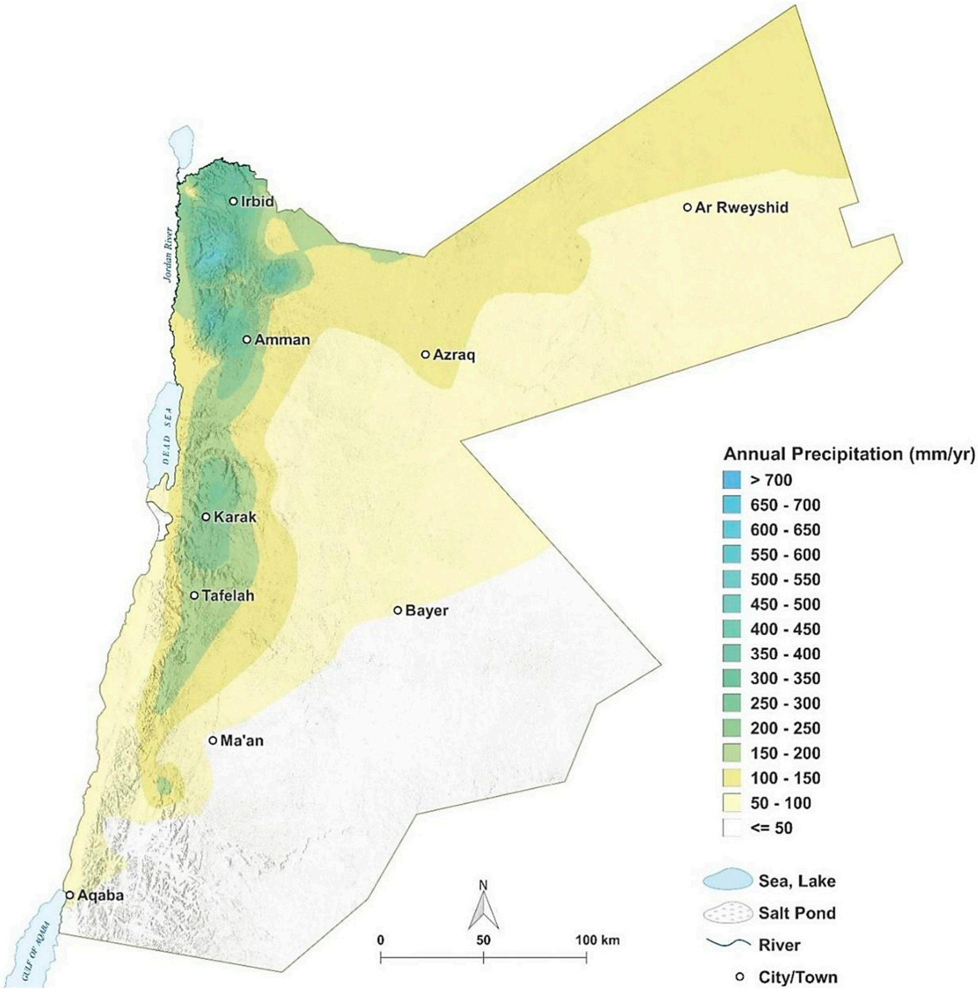

Figure 1. Annual precipitation in Jordan [17].

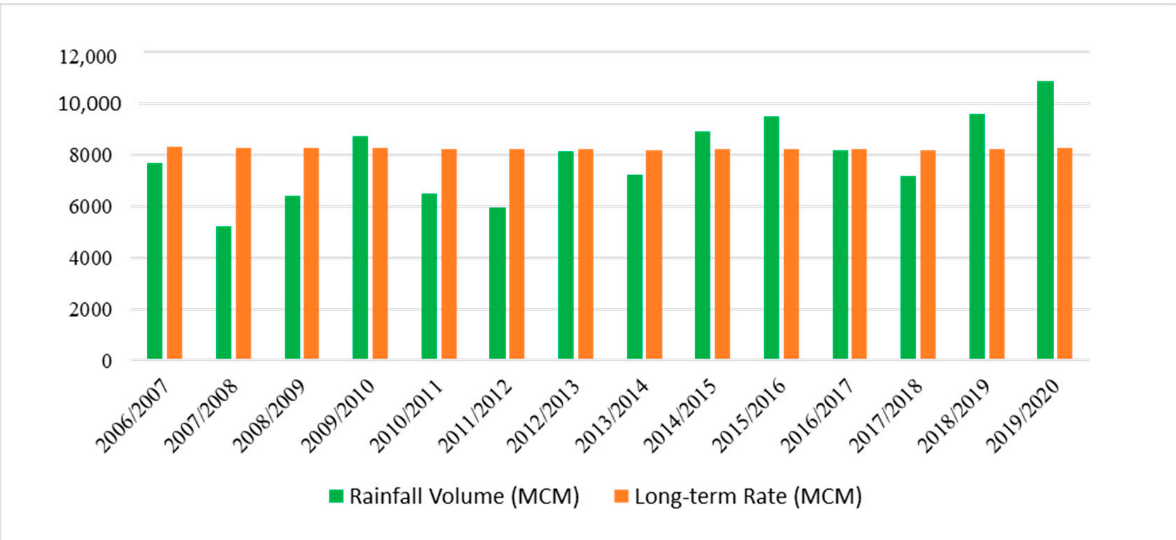

Figure 2. Rainfall volumes in Jordan for water years and long-term rate (2010–2020) [14].

In this paper, we provide a comprehensive review of the current state of water resources in Jordan, including an examination of the available water resources, present and future trends, and the challenges and opportunities faced by the country. The purpose of this review is to provide insight into the current situation and highlight opportunities for a more sustainable future in the management of water resources in Jordan. By examining the available water resources and trends, we aim to identify the challenges faced by water resources in Jordan and explore opportunities for improving the sustainability and management of these resources. Ultimately, this paper provides a resource for policymakers, researchers, and other stakeholders who are working to address the complex water resource challenges faced by Jordan today.

2. Literature Review

Water resource management in Jordan presents a multifaceted challenge due to the nation's limited water resources and the increasing demand [18]. The situation is further complicated by the significant impact on the Jordan River, a vital water source, resulting from actions by neighboring countries and the looming threats of climate change [19]. As a consequence of these challenges, there has been a growing recognition of the need for improved water resource management in Jordan to ensure sustainable water supplies and mitigate the adverse consequences of water scarcity for the environment, economy, and society [20]. Numerous studies have delved into the current challenges and future prospects of water resource management in Jordan [21]. This literature review aims to provide a comprehensive analysis of the present state of water resource management in Jordan, emphasizing the importance of sustainable water supplies and highlighting the adverse effects of water scarcity.

The Water Authority of Jordan (WAJ) is responsible for the operational management of water resources and water supply and wastewater treatment. The Ministry of Water and Irrigation (MWI) plays a central role in water management in Jordan, and the National Water Strategy of Jordan aims to build a resilient sector based on a unified approach and transition towards sustainable management of water and sanitation for all people in Jordan [22]. The strategy covers five pillars and themes: integrated water resources management, water, sewage and sanitation services, water for irrigation, energy and other uses, institutional reform, and sector information management and monitoring [22].

Water law and resource ownership in Jordan are governed by the Water Authority Law of 1988, which was amended by Law No. 22 of 2014. According to Article 25 of the law, all water resources, including surface and groundwater, regional waters, rivers, and internal seas, are considered state-owned property and cannot be used or transferred except in compliance with this law [23]. Nevertheless, the law also facilitates the issuance of licenses to water users and the formation of water user associations. The licensing of water users is provided by the Ministry of Water and Irrigation, which is responsible for overall water resource management in Jordan [24].

The licensing process involves the issuance of permits to water users, which specify the amount of water that can be used and the conditions under which it can be used. The permits are issued for a specific period, and the water users are required to renew them periodically. The permits also specify the fees that the water users are required to pay for the water they use [22]. Water users in Jordan are required to pay for the water they use, and the rates are set by the Water Authority of Jordan based on the cost of water production, treatment, and distribution [25]. The rates are reviewed periodically to ensure that they reflect the actual cost of water production and distribution. The government has also implemented a tariff structure that provides different rates for different categories of water users, such as households, commercial, and industrial users [26].

Leakage in old pipes, administrative errors, illegal water connections, inaccurate metering of the supplied and/or consumed water, and improper billing of water are some of the reasons for non-revenue water use. Illegal use of water in Jordan can occur in various ways, such as unauthorized drilling of wells, illegal water connections, and overpumping of groundwater beyond the permitted limits. The government enforces legal action for illegal water use and has implemented measures to combat illegal water use, such as imposing fines and penalties, confiscating equipment, and disconnecting illegal water connections. The implementation of the legal framework and administrative policies is crucial to ensure equitable and sustainable water use in Jordan [27,28].

The quality of water in Jordan is also a significant concern. Deteriorating water quality is one of the factors exacerbating the country's precarious water situation [29]. The use of treated sewage for irrigation is one strategy to ensure the quality of water resources in Jordan [24]. Furthermore, Jordan is highly vulnerable to the impacts of climate change, which not only diminishes water availability but also worsens water scarcity. The National Water Strategy of Jordan (2016–2025) seeks to enhance water quality and sanitation. In response to the growing water scarcity, nonconventional water supply sources are being considered to address the shortfall. Among these options, water reuse is gaining prominence, especially for agricultural purposes. The government is actively working to improve wastewater treatment for agricultural use [22].

The unequal distribution of water resources in Jordan and persistent water scarcity are among the foremost challenges of water resource management [20]. In spite of the scarcity of water resources in the country, some areas, particularly urban centers, exhibit high water consumption rates. This unequal distribution has led to overextraction of groundwater, resulting in aquifer depletion and aggravating long-term water scarcity [18,30,31]. Climate change compounds these issues, with rising temperatures, reduced precipitation, and increased evaporation rates collectively diminishing water availability and exacerbating water scarcity. Climate change is also expected to heighten the frequency and intensity of droughts and floods, further impacting water resources [32–35].

The adverse effects of water scarcity in Jordan extend to environmental, economic, and societal realms. These include soil degradation, desertification, and loss of biodiversity, with reduced agricultural productivity, higher water costs, and limitations on economic growth adversely affecting the economy. On a societal level, water scarcity leads to health problems, social unrest, and migration [36,37].

Despite these challenges, there are opportunities to enhance water resource management in Jordan. Innovative technologies such as water reuse, desalination, and rainwater harvesting offer promise for augmenting water availability and mitigating scarcity [38–40]. Moreover, the implementation of improved water management policies, including water pricing mechanisms and water conservation measures, can curtail consumption and boost overall efficiency [18,41].

Jordan's water scarcity challenges underscore the pressing need for action. The country serves as a global example of the difficulties posed by climate change and rapid population growth [36,42]. To address these challenges and ensure sustainable water supplies, researchers recommend adopting a nexus approach that considers the interdependence of water, energy, and food [43,44]. They also advocate for a multi-sectoral approach to reform the water sector and highlight the significance of using Geographic Information Systems (GIS) for planning and monitoring freshwater supplies. In the face of these challenges, it is crucial that Jordan continues to innovate and implement comprehensive solutions to ensure a sustainable water future for the country [42].

