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Challenges to Sustainable Water Management in Jordan

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Abstract

Water crisis in Jordan is the most critical common limitation to the country's financial development and advancement. The crisis is exacerbating with time, because of the quick increase in population that is associated with sudden refugee fluxes and because of the inefficient use of water which both have made exceptional demands on water resources. The importance of this paper lies in estimating the effectiveness of technical water management and assessing the extent of management capacity in the reduction of water scarcity in the Kingdom of Jordan.

Despite the governmental efforts to manage the country's limited water resources and the relentless search for alternative supplies, the adopted political, financial, and technical responses are still limited to maintain a balance between demand and supply. Several of the inspected adaptation measures include desalination, reuse of treated wastewater and greywater, storm water collection, rationale/efficient water use, among others. The results indicated that these measures can reduce the impact of water crisis; however, they are not enough to compensate for the kingdom's future demands and for a better financial development. Accordingly, only mega-projects are preferred which may sound the only solution to escape the bottleneck of the crisis. A multidimensional incorporation of all water related parties at all levels of the citizens, the government, and politicians is required. It is important to direct the policies of the water sector towards water resilience and governance. One of the most important actions to consider is to make proactive and contingency plans enhanced by the policies and legal frameworks at the national level to ensure a sustainable water resilience and governance.

Keywords: water, crisis, management, adaptation, wastewater, desalination, red-dead sea project, Jordan.

1. Introduction

Jordan, a country of the Middle East region, is located to the east of the Mediterranean Sea with an average area of about 89,210 km^2. The country is bordered by Syria from the north, Iraq from the northeast, Saudi Arabia from the southeast and the south and by Palestine from the west (Figure 1). Due to the dry and semi-arid climate, the sound administration of water resources has been an issue in Jordan since the establishment of the Kingdom of Jordan in 1946.

From the physiographical standpoint, the country can be divided into four districts: (1) The Ghors (marshes) in the western portion of the country, which is comprised of three zones: The Jordan Valley which begins at Lake Tiberius in the north, the swamps along the Dead Sea and the Wadi Araba which expands in a southerly heading to the northern shores of the Red Sea (total region: 5000 km^2); all of the Ghor regions are found to be below the sea level (2) The highlands, which run from the north to the south at an elevation of between 600 m and 1600 m over the sea level (total zone: 5510 km^2), (3) The plains, which extend from the north to the south along the western borders of the desert (Badiah) (total region: 10,000 km^2), and finally (4) The desert region (Badiah) in the east, which is an expansion of the Middle Eastern desert (total region: 68,700 km^2) (MoEnv, 2015).

Jordan's climate is characterized by long hot and dry summers and wet cold winters. The temperature increases towards the south, with the special case of a few southern highlands. Precipitation shifts impressively with area, primarily due to the country's topography (Al-Kharabsheh, 2013). The precipitation diminishes from 600 mm at the northwestern part of the country to less than 100 mm at the extraordinary southeastern deserts; more than 93% of the country receives a precipitation of less than 200 mm (Figure 2 and Table 1). Looking over time; and due to climatic change impacts and drought events, the annual precipitation volume is being negatively deviated from the long term mean (Table 2). Based on the third national communication report to UNFCCC, Jordan is expected to have a warmer and drier climate with a potential increase in air temperature from +2.1 °C to +4°C and a decrease in the annual rainfall from 15% up to 35% in 2100 (MoEnv, 2014).

In 2017, the yearly precipitation for the country was of 8165 MCM, from which 93.5% are lost through evaporation, while 2.1% is considered floods and 4.4% flows as groundwater recharge (MWI, 2017). The level of the Dead Sea falls each year by 85 centimeters (cm), due to broad water utilization in the Dead Sea basin. Watered soils along the Jordan Valley are showing signs of salinization since the characteristic floods are no longer accessible to flush the flooded land and filter the salts (MWI, 2017).

Jordan is among the countries with the scarcest renewable water resources per capita in the world; it ranked the second poorest in 2017, with only 100 m^3 per capita per year which appears to be diminishing each year, and is expected to reach almost 80 m^3 in the year 2020 (MoEnv, 2014; World Bank, 2007; MWI, 2017). This is far below the

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per capita water resources accessible in other countries of the Middle East, which may reach almost 1000 m^3 (FAO, 1995). Water demand surpasses the accessible renewable water supply, to the extent that the groundwater table in nearly the entire country is falling. The demand on water is rising due to populace development, higher living measures, refugee problems, the extension of inundated lands, and industrialization (UNICEF, 2006).

As a result of all of the aforementioned circumstances including the increasing demands on the water supply due to the population growth and the high needs being exacerbated and magnified by the sudden refugees' influxes into the country, in addition to the fact that Jordan's surface water resources are shared by the neighboring countries whose control has partially deprived Jordan of its fair share of water, the gap between water supply and demand is becoming bigger and wider creating a "Jordanian water resources' scarcity" which is considered the most important environmental and social challenge facing Jordan nowadays. The current use already exceeds the renewable supply, which is covered by over-drafting renewable and nonrenewable supplies especially at highland aquifers, resulting in lowered water tables and a declining water quality.

Several ideas and measures have been highlighted recently and even implemented to reduce the pressure on the water demands and supplies by all sectors including a rational use of water, water recycling, improvement of irrigation techniques, reducing water loss in distribution, water harvesting, and desalination; however, a sustainable solution to meet all demands has not been reached yet. The objective of this paper is to highlight the water needs, the designed and implemented solutions, and discuss their sustainability to overcome the national actual needs overtime.

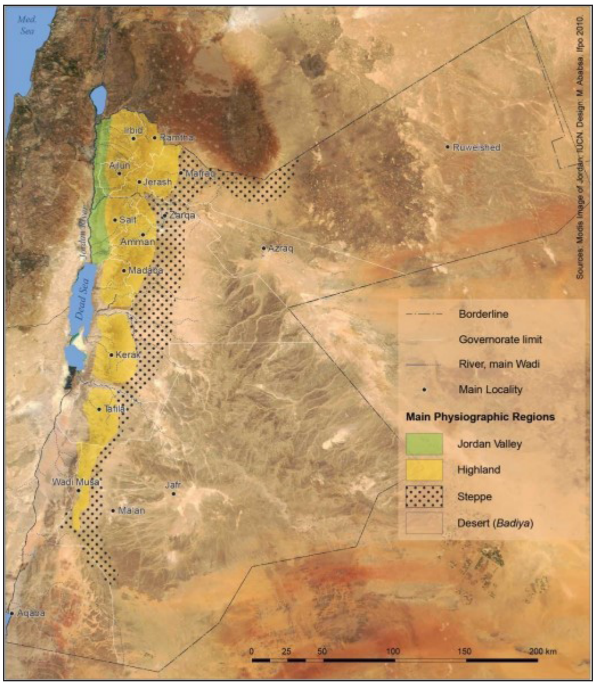

Figure 1. Location Map of Jordan. (Ababsa, 2013)

