Vulnerability of the Drinking Water Resources of the Nabataeans of Petra – Jordan

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ABSTRACT

This article deals with pollution/toxicology in an archaeological frame. Although the Nabataeans had created a highly sophisticated water supply system, the water sources feeding the system can, according to recent evaluations, be considered as highly vulnerable to human activities within the catchment area of these resources or even to sabotage actions. The natural water quality of the sources, even after recent urban and agricultural development, is still suitable for drinking purposes and there are no signs in these waters of components, which may cause chronic of acute poisoning. The recharge, flow and discharge analyses show that only a few weeks are required for the recharge water of the close vicinity (10-20km) to reach the spring discharge sites. The extended Nabateans civilization ended abruptly within two years 106-108 A.D. The Romans surrounded the Nabataean city and conquered its outskirts. They most probably could not enter the near-Petra area to control the springs of Wadi Musa; supplying Petra. But, it seems that the catchment areas of these springs were known to them as they were to the Nabataeans.

Could the Roman have misused the vulnerability of these water sources? Had the high vulnerability of the spring waters of Petra and Wadi Musa been the weak point leading to the end of the Nabataean civilization? These questions are discussed in the article, recognizing the necessity of further analysis and evaluation of the whole water supply system for evidence of eventual poisoning of the supply water.

KEYWORDS: Petra, Nabataeans, Romans, Water vulnerability, Water quality, Water supply.

INTRODUCTION

In summer 2007, the ancient city of Petra was declared as one of the seven world wonders. It occupied the second rank in regard to its unique characteristics among which is its water management system.

A good account about the Nabataean civilization can be found in the "History of Jordan" part of King Hussein bin Talal web site (Electronic Ref. 1). Before Alexander's conquest, a thriving new civilization had emerged in southern Jordan. It appears that a nomadic tribe known as the Nabataeans began migrating gradually from Arabia during the sixth century BCE. Over time, they abandoned their nomadic ways and settled in a number of places in southern Jordan, the Naqab desert in Palestine and in northern Arabia.

Their capital city was the legendary Petra, Jordan's most famous tourist attraction. Although Petra was inhabited by the Edomites before the arrival of the Nabataeans, the latter carved grandiose buildings,

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temples and tombs out of solid sandstone rock. They also constructed a wall to fortify the city, although Petra was almost naturally defended by the surrounding sandstone mountains.

Building an empire in the arid desert also forced the Nabataeans to excel in water conservation. The Nabataeans were exceptionally skilled traders, facilitating commerce between China, India, the Far East, Egypt, Syria, Greece and Rome. They dealt with such goods as spices, incense, gold, animals, iron, copper, sugar, medicines, ivory, perfumes and fabrics, just to name a few. As a fortress city, Petra became a wealthy commercial crossroad between the Arabian, Assyrian, Egyptian, Greek and Roman cultures. Control of the crucial trade route between the upland areas of Jordan, the Red Sea, Damascus and southern Arabia was the lifeblood of the Nabataean Empire. Little is comparatively known about the Nabataean society. However, they spoke a dialect of Arabic and later on adopted Aramaic. Much of what is now known about the Nabataean culture comes from the writings of the Roman scholar Strabo. He recorded that their community was governed by a royal family, although a strong spirit of democracy prevailed. According to him, there were no slaves in the Nabataean society, and all members shared in work duties. The Nabataeans worshipped a pantheon of deities, chief among which was the Sun God Dushara and the Goddess Allat. As the Nabataeans grew in power and wealth, they attracted the attention of their neighbors to the north. The Seleucid King Antigonus, who had come to power when Alexander's empire was divided, attacked Petra in 312 BCE. His army met a relatively little resistance and was able to sack the city. The quantity of booty was so great, however, that it slowed their return journey north and the Nabataeans were able to annihilate them in the desert. Records indicate that the Nabataeans were eager to remain on good terms with the Seleucids in order to perpetuate their trading ambitions. Throughout much of the third century BCE, the Ptolemies and Seleucids warred over control of Jordan, with the Seleucids emerging victorious in 198 BCE. Nabataea remained essentially untouched and independent throughout this period. (Electronic Ref. 1).

The assassination of Julius Caesar in 44 BCE augured a period of relative anarchy for the Romans in Jordan, and the Parthian kings of Persia and Mesopotamia took advantage of the chaotic situation to attack. The Nabataeans made a mistake by siding with the Parthians in their war with the Romans, and after the Parthians' defeat, Petra had to pay tribute to Rome. When they fell behind in paying this tribute, they were invaded twice by the Roman vassal King Herod the Great. The second attack, in 31 BCE, saw him take control of a large swath of Nabataean territory, including the lucrative northern trading routes into Syria. Nonetheless, the Nabataeans continued to prosper for a while. King Aretas IV, who ruled from 9 BCE to 40 CE, built a chain of settlements along the caravan routes to develop the prosperous incense trade. The Nabataeans realized the power of Rome, and subsequently allied themselves with the Romans to quell the Jewish uprising of 70 CE. However, it was only a matter of time before Nabataea would fall under direct Roman rule. The last Nabataean monarch, Rabbel II, struck a deal with the Romans that as long as they did not attack during his lifetime, they would be allowed to move in after he dies. Upon his death in 106 CE, they surrounded the city and claimed the Nabataean Kingdom and renamed it Arabia Petra. The city of Petra was redesigned according to traditional Roman architectural designs, and a period of relative prosperity ensued under the Pax Romana. The Nabataeans profited for a while from their incorporation into the trade routes of the Roman Near East, and Petra may have grown to house 20,000-30,000 people during its heydays. However, commerce became less profitable to the Nabataeans with the shift of trade routes to Palmyra in Syria and the expansion of seaborne trade around the Arabian Peninsula. Sometime probably during the fourth century CE, the Nabataeans left their capital at Petra, still no one really knows why (Electronic Ref. 1, Hammond, 1973).

