INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.geologi.esdm.go.id
ISSN 2355-9314, e-ISSN 2355-9306

Documentation, Analysis and Reconstruction of the Paleo-landuse of Wadi Musa with Special Reference to the Nabataean Period: A Geomatic Study based on Archaeological Evidence

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Manuscript received: July, 17, 2020; revised: December, 21, 2020;
approved: April, 5, 2021; available online: September, 23, 2021

Abstract - Archaeologists and historians throughout time have relied mainly on textual, architectural, and art-historical analyses to understand the historical context of civilizations. This traditional approach has been challenged, however, by the current new practices in archaeological studies, which tend to rely on more scientific methods (*e.g.* information systems) to understand the wider context of the socio-cultural aspects of past societies. For example, the Nabataean studies, which for more than seventeen decades after the rediscovery of Petra in 1812, are based on the art historical analysis of the rock-cut facades of the the city of Petra. The wider story of the socio-cultural, political, and economic aspects of the Nabataean culture is still not well understood. Just recently archaeological research was undertaken to improve the understanding of the Nabaatean phenomenon from outside Petra. This paper discusses this new attempt to investigate the spatial organization and land use of Wadi Musa during the Nabataean period based on GIS analysis and new archaeological discoveries. Utilizing GIS in discovering historical phenomena provides a new perspective for analysis, whereby structures are treated not as individual archaeological items but rather as a system. This paper also presents a case study that demonstrates the significance of using GIS for historical research by shedding light on the temporal variation of Wadi Musa settlements with special focus on the paleo-landuse of the Nabatean period. The resulting reconstructed map indicates that Wadi Musa was well planned with special zones for elite residents, industry, rural communities, and agriculture. Social segregation/stratification is also well indicated in the plan of the city. The reconstructed map indicates that the strategy for Nabataean land use for Wadi Musa was to use it as a green zone around the city of Gaia.

Keywords: well log, log prediction, regression, artificial intelligence, machine learning

How to cite this article:
Al Farajat, M., Twaissi, B.S., Al Hasanat, M.B., Al-Rawabdeh, A., Al Falahat, H., Hijazeen, E., and Al Eide, E., 2021. Documentation, Analysis and Reconstruction of the Paleo-landuse of Wadi Musa with Special Reference to the Nabataean Period: A Geomatic Study based on Archaeological Evidence. *Indonesian Journal on Geoscience*, 8 (3), p.427-441. DOI: 10.17014/ijog.8.3.427-441

Introduction

Background

The Nabatean culture represents an interesting phenomenon in the classical period (fourth century B.C. through second century A.D.) as it originated from a nomadic background. The Nabataeans were able to establish their own autonomus kingdom, which stretched along a wide geographical area extending from Busra in the north (now southern

Syria) to Madain Saleh in the south (in modern Saudi Arabia) with Petra as its capital. The Nabataeans were considered the masters of caravans at that time as they monopolized the trade of the most demanded goods of that time (*e.g.* spices, frankincense, myrrh, balsam, and other aromatic goods) (Groom, 1981; Johnson, 1987).

Petra is one of the world richest and largest archaeological sites. Due to its outstanding universal value, Petra was designated as a UNESCO World Heritage site in 1986, because it represents a unique artistic achievement for the Nabataeans. Archaeological excavation focusing exclusively on the archaeological sites of Petra proper (*i.e.* the rock cut city) has been conducted in the area for more than eighty-five years, whereas the peripheral area of the urban city, including Wadi Musa, has been neglected. It is believed that a better understanding of domestic life in Petra and Nabataean social life in general, can be imagined by examining the area with a wider perspective that would include the periphery of Petra. Current archaeological investigations in Wadi Musa, though salvage in nature, indicated that the boundaries of Petra extended well outside the traditional archaeological site of Petra and included Wadi Musa. The historical evidence suggests that Wadi Musa, in contrast to Petra proper, has had a long history of human occupation extending from the Epipaleolithic period (14,000 - 8,500 BC) up to modern times. This paper will illustrate the settlement pattern of Wadi Musa through time with greater focus on the Nabataean period (fourth century B.C.- second century A.D.) in an effort to determine how Wadi Musa was planned during this period and what land use strategy was employed by the Nabateans in this area.

The nature of land use is a critical issue nowadays. The severe impacts of poor planning on the environment, natural resources, biodiversity, and the welfare of the country affect the future of nations worldwide due to serious threats to their sustainability and economic well-being. At present, land use planning is implemented based on scientific methods and is governed by several factors: geology, topography, land cover, soil fertility, natural hazards, biodiversity, natural resources, ownership of lands, *etc*. Optimized land use can be achieved by the nature of the land use unit.

The rapidly developing tools for archaeologists who study ancient land use and settlement patterns are becoming increasingly used in practice with the development of GIS technology and the availability of digital environmental data. GIS is now a proven effective tool that has revolutionized archaeological study techniques and has been used to understand ancient settlement patterns (Topouzi, 2010), ancient landuse (Hill, 2004; Hill *et al*., 2016), to pinpoint locations of past settlement (Winemiller, 2014), and to understand ancient landscape (Bevan and Conolly, 2004; Lawrence *et al*., 2012).

The study presented in this paper had the following ojectives: (a) understanding the historical context of Wadi Musa using GIS applications, and (b) recognizing the settlement patterns of Wadi Musa throughout time by studying its paleolanduse with special reference to the Nabatean period.

Studied Area

The studied area was the city of Wadi Musa, which covers approximately 9 km^2 and is located in the southern part of Jordan, about 240 km south of the capital city of Amman. The area is best described as a wide valley that is part of a large catchment bounded by high mountains in all directions. The topographic elevations of the city range from 400 m to 1,400 m above sea level. Most of the rocks forming the geology of the city are limestone and marl with thin layers of chert and mud. Morphologically, the city is composed of mountainous areas, valleys, flat areas, ridges, and extended wadis that normally flood in the winter (Figure 1).

