Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.12, No.6, 2022

Restoration and Conservation of Exhausted Water Environments

Jamal A. Radaideh*
Al Balqa Applied University PO box 206, Al-Salt 19117- Jordan
* E-mail of the corresponding author: jamrad08@bau.edu.jo

Abstract
In this paper, the foremost important elements of the Jordanian water environment and its components will be discussed, the challenges it faces, and ways to preserve, maintain and sustain its elements for current and future generations. The Jordanian water environment has been depleted for many decades in the absence of awareness programs for stopping its deterioration. Special consideration is given to water scarcity, climate change, population growth, and pollution.The scarcity of water represents the greatest environmental threat for Jordan making it the fourth-lowest country in water availability in the world and stands for the biggest challenges facing sustainable development in Jordan. Wastewater and pollution accompanied by a lack of proper management are further challenges to the environment. Over-pumping of groundwater represents another challenge that causes deterioration of the quantity and the quality of most groundwater sources.The paper suggests some environmental protection measures for water resources from further deterioration.
Keywords: Environmental components of Jordan, exhausted environments, water scarcity, pollution.
DOI: 10.7176/JEES/12-6-06
Publication date: June 30th 2022

1. Introduction

In the 60ths and until the 70th years of the last century, Jordan was a country relatively free of environmental problems. As a result of massive modernization and population growth accompanied by scarce natural resources, several environmental problems arise. The rapidly growing population began to use and consume more resources than the country could offer. Urbanization became the main source of contamination of water, air, and the environment.

Jordan's area is about 89.7 thousand km^2, 80% of which is desert receiving less than 50 -100 mm of rain annually. Recently, forced migration fluxes brought 2.5 million people from neighboring countries, raising the population of the country to more than ten million people. The population living in the country is estimated to be 10.4 Mio. in year 2022 and expected to reach 10.61 Mio., 11.12 Mio. and 11.84 Mio. in the years 2025, 2030, and 2035 respectively [DoS, 2019)]. Despite its small area, Jordan is divided into three natural and climatic regions involving seven different climatic ecosystems. The Jordan Valley region, including the Jordan River and the Dead Sea area, extends from the eastern depressions to the southern borders of Lake Tiberias in the north. The mountainous heights extend from the Jordan Valley on the Yarmouk River in the north to Aqaba and the Eastern Desert or the Badia region. Jordan is dominated by arid deserts, the rift valley, and highlands and plains. and is also characterized by a unique topographic nature, where the western part represents the world's lowest valley that lies north-south between two mountain ranges in length of about 400 km and width that varies from 10 km in the North to 30 km in the South and elevation between 170 – 400 meters below Mean Sea Level (MSL). To the east of this mountain range, a semi-desert plateau extends to cover approximately 80% of the total area of the country.

Jordan's climate is a mixture of the Mediterranean basin climate that prevails in the northern and western regions of the country, the tropical dry climate prevails in the Jordan Valley, and the Desert climate prevails within the majority of the country. In general, the weather is hot and dry in summer and pleasant and humid in winter. The Jordan Valley area has semitropical climate features with a hot summer and mild winter. Precipitation is extremely variable and is confined largely to the winter and early spring seasons ranging from over 500 mm in the highlands to less than 50 mm in the eastern region (Badia) [Department of Meteorology, 2022]. The long-term average annual precipitation is ≈ 8217 MCM. The high temperatures and low humidity in Jordan cause very high evaporation rates. The long-term average evaporation rate is 85-92% of precipitation over the entire area of Jordan. Potential evaporation ranges from 1600 mm/a in the northern Highlands to more than 4000 mm/a in the southern and eastern desert regions. According to 10 years of records from 2005-to 2015, the rainfall rate is between 100-500 mm. The evaporation rate constitutes about 93.3 % of the total rainfall. The infiltration rate is approximately 4 - 4.5% and only a small portion around 2.41 % appears as runoff [MWI, 2017].

The following paragraphs explain Jordan's water environment and demonstrate the challenges faced and highlight the best measures to deal with these challenges to mitigate their effects on the water environment of the country.

2. Water resources and scarcity

Jordan is a poor water region with a per capita water share of 130 m^3/person /year as estimated in 2019, which is expected to fall to about 90 m^3/person /year and less in 2025, well below the globally recognized limit of severe water scarcity of 500 m^3/person /year. The domestic water supply in the Jordanian communities is generally intermittent. Water is delivered once a week in big cities like Amman, Irbid, and Zarqa and once every two weeks in some rural areas. High temperatures and changes in precipitation patterns increase water scarcity and may lead to a breakthrough in epidemiological diseases. The problem of water scarceness in Jordan is chronic due to limited water resources, low annual rainfall rates, and high evaporation losses. About 90% of Jordan's area is desert and dry with long-term rainfall of less than 100 mm, with an evaporation rate exceeding 93% of initial rainfall. In addition, over-pumping of groundwater, population increase, and improved living styles are leading to more water consumption and pollution.