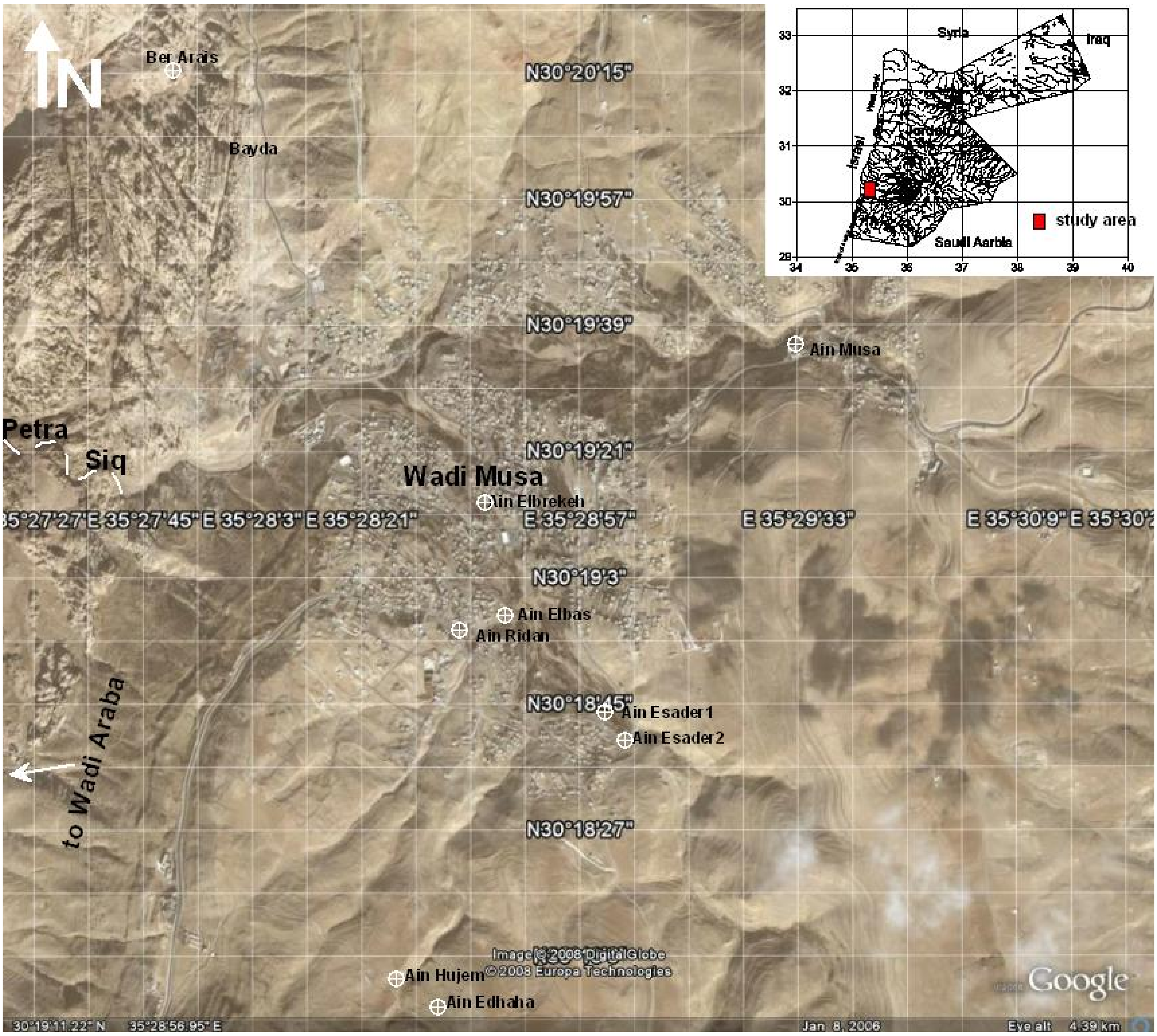

Figure 1: Location of Petra in Jordan, and locations of the water sources of the Nabataeans. Springs issue from limestone formations building the high mountains east of Petra

Petra is located in the heart of the mountainous desert of southwest Jordan (Fig. 1), but importantly, adjacent to an ancient route leading from the Plateau to Wadi Araba. In detail, the site occupies an open valley surrounded by mountains. Routes through the mountains follow deep clefts or siqs. Although the formal entrance to Petra was through the Siq, general access is also possible from the north. The gorges were formed when the force of desert flash floods exploited lines of weakness in the rocks (faults, joints and fractures) over many hundred thousands to millions of years, and is continuing today. The properties of the rock itself may have persuaded the Nabateans to site their city here; it was evidently suitable for rock carving and excavating, as well as being aesthetically pleasing to look at. In addition, spring water was available in the close vicinity of the site, which made the site a unique one for establishing the city and protecting it (Electronic Ref. 2).

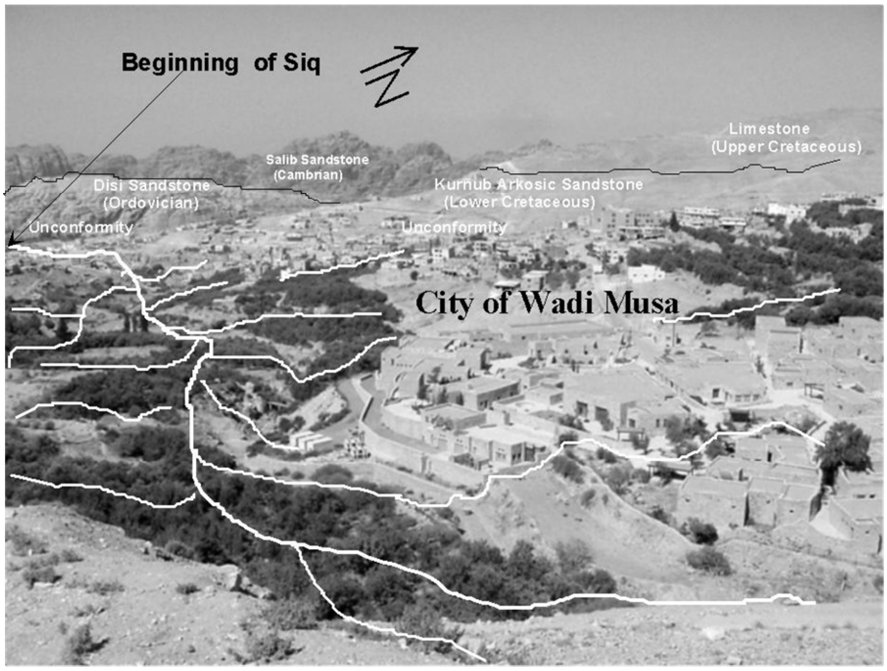

Figure 2: **Image of the city of Wadi Musa and the surrounding mountains, illustrating the geology (outcropping formations) and drainage system (in white lines) of upstream springs' water to Petra via the narrow path of the Siq**

The springs in the eastern surroundings of Petra which supplied the ancient city with water are still flowing today. Nabataeans were highly skilled water engineers, and irrigated their land with an extensive system of dams, canals and reservoirs. The quality of the water of the springs is still good for direct use for drinking purposes, because the catchment area is free of industries, fertilized agriculture and other activities, and, therefore, it is concluded that the present water quality represents the water that the Nabataeans were using for their drinking purposes (Akasheh, 2003).

Studying the quality of water and hydrology of springs may contribute to the anthropological studies of that ancient civilization, the life style of its people, their socio-economics and even their conflicts. In this study, it will be demonstrated that the water sources of the Nabataeans were and still are highly vulnerable and the question to be addressed in that context is: Could the Nabataean civilization have been ended by intended or unintended misuse of the vulnerability of the spring water sources by their enemies?

