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Impacts of Human Activities on Archeological Sites in Southern Egypt Using Remote Sensing and Field Data

ABSTRACT

The famous archaeological sites of Egypt are potentially affected due to human activities that constitute the main threats through rising of groundwater level as a result of seepage of drainage and sewage water, despite of the arid and hyper arid conditions. This area witnessed several changes during the last four decades, particuarly loss of agricultural/arable lands to residential and commercial development. The characterization and evolution of human activities were examined and discussed based on spatial and temporal analysis and interpretation of remote sensing data and field survey. Multi-temporal analysis using Principal Component Analysis (PCA), classification and Normalized difference vegetation index (NDVI) techniques were applied to a series of satellite images. Increasing population and the lack of reticulated wastewater systems allowed recharging and pollution of groundwater in the study area. Results of the chemical analysis of the collected groundwater samples indicate that sodium chloride and sodium sulphate are the two most common destructive salts in the groundwater. Such salts were observed in the deteriorated monuments of the studied temples and foundations. The dewatering processes help in preserving the monuments from deterioration by reducing the groundwater level from 73 to 71.30 and from 73 to about 71 at Karnak and Luxor temples, respectively.

Key words: *groundwater; multi-temporal analysis; archaeological site; deterioration; remote sensing; dewatering; Egypt*

Fathy Abdalla[1]
Karem Moubark[2*]
Mohamed Abdelkareem[3]

[1] Deanship of Scientific Research, King Saud University, Saudi Arabia; and Geology Department, Faculty of Science, South Valley University, Egypt
[2] Geology Department, Faculty of Science, South Valley University, Egypt
[3] Geology Department, Faculty of Science, South Valley University, Egypt; and Center for remote sensing, Boston University, USA

*Corresponding author:
k_moubark@yahoo.com

INTRODUCTION

Egypt has a number of archaeological sites. The most significant of which is of Pharonic cultures that are mainly located in southern Egypt such as the Luxor, Aswan and Qena governorates (**Figure 1a**). Luxor and Karnak temples represent the most important Pharaonic temples in the east bank of Luxor, the old capital of Egypt (1567-1085 BC). The Hathour temple in Dandara village is located about 10 km south-west of Qena City on the west bank of the Nile River (**Figure 1b**). Deterioration of these historical sites is the result of human activities through rising of groundwater level, where water can easily penetrate and remain into the building stone. This causes a destructive influence due to the absorption and high rates of evaporation that causes cracks in the monuments structure (*Moubark 2013*).

Remote sensing technique provided significant information on land-use/cover changes in space and time. Such technique is effective in managing degradation level of vegetated areas and wetlands, rate of urbanization, intensity of agricultural activities, and other human-induced changes (*Yüksel et al. 2008*). Integrated remote sensing data and field survey through Geographic Information System (GIS) analysis is an accurate and cost-effective approach for mapping land use/cover maps that are important in understanding rate and change over space and time (*Ahmed and Graham 2014; Moubark 2013*). Landsat images (30 m spatial resolution) have been effectively applied in various fields such as geology, agriculture, urban planning, mapping natural resources, and change detection approaches. In addition to Landsat images, the Advanced Spaceborne Thermal Emission and Reflection (ASTER) images (15 m spatial resolution) can provide useful information in mapping and classification procedures for vegetation and residential rate as a result of its moderate spatial and spectral resolution. Several approaches were applied to detect changes in space and time such as image classifications and transformations. The PCA technique has been successfully employed by many authors (*Byrne et al. 1980; Ingebristen and Lyon 1985; Fung and Le Drew 1987*).

The present study is located along the Nile Valley between Qena and Luxor governorates (**Figure 1a**). It is characterized by a rapid and continuous increase in illegal urbanization along the old fertile land of the Nile

Valley. Moreover, it experienced major development of the desert fringes that surrounds the Nile Valley. Noticeably, urbanization and agriculture in this area was changed significantly since erecting the High Dam in Aswan, south Egypt (1968). Such development in the Nile Valley threatens the archeological sites resulting of the rise of groundwater level (*Ahmed and Graham 2014*), and the seepage of drainage and sewage water (*Abdalla et al. 2008*). Therefore, mapping land use/cover changes specially urbanization and agricultural is significant in understanding the deterioration problems in the most famous and the most affected archaeological sites (e.g., Dandara, Luxor and Karnak temples) in southern Egypt. Monitoring of changes in land-cover/land use would help in control the monuments deterioration in the study area due to rising of the groundwater level. Three areas were selected as a case study sites representing the most important temples in Egypt and of high priority regions for protection from deterioration due rising of groundwater. To achieve these tasks, several approaches were carried out including image transformation, classifications, and field investigations in the present study.

The study aimed to analyze the role of anthropogenic activities through mapping land use/cover changes around temples area in southern Egypt from 1984 to 2015, and its adverse impacts in the rising groundwater level. This objective achieved by using remote sensing data and GIS techniques. Field observations and investigations were carried out to measure groundwater level, collect groundwater samples and to investigate the dewatering system in the temple areas.

Geologic and hydrogeologic setting

The study area extends along the Nile Valley that mainly consists of fertile lands from Luxor to Qena towns along what is known Qena Bend. In this area, the Nile valley was outlined by precipitous plateau that topped by massive limestone (**Figure 1b**). Several geomorphic features mainly of sedimentary origin can be recognized in the surrounding area (*Said 1962*) are the alluvial plains of the Nile, the calcareous structure plateau, and the desert hydrographic basins (**Figure 1 b**).

From the hydrogeological point of view, the prevailing climate in this area (**Figure 1a**) is most likely arid to hyper-arid with short rainfall showers from time to time (*Abdelkareem and El-Baz 2015 a*). Precipitation varies from 0.00 to 1.68 mm d^{-1} (NASA Tropical Rainfall Measuring Mission [TRMM] data) (**Figure 1a**). This condition resulted in a dry hydrograph of the surrounding valleys that contributed no sediments to the river. The lowest temperature of the year was recorded in January (coldest month) with average maximum value of 23.05°C and the highest temperature was in June (hottest month)