Main water sources in Jordan are divided into two categories: groundwater and rain-fed surface water. Groundwater supplies are of two types; renewable and fossil. The available amount of renewable groundwater from all basins was estimated at 418MCM/a [MWI, 2017]. The region suffers greater water scarcity than any other country on a global basis, due to the interaction between low annual precipitation, high evaporation rates, successive years of drought, and the country's complex hydro- and geopolitical context. Water is, therefore, the single natural constraint on the economic growth of the country. The optimal control of water allocation between regions, the timing of the allocation, as well as the quality and quantity of water, have been critical development factors for many years. The total available water per capita is 88 % below the accepted international water poverty line of 1,000 m^3 per year. All existing water resources are exploited and so far utilized. Many groundwater resources are over-abstracted, while water demand is continuously and constantly growing [Al Naber and Molle, 2017a]. The sources of water in Jordan include traditional sources such as rain, surface water, and groundwater, including non-conventional sources such as treated sewage and desalinated water.

The water sector in Jordan is confronted with many challenges. The most important of these is the impact of climate change on water resources. The major impacts of climate change on the water sector include groundwater depletion, salinity and surface water pollution, the disappearance of small springs, and a significant reduction in the discharge of major springs. Increased evaporation and reduced precipitation lead to poor nutrition and replenishment of water sources, and reduced surface and groundwater reserves. In the long run, this effect can lead to serious soil degradation and accelerate desertification [MoEnv and UNDP, 2014]. High temperatures increase the rate of evaporation of water in the atmosphere, which leads to an increase in the ability of the air to carry water. Increased evaporation reduces soil moisture levels, which in turn increase the frequency of drought in the area and increase the likelihood of desertification. In addition to the decrease in moisture content in the soil, a decrease in infiltration rates is caused leading to a decrease in the rate of recharge in groundwater. In Jordan alone, according to the kingdom's MWI reports, climate change and the refugee crisis have reduced water availability to 130 CM/capita. The report also predicts that climate-related water scarcity could cause economic losses estimated at 6%-14% of GDP by 2050 - the highest in the world [MWI, 2017].

Another challenge facing the water supplies is represented by the loss of water in network pipes (unaccounted for water UFW). The amount of UFW averages 43.8% of total water supplied throughout the country, 36.2 % in Amman and 41.2% in Zarqa to over 55 % in Mafraq [Al-Ansari et al. 2014]. The Jordanian government must take the initiative in renovating or replacing the old and rusty water pipes that supply private homes with domestic water supplies.

The water supply in Jordan relies mainly on resources that are located far away from consumers. Consequently, the water sector involves an energy extensive operation by deploying large water pumping, treatment, and distribution facilities. The estimated power requirement for water pumping amounted to about 15 % of the total power production of Jordan, which relies predominantly on imported fossil fuels with a significant impact on the environment. The specific energy consumption for the same year was 7.51 kWh/m^3 mainly for water supply and wastewater treatment [MWI, 2017].

2.1 Surface-water:

Surface water comes from rivers, running springs, and valleys, as well as floodwaters during rainy seasons, with an estimated quantity of 713 million m^3 distributed over 15 surface water basins. The surface water of Jordan depends mainly on rainfall over the territory of the country, and water originating in other countries and entering Jordan via cross-border Rivers. In addition, treated wastewater is collected in reservoirs and mixed with fresh water for irrigation purposes. Jordan is recognized as a semi-arid region with a climate ranging from the Mediterranean to arid, with approximately 80 % of the country's territories receiving less than 200 mm/a of precipitation. Less than 4% of the country receives over 300 mm. Jordanian agriculture is therefore .heavily dependent on irrigation. Table 1 shows the volume of annual rainfall for the period 2007–2017. The long-term average volume of precipitation is estimated to be about 7,291 million m^3, but the evaporation rate accounts for over 92 % of this total. Between 1972 and 2017, Jordan's average precipitation in depth remained stable at around 111 mm per year [JMD, 2010].