The Nabataeans tried to minimize the risks their water supply may be exposed to, but were their adequate precautions, or could their enemies have exploited the vulnerability of the spring water sources to make the water supply unsafe?

METHODOLOGY

The water sources feeding the different springs were delineated using hydrogeological methods, the catchment areas were defined, the time needed for recharge water to reach the discharge sites (springs) was calculated and the vulnerability of groundwater sources feeding the springs was elaborated.

Karstic springs, such as some of those feeding Petra, are highly vulnerable and present major concerns for the water quality, especially when the catchment area of these springs is under the control of others.

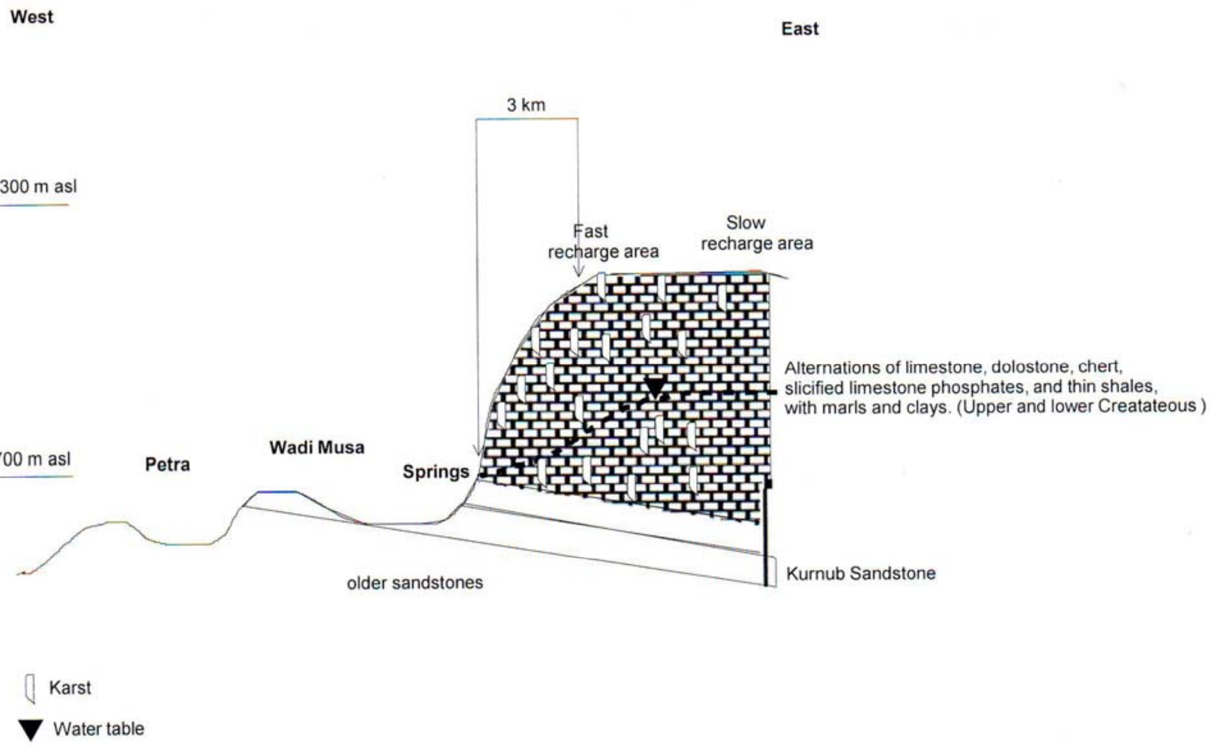

Figure 3: Schematic hydrogeological cross-section showing the recharge, flow and discharge mechanisms of the karst aquifer east of Petra and the dimensions of slopes and distances

Flow paths and required flow times from the recharge areas to the discharge areas were determined using information from the study area and other areas in Jordan (Al-Farajat, 1997).

Water samples were collected from the different springs in the mountains overlooking Petra, and exposed to chemical analysis to clarify their suitability for drinking purposes. The American Standard Method for Water Analysis and German DI- Norms were used in the analysis of different parameters.

Geologic Setting

The geological succession in the study area is as follows (from bottom to top): Pre- Cambrian Basement of granite rocks; -Unconformity- Salib Sandstone (Cambrian): thin unit resting on the unconformity; Umm Ishrin Arkosic Sandstone (Cambrian): most of the monuments are carved in the middle part of this unit, Liesegang banding is abundant; Disi White Arenite Sandstone (Ordovician): white domes near Wadi Musa and behind the Resthouse; -Unconformity- Kurnub Sandstone (Lower Cretaceous): soft sandstones, occupying the graben (valley) in the centre of Petra, also visible behind Wadi Musa; Limestone (Upper Cretaceous): above Wadi Musa along the mountains east of Petra, Musa (Moses) spring flows from here.

Most of the springs in the area issue from the Upper Cretaceous Formations, composed of carbonates rocks. Some other springs issue from the underlying Lower Cretaceous Sandstone Formations (Figures 2 and 3).

Nabataean Hydrology

The first historical reference to the Nabataean hydrology is found in *The Bibliotheca Historica* of Diodorus Siculus who mentioned that the Nabataeans used to dig subterranean reservoirs lined with stucco. After filling these reservoirs with rainwater, they closed the openings, making them even with the rest of the ground, and they left signs that are known to them but are unrecognizable by others‖ (XIX.94.6-9). This account is confirmed by the abundance of remains indicating well-planned hydrological systems and astounding dexterity in managing and acquiring vital resources. The advanced techniques in constructing and preparing these devices to provide water in due course stimulated an agricultural renaissance aimed primarily at satisfying daily requirements.

Intensive investigation of archaeological remains of ancient agricultural sites may provide wealth of information related to water use. The archaeological remains, which have already been discovered throughout Nabataea, indicate the importance of such investigation. The Nabataeans constructed channels to carry water from springs to drinkers (Fig. 4). This type is divided into two major types of channels:

Figure 4: Water cistern in Petra

(a) Closed pipes

These are made of pottery, sometimes laid in rock-cut channels or inlaid in the rocks. The Nabataean skilled hydrologists used to build small bridges to support these channels if there was a cut in the rock. The purpose of these closed channels was to provide water for household uses.

(b) Open channels

This type, covering most Nabataean agricultural sites, was intended for the provision of water for agriculture. The open rock-cut channels in Petra were furnished with strainers to strain the descending water. During the survey in Bayda, for example, many channels of this kind were noticed by other researchers.