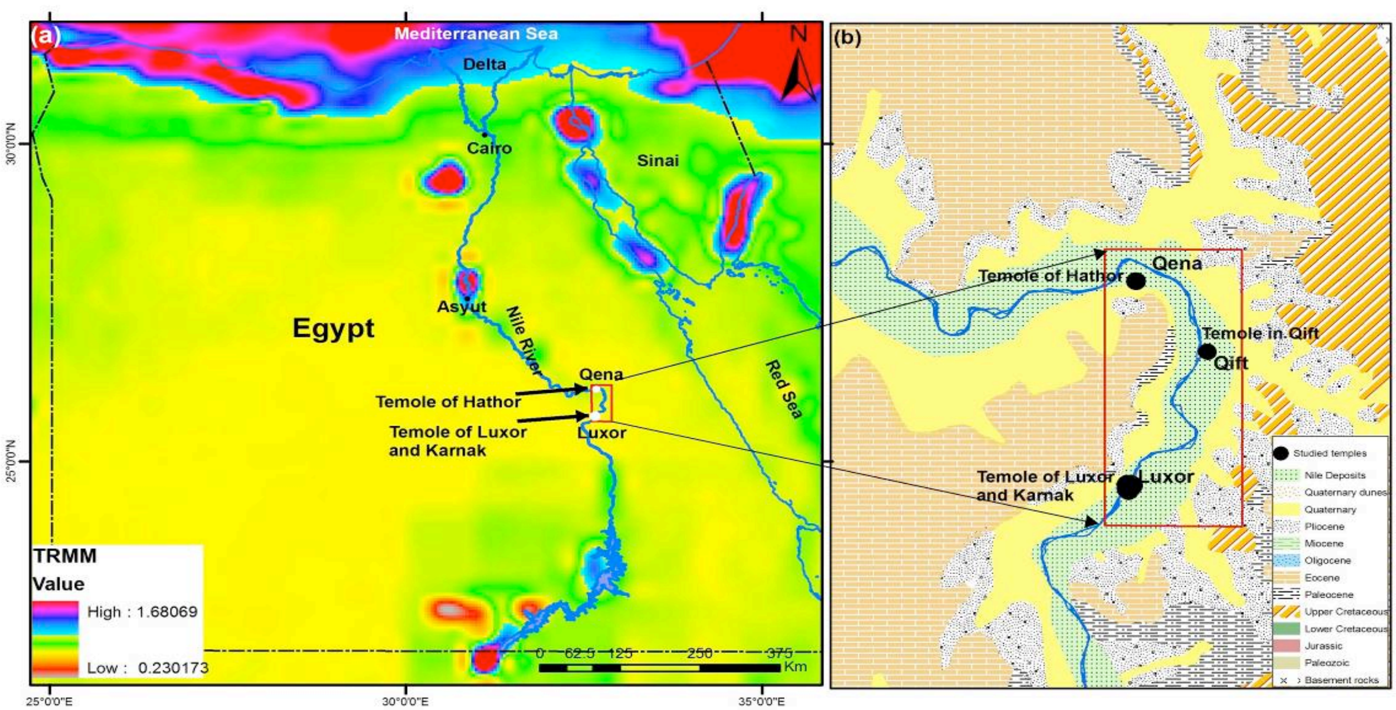

Figure 1. Interpolated Tropical Rainfall Measuring Mission (TRMM) data covering Egypt during 1998 to 2012, showing the variations in rainfall. The higher precipitation rate is about 1.68 mm d^{-1}; however, some areas record no precipitation 0 mm d^{-1}. The temples of Hathor, Luxor and Karnak marked in black; (b) Geologic map of the present study after EGSM (1981).

with average maximum value of 41.12°C. Rainfalls are rare, however, randomly rainfall storms sometimes occur. The mean annual value of rainfall over the area is less than 5 mm yr^{-1}. The annual mean value of wind speed ranged between 4.06 m s^{-1} at Luxor and 1.80 m s^{-1} at Qena. The surface water system in the study area includes the Nile River and small irrigation canals and drains. The Quaternary water-bearing sands and gravels represent the main groundwater aquifer in the study area.

The Quaternary aquifer extends in the studied areas along the Nile River. It is composed of graded sand and gravel with some intercalated clay lenses of Pleistocene age. Its thickness varies from 95 m to about 5 m near the fringes of the Nile Valley. The aquifer becomes semi-confined where an upper silty clay layer (Holocene age) with an average thickness of 13 m confines the aquifer adjacent to the River Nile. This capped silty clay layer terminates near the fringes of the Nile River (*Abd El-Bassier 1997; Abdalla et al. 2009; Moubark 2013*). The aquifer mainly recharges from irrigated water where several canals such as El Kelabia, Asfun, and their tributaries inflow from Nile River. Lateral flow occurs from the River Nile to the aquifer in the upstream parts of Esna and Naga Hamadi barrages that contributed in rising of the groundwater table. While the main discharge is into the Nile River, outflow across external boundaries, capillary upward flow from shallow water table due to evapo-transpiration, groundwater pumping from wells for irrigations and domestic purposes especially in new reclamation areas and dewatering projects.

DATA AND METHODS

Remote sensing data

Images from Landsat, ASTER, and ASTER Global Digital Elevation Model (GDEM) were collected. The image pre-processing, classifications, PCA, and NDVI were carried out using the ENVI 5 software. ArcGIS software packages (e.g., ArcGIS 9.3.1) offer a number of useful tools for working with spatial data (e.g., Interpolation, 3D visualization, contouring and classification) (*Abdelkareem and El-Baz 2015 b*). The image processing was performed in subsequent stages to find optimum results in order to map land use/cover and calculate statistics.

Landsat images archive is accessed from the Global Land Cover Facility and United States Geological Services (USGS) websites were used for image processing and transformation. Six bands 1–5 and 7 (30-m resolution) were used. The false color composite 7, 4, 2 in R, G, and B, respectively, (Landsat TM 5) and 7, 5, 2 (R,G, B) (Landsat 8) were used to discriminate different classes. Landsat images of 1984 (Landsat TM-5; 1984-09-13), acquired from Global Land Cover Facility website. The image of 2015 (Landsat-8 satellite image; 175_042; 2015-09-19) was used in the present study. Such images were used to detect changes in human activities over times against the old Nile Valley fertile lands. Land- use maps of the study area through the period from 1984 to 2015 were extracted using image classification, PCA, and NDVI based on the used remotely sensed data and field observations. Subset image were used to characterize the land use/cover features covering the study area (**Figure 1**).

ASTER is an instrument sensor system aboard the satellite Terra launched on December 18, 1999. Aster Level 1b (L1b) processed data are available in the USGS website (*Abdelkareem and El-Baz 2015 b*). Subset of two scenes (2010-03-30) covering the study area was processed using ENVI v. 5. Visible/Near-Infrared (VNIR) bands of 15 m spatial resolution were used in classification and band transformation techniques. Land use/cover extracted using ASTER image including different classes based on variations in spectral properties. The residential and agricultural activities and their impact on human activities and sustainable development were analyzed.

