

1 (Article)

## 2 **Geo-Environmental Estimation of Land Use Changes** 3 **and Its Effects on Egyptian Temples at Luxor City**

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18 **Abstract:** Over the years, the Egyptian temples at Luxor city have been intensely investigated, but  
19 most of these studies just focused on the classical sides of the archaeological and historical  
20 descriptions. Many of the environmental problems are inevitable results of the unplanned urban  
21 crawling around the monuments temples. This paper aims at assessing the environmental changes  
22 around some temples of Luxor City using Remote sensing and GIS techniques. In particular, a  
23 historical database made up of Corona and Landsat TM data have been investigated along with the  
24 new acquisitions of Quickbird2 and Sentinel2. Results from our investigation highlighted rapid  
25 changes in urban and agricultural areas, which adversely affected the Egyptian monumental  
26 temples causing serious degradation phenomena. Using the information obtained from our  
27 RS&GIS based analysis, mitigation strategies have been also identified for supporting the  
28 preservation of the archaeological area.

29 **Keywords:** environmental risks; satellite data; GIS techniques; Egyptian temples  
30

### 31 **1. Introduction**

32 Recent improvements in earth observation techniques offer advanced technical characteristics  
33 which can enhance new applications including investigations addressed to cultural heritage and  
34 landscape. In particular, the most recent missions as the ESA sentinel offer for free data  
35 (systematically acquired for the entire globe) are specifically concerned with risk estimation and  
36 monitoring. Moreover, long and rich historical archives (as those available from declassified satellite  
37 data, Landsat TM, etc) provide significant past-related information that can be very useful for  
38 changing detection investigations. Both recent and archived data, jointly used, can offer an  
39 invaluable source of information for a wide variety of applications, including investigations  
40 addressed to archaeology and cultural landscapes ranging from the documentation to the  
41 enhancement, from the monitoring to the management.

42 In particular, remote sensing for archaeology has been widely applied for discovery [1-3] and  
43 monitoring [4,5] in middle East [6] and in Egypt for many application domains including discovery  
44 and documentation [7] and, more recently, also conservation and monitoring purposes [8-13].  
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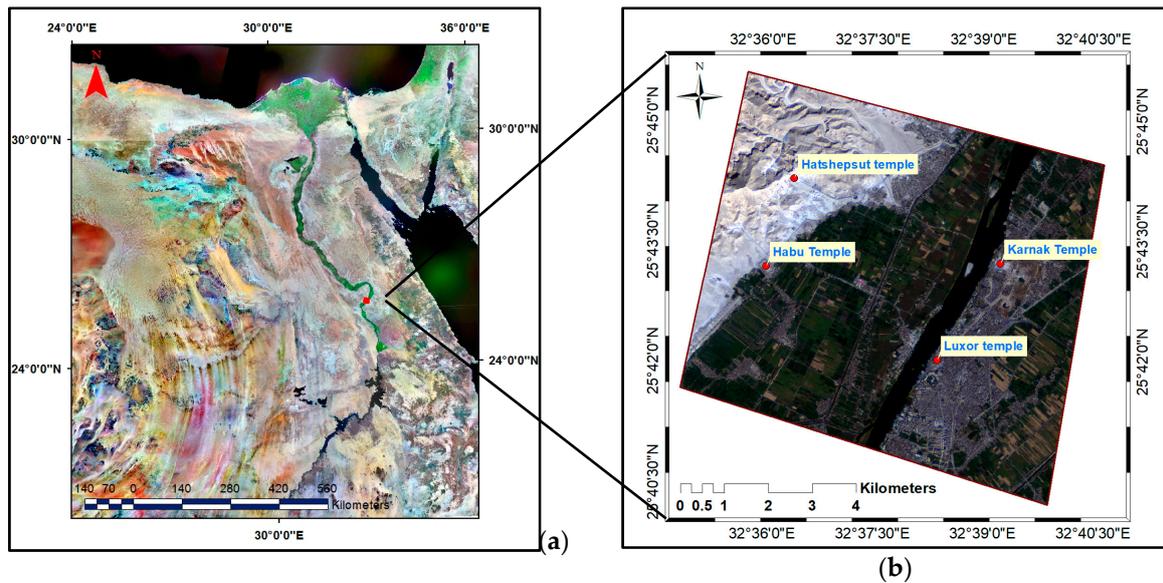
46 Conservation and protection policies to preserve cultural heritage and landscape is a pressing  
47 issue today, especially for sites and areas that significantly represent the cultural identity of a  
48 territory, population, country, and civilization. It is important to highlight that archaeological sites,  
49 cultural properties and landscape are “non-renewable resources, and they hold specific cultural  
50 values for mankind, that need to be preserved for the present and future generations”; further, it can  
51 be added that such “assets are also important economic resources; and, in view of increasing public  
52 interest, an organized approach to decision making would assure the conservation and preservation  
53 of the various values of the archaeological sites and cultural landscape, including their educational  
54 and economic potential” (UNESCO [14-15]).