Geological Setting in Wadi Musa

The geological succession in the studied area is as follows (from bottom to top): 1) Pre-Cambrian basement of granite rocks; 2) Unconformity-Salib Sandstone (Cambrian): a thin unit resting on the unconformity; 3) Umm Ishrin Arkosic Sandstone

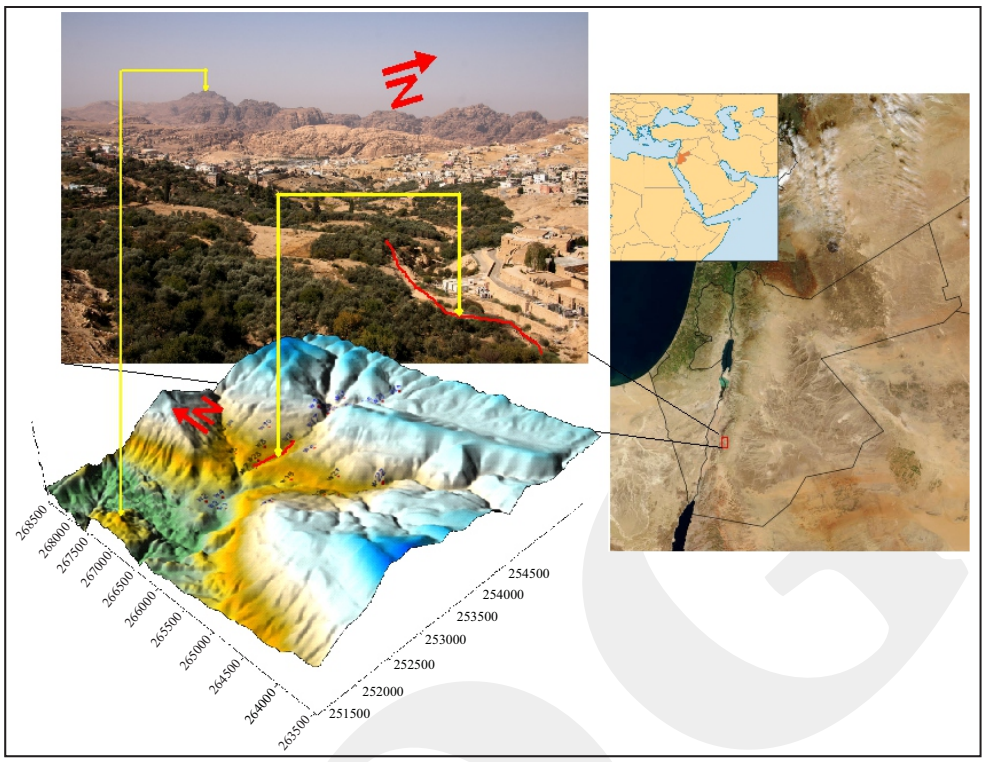

Figure 1. Topography and location of Wadi Musa City.

(Cambrian): most of the monuments are carved in the middle part of this unit, Liesegang banding is abundant; 4) Disi White Arenite Sandstone (Ordovician): white domes near Wadi Musa and behind the rest house; 5) Unconformity-Kurnub Sandstone (Lower Cretaceous): soft sandstones, occupying the graben (valley) in the centre of Petra, which is also visible behind Wadi Musa; and 6) Limestone (Upper Cretaceous): above Wadi Musa along the mountains east of Petra, the Musa (Moses) spring flows from here. Most of the springs in the area issue from the Upper Cretaceous Formation, composed of carbonate rocks. Some other springs issue from the underlying Lower Cretaceous Sandstone Formation (Barjous, 2003).

Methodology

The archaeological data used in this research were based on previous archaeological works in the area, mainly the salvage works conducted by the Department of Antiquities of Jordan during the implementation of the sewage and waste water net project (Amr *et al.*, 1997, 1998, 2000; Amr and Al-Momani 1999, 2000, 2001), the intensive survey of the Wadi Musa suroundings conducted by Tholbecq (2001, 2003), and a field survey by the authors conducted in June 2015 to document the ruins and archaeological remains using GPS. The data collected were used to classify the ruins according to their ancient functions, which were reconstructed and re-delineated by entering the data into a GIS environment, relating them to each other, and classifying the data and gathering them into maps that were ultimately used to produce an ancient land use map. The main objective was to definitively determine the land use planning criteria of the Nabataeans followed and compared it to our modern scientific land use and urban planning methods.

Results

Climate and Biodiversity in Wadi Musa

Mediterranean climatic conditions prevail in the studied area with average annual precipitation

of around 250 mm. The two major wadis passing through Wadi Musa (Wadi El-Sadder and Wadi Ain Musa) are full of grapes, figs, olives, and apricots. The Ain Musa and Ain El-Sadder springs irrigate the fields, which extend along the two wadis. The fertile soil in flat areas permits good productivity for fruits, olives, and vegetables. The city is rich with water springs, and until now most of the population prefers to use them for drinking purposes despite the presence of other water supplies (Oran, 2005).

The Petra region is a unique place for plant geographers and is of great interest to botanists for its diversity. Three bio-geographical regions intermesh here: the Mediterranean, the Irano-Turanian, and the Sahel-Arabian regions. Furthermore, Petra is characterized by a dramatically changing landscape ranging from 290 m above sea level in the southwest up to 1,700 m above seal level in the north, where the Hisheh oak tree forest is located. The region encompasses three different microclimates, which explain the diversity of the region's flora.

The fauna of Petra is of equally great diversity with 332 species identified within the region, of which the majorities are insects and birds (RSCN, 2013). The Petra region contains about 15 - 17% of all the items on Jordan's unusually rich species list and 39% of the families, indicating a rich biodiversity environment and economic growth to maintain sustainability (UNDP, 2014). Building the land-use unit map depends on many variables in the GIS layers, which normaly consist of two types: environmental layers and economic layers.

Environmental layers include land sensitivity layers, which comprise maps of groundwater vulnerability against pollution (*e.g.* some spatial variables like natural recharge, depth to groundwater, and aquifer types), spatial risk of flood, spatial risk of landslides, maps of agricultural soil, maps of forests and natural green cover, maps of holy and/or archaeological sites, maps of significant views, topographic maps, climatic types, maps of natural resources and biodiversity habitats, topographic slopes, and land aspect models (Hamdan and Al-Rawabdeh, 2020).

The economic layers include the distance to public services and its networks, the distance to marketing centres, and the distance to the water supply and resources.

Public welfare issues are taken into consideration when overlooking lands are chosen for recreation or tourism projects. Security issues often are of importance for some countries.

Current Land Use in Wadi Musa

The existing land use in Wadi Musa passed through different phases of development; several layers were modeled to elaborate the most land factors that have been taken into consideration through the different authorities that planned the city through the last five decades. Qualitative-quantitative modeling conducted using IDRISI GIS and SURFER 8.0 (Figures 2 and 3).

Normally, the variables of the same layer are given as rates, while the layers themselves are given weights according to their importance and impact.

Occupation History of Wadi Musa with Special Reference to the Nabataean Period

Wadi Musa has received very little archaeological attention, with all the past archaeological work was salvage in nature because of the predominantly modern town and the dramatic growth of the population and modern investments. The most comprehensive archaeological work in the Wadi Musa was conducted by Khairieh Amrin conjunction with a waste water project in the late 1990s, upon which the study presented in this paper is mainly based (Figure 4). The evidence recovered by Amr shed some light on its occupation history.