Band ratios were used to enhance the spectral differences between bands and to reduce the topographic effects. Dividing one spectral band by the other produces an image that provides relative band intensities. Using ASTER data, the Normalized Difference Vegetation Index (NDVI) = (Band 3-Band 2)/(Band 3+Band 2) was applied; where Band 3 is near infrared and Band 2 was visible red reflectance in order to map vegetation in the present study (*Crippen 1990*).

Principal Component Analysis (PCA) technique is a mathematical technique that commonly used in image processing and change detection analysis that transforms a number of correlated spectral bands into a smaller number of uncorrelated spectral bands known as principal components (*Fung and Le Drew 1987*). The statistic factors were analyzed to define which PC image can be used to highlight the target class based on the eigenvectors of selected bands. The first component contains the greatest variances that decrease through the second PC and third etc. In this paper, we collect the multispectral components from each individual year (using bands 1,2,3 for Landsat-5 (1984); and 2,3,4 of Landsat 8 [2015]) prior to a second principal component analysis for multi-temporal change detection (e.g., Fung and Le Drew 1987). Such analysis collects the first and second components of each individual year before the multi-temporal PCA using images of years 1984 and 2015.

The unsupervised classification was used to obtain a classified image representing the main land cover units based on the spectral characteristics. This helped in preparing land use and in change detection maps to understand the relationship between the deterioration effects and the surrounding human activities. Unsupervised K-Means clustering used in land use/cover because it was both relativelye easy to calculate and useful to apply.

Visualization was done by preparing 3-D perspective preview (**Figure 2**), overlaying various data such as contours, field samples, temple area on the interpolated groundwater data (**Figures 7** and **8**).

Hydrogeological field data

To understand the groundwater conditions in the study sites groundwater level, twelve groundwater samples (eight from Luxor and four from Dandara area) were in and around the temples area to determine the most common destructive salts in the groundwater, dewatering system in Karnak and Luxor temples. The physical properties e.g., electric conductivity (EC), temperature (T), pH and salinity were measured in the study area by using multi-parameter portable meter (Hach test kits). Laboratory work included chemical analysis for major anions (HCO_3-, SO_4^{2-}, Cl-) and major cations (Ca_2+, Mg_2+, Na+, K+) and was carried out at the Environmental Research Laboratory in the Faculty of Science, South Valley University.

RESULTS AND DISCUSSION

Remote sensing

ASTER GDEM analysis. The ASTER GDEM and 3D perspective view (**Figure 2 and 3a**) indicate that the Nile Valley broadens and the flat strips of cultivable lands, extending between the river and the cliffs that bound its valley on either side, gradually increase in width northward. The area was outlined by an elevated plateau on both sides of the Nile. The elevation reaches its peak in the northwest and declined east, west and southward. The selected temples located in a low lies in the young alluvial plains of the Nile in Luxor and Dandara area. Near Luxor, the river made a great bend bounded by elevated limestone cliffs.

The topographic variations (**Figures 2 and 3a**) of study area have a critical role in deterioration of archaeological sites. Generally, the studied temples were located on the alluvial plains that slope commonly to the north and west that represented by the cultivated younger plain occupyingthe central part of the Nile Valley and older reclaimed plain at the desert fringes. Topography controls the direction of seeping water through the underground. The studied temples stand in a lower elevation comparing with its surrounding urbanized and agricultural lands especially the Karnak and Dandara (Hathour) temples (**Figure 3**). In case of Dandara (Hathour) (**Figure 3b**), the temple stands 1.6 km from the Nile and at about 70 m (a.s.l), however, the surroundings elevation rises up to 95 m (a.s.l). Such topographic position facilitates the infiltration of groundwater into the temple area.However, the entrance of Karnak and Luxor temples is located about 70 m and 50 m from the Nile River, respectively (**Figure 3d**).

Land-use/cover classifications

Using VNIR of ASTER data (**Figure 4a**), the supervised classifications successfully displayed the land-use/cover classes (**Figure 4b**). This expert classification provided valuable results in terms of distinguishing urban (~ 9.053%), vegetated lands (~ 30.135%; area: 537.981.300 m^2), non-vegetated lands (~ 2.386%), water bodies (~ 2.270%), and bare lands (56.157%). The roads in the study area could not be easily discriminated during the classification operation due to the similar reflectance values with other raster cells such as the non-vegetated lands. Moreover, distinguishing non-vegetated arable land from water bodies and urban zone was difficult, because of the close spectral characteristics between the two.

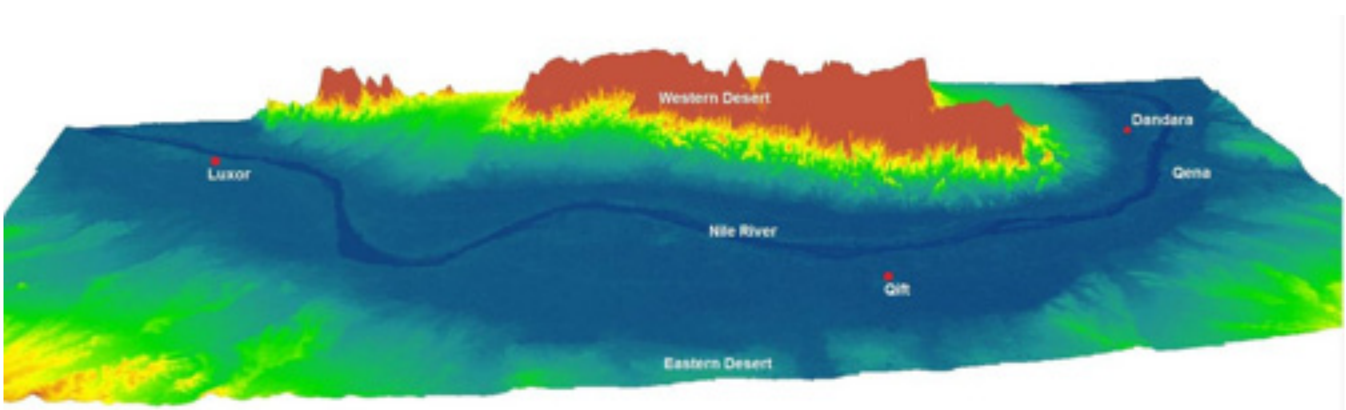

Figure 2. 3-D perspective view of the study area showing the studied temples in red points.