55 Recently, many researchers, showed that Radar, Hyperspectral, and Multispectral satellite  
56 images can be used to enhance the status of archaeological environments in order to detect  
57 subsurface remains. Optical satellite remote sensing has played an important role in the field of  
58 archaeological studies over the last years. Reflection of crop and soil vegetation are well-known  
59 indicators of the presence of ancient buried and surface remains. Until now, new remote sensing  
60 applications have been developed in discovering, monitoring, documenting and preserving cultural  
61 resources. Typically these techniques have been exploited by means of optical multispectral sensors .  
62 On the other hand, remote sensing indicators of land and groundwater can provide useful data  
63 where practical classical methods can't provide it. Integrated remote sensing and GIS are widely  
64 used in groundwater mapping, has made them the focal point of many geo-archaeological studies,  
65 Starting from aerial photos [16-20].

66 This paper aims at assessing the current status of the temples of Luxor City using Remote  
67 sensing and GIS techniques to identify and map areas affected by uncontrolled urban expansion and  
68 changes in land use that are considered as some of the critical threats for these cultural properties  
69 [21-22] (<http://whc.unesco.org/en/soc/3597>). To quantify over the years the urban sprawling,  
70 historical multi-temporal satellite data made up by Corona, Landsat have been investigated along  
71 with the new acquisitions provided by Quikbird and Sentinel 2. Results from our multi-date and  
72 multi-sensor data analysis provided quantitative information on changes in agricultural areas as  
73 well as on the uncontrolled urban expansion, occurred around the Egyptian monumental cities.  
74 Based on the integration of ancillary information with the outputs obtained from Remote Sensing  
75 and GIS-based analysis, a mitigation strategy is also herein proposed.

## 76 1.1 Study area

77 Thebes in Luxor, situated about 900km south of Cairo around the River Nile banks [23]  
78 (Latitude: 25°41'56" N, Longitude: 32°38'31" E, Elevation above sea level: 89 m), is considered one of  
79 the largest, richest, and best-known archaeological sites in the world. The resources accruing made  
80 possible a massive building of temples all over the country mainly in the Thebes' great centre where  
81 Karnak and Luxor were developed (in the East side) along with the great complexes mortuary (in  
82 the West side) which includes the Hatshepsut and Medinet Habu [24] (Fig.1a, b).



83 **Figure 1.** Map of Egypt by Landsat7 (a) and study area by Sentinel-2 11/2016 (Composite RGB 4, 3, 2)  
 84 (b).

## 85 1.2 Luxor city temples:

### 86 1.2.1 East Luxor city temples

87 Karnak and Luxor temples are recognized to be clear examples of the development and growth  
 88 of the magnificent Egyptian temples [25]. The great temple of Karnak was dedicated to Amon, the  
 89 local god of Thebes [26]. During the New Kingdom, a new processional style on the north-south axis  
 90 was created and still today evident in the Luxor and Amun temples and in the precinct of Mut to the  
 91 south. The temples had an impressive hypostyle hall and ten massive pylons interspersed with  
 92 courtyards (the largest hypostyle hall ever built [27]). The roof is supported by 20 columns in two  
 93 rows and 32 square pillars [28] (Fig.2). The great festival hall, measuring 52 feet in depth and 144 feet  
 94 in width.

