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Threats to the Thermal Mineralized Waters Used for Therapeutic Purposes in Jordan

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Abstract

Although Jordan is a country with very limited water resources, the country is rich in its thermal mineralized water possessing curative properties, historically used for the therapy of a variety of ailments. Due to the country's increasing water demand resulting from population growth, urbanization, and industrialization, extractions from the groundwater sources feeding the thermal mineralized springs has started to affect negatively the discharged quantities from the springs. In addition, urbanization, mining activities, over-exploited groundwater resources in general and severe drop in the level of the Dead Sea are leading to declining discharge of springs in general, and thermal mineralized in special, deteriorating water quality and contamination by human activities. In this article, the current quantitative and qualitative situation of the thermal mineralized springs is given and the threats to their discharges and quantities are discussed. In addition, some water policy changes and measures are suggested to conserve these therapeutic waters for the use of generations to come and to alleviate their depletion and quality deterioration on the social and economic state of Jordan.

Keywords

Thermal Mineralized Water, Depletion, Quality Deterioration, Over-Extraction, Jordan

1. Introduction

The water resources in Jordan as a country positioned in the arid to semi-arid climatic zone of the Globe are limited but the country is blessed by the abundance of thermal and mineralized waters found in the underground of its territories, and discharged along the eastern escarpment of the Jordan Rift Valley (**Figure 1**).

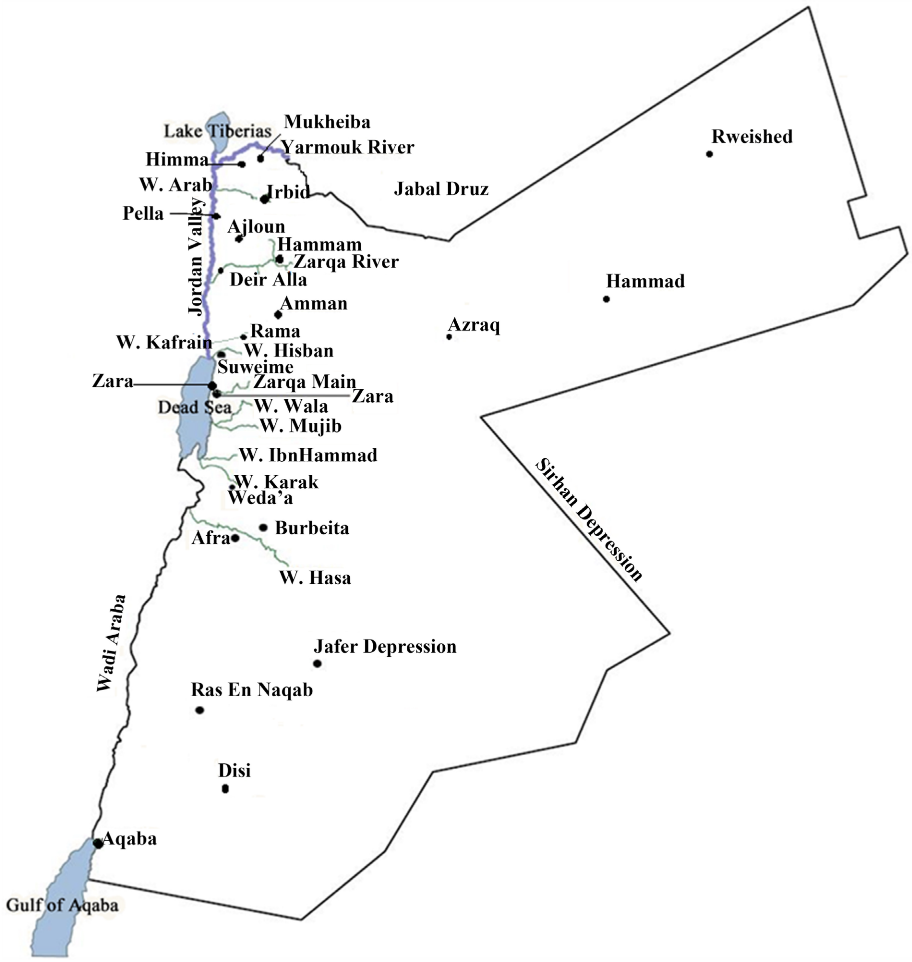

Figure 1. Main locations and sites of mineralized thermal springs in Jordan.

Historically, as gained by experience, these water sources were used in the therapy of a variety of ailments such as, rheumatism, disturbances of blood circulation, skin diseases, sterility, gynecology, respiratory system and as tranquilizing agent.

The remains of archaeological sites around them evidence the historical use of the thermal springs for curative purposes. Such ruins are those of King Salmon Residence in Afra, Herodias in Zarqa-Ma'in and Zara (Therma Kallirrhoes) (Bible: Genesis 36, 24, Ant. 17, 6, where Herod the Great looked for cure from Rheumatism). Here the ruins of a Sea Port and buildings are found in Pella (Tabakat Fahl) near Khirbet Saleh and Abu Thableh thermal mineralized springs where the ancient city of Pella was founded (**Figure 1**).

