

Status of Groundwater Resources in Jordan

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Abstract This study focuses on the actual status of groundwater in Jordan after years of depletion in the absence of programs that take care of strategies for protection and sustainability and impacted by the scarcity of natural resources, climate change, the growing population, and pollution due to increasing activities in industry and agriculture. Groundwater resources are essential and represent Jordan's main water supply source, which necessitates careful planning and management to sustain water supply and human socio-economic development. However, these vital resources are permanently under the massive pressure of degradation by both mismanagement and over-exploitation which leads to contamination and a decline in water levels. This paper shows the state of groundwater resources in Jordan and deals with the weakness of groundwater as the main source of water supply and protection strategies to meet the many challenges it faces. Significant loss of saturated thickness and growing extension of unsaturated zones, inversion of flow directions toward areas of extensive groundwater abstraction, and increasing the number of dried springs are clear indicators of the severe overuse of groundwater resources. These impacts determine the reliability of groundwater for future water supplies, people's health, and food security.

Keywords: *groundwater resources, overexploitation, depletion, decline, drying up, Jordan*

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1. Introduction

Freshwater resources in Jordan are limited and extremely vulnerable to both human interventions and climate change. In arid regions and during the dry and wet seasons, the recharge rates of groundwater aquifer systems vary significantly; they increase in the wet climatic period and decrease in the dry period. Human intervention in hydrologic systems, such as the construction of dams (reservoirs) to store and expand the utilization of surface water, a lack of development programs for the evaluation of alternative renewable water resources, or the legal and illegal pumping of fossil groundwater without recognizing how these processes could affect these groundwater systems on a regional scale.

Groundwater is a key water resource in the fight against poverty, food and water security, socio-economic growth and development, and the resilience of societies and economies to climate change. Reliance on groundwater will increase, mainly due to growing water demands by all sectors combined with increasing variation in rainfall patterns.

Jordan's area is 89.3 thousand km², three-fourths of which is desert receiving less than 100 mm of rain annually. The population of Jordan has been affected by a number of factors including, demographic, political, economic, and forced refugee migration from neighboring countries. Forced migration fluxes brought 2.5 million people from neighboring countries, raising the population

of the country to more than ten million people. The expected number of people living in the country is estimated to reach 10.61 Mio. 11.12 Mio. and 11.84 Mio. in the years 2025, 2030, and 2035 respectively [1].

Despite its small size, the diversity of Jordan's topography and landscape contrasts with its actual size and can only be found in large countries. Western Jordan is mainly characterized by a Mediterranean climate with hot, dry summers, cold, wet winters, and two short transition seasons. However, about 75% of the country can be described as having a desert climate of less than 100-200 mm. of rain annually. Jordan is divided into three main geographic and climatic regions: the Jordan Valley, the Highlands Plateau, and the Eastern Desert or Badia. The Mediterranean climate prevails in the western heights of Jordan, where summer is moderate and dry and the winter cold and rainy. The desert climate prevails in Badia and is characterized by hot summers and cold winters. The Jordan Valley region has a subtropical climate with hot summers and warm winters. The average annual temperature ranges between 22 and 25 °C in the Jordan Rift region, and 18 to 21 °C in the Badia. In the highlands, the average temperature ranges between 14 to 18 °C [2]. Precipitation is fluctuating and variable and its occurrence are largely limited during the winter and early spring, with an amount ranging from 550 mm in the mountainous heights to less than 50 mm in the eastern regions having a desert climate. The long-term average annual precipitation is ≈ 8217 million cubic meters. The Eastern Desert (Badia) lies east of the mountainous region and covers about 80% of the land area of Jordan has low precipitation.

According to 50 years of records, the rainfall rate is between < 100 and 520 mm. The evaporation rate constitutes about 88 % to 93 % of the total rainfall, while an infiltration rate of approximately 4 -10% was recorded [3].

2. Water Scarcity

Water scarcity in Jordan is exacerbated by several factors including excessive drought periods resulting from decreased precipitation and its uneven spatial and temporal distributions, increasing economic development needs, effects of climate change, and the high population increase accompanied by the hosting of refugees from neighboring countries. In terms of water availability, Jordan ranks as the second world's water-poorest country with 40% of its water resources being shared with neighboring countries. The region suffers from water scarcity due to the interaction between low annual average precipitation and successive years of drought, and the country's complex hydro- and geopolitical context. Water is, therefore, characterized as the most important natural constraint affecting the socio-economic growth in Jordan. Although all available water sources were developed and exploited, the total available water per capita is still 88 % below the global line for absolute water scarcity of 500m³ [UNDP, Jordan, 2019].

Many groundwater resources are over-abstracted, while the demand for water is continuously and constantly growing. The sources of water in Jordan include traditional sources such as rain, surface water, and groundwater, including non-conventional sources like water coming from sewage treatment and desalination plants [3].

