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Original Article

# Detecting the Effect of Groundwater Seepage on the Archaeological Site of Habu Temple of Luxor, South Egypt, Using the Dc Resistivity Tool

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ABSTRACT

Egyptian antiquities are considered the most critical monuments on the earth and show their renaissance in Habu Temple at Luxor area. The objective of the study is utilizing the DC resistivity, to identify the effect of groundwater seepage on the site of archaeological Habu Temple. Nine vertical electrical soundings (VESs) have been carried out, to delineate the subsurface geoelectric units to realize the subsurface geologic structures, the effect of Groundwater on Habu Temple and standing behind the hydrogeologic conditions of the study area. The quantitative interpretation showed that, the near surface sequence of the subsurface in the investigated area splits into four geoelectric units. The 2nd unit, consisting of sand and gravel, is the major Quaternary aquifer, while the 3rd unit consists essentially of clay, representing the bottom of this aquifer. The agricultural activities, urbanization and flash cause the rising of groundwater level, capillary effects and the salt amount in the groundwater and rock material, thus degradation of the archaeological sites. Integrated groundwater administration, by the sharing and cooperation of the different water users, should be taken into consideration, to avoid raising the groundwater levels toward and around the archeological sites, is recommended. Also, irrigation systems of drip and sprinkler are recommended, as the best systems to improve irrigation water on the farms of the study area.

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## 1. Introduction

The preservation of cultural heritage is one of the most important strategic priorities, to ensure the survival of cultural treasures for future generations in Egypt and the world and all countries, that have an extraordinary cultural heritage, must be preserved from environmental influences and other human activities. UNESCO (http://whc.unesco.org/en/conventiontext/) has emphasized that, cultural heritage is seriously threatened, not only by the traditional causes of damage, but also because of changing the socio-economic conditions of the society, that could further deteriorate the situation. Climate change, extreme weather and sudden ecological or geological impacts, are among the most important causes of the deterioration of cultural heritage sites, as well as the urban sprawl.

In the past, Medinet Habu was built as a walled area surrounded by a city, with an administrative center and a temple, to protect the area's inhabitants during times of war. But, it has become a walled city for Coptic Christians living in the area. This has led to the fact that most, of these temples suffer from poor environmental conditions, in addition to the continuous increase in population, caused many environmental problems in the surrounding archaeological areas, as a result to the urban and agricultural extensions.The high level of saline groundwater is one of the most important environmental problems, affecting the discovered and buried archaeological sites in Luxor this is especially after the construction of the High Dam south of Aswan, which helped to expand agriculture in the parts around the temple. Saline groundwater, by capillary pressure, rises to the temple rocks, where salts accumulate within pores and on the temple rock surface, due to the evaporation of groundwater by high temperature in these arid areas. Rodriguez Navarro and Doyne (1999) sated that, the crystallization of the residual salt in the rocks breaks and destroys them, helps its erosion through physical processes and winds, and thus the rocks degradation in archaeological sites.

Geophysical methods have been performed in wide scales for the study of groundwater, that is considered one of the main factors of degradation of the archaeological sites (e.g., Albouy et al., 2001; Ismail, 2003; Dobecki, 2005; Asfahani 2007; Elwaseif et al. 2012; Abd El Hameed et al. 2017; Sharaf el din et al. 2017, 2019). Ismail (2003) studied the layer resistivity and thickness, by using electromagnetic methods, which are considered good for estimating the layer thickness, but not their resistivity values. Asfahani (2007) used the geoelectrical method, at the Valley of Khanasser (Syria) and identified the shape and nature of a deep aquifer, by using electromagnetic and resistivity surveys. In addition to a chemical analysis of some collected samples of water from the sacred Memnon Lake. Elwaseif et al. (2012) found that, the subsurface was divided into four shallow geoelectrical layers and the flow directions of groundwater were from the central area to the west, inducing a rise of the levels of groundwater and salinity in the monuments area.

Abd El Hameed et al. (2017) studied the main aquifers in the southern part of Wadi Qana , by 54 Vertical Electrical Soundings where the interpretations revealed seven geoelectrical layers , two of them water-bearing layers , representing the two main Quaternary aquifer and Nubian aquifer. Sharafeldin et al. (2017) and (2019) by integrating the geologic measurements with other geophysical techniques, delineated the groundwater table and studied the aquifers in the Giza Pyramids area. However, the main objective of the study is utilizing the DC resistivity data, to identify the effect of groundwater seepage on the site of archaeological Habu Temple, based on geophysical techniques.