3. Available Water Resources in Jordan

Sustainable water sources in Jordan are derived from four main resources: surface water, groundwater, desalinated water, and treated wastewater. Freshwater resources in Jordan consist mainly of groundwater and surface water. Desalinated water and treated wastewater are other important nonconventional resources that help to bridge part of the gap between supply and demand, especially in the municipal and agricultural sectors. The different available water resources in Jordan are as follows.

3.1. Conventional Water Resources

Conventional water resources pertain to renewable sources, which encompass natural bodies like rivers, lakes, freshwater wetlands, or subterranean aquifers. In Jordan, this category includes both groundwater and surface water sources. In the year 2019, the cumulative volume derived from these conventional sources reached approximately 906.7 MCM, reflecting a noteworthy variance of 25.2% when compared to the 2018 volume, which was around 678 MCM. The following provides a concise delineation of these resources.

3.1.1. Groundwater

Groundwater, also known as subsurface water, is fresh water found below the surface in rocks and soil. It is also water that is flowing inside aquifers beneath the water table. The storage capacity of subsurface water is much greater than that of surface water, and its turnover is slow. Jordan has 12 main groundwater basins, which are dispersed among 11 hydrological units, as shown in Figure 3 [14]. Groundwater is the main source of water in Jordan, accounting for 60% of all uses and 76% of sources for drinking water [45]. To meet the high water demand, wells have been drilled intensively. According to the Ministry of Water and Irrigation, the number of private and governmental legal operating wells until 2020 was 3208 [14]; the number of pumping wells according to the WIS database was 5160 until 2017 [45]; and they were mainly located in the highly populated northern and central governorates [14]. However, many illegally operated wells are uncovered and backfilled every year. Between 2007 and 2020, the Ministry of Water and Irrigation closed approximately 1548 illegal wells [45]. Unfortunately, the current state of groundwater is critical, where the quantity of overpumping from groundwater is estimated at 200 MCM [14], and most basins have been extracted above safe yields. This has led to a significant decline in the water table within major aquifers. The rate of decline is alarmingly rapid, averaging about 2 m per year, and in severely affected areas, this decline can reach 5 to 20 m per year [14]. As a result, this decline is affecting the quality of groundwater, causing it to exceed the allowable limits set by Jordanian Standard Specification for Drinking Water Quality Guidelines No. 286/2015, which was used as a guide for assessing water quality. Furthermore, this predicament is exacerbated by the escalating pumping costs and the widespread drying up of wells in the central and northern regions [46,47]. Groundwater is considered a major immoderate source; over the past period, the pumping from groundwater expanded from 479 MCM in the year 2006 to almost 508 MCM in the year 2012, while the safe yield of these aquifers is only 275 MCM [48].

3.1.2. Surface Water

Surface water is water in a river, lake, or freshwater wetland. Precipitation naturally replenishes surface water, and evaporation, evapotranspiration, subsurface seepage, and discharge to the seas naturally deplete it. The second most important source of water in Jordan is surface water, which accounts for 31% of all water used across all sectors and is primarily used for drinking and agriculture [49]. There are 15 surface water basins, including transboundary shared basins [17], that discharge into the Dead Sea, Red Sea, and desert mudflats [50]. Table 1 shows the elements of the hydrological water budget for all surface basins in Jordan.

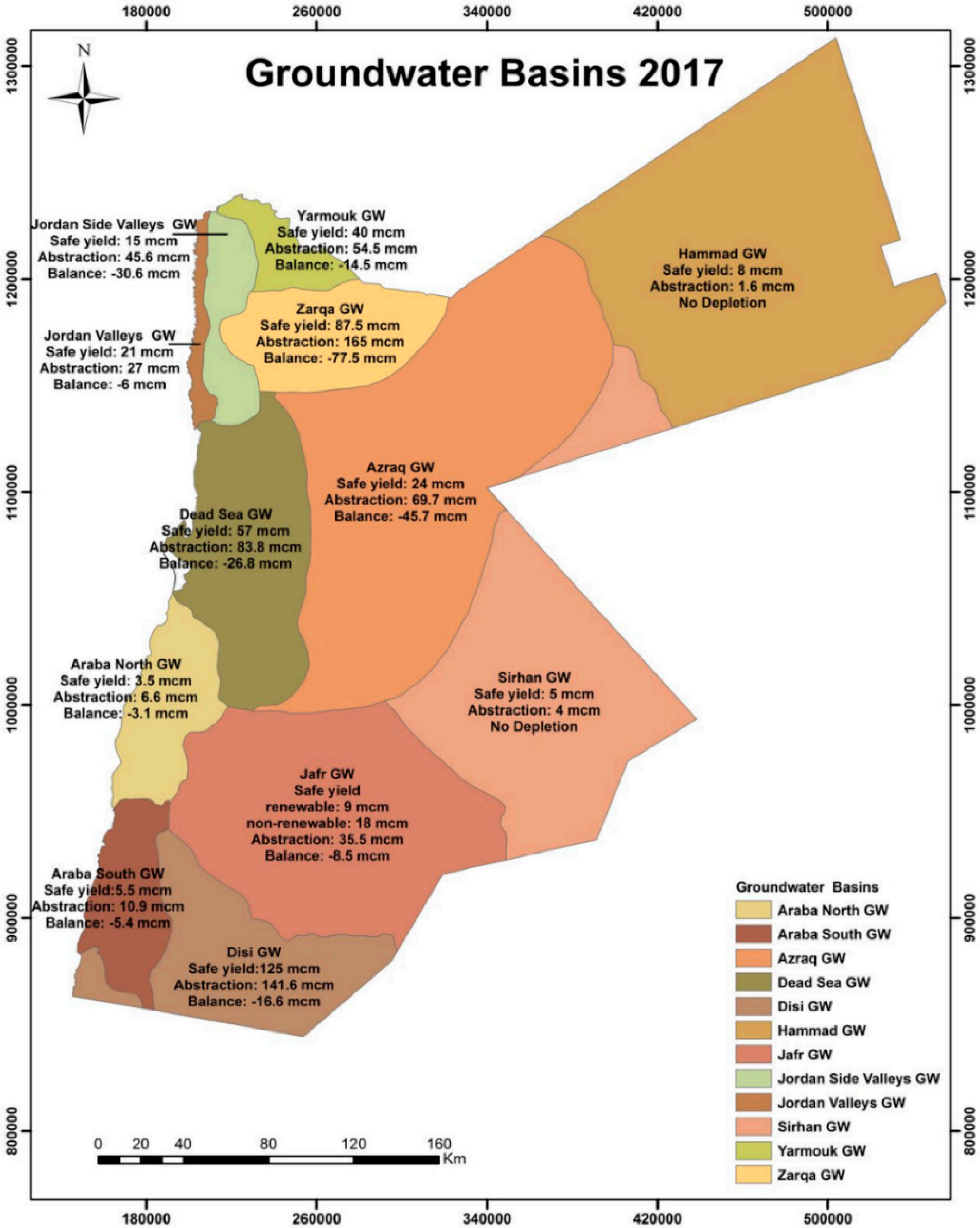

Figure 3. The primary twelve groundwater basins in Jordan [7].

Table 1. Elements of the hydrological water budget for all surface basins in Jordan [49].

Basin Name	Area (km^2)	Rainfall Volume (MCM)	Rainfall (mm)	Runoff Coefficient *	Surface Runoff Volume (MCM)	Evaporation (MCM)	Ground Recharge Volume (MCM)
Al-Hamad	17,738.7	1148.9	64.8	1.3	14.9	1119.9	14.0
Al-Sarhan	15,732.9	1101.9	70.0	0.8	8.6	1079.8	13.4
Al-Azraq	12,163.7	1382.8	113.7	1.7	23.4	1310.9	48.5
Al-Mujib	6608.1	1494.9	226.2	4.0	59.6	1329.0	106.3
Al-Hasa	2529.6	308.0	121.7	1.4	4.3	283.0	20.6
Amman-Zarqa	3588.4	1086.0	302.6	4.6	50.0	944.8	91.2
Al-Yarmouk	1362.6	501.5	368.1	7.1	35.6	428.8	37.1
The Dead Sea	1681.1	375.9	223.6	3.8	14.2	345.5	16.2
Northern Side Valleys	964.6	429.5	445.3	3.7	15.7	384.6	29.2
Southern Side Valleys	730.2	262.6	359.6	3.6	9.5	235.3	17.9
Jordan Valley	693.1	287.5	414.9	3.6	10.4	254.2	23.0
North Araba Valley	3010.7	254.2	84.4	1.3	3.2	241.6	9.4
South Araba Valley	5670.2	185.5	32.7	0.9	1.7	180.1	3.7
Al Disi	4234.2	130.9	30.9	0.7	0.9	128.9	1.2
Al Jafr	12,129.6	617.6	50.9	0.8	0.8	604.7	8.0
Total/Average	88,837.5	9567.7	107.7	2.3	2.3	8871.0	439.8

* The runoff coefficient is the percentage of rainfall that flows into the valleys.

The largest surface water supply is the Yarmouk River, which is located to the east of the Jordan Valley Basin. This river accounts for nearly half of Jordan's total surface water resources. Nevertheless, the flow rate of the river has significantly decreased due to the Syrian crisis and substantial water consumption on the Syrian side [50]. The water of the Yarmouk River is of good quality, with total dissolved solids within the range of 400–800 ppm. The second-largest tributary of the Jordan River is the Zarqa River. It is the only river that entirely resides within Jordan's territory [26,51], with a permanent average flow of 92 MCM per year [17]. The river basin is considered the most important surface water basin since it has more than 60% of the population, 80% of the industries, and several agricultural areas [17]. In the last decade, the river water quality has deteriorated because of large discharges of sewerage and industrial effluent. The river is controlled by the King Talal Reservoir, where the ratio of treated wastewater ranges from 45 to 60%. The Zarka River water is used principally for irrigation and stock watering, where sustainable rangeland management in the river basin has increased edible biomass, carbon sequestration, and sediment stabilization [2].

Jordan has several sporadic streams (wadis) spread throughout the surface water basin regions. The principal wadis are listed in Table 2. It is worth mentioning that the base flow includes the WWTP effluent discharge to the wadis, as in the case of Wadi Shuaib, Wadi Karak, and Wadi Fifa [52]. In addition, there are 861 documented springs in Jordan that are categorized as surface water sources [11,34], with an estimated total average annual discharge of 125 MCM/yr based on data from October 2012 to September 2017 [12]. The springs have a significant fluctuating discharge rate that ranges from 1 m^3/h up to

1000 m^3/h [12]. The Ministry of Water and Irrigation reports that, out of the 624 springs for which historical data have been collected, 478 have perennial discharge, 16 exhibits seasonal dry behavior, and 130 have recently dried up [12]. To evaluate the status of 591 springs that had no flow measurements between 2015 and 2018 but still had flow measurements from 2013 to 2015, BGR and MWI conducted two national surveys in 2018. The findings showed that 195 of the 591 springs were dry, 12 could not be located in the field, and 361 of the 591 springs were perennial.

Table 2. Details of main wadis in Jordan [53].