The physical and chemical properties of these water and the geologic conditions governing their discharges were studied in some details by Salameh and Rimawi (1997), Abu Ajamieh et al. (1988), Sawarieh and Massarweh (1993), Bender (1968).

The curative agents and properties of these thermal mineralized springs were obtained by comparison with the curative agents of similar sources worldwide, of which the curative potentials are well known (Cleartrip, 2022; Doughty, 2019;

Solimene, 2018; Giampaoli & Romano, 2014; Dramdahl, 2012; Harari, 2012). In addition, field tests on patients suffering of a variety of aliments including locomotive apparatus, rheumatism, blood pressure, skin diseases and other ailments were performed and documented by Salameh et al. (1991).

The distribution of curative waters in Jordan along the Rift Valley enjoys special climatic conditions with long dry summers and cool wet winters and with air oxygen concentrations increasing with decreasing altitude down towards the Jordan Rift Valley at 200 - 430 m below sea level. Also with decreasing altitudes solar radiation attenuates due to absorption by the thickening atmosphere and therefore, cosmic rays become weaker around these curative springs than elsewhere with similar latitude and altitude positions (Doughty, 2019; Kudish, 2012; Harari, 2012; Dramdahl, 2012; Salameh, 2010).

Different factors and human activities are gradually threatening the sustainability of these curative water sources such as urbanization and construction, industrialization and mining of minerals, agricultural activities, groundwater over-exploitation, inadequate development of curative water sites, and the drop in the Dead Sea level (**Figure 2**).

In this article, the physical and chemical characteristics of the thermal mineralized springs will be stated and their potential use as curative water indicated. After that the human activities leading to the deterioration of these waters in quantity and quality will be discussed, and measures to conserve them and alleviate the negative developmental impacts proposed.

It is of utmost importance to study the evolution of these springs' water, the origin and history of that water during its journey from the recharge to the discharge areas, and the composition resulting from water rock interactions. This will allow defining the policies, programs, and action plans necessary to protect

Figure 2. Drop in the Dead Sea level as seen on the recent terraces. The drop during the last 5 decades measures around 37 m in height and is a result of the extraction of the water sources, which used to feed the Dead Sea, by the different countries within the Dead Sea catchment area.

them from depletion and quality deterioration with all the latter detrimental consequences to therapeutic tourism, to the environment, and to their present and future social and economic benefits.

Considering the wealth of Jordan on therapeutic sites of thermal mineralized water, Dead Sea water and unique atmospheric oxygen content, Dead Sea water spray containing salts, air pressure, and low cosmic and ultraviolet radiation Jordan can develop these resources to serve Jordanians and the world in alleviating a variety of ailments and sufferings.

2. Methodology

For the preparation of this article the available information on the hydrology, hydrogeology, hydrochemistry of the thermal mineralized water systems has been collected from existing literature and available information in the ministry of water and irrigation of Jordan. This information has been interpreted towards clarifying the fate of these groundwater systems and their continuity in the future. The threats, the groundwater systems and thermal mineralized spring discharges have been analyzed using common hydrogeological and hydrochemical methodologies. The recent and older water analyses were carried out using American Standards for the Examination of Water and Wastewater (2017) and the German DIN (2014). (Titration, flame and spectrophotometry and atomic absorption) The therapeutic properties of the water are obtained from international literature on the subject and from studies carried out in Jordan (Doughty, 2019; Solimene, 2018; Giampaoli & Romano, 2014; Salameh et al., 1991).

3. Results and Discussion

Historically, the thermal mineralized water in Jordan was known to discharge along the eastern slopes of the Jordan Rift Valley extending from the southern end of the Dead Sea northward to the Yarmouk River gorge, a distance of around 200 km. Their issuing sites range in elevation from 350 masl in Afra, a tributary of Wadi El-Hasa, the most southeastern feeder wadi of the Dead Sea, to the Dead Sea level of 400 mbsl in Zara area at the Dead Sea shores, and to 200 mbsl in Himma (Mukheiba) area at the Yarmouk River entrance into the Jordan Valley (**Figure 1**).

The composition of these springs differs from one area to another in accordance with the geology of their flow regime, the composition of the rocks they encounter along their flow paths, the depth they percolate down to (temperature and pressure) and accordingly to water rock interactions.

However, although the composition of the thermal mineralized water differs widely from one area to another, in Jordan, some systematics in the evolution of the composition can be deduced based on the origin of their water, the composition of the percolated aquifers, confining conditions and their depths and flow history (Salameh & Hammouri, 2008; Salameh & Rimawi, 1997; Rimawi & Salameh, 1988; Salameh & Udluft, 1985). **Table 1** lists the composition of the

Table 1. Composition and properties of the main thermal mineralized waters in Jordan from south to north: Afra, Weda'a, Ibn Hammad, Zarqa Main (Al-Shallal), Zara, Suweima (JICA well 5) Rama well, Deir Alla, Abu Thableh, North Shuna, and Himma sp. (Updated after Salameh & Rimawi, 1997).