Table 1. Summary of annual rainfall rates in Jordan for the period 2007-2017 and shares of evaporation, surface runoff, and Infiltration rates [3]

Year	Aver. Rainf. MCM	Long-term Rate MCM	Aver. Evapor MCM	Average Groundw. Recharge MCM	Average of Floods MCM
2006-2017	7480.4	8224.6	6976.4 = 93.2%	326.5 = 4.3%	176.7 = 2.3 %

Water supplies in Jordan (in 2020 about 1312 MCM) are derived from three main resources; 27 – 30 % of the water is coming from surface water, 58.5 % from groundwater, and 14% from treated wastewater. Freshwater resources in Jordan consist mainly of groundwater and surface water. Treated wastewater and brackish water desalination are other important non-conventional resources that help in bridging part of the demand, especially in the municipal and agricultural sectors.

Table 2. Jordan water use (MCM/a) by sector [5,6]

Year	Domestic	Industrial	Agriculture	Total
2015	463 ≈ 36.2 %	112 ≈ 8.75 %	704 ≈ 55.04 %	1279
2020	517 ≈ 39.4 %	130 ≈ 10%	665 ≈ 50.7 %	1312
2025	652 ≈ 42 %	182 ≈ 11.7 %	716 ≈ 46.1 %	1,550

Table 2 provides a summary of the main sources of water for each key consumer category in Jordan.

Despite the slight decrease in the amount of agricultural water, agriculture remains the largest consumer, even though a quarter of the irrigation water originates from WWTPs effluents. Irrigation using surface water and treated wastewater is predominant in the Jordan Valley, while groundwater-based irrigation is characteristic of the highlands. The contribution of groundwater amounts to 61% of the total water supply in Jordan. 51 % of available water is used in Agriculture, 46% from groundwater sources. The total surface water supply developed in the year 2014 was about 259 MCM, and this forms 27% of the total water supply in Jordan [MWI, 2017]. To bridge the large gap between supply and demand for water in recent times, attention has turned to the exploitation of fossil groundwater and the use of non-conventional water resources. Underground water from the non-renewable Disi aquifer (annual abstraction 147 MCM/year) is being used to meet Jordan's water supply for domestic use, while treated wastewater (≈125 MCM/year) is used to meet the country's agricultural requirements [5-6].

Table 3. A projection summary of the main available sources (MCM) of water and total demand (MCM) required in years 2015 – 2025 [8]

Year	2022	2023	2024	2025
Total resources (Avail.) MCM	1237	1251	1253	1280
Sustain. resources MCM	1106	1125	1131	1341
Non-sustain. resources MCM	131	126	122	121
Total demand MCM	1493	1503	1536	1550
Dtifice* (Available – Demand) MCM	-256	-252	-283	-270
% of deficit	17.1	16.8	18.4	17.4

*with noitcartxe-revo of GW.

As indicated in Table 3, the water shortage (deficit) in Jordan is a problem of a chronic nature and will continue in the coming years. If current domestic, agricultural, and industrial water consumption practices are not properly managed and improved, the water supply in Jordan will deplete in quantity and quality in the very near future. Maintaining a balance between demand and supply has been a serious challenge in recent years and will probably become even more difficult in the future. It should be stressed that the amounts of surface water that can be developed are unpredictable, and cannot be made available on a permanent and sustainable basis due to geopolitical reasons, as well as due to variability in rainfall and the effects of climate change. Renewable groundwater is overexploited and dependent on inconsistent precipitation. Deep fossil and brackish sources are at some risk of quality deterioration in the medium term, and they will be exploited within decades. In summary, the current balance of supply and demand will be increasingly negative and difficult to adjust.

3. Most Important Outcropping Aquifers of Jordan

The geological sequence in Jordan is divided into lithostratigraphic units based on hydrogeological relevance; these units describe the structural succession of

aquifers and aquitards. The complex aquifer system of Jordan is defined by three major hydro-geological aquifer units [9]:

- The upper cretaceous B2/A7 limestone aquifer is known as the most important aquifer in Jordan and the A1-A6 limestone-marl aquifer-aquitard –group.

- The Basalt and the older alluvial aquifer both are considered one of the main aquifer systems in Jordan and extend from the basin center to the north and northeast. This shallow (upper) aquifer system consists of tertiary and quarterly sedimentary and igneous rocks (alluvial, basalt B4/B5).

- The third aquifer system is the sandstone aquifer system, which occupies the central part of Jordan (Kurnub - Zarqa - Ram) in addition to the Disi sandstone aquifer system.

To assess the overall groundwater conditions, it is necessary to understand the aquifer geometry. The Plateau Basalt Formation outcrops in the northeastern part of Jordan with a thickness of 400m. The younger alluvium Formation consists of thin deposits overlying the basalt mainly found in the cemented out-wash and the old river terraces. Both formations belongs to Jordan Valley group.

