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# Influence of Population Growth on Supply, Demand, and Quality Issues of Water Resources in the Yarmouk River Basin in Jordan

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KEYWORDS

Yarmouk River Basin

Population growth

Water supply-demand and quality issues

Water resources management

Decision-makers

**ABSTRACT**

This study was carried out to investigate the influence of population growth on supply, demand, and quality issues of water resources in the Yarmouk River Basin in Jordan for twenty years. The population growth data for the years 1997 and 2017 was derived from four Jordan governorates, i.e., Mafraq, Irbid, Jerash, and Ajloun, as well as for the population of the Yarmouk Basin was calculated, where a part of the population of these governorates resides within Basin. The water supply and the number of wells were also determined during this study. Various physicochemical parameters of water, like pH, EC, TDS, DO, $NO_2$, and $NO_3$, were also evaluated. Water supply, demand, and quality issues were also identified in collaboration with relevant stakeholders. The study showed an increase in the Kingdom's population in four governorates from about 1.27 to 2.88 million inhabitants, while the population of four governorates in the Yarmouk Basin increased from about 639,992 to 1.53 million inhabitants, and it is more than doubling. Comparing the population with the water supply, the numbers of wells and their uses showed significant changes, as evidenced by the substantial increase in the water supply. The studied physiochemical parameters were within the permissible limits of the National Standards. The critical water issues reported in the study area are difficulties in law enforcement and rapid population growth, which interactively affect the water supply. The study's findings will assist decision-makers in managing future water supplies as they face challenges in securing additional water, and there is an urgent need for research and future scenarios to meet water needs.

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## 1 Introduction

Rapid population growth has put unprecedented pressure on water resources to meet the population's demand, affecting the quantity and quality of water supplies (Mongelli et al. 2019). By 2050, more than half of the world's population (about 57%) will live in areas of water scarcity for at least one month each year (Boretti and Rosa 2019). Domestic water demand is expected to increase significantly from 2010 to 2050 in all the world regions except Western Europe. The highest water demand will increase (over 300%) in Africa and Asia (Wada et al. 2016). In developing countries, the rapid increase in population pressure has affected agricultural production (Maitima et al. 2009; Shammout et al. 2018), which also causes alterations in the earth's surface and significantly impacts groundwater recharge (Costa et al. 2003; Shammout et al. 2013).

Most studies agree that population growth via urbanization significantly increases the potential for surface runoff in a given basin and reduces the groundwater quantities and qualities (Chow et al. 1988; Shammout et al. 2018). The influence of population on water resource responses by assessing the relationship between uses and water quantities provides a basis for groundwater management practices in basins. Without proper water supply management, changes in the land basin will continue, and the surface storage and capacity of the soil to store water will also be reduced (Chow et al. 1988; Shatanawi and Shammout 2011). Hence, water management techniques may alleviate water scarcity (Boretti and Rosa 2019). There are some crucial points for countries that suffer from water scarcity as Jordan, in terms of water management scenarios, such as raising efficiency in the water distribution system and allocating alternatives to water resources that positively affect the quantities and quality of water supplies and can prevent water deterioration (MWI 2017a).

In Jordan, precipitation is restricted mainly to the winter season, ranging from over 500 mm in the highlands to less than 50 mm in the east. Moreover, about 8% of annual rainfall flows as a flood and recharges groundwater. The supply of available water resources is less than the water demand. According to Jordan's Water Strategy 2009, the country's annual per capita available water is less than 150 $m^3$ yearly (MWI 2009). By 2025, the per capita share of water is expected to decrease by approximately 90 $m^3$ per person per year, which might place the Kingdom in a state of water scarcity (El-Naser 2009). This means that the gap between water availability and demand for water resources will increase, the population will suffer from severe water poverty, and water basin biology will likely be threatened (Shammout 2020). Jordan has fifteen surface water basins (MWI 2015; MWI 2016) and two rivers, i.e., Yarmouk and Jordan Rivers, with a permanent flow. Yarmouk River is the crucial water source for the King Abdullah Canal, which supports agricultural expansion in the Jordan Valley (FAO 2009). Figure 1 shows the surface water basins in Jordan and the location of the Yarmouk River Basin among the basins.