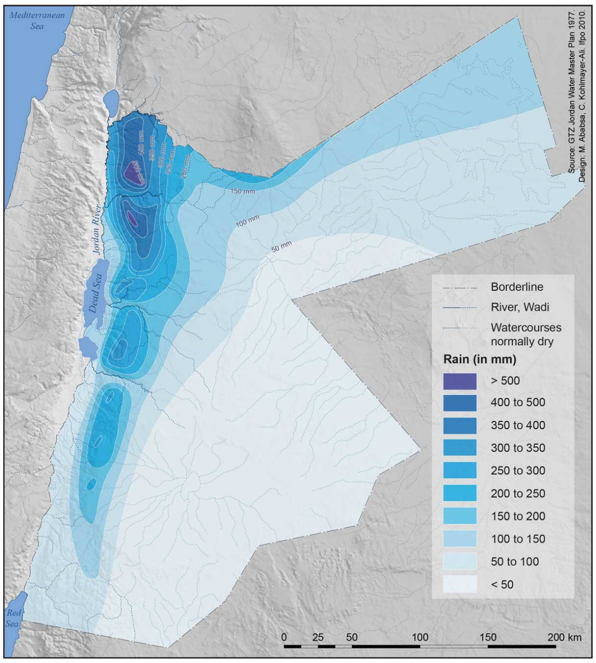

Figure 1. Location Map of Jordan. (Ababsa, 2013)

Table 1. Climatic classification agreeing to precipitation dispersion in Jordan.

Zone	Annual Rainfall (mm/year)	Area (km^2)	Area as a percentage of the total area of Jordan
Semi- humid	500-600	620	0.7 %
Semi- arid	300-500	2,950	3.3 %
Marginal	200-300	2,030	2.2 %
Arid	100-200	20,050	22.3%
Desert	< 100	64,350	71.5 %
Total		**90,000**	**100 %**

Table 2. Annual precipitation deviation from a long term rate (MWI, 2017).

Year	Rainfall Volume (MCM)	Long-term Rate (MCM)	Deviation from Long term Rate
2006/2007	7683	8313	-630
2007/2008	5194	8269	-3075
2008/2009	6379	8243	-1864
2009/2010	8728	8249	479
2010/2011	6477	8225	-1748
2011/2012	5943	8195	-2252
2012/2013	8120	8194	-74
2013/2014	7228	8181	-953
2014/2015	8884	8191	693
2015/2016	9483	8207	1276
2016/2017	8165	8206	-41

2. Population Growth

Based on the logistic modeling of the growth rate in Jordan (equation 1), it seems that the sudden refugees' influxes are considered the most unstable growth factor affecting the population growth and the related political and financial development in the country (Figure 3). The populace development is around 3.4% not counting variances caused by universal political occasions, while it exceeded 5% when counting sudden refugee influxes.

$$Population = \frac{\left(\frac{a}{b}\right) \times c}{\left(c + \left(\frac{a}{b} - c\right)\right) \times e^{-(a \times year - 1952)}} \quad . . \text{ Equation 1}$$

where a and b are birth and death rates, c is the population at time zero (in this case the intial data is 1952).

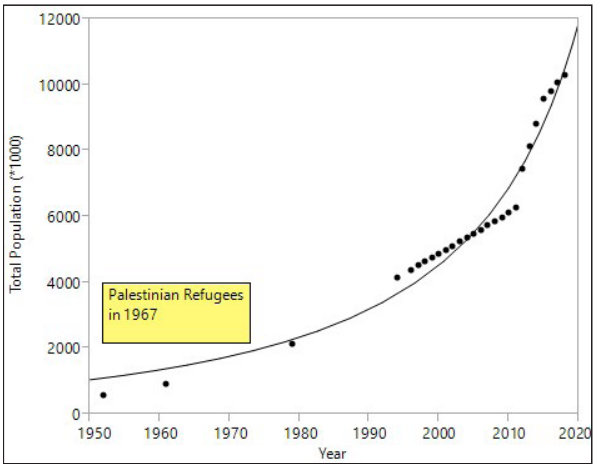

Figure 3. Population growth rate in Jordan including the sudden refugee fluxes.

These sudden fluxes are considered a threat to the water security of the kingdom of Jordan not only temporarily through managing the available resources and connection networks, but may have consequences even on the long run. According to MWI (2017), the increase in demand for domestic water in the northern governorates has increased by 40% over the last few years as a result of hosting Syrians. Each Syrian refugee costs the water sector around 440JD/year. These impacts will worsen for generations and decades to come, if solutions are not found to ensure the sustainability of the available resources. One of the most important consequences that have been explained so far is the lack of water stability, lack of extension, raising tariffs, and the environmental impact associated with the inability to maintain the available resources, the decrease of the underground level, and the ensuing increase in poverty, unemployment, and indebtedness.

Approximately 90% of the population of Jordan is concentrated in the northern and central portions of the country, where precipitation is most elevated and most of the water resources are available there. About 90% of the drinking water supplied to the capital comes from sources distanced 125 to 325 km away and elevated up to 1200m with five pumping stages, while 42 % of the drinking water supplied to the northern governorates comes from sources distanced 20 to 76 km away and elevated up to about 1200m with four pumping stages (which indicates the higher cost for the water supply).

3. Available Water Resources and their Employments

Utilized water in Jordan is derived from three main resources; 27% of the water is derived from surface water, 59% from groundwater, and 14% from treated waste water. Fresh water resources in Jordan consist mainly of groundwater and surface water. Treated wastewater and brackish water desalination are other important non-conventional resources that help bridge part of the gap between supply and demand especially in the municipal and agricultural sector. The different available water resources in Jordan are as follows:

3.1 Jordan's Surface Water Resources

Surface water is dispersed unevenly in fifteen basins (Figure 4). The biggest source by distance is the Yarmouk River, which is located to the east of the Jordan Valley Basin. This river provides nearly 50 % of Jordan's surface water resources; however, due to the Syrian crises and the huge consumption from the Syrian side, the flow rate of this river is decreasing substantially. The normal yearly base-flow of all rivers in Jordan is approximately 451.4 MCM and the normal yearly flood stream is around 255.5 MCM. Flood flows represent 3.04 % of the total yearly precipitation (Table 3).