The deep sandstone aquifer system consists of several units: Ram, Khreim, Zarqa and Kurnub. The Ram Group is an important porous aquifer that extends across all of Jordan and dewater towards the Dead Sea. In western Jordan, the Kurnub aquifer directly overlies the Ram Group aquifer, forming a combined aquifer complex (Margane et al., 2002). In eastern Jordan, low-permeability strata from the Khreim Group separate the two sandstone aquifers.

At the country scale, several formations in the Upper Cretaceous Ajlun Group are usually grouped together as the A1/A6 Aquitard. The Naur limestone aquifer (A1/A2) thins from nearly 300 m thick in the north to approximately 150 m thick in Wadi Mujib and only 25 m thick at the Ras – en- Naqb escarpment in the south. In general, the A1/A2 and over-laying formations dip gently to the east due to the uplift of the Dead Sea Rift shoulders. However, the A1/A2 and A4 aquifers are important for local water supply, especially in areas where the overlying A7/B2 aquifer has nearly dried up. The A3 aquitard (Fuhais Formation) has an average thickness of approximately 50 m and thins to the south, and it structurally follows the underlying A1/A2 Formation. There are no indications of the A3 Aquitard in the lower Zarqa River, the Baqa'a Valley northwest of Amman or between Amman and the northern Dead Sea. The thickness of the A4 aquifer (Hummer Formation) is comparable to that of the A3 aquitard, and it discharges through several springs. A4 aquifer is hydraulically connected to the underlying A1/A2 aquifer or the overlying A7/B2 aquifer due to faulting and karstification [9].

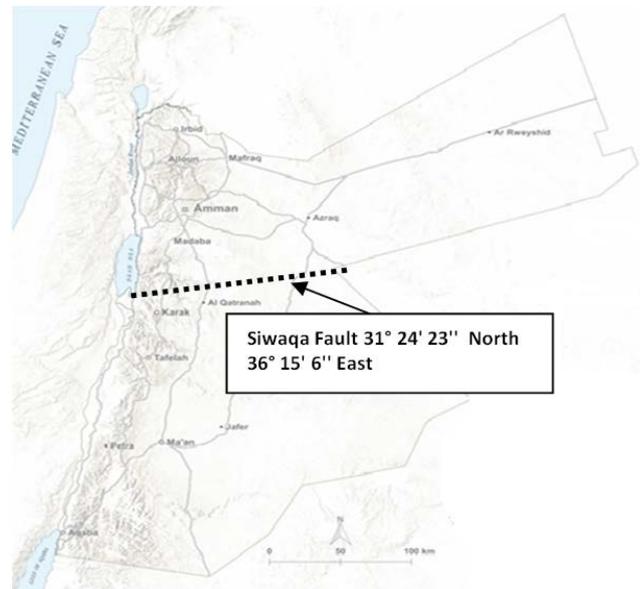
The (A7) Formation, outcrops extensively both in the north, central and south parts of Jordan. It consists of limestone and dolomitic limestone with a thickness ranges between 50-350 m dipping to the east and northeast. The (B2) Formation is a cyclic deposit of chalk, phosphate, silicified phosphate, limestone, and Chart. Its thickness reaches about 50m. The A5/A6 Aquitard, separates the A4 aquifer from the overlying A7/B2 aquifer, although there

is some evidence that this separation does not always exist, likely due to karstification [10,11,12,13].

Table 4. Aquifers, identifiers codes, and lithologies of major aquifers in Jordan [After Salameh and Bannayan, 1993 [11]

Group	Aquifer Units Identifier Code	Thickness	Primary Lithology
Jordan Valley JV	Alluvium ALL Basalt BA	>300 m 100 – 350 m	Sand, Gravel Basalt
Balqa B	B1 Aquifer B2 Aquifer B3 Aquifer B4 Aquifer B5 Aquifer A7/B2 Aquifer	20 – 90 m 20 -140 m 80 - 320 m 0 - 310 m 0 – 550 m 60 -340 m	Chalk, Limestone
Ajlun A	A1,2 Aquifer A3 Aquifer A4 Aquifer A5,6 Aquifer	30 – 220 m 30 – 90 m 30 – 100 m 40 - 120 m	Limestone, Dolomite
Kurnub K	K1,2 Aquifer	120 – 350 m	Sandstone
Zarqa Z	Zarqa Aquifer	0 - >1250 m	Limestone, Dolomite, Sandstone
Khreim KH	Khreim Aquifer	0 - >1600 m	Sandstone
Ram Disi D	Ram Disi Aquifer	0 - >1500 m	Sandstone

Groundwater basins in Jordan are divided in relation to Siwaqa fault (31° 24' 23" North, 36° 15' 6" East) into two groups, the first of which is located to the north of Siwaqa fault and can be easily differentiated, while the other, which lies to the south of Siwaqa fault, the units are similar and cannot be clearly distinguished from one another [11].