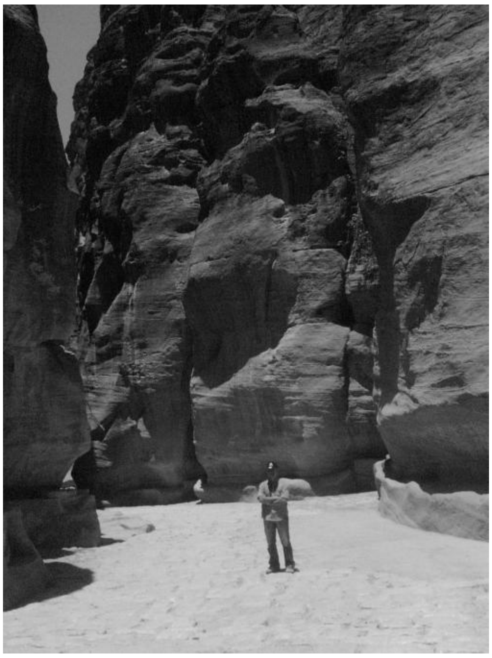

Figure 5: Canals carved along the walls of the Siq to convey water to Petra city

The channels are carved in the rock to conduct water to cisterns (Fig. 5), reservoirs and dams. In most of the rocky Nabataean sites, especially in Bayda, the Nabataeans carved also many channels into the upper parts of the mountains to collect and carry rainwater to cisterns and other collecting vats. In order to collect larger amounts in the same vat, many channels were cut close to each other (Glueck, 1966: 5; Al-Muheisen, 1986).

The Nabataean epigraphy provided terminology connected with agricultural and hydrological installations. Many terms could be classified under this heading, such as *gb'* "well ‖ *b'r* ―cistern‖ *nb'* ―spring‖‗*yn* ―water spring‖ and *skr'*or *mdr'* ―dam‖ or ―watercourse‖ (Al-Theeb, 2000: 60, 39, 190, 149; Yadin *et al.,* 2002: 94).

Figure 6: Ain Edhaha and the surrounding jointed layers

Figure 7: Ein Hujiem issues from a joint

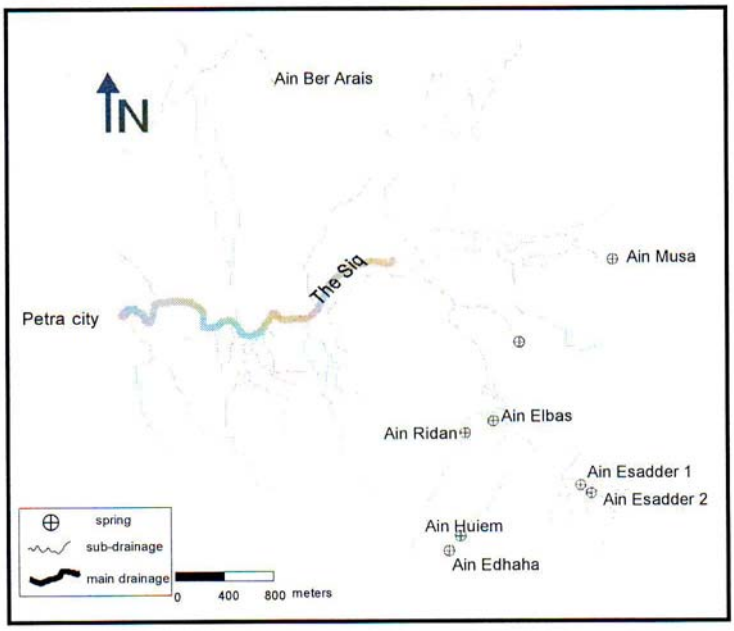

Figure 8: Location of the springs on the drainage net in the close surrounding of Petra

Spring Hydrogeology

The majority of springs issue east of Petra from the Upper Cretaceous rocks composed of karstified and jointed silisified limestone to marly limestone. Ain Musa, Ain Hujiem, Ain Edhaha, Ain Ridan and Ain Elbasa are examples on these springs. Ain Ber Arais issues from the Lower Cretaceous Sandstone Formations. Figure 6 shows the highly jointed carbonate rock formations around Ain Edhaha. The widened joint from which Ain Hujiem issues is a good example on the karst phenomena in the area (Fig. 7).

The spring water is diverted by the sub-drainage nets into the main drainage canal leading the water into Petra through the Siq (Figs. 8 and 9).