## 2. Area description

The study area lies between long. 32o 35' & 32o 37' E and lat. 25o 42' & 25o 44' N (Fig. 1), where Luxor city is considered an essential center of the ancient Egyptian culture. The agricultural lands cover about 73.8 % of the total area. On both flanks of the Nile, urban areas occupy about 19.4 % and about 6.8 % is a barren desert. The culture of ancient the Egyptians along, the Valley of Nile valley, was printed from the famous pharaonic monuments, which remained in good shape for preservation. Many archaeological sites are located on both flanks of the Nile, such as the temples of Karnak, Luxor, Medinet Habu, Memnon monument and Ramsium, in addition to the Pharaonic tombs located along Kings Valley and Queens Valley (Baines and Malek , 2000). Habu temple is located at the southeast of the village of Qurna, west of Luxor, on the edge between the ancient agricultural land of the Nile valley and the limestone hill to the west. Habu inscriptions, which discuss how protected Egypt's northern border from the waves of external invasion, represent one of these presentations of the power. While his claims should not be taken literally, the inscriptions have a value by ideological messages, that served to strengthen his authority (Peters, 2011). The study area (Fig. 1) is characterized by arid climatic conditions, where the average temperature reaches 42 °C and the mean medium is 23.1 °C, with large annual ranges in the summer and abnormally cool or cold in the winter. The monthly rate of relative humidity is about 35.4 %, where it ranges from 30% in the summer to 50% in the winter. It plays a vital role in the evaporation, evapotranspiration and dew consideration processes in the area. The evaporation rate in the investigated area is about 14.6 cm in June and 3.1 cm in December. Also, the wind speed is about 5.9 km / h. No enough rain receives to the area along the year, where in winter and spring, the intermittent rainfall causes torrential floods. The monthly rainfall range is between 0 to 0.3 mm. (Ahmed, 2003; Egyptian Environmental Affairs Agency, EEAA, 2005; and Tyson 2010).

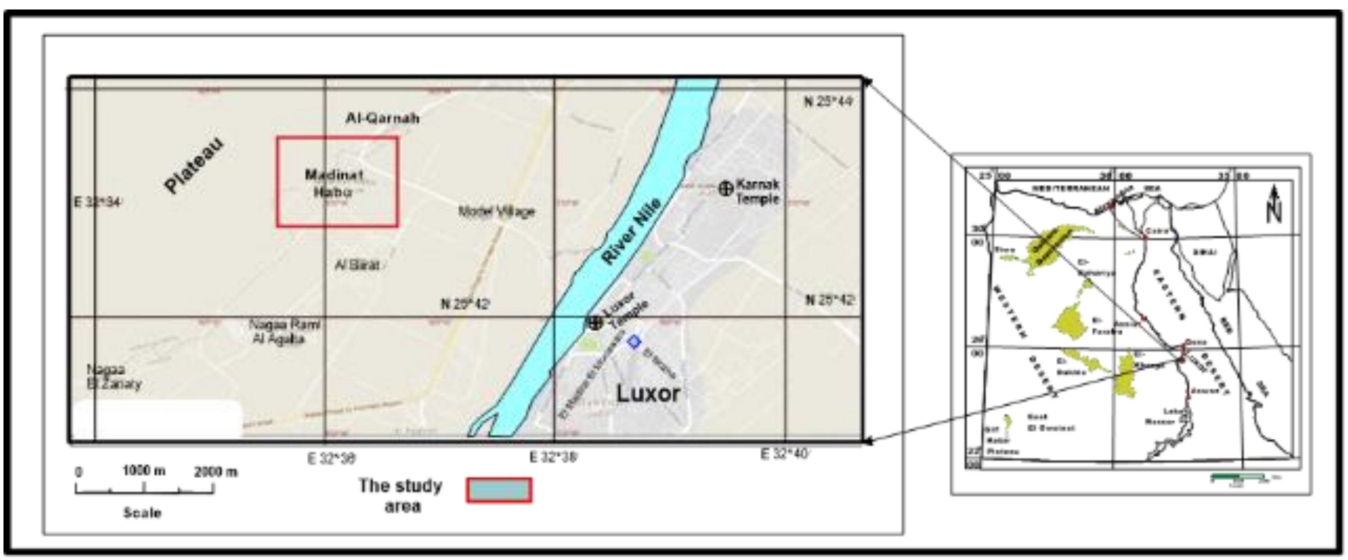


*Fig. 1: Location map of the study area.*

## 2.1. Geologic and geomorphologic settings

Qena area was studied by many geologic authors, such as (Said 1962, 1981, 1983 and 1990; Ahmed 1983; Issawi and McCauley 1992; Abdel Gowad 2010; Elwaseif et al. 2012; Abd El_Hameed et al. 2017; and Askalany et al. 2017). The study surface area is covered by old alluvial plains (Quaternary deposits) and young alluvial plains, which are restricted to the Nile Valley area. They young alluvial plains have the old agricultural lands to the east, and southeast of Habu temple. Also, the new areas of development are found to the northwest of the temple area, near the limestone plateau (Qurna Village). In the study area, the rugged limestone hills rise over the surface of the modern sediment and have been dissected by dry wadis, such as in El Sheikh Abd El Qurna site, where they reach a maximum height of 450 m (a.s.l). The surface slopes of this hilly area are arising from west to east, toward the flood plain. The plateau surface in the study area ranges from 80 meters (a.s.l.) east of the temple to 90 meters (a.s.l.) west of the temple.