4. Challenges Facing Groundwater Resources

4.1. Overexploitation

Groundwater is the main water supply source in Jordan and is mainly utilized by the domestic, industrial, agricultural, and tourism sectors. Due to the huge gap between water supplies and the demand of these sectors,

groundwater is increasingly put under massive pressure. The groundwater resources are overexploited and require rehabilitation and some of them have been totally depleted and rehabilitation of some of these groundwater resources may have become technically impossible. Of the 12 major groundwater basins, nine are over-extracted at rates ranging between 118% - 365 % of the safe yield of these basins. The quantity of over-pumping from groundwater is estimated at about 205 MCM/a [MWI 2017]. The data in Table 5 indicates that the size of the depletion that the aquifers suffer from, as it is currently withdrawing an amount of 624 MCM/year, while the safe withdrawal should not exceed 418.5 MCM/year, i.e. an increase of 205 MCM annually and this percentage is equal to 50% over the safe withdrawals allowed. This depletion is involving renewable as well as non-renewable resources.

4.2. Drawdown of Groundwater Table and Environmental Consequences

The continuous decline in groundwater levels and the drying up of wells and springs are among the factors indicating the very critical groundwater resource conditions in Jordan. For this purpose, the Jordanian Ministry of Water and Irrigation has been running a network of wells for monitoring groundwater for decades. The number of monitoring wells is about 254 distributed on water basins, 144 of which have been equipped to enable online monitoring of groundwater-surface levels on a continuous basis. Water quality monitoring samples are also taken regularly to follow up any changes in water quality on temporal and spatial basis.

Table 5. Status of extraction rates from groundwater basins in Jordan [3,4,5,6]

Basin	Safe yield MCM	Actual abstraction (MCM)	Balance MCM	% of safe Yield Abstraction/safe yield x100
Yarmouk	40	54.16	- 14.16	135
Amman Zarqa	87.5	166.11	- 78.16	190
Jordan River Side Wadis	15	46.73	- 31.73	312
Dead Sea	57	89.98	- 32.98	158
Azraq	24	52.54	- 28.54	219
Wadi Araba North	3.5	6.33	- 2.83	181
Wadi Araba south	5.5	8.48	- 2.98	154
Jafer non-renewable	9	32.85	- 21.85	365
Disi, non-renewable	125	146.96	- 21.96	118
Jordan Valley	21	17.02	3.98	81
Hammad	8	1.87	6.13	23
Sirhan	5	1.71	3.29	34
Total	418.5	624.74	- 235.19	Σ149

A previous study [12,13,14] monitored groundwater levels in six groundwater basins in Jordan from 1960 to early 2013. On the basis of collected data for 117 wells, groundwater levels in the six basins were declining, on average about 1 m/yr, in 2010. The

highest average rate of decline, of about 1.9 m/yr, occurred in the Jordan Side Valley basins. The highest drop rate ever recorded in an individual well was about 9 m/yr. In terms of saturated thickness, 30 to 40 percent of it, on average, was expected to be exhausted by 2030. Five percent of the assessed wells were expected to have zero saturated thickness by 2030.

As reported by [3,4,5,6], 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. Recent documentations indicate that the groundwater level in the main aquifers drops at a rate of 2 m/a, but the decline in some depleted areas reaches 5 to 20 m/a.

A comprehensive study carried out in 2017 by MWI/BGR [15], established a nationwide groundwater flow model which adequately represents the groundwater development in the past and forecasts future developments under different conditions and scenarios. Reliable groundwater level data from all available monitoring points in Jordan was collected and used to draw groundwater contour maps, depths to groundwater maps, saturated thickness maps and difference maps 2000 - 2017 which represents the difference between the groundwater contour lines from the year 2000 and those from 2017 and provides an indication of groundwater level changes over the last 18 years for each aquifer. Provided data from monitoring wells are summarized in Table 6.