The Yarmouk River drains into the basaltic plateaus of the Hauran in Syria, an area of fair rainfall and strong runoff. The typical monthly flows of the Yarmouk River at Adasiyia are between 4 and 5 MCM during the dry season and between 17 and 40 MCM during winter. About 110 MCM per year of the Yarmouk River, Al-Wehda dam and the Mukhieba Wells are diverted to KAC, 70 MCM of which are pumped to the Zai water treatment plant which supplies west Amman. The remaining 40 MCM are used for irrigation in the Jordan valley (MWI, 2013). The Zarqa River is the second largest tributary of the Jordan River. The mean rainfall for the watershed is 273 mm, and the median annual stream flow is 70 MCM. In the year 2013, the annual discharge was a record of 135 MCM (AFD and CMI, 2011).

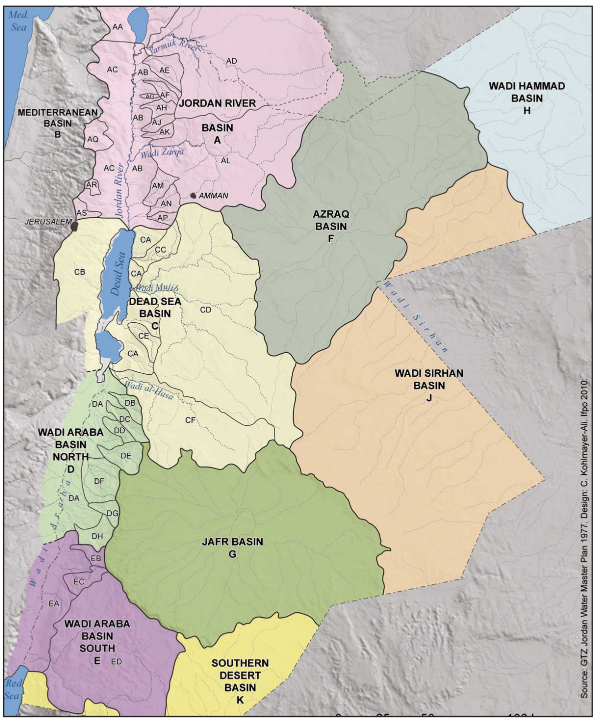

Figure 4. Surface Water Basins in Jordan (MWI Files).

Table 3. Surface Water Basins in Jordan (From GTZ Water Master Plan, 2004).

No	Surface Water Basin					Basin Code	Catchment Area (km2)	Average Annual Rainfall (mm/year)
	Basin/Area			Basin Name				
1	Dead Sea Basin	Jordan River Subbasin		Yarmouk		AD	1,426	280
2				Amman-Zarqa		AL	3,739	220
3				Jordan Valley		AB	780	270
4				Jordan Valley Rift Side Wadis	North	AE, AF, AG AH, AJ,AK	946	490
5					South	AM, AN, AP	736	370
6		Dead Sea Subbasin	Central Basins	Mujib		CD	6,727	180
7				Hasa		CF	2,603	130
8				Dead Sea Rift Side Wadis		C	1,508	240
9				North Wadi Araba		D	2,953	180
10	Eastern Desert Basin			Azraq		F	12,400	85
11				Hammad		H	18,047	85
12				Sirhan		J	15,733	45
13				Jafr		G	12,363	45
14	Southern Basins			South Wadi Araba		E	3,742	75
15				Southern Desert		K	6,296	15
Total							90,000	100

3.2 Jordan's Groundwater Resources

Groundwater is the major water resource for municipal water use. In most urban sites, water is supplied on an intermittent, rationed basis that requires household storage in cisterns and/or roof tanks. Jordan's groundwater is dispersed across twelve basins (Figure 5). The main types of aquifers in Jordan are limestones, sandstones, and basalts (GTZ, 1995). The sum of recharge in a renewable aquifer determines the safe yield, which can be withdrawn each year without imperiling groundwater supply in the future. Numerous ponders and gauges have been carried out on groundwater resources in Jordan. Based on these, it can be concluded that the safe yield of all renewable aquifers is 275 MCM per year, while the safe yield abstraction quantity from nonrenewable groundwater for fifty years is about 143 MCM (Al-Hadidi and Al-Kharabsheh, 2015).

The number of working wells in Jordan exceeds 3211 wells; however, there are many unauthorized wells that increase the non-revenue water percentage each year. The quantity of over-pumping from groundwater is estimated at about 200 MCM. It should be taken into account that 52% of the available water is used for agriculture, and 46% of which comes from groundwater sources. Recent documentations indicate that the groundwater level in the main aquifers drops at a rate of 2 meters per year, but the decline in some depleted areas reaches 5 to 20 meters.

Jordan's major non-renewable aquifer is in the Disi region in the south, where the final major recharge happened approximately 10,000 years ago, when the climate in the region was more humid. This is the fundamental non-renewable resource directly exploited in Jordan. A few studies have concluded that the safe yield of the aquifer is 125 MCM/y for 50 years and its water quality is generally less than 500 mg/l. Other nearby nonrenewable groundwater resources are found in the Jafr Basin with a yearly safe yield of 18 MCM/y.

The request to cover the needs of the diverse divisions has expanded from 639 MCM in the year 1985 to 1279 MCM recently, and is anticipated to increase to more than 1312 MCM in the year 2020 (Table 3). The source of these requests is surface water, groundwater, and treated wastewater (Table 4). Groundwater is considered a major immoderate source amid the past period, Table 5 shows that 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 (USAID, 2009).

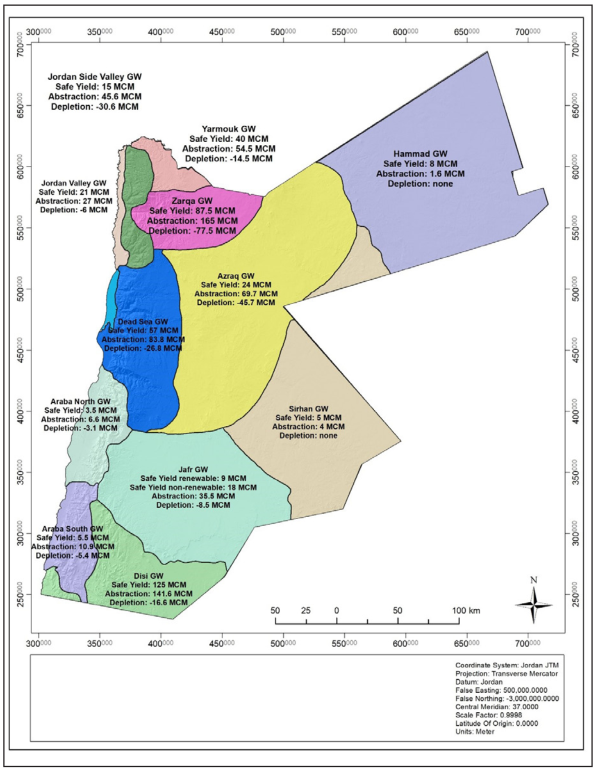

Figure 5. Groundwater Basins in Jordan.