The geologic setting of the study area has been studied by many authors (Said ,1983 and 1990; Issawi and McCauley ,1992; El Hosary ,1994; Wendorf and Schild , 2002; Kamel , 2004; EL-Bayomi ,2007; Ahmed ,1983; and Ahmed and Fogg, 2014). Figure (2) shows the surface geologic map at Luxor area, where the sedimentary succession, from top to base, is summarized as follow:

- Holocene deposits consist of Arken Formation (the Modern River Nile sediment), which contains a layer of silty clay (18.5 m thick). This formation overlays the Quaternary aquifer, where it has thick sediments in the middle part of the Nile Valley and gradually decreases toward the east and west, until it disappears totally at both sides of the Nile Valley.

  -Pleistocene sediments include (Qena Sand, Abassia Formation, Armant Formation and Wadi deposits. The Qena Sand (Middle-Late Pleistocene sediments of the Prenile) is consisted of massive cross-bedded fluvial sands and intercalated with clay lenses. The Qena Sand is overlain by the Abbassia Formation, which comprise conglomerates deposited by the ephemeral rivers and occupied the channel of the Nile, during the Middle Pleistocene. Armant Formation represents the Plio-Pleistocene sediments (Protonile–Prenile), where it is composed of clays, sands and conglomerates. The Pleistocene sediments are considered the main aquifer of the Nile Valley. Units of Tertiary rock, include the following formations: Madamud Formation (Pliocene sediments of the Paleonile, which contain brown clays, interbedded, with thin and fine-grained sand, and silt. These sediments reflect about 20% of the sediments of the river in the Nile Valley and cropped out along the banks of the valley and in many wadis, which drain into the valley. It is considered the Quaternary reservoir bottom of the Nile Valley and may appear on the surface in the desert areas near the Nile Valley.
- Lower Eocene–Palaeocene sediments include Thebes Formation, Esna Shale and Tarawan Chalk. The Eastern Plateau and Western Plateau are consisting of hard limestone, related to the Lower Eocene and bordering the Nile Valley to the east and west. The lower Eocene, Thebes Formation is formed of limestone with flint bands. The Paleocene-Eocene sediments comprise the carbonate unit of Tarawan Chalk, that overlying the Dakhla Shale (dark grey papery shale and marl, with interbedded sandstone, siltstone and limestone) and underlying the Esna Shale (laminated green and grey shale). Habu temple is located near the western plateau, west of Luxor. In the study area the Upper Cretaceous sediments reflect the Dakhla Shale, which consists of chalks and marls the Duwi Formation, which includes the alternating beds of claystone, sandstone, siltstone and oyster limestone, intercalated with phosphate and phosphatic beds, and Quseir Shale, that comprises the thin bedded shale of highly variegated color, siltstone and sandstone

## 2.2. Hydrogeologic setting

In the study area, there are two groundwater aquifers, which include Holocene aquifer and Pliocene–Pleistocene aquifer.

*a. Holocene aquifer*

This aquifer is comprising two hydrogeologic units, the Upper Holocene aquitard (Arkin Formation) and the Lower Pleistocene aquifer (Figure. 3). Said (1981) said that: " Holocene aquitard, including the unconfined aquifer is equivalent to the Neo-Nile sediments". This layer has greater thickness near the river channel and disappears near the valley fringes, and has low permeability, thus acting as an aquitard to the underlining aquifer (Ahmed ,2009& 2013; and Kamel , 2004). Pleistocene sediments mainly consist of unconsolidated pebbly and boulder gravel, changed laterally into medium to coarse sands and gravels. The thickness of these sediments is about 64.5 m. in Luxor area (Kamel ,2004). These sediments overlay the Madamud Formation, which includes a unit with thickness > 100 m. of brown clay (Pliocene age). Irrigation water and its infiltration from irrigation channels through the Holocene aquitard are the main recharge source of Pleistocene aquifer. It is a high-quality product of water (Shamrukh and Abdel-Wahab ,2008; Ahmed, 2003; Kamel 2004). Groundwater pumping for land irrigation and people drinking purposes are the main discharge of this aquifer.

*b.Pliocene–Pleistocene aquifer*

This aquifer consists of clay, sand and gravels, and has a maximum thickness near the Quaternary aquifer but decreases toward the boundaries on both sides of the Nile Valley, towards the Eocene limestone (Ismail et al, 2005; and Ahmed et al., 2014). This aquifer has a low productivity. Excess irrigation, from the reclaimed and desert lands, and from the deeper aquifer systems, acts as aquifer recharges, but the aquifer discharge is through the groundwater pumping or to the adjacent groundwater aquifers.

In the study area, the Pleistocene sediments (aquifer) are located east of the temple part, but the Holocene sediments (aquitard) disappear near the temple and are less at the valley edges. Water system in the study area comprises two types, one of them is the Nile and the canals along its banks, where Ramses canal is located to the east with about 150 meters from the temple, while the Nile runs parallel to Ramses, about 7 km from the temple part.