Table 6. Observed declines of groundwater table at monitoring wells during 2000 -2017 [15]

Monitoring well ID	Aquifer	Drawdown of GW surface (m)	Long-term average of decline m/yr
AL1521	A7/B2 near Mafraq	51	2.95
K 1000 ED 1328	Ram-Disi Aquifer	12.6 23	0.6 0.55 m
AL3522	A4	10	0.65
Za'tari	A1/A6	10	0.61
Azraq	B4/B5	18	≈ 0.96

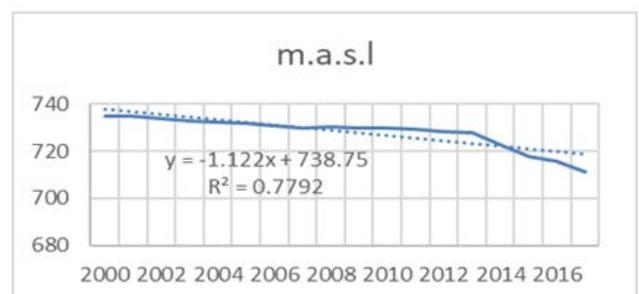
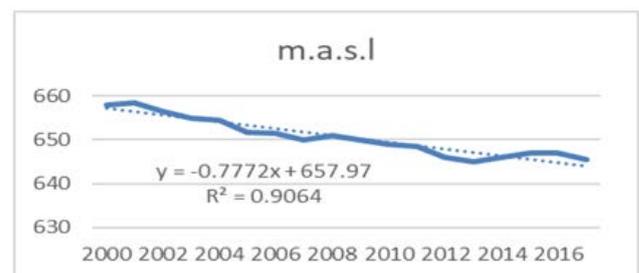


Figure 1. Decline curve and trendline for well K1000 and well ED1328/Ram-Disi Aquifer during 2000 – 2017 [15]

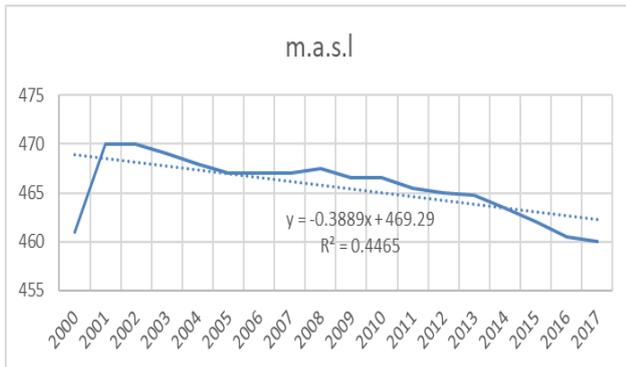


Figure 2. Decline curve of groundwater in the A4 aquifer at well Al3522 during 2000 – 2017 [15]

Results of surveys revealed that the water measurements of groundwater levels and its quality, which are carried out permanently through the network of monitoring wells, showed that the level of groundwater in some areas of the Dead Sea basin decreased by (30) meters, in the Azraq basin (20) meters, Amman-Zarqa (35) meters, and in the Yarmouk basin (31 meters). This drop was accompanied by significant increases in salinity rates, as it rose in the wells of the Dead Sea basin from (400 to 1100) parts per million, meaning a threefold increase in salinity. In addition, information indicated that the areas in which there are a large number of wells recorded a decline that exceeds those in which there are fewer pumping water wells. It was found that the Wadi Al-Arab region in the north of the Kingdom recorded a sharp decline of 170 meters. It also showed that the water basins in the southern regions (Karak and Tafileh) recorded a decline of more than (100) meters in the level of groundwater and can be considered dry, especially in the southern regions. As for the areas of Ma'an, it showed that the groundwater decreased within its natural limits, especially in northern Ma'an during the past 20 years, with indicators confirming that these regions rely on the extension of the non-renewable groundwater coverage. The areas around Amman recorded a significant decrease in the level of the groundwater surface, ranging between 50-100 meters, and they are classified as currently dry areas. The area extending from Madaba – to Qatraneh recorded a drop of more than 50 meters, while the results indicate the possibility of drying out the areas west and southeast of Qatraneh completely. After 25 years of exploitation, Disi groundwater levels dropped by around 25 m signaling several environmental consequences such as: dropping water levels, mobilization of some salty water bodies in geologic units connected vertically with Disi aquifer, and irrigation return flow waters with their high salt contents, biocides, and fertilizers concentrations.

The saturated thickness of groundwater which was derived from the groundwater contour map shows that the most important aquifer in Jordan A7/B2 is becoming partly dry. The map of the groundwater level difference from 1990 to 2017 indicates that the drawdown over the last 20-30 years is alarmingly high and the decrease in saturated thickness varies between 20-50 meters [9]. Locally in areas where the aquifer is still under confined conditions, the groundwater equipotential surface has declined by more than 150 meters. In areas where A7/B2 aquifer is no longer saturated, especially in northern parts

of Jordan, wells have been deepened into the deeper aquifers A4, A1/A2 [15]. Generally, decreasing groundwater levels and increasing unsaturated areas will have serious operational and economic consequences for water supplies to private and public users.