Name	Catchment Area (km^2)	Average Rainfall (mm/year)	Base Flow (MCM/year)	Flood Flow (MCM/year)	Total Flow (MCM/year)
Wadi Arab	246	154.0	1.70	4.00	5.70
Wadi Ziglab	100	70.0	7.64	0.38	8.02
Wadi Jurum	23	15.0	8.53	0.29	8.82
Wadi Yabis	122	85.0	2.50	1.49	3.99
Wadi Kufrinja	103	80.0	6.91	1.08	7.99
Wadi Rajib	95	70.0	4.99	1.12	6.11
Wadi Shueib	193	90.0	7.92	1.96	9.88
Wadi Kafrein	159	88.0	12.40	2.80	15.20
Wadi Hisban	88	35.0	3.46	1.23	4.69
Zarqa Ma'in	269	67.0	17.24	2.95	20.19
Wadi Karak	199	43.0	5.89	1.29	7.18
Wadi Mujib and Wala	6727	884.0	31.38	33.62	65.00
Wadi Hasa	2603	334.0	26.26	5.47	31.73
Wadi Feifa	162	30.0	3.91	0.39	4.30
Wadi Kuneizerh	217	38.0	1.43	0.57	2.00
Wadi Dahel	107	20.0	0	0.22	0.22
Wadi Fidan	287	51.0	1.64	0.18	1.82
Wadi Bweirdh	513	125.0	0.80	0.22	1.02
Wadi Musa	165	30.0	0	0.17	0.17
Wadi Hawwar	245	37.0	0	0.28	0.28
Wadi Abu Barqa	141	12.0	0	0.46	0.46
Wadi Rukaya	210	18.0	0	0.34	0.34
Wadi Yutum	2323	73.0	0	0.53	0.53

When taking into account the influence of changing climates, the steady rise in the number of dry springs since 1987 is a sign of ongoing groundwater resource exploitation [45]. However, there were a few reported cases of increasing discharge from some springs, which was attributed to groundwater recharge from leaky water supply networks [12]. The 5-year average spring discharge distribution shows that high recharge areas have high spring discharge, and springs from individual aquifers follow the same discharge variation [45]. In 2016, the share of springs in the drinking and irrigation water supplies was 20.41 MCM and 21 MCM, respectively [8]. There were only 23 springs that provided drinking water [8,45], the majority of which were situated in the northern highlands close to Amman, Zarqa, and Balqa; farther north, in Ajlun, Jarash, and Irbid; and a few springs located in Karak. Although there is a lot of discharge, it is important to note that bacterial pollution prevents many running springs from being used for drinking water [45].

3.2. Nonconventional Water Resources

Different nonconventional water resources are considered potential sources of water supply in Jordan. These include treating wastewater, harvesting water, and desalinating brackish water and seawater. Below is a brief description of these resources.

3.2.1. Treated Wastewater

Approximately 94% of Jordanians have access to fresh water through the public network, and 93% have access to clean sanitation services (63% through the public sewer network and 30% through other safe ways) [12]. As a pioneer in the reuse of treated wastewater, Jordan treats 90% of its annual wastewater production (around 178.2 MCM) at 32 wastewater treatment plants to ensure compliance with irrigation and industrial reuse regulations. This wastewater is then either directly or indirectly used in agriculture [12]. The two tables that follow (Tables 3 and 4) provide an overview of the current state of wastewater treatment plants, their characteristics, and the ultimate use of treated wastewater.

3.2.2. Water Harvesting

In terms of nonconventional water sources, Jordan primarily depends on rainfall. A sizeable portion of Jordan's water budget is made up of the amounts lost to evaporation from soils and temporary open water bodies [49]. Over a large area, rainwater is dispersed and, if properly collected, could significantly increase the nation's water reserves. There are many uses for this water, but agriculture is the first of them. Water harvesting methods can generally be divided into two categories: (1) macro-catchment, floodwater harvesting, and diversion methods and (2) micro-catchment methods, where the catchment area and the cropped area are separate but close to one another [55]. Micro-catchment, as defined by Boers et al. (1986), is a system with a collection area that is less than 100 m in length. On the other hand, macro-catchment methods gather runoff water from hillsides or small, dry watersheds [56]. The Jordanian government has undertaken extensive efforts to maximize the efficient utilization of rainwater resources. This includes the construction of large dams, collectively capable of holding 338.3 million cubic meters of water (as detailed in Table 5), and the implementation of various smaller water harvesting projects such as desert dams, earthen ponds, and concrete ponds (as outlined in Table 6). Jordan faces a significant challenge with water loss due to evaporation, which accounted for a staggering 93% of the total annual rainfall in 2020, as mentioned previously [14]. The loss associated with evaporation from the ten main dams in Jordan on sunny and windy days amounted to about 800 thousand cubic meters in 2015 [57]. In response to this concern, the Jordan Valley Authority (JVA) is contemplating the introduction of a hollow spherical cap system into major dams to curtail water evaporation. It is important to note that water from these dams, if not employed for agricultural purposes, naturally flows downstream to other regions or is preserved in alternative reservoirs. Additionally, there is an estimated collection of 7 million cubic meters of water from households and 15 million cubic meters from desert and rural areas, contributing to water conservation efforts.

Table 3. Characteristics of wastewater treatment plants in Jordan [49,54].

Plant	Designed Capacity (m^3/Day)	Operation Year	Effluent Biochemical Oxygen Demand over 5 Days (BOD_5)
Abu Nuseir	4000	1986	1100
Aqaba-Mechanical	12,000	2005	420
Aqaba-Natural	9000	1987	900
Baqa	14,900	1987	800
Ekedar	4000	2005	1500
Fuheis	2400	1997	995
Irbid Center	11,023	1987	800
Jerash-East	9000	1983	1090
Jiza	4000	2008	800
Karak	5500	1988	800
Kufranja	9000	1989	850
Lajoon	1000	2005	1500
Ma'an	5772	1989	700
Madaba	7600	1989	950
Mafraq	6050	1988	825
Mansorah	50	2010	
Meyrad	10,000	2011	800
Mutah and Adnaniyyah	7060	2014	
North Shouna	1200	2015	1200
Ramtha	7400	1987	1000
Salt	7700	1981	1090
Samra	360,000	1984, 2008 [a]	650
Shallaleh	13,750	2014	762
Shobak	350	2010	1850
South Amman	52,000	2015	750
Tafila	7500	1988	1050
Tal Mantah	400	2005	2000
Wadi Arab	21,023	1999	995
Wadi Esseir	4000	1997	780
Wadi Hassan	1600	2001	800
Wadi Mousa	3400	2000	800
Zaatari MBR	1600	2015	1130
Zaatari TF	1726	2015	1130

[a] year of expansion.

Table 4. The use of treated wastewater [49,54].

Plant	Type of Treatment					Treated Wastewater Use										
						Irrigation										
	Activated Sludge	Oxidation Ditch	Trickling Filter	Membrane Bioreactor	Stabilization Ponds	Food	Palm	Nurseries	Windbreakers	Forest Trees	Polo Fields	Olive	Fruit Trees	Ornamental Plants	Landscape	Industrial
Jiza	*					*				*				*		
Karak	*					*				*		*				
Kufranja	*		*			*				*		*				
Lajoon					*	*										
Ma’an	*					*						*				
Madaba	*					*		*				*				
Mafraq					*	*										
Mansorah					*											
Meyrad	*											*	*			
Mutah and Adnaniyyah	*					*										
North Shouna					*											
Ramtha	*					*										
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South Amman	*					*						*				
Zaatari TF			*													
Abu Nuseir	*													*		
Aqaba-Mechanical	*														*	*
Aqaba-Natural					*		*		*						*	
Baqa			*								*	*				
Ekedar					*							*	*			
Fuheis	*					*						*				
Irbid Center																
Jerash-East	*											*	*			
Tafila																
Tal Mantah	*		*													
Wadi Arab	*															
Wadi Esseir		*										*				
Wadi Hassan	*							*				*	*			
Wadi Mousa	*					*						*				
Zaatari MBR				*												

* indicates that the specific type of treatment or wastewater use is applicable to the corresponding location in the table.

Table 5. Dams design capacity, storage, inflows, and outflows in 2020 [14].

Dam	Design Capacity (MCM)	Total Inflows (MCM)	Total Outflows (MCM)	Storage, End of 2020 (MCM)
Wehdeh	110	61.56	53.17	13.75
Wadi Arab	16.8	11.36	9.04	5.23
King Talal	75	156.6	169.05	34.87
Zeqlab	4	0.91	0.57	0.9
Kufranjeh	7.8	16.74	16.21	3.69
Karameh	55	4.1	1.26	23
wadi Shueib	1.4	18.29	18.39	1.42
Kafrain	8.5	18.56	18.28	4.08
Zrqaa maeen	2	1.6	1.73	0.22
Allajon	1	0.8	0.75	0.13
Tanour	16.8	7.15	6.63	2.37
Wala	8.2	20.73	21.15	5.52
Mujeb	29.8	26.2	29.12	7.74
Karak	2	1.94	1.82	0.23
Total	338.3	346.54	347.17	103.15
Percentage of storage from design capacity				30.5%

Table 6. Water harvesting projects (desert dams, earth ponds and concrete ponds) [14].

Water Harvesting Type	Count	Design Capacity (MCM)
Desert dams (constructed)	63	96.55
Concrete ponds	65	0.295
Earth ponds (constructed)	276	25.2
Earth ponds (under construction)	6	0.268
Total	410	122.45

3.2.3. Desalination of Brackish and Seawater

The most promising nonconventional method for increasing the nation's water resources appears to be the use of brackish water, either for direct consumption or after desalination. Numerous sources of brackish groundwater have been identified in diverse regions across the country. Tentative estimates from MWI of stored volumes of brackish groundwater for the major aquifers suggest immense resources, but not all of these quantities will be usable. As such, when referring to statistics about brackish water, the quality, quantity, and location of this resource need to be carefully studied to assess its potential for utilization.

Modern desalination technologies applied to brackish water offer effective alternatives in a variety of circumstances. According to reports from the Jordanian Ministry of Water and Irrigation, the quantity of brackish water, which is extracted from saline layers such as the Zarqa Group layer and includes the water of the Abu Al-Zeghan wells field, reached 3.69 MCM after desalination to be pumped into the water network and used for municipal purposes [49]. As for the desalination of seawater in the Aqaba Governorate, the quantities of water produced after desalination were estimated at 3.12 MCM. Thus, the total amount of nonconventional water for the year 2019 was about 185 MCM, which corresponds to 13% of the total water sources in Jordan [49].

4. Present and Future Trends in Jordan Water Resources

Water law and resource ownership in Jordan are governed by the Water Authority Law of 1988, which was amended by Law No. 22 of 2014. According to Article 25 of the law, all water resources, including surface and groundwater, regional waters, rivers, and internal seas, are considered state-owned property and cannot be used or transferred except in compliance with this law [23]. Nevertheless, the law also facilitates the issuance of licenses to water users and the formation of water user associations. The licensing of water users is provided by the Ministry of Water and Irrigation, which is responsible for overall water resource management in Jordan [24].

The licensing process involves the issuance of permits to water users, which specify the amount of water that can be used and the conditions under which it can be used. The permits are issued for a specific period, and the water users are required to renew them periodically. The permits also specify the fees that the water users are required to pay for the water they use [22]. Water users in Jordan are required to pay for the water they use, and the rates are set by the Water Authority of Jordan based on the cost of water production, treatment, and distribution [25]. The rates are reviewed periodically to ensure that they reflect the actual cost of water production and distribution. The government has also implemented a tariff structure that provides different rates for different categories of water users, such as households, commercial, and industrial users [26].