The second water system, which locates the dry valleys in the temple vicinity part, acts as a rain drainage system, in case of their occurrence (Fig.4). Also, the Nile operates as a bank in most areas. The irrigation water is the main source of the tank in Luxor area and surrounding areas, including the temple part. There are many Trenchant Septic tanks to the southeast of Qurna village, which mixes the drainage water and surface water, causing local groundwater pollution to the temple part, that increased erosion in the archaeological area.

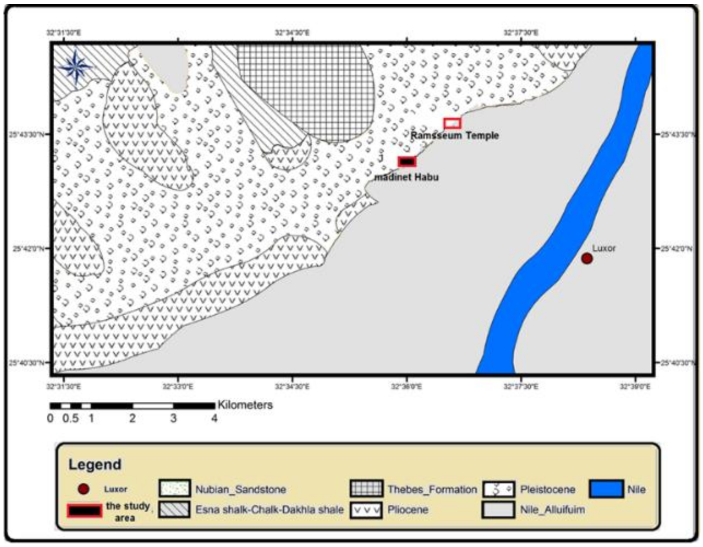


Fig.2: Surface geologic map of Luxor area, as modified after Elfadaly et al, 2018.

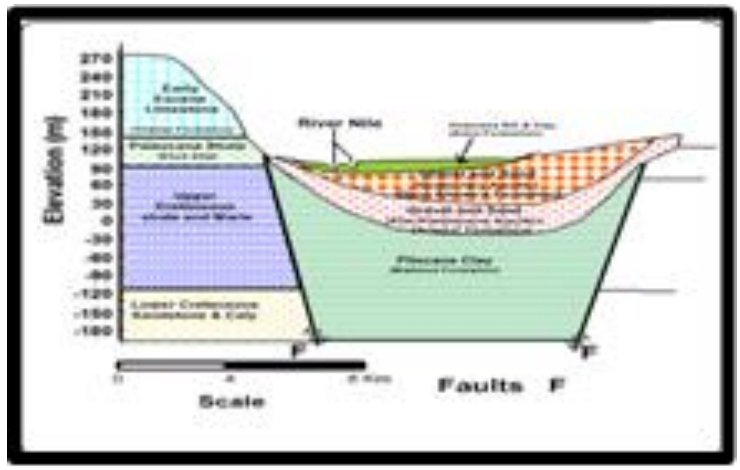


Fig.3: Simplified hydro-geologic section at Luxor area, as modified after RIGW (1997) and Ismail et al. (2005).

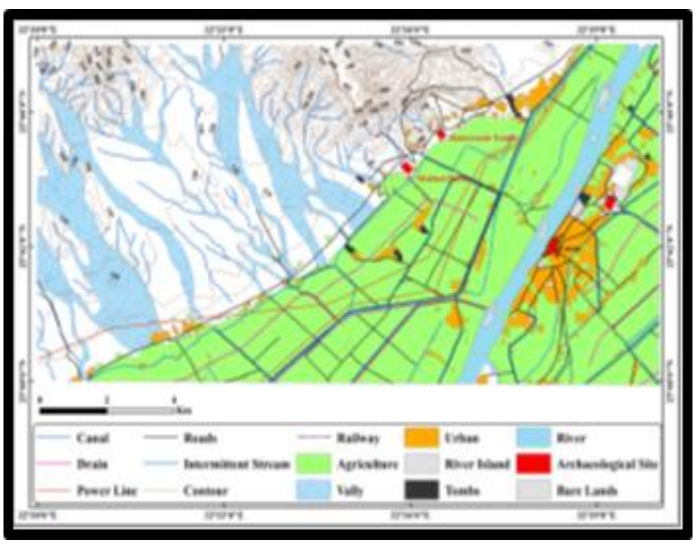


Fig.4: Topographic map of the study area, (after Elfadaly et al, 2018)

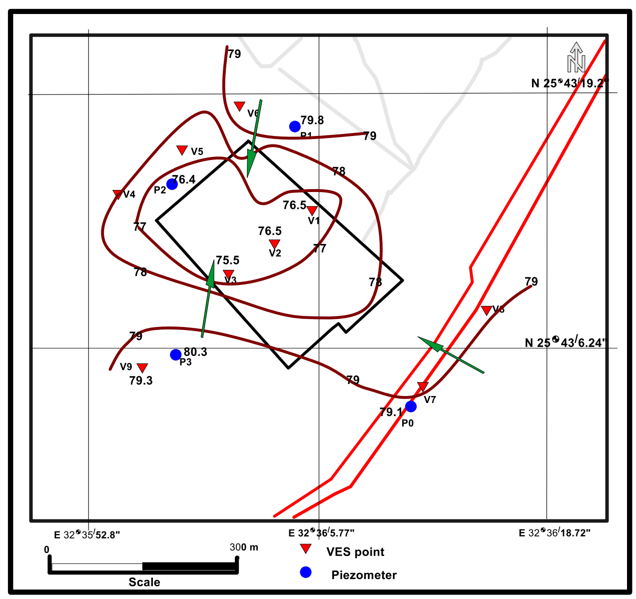


Fig.5: Piezometric pressure contour map of the study area.