Table 1: Average annual rainfall rates, evaporation, groundwater recharge rates, and flood rates in MCM /a for the period 2007-2017 [MWI, 2017, MWI, 2016a].

year	Rainfall Volume	Long-term Rate	Evaporation	Groundwater Recharge	Floods
2006/2017	7480.36	8224.63	6976.45 ≈ 93%	326.54 ≈ 4.3%	176.72 ≈ 2.2%

A great challenge facing surface water besides being limited is the decreasing quality. The Zarqa River, the only major river that originates and flows within Jordan's borders, is highly polluted. This is due to its presence within Jordan's main industrial zone, which hosts about 70% of the country's small and medium-sized industrial enterprises. Most of these industrial establishments discharge their wastewater untreated into the Zarqa River. Meanwhile, 50% of the river's water flow comes from the As-Samra Wastewater Treatment Plant, which treats ¾ of Jordan’s wastewater. Accordingly, the water of Zarqa River is contaminated by industrial waste that includes trace elements and heavy metals such as mercury, nickel, arsenic, lead, selenium, and cadmium and is considered the main pollution source of King Talal Dam [Al-Omari et al. 2017]. The Jordan River is highly saline because all saline and brackish water springs are diverted around Lake Tiberias to the Jordan River; it also receives return flow from irrigated fields that are heavily polluted with untreated wastewater and agricultural fertilizers and is therefore not suitable for any use in its present state. The water of the Dead Sea is highly saline and is not suitable for irrigation or domestic use. The quality of the Yarmouk River although in an acceptable condition at present, its water quality could change due to the discharge of Ramtha Wastewater Treatment Plant effluent.

There are currently 14 operating dams in Jordan with a total storage capacity of 344 MCM. According to data from 2019, these dams have received 306 MCM from which 281 MCM were utilized. The Jordanian Standard Specification No. 1766 / 2014 [JS 1766, 2014] was guided to evaluate the results of water quality tests performed during 2019. The results indicated that the dam’s water is suitable for unlimited cultivation due to the absence of Nematode eggs and low E.coli. Programmed monitoring of the water quality of all major rivers and discharge Wadis of Jordan is of great necessity because the effluent of most wastewater treatment plants of the country is discharged into those rivers or valleys.

Total developed surface water supplies were 274 MCM in 2020, making 27% of Jordan’s total water supply. From this amount, the domestic share was 45 %, the agricultural share is 53.3 % and the industrial share is about 1.5 %.

2.2 Groundwater:

Groundwater resources in Jordan are found in twelve major aquifers, two of which are fossil (Jafr, Disi). Groundwater is of excellent quality and is considered the key source of water supply in the country therefore, is given priority to supply the population with drinking water [Ibrahim, 2019]. However, there are many potential sources of contamination affecting surface and groundwater such as industrial and municipal wastes, excessive use of pesticides and chemical fertilizers in agriculture, and over-pumping far beyond the safe yield leading to the intrusion of saline water and the content of septic tanks in certain aquifers. At the national level, it's calculated that the extraction of groundwater resources exceeds the safe extraction rate by over 50 %. The long-term annual safe yield has been estimated at around 418 million m^3, while over-abstraction stands at around 190 million m^3 [Al Naber, 2017a]. Planned actions are needed to scale back abstractions to self-sustaining levels. This can be done by a phased reduction in irrigation abstractions and the substitution of groundwater with treated wastewater as far as possible; sustained improvements in water use efficiency in irrigation; and the construction of alternative water sources to alleviate pressure on groundwater resources. The main source of fossil groundwater is the Disi aquifer in the south of the country. Annual abstraction is estimated to be about 125 million m^3, enabling the aquifer to sustain this yield for 50 years. Water from the Disi aquifer is conveyed for use in the north of Jordan via the Disi-Amman conveyance system, which supplies Amman city with freshwater, Aqaba with 14 MCM/year for municipal and industrial uses and 51 MCM/year for irrigation purposes. As reported by [MWI, 2016b], from the 12 major groundwater basins, six are over-extracted, four are at capacity, and two are underexploited. The Jafer basin is the other alternative for non-renewable groundwater resources in Jordan. This aquifer will provide Jordan with eighteen MCM/year, over the subsequent forty years. Delivered data showed that from the total number of springs in Jordan, 361 are perennial, 23 are intermittent, and 195 are dry. These are discouraging statistics about the state of the groundwater basins and their continuous decline year after year. In some basins, the annual decline reached 5 meters annually, while other water basins recorded a sharp decline that reached 60 meters during the past 15 years. This caused the drying up of the main water layers in the northern regions and their salinization in other regions. The number of springs that dried per year between 1995 and 2014 is 140 [MWI, 2016b].

Falling water levels and increasing unsaturated areas will have serious economic and operational consequences for water extraction for public and private users. Water levels at higher depths require more energy to raise the water and therefore higher operating costs. Moreover, existing wells must be deepened, riser lines extended, and pumps replaced with more powerful ones to adapt to lower depths. A large number of operating wells will be stopped working because the salinity of the water increases with depth. Otherwise, the water will need to be treated and desalinated using expensive techniques.

Table 2: A projection summary of the main available sources of water and total demand required in the years 2020 – 2025 [MWI, 2017, MWI, 2016a].

Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Total resources	1082	1165	1237	1251	1253	1459
Sustainable resources	942	1030	1106	1125	1131	1341
Total demand	1455	1485	1493	1503	1536	1550
Deficit with over-extraction of GW	373	320	256	252	283	288
% of deficit	25.6	21.5	17.1	16.8	18.4	18.6

Table 2 provides a summary of the main sources of water for each key consumer category in Jordan. Jordan's agriculture sector consumes over 50 percent of the country's water supply in 2020. Although the share of agriculture in water is decreasing, it still occupies the first position in terms of water use. The domestic share of the water supply is about 40 % while industry consumes 8-10 % of the water supply. The shortfall in securing water supplies remains and fluctuates around 20 % despite all efforts to reduce it, signalizing a chronic water scarcity.

To bridge the large gap between water supply and demand, attention has turned to the exploitation of non-renewable groundwater. Underground water from the fossil Disi aquifer (≈ 125 MCM/year) is being used to meet Jordan's water supply for domestic uses, while treated wastewater (≈140 MCM/year) is used to meet part of the country's agricultural needs.

A previous study [US Geological Survey Open-File Report, 2013] monitored changes in groundwater levels and salinity in six groundwater basins in Jordan from 1960 to early 2011. Based on collected data for 117 wells, groundwater levels in the six basins were declining, on average about -1 meter per year (m/yr), in 2010. The highest average rate of decline, -1.9 m/yr, occurred in the Jordan Side Valleys basins, giving that some individual wells decline by -9 m/yr. From 30 to 40 percent of the saturated thickness, on average, was forecasted to be depleted by 2030. Five percent of the wells evaluated were expected to have zero saturated thickness by 2030.

The government of Jordan must start a water supply management initiative by enforcing regulations on water extraction from groundwater aquifers. The absence of strict laws is leading to illegal groundwater well drilling, careless use of water, and unsustainable extraction of water from aquifers. Aquifers in Jordan are being used at twice the natural recharge rate which is threatening the natural replenishment process and may eventually lead to drying up. The issue and enforcement of new regulations for charging fees for all extracted groundwater for municipal, industrial, and commercial uses and irrigation, is immediately required.

2.3 Non-conventional sources

Given the constant shortage of water resources, Jordan has seriously practiced the use of treated wastewater for irrigation purposes. Wastewater that is treated according to international standards is mixed with fresh water in storage tanks and then used in agriculture. In 2014, over 128 million m^3 of treated wastewater was used for irrigation, making about a quarter of all water used for irrigation in Jordan. However, wastewater reuse can also be risky for human health as well as for crop consumers as wastewater can contain enteric viruses, pathogenic bacteria, and protozoa. Some chemical wastewater components, such as nitrogen, and phosphorus, may have both positive and negative effects on plant growth, crop yields, and the surrounding environment. Other constituents such as suspended solids, and high salt levels loads, can be disadvantageous for agricultural soils and irrigation infrastructure.

In Jordan, decentralized wastewater management and reuse are promoted by the National Water Strategy 'Water for Life' 2008–2022 [MWI, 2016a]. According to this strategy, by 2022 the amount of treated wastewater for reuse should reach 15 percent of the total renewable water resources available. Moreover, the strategy stresses the need to build decentralized treatment plants to serve semi-urban and rural communities and to explore the potential for using treated wastewater for aquifer recharge. The Jordanian standards [JS 893, 2006] for water reuse are based on reuse categories depending on the type of crops and areas to be irrigated. The standard prohibits the use of reclaimed water for irrigating vegetables to be eaten raw. Furthermore, it is prohibited to employ sprinkler irrigation for applying reclaimed water, except for irrigating golf courses. In addition, the Jordanian standards provide guidance values for a range of chemical wastewater components.

The option of desalination seems to be an ideal solution for Jordan's water problem in the long term. However high energy cost remains a major obstacle, as well as the fact that Jordan's sole access to the sea on the

Gulf of Aqaba is located far from the urban centers [Qtaishat et al. 2017]. There are currently 27 private desalination plants under operation located in the Jordan Valley with a production capacity of 1,000 m^3/h used for irrigation purposes. Six desalination plants have been operated for drinking water purposes in separate areas operated by the Ministry of Water and Irrigation. The total production capacity of these plants is estimated at 5,500 m^3 / hour, mostly used for drinking water (MWI, 2021). More than 50 brackish water desalination plants have been installed by farmers in the Jordan Valley and Dead Sea area for irrigation purposes. In all plants, reverse-osmosis technology is applied. The plants' capacities are 360 to 2400 m^3/d. The total water abstracted is about 11.7 MCM, whereas the total desalinated amount reaches 7.7 MCM and the brine discharge is about 4.1 MCM. The only energy source used to run these plants is the electric power grid. The average investment cost per cubic meter for the installed capacity of the desalination plants ranges between \$124/ (m^3/h) for small plants and \$63.5/ (m^3/h) for large plants; with an average of \$89/ (m^3/h). The average desalination cost is ranging from (\$0.33/m^3) per cubic meter for large plants and \$0.48/m^3 for small plants. This figure does not include any water pre-treatments, storage costs, or brine disposal costs as they vary from one source to another, and the required energy has been estimated at 1.9-3.2 kWh/m^3 of water produced depending on the quality of the raw water flow and the TDS required from outflow [Qtaishat et al. 2017].