Variable	Afra	Weda'a	Ibn Hammad	Al-Shallal	Zara	Suweima JICA 5	Rama	Deir Alla	Abu Thableh	N. Shuna	Himma
EH-value	nm	nm	nm	15.8	25.5	nm	19.4	22.8	11.8	12.3	11.45
Temp ˚C	46.6	32	45.5	56.6	46.8	35.5	31.8	35.5	36.1	52.7	41.4
pH-Value	7.12	6.5	6.5	6.3	6.76	6.12	6.37	6.4	5.09	7.06	7.12
EC μS/cm	563	620	805	3051	1560	8680	4190	8100	1300	981	1336
TDS mg/L	297	402	520	2279	1114	5204	3840	5347	1112	863	1117
Na^+ meq/L	1.58	1.70	4.50	19.52	7.86	57.75	29.01	41.91	8.72	3.3	5.86
K^+ meq/L	0.05	0.22	0.19	1.11	0.63	4.5	2.42	4.03	0.46	0.12	0.43
Mg^{2+} meq/L	1.49	1.22	1.76	3.22	1.90	12.8	8.82	9.59	4.70	3.66	2.69
Ca^{2+} meq/L	2.36	3.80	1.64	7.23	4.58	44.86	11.84	32.4	7.20	4.07	6.24
Cl^- meq/L	1.98	2.51	3.80	21.52	9.62	64	28.04	44.1	9.34	2.83	6.03
NO_3^- meq/L	0.0	0.0	0.05	0.1	0.04	0.79	0.04	4.4	0.03	0.02	0.05
SO_4^- meq/L	1.38	1.77	1.72	3.82	2.77	11.17	7.7	26.98	3.31	1.75	3.44
HCO_3 meq/L	2.15	2.95	2.50	4.8	2.84	20.72	13.1	19.69	7.13	6.37	5.53
CO_3^{2-} mg/L	102	nm	100	215	90	nm	416	0.0	150	59	79
F^- mg/L	0.2	0.3	0.50	0.31	0.25	2.4	0.61	2.10	1.8	0.61	0.81
Br^- mg/L	0.03	0.05	2.5	7.74	4.20	5.6	6.44	2.80	0.7	0.91	3.13
I^- mg/L	0.005	nm	0.005	0.11	0.08	nm	0.14	0.08	0.08	0.5	0.1
Fe mg/L	0.1	1.53	2.0	.0.09	0.114	1.72	1.34	1.0	0.20	0.12	0.18
Mn mg/L	0.003	0.17	4.0	0.6	0.56	0.08	0.13	0.06	0.010	0.007	0.008
Cd mg/L	nm	nm	nm	0.01	0.003	<0.002	0.0006	nm	0.003	0.0024	0.0027
Zn mg/L	0.002	0.012	0.20	0.06	0.24	0.1	0.015	nm	0.019	0.002	0.018
Pb mg/L	0.002	0.014	nm	0.02	0.014	0.15	0.027	nm	0.03	0.03	0.03
Rn nCi/L	19.4	16.2	0.59	4.1	5.6	12.6	15.8	4.2	10.2	10.2	31.5
H_2S mg/l	smell	smell	0.2	0.3	0.25	0.16	0.80	0.01	0.02	12.5	8.8
NH_4^+ mg/L	nm	nm	nm	0.9	0.56	0.26	4.21	2.4	2.6	1.15	2.62

Dl: detection limit.

main thermal mineralized springs in Jordan from the southernmost springs in Wadi Afra a southern tributary of Wadi El-Hasa to the north in Himma area on the Yarmouk River southern side.

3.1. Groundwater Systems of the Mineral Springs

3.1.1. Afra to the NE Edge of the Dead Sea

The water of the thermal mineralized springs issuing between Afra in the south and the NE edge of the Dead Sea in the north (Suweima and Rama areas) originates from recharge in Aqaba Mountains and Disi areas. Here, the deep clastic sandstone system of Precambrian, Cambrian, Ordovician Silurian and Lower Cretaceous ages builds the geologic column and form one vertically and horizontally interconnected aquifer (**Table 2**), in which the groundwater flows in N-NE direction. The area north of Ras en Naqab Escarpment is covered by Upper Cretaceous calcareous rocks and receives direct recharge, where parts of the groundwater in these calcareous rocks containing residues of evaporates percolate down into the deep sandstone aquifer increasing the latter salt contents and temperature due to higher burial depth (**Table 3**). These increases occur gradually along the groundwater flow direction towards northeast. As can be seen from **Table 1** the salinity increases from around 500 µS/cm in Afra springs to in Weida'a 620 µS/cm and to 850 µS/cm in Wadi Ibn Hammad and to 1200 µS/cm in Mujib-Zara area.