The earliest period of human occupation at Wadi Musa is the Epipaleolithic 14th - 8th millennium B.C., which is represented by lithic assemblages excavated in Wadi Musa (Figure 4 (sites W6 and 15, and Figure 5). A large farming community evolved in the area during the Pre-Pottery Neolithic B (PPNB) period that goes back to the 7th millennium B.C. and is represented by a 7.5 ha settlement that was uncovered in the Basit area in the northwestern corner of the city

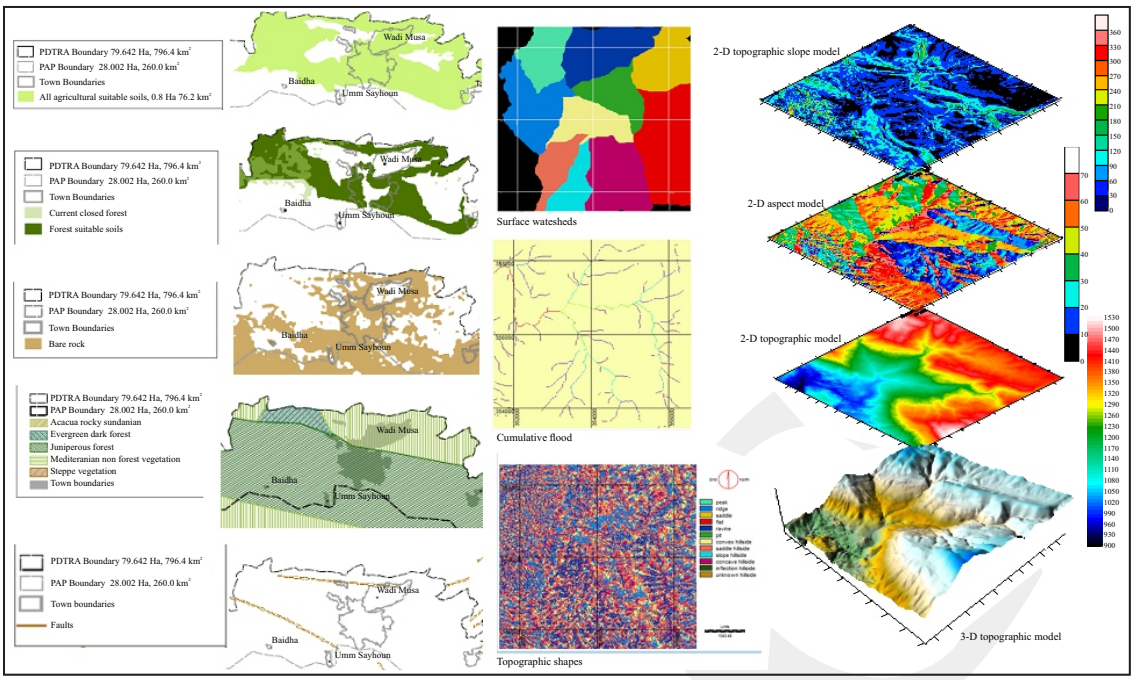

Figure 2. Different models of Wadi Musa City via IDRISI GIS and SURFER. (Coordinates of the four right side maps see Figure 1).

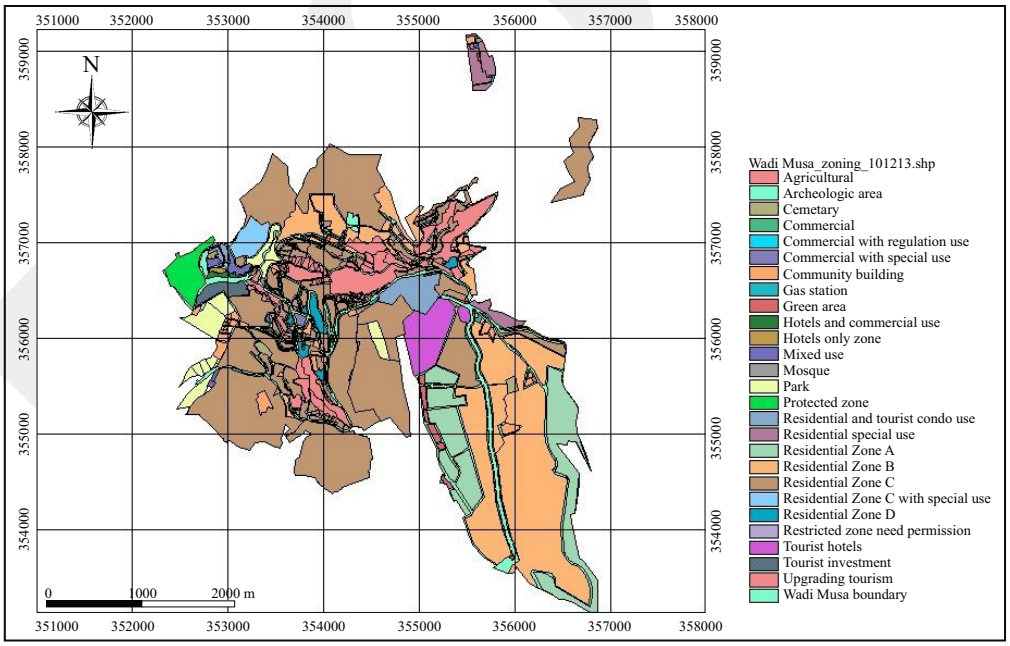

Figure 3. Current land-use plan in Wadi Musa.

(Figure 4, site W8, and Figure 5). The village included complex structures composed of small rooms with red painted plaster floors and subfloor channels as well as walls built of stone and mortar standing to a height of more than 2 m, which may indicate two-storey houses and suggest a more complex Neolithic Wadi Musa society (Amr and Al-Momani 2001, Rolefson 2002).