Balancing supply and demand

Balancing supply and demand is one of the important mitigation measures that should be taken to sustain water environments. Water use in Jordan targets three different main sectors: agriculture, municipal supplies, and industry. Agriculture is by far the largest consumer of the country's water resources, accounting for roughly 51% of the total water supply, while 45% goes to municipal uses, and 4% goes to industry.

Recent trends showed a rapid increase in water consumption for municipal use. The observed data indicate that municipal water consumption increased by an average of 10.5 % per year from 2001 –to 2020, while the increase ranged from 6.6% and 3% within the industrial and agricultural sectors respectively. This fact has resulted from both the increasing population and the greater water requirements due to raised standards of living and refugees. Increases are expected to continue in the future as urban populations get higher and consequently claim more water to meet their needs.

Table 3: A summary of the main sources of water for each key consumer category for the year 2019 [MWI, 2016c].

Source	Domestic	Industrial	Irrigation	Total	% of share
Surface water	124	4.8	146	278.8	27.3
GW	337.6	31	237.6	606.2	59.5
TWO	0	2.2	131	133.2	13
Total used	461.6	38	514.6	1018.2	100
Sector share	45.3%	3.7 %	50.5 %	100 %	

Table 5 indicates that, in the case of domestic (urban) use, about three-quarters of all water supply is groundwater-based, about 50 % of which originates from non-renewable deep sources. Industrial water use is about 3.7 % of overall water consumption, mainly (81.6 %) coming from groundwater sources. Statistical data also indicate that from the total domestic water consumption in Jordan gray water constitutes between 60% and 80% of the water consumed.

Surface water sources are unpredictable for geopolitical reasons, and due to the variability of annual precipitation and climate change impacts. Renewable groundwater is overexploited and in the medium term is also dependent on inconsistent precipitation. Deep fossil and brackish sources are at some risk of quality deterioration in the medium term, and they will be entirely exploited within decades. In summary, the current balance of supply and demand will be increasingly negative and difficult to adjust.

3. Water quality

Besides being scarce, water quality poses a major challenge to the water resources sector. Apart from the chronic shortage of water resources, pollution is one of the main reasons limiting the availability of usable water for different purposes. The severe scarcity of water in Jordan necessitates great efforts to conserve every drop of water.

Pollution of water resources is attributed to high population growth, intensive agricultural activities, urbanization, industrialization, and the arid to semiarid climate [MoEnv and UNDP, 2014]. These factors combined help the wastewater to reach water sources, leading to their pollution. In towns and villages of Jordan, lacking public sanitation services, discharges of wastewater from septic tanks and cesspools infiltrating into the groundwater escalate the pollution problem. This increases the pressure on the water resources by increasing the salinity, nitrate, sulfate, ammonia, phosphate, and organic materials contents.

For the assessment of water quality in Jordan, instantaneous samples were taken from different water sources and analyzed as part of a comprehensive environmental study conducted during the year 2020 [MoEnv., 2020]. The evaluation of the physical-chemical and microbiological properties of raw water for drinking water purposes is based on the Jordanian Standard for Drinking Water 286/ 2015 [JISM, 2015]. In this study, more than 119 composite samples were taken, 16 samples from Groundwater wells and springs, 22 samples from streams and valleys, 10 from dams, 24 from industrial wastewater effluents, and 38 from domestic wastewater effluents, and 19 samples of sludge from different locations. Monitoring and sampling stations were selected and identified to be representative of all operating water basins without any exception.

Table 4: Monitored Quality of spring water and Groundwater [MoEnv., 2020].