95 The design of Luxor temple clearly shows still today the attractive influence it played for its first  
 96 enormous court out of straight alignment. This space becomes a sloping parallelogram to reach the  
 97 route from Karnak temple and join it to the axis of the sanctum at Luxor temple [29]. The central  
 98 doorway gave its access to 8 columned hall, with another direction doorway in the opposite wall.  
 99 The centre of a castrum, the southern doorway of Luxor temple was blocked with an apse when the  
 100 Romans re-used it [30] (Fig.3).

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102 **Figure 2.** The main façade of Karnak temple at  
 103 east Luxor [31].

**Figure 3.** The main façade of Luxor temple at east  
 Luxor [32].

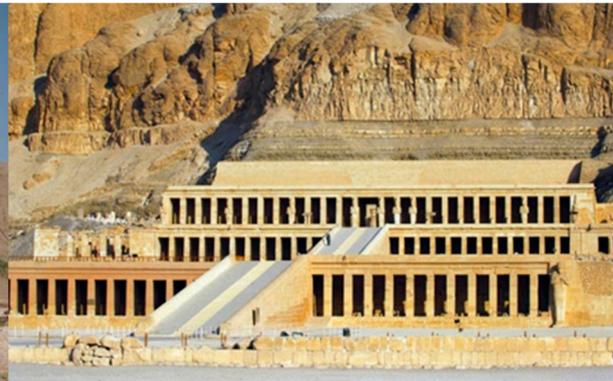
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### 105 1.2.2 West Luxor city temples

106 Some of the temples in Upper Egypt have a tower above the ancient plain. The best preserved  
 107 mortuary temple is known as Medinet Habu of Ramses III, and is related to the 20th dynasty and  
 108 located in the district on the west bank of the Nile [33]. As the living king at Medinet Habu, the king  
 109 Ramses III writes upon the walls of the temple: "I built my house-of-millions-of-years for the (Amon)  
 110 in the Thebes necropolis [34]. Until now, Medinet Habu as it is now called, still exists as the most  
 111 famous temples on the west bank of the Nile, and the most extensively constructed of the principle  
 112 temples of Egypt. The fallen walls, empty rooms, celebrations, and devotions, which once happened  
 113 there, often give only suggestions of the rituals [35] (Fig.4).

114 The tradition of ancient Egyptian buildings often displays a striking harmony with the  
 115 properties of Egypt's natural environment: the horizontal line, mounds, pyramidal masses of the  
 116 desert, and rectilinear textures of the cliffs of the Nile Valley. The Mortuary Temple of queen  
 117 Hatshepsut plays an example of these [36]. The original sanctuary was built by the queen  
 118 Hatshepsut. There is doubt that the third room of the Sanctuary showed to be a niche, decorated to  
 119 offer the god Amun. There are enough remains of the niche facade, with representations of the  
 120 queen Hatshepsut and the king Tuthmosis III on both sides of the entrance, the main sanctuary  
 121 divide to two rooms and three enormous niches in the second room [37] (Fig.5).

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123 **Figure 4.** The main façade of Medinet Habu  
 124 west Luxor [38].