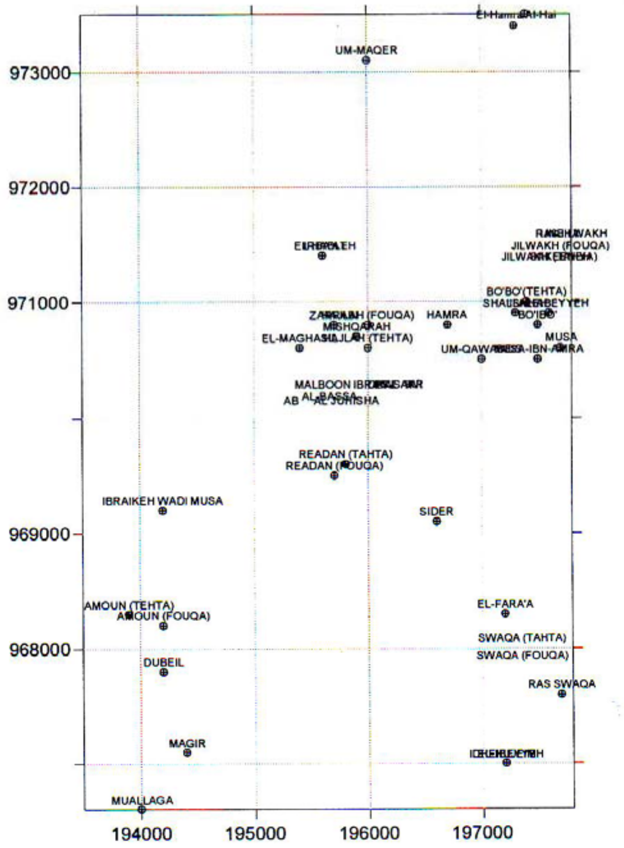

Figure 9: Locations of all springs around Petra on the local coordinate system

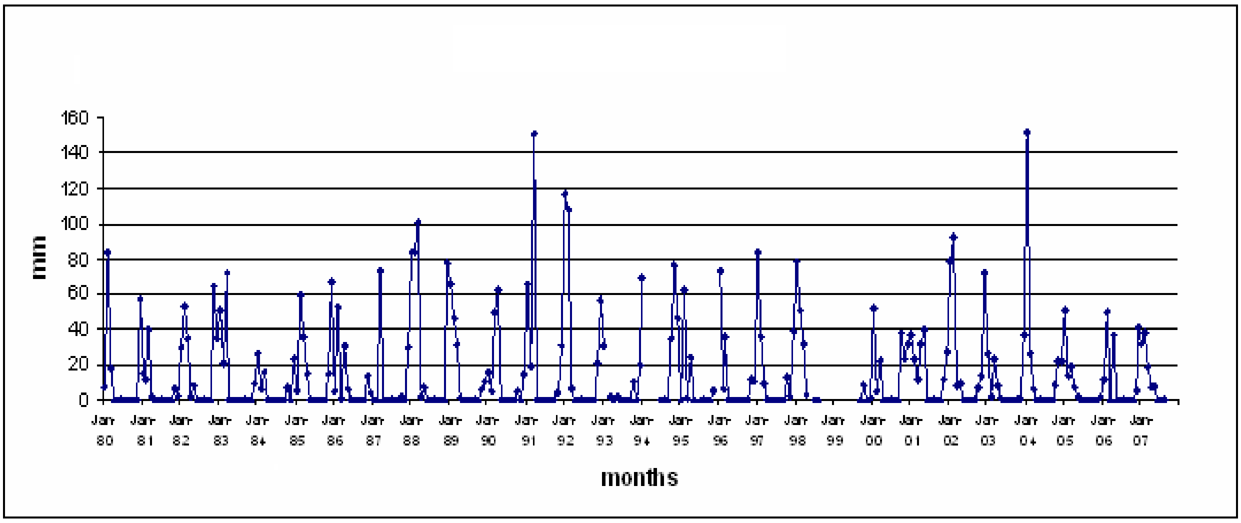

Figure 10: Monthly rainfall amount distribution from 1980 to 2007

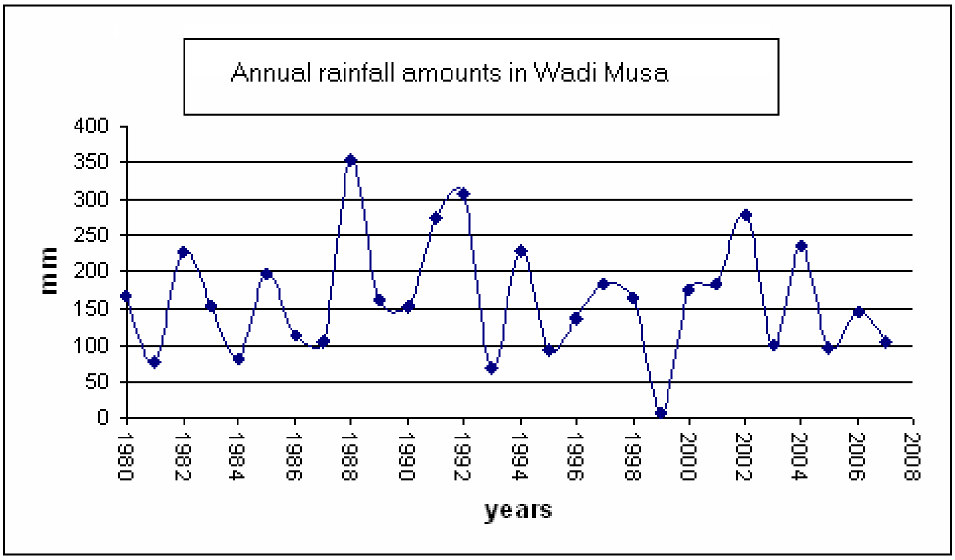

Figure 11: Annual rainfall amount distribution from 1980-2007

Figures 10 and 11 illustrate the monthly and annual historic records of rain in Wadi Musa to correlate them with discharge of the gauging station. The discharge of springs is plotted in Figure 12. On the other hand, water quality evolution with time has been prepared. Ain Musa spring serves as an example (Fig. 13).

Hydrochemistry of Groundwater

Water samples collected from the springs during the summer of 2007 were analyzed in the laboratories of Al-al-Bayt University. The results are listed in Table 1. The analysis included measurements on the physical parameters of T, EC and pH on site. The major anions and cations in addition to BOD and COD were tested in the laboratory. No analysis has been made on heavy metals because the area is free of any industrial activity. Samples ware classified using Piper diagram (Fig. 14), Durve Plots (Fig. 15) and Schoeller Graphs (Fig. 16). It is obvious that the water is free of pollution except Ain Elbasa, which is located in an area not yet served by a central sewage system. All samples show fresh type of water with TDS values of less than 1000 mg/1.

DISCUSSION

The spring water of Wadi Musa issues mainly from highly jointed, fissured and karstified Upper Cretaceous limestone. The major recharge area of these springs lies further east at distances of a few to about 15 km from the spring location sites.

The recharge areas are generally barren, without any soil cover or with soil covers of a few centimeters in thickness. This allows rainwater to infiltrate very fast into the bedrock, herewith escaping evaporation. After reaching the highly fissured, jointed and karstified bedrock, the water flows very fast towards the discharge sites at springs.

The lag time between direct recharge by rainwater and discharge out of springs is a few days (Fig. 10 correlation with Fig. 12).

The hydrograph analysis of the springs in Wadi Musa shows two types of groundwater recharge/discharge mechanisms:

- one type of short term recharge – discharge pattern, and
- another with long term recharge – discharge pattern.

As mentioned above, the short term pattern originates from direct recharge of precipitation water along the immediate highlands east of Wadi Musa area, whereas the long term pattern water is recharged further east of the mountain chain along the plateau, where also thin soil covers exist and the recharge water requires a few months up to many tens of years to reach the springs of Wadi Musa. (Fig. 3).