There was a little evidence of late pottery in the Neolithic and Chalcolithic/Early Bronze Age periods; and the sixth through fourth millennia B.C. are represented only by a small assemblage of

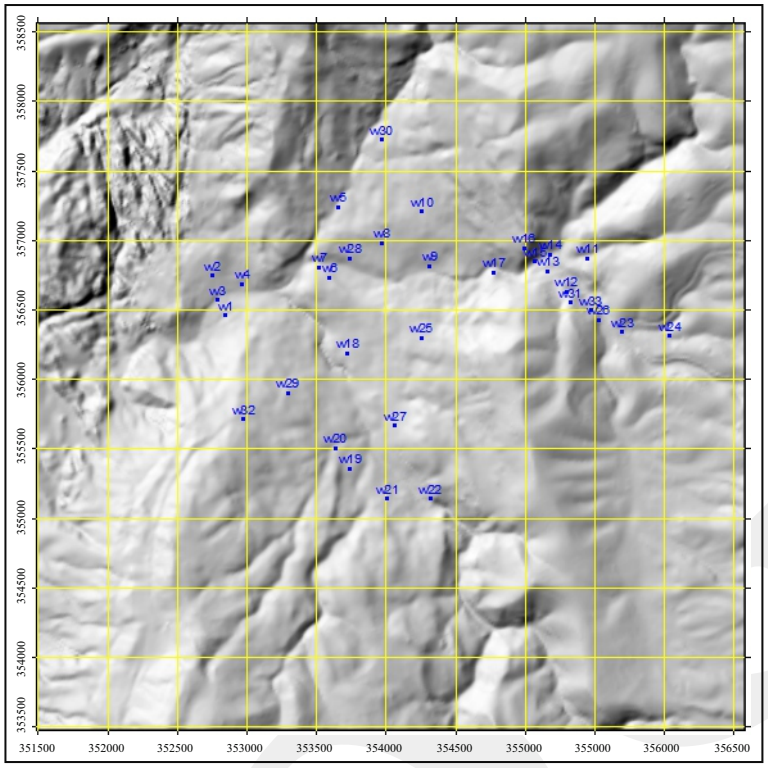

Figure 4. Map of recorded sites in Wadi Musa (based on Amr *et al*. 1998, Amr and Al-Momani 2000, and Amr and Al-Momani 2001).

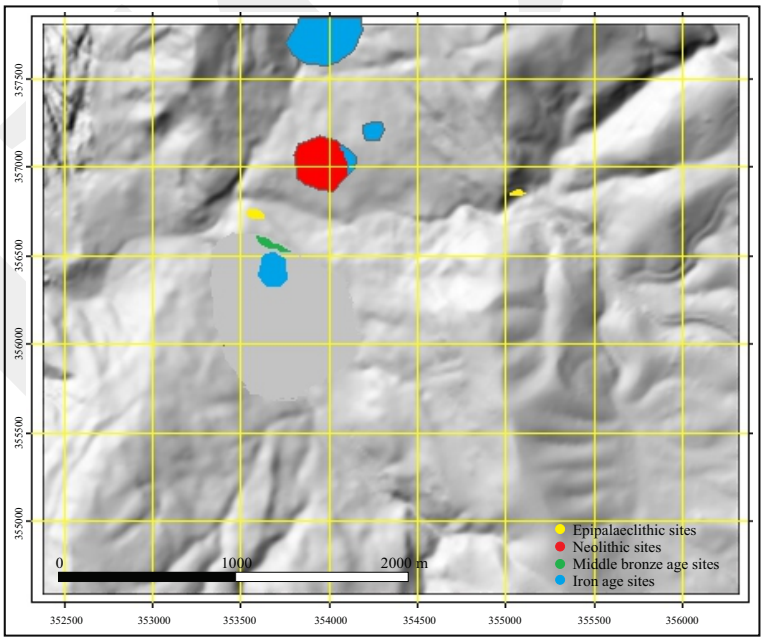

Figure 5. Map of ancient period sites discovered at Wadi Musa.

lithic artifacts (Rolefson, 2002). However, the area appears to have been more densely re-inhabited during the Middle Bronze Age II, 1990 - 1550 B.C. (Figure 5). The evidence of this period was discovered in the centre of the modern city in the form of strongly built walls and two lime-kilns that indicated a complex residential pattern (Amr and Al-Momani, 2001).

After the middle Bronze Age, the area most likely was abandoned or a process of nomadization for the previous inhabitants may have occurred for an unknown reason. Only during the Iron Age II period was the area resettled again as revealed by the Edomite settlement at Tawilan (Figure 4, site W10), which spanned only two centuries (8th through 7th BC) (Bennett and Beinkowskie, 1995). Other evidence of this period was uncovered in three other spots in Wadi Musa (Amr and al-Momani 2001; Figure 4, sites W8, 10, 13, and 30); and Figure 5).

There is no evidence of human occupation in the area during the period between the sixth century B.C. and the Nabataean period; and during this time, it is likely that the area was dominated by nomadic people active in long-distance trade who were known later to be the Nabataeans (Twaissi and Nassarat, 2012).

The importance of Wadi Musa during the Nabataean period was only recognized through a few inscriptions that mentioned the Nabataean name of this area as "al-Ji/Gaia." Although the archaeological knowledge of Wadi Musa was limited and was mainly obtained from past salvage works, the evidence of the Nabataean period settlement clearly indicated that it was the most intensive period among all those represented. Depending on the salvage work done, the limit of the Nabataean City of Gaia was also defined to correspond roughly with the modern mid-town. The archaeological and epigraphical evidence from the area shows that there was a temple at the centre of the city (Figure 4, site W18; Figure 5), dated based on pottery to the Nabataean period with an earlier phase probable (the Hellenistic period) (Ibrahim and Kurdi 1978; Zayadine 1981). In addition to the temple, several residential areas were also defined in al-Brayka, the Suq, al-Maslakh, al-Zuhur, and al-Falahat quarters of the modern town. All these residential quarters were shown to be Nabataean monumental and luxurious structures that were described as villas/palaces. More than twenty villas were already identified in this part of the modern city and supposedly formed the Nabataean City of Gaia (Figure 6). These villas were characterized by elaborate building techniques, plastered walls, flag-stones pavements, and evidence of frescos and wall painting. Mosaics and *opus sectile* pavements were also recovered in some of these supposed villas. Moreover, one of these villas was shown to be furnished with a private bathhouse (Amr *et al*., 1997; Amr and Al-Momani 2000;

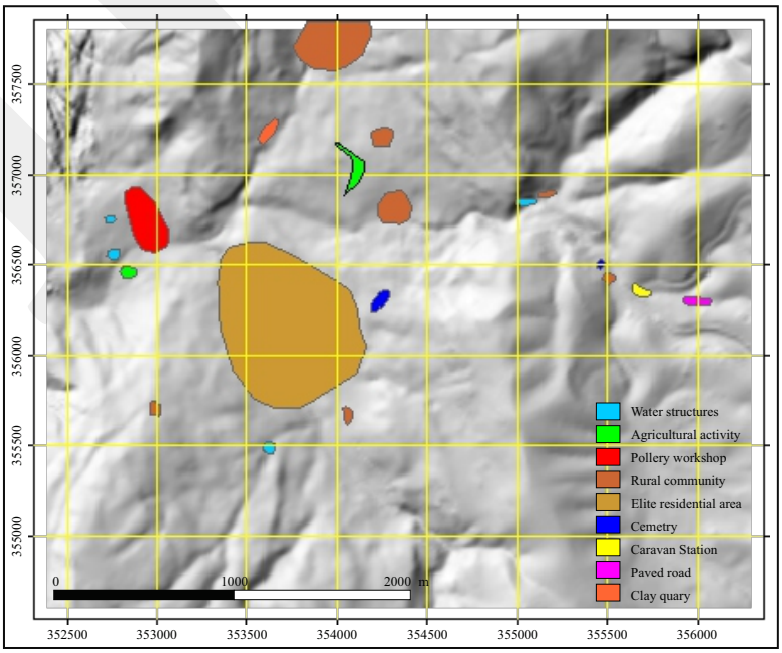

Figure 6. Sites of Nabataean period in Wadi Musa.