**Figure 5.** The main façade of Hatshepsut temple at  
 west Luxor [39].

### 125 1.3 Environmental status

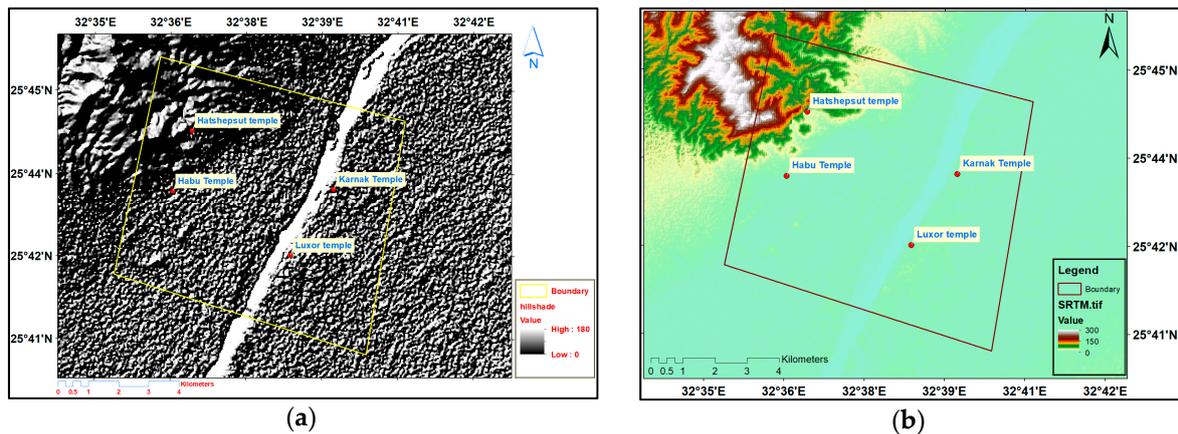
126 Luxor climate is severely arid and is classified as hyper-desert and extreme Mediterranean  
 127 type [40]. The rate of annual rainfall in the maximum average is about 0.2 mm. The temperature  
 128 maximum average ranges between 11°C in winter season and 44°C in the summer. The wind ranges  
 129 between 14.2 mph as maximum and 4.5 mph. Relative humidity is 56% in maximum and 17% in  
 130 minimum average [41].

131 After the construction of Aswan High Dam in the 1970, in the whole valley the Nile river has  
 132 deposited layers of fine-grained alluvial soil with several meters thick. The result of this is a  
 133 concentration of salts in the upper soil layers under and near the surface of the temple walls. This  
 134 played a critical role contributing to the deterioration of the Pharaonic monuments in Egypt [42]  
 135 (Fig.6a, b). On the other hand, the monuments in Upper Egypt comprise sensitive sandstones  
 136 originating from the Gebel el-Silsila region [43].

137 The groundwater level ascended with values vary between 18 cm and 1 meter, with an average  
 138 of 30 cm/year. The depth of the groundwater in Luxor City area varies between 2 and 7 m from the  
 139 ground surface. The shallowest depth of the groundwater level is recorded in El Karnak area, while  
 140 the deepest level occurs at the desert areas east of the city. During the last four years, the depth to the  
 141 groundwater level is in a continuous decreasing at 5 cm/year in Luxor temple area and at 30 cm/year  
 142 in El Karnak temple area [44]. For an average terrain, the depth of the groundwater fluctuated

143 between about 4 m for well number 4 (beside Nile River) and about 0.80 m around Ramesseum  
144 Temple.

145 The problems of rock deterioration (spalling and fracturing) are particularly critical in the  
146 Theban Necropolis mainly related to humidity and moisture changes of the bedrock [45]. The  
147 deterioration of archaeological sites at Luxor is mainly due to the capillary raising of groundwater  
148 [46] and tends to decrease the durability of monumental sandstones, as in the case of the reliefs of  
149 Hatshepsut (identifiable by the presence of a feminized grammatical form in the accompanying  
150 inscription). Moreover, these sandstone blocks, lying directly on the earth, and, therefore, are easily  
151 penetrated by groundwater and are in an extremely deteriorated state [47] (Fig. 7a, b – 10a, b).  
152



153 **Figure 6.** Hill shade (a) and 2D (b) showing the topographic and elevation properties around the  
154 study area.