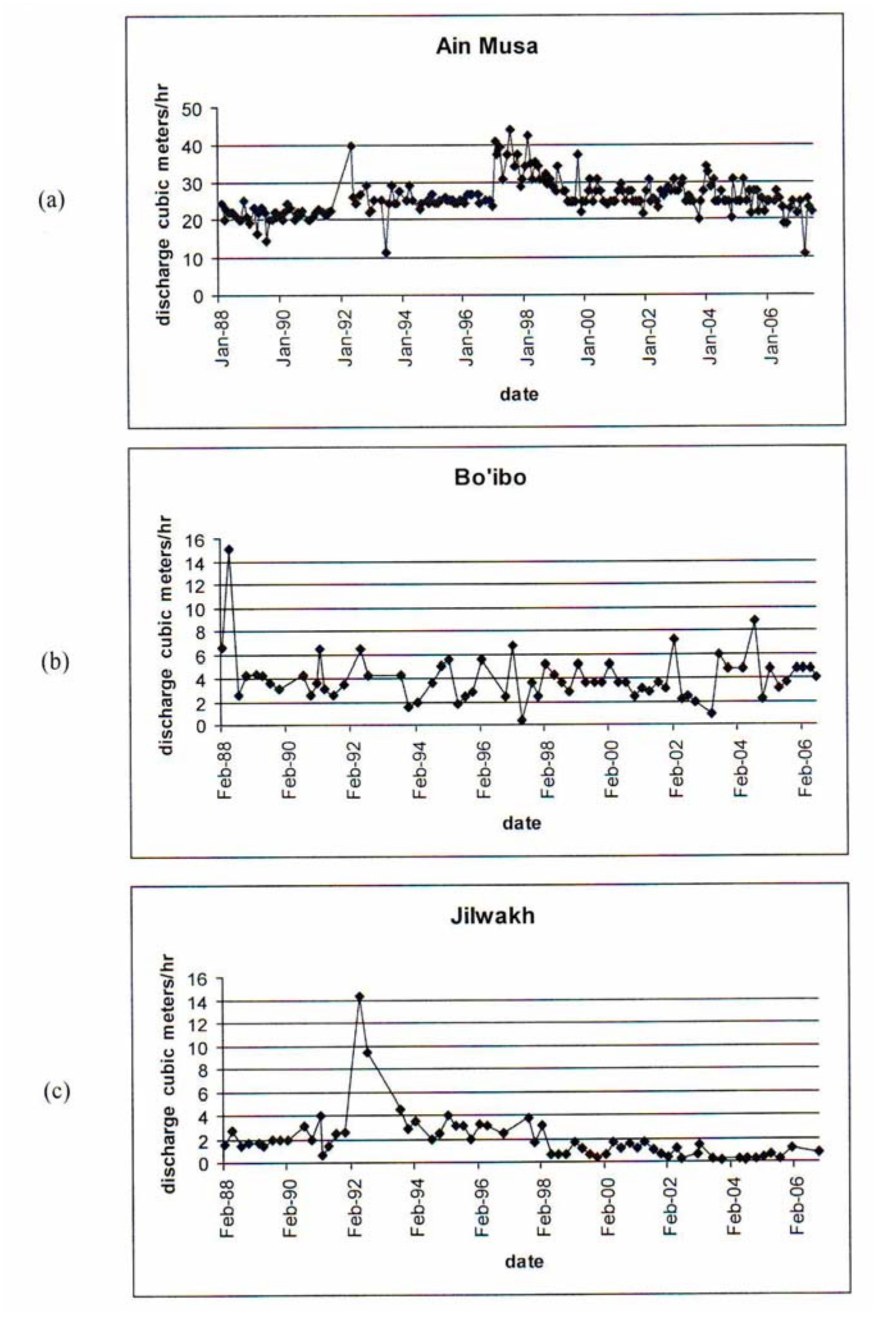

Figure 12: The increase in spring discharge takes place in Jan.-March and the major rain events in Jan.-Feb. (fast recharge discharge)

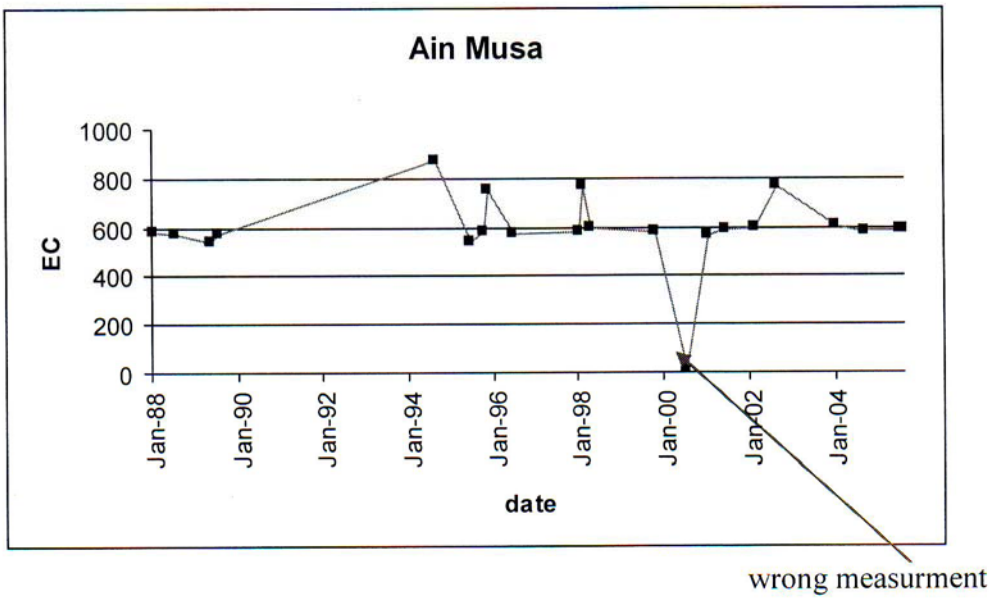

Figure 13: Salinity decrease due to the fast recharge track of rain water indicating the vulnerability of Wadi Musa springs

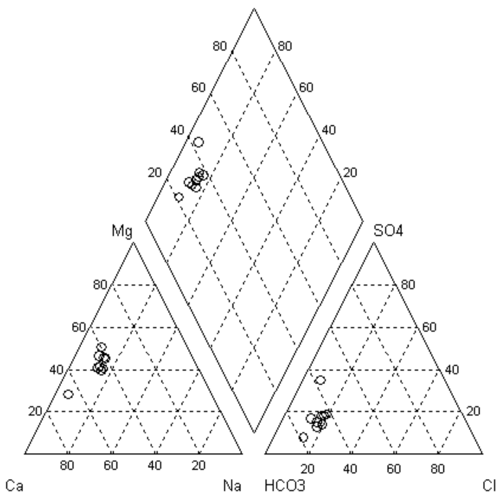

Figure 14: Piper plots of the water samples, reflecting rain water slightly reacting with carbonate rocks

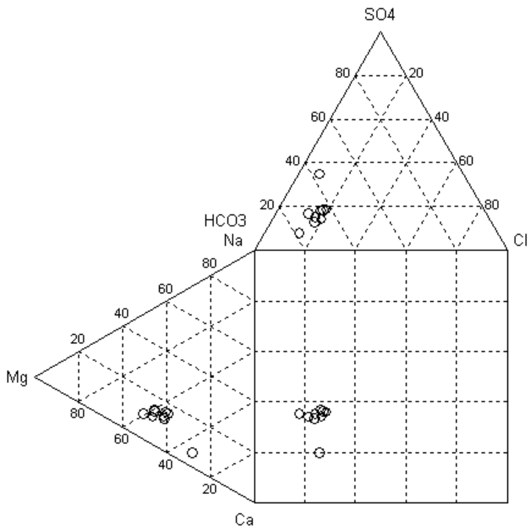

Figure 15: Durve plots of the water samples, also reflecting rain water slightly reacting with carbonate rocks