Figure 7. Underground Nabataean water tunnel in Wadi Musa.

Amr and Al-Momani 2001; Twaissi, 2001).

The evidence also shows that the water supply of the city was supported by a complex hydraulic system (Figure 7) that was connected to these villas; and many cisterns and water basins were also recorded in different parts of the city (Amr and Al-Momnai, 2000).

Further indication of the importance of Wadi Musa and its layout is that caravan routes were structured to avoid Wadi Musa. This suggestion is based on the fact that at the southeastern entrance of Wadi Musa, there were two large animal enclosures that were associated with large quadrangular structures, which were interpreted as indicating the farthest point that caravans could reach and to avoid entering Wadi Musa directly (Tholbecq, 2001).

A number of smaller residential areas were recorded on the immediate periphery of Gaia. This periphery also was served by several water reservoirs and cisterns (Amr *et al.*, 1998; Figure 4, sites W2, 3, and 9) with similar engineering skills displayed as in other Nabataean sites. In addition, there is evidence that bridges were also erected across streams and wadis. The best-preserved bridge is located at Wadi Khalil (Figure 4, site W15); Amr *et al.,* 1998; Falahat *et al.,* 2001).

The only properly excavated Nabataean residential centre in the periphery of Gaia was Khirbit al-Nawafleh at the northeastern edge of Wadi Musa (Figure 4, site W9). The excavations revealed a Nabataean village with several houses that all indicated a good economic status for the inhabitants, but not like the inhabitants of Gaia. The floors of these houses were paved with flagstone pavement. Moreover, one of the houses was furnished with a kitchen and clay oven (*tabun*) (Amr *et al.*, 2000). This village was supplied with water by a large reservoir with a total storage capacity of about 530 m^3 that included a complex channels system similar to that at al-Humayma (Figure 8). Moreover, an olive press that was dated to the early first century A.D. was also uncovered in the village (Amr *et al.,* 2000), attesting to the presence of intensive orchard and agricultural activities in the area and the permanent sedentary lifestyle of its inhabitants.

The most intensive Nabataean pottery workshops known to us so far were discovered at the northwestern edge of Wadi Musa at al-Zurraba area (Figure 4, site W4) where about twelve

Figure 8. Outlet of a Nabataean water reservoir at Khirbet an-Nawaflih.

pottery kilns have been discovered since 1979 (Zayadine, 1982; Amr and Al-Momani, 1999; Amr and Al-Momani 2001; and Amr and Zayadine, 2002). However, light industrial activity also was located within the city walls but at the edge of the city, such as the olive pressing centre in the Badd area of Gaia (Figure 6) where several oil pressing stones were discovered (Amr and Al-Momani, 2001).

Other discoveries in Wadi Musa included cemeteries or family tombs (Figure 4, sites W25, 27, and 33); also, evidence of burials and cemeteries was found outside the boundary of Gaia (Amr and Al-Momani, 2001; Figure 4, sites W 25, 27, and 33).

Based on the evidence found in Wadi Musa and the survey of the ash-Sharah area, it was determined that the Nabataean city of Gaia was protected by two zones of fortifications. In her archaeological works, which accompanied the infrastructures works of the Wadi Musa water system, Khairieh Amr noted the existence of a huge wall surrounding Gaia, parts of which were uncovered in different areas of the modern town (Amr and Al-Momani, 2001) (Figure 9). The second zone of fortification encompassing Petra and Wadi Musa was recorded by Tholbecq (2013). His survey for ash-Sharah represented this second zone as a series of watch towers and small forts running along the ridge of the Wadi Musa basin that were connected with long walls (Tholbecq, 2001).

The evidence found of later periods (Late Roman-Early Islamic) show continuity in human settlement, but on a smaller scale than the Nabataean period (Figure 4, sites W6, 9, 18, 19, 30, and 32; Figure10). However, the evidence also suggests that Wadi Musa was more densely re-inhabited from the Ayyubid/Mamluk period on, which was well attested by several settlements and cemeteries of these periods as well as several water mills dating back to the Early Ottoman period (Amr and Al-Momani, 2001), indicating that the communities were more rural and agricultural-based (Figure 4, sites W6, 8 - 14, 17 - 19, 21, 22, and 27 - 31) and Figures 10 - 13).

Figure 9. Modern wall on top of ancient fortified wall in Wadi Musa.

On the basis of provided evidences, Wadi Musa has had long and continual human occupation since the 14th millennium B.C. The Nabataean period, however, was the golden age of the city. During this period, the city had a well planned modern mid-town that included an elite quarter occupied by the Nabataean upper class, which was protected by a fortified wall. Social segregation/ stratification during the Nabataean period was indicated by the luxurious houses located behind the city walls. Peripheral rural communities as well as heavy industries, such as pottery production, and family tombs were located outside the boundaries of the city (Figure 6). The evidence available suggests that the Petra proper and Wadi Musa formed one unit (*i.e.* the greater capital of the Nabataean Kingdom), and the combined GIS maps (Figures 14 - 20) show that it was a well planned city. In addition, the land use strategy in Wadi Musa was to maintain a green zone around the city of Gaia. As a testament to the Nabataean planning scheme, the modern midtown of Wadi Musa has remained a favourable residential area to this day.