In central and southern parts of Jordan, where the Khreim aquitard and Zarqa aquifer are thinned out, the Kurnub and Ram/Disi sandstone are from one hydrogeological unit. Around Amman to the northwest, the Zarqa group separates the Kurnub aquifer from the Ram/Disi aquifer with a difference in the hydraulic head of more than 100 m. In southern Jordan, the deep Ram/Disi aquifer first flows from Saudi Arabia to the northeast, turns to the northwest, and finally discharges into the Dead Sea. The area around Salt and Ajloun cities, where the Kurnub aquifer outcrops, appears as a dome, that indicates a recharge area, from which groundwater flows in all directions but dominantly towards the Jordan Valley.

Shallow groundwater depths are located near wadis and in the southern parts of aquifers, where the depth is generally between 50 and 200m below ground level. The depth to aquifer (i.e., the depth required to reach the groundwater in a potential well) varies between 100 and 400 meters. In northern parts of the country, the depth to groundwater is commonly much greater and varies between 200 and 400 m. The actual depth to the top of the aquifer is between 500 and 1000 m below the ground surface.

The A1/A2 and A4 aquifers are of high significance, especially in northern Jordan, where the overlying A7/B2 aquifer is partially exhausted. Groundwater from these aquifers is recharged in the mountains Ajloun and As-Salt, before they flows mainly toward the Jordan Valley, north and east. Recharge also occurs at Jabal El-Arab in Syria and enters the country to the south/southwest. Only minor changes in the regional groundwater flow pattern occurred in southern regions of Jordan between 2000 and 2017. However, the situation in the northern parts of the country is very different. In this area, groundwater flow directions appear to have major changes and, in some cases, to have turned by 180°. The increasing pumping activities and the formation of regional depression cones that dominates the groundwater flow pattern are the only plausible cause for this change.

The southern outcrop areas indicate groundwater recharge with an easterly flow direction, following the dip of the aquifer base, and the groundwater level gradient decreases towards the Jafr basin in the eastern part of Jordan. In the northern parts of Jordan, groundwater flows from the recharge points around Ajloun and Jerash in northeast and east directions [16]. Some recharge occurs occasionally at Jabal El Arab in Syria and enters Jordan as lateral inflow to the south. Prior to 1995, groundwater inflow from Syria mainly flowed southeast towards the Azraq depression, however, due to intensive agricultural abstractions, a large cone of depression has developed and forced groundwater to flow towards the Yarmouk basin. North of Ajloun, the groundwater flow direction turns from north to northwest towards the Jordan Valley, following the overall dip of the geological strata. The groundwater level in southern areas has declined by more than 100 m, and the aquifer has changed to an unsaturated state. Table 7: gives a summary of the state of the water basins and what they became after years of depletion and over-pumping.

Table 7. Actual state of most important outcropping aquifers of Jordan [9-15]

Aquifer	Depth to groundwater-surface (m)	Saturated thickness (m)	Observed differences in groundwater level in (m)*
Ram/Disi	≤ 200 - ≥ 800		20 -50 to 100 in some parts
A1/A2 and A4	North of Siwaqa fault ≤100 - ≥ 400 North of Ajloun 200 – 700	north of siwaqa fault ≤100. Around Amman 100 - 200	≤ 100 in west increases to 300 m in the east. North of Amman increases to 400 m
A1/A6	≤100 - > 400 m ≤ 200 m south of Tafila	south of siwaqa fault 200 – 400	
A7/B2	- in southern area 50 -200 - in northern parts 200 – 400 - south of Jabel el Arab 500 -1000	west of Jafer area ≤ 100 Around Irbid ≥300	0 - 100

* Between year 2000 and year 2017.

All observed and obtained details are very alarming, as the groundwater levels and the productivity of wells decreased significantly in the areas east of Mafraq, Al-Dulail and Al-Hallabat and reached more than 95 meters as a result of the over-pumping operations in those areas. Groundwater in the west regions changes flow direction and now flows towards the Jordan Valley after it was flowing towards the northwest, which led to a large-scale drop in the level of groundwater. A similar case is observed in the northwestern regions of Mafraq, as the groundwater flows from the northeast to the southwest. In Jabal Al-Druze area and east of Mafraq, the movement of groundwater has changed from the north and southwest to become to the southeast, also in the Azraq area, the movement of the water paths changed by more than 180 degrees from the southeast to the northwest [15].

4.3. Drying up of Springs

According to data from the Ministry of Water and Irrigation [MWI, 2017], the maximum annual total discharge of springs reached about 249 million cubic raey/sretem in the early seventies, and the discharge has decreased steadily since that time by more than 115 million cubic raey/sretem to reach 136 MCM/aeYr by the year 2010. Of the total number of springs investigated, 58% are perennial, 3.75 % intermittent, and 21% are dry. These discouraging statistics about the state of the groundwater basins and their decline year after year. Some basins experienced a continuous decline of 5 meters annually, while some other 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 total number of springs that dried from 1995 to 2014 is estimated at about 141 wells.