North of Mujib-Zara area, Late Permian and Triassic rocks containing evaporate residues intercalate between the Silurian-Ordovician and older sandstones and the Lower Cretaceous sandstones herewith adding to the deep sandstone aquifer system new geologic formations. The groundwater percolating through the Late Permian-Triassic rocks dissolve the evaporates and causes increases in the water discharged from the deep sandstone aquifer system in the area of Zarqa Ma'in and north of it to the north eastern edge of the Dead Sea.

The thermal water temperature increases or decreases according to the mixing ratios of water percolating down from the Upper Cretaceous aquifers, the percolated depth of the groundwater, and the contact with the atmospheric air in the discharge area.

The discharge temperature (**Table 1**) changes from 45˚C in Afra to 32˚C in Weda'a, to 45˚C in Wadi Ibn Hammad, to 56.5˚C in Zarqa Ma'in Shallala spring, and to 35˚ in Suweima. SiO_2 geo-thermometry gives reservoir temperatures of 75˚C - 82˚C (Sawarieh, 2000; Rimawi & Salameh, 1988; Vlastimil, 1988; Salameh, 1986; Salameh & Khudeir, 1983; Truesdell, 1978).

The pH of the water ranges from 6.12 to 7.12, although all these waters contain H_2S and CO_3 gases, which lower the pH values to below 6.00, but spring water contact with the atmospheric air accompanied with the release of H_2S and CO_2 gases before discharge seems to be responsible for the increased pH values.

Table 2. Geologic column in Disi Mudawwara area (Based on BGR & MWI, 2017).

Formation age	Thickness (m)	Type of rocks	Main hydraulic characteristics	General consideration
Lower Cretaceous	70 - 150	Mainly coarse grained sandstone with some clay lenses	One aquifer	One major interconnected sandstone and siltstone aquifer containing fresh water
Ordovician	820 - 970	Coarse, medium and fine-grained sandstone with some silt and conglomerate.	One inter-connected aquifer	
Cambrian	380 - 400			
Precambrian	0 - 150	Semi-consolidated alluvium and colluvium		
Granitic basement		Mainly granite	Aquifuge	

Table 3. Geologic column in Plateau area north of Ras en Naqab to the northern end of the Dead Sea (Based on BGR & MWI, 2017).

Formation age	Type of rocks	Thickness (m)	Main hydraulic characteristics	General consideration
Surficial recent deposits	Recent gravels, sand and silt, basalts	Up to 50	Local aquifer when conditions allow	Irrelevant as a source of water
Eocene	Chalk marl and chert	Up to 150	Appropriate local aquifer	Local water supply in Jafr area
Upper Cretaceous-Tertiary	Bituminous Marl	200 - 300	Aquitard	Aquitards, confining layer
Campanian Maastrichtian	Silicified limestone overlain by beds of phosphatic chert	ca. 70	Excellent aquifer	Good to excellent Aquifer
Turonian-Santonian	Massive sandy limestone	55	Good aquifer	
Cenomanian	Alternating beds of limestone, dolomite, marly limestone, dolomitic limestone, sandstone, marl and some gypsum layers	ca. 300	Poor aquifer. In many areas springs issue from the limestone and dolomite beds	In general, poorly developed aquifer with some good yield aquifer layers. On a regional scale it allows water to vertically pass through
Lower Cretaceous	Coarse, medium and fine-grained sandstone	160 - 200	Good aquifer	Good to excellent aquifer, S of Mujib it directly overlies Silurian deposits
Triassic	Siltstone, sandstone calcareous sandstone	0 m N of Mujib, >400 m at the NE edge of the Dead Sea	Poor to good	Sediments start north of Mujib, containing brackish water
Permian	Sandstone, siltstone, conglomerate	0 m N of Mujib-300 m at the NE edge of the Dead Sea	Good aquifer	Good aquifer containing fresh to brackish water
Silurian-Cambrian sandstone series	Mainly coarse, medium and coarse-grained sandstone	1300 - 1400	Excellent aquifer	Excellent aquifer

The salinity of the water increases systematically from south to north, because of the gradual addition of down percolating Upper Cretaceous calcareous aquifer water containing residues of evaporates into the deep sandstone aquifer system, which possesses originally low salinity of about 500 μS/cm. This increase reflects the systematic gradual increase in the concentrations of the salinity parameters of Ca, Mg, Na, K, Cl, and SO_4 from south to north.

The other contribution to the composition of the thermal waters originates from dissolution of evaporates and carbonates from the, in the area to the north of Mujib River, intercalated Late Permian/Triassic rocks and the release of these salts into the sandstone aquifer system hosting the thermal mineralized water.

Bromide concentration shows strong increases from south to north from 30 μg/l in Afra to around 6000 μg/l in areas receiving Late Permian-Triassic water in Zarqa Ma'in and to the north of it.