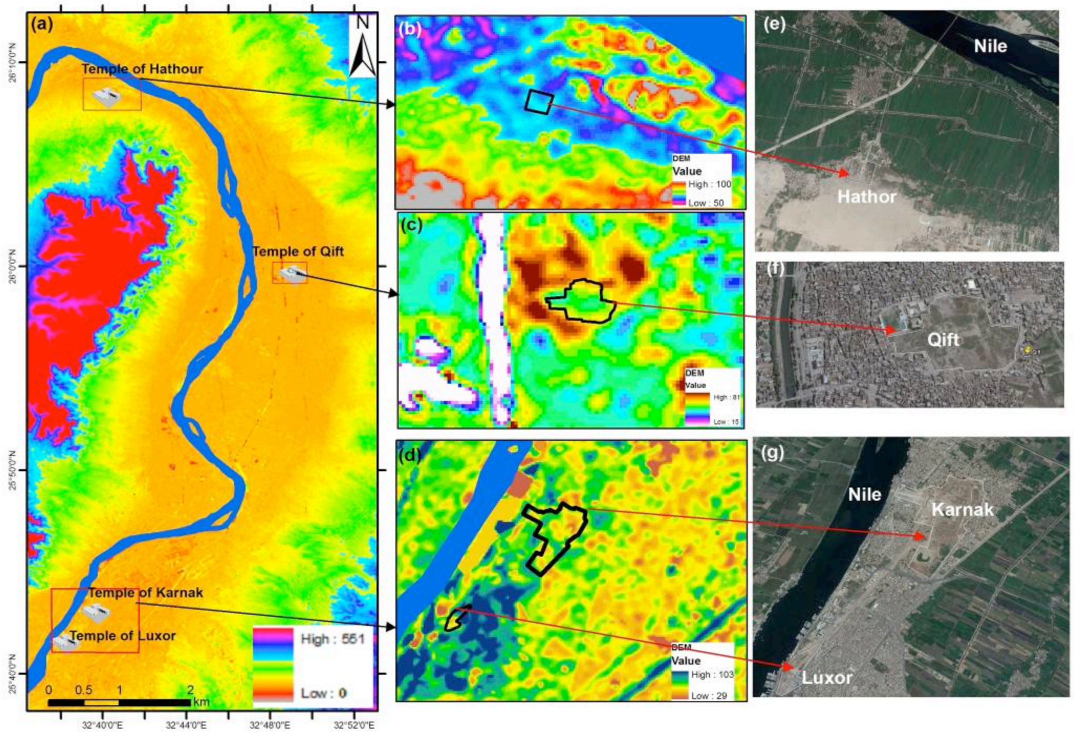

Figure 3. (a) ASTER-GDEM covering the study area (b, c, d) Subsets of ASTER DEM of Dandara, Qift, and Luxor-Karnak, respectively. (e, f, g) close-up view of the studied areas from Google earth.

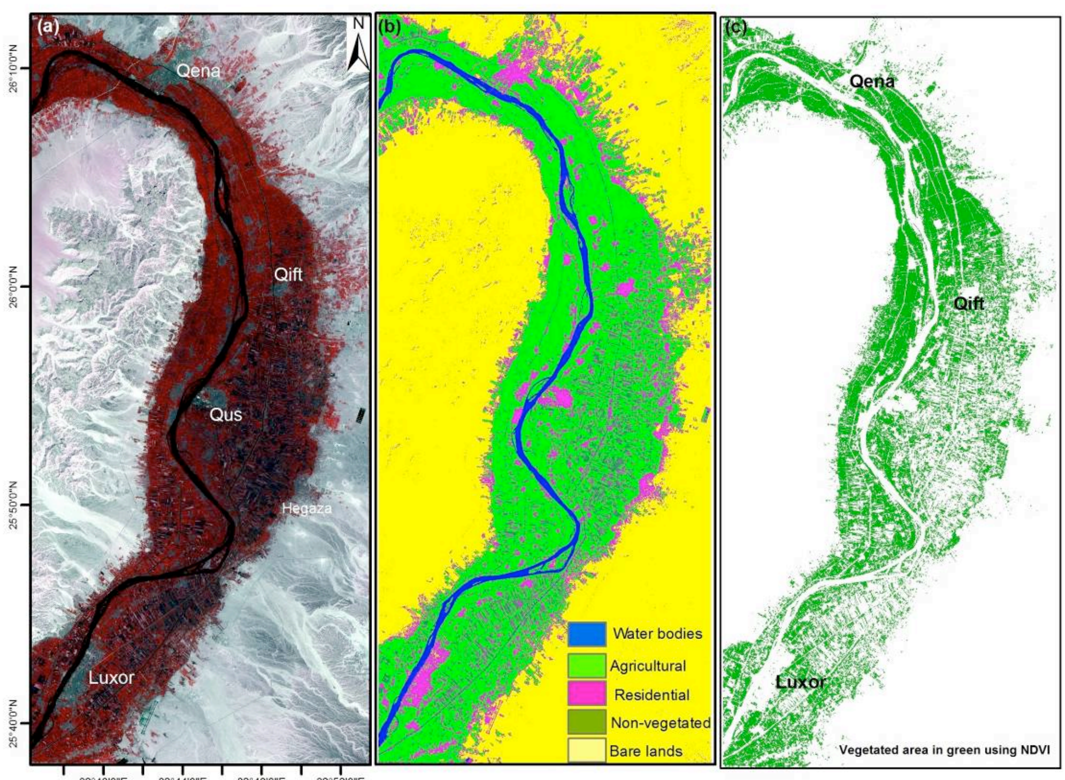

Figure 4. ASTER data covering the study area; (a) ASTER VNIR bands 3,1,2 in R, G, and B respectively; (b) Supervised classifications of the present study using ASTER data; (c) vegetated area in green using NDVI transformation.

Based on the extracted vegetated areas using NDVI (29.836%) (Area: 532,653,525 m^2), there was a reasonable agreement with those extracted from the classification method with difference ~0.30% (**Figure 4c**). In agricultural areas, some problems arise from variations in soil moisture, growing seasons, crop planting, harvesting, irrigated, non vegetated areas and mixed pixels. The overall accuracy is 88.7353% and Kappa Coefficient = 0.8490.