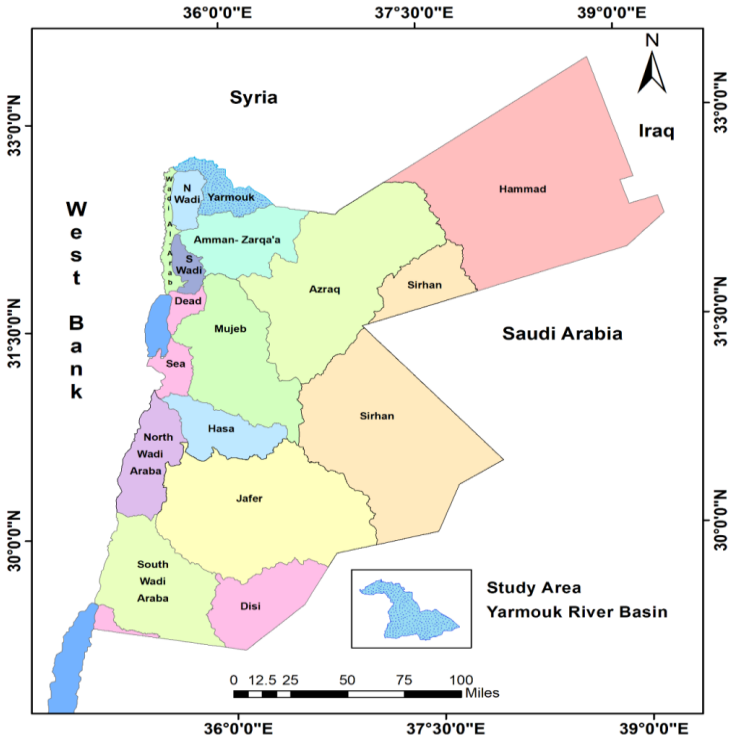


Figure 1 The surface water basins in Jordan and the location of the Yarmouk River Basin among the basins

This study was applied to the Yarmouk River Basin in Jordan, a transboundary water basin. This River Basin is under the pressure of various agricultural, domestic, and industrial activities. The problem of this Basin is exacerbated because water resources systems cannot absorb the shocks caused by the natural contradiction with the sudden increase in population and water uses, increasing in water demand for domestic and irrigation uses. The groundwater and surface water are insufficient to meet domestic and agricultural demand. These problems are attributed to the scarcity of water as well as wide fluctuations in annual rainfall, climate change, and prolonged drought over the past decades. These factors have reduced the water resources and led to the deterioration of the Yarmouk Basin. For these problems, the Yarmouk River Basin was selected as a case study for the project WE/2/08/2017, funded by the Scientific Research and Innovation Support Fund-Ministry of Higher Education and Scientific Research, Jordan. Studying the influence of population growth on supply-demand and quality issues of water resources for the Yarmouk River Basin is essential for understanding and managing the Basin. The specific objectives of this study were to determine the population growth in Jordan for four governorates and the Yarmouk Basin for the years 1979 and 2017. This study was also carried out to assess the influence of the population's needs on responses of groundwater supply wells and quality and identify water supply-demand issues that may help decision-makers manage water resources.

## 2 Materials and Methods

### 2.1 Study Site

The Yarmouk River Basin drains an area of about 1393 km$^2$ inside Jordan, of which more than 50% is covered by vegetation irrigated by the available water resources, mainly groundwater. A warm, semiarid climate characterizes the Yarmouk River Basin, where precipitation especially falls between October and March, and short grasses and drought-resistant shrubs are the dominant vegetation. The average annual rainfall for 1983-2015 was 239 mm/year. In January, an average temperature was recorded above 5°C, while in summer, temperatures may exceed 30°C.