3.3 Jordan's Wastewater Resources

The Water Authority of Jordan (WAJ) is responsible for domestic wastewater management. On the other hand, the Aqaba Water Company and the Yarmouk Water Company are responsible for the operation of the WWTP in their regional delineations. Currently, there are twenty-seven working wastewater treatment plants (WWTP) in Jordan that are designed to treat 407,930 cubic meter per day. Table 4 shows the quantities of wastewater discharged to the working WWTPs in 2017. Samra WWTP receives more than 70% of wastewater diverted to WWTPs, while the Mansourah WWTP for septic tanks receives only around 0.005% of the total wastewater discharged.

The ratio of water used in the industrial sector in relation to the total use is very small and is estimated at about 5%. In industrial states, industries usually have WWTPs or pretreatment units inside their vicinity where they work before discharging their wastewater to the central WWTPs or to other locations to be used for tree irrigation or in the nearby Wadis. Also, many industries (food processing, yoghurt, etc) are connected to the sewage network as their wastewater complies with connection requirements.

The reuse of wastewater is now regulated by several sets of standards, including ones governing the discharge of toxic materials to sewers and others that established standards for reuse of wastewater and the processing and use of sludge. Challenges facing the expansion of the re-use of reclaimed wastewater from industries include the location of these industries relative to wastewater treatment facilities, the quality of treated wastewater relative to industry standards, the cost of refining the treatment levels to higher standards, and the cost of building new conveyances from central wastewater treatment facilities to industrial sites.

Table 6. Wastewater treatment plants in Jordan (WAJ Files).

No.	Treatment plant name	Year of commissioning	Treatment technology	Design flow (m^3/day)	Actual average flow (m^3/day) 2010	Operator
1	Aqaba Natural	1987	Stabilisation ponds	9,000	6,371	AWC
2	Aqaba Mechanical	2005	Extended aeration	12,000	9,846	AWC
3	Al Baqa	1987	Trickling filter	14,900	10,209	WAJ
4	Fuheis	1997	Activated sludge	2,400	2,221	WAJ
5	Irbid Central	1987	Trickling filter & activated sludge	11,023	8,132	YWC
6	Jerash (East)	1983	Oxidation ditch	3,250	3,681	YWC
7	Al Karak	1988	Trickling filter	785	1,753	WAJ
8	Kufranja	1989	Trickling filter	1,900	2,763	YWC
9	Madaba	1989	Activated sludge	7,600	5,172	WAJ
10	Mafraq.	1988	Stabilisation ponds	1,800	2,009	YWC
11	Ma'an	1989	Extended aeration	5,772	3,171	WAJ
12	Abu Nuseir	1986	Activated sludge R, B, C	4,000	2,571	WAJ
13	Ramtha	1987	Activated sludge	7,400	3,488	YWC
14	As Salt	1981	Extended aeration	7,700	5,291	WAJ
15	Tafila	1988	Trickling filter	1,600	1,380	WAJ
16	Wadi Al Arab	1999	Extended aeration	21,000	10,264	YWC
17	Wadi Hassan	2001	Oxidation ditch	1,600	1,132	YWC
18	Wadi Musa	2000	Extended aeration	3,400	3,029	WAJ
19	Wadi as Sir	1997	Aerated lagoon	4,000	3,624	Miyahuna
20	Al Ekeder	2005	Stabilisation ponds	4,000	3,908	YWC
21	Al Lijoon	2005	Stabilisation ponds	1,000	853	YWC
22	Tall Almanta	2005	Trickling filter & activated sludge	400	300	
23	Al Jiza	2008	Activated sludge	4,000	704	
24	As Samra	1984	Activated sludge	267,000	230,606	Suez-Morganti
25	Al Merad	2010	Activated sludge	10,000	1,000	
26	Shobak	2010	Stabilisation ponds	350	100	WAJ
27	Al Mansorah	2010	Stabilisation ponds	50	15	
Total				**407,930**	**323,951**	

4. International Waterways

An International Waterway refers to a river whose streams are shared between two or more countries. Most of Jordan's water resources are shared with other countries. The Jordan River is the biggest river of the country, yet the Israelis redirect most of its water. Water allocation to riparian nations is one of the most troublesome territorial issues (GTZ, 1999). Other critical shared-water resources are the groundwater resources of North Jordan (Azraq, Yarmouk, and Amman-Zarqa basins), where a critical rate of the natural recharge likely occurs in Syria. Extra Syrian improvement of groundwater in these basins decreased the accessible safe yield to Jordan.

The Yarmouk River framework is the fundamental surface water resource. Given the extraordinary shortage of water resources in the locale, the significance of creating satisfactory water resources allocation procedures was recognized as early as the 1930s. In spite of the fact that no comprehensive agreement exists on sharing the jointly owned water resources, eleven plans for water utilization were arranged between the years 1939 and 1955. The final one was the Johnston Arrangement of 1955, which conducted a fair water-sharing plan between Jordan and Syria (World Bank, 2007).

The Peace Treaty which was signed in 1994 by Jordan and Israel guaranteed Jordan its right to an additional 215 MCM of water annually through new dams, diversion structures, pipelines, and a desalination/ purification plant. The ANNEX II of the Peace Treaty document, for Water and Related Matters contains seven articles which defined the allocation, storage, operation and maintenance, monitoring, water quality and protection, notification and agreement, and co-operation.

The agreement stipulates that during the summer period from May 15 to October 15 of each year, Israel shall receive 12 MCM, and Jordan is to keep the rest of the Yarmouk water flow. During the winter period, from October 16 to May 14 of each year, Israel is entitled to receive 13 MCM, and Jordan is to keep the rest of the flow. Furthermore, Israel is entitled to borrow an additional 20 MCM during the winter period, to be transferred back to Jordan during the next summer. With regard to excess flood waters from the Yarmouk that would otherwise flow into the Lower Jordan River, it was agreed that both Jordan and Israel are allowed to utilize this water in equal portions for their own purposes.