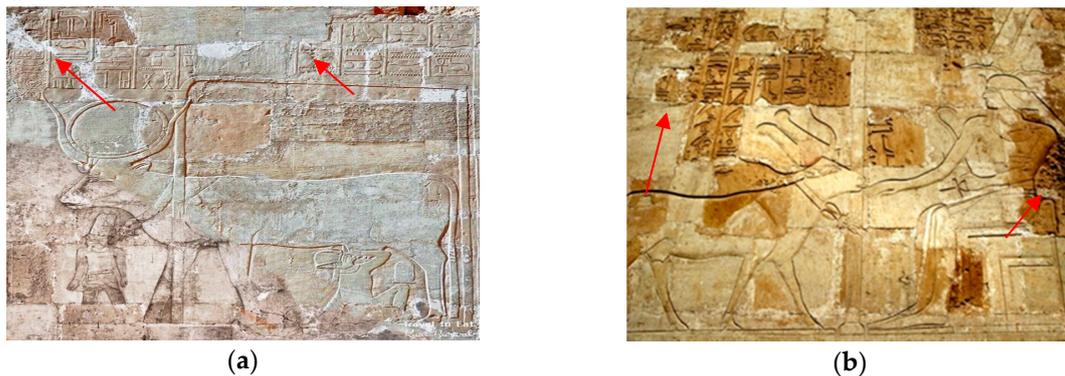
155 **Figure 7.** Deterioration in the walls of El Karnak temple (a, b).



156 **Figure 8.** The walls Deterioration in Medinet Habu temple (a, b) [48].



157 **Figure 9.** Deterioration in the walls of Luxor temple (a, b) [49].



158 **Figure 10.** Deterioration in the inscriptions and writings in the walls of Hatshepsut temple (a, b) [50].

## 159 2. Materials and Methods

### 160 2.1 Materials

161 The required satellite imagery (Table 1) for the study area were downloaded from the USGS  
 162 Earth Explorer (SRTM, Landsat TM 1984, Corona-3 1964) and from ESA web site Sentinel 2). Finally,  
 163 the National Authority for Remote Sensing and Space Science (NARSS) provided the high resolution  
 164 data (Quickbird 2005) and the collection of topographic sheets 1:50 000 from the Survey of Egypt.  
 165 Hydrogeological and Geological sheet was collected from National authority for remote sensing and  
 166 space science. The ground truth data were in the form of reference data points collected using  
 167 randomly points by Quickbird image. Processing the images interpretation is done in Envi 5.1  
 168 software.

169 **Table 1.** Main satellite images properties.

Number	satellite	Sensor	Resolution (M)	Acquisition date	Source
1	Corona	KH-4A	1,8 m	Aug 1964	USGS
2	Landsat	TM	30 m	Oct 1984	GLCF
3	Quickbird 2	XS/P	0,6 m	Nov 2005	NARSS
4	Sentinel	2A	10 m	Nov 2016	USGS

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173 2.2 *Methods*174 2.2.1. *Image processing*175 • *Band combination*

176 Remote sensing data have become one of the important source of information for studying  
 177 vegetation, from global continental down to a local scale [51]. In particular, spectral vegetation  
 178 indices are widely used for monitoring, analysing, and mapping temporal and spatial variations in  
 179 vegetation structure and in biophysical parameters [52]. Vegetation is one of the most important  
 180 components of the ecosystems [53]. The use of Index-based built-up area is a very simple and rapid  
 181 method for mapping urban area and sequentially monitoring urban expansion [54]. Moreover,  
 182 bare-soil plays an important role as indicator of urban expansion [55]. In this study, the BSI and  
 183 BRBA indices are used and computed from TM and Sentinel 2 (see equation 1 to 4). These indices are  
 184 related to built-up area and to bare soil, respectively.

185 In particular, to compute Band Ratio for Built-up Area (BRBA) TM band 3 and 5 and Sentinel2  
 186 band 4 and 12 were used, respectively. These indices are expressed as [56]:

$$187 \quad BRBATM = Red/SWIR \text{ in Landsat 4,5 TM} \quad (1)$$

$$188 \quad BRBASent2 = Red/SWIR \text{ in Sentinel 2} \quad (2)$$

189 Assessment the BSI (bare soil index) showed that the areas covered with mulch has different  
 190 physicochemical properties of sand dunes with other area [57]. Bare Soil Index (BSI) is a numerical  
 191 indicator [58], based on blue, red, near infrared, and short wave infrared spectral bands to assess soil  
 192 variations [59]:

$$193 \quad BSITM = ((SWIR+Red)-(NIR+Blue))/((SWIR+Red)+(NIR+Blue)) \text{ in Landsat TM4,5 (3)}$$

$$194 \quad BSISent2 = ((SWIR+Red)-(NIR+Blue))/((SWIR+Red)+(NIR+Blue)) \text{ in Sentinel2 (4)}$$