## 3. Material and Methods

### 3.1. Geoelectric Investigation

The geoelectric investigation was used in the study area, where nine Vertical Electrical Soundings (Veses) of AB/2 spacing, ranging from 1 to 300 m of Schlumberger configuration. The data were measured by using SYSCAL–R2 resistivity meter. Some of the VESes stations were measured, close to the drilled water wells, to establish geoelectrical models of interpretation, based on the geologic and hydrogeologic data available nearby these wells. Two methods of interpretation were carried out. The manual method is the first method, which depends on matching the curves of two layers (Koefoed , 1979). In the second method, depending on the interpreted manual model, as an initial model, the IPI2WIN (2005) program is used for calculating the final true resistivities and thicknesses for availably shallow the subsurface layers. The results of the quantitative interpretation of the VES stations (1,2,3&9) by using IPI2WIN software, are represented in Figure (6), as examples. Three geoelectrical cross sections were drawn, by using the interpreted data (resistivities and thicknesses ) named A'A& B'B, that take these SW - NE direction and C'C, that takes the NW-SE direction (Fig.7). The geoelectrical cross section A'A was located behind the temple and parallel to the mountain, while the cross-section BB', that has VESes 1, 2&3 were located inside the temple, and VES 9 was located at the south west of the temple, in the agricultural land. The geoelectrical cross-section C'C was located perpendicular to the other two cross-sections, where VES 2 was located inside the temple. Each section reveals the lateral and vertical variations of the geoelectrical sequence, that reflects the lithologic changes of the different layers and groundwater impacts along the profile direction. Figures (8-10) show the geoelectric cross-sections A'A, B'B& C'C, where the subsurface sequence in the study area can be divided into four geoelectrical units.

## 4. Results

Description of the geoelectrical units,that located under the area of Habu Temple, is as follow:

a. *The surface geoelectrical* unit contains values of resistivity ranging between 9 Ohm.m and 90 Ohm.m. The surface unit is composed of sand, and a mixture of sand and clay in some places. Under the temple, the surface unit is composed of a transported soil, while outside the part of temple (VES No. 9), the surface unit represents the soil. The surface geoelectrical unit thickness ranges between 0.5 m and 9 m, and is found under all the VESs of the study area. Figures (5, 8, 9 & 10) show the peizometric pressure map and the geoelectric cross-sections, where the groundwater level is appeared toward the bottom boundary of the surface unit (except in the cross-section A'A). Also, the water flows from the northern, southern and south eastern directions, at VESs 9, 1, 7 & 5 toward the location of the Temple at VESES 2 and 3.

b. *The second geoelectrical* unit is located under all the VESs of the study area and contains values of resistivities ranging from 13 Ohm.m. to 150 Ohm.m. This unit consists of gravel and sand, with some lenses of clay at VESes 1, 3, 7 &9. This unit is considered as the main Quaternary aquifer and comprises thicknesses range between 5 m. and 18 m. This thickness decreases significantly toward the western plateau, while it increases toward the east and south (Figs. 8 & 9). This thickness decreases toward the temple location at VES no. 2

**c.** ***T****he third geoelectric unit* represents the bottom of the Quaternary aquifer and is considered as the secondary aquifer in the area (Pliocene-Pleistocene aquifer) (Elwaseif, et al., 2012). According to Ismail (2003), the values variation of resistivities between the Pliocene-Pleistocene aquifer and the Quaternary aquifer of the is because of the clay content and the medium to low values of salinity within the Pliocene-Pleistocene sediments (700. 2600 ppm).

d. *The fourth geoelectrical unit* has high resistivity values, reflecting the limestone of the Lower Eocene. The values of resistivity range between 300 Ohm.m. and 800 Ohm.m.