Decreasing groundwater levels and drying out production wells and springs are indicators of extremely critical groundwater resource conditions. Groundwater over-abstraction is mainly a cause of excessive salinity and pollution, both limit the effective availability of groundwater for many uses. Besides groundwater overdraft, point, and non-point-source contamination from agriculture, industrial and domestic uses are also major causes of water quality problems in Jordan [17]. For Jordan, the feasible remaining alternatives to increase groundwater supply could be artificial groundwater recharge, the use of groundwater of less quality, and the use of fossil groundwater resources. The problem of seawater interference in groundwater results from the

presence of an imbalance in the hydraulic equilibrium between the aquifer water and seawater due to the increasing withdrawal of the aquifer water, and consequently the decrease in its level. The movement of the seawater interface front in the waters of the aquifer, especially adjacent to the coastal region, is affected by several factors, some of which are related to the aquifer, and represented in the hydrogeology and hydrology of the aquifer, in addition to the water budget of the aquifer, and others are related to seawater represented by the physical and chemical characteristics of seawater [17]. Climate changes and the accompanying sea-level rise are considered one of the factors affecting the movement of the interference saltwater front. In addition, decreasing groundwater levels and increasing unsaturated areas will have serious economic and operational consequences on water mining for private and public users. Water levels at higher depths require more energy to lift water and consequently higher operational costs. Furthermore, existing wells must be deepened, riser lines must be extended, and pumps must be exchanged with more powerful pumps to adapt to lower depths. A significant number of operating wells will be set out of operation, because the salinity of water increased with depth, eventually water will need treatment and desalination by cost-intensive technologies and disposal of brines.

All surveys and data received from the water departments indicate that all groundwater basins are depleted to a large extent, including non-renewable ones, and this is another evidence of the failure and inadequacy of water policies and strategies designed to preserve groundwater resources and the sustainability of their functioning so that it can be said that groundwater depletion And the continuation of its deterioration will inevitably come if the pumping continues at its current pace.

4.3. Groundwater Quality

Groundwater quality is a very important issue at the national level in Jordan because it is the main source of water for drinking, agriculture, industrial purposes and many other uses. The severe scarcity of water in Jordan necessitates great efforts to conserve every drop of water. Different from the chronic shortage of water resources, pollution is one of the main reasons limiting the availability of usable water for various purposes. Jordan should work to protect its available water resources through the implementation of water quality monitoring programs and the use of its results in making the decisions required to protect these sources.

Pollution of water resources is attributed to high population growth, agricultural activities, industrialization, and arid to semiarid climate [18]. These factors resulted in the infiltration of wastewater into spring and groundwater resources. In towns and villages of Jordan, wastewater from septic tanks and cesspools infiltrating into the groundwater escalates the pollution problems. The deteriorating groundwater quality leads to increasing pressure on water resources by increasing the proportion of salinity, nitrates, sulfates, ammonia, phosphates, and the contents of organic matter, and determines the suitability of water for use. Jordan's groundwater resources are generally on the verge of critical quality. However, there are many potential sources of contamination of surface and groundwater, which may contribute to further deterioration. Some of these sources are caused by industrial and municipal wastes, excessive use of pesticides and chemical fertilizers in agriculture, over-pumping of groundwater far beyond the safe yield, intrusion of saline water, and the seepage of septic tanks in certain aquifers. The average annual abstraction rate from all groundwater basins in Jordan exceeds the renewable average of recharge at about 159% of that average. The over- abstraction ratios range between 146% of some minor aquifers and 235% of major ones. The difference between the amounts of renewable water and the extracted amounts is slowly leading to depletion and mineralization of the country's groundwater resources [6].

For the assessment of water quality in Jordan, instantaneous samples were taken from different water sources and laboratory tests were carried out by a comprehensive study conducted during the 2016 - 2019. The Jordanian Standard for Drinking Water 286/2015 was adopted as basic reference to evaluate the physical and chemical properties, in addition to the

microbiological criteria for the quality of raw water for drinking water purposes. Monitoring and sampling stations were selected and identified to be representative of all operating water basins without any exception [19].

4.3.1. Microbiological Contamination Levels

The microbiological contamination of spring water was studied over a five-year period in several locations of Jordan. In this study, several indicator organisms and pathogens used to evaluate the microbial contamination of water include total coliforms count, faecal coliforms, faecal 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.

All results of water analysis carried out on spring water confirmed the positive presence of *Escherichia coli* (*E. coli*) microspecies. Results indicate that the concentration of *E. coli* in water were influenced by natural and anthropogenic sources, and announce that the contamination of the springs were ranged from 0.16 – 2.98 MNP/100 mL. The results of the water analysis as shown in (Table 8) 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 Jordanian standard for drinking water [20], 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.