At the lower Jordan River, the agreement stipulates that during the summer period of each year, Jordan shall receive 20 MCM from the Lower Jordan River upstream of the Yarmouk from Israel. During the winter period, Jordan shall receive an additional 20 MCM from Israel from the LJR south of the Yarmouk. With regard to the remaining water flows in the LJR south of the Yarmouk, it was agreed that both Jordan and Israel are allowed to utilize this water in equal shares for their own purposes, provided that neither party would harm the water quality of the LJR. A Joint Jordanian – Israeli Water Committee has been established to monitor the actual water flows and water allocations.

In terms of saline springs and additional water resources, the agreement stipulates that Jordan is entitled to receive 10 MCM of desalinated water from Israel, originating from the saline springs near Lake Tiberias, provided that this is financially feasible. If so, it has been agreed not to discharge the brine into the LJR basin. Currently, this saline water is conveyed from these springs directly to the LJR through the Saline Water Carrier by Israel. The agreement confirms that Israel will explore the possibility of financing the operation and maintenance cost of supplying this desalinated water to Jordan, while Jordan will explore the possibilities to finance the required capital expenditures. Finally, the agreement includes the intension to jointly develop an additional 50 MCM of drinkable water, without yet specifying its source, for the benefit of Jordan.

Unfortunately, out of the 215 MCM, Jordan is already receiving between 55 and 60 MCM of water from across the border with Israel through a newly-built pipeline. Jordan is also entitled to build a series of dams on the Jordan and Yarmouk rivers to impound its share of flood waters. To this end, the Karama Dam in the Jordan Valley has been built to store 55 MCM of water, mainly from the Yarmouk, and its yield will be used to help irrigate some 6000 hectares in the southern Jordan Valley (Wardam, 2004; Royal Haskoning DHV, 2015).

5. Analysis of Water Demand and Supply

There is a huge gap between water demand and supply in Jordan, where the sustainable water supply is limited while the demand is rising rapidly. In 2017, the estimated water demand quantity for all sectors was 1412 MCM. Table 7 and Figure 6 show the quantities of water utilized by users from 1985 till 2017. It is apparent that most of the water is used by the agricultural sector through irrigation practices. Agriculture consumes about 53% of the total water supply; however, it accounts for 6% of Jordan's Gross Domestic Product (GDP) and 12% of this were natural products and vegetables. Around 10% of the labor force was utilized in agriculture. The Ministry of Water and Irrigation updated its strategies to hold agricultural water use at 700 MCM in the future, so a strong challenge will be to generate a greater deal of value by utilizing that amount of water

The irrigated cultivation potential in Jordan was evaluated at around 840,000 ha. Nevertheless, taking into account the possibly accessible water resources, the irrigation potential is around 85,000 ha, which also includes areas that are irrigated currently (MWI, 2008).

In spite of the fact that water system has been detailed in Jordan for an exceptionally long time, especially in the Jordan Valley, serious irrigation ventures have been executed since 1958 when the Government chose to redirect a portion of the Yarmouk River water and build the King Abdullah Canal. The Canal was 70 km long in 1961 and was expanded three times between 1969 and 1987 to reach the length of 110.5 km. The development of dams on the side channels and the redirection of the streams from other channels have permitted the advancement of irrigation over a huge region. At the same time, wells were bored in the Jordan Valley to abstract groundwater, for residential and irrigation purposes (MWI, 1997 and 1999):

Irrigation in the highlands relies on groundwater resources. The irrigation system depends on wells which are from 100 to 5,000 m deep, which convey water to the agrarian lands (JICA, 1995). There are three types of irrigation development supporters in these regions:

- Private holders who have obtained credits from the Agriculture Credit Organization (ACC) for boring, pumps, and developing water system frameworks
- Bedouin-settlement water system ventures worked and kept up by the Service of Farming and the Water Authority
- Private companies working on large-scale ventures in the southeast of the country.

Figure 6 shows that the industrial use is almost stabilized due to low investments within the country; however, the main consumer, that is the agriculture sector, is flocculating by time depending on marketing windows. On the other hand, the municipal use is increasing tremendously indicating the urge needs to compensate for the fast population growth.

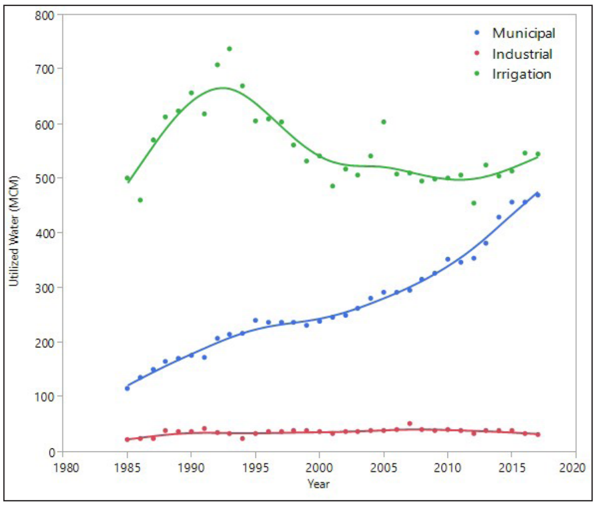

Figure 6. Quantities of water utilized by sector from 1985 till 2017.

Looking closely over the year 2016, the total water use was 1044 MCM, which went to supply the municipal, industrial, irrigation, and livestock demands by 43%, 3.1%, 52.4%, and 0.7% shares, respectively (Table 8). Most of the water supply is derived from groundwater (59%) followed by surface water (28%), while the non-conventional supply only provided 13% of the needs. This illustrates how much of the renewable groundwater is being depleted, while surface and non-conventional water supplies represent only minor gaps fillings. In addition, it is important to indicate that the estimated non-revenue water is 48% in 2017 compared to 43% in 2010; it is divided to more than 50% as administrative losses and less than 50% as physical losses from the networks.

Table 7. Recent and Anticipated water utilization in Jordan by division in MCM (MWI, 2013, 2015, and 2017).