Land-use/cover change detection

Using Principal Component Analysis. Applying PCA to estimate the major changes in land-use that reflects the human activities were estimated for two years of September 1984 and September 2015 (**Figure 5**). The selected PC1 and PC2 of each individual year processes for a second PCA (**Table 1**). The results of the first PC1 of the second PCA do not contain contrast between the condensed components. However, display strong positive correlation between PC1 (0.66846) of year 2015, however, no correlations with PC2 of both years 1984 (-0.0003) and 2015 (0.00432) were noted(**Table 1**). The water bodies displayed higher reflectance rather than the vegetated and residential areas. The second component (PC2) displays an integrated average of PC2 of both years, which was correlated with NIR data. However, it displayed no correlation with the first component (visible bands) from both years. Therefore, vegetated areas look brighter against urban and water bodies. The dark pixels in PC3 revealed that such areas had more green vegetation in 1984 than 2015 as the component strongly loaded from the second component (NIR) of year 2015 but negative in year 1984. The fourth component revealed the detected changes as display in brighter pixels between the two dates. It displayed positive correlation with the first components of years 1984 and 2015. Such result more closely matched with that of the extracted component in **Table 1** (PC6). The brighter pixels displayed the detected change between 1984 and 2015. Most of these were occurring in the east and west of the Nile Valley due to the reclamation of the bare lands for agriculture and urbanization (**Figure 5**).

Using unsupervised classifications. The unsupervised classification successfully clustered four components that include the agricultural, residential, water bodies and bare lands. Land reclamation dominated over bare lands along the Nile Valley. Urbanization activities versus the arable lands in most towns and cities e.g., Luxor, Qena, Qift, and Qus were dominated. In general, urbanization activity increased since 1984 versus bare and agricultural lands, and vegetation increased against bare lands as made evident by reclamation. This study found some difficulties in discriminating the agricultural non vegetated lands (2015). This was due to the close reflectance with residential areas, therefore mixed pixels of residential and agricultural lands

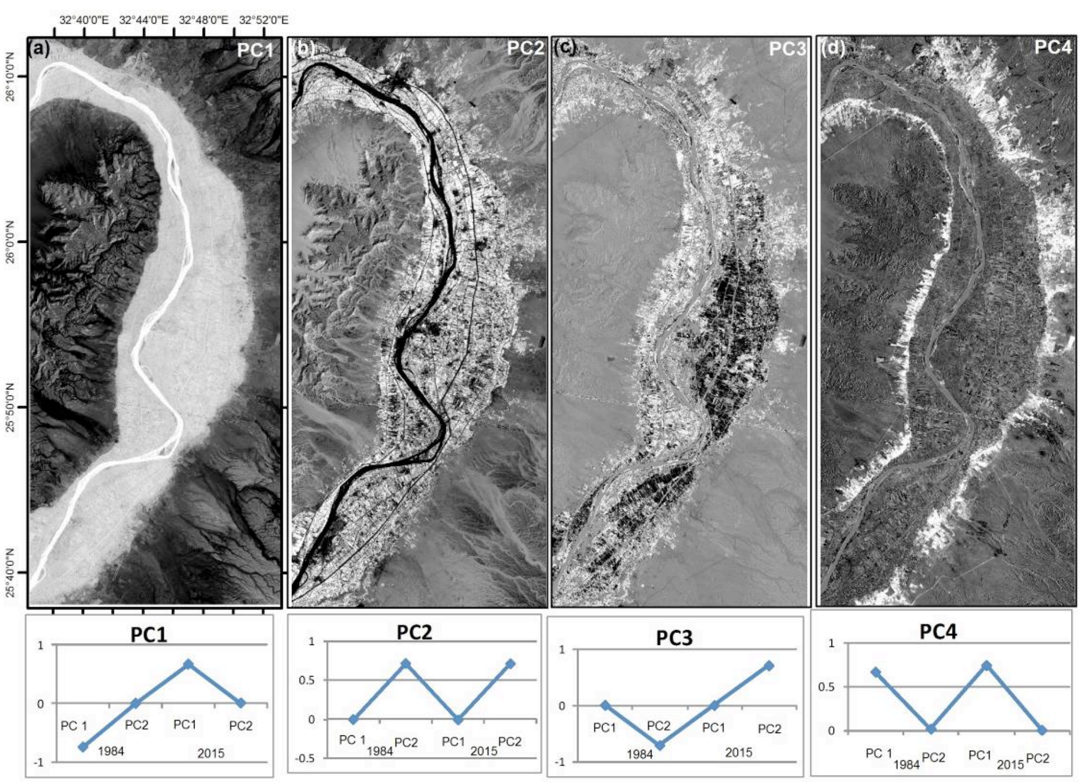

Figure 5. Multitemporal second Principal Components PC1, PC2, PC3, and PC4 from selected PC1, and PC2 of transformed multispectral data of each individual year (e.g., 1984 and 2015).

Table 1. Principal component of selected PC1, PC2 of years 84, and 2015.

	PC1 84	PC2 84	PC1 2015	PC2 2015	Eigenvalue
Means	146.730985	135.1008	112.3453	130.1019	
StDev	76.976705	45.44386	69.84979	45.3079	
PC1	-0.743737	-0.0003	0.66846	0.00432	69.18747
PC2	-0.005606	0.70997	-0.0104	0.70414	18.94867
PC3	0.008471	-0.7041	0.0045	0.71005	8.648642
PC4	0.668395	0.01452	0.74366	0.00171	3.215214

were common in 2015. Changes in vegetation about 3% however residential increased about 5% includes urban, industrial, commercials and constructed road networks. This classifications displayed densely increasing urbanization around villages, and towns. Though the increase in building was not aligned to the approved plan and many of these constructions ware illegal. There were notable differences between the two dated images, which clearly detected changes in urban and agricultural areas (**Figure 6**).

Change on land-use/cover. Multi-temporal analysis using multispectral data detected major changes in land-use/cover recorded since 1984 based on remotely sensed data and field observations. Land- use/cover maps show that the study area has three main distinct zones. These zones were: agricultural areas, residential and industrial/commercial along with some open areas, and bare lands (desert) along the Nile Valley in eastern and western parts of the study area.

Agricultural areas have changed dramatically from year 1984 to year 2015 versus the bare lands (**Table 2**). This change has both negative and positive impacts. The positive impact recorded in increasing of the cultivated lands versus the bare lands that help in the development of south Egypt. However, the negative impacts recorded on using traditional methods of irrigation (e.g., flood irrigation), and excessive use of fertilizers and pesticides. Increase in cultivated lands would require more water for irrigation. The classic mode of irrigation recharged the shallow aquifer because the excess in water infiltrated through the below deposits. Such infiltrated water carries pollutant, fertilizers, and other soluble salts that have significant effects on environment. In case of Dandara temple (**Figure 6**), the agricultural zone increased around the temple in 2015 rather 1984. This would mean seepage of groundwater on the surface surrounding the temple. However, the agricultural lands surroundings Luxor, Karnak and Dandara temples negatively changed versus residential areas (**Figure 6**).