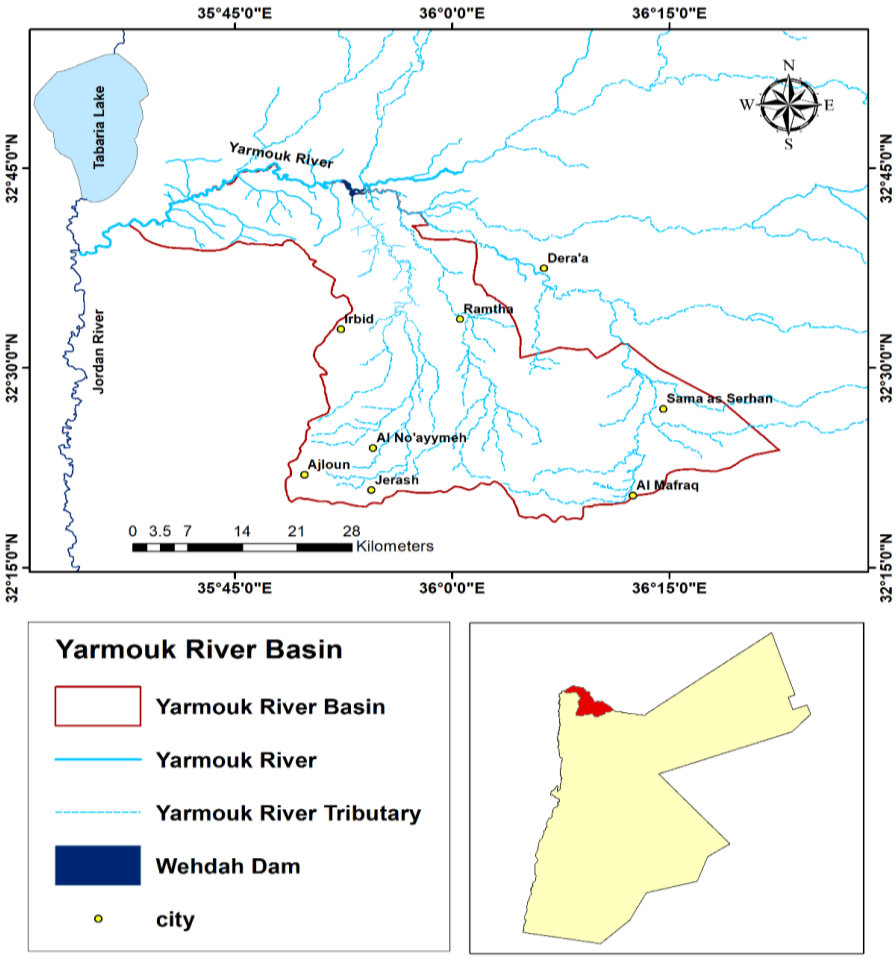


Figure 2 Location of the Yarmouk River Basin and its tributaries, the Yarmouk River, Wehdah Dam, and the main cities.

The Yarmouk flows along the Syria-Jordan border and into the Lower Jordan River. It is considered the main tributary of the Jordan River, and its historic flow was estimated at 480 MCM but is now dramatically reduced. The Yarmouk River provides about 50% of the Jordan River water flow (Avisse et al. 2020). The elevation is about -200 m in the Jordan Valley and about 1150 m in the Basin's upper boundary, RasMunif. The main wadi's included in the study area are Wadi al Shallalah, Wadiar Raggad, Wadi Al Showmar, Al Ghadir Al Abyad, and Shaqq al Barid. The main cities in the Yarmouk Basin in Jordan are Ramtha, Ajloun, Jerash, and Al Mafraq. These cities belong to the four main governorates: Mafraq, Irbid, Jerash, and Ajloun. There are five treatment plants, i.e., Al Akaidar Treatment Plant, Wadi al Shalalah Treatment Plant, Mafraq Treatment Plant, Wadi Hassan Treatment Plant, and Ramtha Treatment Plant in the Basin. The treated wastewater is used for irrigation. The main dam on the Jordanian side of the Yarmouk Basin is Wehdah Dam, which is used for irrigation. Numerous dams and canals in Syria have been built on the river's tributaries in the upper part of the Basin to enhance surface water availability (Obeidat et al. 2019). Figure 2 shows the location of the Yarmouk Basin and its tributaries, the Yarmouk River, Wehdah Dam, and the main cities.

### 2.2 Determining population growth, quantities, and quality of groundwater wells

In this study, population growth in Jordan for four governorates (Mafraq, Irbid, Jerash, and Ajloun) and the Yarmouk Basin was determined for the years 1979 and 2017 in terms of identifying the basin objects as (a) Hashemite Kingdom of Jordan governorates (b) Yarmouk Basin governorates (c) Communities that are located within the entire Yarmouk River Basin-Jordan and (d) Communities population. These data were determined at the Water, Energy, and Environment Center of the University of Jordan and in cooperation with the relevant Yarmouk Basin water managers. Population and the amount of water provided to the entire Yarmouk Basin were determined. Physicochemical parameters for the Al-Mukheiba wells were also analyzed (Table 1).