According to the most recent data from the Ministry of Water and Irrigation's 2019 water budget report, as shown in Table 7, the available water from all resources in 2019 was 1104.8 MCM, distributed as 54.4% groundwater, 30.8% surface water, 14.5% treated wastewater, and 0.3% sea desalinated water, which is used mainly for domestic and agricultural purposes (almost 95%), as shown in Figure 4 [49]. However, a notable concern lies in the largely unregulated extraction of groundwater and the presence of high levels of non-revenue water (NRW) [58,59]. NRW, often resulting from leaks, theft, or metering inaccuracies, refers to water that is produced and transported but not billed to customers. This leads to a critical issue where the estimated water demand may significantly fall short of the actual water usage. To address these issues comprehensively, the water sector in Jordan is not only governed by a robust legal framework but also requires sustained efforts to ensure the efficient management, allocation, and regulation of its vital water resources [16,59].

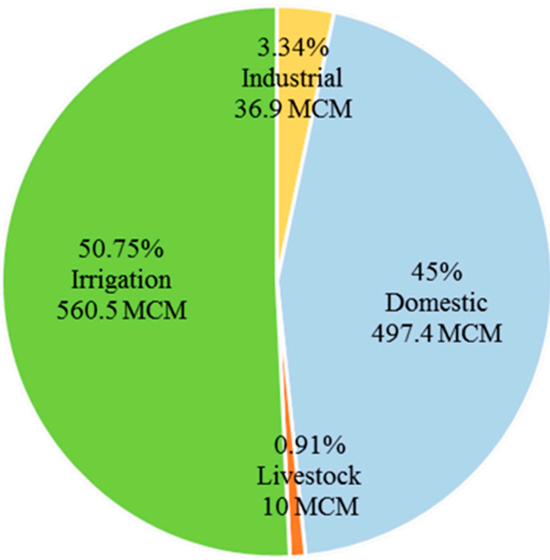

Figure 4. Water uses for 2019 (created based on [49]).

Table 7. Water budget (MCM) in 2019 [49].

Water Source	Domestic	Irrigation	Livestock	Industrial	Total
Surface water	140.54	184.14	8.1	7.66	340.44
Jordan Valley	116.74	141.14	0	7.48	265.36
King Abdullah Canal (KAC)	78	101.71	0	0	179.71
Sothern Ghor and Wadi Araba	38.74	39.43	0	7.48	85.65
Highlands	23.8	43	8.1	0.18	75.08
Springs	21.67	15	0	0.18	36.85
Baseflow and floods	2.13	28	8.1	0	38.23
Treated wastewater (TW)	0	157.4	0	2.5	159.9
TW registered in JV	0	114	0	0	114
TW registered in HL	0	43.4	0	2.5	45.9
Groundwater	355.02	219	1.97	25.41	601.4
Renewable GW	235.14	190.23	1.91	20.7	447.98
Nonrenewable GW	116.18	28.77	0	4.71	149.66
Desalination	3.7	0	0	0	3.7
Sea desalination	1.81	0	0	1.31	3.12
Total	497.37	560.54	10.07	36.88	1104.9

Jordan relies heavily on groundwater, with 54.4% of all uses and 59% of domestic supplies. Figure 5 illustrates that even though renewable aquifers account for the majority of the groundwater supply (74.5%), those aquifers have been extensively exploited above their safe yields, as shown in Table 8, which has led to declining water quality, rising pumping costs, and the drying up of numerous wells in the central and northern regions [46,49]. Every year, many new wells are drilled to replace the dry ones. In addition to the more than 3208 legal wells that are currently in operation, there are a large number of illegal wells as well [14].

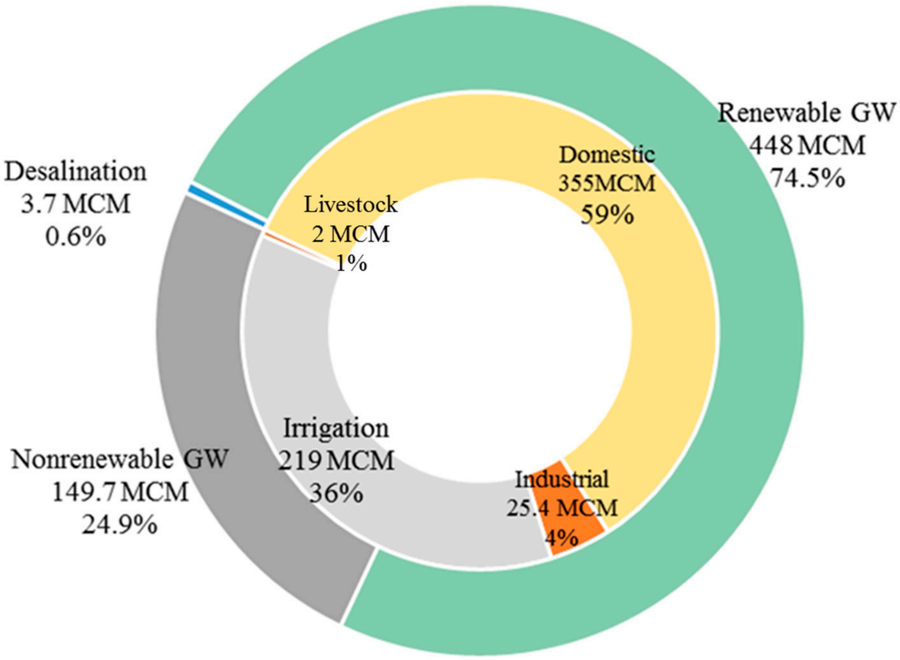

Figure 5. Groundwater sources and sectoral use for 2019 (created based on [49]).

Table 8. Quantities of groundwater extracted from Jordanian water basins and their safe yields in 2019 [49].

Ground Water Basin	Extraction (MCM)								Safe Yield (MCM)	Balance (MCM)	Safe Yield %	Number of Wells
	Domestic		Livestock Remote Areas	Industrial	Agriculture		Recreation	Total				
	Private	Governmental			Private	Governmental						
Yarmouk	0.75	14.46	0.14	0	17.71	16.65	0	49.71	40	−9.71	124.3	237
Wadi Araba south	0	0	0.05	0	8.14	1.18	0.03	9.4	5.5	−3.9	170.9	57
Wadi Araba North	0.03	1.14	0.8	0	3.95	0.5	0	6.42	3.5	−2.92	183.4	35
Jordan Valley	0.24	9.87	0.06	0.02	14.41	0.47	0	25.07	21	−4.07	119.4	352
Jordan Rift Side Wadis	0.41	40.44	0.01	0	2.93	0.06	0	43.85	15	−28.85	292.3	140
Jafer	0.37	14.42	11.63	0	9.15	0	0	35.57	27 [a]	−8.57	131.7	177
Hammad basin	0.02	1.32	0.03	0	0.2	0	0	1.57	8	6.43	19.6	10
Disi	0	116.18	0	0	25.93	2.84	0	144.95	125 [b]	−19.95	116.0	112
Dead Sea	1.2	44.94	7.33	0.56	25.14	4.57	0.25	83.99	57	−26.99	147.4	467
Azraq basin	1.46	20.81	1.14	0.33	30.17	0	0	53.91	24	−29.91	224.6	574
Amman Zarqa	4.79	81.83	4.22	1.05	71.65	0	0.05	163.59	87.5	−76.09	187.0	1022
Total	9.27	345.41	25.41	1.96	209.38	26.27	0.33	618.03	413.5	−204.53	149.5	3183

[a] The safe yield for the renewable portion of the Jafer is 9 MCM, and its nonrenewable portion is 18 MCM for 50 years (MWI, 2016). [b] The Desi aquifer is nonrenewable, and its safe yield is 125 MCM for 50 years [60].

Like groundwater, surface water is mainly used for domestic and irrigation purposes (95.4%). Approximately (77.9%) of this water originates from the King Abdullah Canal (KAC), Southern Ghor, and Wadi Araba, as shown in Figure 6.

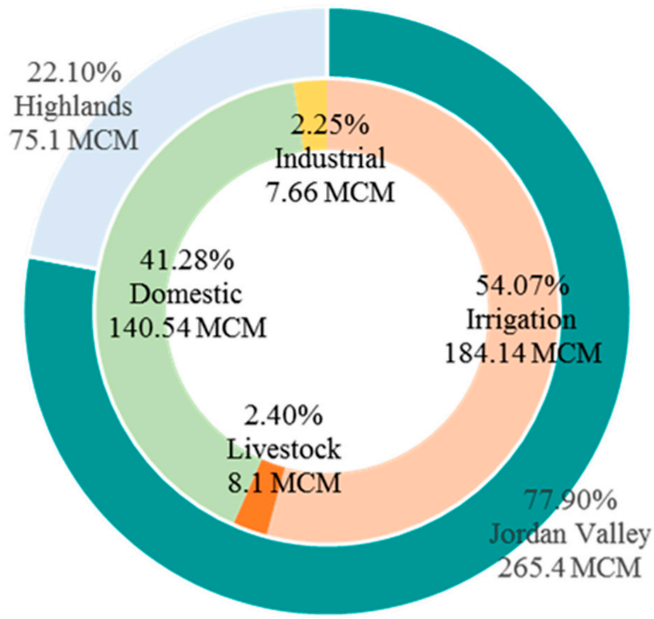

Figure 6. Surface water sources and sectoral uses for 2019 (created based on [49]).

According to reports prepared by the Ministry of Water and Irrigation in recent years, in 2019, Jordan witnessed an improved surface water budget due to increased rainfall and a decline in evaporation rates in contrast to previous years, as shown in Table 9 [49,61]. However, it is important to note that the dams remain significantly below their storage capacity at approximately 31%, as shown in Table 10.

Table 9. Surface water budget 2019 [49].

	MCM	Percentage of Rainfall	Long-Term Average	Percentage to Long-Term Average
Rainfall volume	9567.7		8191	116.8
Evaporation	8871	92.7	7582	117.0
Floods	256.8	2.3	195	131.7
Groundwater recharge	439.8	4.6	419	105.0

Table 10. Storage capacity and water reserves of dams in 2019 [49].

Dam	Design Capacity (MCM)	Storage (MCM)	% of Design Capacity
Wihdah	110	5.3	4.82
Wadi Alarab	16.79	2.84	16.91
Zeglab	3.96	0.56	14.14
Kufranjah	7.8	3.2	41.03
King Talal	75	47.59	63.45
Alkarameh	55	20.16	36.65
Wadi Shueib	1.43	1.51	105.59
Alkafren	8.45	3.81	45.09
Zarqa Maen	2	0.35	17.50
Alwaleh	8.2	5.91	72.07
Almojeb	29.82	10.2	34.21
Altanor	14.7	1.9	12.93
Alajoun	1	0.096	9.60
Alkarak	2	0.112	5.60
Total	338.25	103.6	30.63

The current and projected future water shortages, new technologies, and the significance of sustainable development have all increased awareness of the use of nonconventional water sources. Significant nonconventional resources include treated wastewater and desalinated sea and brackish water [58]. Currently, the reclamation of treated wastewater and the desalination of sea and brackish water are the only nonconventional water resources in Jordan's water budget. Treated wastewater is primarily used for irrigation (98.4%), with a tiny amount used in industry (1.6%). Most of the treated wastewater comes from wastewater treatment plants (WWTPs) registered in the Jordan Valley (71.3%), as shown in Figure 7. Because of the small coastal area in Jordan, seawater desalination has been considered on a limited scale (0.3%) as a source. The desalinated seawater is only used in Aqaba for domestic and industrial applications, as shown in Figure 8.