The residential settlements were condensed in cities and villages. Urbanization increased through the past three decades versus bare land and arable agricultural areas. In most cities, the new residential areas have no sewer system to collect and treat the sewage. Sewage was disposed and collected into an underground sewage trenches feeding and polluting groundwater. Closeness of the residential areas to

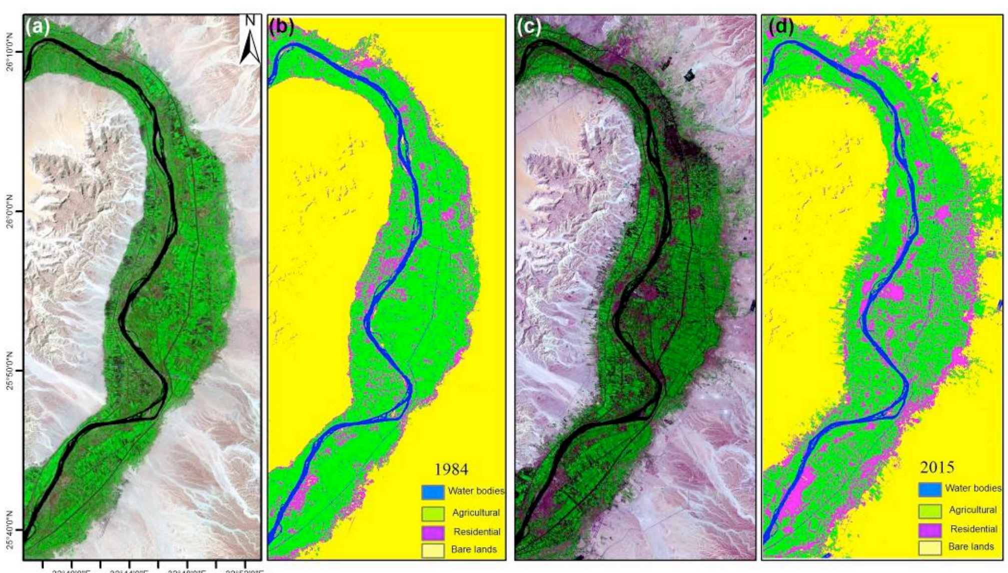

Figure 6. Land-use/cover map of the study area using Landsat data from 1984 to 2015; (a) Landsat-5 of 1984; (b) land-use/cover using Landsat-5 of 1984; (c) Landsat-8 of year 2015; (d) land-use/cover of Landsat-8 of year 2015.

Table 2. Changes over 1984 to 2015 using unsupervised classification

	1984%	1984 area acre	2015%	2015 area acre
Agricultural	26.72	117820.7658	29.862	131740.5
Water	2.831	12483.87692	2.795	12332.25
Residential	6.636	29262.25406	11.786	51996.89
Bare lands	63.813	276578.58	55.376	245087.5

the Nile complicate the problem, because water mixed with those of seepage of drainage wastewater from industrial and residential areas. Therefore, seepage on the ground surface dominated in most residential areas that affected building, monuments and archaeological sites. Most of the study area was under particular anthropogenic activities since building the High Dam. Illegal activities on agriculture and residential considered the main deteriorating factors on archaeological sites. The increases in land use/cover areas allowed the seepage of drainage water underneath the temples and facilitating the deterioration of foundations. Generally, Karnak and Luxor temples were surrounded by water bodies (The Nile and small channels), highly vegetated and urbanized area.

Hydrogeological conditions

Field observations. Field data analysis revealed that the groundwater elevation in Luxor area ranged between 71.5 to 74.5 m with an average of 73.5 m. From the field measurements of the groundwater level, it was concluded that there were two regional groundwater flow directions; the first is northward direction and the second towards the River Nile. In addition, there were local in flow directions towards Karnak, Luxor and Dandara Temples (**Figure 7**). The map shows that, groundwater level at the desert firings was higher than those at floodplain areas near the Karnak and Luxor temples indicating movement of groundwater eastwards towards temples area. Also in the southern parts of the temples area, the map showed movement of groundwater northward parallel to Nile River course. Therefore, groundwater movement in Luxor area was controlled by variation in topography of the study area as shown from the piezometric map. In case of Dandara (**Figure 7b**), the flow eastward towards the Nile River; however the area really was impacted due to the surrounding anthropogenic activities.

Twelve groundwater samples (eight from Luxor and four from Dandara area) were taken from boreholes located within and around Karnak, Luxor and Dandara temples to evaluate the most common destructive salts in the groundwater. The hydrochemical composition indicated an alkaline character of groundwater with maximum salinity 1285, 933 and 955mg l^{-1} beneath the Karnak, Luxor and Dandara temples, respectively. The distribution of major anions and cations in groundwater samples showed that chloride was the most common anion followed by suphate and bicarbonate, while sodium (Na) was the most common cations followed by magnesium, calcium and potassium. The high Na concentration may be attributed to the presence of halite in the detritus deposits within the Quaternary aquifer, increase of evaporation from the shallow water table, and high temperature in addition to the sewage and livestock wastes infiltration. The increase of chloride and suphate concentrations might be due to the increase of evaporation processes from the shallow aquifer, the heaviest application