Population growth was computed according to the demographic records provided by the Jordanian Department of Statistics (DoS 1997; DoS 2017), as well as the water supply from the basin wells for the same targeted years was computed based on the open files of the Ministry of Water and Irrigation (MWI 1997; MWI 2017b). The total population in the entire Yarmouk Basin was computed, where part of these governorates is located there. The Basin's groundwater wells were used to extract quantities of water supply using ArcMap10.8.1. The number of running wells between 1997 and 2017 was computed to study changes in water quantities and the number of open wells compared to changes in population growth.

Water analyses were conducted in the laboratories of the University of Jordan, and the Ministry of Water and Irrigation, according to the Standard Method (American Public Health Association 2012). The analysis was carried out on Al-Mukheiba wells because these wells are an essential water source in the Yarmouk River Basin and provide domestic water needs. The studied parameters were pH, EC, TDS, DO, $NO_2$, and $NO_3$. Table 1 shows the parameters and method number used for analyses.

### 2.3 Identifying water supply-demand and quality issues

This study builds a network of expertise and knowledge exchange, sharing its findings, generic data, and best practice examples, where information shared by local related stakeholders, experts, and scientists is the basis to bridge the gap between supply and demand and protecting the water resources of the Yarmouk Basin. The following criteria have been implemented to identify water supply-demand and quality issues:

1 Meetings and interviews were conducted to enhance collaboration between the project team, relevant water managers, and decision-makers in identifying water issues and driving forces for preserving the Yarmouk River Basin.

2 Collecting the required data relevant to the Basin and research objectives, these data were compiled from the Department of Statistics, Ministry of Water and Irrigation (MWI), Ministry of Agriculture, Agriculture Department of Mafraq Governorate, and Directorate of Agriculture of Irbid Governorate.

3 Evaluating the collected data to ensure its compatibility with supply-demand describes water shortages and the balance of demand-supply across the Basin.

4 Determining water supply, demand, and quality issues in cooperation with the related water managers.

Table 1 Parameters and method number of analyses as per American Public Health Association (2012).

| Parameter | Symbol | Method | Number |
|---|---|---|---|
| Potential of Hydrogen and Dissolved Oxygen | pH, DO | Meter at Field | SM4500-H+B, and 4500 OG |
| Electrical Conductivity | EC | Laboratory Method | SM 2510B (Ref: CHI-EC) |
| Total Dissolved Solids | TDS | Calculation by Analysis | 1030 E |
| Nitrite, Nitrate | $NO_2$, $NO_3$ | Ion Chromatography | SM 4110B |

Table 2 Population of governorates in Jordan for the years 1997 and 2017

| Governorate | Jordan Governorate Population 1997 | Jordan Governorate Population2017 | % Growth Rate 1997 to 2017 |
|---|---|---|---|
| Mafraq | 196,381 | 580,000 | 5.66 |
| Irbid | 830,901 | 1,867,000 | 4.13 |
| Jerash | 135,663 | 250,000 | 3.10 |
| Ajloun | 105,046 | 185,700 | 2.89 |
| Total/% | 1,267,991 | 2,882,700 | 4.2 |

Table 3 Population, well supply uses, and the number of running wells in the Yarmouk River Basin for the years 1997 and 2017

| Yarmouk Basin Population 1997 | Yarmouk Basin Population 2017 | Yarmouk Basin Domestic Supply 1997 | Yarmouk Basin Domestic Supply 2017 | Yarmouk Basin Irrigation Supply 1997 | Yarmouk Basin Irrigation Supply 2017 |
|---|---|---|---|---|---|
| 639,992 | 1,526,375 | 11 MCM (35 Wells) | 21.5 MCM (62 Wells) | 28.8 MCM (110 Wells) | 33.3 MCM (125 Wells) |

## 3 Results and Discussion

### 3.1 Influence of population growth on the groundwater responses

The influence of population needs on groundwater supply wells responses for 1997 and 2017 (Table 2) shows that Yarmouk River Basin was forceful in terms of population changes. Results presented in Table 2 summarized the population of the governorates in Jordan for the years 1997 and 2017; these data revealed that the population has significantly changed as Mafraq increased from 196,381 to 580,000 inhabitants, Irbid from 830,901 inhabitants to 1.87 million inhabitants, Jerash from 135,663 to 250,000 inhabitants, and Ajloun from 105,046 to 185,700 inhabitants. The overall population of Jordan in four governorates increased from about 1.27 to 2.88 million inhabitants. It is clear (Table 2) that the increases in growth rate percentages over twenty years were concentrated in Mafraq at 5.66%, followed by Irbid at 4.13%, then Jerash at 3.10%, and Ajloun at 2.89%. The reason for this is the influx of Syrian Refugees residing in the Mafraq governorate due to its proximity to the Syrian border (UNHCR 2015). These numbers put pressure on water resources, especially groundwater, to meet the population's needs, where groundwater wells are the primary source in Jordan for water use (MWI 2016; Shammout et al. 2021).