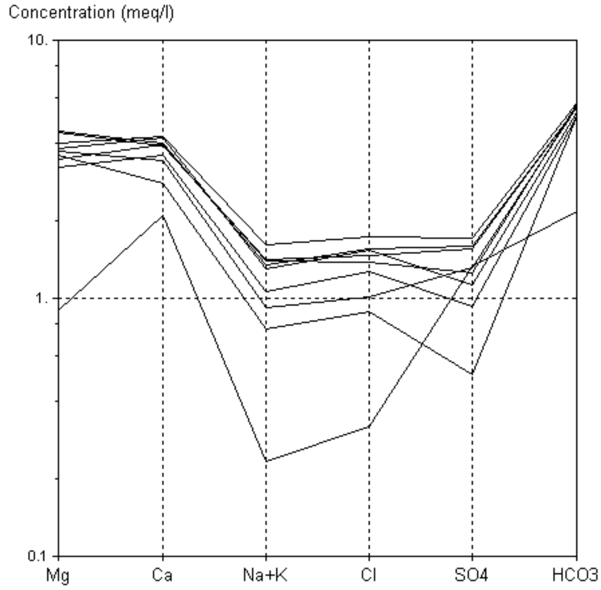

Figure 16: Schoeller diagram of the water samples, indicating their same origin except samples which originate from the sandstones of the lower Cretateous

Table 1: **Composition of the major springs in Petra area**

Sampling site/parameter	pH	EC	Temp.	TDS	Na	K	NO_3	PO_4
Ain Hujiem	7.95	569.00	18.20	287.00	20.06	1.67	25.29	0.00
Ain Esader1	7.42	690.00	18.30	342.00	31.60	1.77	3.42	0.00
Ber Arais	7.28	199.00	13.00	100.00	4.25	1.87	4.55	0.00
Ain Musa	7.38	570.00	18.00	285.00	23.40	1.87	8.32	0.00
Ain Elbrekeh	7.63	798.00	18.67	456.00	29	1.78	32.22	0.00
Ain Esader2	7.54	700.00	18.21	421.00	30.21	1.54	4.21	0.00
Ain Ridan	7.10	782.00	18.01	465.00	31.21	1.24	14.51	0.00
Ain Elbas	7.12	1100	18.75	523.00	35.21	2.85	140	0.02
Ain Edhaha	7.47	455.00	16.50	233.00	16.20	2.07	0.00	0.00
Sampling site/parameter	SO_4	**Ca**	**Mg**	**Cl**	HCO_3	CO_3	**BOD**	**COD**
Ain Hujiem	63.40	68.14	45.00	36.00	336.80	0.00	0.00	0.00
Ain Esader	74.80	78.16	53.46	51.77	336.80	0.00	0.00	0.00
Ber Arais	64.00	42.00	10.94	11.25	131.80	0.00	0.00	32.00
Ain Musa	44.70	72.00	38.88	45.00	307.50	0.00	0.00	0.00
Ain Elbrekeh	53.98	83.34	46.43	54.21	321.11	0.00	0.00	0.00
Ain Esader2	76.21	80.21	54.21	55.27	335.01	0.00	0.00	0.00
Ain Ridan	60.21	79.21	42.14	48.68	345.24	0.00	0.00	0.00
Ain Elbas	82.12	85.21	48.21	61.24	345.88	0.00	0.03	12.0
Ain Edhaha	24.30	56.00	43.74	31.50	307.50	0.00	0.00	0.00

The part of water with a short term recharge, flow discharge forms a main component of the water of Wadi Musa springs and is highly vulnerable in terms of its quantity and quality.

Spring discharges react very fast to rainfall event in the recharge areas of these springs, hence causing a quantitative vulnerability.

The qualitative vulnerability is governed by a variety of factors as discussed below:

- Soils within the immediate recharge areas, a few km from the spring discharge sites are very thin or missing. This means that infiltration water percolates down very fast towards the springs, without reacting with the soil components or without undergoing self-purification processes if hazardous components are introduced into it (Figs. 12 and 3).
- Fast flowing paths between recharge and discharge sites due to fissures, joints and karst openings do not allow natural processes of dissolution, precipitation, oxidation and reduction to completely take place and change the nature of the infiltrating water.
- The level of groundwater feeding springs lies at about 200-300 meters below the recharge areas. In karst aquifers, this means very fast down percolation of recharge water, which may take only a few hours to reach the groundwater table. In a tracer test carried out on a similar area in north Jordan (Al-Farajat, 1997), it took the tracer 4 hours to cross a distance of about 800 meters where the control wells are sited.
- The springs in Wadi Musa show after the rainy seasons lower EC values, indicating the fast recharge by rainwater.

The above elaborations show that Wadi Musa springs are highly vulnerable in quantity and especially in quality. Petra depended during Nabataean times in its water supply on Wadi Musa springs.

The Nabataeans protected and controlled their water supply in a very sophisticated way as can be shown in the example of their techniques in diverting, transporting and storing the water. But it seems that the head waters of the fast vulnerability track recharge water (Fig. 3) were before the defeat of their regime studied and maybe controlled for some years by their enemies. The Romans seem not to have been able to reach the spring sites of Petra, because of the very high slopes overlooking Petra and the control of these slopes by Nabataeans. But, the Romans controlled the highlands to the east, the recharge areas of springs. Cuervo (1988) pointed to that the Romans were also masters in studying and designing water systems. Casado (1985) explained how the Romans, influenced by near-eastern culture from the Etruscan age onwards-developed a sort of engineering in which the authorship of the execution and conception of their works is evident.

In Roman times, poisoning at the dinner table or in common eating or drinking areas was not unheard of, or even uncommon, and was happening as early as 331 BC. Poisonings would have been used for self-advantageous reasons in every class of the social order. The writer Livy describes the poisoning of members of the upper class and nobles of Rome, and the Roman Emperor Nero is known to have favored the use of poisons on his relatives, even hiring a personal poisoner. His preferred poison was said to be cyanide. Nero's predecessor, Claudius, was allegedly poisoned with mushrooms or alternatively poisonous herbs. However, accounts of the way Claudius died vary greatly. Halotus, his taster, Xenophon, his doctor and the infamous poisoner Locusta have all been accused of possibly being the administrators of the fatal substance, but Agrippina, his final wife, is considered to be the most likely to have arranged his murder and may have even administered the poison herself. Some report that he died after prolonged suffering following a single dose at his evening meal, while some say that he recovered somewhat, only to be poisoned once more by a feather dipped in poison which was pushed down his throat under the pretense of helping him to vomit, or by poisoned gruel or an enema. Agrippina is considered to be the murderer, because she was ambitious for her son, Nero, and Claudius had become suspicious of her intrigues (Electronic Ref. 3).