The concentrations of the other components such as HCO_3, Fe, Mn, Pb, CO_3 and radon depend on the contact of the aquifer water with the atmospheric air in their discharge sites resulting in volatilization, dissociation, disintegration or precipitation of these components.

3.1.2. Northeastern Edge of the Dead Sea to Zarqa River

In the area extending from Suweima at the NE edge of the Dead Sea to Zarqa River in the north (Deir Alla) many thermal mineralized springs and seepages used to discharge along the eastern side wadis of the Jordan Valley. In Deir Alla at the entrance of Zarqa River into the Jordan Valley the thermal mineralized springs which used to issue from the Triassic and Jurassic rock series had before over-pumping started been used in therapeutic purposes. Also in Suweima area several springs and seepages used to discharge thermal mineralized water. That thermal mineralized water was encountered in boreholes sunk into the Triassic-Jurassic formations such as JICA wells 1-6 (JICA, 1995). The composition of this water is listed in **Table 1** on the examples of Suweima (JICA well 5), Rama and Deir Alla springs. These water sources show somehow similar composition and their temperature ranges from 31˚C - 35˚C with different dissolved amounts of sulfates and halite.

The main source of their composition originates from the water rock interactions and reduction processes with the Jurassic and Triassic rocks containing residues of evaporates and organic matter.

3.1.3. Zarqa River to the Yarmouk River

In the area north of Zarqa River the thermal mineralized water issues from the upper most calcareous rock sequence of the Upper Cretaceous rock series composed of limestone, chert and phosphates which in this area are confined by a thick sequence of Uppermost Cretaceous-Tertiary bituminous marls (**Table 4**).

Table 4. Geologic column in the area east of the Jordan Valley eastern highlands (Based on BGR & MWI, 2017).

Formation age	Type of rocks	Thickness (m)	Main hydraulic characteristics	General consideration
Neogene to recent	Basalts	Up to a few 100 m	Excellent aquifer	In Central north Jordan
Paleocene Eocene	Chalk marls	0 - 60 m	Medium aquifer	NW of Irbed City and in Azraq and Hammad areas
Maastrichtian Paleocene	Bituminous marl	200 - 300 m	Aquitard, confining layers	
Campanian Maastrichtian	Silicified limestone overlain by beds of phosphatic chert	Around 70 m	Excellent aquifer	Main water aquifer
Turonian	Marl lenses	0 - 20 m	Lenses of an aquiclude	On very small scale of 100 m aquiclude
Turonian Santonian	Massive sandy limestone	60 m	Excellent aquifer	Excellent karst aquifer
Cenomanian	Alternating beds of limestone, dolomite, marly limestone, sandstone, marl and some gypsum layers	Around 300 m	Poorly developed aquifer. In many areas springs issue from the limestone and dolomite beds	In general, poorly developed aquifer with some good yields aquifer layers
Lower Cretaceous	Coarse, medium and coarse-grained sandstone	200 m	Good aquifer	Deep aquifer containing brackish water

The salinity o the thermal mineralized water in this area is relatively low 980 - 1336 µS/cm. The temperature of the discharged water ranges from 36.1˚C to 52.7˚C. SiO_2 geothermal measurements give reservoir temperatures of 60˚C - 65˚C. The curative properties of the water in this area are related to its temperature, H_2S, radon and CO_2 contents and to the mineral assembly and ionic ratios.

The aquifer containing the thermal mineralized water is recharged along its outcrops in the Ajlun Mountains and the highlands at a distance of 20 - 25 km southeast and east of the discharge areas.

The water constituents originate from water-rock interaction of the infiltrating rainwater with the matrix of calcareous rock aquifer. However, in areas where the aquifer becomes confined by the overlying Bituminous Marl Formation reducing conditions prevail, producing H_2S, CO_2, and NH_4 gases lowering herewith the pH value of the groundwater which results in the dissolution of some trace elements including uranium disintegration series daughters such as radium, which, within that series, disintegrates into radon gas.

The curative properties of the water in this area are related to temperature, H_2S, radon and CO_2 contents and to the combination of cations and anions.

3.2. Threats to the Thermal Mineralized Springs

The thermal mineralized springs and waters in Jordan and worldwide (Fricke, 1993) are vulnerable to a variety of human activities and natural impacts and the depletion or deterioration of these thermal mineralized waters represents a big loss to the unique nature of their discharge areas, to the economy, and to the health and tourism sectors in Jordan. In addition, their national, regional and international use for therapeutic purposes represents also cross-cultural interface sites.

Therefore, conserving and protecting these thermal mineralized springs should be a target for the country to achieve and to protect them from depletion and degradation.

The Natural and human activities endangering the thermal mineralized springs are:

- Drop in the Dead Sea level.
- Over exploiting the feeding groundwater bodies of thermal mineralized springs.
- Drilling of wells into the thermal mineralized water aquifers and extracting their water or leaving the wells to discharge uncontrolled (emptying of aquifers).
- Pollution by human activities in the up-gradient areas.