Year	Municipal	Industrial	Irrigation	Total
1985	116	22	501	639
1986	135	23	461	619
1987	150	24	570	744
1988	165	39	613	817
1989	170	36	624	830
1990	176	37	657	870
1991	173	42	618	833
1992	207	35	709	951
1993	214	33	737	984
1994	216	24	669	909
1995	240	33	606	879
1996	236	36	610	882
1997	236	37	603	876
1998	236	38	561	835
1999	232	38	532	802
2000	239	37	541	817
2001	246	33	487	766
2002	249	37	517	803
2003	262	36	506	804
2004	281	38	541	860
2005	291	38	603	932
2006	291.4	40.5	508.6	840.5
2007	294.5	50.8	510.2	855.5
2008	315.7	40.5	495.6	851.8
2009	326.8	39.3	498.2	864.3
2010	352	41	500.8	893.8
2011	346.8	39.4	505.8	892
2012	353.8	33.9	454.8	842.5
2013	381	39.3	525	945.3
2014	429	39	504.3	972.3
2015	456.5	37.9	514.4	1008.8
2016	456.9	32.46	547.04	1036.4
2017	469.7	32.1	544.7	1046.5

Table 8. National Water Supply and Consumptive Use (MCM) by Sector for the year 2016

Row Labels	Municipal	Industrial	Irrigation	Livestock	Total Water Uses	Share%
1-Surface Water	**123.75**	**3**	**155**	**7**	**288.75**	**28%**
A. Jordan Rift Valley	101.86	3	89.16	0	194.02	
KAC	68.82	0	52.88	0	121.7	
Sothern Ghor &W. Araba	33.04	3	36.28	0	72.32	
B. Highlands	21.89	0	65.84	7	94.73	
Springs	20.41	0	21	0	41.41	
Base & Floods	1.48	0	44.84	7	53.32	
2. Treated Wastewater	**0**	**2.1**	**134.24**	**0**	**136.34**	**13%**
TW Registered in JV	0	0	101.12	0	101.12	
TW non-registered in HL	0	2.1	33.12	0	35.22	
3. Groundwater	**333.15**	**27.37**	**257.8**	**0.63**	**614.48**	**59%**
Renewable GW	211	23	231.11	0.63	465.47	
Nonrenewable GW	117.95	4.37	26.69	0	149.01	
Desalination	4.2	0	0	0	4.2	
Total Utilized Water Res.	**456.9**	**32.46**	**547.04**	**7.63**	**1044**	**100%**

6. Future Water Demands

Water strategy of Jordan (2007 and 2009) indicated that the total water use in 2015 amounted to 1400 MCM, which is probably less than the actual water use due to the partially uncontrolled abstraction of groundwater, in particular by agricultural farms in the highland areas. The recorded water use through agriculture amounted to 537 MCM in 2009, which is 61% of the total water used. Water for municipal uses was in the second largest position with about 34%, while the industry and tourism sectors consumed the remaining 5%.

Municipal water use comprises domestic water use at the household level and water for services, such as commerce, health, education, workshop, governmental offices, and communal green spaces. This sector receives water through the public water network which is managed by the WAJ and Jordan's three public utilities. The total municipal water use is expected to increase to about 730 MCM in 2020 according to Jordan's water strategy, and is expected to increase to 778 MCM in 2025 (Table 9).

Industrial water use includes both industries that do not receive their water from public water networks and industries with their own water wells. Groundwater comprises about 90% of the main sources of water used for industry. Industrial water use increased sharply over the last decade up to 50 MCM in 2015, but the annual growth rates differ considerably.

Jordan's Water Strategy estimated water requirements for oil-shale and nuclear-power industries to reach about 25 MCM in 2020. The projections by the MWI predicted industrial water use at 70 MCM in 2025.

Apparently, Jordan is directly over-exploiting its water resources by between 10% and more than 100%. Water levels are dropping, groundwater resources are being mined, salinization and salt-water interruption are watched, and the household water supply does not reach satisfactory measures.

The increasing cost of water supply is adding to the large burden of the fiscal budget in terms of new capital expenditure and subsidy needs. The gap between current tariff levels and full cost recovery is too big to be bridged by tariff increase alone. Full cost recovery is too expensive for the majority of water users, especially for low-income residents. Thus, prospects of reducing water subsidies are very likely.

Water deficits will continue to grow, and the gap between demand and supply will lead to an increase in bulk water supply costs for priority domestic use from the average current levels of 0.35 JD /cubic meters to 0.95-1.10 JD /cubic meters or even more.

Table 9. Future Water Demand over the Period 2020-2025 (MWI, 2016)

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	**1,455**	**1,485**	**1,493**	**1,503**	**1,536**	**1,548**
Deficit in MCM/a	**(373)**	**(320)**	**(256)**	**(252)**	**(283)**	**(88)**

7. Water Management Options

Several policies, strategies and plans have been developed by the government to enhance the development, management, and use of water resources. Jordan's "Water for Life" strategy 2008–2022 highlights the future challenges to be addressed through proper policies and regulations. The following are some of the adopted and suggested options:

7.1 Water Harvesting

Rainwater is the prime source of water in Jordan. The quantities lost to evaporation from temporary open water bodies and soils represent a significant part of the water budget in Jordan. Rainwater is dispersed over a wide area and, if properly collected, could provide a significant addition to the water reserves of the country. The simple model of rooftop water harvesting shows that the average design-rainfall is about 400 millimeters per year, and the losses are about 20%. A rooftop of 100 square meters can easily harvest 32 cubic meters per year. On the other hand, flood water harvesting at macrocatchments can collect considerable amounts of water in small dams across intermittent rivers and Wadis. Furthermore, micro-catchment water harvesting is widely implemented in the study area. Example techniques include earth and stone bonds, terraces and pots. The observed storage media include soil, tanks, underground cisterns, small check dams and one large dam which is the King Talal Reservoir (KTD).

The government of Jordan has tried to harvest each drop of rain as much as possible through constructing large dams with a total capacity of 335 MCM (Table 10), and other micro water-harvesting projects such as desert dams, earth ponds, and concrete ponds (Table 11). The harvested water is being used for irrigation purposes followed by municipal use

Table 10. Water harvesting dams in Jordan up to the year 2017.

Dam	Design Capacity (MCM)	Total Inflows (MCM)	Total Outflows (MCM)	Storage End of 2017 (MCM)
Wehdeh	110	72.957	93.658	4.063
Wadi Arab	16.8	0.58	11.277	3.52
Zeqlab	4	0.488	0.361	0.371
Kufranjeh	7.8	1.158	1.165	0.857
King Talal	75	115.809	141.791	28.215
Karameh	55	1.694	6.213	13.837
wadi Shueib	1.4	6.396	7.344	0.472
Kafrain	8.5	10.134	10.913	2.443
Wala	8.2	1.57	7.938	0
Mujeb	29.8	1.357	6.328	2.917
Tanour	16.8	7.014	20.674	5.425
Karak	2	0.437	0.281	0.156
Total	**335.3**	**219.594**	**307.943**	**62.276**
Percentage of storage from design capacity	**18.6%**			

Table 11. Micro-scale water harvesting projects in Jordan up to the year 2017.