Pyatt et al. (1999, 2000, 2002, 2004) studied historic pollution/toxicological issues in south Jordan during the Nabataean and Roman periods. They considered the general topic of heavy metal contents of skeletons from that time period. That area in southern Jordan was a main mining area of copper with all its accompanying heavy elements such as iron, lead, mercury, cadmium… etc. Bioaccumulation and human health impacts are reflected in the skeletons of humans contents of these heavy elements. The authors concluded that the environment during Nabataean and Roman times was heavily polluted by the mining processes in the copper mines in Wadi Finan (some kilometers to the north of Petra city). Samples from the skeletons contained high metal loads due uptake by diverse processes.

Most probable is that these heavy elements were not only a cause of chronic diseases and death due to their accumulation in bodies of human beings and other living organisms, but also as a cause of acute poisoning and death due to misuse.

Considering results of previous studies and our own results may change the picture towards approaching a more acceptable end of the Nabataean civilization.

Expressed more explicitly, could the enemies (Romans) have recognized the vulnerability of the water supply system of the Nabataeans and misused it, or have they used the fact of water supply vulnerability to force the Nabataeans to give up whenever they needed to do so?

The natural conditions of the water supply system indicate that such a possibility does exist. But the question which remains is to prove that the vulnerability was misused by the enemies. Such a proof requires rigorous analyses of precipitates in cistern waters and soils, which may still contain remains of whatever poisonous substances, which could have been used to end that civilization, or to assist in adding pressures on it to give up at any desired time the enemy may have wished.

CONCLUSION

The analysis of the hydrogeological regime of recharge, flow discharge of the spring water in Wadi Mousa indicates a high vulnerable system to pollution along the immediate highlands where recharge takes place. This result is strongly supported by the presence of a karstified limestone aquifer with wide openings, by a thin or missing soil cover and by the short distance between the recharge and the discharge areas measuring a few kilometers.

The Nabataeans developed a highly sophisticated system of water supply in between the spring sites in Wadi Musa and used places inside Petra itself. But, it seems that their protection strategy did not extend to the recharge areas along the mountains, a few kilometers east of Wadi Musa.

The natural water quality of the springs is excellent and it seems that it has naturally not changed since those times and, therefore, natural deterioration of water quality could not have caused the end of the Nabataean dynasty.

In this article, the high vulnerability of the water supply system has been established, but the question is now to discover in the water structures or soils inside Petra signs of intended sabotage of metal poisoning which could have caused the surrender of the Nabataeans to their enemies.

REFERENCES

Akasheh, T. 2003. Nabataean and modern water shed management around the Siq and Wadi Mousa in Petra, in *Hashemite University Report*, The Hashemite University, Zarqa, Jordan. Zarqa: Hashemite University Press, 1-15.

Al-Farajat, M. 1997. Karstification in B4 unit in Irbid and its role in enhancing human impacts on groundwater resources, M.Sc. Thesis, University of Jordan, Amman, Jordan.

Al-Farajat, M., Al-Salameen, Z. and Mashagbeh, A. 2007.

Geophysical and hydrological based archaeological survey of ancient water structures along Wadi Al-Madras in Petra. *Journal of Applied Geophysics*, (The Egyptian Society of Applied Geophysics), 6 (1): 169-177.

Al-Muheisen, Z. 1986. Techniques hydrauliques dans le Sud de la Jordanie en particulier a l'époque nabatéenne. Ph.D. Thesis, Sorbonne.

Al-Theeb, S. 2000. Al-Mu'jam an-nabattiy: dirasah muqaranah lilmufradat walalfath an-nabattiyah. King Fahad Library, Riyadh.

Auge, C. and Denzer, J. 2000. Petra, lost city of the ancient world. New York (NY): H. Abrams, Inc. Publishers.

Bibliotheca Historica of Diodorus Siculus (XIX.94.6-9).

Casado, C. 1985. Ingenieria Hidraulica Romana. Colegio de Ingenieros de Caminos, Canalesy Puertos. Ediciones Turner, Madrid.

Cuervo, S. 1988. Landscape and urban planning, 16, 93-103, Elsevier Science Publishers B.V., Amsterdam - Printed in The Netherlands WATER, A CULTURAL HERITAGE ETS Ingenieros de Mantes, Universidad Politknica de Madrid (Spain).

Glueck, N. 1966. The story of the nabataeans: deities and dolphins. Cassell, London.

Hammond, P. 1973. The Nabataeans – their history, culture and archaeology, (Studies in Mediterranean Archaeology 37). Gothenburg: Gothenburg Publishers.

Oleson, J. 1990. Al-Humeima hydraulic survey, 1989 Preliminary Field Report. *ADAJ,* 34: 285-311.

Oleson, J. 1995. The origins and design of Nabataean water-supply systems. *SHAJ*, 5: 707-719.

Pyatt, F.B., Barker, G.W., Birch, P., Gilbertson, D.D., Grattan, J.P. and Mattingly, D.J. 1999. King Solomon's miners-starvation and bioaccumulation? An environmental archaeological investigation in southern Jordan. *Ecotoxicol. Environ. Saf.*, 43: 305–308.

Pyatt, F.B., Gilmore, G., Grattan, J.P., Hunt, C.O. and McLaren, S. 2000. An Imperial legacy? An exploration of the environmental impact of ancient metal mining and smelting in southern Jordan. *J. Archaeol. Sci.,* 27: 771–778.

Pyatt, F.B. and Grattan, J.P. 2001. Some consequences of ancient mining activities on the health of ancient and modern human populations. *J. Public Health Med.,* 23 (3): 235-236.

Pyatt, F.B., Pyatt, A.J. and Grattan, J.P. 2002a. A public health problem? Aspects and implications of the ingestion of copper and lead contaminated food by Bedouin. *Environ. Manag. Health*, 13 (5): 467–470.

Pyatt, F.B., Amos, D., Grattan, J.P., Pyatt, A.J. and Terrell-Nield, C.E., 2002b. Invertebrates of ancient heavy metal spoil and smelting tip sites in southern Jordan: their distribution and use as bioindicators of metalliferous pollution derived from ancient sources. *J. Arid Environ.,* 52, 53–62.

Taylor, J. 2001. Petra and the lost kingdom of the Nabataeans. Cambridge (MA): Harvard University Press.

Yadin, Y., Greenfield, J., Yardeni, A. and Levine, B. 2002. The documents from the Bar Kokhba period in the Cave of Letters: Hebrew, Aramaic and Nabataean - Aramaic Papyri. Israel Exploration Society, Jerusalem, Palestine.

Electronic References

1. Official electronic governmental site of King Hussein bin Talal of Jordan http://www.kinghussein.gov.jo/his_nabateans.html

2. Official electronic govenmental site of the Jordan Ministry of Tourism http://www.tourism

3. Wikipedia, the free encyclopedia, history of poison http://en.wikipedia.org/wiki/History_of_poison