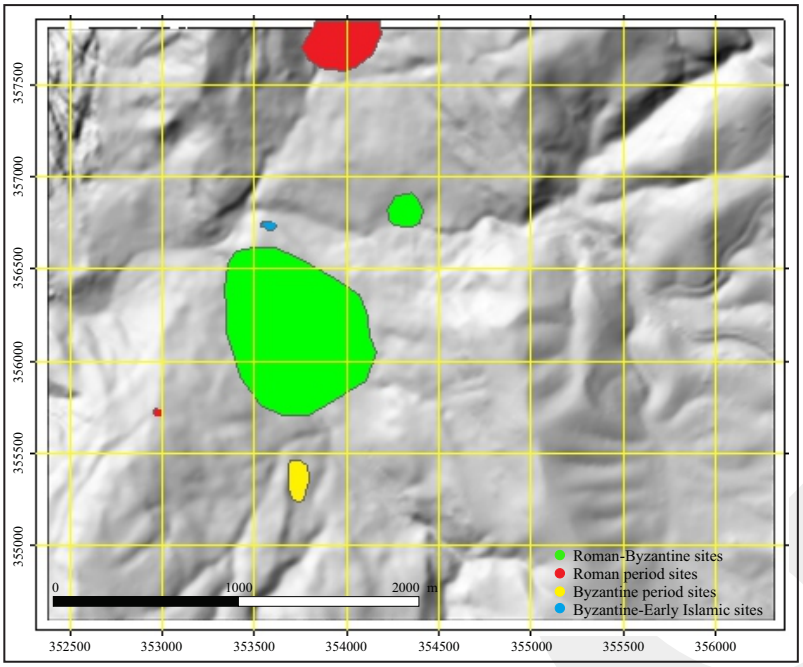

Figure10. Sites of Roman-Early Islamic sites in Wadi Musa.

Figure 11. Late Mamluk-Ottoman water mill in Wadi Musa.

The logical land-use suitability indexes the authorities used was based on the following assumptions:

- Agricultural soils were kept as much as possible for agricultural activities.

Figure 12. Iron Age-Modern field terraces in Wadi Musa.

- Buffers of 100 m were kept from each of the major wadis to avoid risk of flooding.
- Areas with topographic slopes exceeding 20% were notused for any construction purposes, but instead were gardens and/or free spaces.
- Terraces that could be irrigated from water springs were kept for agricultural activities.
- Central flat areas were allocated for public service units and marketing centres.
- Relatively flat overlooking areas were allocated for residential uses.

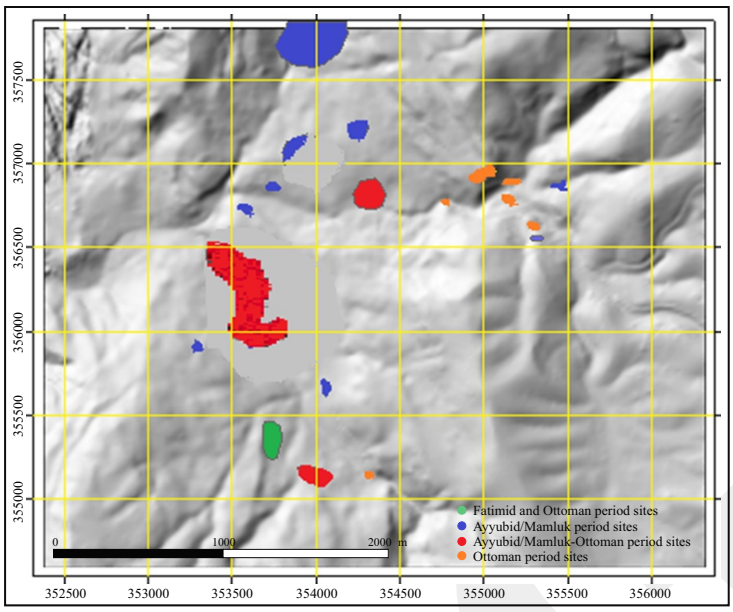

Figure 13. Sites of Latter Islamic periods in Wadi Musa.

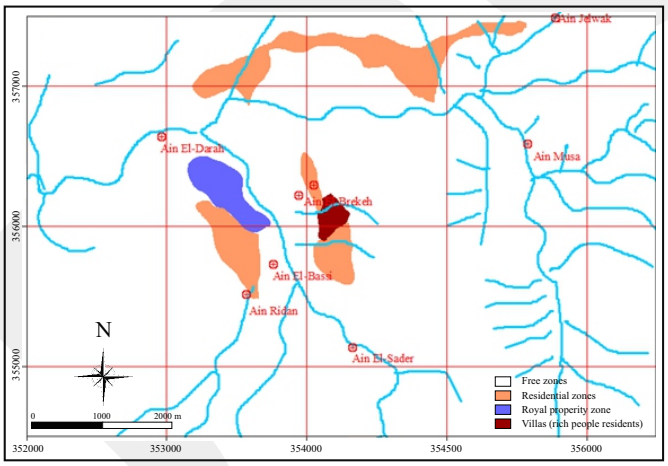

Figure 14. Residential remain zones.

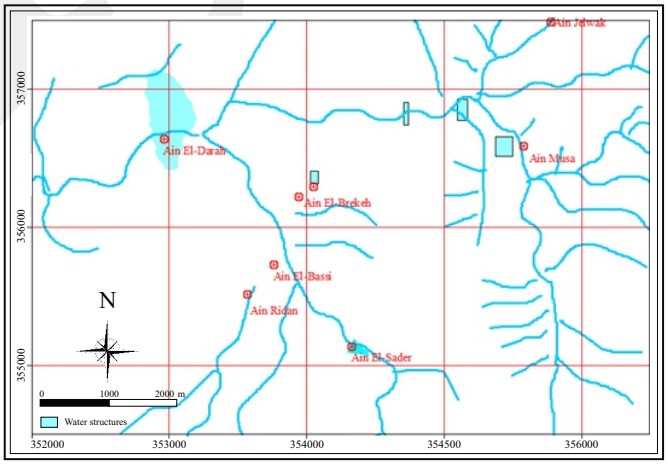

Figure 15. Water harvesting remain zones.

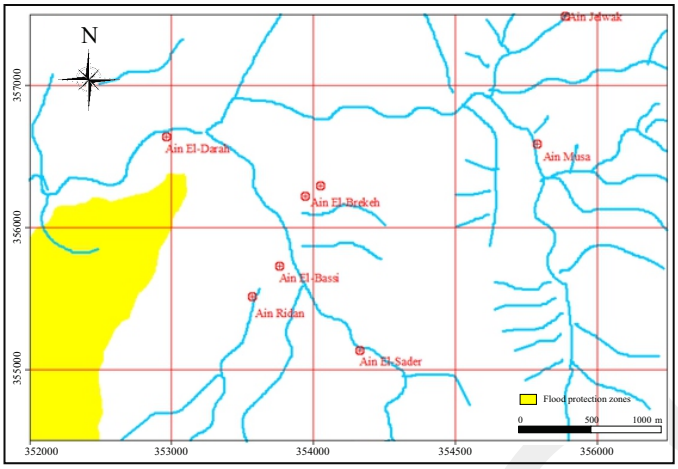

Figure 16. Flood-protection-remain zones.