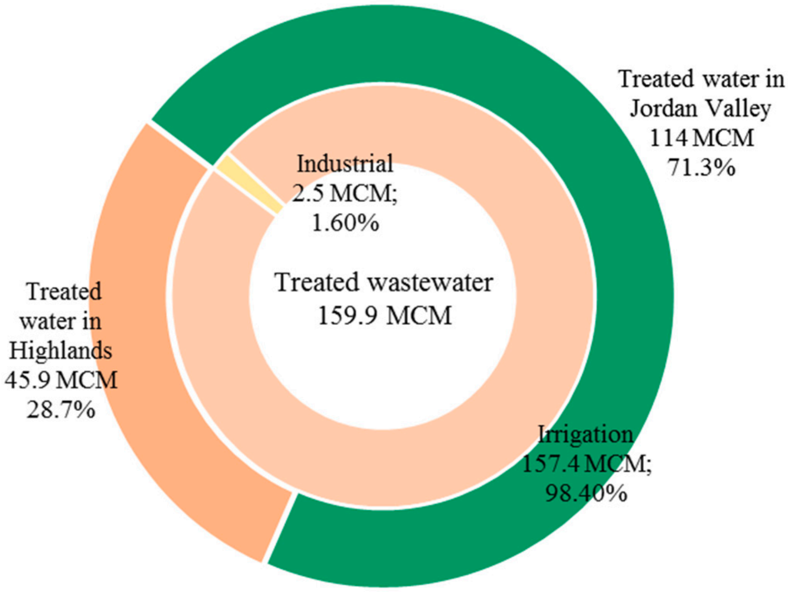

Figure 7. Wastewater use and sectoral applications for 2019 (based on [49]).

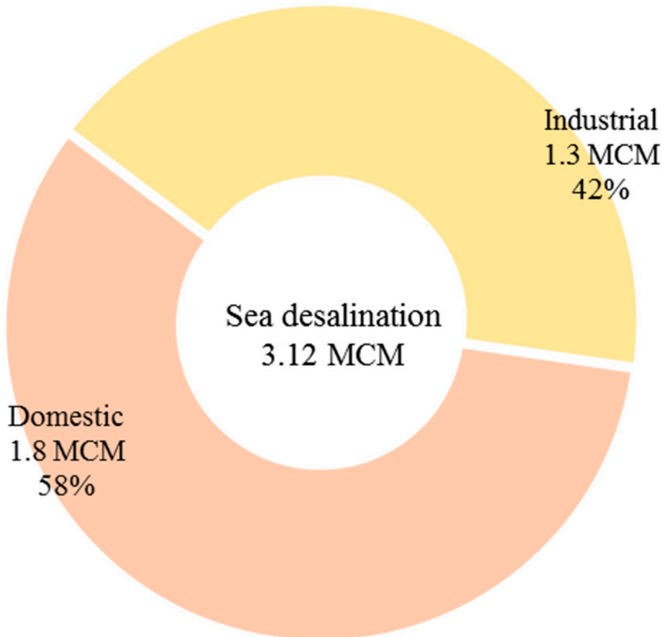

Figure 8. Uses for seawater desalination in 2019 [49].

Figure 9 shows that total and sectoral water use has steadily increased over the last decade, except for the industrial sector, which has slightly decreased. Similarly, the overutilization of resources has increased to meet the increasing demand. The main reasons behind the growing domestic and agricultural water demand could be attributed to government mismanagement of water resources [62], the expanding process of urbanization, the expansion of agriculture activities [45], the inefficient agricultural sector [62], the negative effects of climate change, as well as the influx of refugees [2,58].

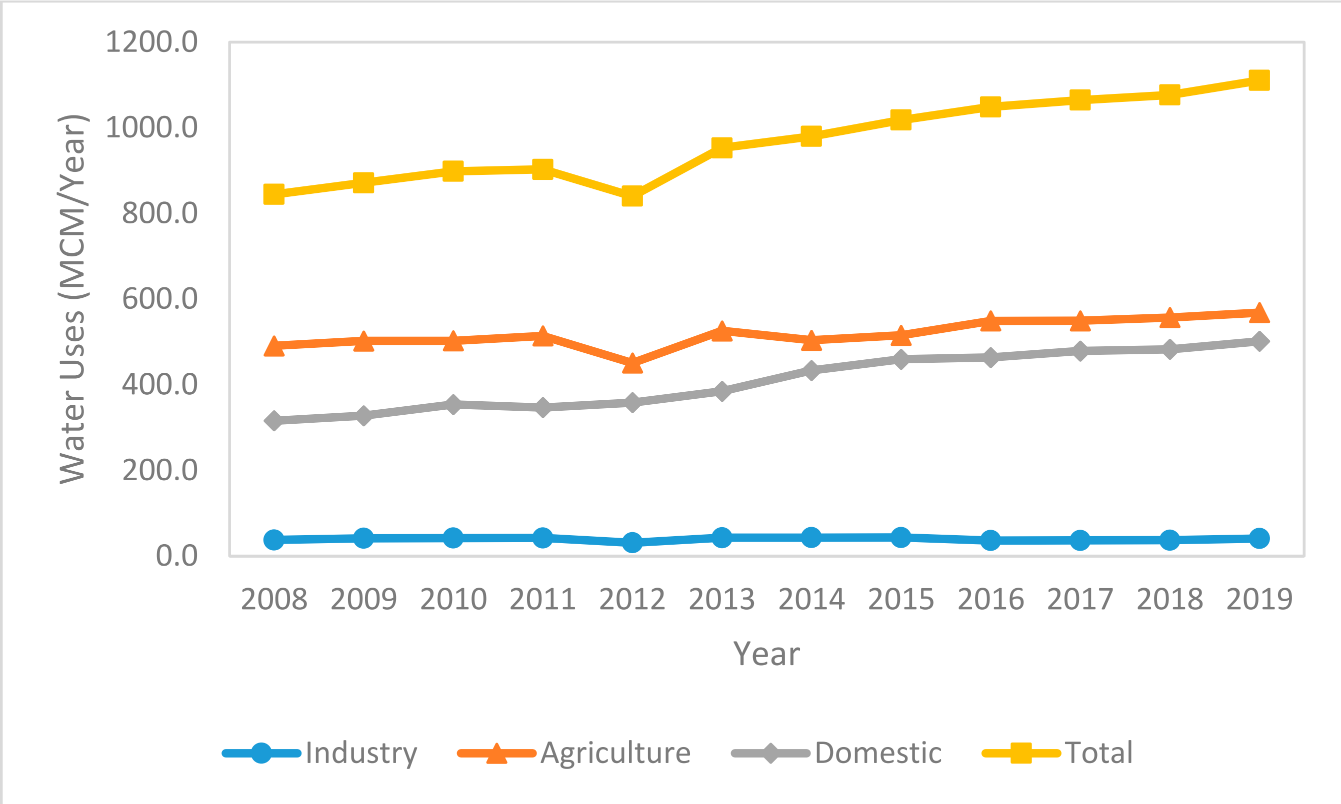

Figure 9. Annual water uses (MCM/year) for different purposes [17,49,61].

The total water demand is expected to increase from 1455 MCM in 2020, according to Jordan's water strategy, to 1548 MCM in 2025, as shown in Table 11. It appears that Jordan is directly overexploiting its water resources by 10% to 100% or more. Jordan's energy mix was projected to consist of 54–62% oil and oil shale through 2020, with a growing demand for energy at a rate of 3% annually [63,64]. Additionally, Jordan has been pursuing nuclear power as a source of energy, with a goal of generating 6% of its electricity from nuclear power by 2020 [65]. The production of oil shale and nuclear power are both water-intensive processes, and the increase in energy demand from these sources is expected to lead to an increase in water demand in Jordan. According to the National Water Strategy of Jordan, power generation from oil shale and nuclear power plants already exceeds 4% of the total surface and groundwater in Jordan, amounting to about 39 MCM in 2023 [9]. Therefore, it is expected that the future water demand from oil shale and nuclear power in Jordan during the period 2020–2025 will increase from 25 MCM in 2020 to 70 MCM in 2025, as shown in Table 11. In terms of additional capital expenditures and the requirement for subsidies, the rising cost of water delivery is adding to the fiscal budget's already heavy load. A tariff increase cannot close the entire difference between the current tariff levels and complete cost recovery. Most water users find full-cost recovery to be prohibitively expensive, particularly low-income residents. Therefore, water subsidies may be reduced. The current average cost of bulk water supply for priority domestic use is USD 0.49 per cubic meter. However, as water shortages worsen and energy costs increase, this cost will rise to USD 1.34–1.55 per cubic meter or even higher because of the difference between demand and supply.

Table 11. Future water demand during the period 2020–2025 (MCM) [22].

Year	2020	2021	2022	2023	2024	2025
Municipal, industrial, tourist demands	730	737	746	755	766	778
Irrigation demand	700	700	700	700	700	700
Oil shale and nuclear power demand	25	48	48	48	70	70
Total demand	1455	1485	1493	1503	1536	1548

5. Challenges of Water Resources in Jordan

5.1. Climate Change, Low Precipitation, and Aridity of the Region

Water storage and investment policies are intricately interlinked with the repercussions of climate change on water resources in Jordan [26,51]. The evaluation of these repercussions is imperative for informed decision-making concerning water resource management and infrastructure advancement. In the Jordanian context, these policies assume a pivotal role in alleviating the consequences of declining precipitation, escalating evaporation rates, and mounting aridity [26,51].

The Climate Risk Profile Jordan report supplies forecasts for prospective evapotranspiration and precipitation levels in Jordan under diverse emissions scenarios until the year 2080. The report predicts a substantial reduction in annual precipitation, amounting to a decline of 20–28% in the southern and northeastern regions of Jordan and a decrease of 10–16% in the northwestern and central regions by 2050. Furthermore, the report signifies a surge in air temperatures by up to 4.5 °C by 2080 compared to pre-industrial levels, exacerbating the susceptibility to heatwaves and jeopardizing the populace's capacity to engage in gainful activities [66]. Consequently, strategic investments in water storage and infrastructure become imperative to counteract the anticipated drop in annual rainfall. Such investments can serve to ameliorate the repercussions of decreased precipitation and provide indispensable water reserves to satisfy the burgeoning water demands.

Simultaneously, these policies assume a critical role in the prudent management of groundwater resources, which are undergoing rapid depletion owing to the combined influences of meager precipitation and overextraction [7]. The implementation of sustainable water storage solutions and the adoption of efficacious management protocols have become essential to preserve the quantity and quality of the available groundwater resources.