Results presented in Table 3 show the population, water supply uses, and the number of running wells in the Yarmouk River Basin for the years 1997 and 2017. The population of four governorates in the Yarmouk Basin increased from about 639,992 inhabitants to 1.53 million inhabitants. Comparison of the population with water supply, wells numbers, and uses for the years 1997 and 2017 showed significant changes, as evidenced by the observed increase in the population and the substantial increase in water supply for domestic water and irrigation. The quantity of domestic supply wells for the Yarmouk Basin in 1997 was 11 MCM with 35 running wells; in 2017, it was 21.5 MCM with 62 running wells. The quantity of irrigation supply wells for the Yarmouk Basin in 1997 was 28.8 MCM with 110 running wells, while in 2017, it was 33.3 MCM with 125 running wells. Parts of the quantities of these supply wells are also supplied to the Jordan valley to meet the population's domestic and irrigation needs. Hence, without proper management of water resources, the deterioration of the Basin will also increase (MWI 2016; Shammout et al. 2021).

Table 4 revealed the coordinates, water use, water kind, location, and average values of physicochemical analysis of Al-Mukheiba wells. The average pH 7.5, EC 895 µS/cm, TDS 501 mg/L, DO 7.60 mg/L, $NO_2$ <0.2mg/L and $NO_3$ <0.5 mg/L was reported. The physicochemical parameters were within the permissible limits as per the National Standards (2015).

Table 4 Coordinates, water use, water kind, location, and average values of physicochemical analysis of Al-Mukheiba wells for the year 2017

| Well Name | X WGS 84 | Y WGS 84 | Water Use | Water Kind | Location | pH | EC (µS/cm) |
|---|---|---|---|---|---|---|---|
| Al-Mukheiba | 35.686173° | 32.703759° | Drinking | Groundwater | Irbid | 7.5 | 895 |
| Well Name | TDS (mg/L) | Depth (m) | Wtl (m) | T (©) | DO (mg/L) | $NO_2$ (mg/L) | $NO_3$ (mg/L) |
| Al-Mukheiba | 501 | 1238 | 11.08 | 37 | 7.60 | <0.2 | <0.5 |

Table 5 Main water supply-demand and quality issues in the Yarmouk River Basin

| Issues | Problems |
|---|---|
| Water Management | (a) Difficulties in law enforcement, (b) Conflict among sectors and lack of a single responsible authority, and (c)Lack of public awareness and extension programs. |
| Groundwater Supply-Demand | (a) Decrease in base flow and aquifer recharge in the Basin, (b)Transboundary upstream abstractions resulted in flow decrease in the river, (c) Uncontrolled population growth and activities related to their needs, (d) Over-pumping of groundwater for drinking has affected groundwater quantity, (e) Higher demand for groundwater for domestic uses compared to supply, (f) Pressure on groundwater by the agricultural sector, and (g) Uncontrolled uses as drilling illegal wells. |
| Quality | (a) Wastewater quantity is increasing with population growth, and the development of sewage systems is highly needed so that water can be reused for agricultural purposes, (b) Land degradation due to overgrazing, deforestation, and urbanization also affects the flood pattern, (c) Unplanned urban growth, and improper land use prevent rainfall from recharging groundwater aquifer, and (d) Over-pumping has exceeded the safe yield limit and thus affected groundwater quality. |