3.2.1. Drop in the Dead Sea Level

The drop in the Dead Sea level, which has been taking place since about 5 decades due to the development and use of its feeding waters, reached now around 37 m. Among the consequences of such a drop, the groundwater bodies in the surrounding areas of the Dead Sea, connected with the Dead Sea water via the interface started to readjust hydro-dynamically to reach at a new equilibrium state (Salameh & El-Naser, 1999, 2000a, 2000b, 2005, 2008). This readjustment is achieved when the groundwater levels drop by the same rate of the sea level. In areas close to the shore (10 s of ms) the readjustment takes place in short periods of time, days or weeks. But, in areas at distances of hundreds to thousands of meters the readjustment takes longer times depending on the hydraulic conductivity of the involved rocks. Nonetheless, such readjustment expressed in dropping groundwater levels is imperative (**Figure 3**).

Many of the thermal mineralized springs, especially those discharging along the eastern escarpment of the Dead Sea are vulnerable to the drop in the Dead Sea level such as, Zara, Zarqa Ma'in and Suweima (**Figure 4**). Therefore, the dropping Dead Sea water level is threatening the discharge of the springs' water and their continuity. Decreasing and ceasing of spring discharges in Zara and Suweima area can be easily seen in these areas close to the Dead Sea (**Figure 4**).

3.2.2. Over-Exploitation of Groundwater Bodies

In the groundwater up-gradient areas of Zarqa Ma'in, Himma, North Shuna, Deir Alla, and Abu Thableh thermal water sites, wells were and are planned to be

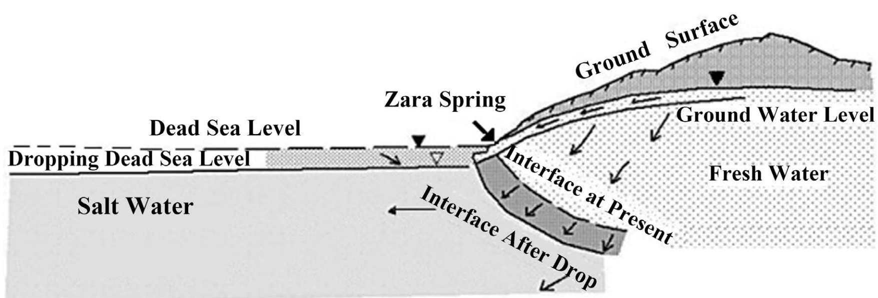

Figure 3. Simplified hydrogelogical cross section illustrating the drop in the level of the Dead Sea, the readjustment of the salt Dead Sea/fresh groundwater interface and the accompanying drop in the groundwater levels (Based on Salameh & El-Nasser, 2000a, 2000b).

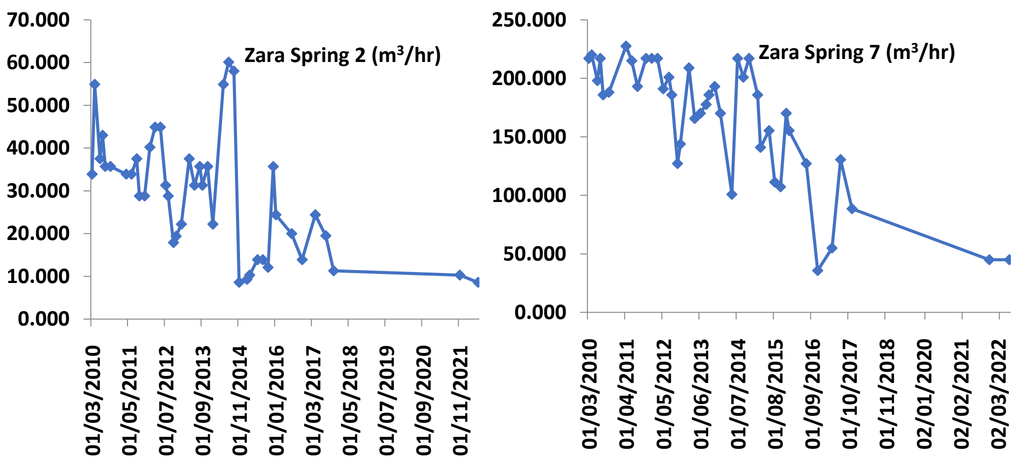

Figure 4. Decrease in the discharge of thermal mineralized springs in Zara area (Springs 2 and 7) as a direct result of the drop in the Dead Sea level and readjustment of the interface of Dead Sea water/fresh groundwater interface (Discharge measurements from the MWI Open Files).

drilled to extract the groundwater for all use purposes. Because these wells tap the same groundwater bodies feeding the thermal springs, the discharge of these thermal springs started decreasing and with the passage of time, the springs will eventually cease. In Himma area (Figure 5), some thermal springs have already dried out and others are threatened to dry out in coming years as a result of drilling Mukheiba and Wadi El-Arab wells (Figure 6).