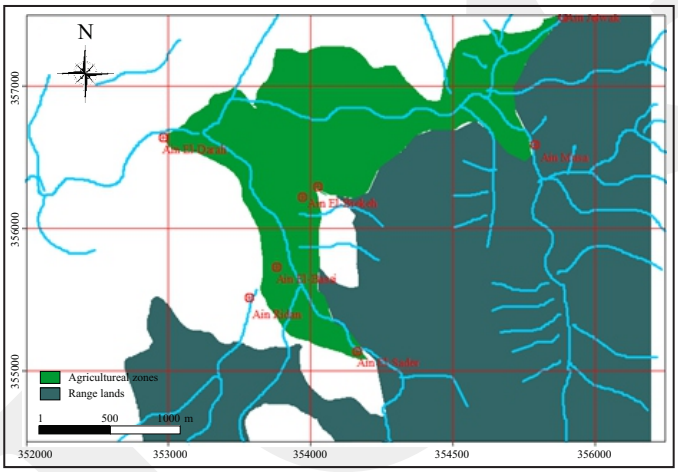

Figure 17. Agricultural remain and terrace zones.

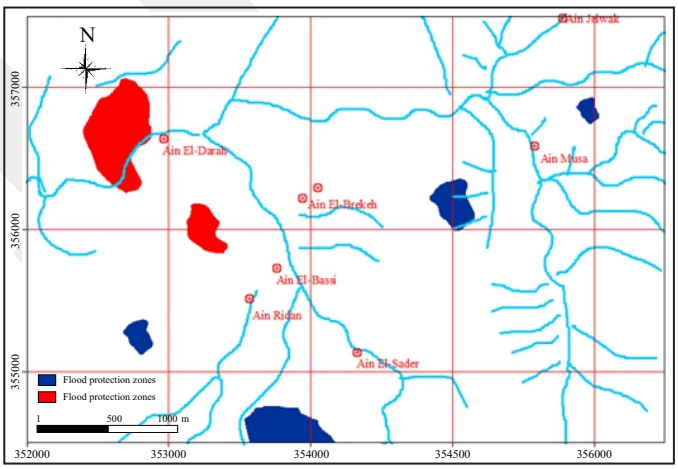

Figure 18. Military control zones.

- Water harvesting provisions and flood protection structures were provided along wadis with flood potentials that drain relatively big catchment areas.

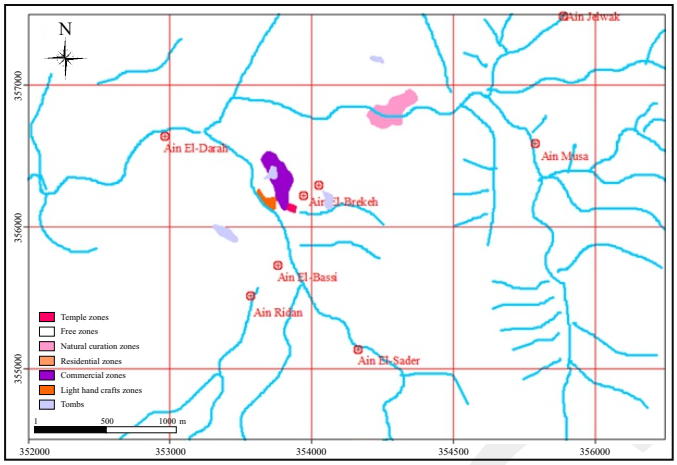

Figure 19. Public service zones.

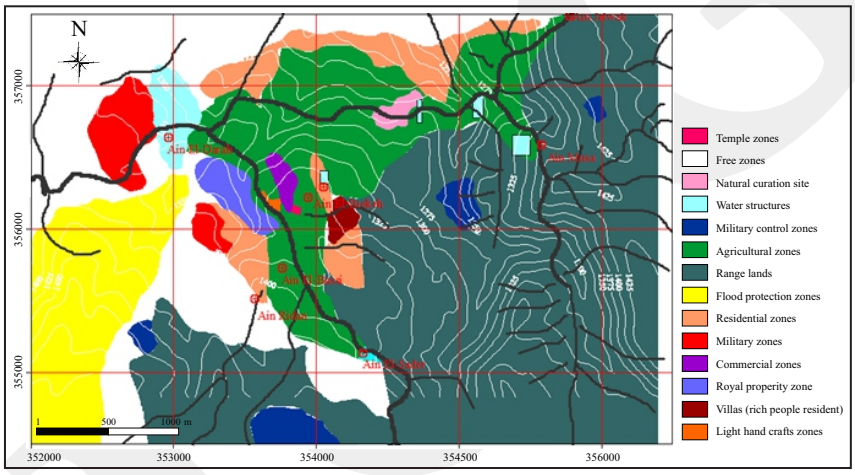

Figure 20. Result of the overlapped layers.

- Hidden areas in the surrounding areas were allocated for heavy industries.

Comparing the reconstructed land use map of the Nabataeans with the land use map of the historical periods (Figure 14) and the current existing land use in the city (Figure 3) and analyzing them visually, it is obvious that all the Nabataean maps utilized early the same criteria used in modern land use planning.

Conclusions

In conclusion, this paper presents a clear evidence that scientific methods were followed in planning the different landuse units during the different occupation periods of the city of Wadi Musa. The historical struggle between the Nabataeans and the Romans also was reflected in the landuse planning of those periods.

Since Petra is considered as one of the 10th most wonderful archaeological places in the world, the landuse of Petra and Wadi Musa indicated that the planning method of Wadi Musa through time was developed in accordance with the envisioned development and extension of the city. The rapidly increasing population and the development of tourist facilities in present days have played a vital role in landuse changes. Until now, historians have mainly relied on textual, architectural, and art-historical analyses of monumental structures to understand their historical context.

This paper found clear evidence that GIS can lend an important new dimension to the analysis of historical phenomena, because structures in GIS are treated not as individual archaeological items but rather as a system. The case study in this paper also demonstrated the significant value of GIS in historical research.

Acknowledgment

Petra Development and Tourism Region Authority is highly acknowledged for allowing exchanging some spatial data from the GIS department.

References

Alhasanat, M., Kabir, S., Wan Hussin, W., and Addison, E., 2010. Spatial analysis of a historical phenomenon: Using GIS to demonstrate the strategic placement of Umayyad Desert palaces. *Geo-Journal*, 77, p.343-359. DOI: 10.1007/s10708-010-9392-4

Al Farajat, M. and Salameen, Z., 2007. Geophysical and hydrological based archaeological survey of ancient water structures along Wadi Al Madras in Petra. *Journal of Applied Geophysics*, Egyptian Society of Applied Petrophysics, 6 (1), p.169-177.

Al Farajat, M. and Salameh, E., 2010. Vulnerability of the drinking water resources of the Nabataean of Petra - Jordan, *Jordan Journal of Civil Engineering*, Jordan University of Science and Technology, 4 (4). p.321-335.