195 • *Supervised Classification of images*

196 The supervised classification technique, herein adopted, was based on the maximum likelihood  
 197 and on training sets (signatures) provided by previous field knowledge. Changes are identified by  
 198 comparing the categorization obtained for each year (Corona 1964, Landsat TM 1984, Quickbird  
 199 2005, and Sentinel-2A 2016) investigated. Using Corona data is very important, for clarifying the  
 200 changes between 1964 and 2016 (the acquisition date for Corona is 1964), and this data is considered  
 201 high-resolution (1.8 M). All of the images are a multi-spectral data, but Corona is one band data. The  
 202 unsupervised classification has been carried out for Landsat TM 1984, Quickbird 2005, and  
 203 Sentinel-2A 2016 in Envi software, but Corona in ArcGIS software. Corona image has been divided  
 204 into ten classes. Five classes have been chosen by re-classes tool in ArcGIS software. The supervised  
 205 layers for all the images have been transformed to digital shapefiles in ArcGIS software to process  
 206 the measurements. Finally, the changes in the areas have been measured to detect the changes  
 207 between 1964 and 2016 in the urban layers.

208 • *Accuracy assessment*

209 In order to assess the accuracy of the obtained change/unchanged areas, the classified change  
 210 images were compared to their corresponding reference data using the traditional Kappa statistic  
 211 and overall accuracy. The accuracy assessment has been obtained by randomly separating the  
 212 dataset into two subsets: training and test. The performance of the classifier has been assessed using  
 213 an independent balanced (number of samples in different classes very close each other) test set, to  
 214 avoid that using unbalanced one, the error rate of the classifier would not be representative of its  
 215 true performance.

216 In detail, the kappa statistics measures the classification accuracy by accounting for omission  
 217 and commission error. Kappa statistic is defined (see equation 5) [60]:

$$218 \quad K = (\text{observed accuracy} - \text{chance agreement}) / (1 - \text{chance agreement}) \quad (5)$$

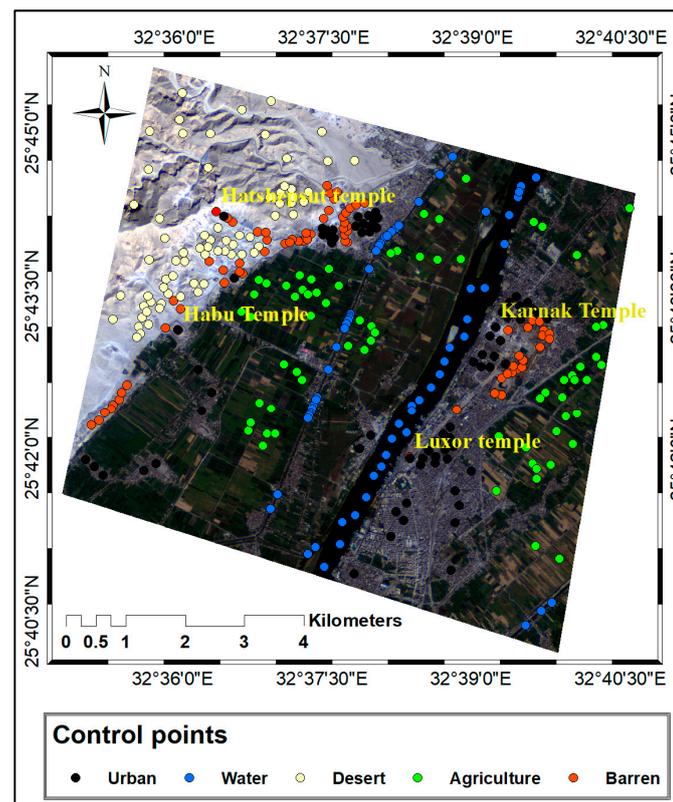
219  
 220  
 221 The classification accuracy was also estimated from in situ test sites selected as the region of  
 222 interests (350 points; 70 points related to urban area, agricultural area, water bodies area, and desert  
 223 area) using both the Kappa coefficient and overall accuracy (Table 2).