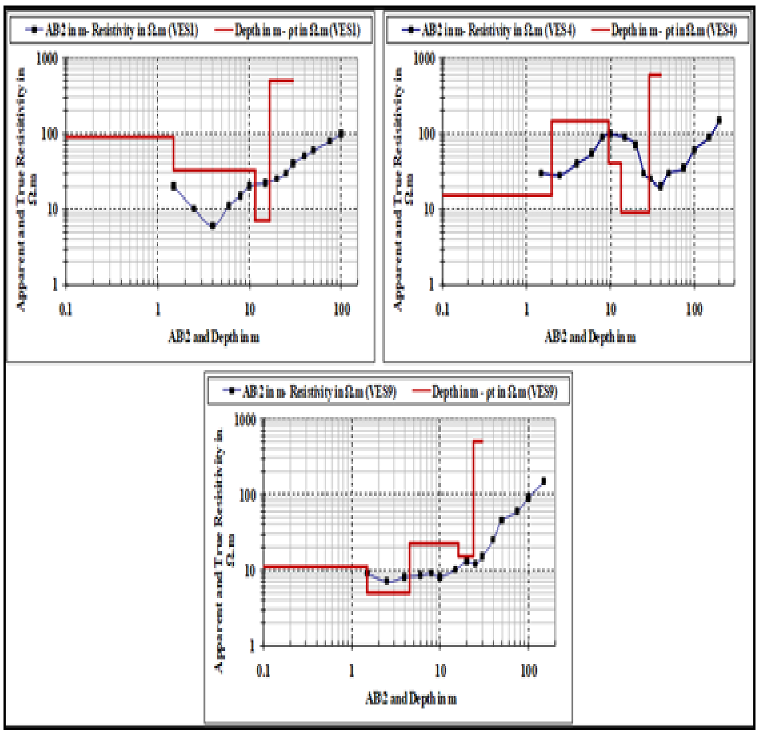


*Fig.6: Measured and interpreted data of VESs No. 1, 4 & 9.*

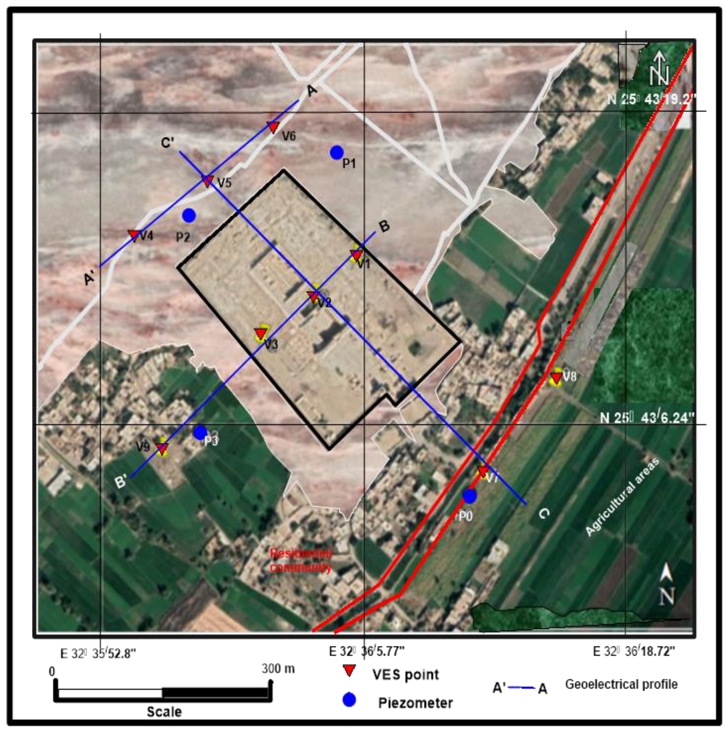


*Fig.7: The Locations of both the VESes and Geoelectrical Cross-sections of the Study Area.*

**Table 1:** Results of interpretation of data for the Temple part of Habu –Luxor area.

| VES .No | P1 | P2 | P3 | P4 | P5 | P6 | d1 | d2 | d3 | d4 | d5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| V1 | 90 | 33 | 7 | 500 | | | 1.5 | 11.5 | 16.5 | | |
| V2 | 12 | 23 | 5 | 400 | | | 2.8 | 10.6 | 17.7 | | |
| V3 | 25 | 7 | 13 | 3 | 700 | | 1.5 | 4.5 | 12.7 | 18.5 | |
| V4 | 15 | 150 | 40 | 9 | 600 | | 2.1 | 9.5 | 13.5 | 29 | |
| V5 | 25 | 60 | 150 | 6 | 800 | | 1.4 | 8.6 | 18.2 | 41 | |
| V6 | 11 | 23 | 83 | 5 | 500 | | 1 | 8 | 23.7 | 43.6 | |
| V7 | 12 | 8 | 15 | 3 | 300 | | 0.7 | 1.5 | 7.1 | 18.2 | 38.3 |
| V8 | 12 | 25 | 3 | 45 | 500 | | 2 | 9 | 25 | 45 | |
| V9 | 11 | 5 | 22 | 15 | 500 | | 1.5 | 4.5 | 15.9 | 24.1 | |