The thermal deep well of Azraq with spa facilities used to produce artesian thermal mineral water, but due to artificial groundwater extractions from the surrounding area, the discharge of the artesian well decreased gradually and stopped with declining piezometric level. This has led to the closer of the spa, which was in operation for about 30 years.

Also along Zarqa River, at around 300 meters east of Jarash Bridge a thermal mineralized spring called El-Hammam used to issue and feed Zarqa River. As witnessed by the ruins around, it has been used as spa since thousands of years.

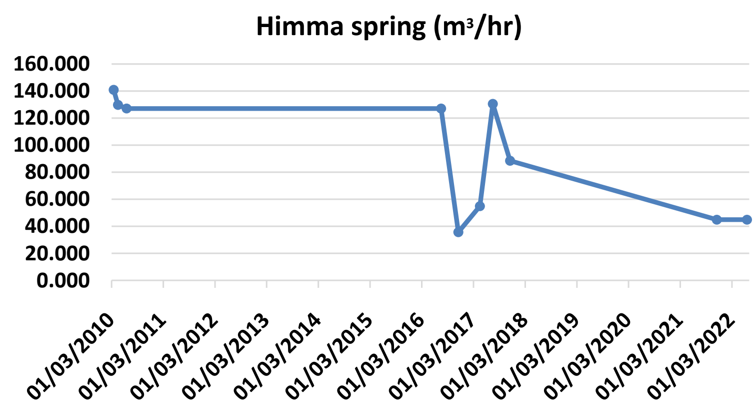

Figure 5. Changes in the discharge of thermal mineralized springs in Himma area as a result of groundwater pumping in the up-gradient area of the aquifer feeding the spring (Discharge measurements from the MWI Open Files).

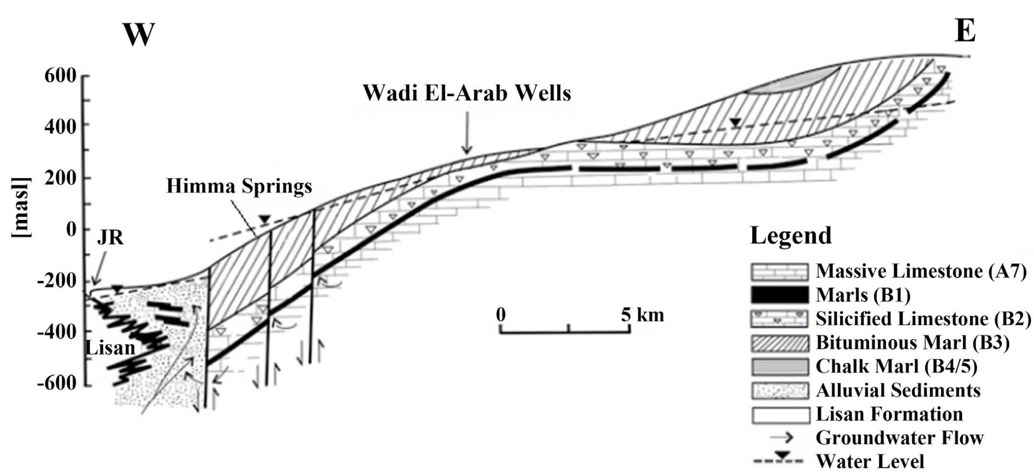

Figure 6. Simplified hydrogeological E-W cross-sections illustrating the position of Himma Springs relative to Wadi El-Arab wells extracting water from the same confined aquifer causing the drop in the groundwater piezometric head and decreasing discharge of the thermal springs (Modified from Salameh, 2004).

During the last two decades, because of well drilling and groundwater extractions from the same aquifer, the spring dried out and the spa site abandoned.

Drilling of wells in Deir Alla (Abu Zighan) at the entrance of Zarqa River into the Jordan Valley had led to total dryness of the nearby Deir Alla thermal springs. The heavy extractions of groundwater from the Jurassic and Triassic aquifer containing evaporates led to accelerating dissolution of gypsum and halite which with time resulted in the formation of underground cavities which widened into caves. The ceilings of such caves collapsed and formed sink holes at ground surface (**Figure 7**).

3.2.3. Drilling of Wells into the Thermal Mineralized Water Aquifers in Down-Gradient Areas

In the course of exploring the deep groundwater along the eastern foothills of the Jordan Valley area a series of deep wells were drilled in the 1980s which encountered brackish artesian water from the Jurassic-Triassic aquifer, and in some places mixed with Kurnub (Lower Cretaceous) aquifer water. North Shuna and other wells to its south of it were drilled into the Upper Cretaceous confined aquifer.