**3.2 Water supply, demand, and quality issues that may help decision-makers in water resources management**

During this study, water supply demand and quality issues were discussed through meetings and interviews with stakeholders in the Yarmouk Basin regarding water management, groundwater supply demand, and Quality. Table 5 shows the primary water supply demand and quality issues in the Yarmouk Basin. The problems attributed to these issues are difficulties in enforcing the law, the conflict between water sectors, the lack of a single responsible authority, and the lack of awareness and extension programs on water issues and water resources management. Another problem associated with the decreased base flow and diminished aquifer recharge of the Basin is the flow in the Yarmouk River is also declining due to upstream abstractions. Also, problems are associated with the growing population activities and their needs. Over-pumping groundwater for drinking has affected groundwater quantity. Compared to supply, high demand for domestic uses creates pressure on groundwater. Further, the agricultural sector and uncontrolled uses such as drilling illegal wells also increase pressure on groundwater. Quality issues are related to the amount of wastewater quantity that increases with population growth, and there is a need to develop sewage systems. Moreover, land degradation due to overgrazing, deforestation, and urbanization affects the flood pattern, and unplanned urban growth and improper land use prevent rainfall from recharging groundwater aquifer (Chow et al. 1988; MWI 2016; Abualhaija et al. 2019; Shammout and Abualhaija 2019; Shammout et al. 2022), and over-pumping has exceeded the safe yield limit and thus affected the quality of groundwater.

Therefore, stakeholders indicated that administrative actions must focus on water technology scenarios, such as reducing losses in the water distribution network, inter-basin water supplies, and reducing consumption against water supply to secure water supplies to meet the population's demand. Moreover, enforcing the law to stop drilling illegal wells will also positively affect.

Jordanian decision-makers face challenges in securing more water for a growing population and agricultural needs. The above results regarding identifying the main water supply, demand, and quality issues of the Yarmouk Basin are of great importance. The results of the study demonstrate that this definition is an important approach for managing water resources because it is greatly influenced by population growth and needs, which can assist water resources managers and decision-makers in sustainable management and finding new sustainable solutions and scenarios for future water supply challenges (Shammout et al. 2013).

**Conclusions**

The Yarmouk River Basin is crucial for many domestic and irrigation uses. The significant problems related to the Basin's water resources arise from the pressure to meet human needs that generate increasing imbalances between the demand and supply of water. Groundwater wells were identified in terms of uses and quantities related to the targeted years of this research, 1997-2017. The amounts of water used and the number of running wells were calculated compared to population growth and needs. The issues of water supply, demand, and quality were identified in cooperation with related actors in the Yarmouk River Basin.

A significant trend of changes in the population of the Yarmouk Basin River from 1997 until 2017 has been observed. Comparing the population to the water supply and the number of wells also showed significant changes, as evidenced by the substantial increase in water supplies for domestic and irrigation water uses. The analyzed water parameters were within the ideal detection limits as per the National Standards. Water supply, demand, and quality issues were identified and showed that water management, supply-demand, and quality are critical to understanding and coping with the challenges of water supply shortages as they are influenced by population growth and needs. The population has more than doubled in twenty years, and decision-makers must consider this to develop future scenarios and research to manage water supply and demand.

**Conflicts of Interest**

The authors declare no conflict of interest.

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**References**

Abualhaija, M.M., Shammout, M.W., Mohammad, A.H., & Abu-Hilal, A.H. (2019). Heavy Metals in water and sediments of King talal Dam the largest Man-Made water Body in Jordan. *Water Energy International*, *62*, 49–62.

American Public Health Association. (2012). Standard Method for the Examination of Water and Wastewater, 22nd ed, American Public Health Association, New York.

Avisse, N., Tilmant, A., Rosenberg, D., & Talozi, S. (2020). Quantitative Assessment of Contested Water Uses and Management in the Conflict-Torn Yarmouk River Basin. *Journal of Water Resources Planning and Management*, *146*(7), 05020010. https://ascelibrary.org/doi/full/10.1061/%28ASCE%29WR.1943-5452.0001240

Boretti, A., & Rosa, L. (2019). Reassessing the projections of the World Water Development Report. *Clean Water*, *2*, 15. https://doi.org/10.1038/s41545-019-0039-9

Chow, V.T., Maidment, D.R., & Mays, L.W. (1988). Applied Hydrology; McGraw-Hill Book Company: New York, NY, USA.

Costa, M.H., Botta, A., & Cardille, J.A . (2003). Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. *Journal of Hydrology*, *283*(1-4), 206-217.doi.org/10.1016/S0022-1694(03)00267-1

DoS. (1997). Department of Statistics-Open files, Hashemite Kingdom of Jordan, Amman, Jordan. Retrive from www.dos.gov.jo.

DoS. (2017). Department of Statistics-Open files, Hashemite Kingdom of Jordan, Amman, Jordan. Retrive from www.dos.gov.jo.