Site	**TCC MNP/100mL**	**E. coli MNP/100mL**	**TDS mg/L**	**TH* mg/L**	**NO_3^- mg/L**	**SO_4^{-2} mg/L**
1) Um Rummana station	2.8E+01	9.4E+00	671	470	33	54
2) Qanyya spring	1.6E+02	3.4E+01	424	376	61	35
3) Al Mohamedia well 1	1.1E+01	6.4E+00	337	267	1.9	39
4) Sara spring	1.9E+01	3.7E+00	429	263	46	36
5) Wadi Al - Sir Spring	1.6E+04	5.9E+02	454	407	36	32
6) Kairawan spring	2.5E+02	3.3E+01	446	424	45	28
7) Tabqat Fahel spring	2.0E+01	1.9E+00	565	506	16	67
8) Al Bahhath spring	1.1E+01	6.4E+00	438	308	38	35
9) Ain Dhana spring	1.7E+02	3.7E+00	391	289	17	16
10) AinTrab spring	1.2E+02	<1.8	329	218	22	9
11) Jaber well 2	<1.8	<1.8	464	236	2.3	37
12) Ruweished well	7.7E+00	<1.8	1417	861	<1.0	605
13) Muwaqar well 17	<1.8	<1.8	424	290	<1.0	60
14) Aqaba storage tank	3.7E+00	1.9E+00	194	118	8.8	18.9
15) Al Bashrya well 140	<1.8	<1.8	262	23	7.3	42
16) Urabi-Za´atary	1.9E+00	<1.8	680	238	22	37
Allowable limits JS 286/2015	**<1.1**	**<1.1**	**<1000**	**<500**	**≤50**	**≤500**

TH*: Total Hardness measured as CaCO3.

3.1 Microbiological contamination

In this study [MoEnv. 2020], several indicator organisms and pathogens were used to evaluate the microbial contamination of water including total coliforms count, fecal coliforms, fecal streptococci, coliphages, Salmonella, and heterotrophic plate counts. Although most E. coli and Enterococci strains cause only mild infections, their presence is indicative of the potential presence of other more pathogenic organisms which are a danger to human health, therefore, they are used as primary indicators of contamination in fresh and marine water quality.

The results of the water analysis as shown in (Table 4) confirmed the positive presence of Escherichia coli (E.coli) and total coliform species in all investigated springs and announced that none of the samples was in full compliance with the JS 286/2015 [JISM. 2015], indicating the pollution of these sources and the essential treatment before utilization. E.coli and total coliform present in water sources have been widely used as an indicator of environmental contamination.

The presence of high levels of coliforms is most likely due to stormwater runoff from livestock grazing, leaking cesspools and agricultural activities, and wastewater discharges from widespread cesspits and septic tanks. Springs located near residential areas have been affected by wastewater disposal more than other springs. These springs are directly fed with the wastewater through fractures, joints, faults, and cracks of sandstone aquifers. Pathogens excreted from infected animals and humans that have been directly introduced to water sources, or maybe transported through overland flow, impact microbial water quality. Municipal or industrial wastes and treatment failures in municipal water systems are generally potential sources of contamination. In addition, soil erosion and suspended sediments may play an important role in transporting fecal bacteria into the water. Land use management within catchment areas such as setting a buffer zone area may be important measures to prevent direct agricultural runoffs and other diffuse microbial inputs into water sources.

3.2 Electrical Conductivity and Total dissolved solids

Results of TDS measurements made for water samples in several dams and springs of the country show that TDS values are fluctuating among locations and are less than 1000 mg/l, except that of Ruweished well with a recorded TDS concentration equals 1417 mg/l, 42 % above allowable limits (table 4).

3.3 Nitrate Levels

Water with a high concentration of nitrate (NO_3^-) is polluted water and is not suitable for human consumption, especially when its concentration exceeds the maximum concentration (50 mg/L) recommended by the World Health Organization (WHO). Intensive use of land resources in arid and semi-arid regions exercises serious pressure on groundwater resources and threatens further socio-economic developments. In Jordan, there is great concern about the identification and control of organic and inorganic pollutants that may reach groundwater. Nitrates are highly mobile and present in domestic, agricultural, and industrial waste in Jordan, thus this study initially focused on nitrate as a pollutant of concern and as an indicator of potential groundwater contamination.

Nitrate pollution had reached 73% above the threshold (50 mg/L) in some cases as presented in table 4, nitrate concentrations are well below the threshold (50 mg/L) for all investigated groundwater wells and springs except for Qanyya spring, where nitrate pollution reach 22 % above the threshold limit of (50 mg/L). A similar trend appeared for the presence of SO_4^{-2}.

4. Wastewater issue and challenges

Wastewater, whether domestic or industrial, is considered the greatest challenge to the environment in general and the aquatic environment in particular. While the water supply reaches about 98% for most of the population centers spread throughout the country, public sanitation services include only 63% of the total population and are concentrated by 75-80% in large-sized cities and towns. The risks of sewage water to the environment may come from several practices. There is a large portion of generated sewage, about 37% domestic and more than 55% industrial is discharged or disposed of in environmentally unsafe ways. Most of the sewage of unserved communities is discharged either to septic tanks or to Wadis without any treatment. The content of these septic tanks, if not lined properly, may infiltrate into the ground and contaminate aquifers, causing significant health and economic risks.