The problem started when the drilling companies were not able to stop the artesian flow of these thermal mineralized water wells. Neither has the water been used for any purpose except the limited use of parts of North Shuna well water in a spa, nor has the discharge of these wells been stopped to conserve the groundwater resources. Moreover, the discharged brackish water from the flowing wells found its way to perennial fresh watercourses causing their original water to deteriorate and the environmental conditions to degrade. Such wells were drilled in Wadis: Hisban, Kafrain, Rama, and North Shuna. Other wells were drilled in Abu Zighan area, east of Deir Alla, which caused the ceasing of discharge of Deir Alla thermal mineralized springs used as a spa.

These artesian wells' water originate from aquifers extending eastward under Jordan. Their water supports all overlying aquifers' groundwater and forms the backbone of all the overlying fresh water aquifers, which produce water for drinking purposes.

The release of the artesian water from the deep aquifer is causing declines in the groundwater levels and the seizure of thermal water springs. It is an emptying process of a groundwater body without any proper use of the extracted water. In addition, some water from the overlying fresh water aquifers will percolate down to substitute the depleting deep aquifer water due to releases through the artesian wells. The downward percolating fresh groundwater will becomes brackish due to the saline nature of the deep aquifers (**Figure 8**).

Such uncontrolled artesian wells discharges will cause further damage to the thermal mineralized groundwater, to fresh surface watercourses and to the environment. Water sector actions are deeply required to stop the deterioration caused by the irresponsible actions of not sealing and closing these unnecessary wells.

Figure 7. Collapses of ceilings of cavities which were created by pumping of Triassic and Jurassic salty water (~15.000 µS/cm) and replacement by fresh water (~1.000 µS/cm) resulting in additional dissolution of evaporates and formation of underground cavities.

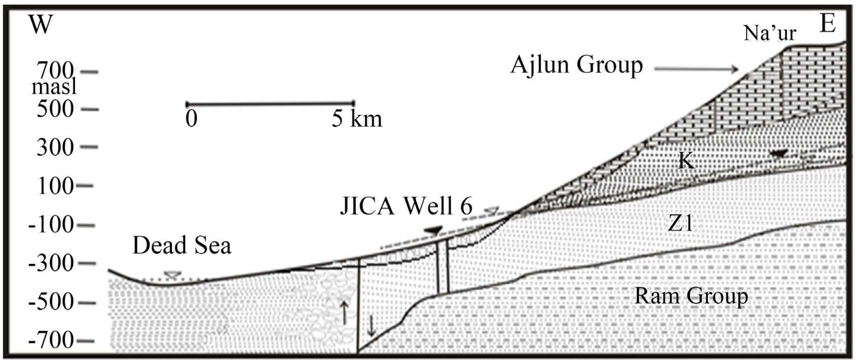

Figure 8. Uncontrolled flow of artesian thermal mineralized groundwater. The flowing water affects fresh surface water bodies flowing along wadis causing increases in their salinity. In addition, some of the thermal mineralized water recharge, along its flow in Wadis, the alluvial surficial aquifer resulting in the deterioration of its water quality (Modified after JICA, 1995).

3.2.4. Pollution by Human Activities in the Up-Gradient Areas

Thermal mineralized springs in Jordan issue along steeply incised side wadis in the eastern escarpment of the Jordan Rift Valley. Generally, the groundwater bodies from which and where they issue are free water table aquifers. Therefore, the groundwater sources in the up-gradient areas of their discharge sites are vulnerable to any human activity producing pollution. As an example, Madaba wastewater treatment plant, which discharges its treated wastewater into the up-stream area of Wadi Zarqa Ma'in and which, with time, find its way through the upper parts of the unconfined aquifer to the thermal mineralized groundwater in the same aquifer.

Himma thermal mineralized springs at the southern bank of the Yarmouk River are also highly threatened by the human activities in El-Himma village and its surroundings such as urbanization, without proper sanitation and lack of sewerage systems and wastewater treatment and reuse schemes, agricultural, and small industries activities. Since about 20 yr., fecal bacteria and other microorganisms have been detected in the spring's water of up to a few hundred fecal bacterial counts per milliliter.

Delineation of protection zones and enforcement of their application have now become an imperative in many areas of the thermal mineralized springs in Jordan.

4. Conclusion

Forced by increasing water demand for municipal uses and due to its limited water resources Jordan resorted to exploiting its deep nonrenewable groundwater resources which has gradually started to negatively affect the discharged quantities from the thermal mineralized springs, threatening with their depletion. Pollution and quality deterioration are also threatening these springs because of environmentally inadequate urbanization, industrialization and agricultural activities. With the passage of time, business as usual, the thermal mineralized springs will deplete and their qualities deteriorate.

In order to avoid such a fate and to guarantee the continuity of these springs quantitatively and qualitatively, it is recommended that extractions from the groundwater sources feeding these springs adhere to the principle of aquifer safe yield. To delineate groundwater protection zones, apply them strictly to all activities affecting the thermal mineralized springs. Adequate water resources planning and resorting to developing new resources for the country have become mandatory tens of years ago. Reluctance to do so has led the country to its present critical water supply situation and groundwater depletion and deterioration.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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