Amr, K., 2002. Additional information of Neolithic al-Basit, Wadi Musa Southern Jordan, *Annual of the Department of Antiquities of Jordan,* XLVI, p.93-106.

Amr, K., Nawafleh, S., and Qarareh, H., 1997. A preliminary note on the Wadi Musa salvage excavation 1996. *Annual of the Department of Antiquities of Jordan,* XLI, p.469-473.

Amr, K., Al-Momani, A., Farajat, S., and Falahat, H., 1998. The Petra National Trust site projects: Archaeological survey of the Wadi Musa water supply and wastewater project area. *Annual of the Department of Antiquities of Jordan,* XLII, p.503-549.

Amr, K. and Al- Momani, A., 1999. The discovery of two additional pottery kilns at Az- Zurraba Wadi Musa, *Annual of the Department of Antiquities of Jordan,* XLIII, p.175-194.

Amr, K. and Al-Momani, A., 2000. Archaeological report on the Wadi Musa water supply and wastewater project (1998 - 2000). Summary report and recommendations (unpublished report preserved in the registration office of the Department of Antiquities of Jordan).

Amr, K. and Al-Momani, A., 2001. Preliminary report on the archaelogical component of the Wadi Musa water supply and wastewater project (1998 - 2000), *Annual of the Department of Antiquities of Jordan,* XLV, p.253-285.

Amr, K., Al-Momani, A., Nawafleh, N., and Al-Nawafleh, S., 2000. Summary result of archaeological project at Khirbet An-Nawafleh/ Wadi Musa, *Annual of the Department of Antiquities of Jordan,* XLIV, p.231-257.

Amr, K. and Zayadine, F., 2002. Nabataean pottery workshops at ez-Zurrabah/Wadi Musa. Unpublished paper presented in the *Second Conference on Nabataean Studies*, *Petra*, (1-3) November 2002.

Barjous, M., 2003. The geology of Petra and Wadi Al Lahyana area, *Map Sheets No. 3050-I* and 3050-IV, Amman.

Bennett, C. and Beinkowski, P., 1995. Excavations at Tawilan in Southern Jordan. *The Antiquaries Journal,* 77, p. 414-415. DOI: 10.1017/S0003581500075338

Bevan, A. and Conolly, J., 2004. GIS and archaeological survey data: Four case studies in landscape archaeology from the Island of Kythera (Greece), *Journal of Field Archaeology,* 29, p.123-138. DOI: 10.1179/jfa.2004.29.1-2.123

Falahat, S., Salameen, M., and Nueimat, F., 2001. al-Jisr al-athary fi Wadi Khalil. (The Archaeological Bridge in Wadi Khalil). Unpublished report deposited in the Petra Antiquities Office.

Groom, N., 1981. *Frankincense and Myrrh: A Study of the Arabian Incense Trade*. London UK: Longman.

Hamdan, I. and Al-Rawabdeh, A., 2020. Groundwater Vulnerability Assessment for the Corridor Wellfield Using DRASTIC and Modified DRASTIC Models: A Case Study of Eastern Jordan. *Open Journal of Geology,* 10 (10), p.991-1008. DOI: 10.4236/ojg.2020.1010046

Hill, J., 2004. Land use and an archaeological perspective on socio-natural studies in the Wadi Al-Hasa, West-Central Jordan, *American Antiquity,* 69 (3), p.389-412. DOI: 10.2307/4128399

Hill, J., Devitt, M., and Sergeyeva, M., 2016. Understanding past and future land use, modeling archaeological sensitivity. *ArcUser*, 20 (1), p.39-46.

Ibrahim, M. and Kurdi, H., 1978. al-Hafreiyat al-Athareiyah Fi al-Urdun 1976-1977. (The archaeological excavations in Jordan 1976 - 1977), *Annual of the Department of Antiquities of Jordan,* 22, p.20-30 (in Arabic).

Johnson, D., 1987. Nabataean Trade Intensification and Culture Change. Ph.D. *Thesis*, University of Utah.

Lawrence, D., Bradbury, J., and Dunford, R., 2012. Chronology, Uncertainty and GIS: A Methodology for Characterising and Understanding Landscapes of the Ancient Near East *In*: Bebermeier, W., Hebenstreit, R., Kaiser, E. and Krause, J. (eds.). Landscape Archaeology. *Proceedings of the International Conference Held in Berlin, 6th - 8th June 2012. Berlin, Excellence Cluster Topoi*. *Special,* 3, p.353-359.

Oran, S., 2005. Plant Biodiversity of the Surrounding Area of "Wadi Musa Wastewater Plant". *Dirasat, Pure Sciences,* 32 (2), p226-246.

RSCN (The Royal Society for the Conservation of Nature), 2013. The Status of Jordan's Birds.

Tholbecq, L., 2001. The Hinterlands of Petra from the Edomite to the Islamic Periods: The Jabal ash-Sharah Survey (1996 - 1997). *Studies in the History and Archaeology of Jordan,* VII, p.399-405.

Tholbecq, L., 2013. The Hinterland of Petra (Jordan) and the Jabal Sharah during the Nabataean, Roman, and Byzantine Periods. *In*: Mouton, M. and Schmidt, S. (eds.), *Mens in the Rocks: The Formation of Nabataean Petra*, p.295-312. DOI: 10.31826/9781463235697-008

Topouzi, S., 2010. The Settlement Pattern of Ancient Icaria through a GIS Approach - A Ph.D. Project (preliminary report). *In*: Nicolucci, F. and Hermon, S. (eds.), Beyond the Artifact. Digital Interpretation of the Past. *Proceedings of CAA2004*, Prato 13 - 17 April 2004. Archaeolingua, Budapest, p.228-231.

Twaissi, S., 2001. A Study for the Nabataean Remains Excavated at Wadi Mousa In 1996, *Unpublished MA Thesis*, University of Jordan, Amman (in Arabic).

Twaissi, S. and Nasarat, M., 2010. Historical circumstances and archaeological evidence for the migration of the Nabataeans into Southern Jordan. *Jordan Journal for History and Archaeology*, 4 (2), p.97-116.

UNDP (United Nations Development Programs), 2014. Mainstreaming Biodiversity into Tourism Development in Jordan/Preliminary Phase/Comprehensive Technical Draft Report.

Winemiller, T., 2014. GIS reveals basis for ancient settlement location. *ArcNews*, 16 (2). 20p.

Zayadine, F., 1981. Recent excavations and restorations of the Department of Antiquities. *Annual of the Department of Antiquities of Jordan,* XXV, p.341-355.

Zayadine, F., 1982. Recent excavations at Petra (1979 - 1981). *Annual of the Department of Antiquities of Jordan,* XXVI, p.365-393.