Jordan operates more than 36 wastewater treatment plants (capacities ranging from 200 – 300,000 m3/d) scattered throughout the country and producing about 430,000 m3/d of reclaimed water. In regards to quality, 85 percent of effluents are of a quality that satisfied the- requirements for irrigation of field crops and forest trees according to the Jordanian Standard No. 893/2006 [JS 893/2006; Abdulla et al. 2016, Najib, 2019].

The problem associated with current wastewater treatment systems is that these technologies lack sustainability. These practices flush pathogenic bacteria out of the residential area, using large amounts of water, and often combine the domestic wastewater with rainwater, causing the flow of large volumes of polluted wastewater. Many treatment systems in Jordan are not efficient and therefore unsustainable, since they were simply copied from European treatment systems without considering the appropriateness of the technology for the type of wastewater generated, culture, land, and climate in Jordan. Many of the installations were abandoned due to the high cost of proper operation and maintenance. The ineffective treatment processes result in high nutrient content, especially nitrogen and phosphorous, in treatment plants outflows causing eutrophication problems in receiving water bodies. Lack of maintenance in wastewater treatment systems due to financial and operational constraints results in inadequate treatment in some plants, and consequently, bad effluent quality. Large quantities of bio-solids (sludge) are accumulated at wastewater treatment plants. Overloading (hydraulic/biological) deteriorates the quality of the wastewater effluent and produces objectionable odors. This condition causes an increase in the retention time of wastewater inside the treatment plant or generates treated wastewater, not in compliance with the Jordanian Standards for reuse.

The first step to controlling sewage risks is to expand public sewage services and include all areas and their facilities to collect the largest amount of generated water and treat it safely. Treatment of wastewater shall be targeted towards producing effluents of quality for reuse in irrigation in full compliance with Jordanian Standards for reuse as a minimum. The transfer of advanced wastewater treatment technologies shall be promoted and encouraged. However, the appropriate wastewater treatment technologies shall be carefully selected with consideration of operation and maintenance costs, energy savings, and their efficiency in attaining and sustaining quality standards. Treated wastewater should be mixed with freshwater to improve quality wherever possible. The crops to be irrigated with treated water must be chosen carefully and in proportion to the characteristics of the irrigation water used, the type of soil, and the economics of reuse and the final use of those crops.

4.1 Sludge and bio-solids

Sludge is the solid organic matter formed during the treatment process of wastewater and consists mainly of solids accumulated at the bottom of the treatment ponds, and the microorganisms that have led to the degradation of the organic matter in the wastewater. According to Jordanian Standard JS 1145/2016 [JS 1145, 2016] for sludge resulting from domestic wastewater treatment, sludge is divided into Wet materials resulting from domestic wastewater treatment processes with a solids content ranging from 2-50%. Dry materials resulting from domestic wastewater treatment processes, with moisture content exceeding 10%.

The analysis of samples taken to evaluate the suitability of sludge for application in agricultural areas showed that

The total amount of produced sludge from all treatment plants is estimated at 5000 CM/day. Of the 36 Wastewater Treatment Plants (WWTPs) in Jordan, only two of the facilities, As-Samra and Al Shallaleh utilize sludge as an energy source. None of the other 36 WWTPs implement a proper Sludge Management Plan, although the accumulated sludge is a major source of health and environmental risks and contributes to Greenhouse Gas (GHG) emissions. Therefore, the challenge is to focus on using sludge as an alternative source of energy and as a means to increase agricultural production and combat desertification rather than seeing it as a product that is harmful to the environment and must be disposed of.

Water quality in Jordan can only be improved by addressing issues such as effective treatment of biological and other toxic contaminants at the source, proper regulation and control of industrial wastewater treatment before discharge, control of crop fertilization materials and volume, preventing over-extraction of groundwater resources and improving wastewater treatment and management. Groundwater vulnerability mapping and delineation of groundwater protection zones should be implemented in different areas in Jordan.

5. Conclusions

Jordan's water environment is fragile and widely depleted, and due to over-exhaustion, it has reached dangerous levels that make it difficult to develop effective solutions for its sustainability. Initiatives to encourage efficient use of water resources will contribute significantly to reducing environmental problems.

Given the scarcity of water resources, coupled with the rapidly increasing population, it is necessary to start planning and prioritizing water allocation and use. Careful water management is essential for every water use sector to ensure sustainability and development.