El-Naser, H. (2009). Management of Scarce Water Resources: A Middle Eastern Experience, Witpress, UK. https://www.witpress.com/books/978-1-84564-414-7.

FAO. (2009). AQUASTAT Trans-boundary River Basins – Jordan River Basin. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy. https://www.fao.org/3/CA2131EN/ca2131en.pdf

Maitima, J.M., Mugatha, S.M., Reid, R.S., Gachimbi, L.N., et al. (2009). The linkages between land use change, land degradation and biodiversity across East Africa. *African Journal of Environmental Science and Technology*, *3*(10), 310-325.

Mongelli, G., Argyraki, A., Lorenzo, M.L.G., Shammout, M.W., Paternoster, M., & Simeone, V. (2019). Groundwater Quality in the Mediterranean Region. *Geofluids*, *2019*, Article ID 7269304. https://doi.org/10.1155/2019/7269304

MWI. (2009). Ministry of Water and Irrigation, Jordan's Water Strategy 2008-2022. https://jordankmportal.com/resources/jordans-water-strategy-2008-2022

MWI. (2015). Ministry of Water and Irrigation, Jordan Water Sector, Facts and Figures2015, Amman, Jordan.

MWI. (2017a). Ministry of Water and Irrigation, Jordan Water Sector, Facts and Figures 2017, Amman, Jordan. https://www.unicef.org/jordan/media/11356/file/water%20stress%20in%20Jordan%20report.pdf

MWI. (2016). Ministry of Water and Irrigation, National Water Strategy of Jordan 2016 – 2025. Hashemite Kingdom of Jordan, Amman, Jordan. Retrived from http://extwprlegs1.fao.org/docs/pdf/jor156264E.pdf.

MWI. (1997). Ministry of Water and Irrigation-Open files, Hashemite Kingdom of Jordan, Amman, Jordan.

MWI. (2017b). Ministry of Water and Irrigation-Open files, Hashemite Kingdom of Jordan, Amman, Jordan.

National Standards. (2015). Jordanian Standards for Drinking Water, No 286/2015

Obeidat, M., Awawdeh, M., & Lababneh, A. (2019). Assessment of land use/land cover change and its environmental impacts using remote sensing and GIS techniques, Yarmouk River Basin, north Jordan. *Arabian Journal of Geosciences*, *12*, 685. https://doi.org/10.1007/s12517-019-4905-z

Shammout, M.W., Shatanawi, M., & Nelson, J. (2018). Curve Number Applications for Restorationthe Zarqa River Basin. *Sustainability*. *10*, 586. doi.org/10.3390/su10030586

Shammout, M.W., & Abualhaija, M.M. (2019). An analysis of long term yearly water flow trend and its impact on sediment yield in King Talal dam. *International Journal of Engineering Research and Technology*, *12*(12), 3041-3049.

Shammout, M.W., Shatanawi, M., & Naber, S. (2013). Participatory Optimization Scenario for Water Resources Management: A Case from Jordan. *Water Resources Management*, *27*, 1949-1962. doi.org/10.1007/s11269-013-0264-9

Shatanawi, M., & Shammout, M.W. (2011). Supply-demand modeling of water resources in Zarqa river basin in Jordan. *International Journal of Applied Environmental Sciences*, *6*, 261-278.

Shammout, M.W. (2020). Native Growth and Conservation of Duckweed (Lemnaceae) in Jordan. *Pakistan Journal of Biological Sciences*, *23*(8),1055-1059. doi: 10.3923/pjbs.2020.1055.1059.

Shammout, M. W., Shatanawi, K., Al-Bakri, J., & Abualhaija, M. M. (2021). Impact of Land Use/Cover Changes on the Flow of the Zarqa River in Jordan. *Journal of Ecological Engineering*, *22*(10), 40-50. https://doi.org/10.12911/22998993/142184

Shammout, M.W., Shatanawi, M., & Awwad A.M. (2022). Fate and Management of Pollution of Hexavalent Chromium Cr (VI) and Heavy Metals in the Zarqa River Basin in Jordan. *Journal of Ecological Engineering*, *23*(2), 108-115. https://doi.org/10.12911/22998993/144417

UNHCR. (2015). United Nations High Commissioner for Refugees, Factssheet-Mafraq Governorate. www.unhcr.org

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., et al. (2016). Modelling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. *Geoscientific Model Development*, *9*, 175–222.