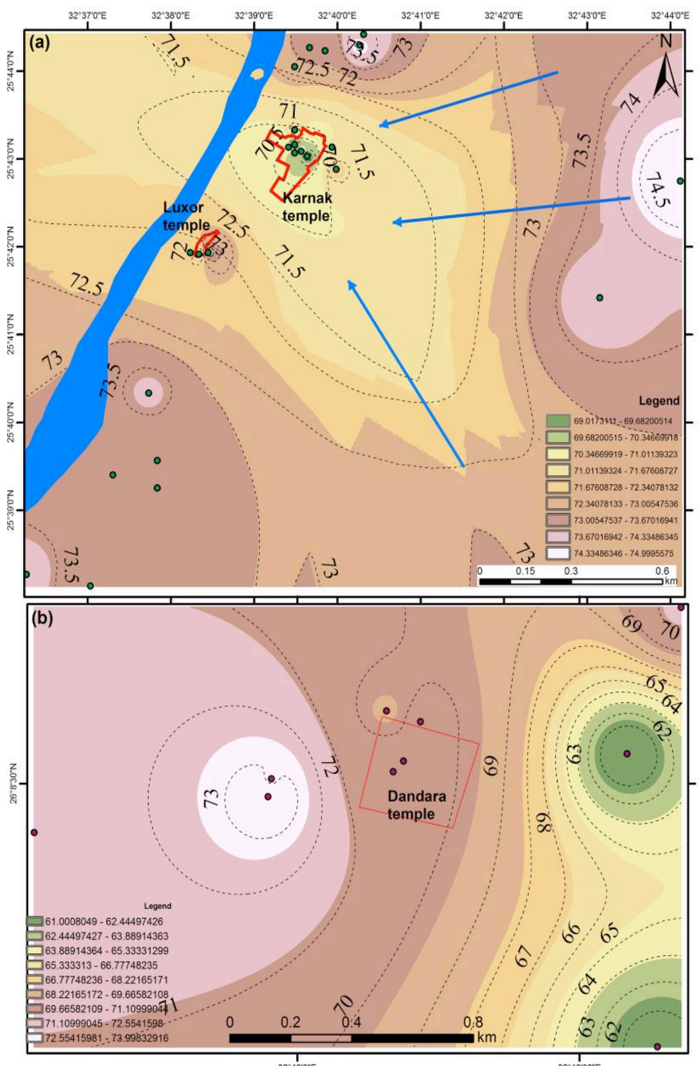

Figure 7. (a) Isopiezometric contour map of Luxor area, arrows show groundwater flow direction; (b) Isopiezometric map of Dandara area.

of fertilizer in the agricultural lands as well as sewage and wastewater discharge.

Based on the chemical analysis of the collected groundwater samples in Luxor area and analysis of the accumulated salt layer taken from Karnak and Luxor temples walls, the two most common destructive salts in the groundwater aquifer were: sodium chloride which crystallize to form the halite (NaCl) and sodium sulphate which can crystallize to form the mirabilite ($Na_2SO_4 \cdot 10H_2O$) at high humidity or the then ardite (Na_2SO_4) at low humidity (*Flatt 2002; Beck and Al-Mukhtar 2010*). The GIS maps (**Figure 8**) for Sulphate (SO_4) and chloride (Cl) distribution in Luxor and Dandara temples area showed that the concentrations increased towards the temple areas.

The abundance of corrosive ions such as Cl and SO_4 were responsible in destroying building stone of archeological foundation in the temple area. Where, crystallization of salt in pore spaces constructed a static pressure leading to the destruction of the foundation stone (**Figure 9**). Moreover, crystallization of salt of groundwater seepage by capillary action on walls led to damage of the structure.

As shown in this study, land-use change detection, was reflected in the field in several ways. The noticeable increase in the agricultural area spatially in the desert fringes led to raise the groundwater level causing the deterioration of some archeological site and houses (**Figure 9**). Furthermore, the absence of agricultural drainage system in the new reclaimed area and the intensive use of fertilizer led to further deterioration. The field investigations have showed that effects of capillary were even lower in

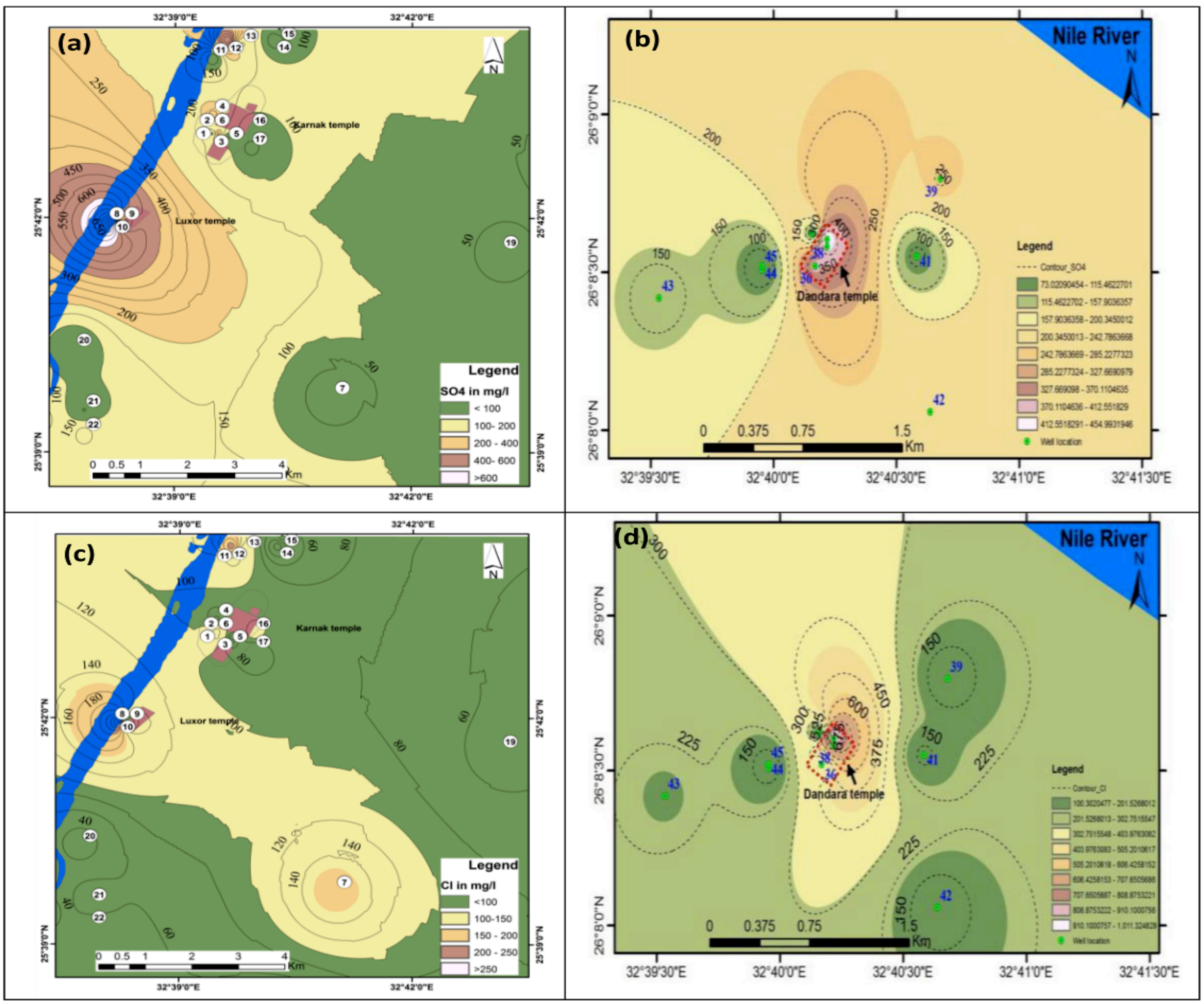

Figure 8. Map shows concentrations of sulphate and chloride in groundwater at Karnak, Luxor and Dandara temples.