In terms of application, the results of this study are of benefit to water managers and water policymakers to take appropriate actions regarding water resource management, allocation policies, and management of irrigated agriculture in Jordan. Emphasis should be placed on the selection of suitable crops with high economic value, the use of appropriate irrigation methods, the use of treated wastewater for restricted and unrestricted irrigation practices, and the exploitation of gray water to irrigate home gardens to reduce consumption.

Create a strong enabling environment with strong national policy and regulatory systems that address water scarcity. Work with civil and institutional society and other stakeholders on the value of water and the importance of preserving it. Initiate climate change response plans that present water scarcity as a priority component, and allocate an adequate national budget to address water scarcity.

6. References

[1] DoS, (2019). Department of statistics. Estimated population of the kingdom by municipality and sex, at End-year (2019). Jordan Statistical Yearbook. http://dosweb.dos.gov.jo/products/statistical-year_book2019/.https://www.populationpyramid.net/jordan/2020/.

[2] Department of Meteorology, (2022). Monthly Meteorological Reports. Amman, Jordan. https://www.weatheronline.co.uk/reports/climate/Jordan.htm.

[3] MWI, (2019). Ministry of Water and Irrigation. Jordan water sector facts and figures and Annual Report 2019. Jordan.

[4] Al Naber, M., Molle, F. (2017a). Controlling groundwater over-abstraction: state policies vs local practices in the Jordan Highlands. Water Policy 19:692–708. https://doi.org/10.2166/wp.2017.127.

[5] MoEnv and UNDP, (2014). Jordan's Third National Communication on Climate Change. Ministry of Environment, and United Nations Development program. https://unfccc.int/resource/docs/natc/jornc3.pdf. Accessed September (2021).

[6] Al-Ansari, N., Alibrahiem, N., Alsaman, M., Knutsson, S. (2014). Water supply network losses in Jordan. Journal of Water Resource and Protection, JWARP 06:p.83 – 96 https://doi.org/10.4236/jwarp.2014.62013.

[7] JMD, (2010). Jordan Meteorological Department. Annual Report of Jordan Meteorological Department, JMD. Amman, Jordan.

[8] Al-Omari, A., Farhan, I., Kandakji, T., Jibril, F. (2017). Pollution sources to Zarqa River: their impact on the river water quality as a source of irrigation water. Proceedings of the workshop, water perspectives in emerging countries: water use in MENA countries 2017, November 03–08, 2017, Marrakech, Morocco.

[9] JS 1766/2014. Jordan Institution for Standards and Metrology. Irrigation Water Quality Guidelines. Amman, Jordan.

[10] Ibrahim, M.N. (2019). Assessing Groundwater Quality for Drinking Purpose in Jordan: Application of Water Quality Index. Journal of Ecological Engineering, 20(3), 101–111. DOI:10.12911/22998993/99740

[11] MWI, (2016a). Ministry of water and Irrigation. National Water Strategy, NWS 2016-2025: Water Sector.

[12] MWI, (2016b). Ministry of water and Irrigation. National Water Strategy, NWS 2016-2025. Groundwater.

Sustainability Policy
[13] MWI, (2016c). Ministry of water and Irrigation. National Water Strategy, NWS 2016-2025: Water Demand. Management Policy. MWI, (2016d). Water budget for the year 2015. Directorate of strategic planning.
[14] U.S. Geological Survey Open-File Report 1061 (2013). Groundwater-Level Trends and Forecasts, and Salinity Trends, in the Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa Groundwater Basins, Jordan. http://www.usgs.gov/pubprod.
[15] JS 893/2006: Jordan Standards and Metrology Organization. Reclaimed Domestic Wastewater. Amman, Jordan.
[16] Qtaishat,T., Seder N., Al-Karablieh. E., Salman. A. (2017). "Economic Analysis of Brackish-Water Desalination Used for Irrigation in the Jordan Valley". Desalination and Water Treatmentm, 72, 13-21.
[17] MoEnv., (2020). Ministry of Environment. Annual Report of the National Water Quality Monitoring Project in Jordan 2020. Government of Jordan, Amman.
[18] JISM, (2015). Jordanian Institute of Standards and Metrology. Drinking water standards No. (JS 286/2015). Government of Jordan, Amman.
[19] Abdulla, F.A., Alfarra A., Abu Qudais H., Sonneveld B. (2016). Evaluation of Wastewater Treatment Plants in Jordan and Suitability for Reuse. Academia Journal of Environmental Science, 4(7),111-117.
[20] Najib I.M. (2019). Effluent Quality Assessment of Selected Wastewater Treatment Plant in Jordan for Irrigation Purposes: Water Quality Index Approach. Journal of Ecological Engineering, 20 (10), 206–216.
[21] JS 1145/2016. Jordan Standards and Metrology Organization. Sludge-Uses of bio-solids and disposal. Amman, Jordan.