Water Harvesting type	Count	Design Capacity (MCM)
Desert Dams (Constructed)	61	88.715
Desert Dams (Under Construction)	1	0.05
Concrete Ponds	65	0.295
Earth Ponds (Constructed)	223	22.122
Earth Ponds (Under Construction)	11	0.525
Total	**361**	**111.707**

7.2 Brackish Water and Desalination

Brackish water for direct use or after desalination appears to offer the highest potential of non-conventional means for augmenting the country's water resources. Several brackish springs have been identified in various parts of the country. Tentative estimates from the MWI of stored volumes of brackish groundwater for the major aquifers suggest immense resources, but not all of these quantities will be feasible for utilization. Accordingly, when referring to the statistics of brackish water, the quality, quantity and location of this resource need to be carefully studied in order to assess its potential for utilization.

Modern desalination technologies applied to brackish water offer effective alternatives in a variety of circumstances. In 2015, there were fifty-two private desalination plants operated by farmers to desalinate brackish water for irrigation purposes desalinating about 10 MCM annually. Brackish water having salinity between 2,000 and 8,000 ppm is pumped from wells of depths between 100 and 150m. The facilities are generally in operation for 24 h/d in summertime and for 8 h/d in wintertime. The only energy source used to run the plants is electric power. Desalinated water is mixed with freshwater, whereby the mixed water has salinity of about 650 ppm. Irrigation water is applied in particular for bananas being a crop of a high market value.

Moreover, there are forty-four public desalination plants and ten other ones under construction to desalinate about 80 MCM annually. All these plants are run or will be run by

WAJ to treat saline water for the supply of drinking water. The units are all of a small size compared to the plants in the Gulf Region.

7.3 Public Investments

Huge investments from public and private sectors regarding the supply of water have been witnessed in the past decades. This has been manifested in the development of public desalination facilities for municipal use and micro and small private desalination facilities for drinking water and agricultural use including the extraction of fossil freshwater from aquifers shared with Saudi Arabia, the exploration of very deep (1,000–2,000 meters) sources of brackish water for eventual desalination,and the study of options for Red Sea- Dead-Sea conveyance to reduce the decline of the Dead Sea level and provide desalinated seawater for municipal and industrial use. The cost of new urban bulk water supply to Amman is expected to exceed US$1.35 per cubic meter as in the case of the Disi-Amman Water Conveyance Project.

The Conveyance of Disi project, completed in 2013, provides around 107 MCM annually of the drinking water to Amman and other middle and northern governorates. However, water that is being used for irrigation is reduced to start supplying the 107 MCM. This source is considered to be almost the major remaining conventional water source that can be utilized for drinking water.

Also, there are private investments in WWTPs especially for As-Samara WWTP. The plant at first utilized the stabilization-lake innovation, but was revamped utilizing the actuated slime innovation in 2008. In 2012, another development occurred that is the increment of the treatment plant to a capacity of 365,000 cubic meters. Treated water is reused basically for irrigation in the Jordan Valley and the highlands, and for restricted businesses, and will be utilized for creating vitality in the future.

7.4 Rational Water Use

The MWI issued a Water Demand Management Policy in 2016. The main objectives of the water-demand management policy, which was approved by the Cabinet in 2008,are: to maximize the utilization of the available water, minimize water losses, conserve water resources, promote effective water use efficiency, to adapt with the challenge of water scarcity in order to reduce the gap between supply and demand (i.e. increase the efficiency of water use to meet water needs of this sector in all regions of the country). This policy also includes construction, standards and specifications, reduction of non-revenue water, reducing water losses, non – conventional water resources, water conserving landscaping, substitution and re-use for irrigation, efficient use of water in irrigation, and water harvesting at the farm scale.

7.5 Red-Dead Sea Project

The Red Sea–Dead-Sea Conveyance Project, sometimes called the Two Seas' Canal, is a planned pipeline that runs from the coastal city of Aqaba by the Red Sea to the Lisan area in the Dead Sea. It will provide potable water to Jordan, Israel, and the Palestinian territories. Also, it will bring water with a high concentration of salts resulting from the desalination process (reject brine) to stabilize the Dead Sea water level, and generate electricity to support the energy needs of the project. The project is going to be carried out by Jordan, and is entirely within Jordanian territories. The project will be financed by the governments of Jordan, Israel, and a number of international donors.

The proposed conveyance would pump seawater 230 meters uphill from the Red Sea's Gulf of Aqaba through the Arabah Valley in Jordan. The water would then flow down gravitationally through multiple pipelines to the area of the Dead Sea, followed by a drop through a penstock to the level of the Dead Sea near its shore, and then through an open canal to the Sea itself, which lies about 420 meters below sea level. The project would utilize about 225 km of pipelines for seawater and brine, parallel to the Arabah Valley in Jordan. The project would also have about 178 km of freshwater pipelines to the Amman area. It also would include several water desalination plants and at least one hydroelectric plant. In its final phase, it would produce about 850 million cubic meters of freshwater per year.

The project would require electric power from the Jordanian power grid, but it would also provide some electricity through hydroelectric power. In sum, this project would probably be a large net-user of energy. The net power demand would have to be satisfied through other power projects whose costs are not included in the project costs. The Kingdom of Jordan plans to build a large nuclear power plant that might make up the difference.

After stumbling for years due to this project's complex nature and huge funding requirements, the MWI announced that Jordan is moving ahead with the first phase of the Jordanian version of the Red Sea–Dead Sea Project. The plan is to draw water from the Gulf of Aqaba at the northern tip of the Red Sea, and transfer it north to the Araba Valley where a desalination plant will be built. Another pipeline will extend from the plant to the Dead Sea. The new project is estimated to cost some $980 million, of which the government plans to secure some $400 million in grants. This project will also provide hundreds of jobs.

7.6 Institutional Environment

The ministries/institutions included in the water division in Jordan include:

1. The Ministry of Water and Irrigation (MOWI), with the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA) as its operational entities
2. The Ministry of Agriculture
3. The National Center for Agricultural Research and Technology Transfer
4. The Ministry of Municipal Affairs
5. The Ministry of Environment

8. Discussion and Recommendations

There is a need for the development of dams and water system projects in the Jordan Valley in order to maximize the utilization of surface water resources some time recently to prevent water from being wasted in the Dead Sea. Restricted extra-undiscovered surface water resources could be created in the Jordan Valley side channels and in the Mujib, Zarqa, Ma'an, and Zara basins.

Future patterns in irrigation are connected to water improvement conceivable outcomes. Aquifers in the Disi-Mudwara, Jafer, and Hamad regions are prime new water sources, which are capable of supplying an extra 100 MCM/year of water for a long time. Full utilization of these resources would require satisfactory administration to maintain a strategic distance from salinization and to decrease extraction from over-utilized aquifers.