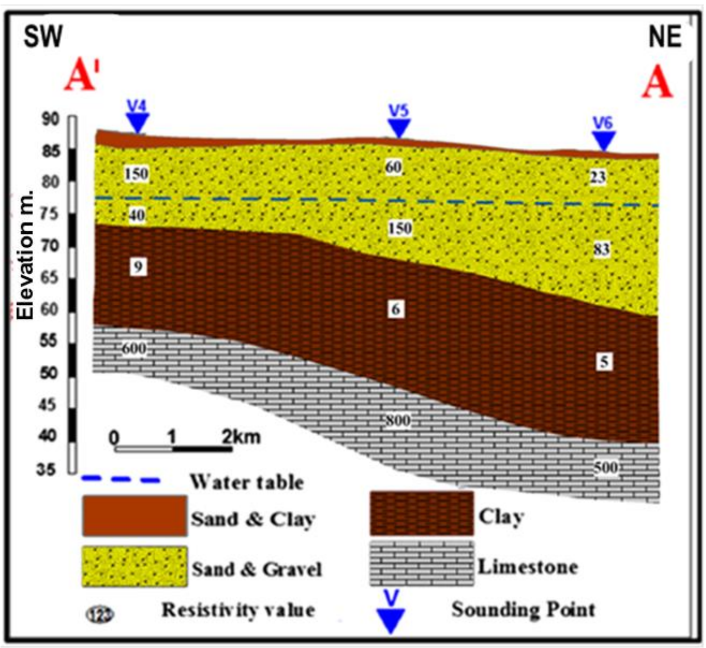


*Fig.8: Geoelectrical cross section A'A.*

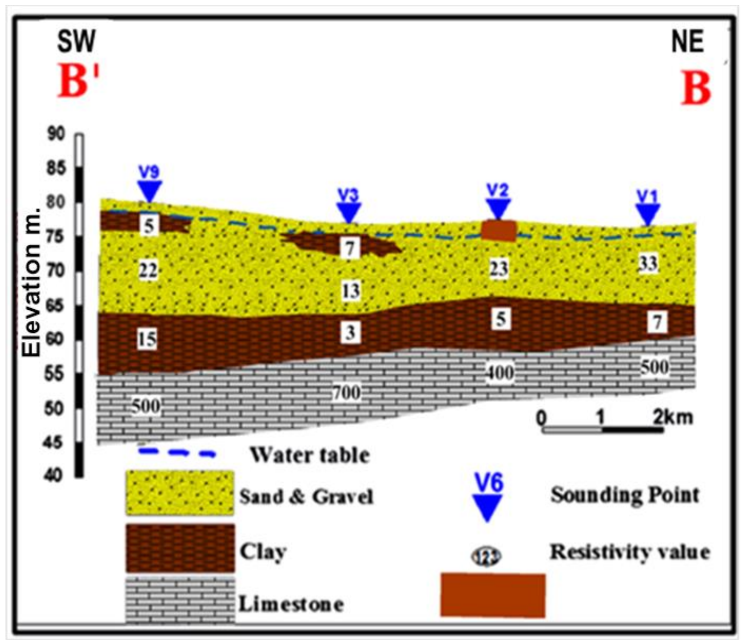


*Fig.9: Geoelectrical cross section B'B.*

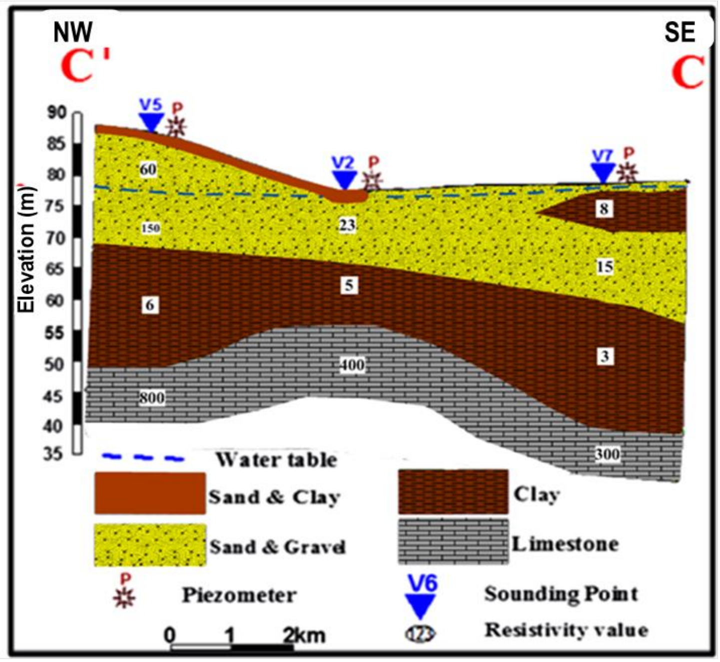


*Fig.10: Geoelectrical cross section C'C.*

## 5. Discussion of the results

In the study area, outside the temple part, the geoelectric cross-sections reveal that, the surface unit consists of an agricultural soil, irrigated from the surface run-off water, through the immersion process. This immersed water percolates the surface sandy layer and saturates its loose sediments, causing deterioration for Medinet Habu archaeological monuments.

The second geoelectric layer represents the main Quaternary aquifer of the sand area. The water content of this layer is sourced from the downward surface irrigated water of the first layer, as well as from the intensive flash flooding, causing flash flood hazard for Medinet Habu archaeological monuments.