Moreover, the robust evaporative force intrinsic to Jordan's climatic conditions is underscored by a publication in Scientific Research Publishing. This source elucidates that climate change is progressively exerting an impact on Jordan's water resources, with the potential evaporation force varying from 1800 mm/year in the cooler northwestern zones to 4200 mm/year in the southeastern regions, three and one hundred forty times the amount of average annual precipitation, respectively, as shown in Figure 10 [67]. These challenges are exacerbated by the fact that the once-significant Jordan River has dwindled in significance due to heightened demands from neighboring nations and overextraction practices [68].

The ramifications of climate change extend to the agricultural sector, where reduced precipitation and escalated evaporation contribute to heightened demand for crop irrigation. Furthermore, an escalation in the frequency of extreme weather events, encompassing heavy precipitation and snowstorms, is expected, leading to flash floods and fluctuations in temperature extremes [69]. These alterations will exert far-reaching effects on Jordan's water supply, inducing augmented soil erosion, inundations, and sediment accumulation in rivers, dams, and reservoirs. Additionally, the foreseeable scenario suggests increasing water salinity and variability, potentially resulting in a reduction in major river flows such as the Jordan River by up to 80% [70].

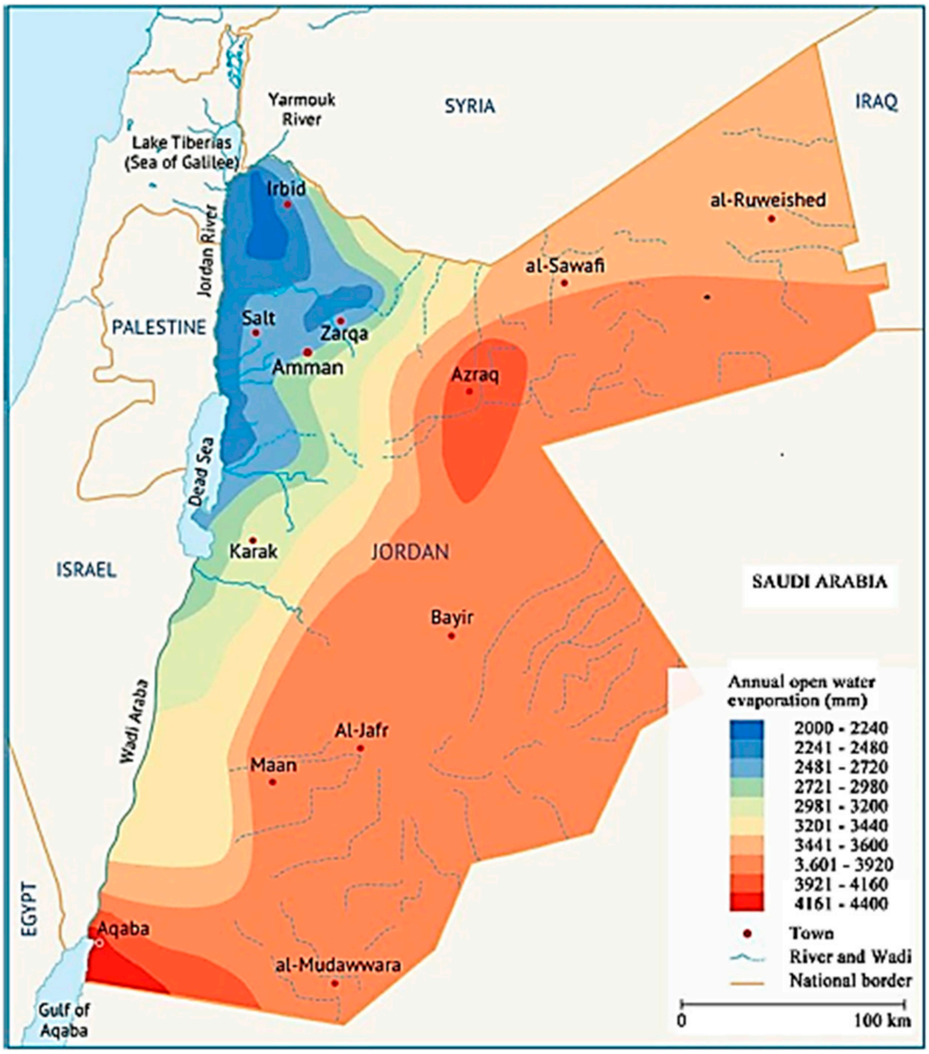

Figure 10. Distribution of potential evaporation across Jordan in mm/year [71].

5.2. Population Growth, and Refugees

Jordan, like many Middle Eastern nations, confronts formidable challenges related to its water resources, driven by population growth and the influx of refugees [72,73]. With an estimated population of 10.5 million for 2021 and a projected surge to 19.04 million by 2050, the nation faces increasing strain on its water supply [54,55]. Hosting a substantial number of refugees has further heightened water demand, especially in refugee camps where resources are limited [74]. To address these challenges, Jordan has been implementing measures such as constructing new water storage facilities and expanding water treatment and desalination plants [37,75], despite these efforts, the challenges of Jordan's water resources remain significant.

The population growth is estimated at 2.1% for Jordanians and 2.2% to 2.9% for other nationalities living in the country [73,76]. The influx of 1.4 million Syrian refugees alone was a major factor in increasing water demand by more than 40%, adding to the burden of the already water-scarce northern and central regions. Despite having the highest rainfall rates and significant water resources, these regions host nearly 90% of the population, and they grapple with rising water supply costs. The refugee crisis compounds Jordan's pre-existing water woes, driven by overextraction, pollution, and inadequate resource management [14]. The rapid population growth pushes the brink of water depletion closer, demanding immediate efforts to ensure water resource sustainability to avert a looming crisis.

5.3. Limited Financial Capacity

Jordan has limited financial capacity to carry out significant projects. Critical projects with low cost–benefit ratios should be the focus of difficult decision-making. Raising fees and taxes could aid in funding the upkeep of current water infrastructure as well as the creation of new projects. However, because of how politically and socially sensitive this is, it is unlikely that there could be any significant rate increases. Jordan relies heavily on external funding sources (e.g., foreign private enterprises, NGOs, foreign aid, and foreign governments). However, foreign funders' priorities do not always coincide with those of the government's goals.

5.4. Public Awareness and Education Campaigns

Jordan is currently grappling with a severe water scarcity crisis where the water demand exceeds the available supply. Nevertheless, a significant portion of the Jordanian population remains largely unaware of the gravity of this issue. Several factors contribute to this lack of awareness, including the normalization of water scarcity, insufficient dissemination of information, a false sense of security resulting from water management efforts, more immediate concerns taking precedence, psychological detachment, and ineffective communication and education campaigns.

To address this awareness gap, the government has embarked on a series of initiatives. These measures encompass media campaigns, the integration of water crisis-related content into educational materials, and the increased involvement of religious leaders in community engagement. These efforts are aimed at cultivating a deeper understanding of the issue and facilitating the effective implementation of sustainable water management strategies.

The ongoing water scarcity challenge in Jordan has created a complex scenario wherein a substantial portion of the population remains uninformed about the critical nature of the problem. While over 98% of Jordanians presently have access to secure water supply services, and sanitation services extend to more than 63% of the population, the government is actively working to raise this coverage to approximately 70% in the near future through initiatives led by the Ministry of Water and Irrigation [8].

Nonetheless, it is imperative to acknowledge the prevalent issues of water supply interruptions and unreliability across Jordan. The statistical figures related to connection rates often do not accurately convey the reality that numerous urban and rural communities routinely experience extended periods without access to piped water, sometimes lasting for weeks.

Confronting these challenges, the government continues to grapple with the task of educating the public about the escalating water crisis and encouraging citizens to adopt water conservation practices. This underscores the pivotal role of education, not only in imparting practical water conservation techniques but also in explaining why water conservation is a matter of paramount significance.

5.5. High Levels of Non-Revenue Water

Jordan's water resources are facing various challenges, with high levels of NRW being one of the major concerns. The levels of NRW in Jordan have reached as high as 60% in some areas, affecting the country's water supply system by reducing the availability of water and increasing scarcity [77]. This also has a negative impact on the economy, as the government invests large amounts in water production and transportation infrastructure but is unable to recover the costs due to high NRW levels. The government has taken measures to reduce NRW, including repairing and replacing aging water distribution networks, installing new metering systems, and educating customers on reducing water waste. However, high NRW levels remain a significant challenge, and the accompanying financial loss for the government is approximately USD 500 million per year [78]. Projects for the reduction in NRW were ongoing through June 2023, with a budget of USD 60 million [29]. In addition, the International Monetary Fund (IMF) has approved a USD 1.3 billion extended arrangement under the Extended Fund Facility for Jordan, which includes efforts to limit losses in the energy and water sectors [79]. The exact amount of effort or money spent on these measures is not specified in the search results, but the 2022 budget for Jordan forecasted USD 15 billion in state spending, including funding for water conservation initiatives [80].

5.6. Managing Shared Water Resources

Jordan confronts a multitude of challenges when it comes to water resource management and allocation with neighboring countries. One of the key predicaments is the uneven distribution of water resources among Jordan and its neighbors, which has created a significant burden on the country's water security. The country has limited water resources and is highly reliant on shared rivers and aquifers with neighboring countries, which account for approximately 26% of the country's total water resources, and most of these resources originate outside the country's borders [14]. Throughout its history, Jordan has faced challenges in accessing its equitable share of these shared resources due to the actions of upstream neighbors who have overexploited these water sources. Here, we will examine the key provisions and agreements that have been made between Jordan and other countries regarding these shared water resources. The Johnston Plan, proposed in 1955, aimed to address the allocation of water in the Jordan River Basin among the riparian states. The plan's proposed allocations were as follows: 55% to Jordan, 26% to Israel, and 9% each to Lebanon and Syria [81–83]. Mediated by the United Nations, the countries agreed to these allocations, but the plan was never ratified. Instead, riparian states pursued unilateral projects, disregarding the outlined allocations. In 1994, Jordan and Israel signed a peace treaty that included an agreement on the distribution of Jordan River water. Despite the Johnston Plan allocating the largest share to Jordan, the treaty stipulated that Israel would transfer only 50 million cubic meters per year (MCM/yr) of water from Lake Tiberias to Jordan. The treaty also encouraged the two countries to cooperate in addressing the ongoing water shortage in the Jordan River Basin by reducing waste, preventing contamination, and developing additional water resources [83]. Jordan and Syria signed their first bilateral agreement regarding the Yarmouk River in 1953. While the agreement did not specify water resource allocations, it addressed irrigation and power generation through the construction of dams on the river. It also led to the establishment of a bilateral commission for dispute resolution. A 1987 treaty modified the agreement, with Jordan committing to cover the costs of the main irrigation dam (Maqarin or Wihdah Dam) and Syria permitting the construction of additional dams on the river system to provide water to Jordan [83–85]. A new commission was established with fewer oversight powers. Disputes arose over Syria's increased construction of dams and groundwater pumping, affecting the flow of the Yarmouk River into Jordan. The agreement primarily covered surface water resources, leading to controversy and misunderstandings. In 2015, Jordan and Saudi Arabia reached an agreement on the shared Disi fossil aquifer, known as Disi on the Jordanian side and Saq on the Saudi Arabian side. The aquifer primarily lies within Saudi Arabia. The agreement prohibited well drilling within a 10 km buffer zone on each side of the border and outlined measures to prevent contamination of the shared resource. The agreement stipulated that the aquifer should be used for domestic and municipal purposes, not for agriculture, reflecting Jordan's efforts to pump water from the Disi aquifer for domestic and municipal use [83]. These agreements and arrangements have played a significant role in shaping Jordan's access to shared water resources. The history of these agreements has been marked by complexities, disputes, and evolving circumstances. Jordan's challenges in securing its water resources have also been influenced by the actions of its upstream neighbors, which have sometimes led to deviations from the intended allocations and usage conditions. As water resources continue to be a critical issue in the region, effective management and cooperation among neighboring countries remain vital for the sustainable use of these shared resources.