The following activities are expected to handle this urgent situation:

- Desalinization of ocean water (Read-Dead-Sea Canal).
- Reduction of water requested for irrigation

Drinking water quality in Jordan is controlled by the Jordanian Drinking Water Standards, which are based on the World Health Organization drinking water rules. For the reason of observing groundwater quality, an organizer of observation wells is introduced in each of the groundwater basins. Level water is put away in water tanks (more often than not on roofs of buildings) to be utilized until the next turn of water supply.

The limited water resources are exposed to contamination. Also, population growth is expected to increase the pressure on accessible water resources. Moreover, the problematic issue of displaced people has caused the amount and quality of the water resources framework in Jordan to deteriorate, particularly in the north.

Farming accounts for 63% of water demand, while the residential share is 32% and the use by animals and businesses are only 1% and 4%, respectively (Figure 4). The water shortages are caused by water needs in agriculture. The Jordan water procedure plans to expand water supply through three measures:

- More utilization of treated water in farming and industry,
- An increment of fossil groundwater utilization through the Disi Water Conveyance Extension
- The desalination of seawater as part of the Red-Sea-Dead-Sea Canal (500-600 MCM/year).
- The hotspots of water procedures in Jordan are:
- To ensure surface and groundwater resources by cautious management of their use.
- To make great strides in the effectiveness of the administration of both urban water and water system.
- To create an organizational capacity capable of overseeing water resources, backed by an administrative system.
- To include the private sector in the advancement of utilities for effective water utilization and great monetary administration structures.
- To present a socially satisfactory duty framework which might change the situation of depending upon the nature of water utilized (e.g. household, mechanical, water system, etc.) or the type of water (e.g. surface water, groundwater, recovered wastewater).

Jordan's momentous development accomplishments are at risk due to the devastating water shortage, which is expected to become worse by climate change. Precipitation is anticipated to decline essentially, and dissipation and transpiration of plants will increase due to hikes in temperatures.

Jordan's water resources are found to be distant from its population centers, in particular in the Greater Amman region where nearly half of the country's population lives, and which lies at around 1,000 meter over the sea level. To address this challenge, Jordan has created a broad water supply framework to provide water for both irrigation and metropolitan employments. The key components of Jordan's water resources are:

- Al Wahda Dam on the Yarmouk River
- King Abdullah Canal (KAC) in the Jordan Valley which is nourished essentially by the Yarmouk Waterway, the Mukhaibah springs close to the Yarmouk Waterway, and a number of water courses depleting into the Jordan Valley
- As-Samra wastewater treatment plant which treats most of Amman's wastewater releasing it into the Zarqa Waterway
- The King Talal Dam on the Zarqa Waterway from which water returns to the KAC downstream of Deir Alla for irrigation in the Lower Jordan Valley

The percentage of non-revenue water (NRW) - water that is produced but is not discharged to consumers- was evaluated at 44% in 2008. The fundamental reasons driving to this big loss rate are leakage, water passing through meters, illegal connections, unreliable water meters and issues concerning the perusing of those meters.

Measures to diminish the rate of NRW can in this way contribute to relieving the big pressure on water resources. In Amman, the level of non-revenue water has been decreased from an estimated 46% in 2005 to an assessed 34% in 2010. However, during the same period, the normal hours of benefit per week declined from sixty-six hours to thirty-six hours. Water and sewer administrations in Jordan are intensely subsidized. The income covers part of the operation and support costs. The tax framework is an increasing-block framework, beneath which clients pay a higher tax per cubic meter in the event that they expend more water.

Jordan is suffering from serious dry seasons, and while climate change is an issue, the political climate in the Middle East is making things worse. The Jordan River has lost 95% of its characteristic stream since its redirection. Syria and Israel and have built dams along the banks of the stream of the Jordan River and its tributaries (USAID, 2009).

The major challenges facing Jordan in the field of water resources are:

- Desalination is exceptionally vital, but is seriously and subsequently an expensive undertaking. On one side, the capital costs have to be prepared and on the other side, with the current water duties, the essential appropriation of funds will put an overwhelming burden on the national budget.
- Necessary energy generation for large-scale desalination must be available.
- Possible negative natural impacts of expansive desalination ventures need to be moderated.
- The restriction of brackish water resources.
- Lack of skill in Jordan in the field of desalination.
- Use of treated wastewater needs to be carefully checked through a comprehensive hazard-administration framework.
- Greywater and storm water collection systems and treatment frameworks at both the building level and the metropolitan level should be available.

9. Conclusions

In addition to loose water governance in the form of lax enforcement of rules and regulations, the lack of equity and transparency, has resulted in the continuous mining of renewable groundwater resources, with the current extraction rate (50 %) exceeding the safe yields, increasing water salinity, declining water table levels, and increasing pumping costs. The efficient management of scarce water resources is an existential necessity. It is critical to the livelihoods and well-being of Jordan's people and essential to the country's lasting stability. In the absence of securing its water assets, the risks for Jordan will include near-term economic slowdowns, health hazards, social disruptions, and serious conflicts over water resources.

The water sector has gone through significant phases marked by the various challenges imposed by the tremendous growth of population, as well as the rising living standards, and the economic and social development. In spite of that, more than 98% of the Jordanian people are connected to safe-water supply services, while more than 63% are covered by sanitation services. This percentage is expected to increase up to 70% in the coming years through various programs and plans implemented by the Ministry of Water and Irrigation (MWI). Interrupted pumping and the non-reliability of water supply services are common across Jordan. The connection rate does not reflect the fact that many urban and rural communities do not receive piped water for weeks.

However, despite the Government's efforts to manage the limited water resources and its relentless search for alternative supply, the available water resources per capita are falling as a result of population growth. Government's attempts to deal with the scarcity problem focused not only on supply augmentation and supply management, including rationing of water service, but also on demand-management measures, and the adoption of a public information policy. Despite all measures, the coming scarcity problem will remain a major challenge facing water managers and the country at large.

There are clear gaps related to the levels of public awareness, participation in water protection programs, the construction of a comprehensive legal framework for water management, and sectoral priorities for water conservation. Additional methodologies for sustainable water solutions are required such as a reliable data bank, proper research, funding support, and training programs.

The utilization and careful use of water resources require integrated management policies to ensure the sustainability of water and the environment. The existing water policy and by-laws seem to be well focused on the issues. However, there is a lack of enforcement and sustainability.

Among all the detected methods to overcome the water scarcity in Jordan, the Red-Dead Sea project has become the only sustainable solution for ensuring the survival of Jordan's future generations.

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