Figure 9. Field photographs (a, b) seepage damage at foundation of Karnak temple; (c, d) seepage damage at foundation of Dandara temple.

Luxor temple than Karnak temple. Salt crystallization was the most significant because it potentially resulted to damage. It reacted with porous materials irrespective of their chemical composition and further developed other primary causes of decay (**Figure 9**). A solution of salts or a mixture of salts, in groundwater could be transferred by some means to the pores or fissures of the sandstone. Under drying conditions, the water evaporates and the salt deposit on the surface of sandstone, within its pores, or in both positions. A salt growth of florescence appearing in the surface is known as efflorescence. Crystallization process that occurs invisibly within the pores of sandstone is called crypto-florescence or subflorescence.

Dewatering system description. In recent years, the temples in Luxor have suffered from ancient rising groundwater that has degraded the temple structures through a variety of mechanisms (*Parsons 2008; Moubark 2013*). The Egyptian government with the help of the Swedish International Aid Agency and United States Aid Agency responded with a plan to lower groundwater levels at the Karnak and Luxor temples to prevent further damage. The plan was for a permanent drainage system to be in-stalled around each of the Karnak and Luxor temple districts. The mechanism of dewatering system was to capture water from the ground surface before reaching temple area. Permanent dewatering system was installed around each of the Karnak and Luxor temple districts at the end of 2006 and began full-time work in March 2007. The system was designed to lower the water to between 2 and 3 m below the ground surface and thereby to reduce the rate at which water would reach the temple structures. A perforated drain pipe line (5 m depth) surrounded with gravel, sand and geo textile filter captured water from near to the ground surface. A second dewatering mechanism was the deep wells that were drilled about 30 m within the aquifer to reduce the water pressure, then the collected water transport to pump station. The dewatering system around the Karnak district (**Figure 10**) was constructed within the original drain built by Chevrier in the late 1920s measureing about 4.8 km long (*Moubark 2013*). A perforated drain pipe collect the near surface water and transported to manhole each 50 m via gravity. Twelve deep well were drilled around the Karnak temple. Finally, the collected water drains into the River Nile through a pump station. A vertical deep well drained directly into the River Nile. Similar dewatering network was applied around Luxor temple but with a shorter length of 750 m. Six vertical deep wells were drilled inside Luxor

Figure 10. Dewatering system around Karnak temple.

temple and one well inside it.

The discharge rate was about 20000 m^3 d^{-1} and 10000 m^3 d^{-1} at Karnak and Luxor temples, respectively from the groundwater are pumped to the Nile. Because of the dewatering process, the groundwater level decreases from 73 m to about 71.30 masl at Karnak temple, and from 73 m to about 71 masl at Luxor temple. Consequently, this led to change of the piezometric map and groundwater flow direction of the surrounded area (**Figure 10**). This groundwater lowering process led to minimization in the capillary action on walls, which in turn led to reduce effects of damage in the temples. For a span of five years, the groundwater level has been lowered and remained stable through about 5 years as a result of the aforementioned operation. Therefore, it is successful in minimizing deterioration in the temples. Moreover, the dewatering system in Luxor temple is more successful than that of Karnak temple, based on the groundwater level measurements and the hydrochemical composition.

SUMMARY AND CONCLUSIONS

Remote sensing data can be used for mapping and to monitor changes in land-use/cover in space and time. Agriculture and residential activities changed significantly from 1984 to 2015. The agricultural areas increased as compared bare lands and residential increased. Unfortunately, it increased much more than the fertile lands of the Nile. Most of these changes under no control, or not planned resuting to a number of impacts to the surrounding environment. As noted, much of the archaeological sites in south Egypt subjected to deterioration resulting from the rising of the groundwater level. Wastewater infiltrated through the shallow aquifer that caused rising of the water table, which threatened the structure of these historical sites.

The overall results revealed that integration of remotely-sensed data, GIS and field survey was significant in understanding the impact of anthropogenic activities on destruction of the archeological sites. Moreover, it provided a design of a suitable conservation plan to control the monuments deterioration in the study area due to rising of the groundwater level.

The applied dewatering system in temples area succeeded in minimizing the deterioration in the temple walls by lowing the groundwater level from 73 to 71.30 m at Karnak temple and from 73 to 71 m at Luxor temple. Hydrochemical analyses of the collected groundwater samples revealed that ions concentrations increased towards the temple areas than the surrounding areas where sodium chloride and sodium sulphate were detected as the most common destructive salts in the groundwater.

Based on the results of the study, following were recommended to preserve the archaeological sites:

- Raised groundwater table in the study area due to increased irrigation and reduced water level variations in the Nile to be fully recognized as the fundamental problem. This can be solved in various ways such as the need to enhance or improve the irrigation systems in the study area, controlling crop types and water uses.
- Monitoring and planning the development of the residential and agricultural areas is also significant. This can be achieved through the cooperation among local authorities and agencies.
- Construct several drainage trenches surrounding the temples to redirect the flow of excess water and then

pump it into a channel.

- Monitoring of dewatering discharge rate and static water levels via piezometers to assess draw-down effects.
- Monitoring of physical parameters e.g. pH, electrical conductivity and the changes in groundwater chemistry to trace the source of recharge water as well as pollutants.
- Monitoring of deterioration effects on the types of rock weathering of the walls and columns of the temples and doing the appropriate conservation.
- Construct a sewage network in the temples area and the surroundings villages with a continuous care and detection of leakage in the drainage networks.
- Use of the appropriate stones during the restoration processes, where the crystalline test and slake durability test suggest using siliceous sandstone and avoiding the calcareous cemented sandstone.
- Installing a dewatering system to the superficial aquifer that was responsible for the problem. The extracted water may be used for agricultural purposes after required treatment. This system should be constructed along the southeastern corner of the city to control the rising water level. The system could be used to monitor level and quality of the groundwater.
- Water level in the irrigation channels should be lowered, to reduce the rate of groundwater recharge from these channels.
- The maintenance of the agricultural drains around the city should prevent water coming from the surrounding irrigated lands.
- Preparation of a consolidated plan to control and monitor the groundwater level and quality by regular measurements.

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