5.7. Unsustainable Agricultural Water Use

The government of Jordan is faced with a significant challenge in achieving sustainable water use in the agricultural sector. Agriculture accounts for a substantial 80% of total water withdrawal and more than half of the country's freshwater resources [86,87]. Remarkably, agriculture employs only 3% of the labor force and contributes a mere 5% to the gross domestic product [88]. Despite efforts to improve water efficiency and reduce waste, the high water demands of agriculture have led to the overexploitation of groundwater, resulting in declining water tables and increased salinity levels. To address this issue, the government has promoted the adoption of more efficient drip irrigation systems and implemented water-pricing policies aimed at reducing excessive water use and encouraging efficient practices. However, water stress continues to persist, exerting pressure on the availability of irrigation water, leading to higher costs and reduced crop production available for export [89].

6. Opportunities toward a More Sustainable Future

After analyzing the current situation of the water sector in Jordan from various angles, in addition to studying the adapted projects and measures to ensure the security of the water sector, engineering and social science suggestions are presented to deal with the outstanding water security issues and to reach a more robust and sustainable water sector.

6.1. Enhancing Water Supply

Ensuring a consistent supply of high-quality freshwater is crucial for addressing Jordan's water crisis sustainably. The current usage of freshwater resources is unsustainable and needs immediate attention. Strengthening the water distribution network and minimizing non-revenue water loss should be prioritized to mitigate the further reduction in Jordan's already limited water supply. Investing in wastewater treatment plants, rainwater harvesting, and optimizing virtual water utilization can help to alleviate stress on surface and groundwater resources. Additionally, the establishment of desalination plants is vital for the long-term solution and has the potential to substantially increase the overall water availability. However, the search results also suggest that Jordan has limited financial capacity to implement major projects, and hard choices need to be made to target critical projects with low cost–benefit ratios. Increasing tariffs and taxes could help to finance the maintenance of existing water infrastructure and the development of new projects, but this is politically and socially sensitive, and substantial rate increases would probably not be feasible. Therefore, creative solutions are needed to fight Jordan's water scarcity, and the government should consider expanding cooperation with foreign investors and international donors to address the issue.

6.1.1. Curbing Water Losses through Improved System and Governance

Jordan faces significant challenges in its water management, including high levels of water loss and inadequate governance structures. The government has implemented various initiatives aimed at reducing water losses and strengthening governance in the water sector to achieve a more sustainable future for the country. One of the key initiatives to reduce water losses has been the modernization of the water supply system, including the installation of modern water meters, leak repair, and a centralized billing system [67]. The government has also established the Water Authority of Jordan to regulate the sector and ensure efficient and sustainable water use. The Authority has implemented policies to promote public–private partnerships and investment in the water sector. Despite these efforts, water loss was estimated at 50% in 2020, compared to 43% in 2010, and was divided into more than 50% as administrative losses and less than 50% as technical losses from networks. Consequently, there is a substantial amount of work ahead to enhance the water sector further and maintain progress toward a more sustainable future [14]. This includes the implementation of technology-dependent management tools such as farmers' associations, the control of illegal water tapping, and improved negotiation skills for water disputes. In addition, the water sector must also improve its training programs and prevent both natural and human-caused accidents in water supplies and infrastructure. Laws and regulations should be strengthened to include strict control systems for all significant water infrastructure facilities, including effective control against vandalism and destruction [90]. These efforts, along with continued investment and commitment from all stakeholders, will be necessary to achieve a more sustainable future for Jordan's water sector.

6.1.2. Harnessing Desalination for Sustainable Water Resources

Desalination is a technology that involves removing salt and minerals from the sea or brackish water to make it usable for various purposes. This solution has gained popularity in countries with limited water resources, such as Jordan, due to its reliability and cost-effectiveness. Jordan's desalination sector exhibits substantial potential for expansion, largely owing to the country's coastline and abundant solar energy resources. Desalination offers a dependable supply of fresh water, alleviating the strain on limited freshwater reserves and creating new avenues for economic development. Nonetheless, it is important to acknowledge that the process demands considerable energy, substantial capital, and pervasive costs and may adversely affect the marine environment. Jordan has an opportunity to operate desalination and water transmission systems with renewable energy, given the falling technology costs and increasing use of renewable energy [91], most notably the proposed National Water Carrier Project. However, the National Water Carrier Project, which aims to move water from Aqaba to Amman, must ensure public–private partnership (PPP) financing, limit environmental impacts, and be completed on time and within budget. Additionally, alternative remedies are needed in the interim to offset the output from the desalination plants [26,92].

6.1.3. Harnessing the Potential of Wastewater Treatment and Reutilization

The utilization of wastewater treatment and reuse represents a highly promising strategy with significant potential to contribute to the attainment of sustainability goals in Jordan. Recent years have witnessed an increasing recognition of the importance of harnessing treated wastewater for various purposes, including irrigation, industrial operations, and even potable water supply. Statistical data obtained from the Ministry of Water and Irrigation indicate a notable rise in the overall volume of treated wastewater generated in Jordan, increasing from 150 million cubic meters in 2018 to an impressive 170 million cubic meters in 2020 [93]. This growth can be attributed to several factors, such as the escalating water demand, the decline in conventional water resources, and an enhanced awareness of the significance of water conservation and management. The successful application of treated wastewater for irrigation purposes is particularly noteworthy, with several large-scale projects being implemented across the country. For instance, the projects in Jordan have effectively employed treated wastewater for crop irrigation, including vegetables and fruits, yielding remarkable outcomes [94]. The projects have significantly alleviated pressure on freshwater resources and contributed to mitigating water scarcity in the region. Furthermore, the utilization of treated wastewater in the industrial sector holds great promise, offering diverse benefits such as reduced reliance on potable water, energy conservation, and greenhouse gas emission reduction by eliminating the need for long-distance water transportation. Notably, the incorporation of a wastewater treatment and reuse system by the Jordan Phosphate Mines Company resulted in a remarkable 30% reduction in water consumption [95]. Despite the considerable benefits derived from wastewater treatment and reuse, several challenges need to be addressed. Firstly, substantial investments in infrastructure and technology are crucial to ensure optimal wastewater treatment that aligns with international health and environmental standards. Secondly, both the public and private sectors need to be sensitized to the importance of this approach and encouraged to adopt it extensively. Lastly, societal and cultural obstacles related to the acceptance of treated wastewater for various purposes, especially for potable water supply, must be adequately addressed. The utilization of wastewater treatment and reuse in agriculture is pivotal for bridging the gap between water supply and demand, with research indicating that it can increase water availability by up to 48% [96]. Despite the Jordanian government's efforts to enhance the potential of wastewater treatment plants, only 14.5% of the total water resources are currently considered usable after treatment [14]. There is still considerable room for improvement, particularly in promoting the use of treated water, delivering it to users, and implementing substantial capital investments in sewage treatment facilities. Furthermore, implementing policies and regulations that incentivize the use of treated wastewater and discourage the use of freshwater for non-potable purposes could have a significant impact.

6.1.4. Embracing Rainwater Harvesting for Sustainable Water Supply

Rainwater harvesting (RWH) refers to the collection, storage, and use of rainwater for various purposes, including irrigation, domestic use, and industrial processes. This technology has been in use for centuries, but advancements in recent years have made it more accessible, cost-effective, and energy-efficient. As such, it has become a popular solution for countries with limited water resources, such as Jordan. According to data from the Jordanian Ministry of Water and Irrigation, the number of households practicing RWH in Jordan increased from 10% in 2010 to 30% in 2020 [97]. This growth was due to many factors, including increased awareness of the technology, financial incentives, and the availability of affordable RWH systems. The total amount of RWH in Jordan also increased, reaching over 10 million cubic meters per year. Rainwater harvesting offers several benefits to Jordan's water sector. Firstly, it provides a reliable and consistent source of fresh water that is not subject to the same fluctuations as surface and groundwater resources. This helps to mitigate water stress and reduce the chances of crop failure. Secondly, it reduces the pressure on the country's limited freshwater resources, which are being overexploited due to high demand. Finally, it opens up new opportunities for economic growth as it enables the country to expand its agriculture and industrial sectors. This not only contributes to Jordan's economic prosperity but also fosters job opportunities and enhances overall prosperity. It is crucial to acknowledge that various ecosystems and wildlife rely on the continuous flow of water from springs, dispersed rainwater, and instream flows. Preserving these resources and conserving water is of paramount importance for these ecosystems, given their intrinsic value and their contribution to the tourism sector.

There are several positive models of RWH from other countries that Jordan can learn from. For example, rainwater harvesting is a traditional and reviving technique for collecting water for domestic uses in the United Kingdom [98]. In Australia, RWH is widely used for irrigation and domestic purposes, and the government provides financial incentives to households that install RWH systems [92]. These examples demonstrate the potential of RWH to address water scarcity and the importance of government support and financial incentives in promoting its adoption.

Despite its benefits, RWH also has some drawbacks that must be considered. Firstly, the quality of the collected rainwater may be affected by pollutants in the atmosphere, such as air pollution and dust. Secondly, the cost of installing and maintaining RWH systems can be high, especially in rural areas where access to financing is limited. These factors must be carefully managed to ensure that RWH remains a sustainable solution. The government is expected to establish a financing mechanism under the Green Growth Action Plan 2021–2025 to promote RWH initiatives and raise public awareness [26], but cooperation with various sectors and public acceptance of the technology are still challenges.

6.1.5. Optimizing the Utilization of Virtual Water

The term "virtual water" refers to the amount of water embedded in the production process of goods and services, including water used for crop cultivation, energy generation, and product manufacturing. This concept has gained significant attention as a strategy to address water scarcity and promote sustainable water management. In Jordan, virtual water is increasingly recognized as a potential solution to the country's water crisis and a pathway for economic development. According to data from the Jordan Water Project (JWP), in 2020, the virtual water content of Jordan's exports exceeded 1 billion cubic meters [99]. Key export commodities in Jordan, such as fruits, vegetables, and livestock, have substantial virtual water content, contributing to the country's water footprint. By reducing the virtual water content of these products, Jordan can reduce its water consumption and alleviate strain on its finite freshwater resources. One example of utilizing virtual water to promote sustainability in Jordan is the implementation of water-saving technologies and practices in agriculture. This includes the adoption of efficient irrigation systems like drip irrigation and the cultivation of drought-resistant crops that require less water for growth. By reducing water usage in agriculture, Jordan can conserve its limited water resources while simultaneously enhancing agricultural productivity [100]. Another approach to advancing sustainability in Jordan through virtual water involves promoting industries with lower water consumption and producing goods with lower virtual water content. For instance, the country can encourage the growth of industries specializing in low-virtual water products, such as high-tech electronics. Achieving a balance that allows for water conservation without financial losses is challenging but feasible through a combination of water-efficient practices in agriculture, the promotion of low-virtual water industries, and investments in water-saving technologies. This balance is essential for the long-term sustainability of both Jordan's economy and its water resources [101].