Table 8. Quality of spring and groundwater as recorded during 2016 – 2019 [19]

Site	TCC MNP/100mL	E. Coli MNP/100mL	TDS mg/L	TH as CaCO3 mg/L	NO3- mg/L	SO4— 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) AlMohamedia 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) TabqatFahel 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) AinDhana 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
JS 286/2015 Drinking water	<1.1	<1.1	<1000	<500	≤50	≤500

The presence of high levels of coliforms is most likely due to runoffs from livestock grazing sites, leaking cesspools, and agricultural activities. The lack of sewage networks in many populated centers, especially rural areas far from city centers, where cesspits are used to get rid of the wastewater generated in those gatherings. 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 [21].

4.3.2. 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). Data of electrical conductivity (EC) measurements made for water samples in several dams of the country shows that EC- values are fluctuating depending on locations between 500 to 1000 $\mu\text{S}/\text{cm}$, except that of KTD where EC values fluctuated between 2005 $\mu\text{S}/\text{cm}$ to 2465 $\mu\text{S}/\text{cm}$ for the years 2007 - 2014. A convincing explanation for this phenomenon may lie in the fact that KTD mainly feeds on water from the Khirbet Es -Samra plant, the largest treatment plant in Jordan.

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 8, 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-} . The constant increase of nitrate levels is an indication of inflow from contaminated

groundwater plumes from agricultural areas, which are situated northeast of the Wells field. This supports the assumption of a reversed groundwater gradient due to groundwater over-abstraction in the area.

5. Conclusions

This research sheds light on the state of Jordanian groundwater and assesses its ability to provide water for consumption sectors and puts several doubts about the reliability of this source in the future. The importance of the research comes as it encourages decision-makers and developers of strategic water plans for taking drastic but necessary actions to safeguard Jordan's scarce groundwater resources, and alerts the targeted sectors to the necessity of rationalizing water uses and relieving pressure on water resources.

All groundwater basins are over-exploited and the over-pumping rates have reached limits that will inevitably lead to their depletion with the decrease of natural recharge and the absence of any form of artificial replenishment. Increasing unsaturated areas as a sequence result of decreasing groundwater levels will have serious economic and operational consequences on water abstractions for both public and private users. Groundwater levels at greater depths require higher energy to lift the water and consequently increase operational costs. Furthermore, existing wells must be deepened, rise lines must be extended, and pumps must be exchanged with more powerful ones to adapt to lower water levels.

The continuous and significant drop in the level of the groundwater and the problems associated with it, such as the increase in salinity in the wells, the deterioration of water quality due to the leakage of pollutants from cesspits, landfills, and agricultural lands, the change in the direction of groundwater flow and the drying up of wells and springs. The critical water conditions in Jordan are reflected in the increasing over-pumping and an increasing number of springs that dried each year. It is expected that a significant number of wells will dry up in upcoming years because salinity and mineralization of abstracted groundwater increase with depth, and water quality will become a major cost factor, eventually requiring water treatment by cost-intensive technologies and disposal of brines.

To mitigate these conditions and slow or reverse the continuous increase in water supply costs, as well as secure the future water supply, decisive measures are urgently needed. One of the most effective measures for addressing the upcoming water crises is increasing awareness among national, regional, and local key persons and users. Water companies must reduce water losses due to leaking pipes to a minimum. Continuous maintenance or, where necessary, modernization of the water supply networks is needed. In the agricultural sector, water-saving technologies and processes together with the cultivation of low water demand crops must be promoted.

6. Recommendations

To conserve groundwater aquifers in Jordan, legal and financial measures should be set out to control and

gradually reduce groundwater withdrawals with the final objective of maintaining the safe yield of aquifers. It is highly recommended to control the expansion of irrigated agricultural areas which rely on groundwater. Additional measures such as the closure of illegal private wells and strict control of abstractions, revocation of licenses to drill wells, and application of higher fees.

The application of applied research activities, including artificial recharge to increase groundwater supplies, and the employment of new technologies that will optimize the operation and development of groundwater systems should be encouraged and promoted. It is highly advisable to identify alternative water sources, such as desalination of seawater or brackish groundwater. Also, recycle wastewater and allow its use in unrestricted agriculture, groundwater recharge, and other non-domestic purposes.

An essential component of any water strategy is not only the provision of an adequate volume of water but also to ensure that this water is of sufficient quality for the intended uses. There is a need to prevent the decline in the quality of groundwater resources through enrichment and recharge with poor quality water and, particularly in vulnerable shallow groundwater aquifers, to prevent contamination of the water resources through inappropriate activities at the surface (e.g. over-application of fertilizers and pesticides) with consequent leaching to the aquifer. Groundwater resources must be protected from any kind of contamination that could reduce their availability and exacerbate the water crisis. Urban planning, land use planning, and project licensing must consider groundwater vulnerability to reduce the risk of the negative impacts of potentially contaminating activities in highly vulnerable areas.

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