The third geoelectric layer represents the subsurface secondary aquifer of the Pliocene-Pleistocene section of low to medium salinity. Pressure difference between the tight fourth layer and the overlaying open layers, causes upward capillary movement of the implied salty water. Linear structural elements, in the form of faults, play a prominent role for transferring the subsurface groundwater upwardly and the surface water downwardly toward the second geoelectric layer, added to the role of intergranular pore spaces of the sandy layers, causing deterioration for Medinet Habu archaeological monuments. These groundwater aquifers of the three higher layers (principally that of the third layer) may effect on the underlying limestone of the fourth layer, due to the presence of faults and fractures and causing instability for the overlying (third, second and first) layers, consequently initiating collapse for Medinet Habu archaeological monuments.

The morphometric pattern of drainage basins on the western plateau (Fig 4) reflects the possibility of the sudden flooding of rainwater from these basins, which is considered the greatest threat in these areas. Incidents of heavy rains have been noted from ancient times in the Theban Mountains, but these incidents are not useful

During the flash flooding, as that fall in 1994, several tombs in the Valley of the Kings were filled with water or the contained chambers, that are encumbered with the flooding debris. The flash flooding causes the hydraulic power, which led to the bedrock fragmentations and the transportation of these fragments toward the low lands. Measure, the outlets of drainage basins are located near the Temple of Medinet Habu and the Tombs of Queens, so they will affect directly on them by the runoff water, which reaches these drainage basins.

In the Nile River, the water levels are changed during the year from about 6 m, over the course, due to the high flood to low water and during the season of flooding. Fields are normally covered with irrigated water for 40 to 60 days, then the excess of water is discharged, with the excess salts into the river. After the High Dam building, the head of groundwater was increased, due to the increase in surface water delivering, causing irrigation water by immersion in fields and the lack of suitable drainage networks.

Due to the use of perennial irrigation, where more water is applied to the fields by these irrigations, when basin irrigations were employed, inadequate domestic sewers and agricultural drainage systems in Luxor are occurred. So, the inevitable result is that, the saturation of salty water in groundwater is becoming increased. Also, the capillary is increasing with decreasing the grain size and is rising in soils. Silt and clay soil, in homogeneous fine-grained deposits, cause extensive rise in capillary. So, due to the low precipitation and high evaporation during the major part of the year, the capillary zone normally reaches the ground surface and causes continuous transportation of salts through the upward direction in rock strata, which located above the capillary zone and reduces the strength of stone material, as the cement is partly removed. Therefore, swelling and shrinkage of salts can cause a crush of the stone matrix and the surface rock deteriorates (Fig.11). As a result of the previous reasons, the water table is rising and reaches to higher rates, causing a degree in the present deterioration of the archaeological sites, as shown from the report of the Archeological Authority about Memnon Temple, which is suffering from ground water effects.

*Fig. 11: The archaeological deteriorations in Medinet Habu, as a result of the impact of environmental risks (Elfadaly et al., 2018).*

## 5. Conclusions

Nine Vertical Electrical Soundings (VESs) of Schlumberger configuration were carried out, to delineate the subsurface geoelectric layers along three profiles crossing the study area and to realize the subsurface geologic structures and the effect of groundwater seepage on Habu Temple standing behind the hydrogeological conditions of the study area. Interpretation of these VESs were carried out, using the IPI2WIN (2005) program, for calculating the final true resistivities and thicknesses for all the subsurface layers. This interpretation showed that, the subsurface sequence in the study area can be divided into four geoelectrical layers. In addition, the agricultural activities, urbanization, flash flooding and linear faulting cause the rising of groundwater level, capillary effects and salt content in the groundwater and rock material, thus the deterioration of archaeological sites occurs intermittently.

Accordingly, to protect the site of Medinet Habu temple, from the future damage and deteriorations, some recommendations should be taken into consideration, as follows:

1- Management of flooding in the study area, through routes adapted away from the archaeological monuments, should be taken in considerations, to avoid the runoff and flooding hazards.

2- Integrated groundwater management, by the sharing and cooperation of the different water users should be considered, to avoid raising the groundwater levels toward and around the archaeological sites.

3- Drip irrigation systems and sprinkler are the best systems to improve the farm irrigation water in the agricultural fields at the vicinity of the study area.

4- Suitable crops, which need too little quantity of water, should be selected, which bear the salinity, to reduce the demand for irrigation water and to avoid the groundwater level rising.

5- It should re-locate the houses, that are in contact or near to the sites of archaeology to other new far places, to avoid the effects of seepage septic tanks and other domestic supplies, which cause local groundwater pollutions.

6- An engineering system, such as cutoff walls filled with plastic concrete or sheet piles walls, can be used as effective methods for groundwater lowering around the archaeological sites, especially in the parts of water supply toward the southwestern direction of the agricultural area, and also the water supply to the northwest from the Rizaiya area, toward the temple site. Also, a system of horizontal drains should be used at the intended final groundwater level and pumped out of the site to the nearest canal drain.

## Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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