6.2. Optimizing Water Utilization

Enhancing the water supply involves a substantial investment of time and finances. Nevertheless, Jordan has the opportunity to promptly address the issue by curbing highly excessive and inefficient water consumption practices. The current state where ten out of twelve groundwater basins in Jordan are being extracted beyond their sustainable limits calls for immediate action. To mitigate this problem of overexploitation, Jordan can introduce regulations to enhance water efficiency, particularly in agriculture, raise public awareness, and reward and promote more efficient water use and behavior.

6.2.1. Improving Water-Use Efficiency in Agriculture

Improving water-use efficiency in agriculture is crucial for the sustainable development of Jordan, as the country faces increasing demand for food production and limited water resources. Precision irrigation systems, using digital technologies to deliver exactly the amount of water required for crops can significantly reduce water waste. For example, the University of Jordan's Center for Agricultural Research has developed a precision irrigation system that has shown a 25% increase in water-use efficiency [102]. Another effective solution is the promotion of drought-resistant crops, such as the new varieties of wheat and barley developed by the International Center for Agricultural Research in the Dry Areas (ICARDA), which require 30–50% less water compared to traditional crops [103]. Furthermore, employing appropriate crop management strategies like soil conservation, crop rotation, and efficient fertilization can enhance soil health, enabling crops to more efficiently absorb water. This not only reduces the necessity for excessive watering but also mitigates the potential for evaporation and salinization [104]. However, agricultural projects in Jordan are currently hindered by leaky water conveyance systems and outdated irrigation practices [105,106]. Despite the existence of advanced agricultural practices in some areas, the sector as a whole still requires improvement, particularly in terms of the use of metering systems, regular irrigation, soil moisture devices, cameras, telemetry, and leakage detection and monitoring. This will not only make more water available and increase production in both quantity and quality but also create job opportunities for trained workers. Improving the management and practices of the irrigated sector is crucial to reducing water consumption and enhancing agricultural productivity while protecting the rights of others who may benefit from the saved water. More efficient irrigation techniques that can save 30% to 50% of the current water usage are expected to result in a significant increase in agricultural output.

6.2.2. Promoting Public Awareness and Behavioral Change

Public awareness and behavioral change are crucial for creating a more sustainable future for Jordan's water resources. The government launched the National Water Strategy in 2018 to raise public awareness about water conservation and promote a sense of personal responsibility for water use. The strategy includes a nationwide water-saving campaign, which uses various media platforms to reach a wide audience and provide practical water-saving tips [107]. Additionally, the development of water conservation curricula for schools is aimed at fostering a culture of water conservation from an early age [108]. Investment in educational programs that focus on water conservation is crucial to raise public and political awareness of the current water situation. The Green Growth National Plan 2021–2025 is focused on encouraging the public to use more sustainable water alternatives, such as treated wastewater and harvested rainwater. The Ministry of Water and Irrigation has partnered with the Ministry of Education to raise awareness of water scarcity through textbooks, and other initiatives may be developed to increase public awareness in the future [26]. While domestic water use has received the majority of the attention, future campaigns must also focus on the agricultural sector. An environmental assessment can be used to protect the environment and achieve efficient water use by taking into account the effectiveness of water use, its effects on the environment and human health, public awareness, and fair pricing of water in various sectors.

6.3. Creating the Framework

The future of Jordan's water resources is facing obstacles due to the lack of effective coordination among key stakeholders. In order to adequately address the long-term water situation in Jordan, it is crucial to engage in comprehensive collaborative planning and make decisions based on reliable evidence. These decisions should encompass investment and management strategies, taking into account high-quality data and the impact of climate change. Furthermore, the involvement of all relevant parties, such as water users, investors, and donors, is vital. While finance is critical to realize infrastructure projects, fair and inclusive management plans can maximize the utility of existing resources and infrastructures. Given its downstream location, Jordan's water supply is contingent upon cooperation with neighboring countries. The current procedures fail to account for the growing population in Jordan and prove to be ineffective and inadequate. Hence, enhancing cross-border collaboration becomes imperative for discovering enduring solutions to Jordan's water challenges.

6.3.1. Advancing Joint Planning for Sustainable Water Management in Jordan

Advancing joint planning for sustainable water management in Jordan is imperative for ensuring the country's long-term water security and socio-economic development in the face of increasing water stress. Collaborative efforts involving government agencies, local communities, and international organizations can optimize water resources and mitigate the risks associated with water scarcity. By adopting integrated and holistic approaches, considering the interconnectedness of water resources and their impact on agriculture, industry, and domestic use, Jordan can develop sustainable strategies that ensure equitable distribution and minimize conflicts among sectors. Incorporating the private sector is crucial for ensuring financial stability, improving operational efficiency, stimulating innovation, and creating job prospects. Moreover, increased inclusion of marginalized communities bolsters the overall effectiveness of programs. Joint planning facilitates the exchange of knowledge, expertise, and best practices among stakeholders, empowering decision-makers and water managers to make informed choices based on evidence-based practices. Sharing information on water management techniques, innovative technologies, and successful case studies from local and international contexts optimizes resource utilization and minimizes waste. Additionally, joint planning strengthens the resilience of Jordan's water sector by anticipating and preparing for potential disruptions through adaptation measures and infrastructure upgrades. Cooperation on water-related research and development promotes innovation and scalable, sustainable solutions that can benefit other water-stressed regions. Implementing these measures is essential for addressing the challenges within Jordan's water network and achieving sustainable water management goals [26,109].

6.3.2. Enhancing Data Quality and Accessibility

Enhancing the quality and accessibility of data is of paramount importance for the Jordanian Government and the research community. Access to comprehensive data is crucial for developing more informed solutions in the realm of water resource management. At present, the availability of essential hydrological data and related information remains limited and often obscured by paywalls, presenting a significant hindrance to effective planning and decision-making [110].

Hydrological data serve as a linchpin for proactively preparing for extreme events by identifying high-risk areas susceptible to water leakages and other related challenges. Additionally, day-to-day hydrological data play a vital role in optimizing the management and distribution of Jordan's precious water resources, thereby assisting in the identification of leaks and unauthorized water connections [92].

However, it is not only the government and researchers who face difficulties due to this data gap. Academics and researchers working on mapping Jordan's past, present, and future water situation are similarly frustrated by the relative scarcity of available data and resources. This shortage obstructs their efforts to develop the necessary information and data for informed analysis and policymaking. Moreover, the current channels for sharing and disseminating data among key stakeholders, including ministries, are insufficient, further exacerbating the issue [92].

Acknowledging the gravity of this challenge, the government has initiated measures to bolster its data collection capabilities. As indicated in the Green Growth National Action Plan 2021–2025, collaborative efforts between the Ministry of Water and Irrigation (MWI) and the Water Authority of Jordan (WAJ) are underway to implement an updated Geographic Information System (GIS) specifically tailored for newly constructed or rehabilitated water networks. This GIS system is anticipated to efficiently monitor and store data, substantially enhancing the quality and accessibility of information for informed policymaking. Additionally, the plan outlines the implementation of a Joint Work Programme (JWP) model, which is poised to serve as a pivotal strategic planning tool [26,92].

Looking forward, long-term solutions involving advanced and distributed technologies, such as the Internet of Things (IoT) and supervisory control and data acquisition (SCADA) systems, offer promising opportunities for elevating data collection, monitoring, and management processes. For example, remote sensing techniques can be deployed on water network pipes to promptly detect physical leaks. This real-time information can then be relayed to the relevant authorities, significantly reducing response time and improving decision support. Moreover, IoT holds the potential to establish a comprehensive data repository, serving as a robust foundation for evidence-based policy interventions [92,111–113]. The combination of these initiatives will undoubtedly enhance the quality and accessibility of water-related data, empowering stakeholders to make more informed and effective decisions in the field of water resource management.

6.3.3. Promoting Resource Management Amongst Neighboring Regions

Water resource cooperation between neighboring countries is essential for promoting a more sustainable future for water resources in Jordan and the region. By sharing resources, exchanging information, and utilizing new technologies, countries can effectively manage their water resources and improve water security and access. Examples of such cooperation include the Disi Water Conveyance Project in Jordan and the Joint Technical Committee for the Allocation of the Yarmouk River Waters between Jordan, Syria, and Iraq [47,114]. These initiatives have led to increased water supplies, resolved conflicts, and improved cooperation, as well as stimulating economic growth and job creation. Additionally, initiatives such as the Red-Dead Conveyance Project [115] and the Joint Water Commission (JWC) between Jordan, Israel, and the Palestinian Authority have been instrumental in promoting regional cooperation and coordination on water-related matters [116], while the Joint Technical Committee for Water (JTCW), established by the League of Arab States, has helped to build trust and confidence among neighboring countries [117]. Jordan has a unique opportunity to establish a water-energy nexus (WEN) with neighboring countries, particularly Israel and Palestine, to cultivate a mutually beneficial and sustainable partnership. The implementation of the WEN aims to create a regional community centered around desalinated water and solar energy, fostering resource cooperation and enhancing regional stability [43]. With its expansive landmass suitable for large-scale solar power plants, Jordan holds a favorable position to engage in resource-based negotiations. A notable example of collaboration is the water-for-renewable-energy declaration of intent signed in November 2021 between Jordan, Israel, and the United Arab Emirates (UAE). Under this agreement, the UAE plans to construct a solar energy farm in Jordan with an installed capacity of 600 MW of renewable power that will be available for Israel to feed into their grid. In return, Israel would supply Jordan with 200 million cubic meters of desalinated water. This exemplifies the potential for leveraging renewable energy and water resources to forge sustainable partnerships within the region [92,118].

7. Conclusions

Jordan faces a pronounced water scarcity crisis, primarily attributable to its arid region and the increasing variability in climate conditions, particularly with regard to precipitation and rising temperatures. Despite the country's ongoing efforts to manage its limited water resources over recent decades, persistent water security issues prevail due to a lack of proactive decision-making by policymakers. Consequently, the decline in both the quality and quantity of water resources has resulted in social and economic hardships for the population. In order to alleviate water stress, Jordan is implementing a range of measures, including the expansion of water availability through desalination and dam construction, as well as reducing water consumption by enhancing public water supply networks. Nevertheless, water stress levels remain alarmingly high, necessitating the implementation of short-term demand-side interventions and long-term supply-side reforms to ensure a sustainable water future. However, these endeavors encounter financial and governance obstacles, such as the substantial costs associated with supply-side interventions and the limited awareness and incentives for water consumption reduction on the demand side. To overcome these challenges, Jordan must attract private investments by enhancing the business cases and transforming interventions into profitable models. Moreover, significant investments and coordination among domestic stakeholders, neighboring countries, and the international donor community are imperative to raise awareness and foster reduced water consumption. This comprehensive approach holds the potential to secure a sustainable future for water resources in Jordan, ensuring access to clean and safe water for its citizens.

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