224 Results showed that, in the year 1984, the kappa coefficient was 0.73 and the overall accuracy  
 225 was 78.57 percent. For the next period 2005, the kappa coefficient decreased to be 0.65 with 72.71  
 226 percent of overall accuracy. Finally, the kappa coefficient increased to be 0.945 and the overall  
 227 accuracy was of 97.94 percent (Fig.11).

228 **Table 2.** Kappa Coefficient and overall accuracy of ROIs for each period.

Year	Luxor area	
	Kappa Coefficient	Overall Accuracy
1984	78.5714%	0.7306
2005	72.7135%	0.6501
2016	97.9401%	0.9450

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**Fig.11.** Control points used for Sentinel-2A (20 Feb 2017) RGB 4,3,2.

### 233 3. Results and discussion

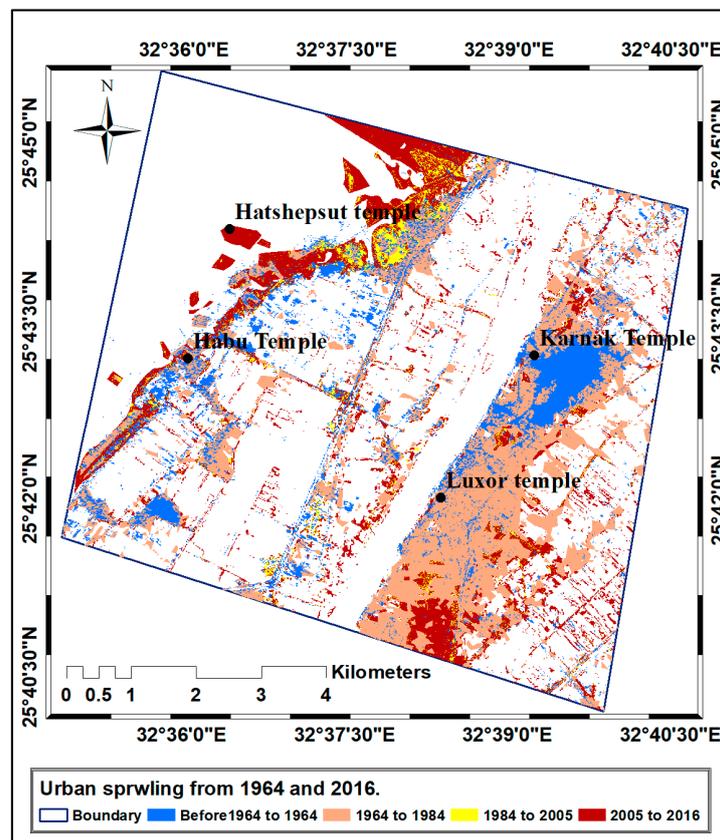
234 The analysis of Corona (1964), Landsat TM (1984), Quickbird (2005), and Sentinel2 (2016)  
 235 imageries acquired for the Luxor area revealed that urban areas increased about 7.792 km<sup>2</sup> from  
 236 1964 to 1984, and about 2.734 km<sup>2</sup> from 1984 to 2005, and finally about 1.763 km<sup>2</sup> from 2005 to 2016  
 237 (Table 3) (Fig. 12, 13). In this study, the urban changes from satellite images taken forms the same

238 study area at different acquisition dates. In particular, the analysis of Corona image, Landsat TM,  
 239 Quickbird, and sentinel-2A in Luxor revealed that urban land increased about 63.4 % from 1964 to  
 240 1984, about 22.31 % from 1984 to 2005, and about 14.34% from 2005 to 2016. These main that the  
 241 increase in urban area has the same way between 1964 and 2016 at Luxor area. It's very clear that the  
 242 increase in Luxor area between 1964 to 1984 has very high percentage 63.4 %. On the other hand, the  
 243 annual average of the increase in the urban layer presented about 236.32 M<sup>2</sup>. Our background about  
 244 the study area expose that this increase related to the tourism activities around the archaeological  
 245 area. Also, It's observed that the encroachment in the urban land at Luxor was in the boundary near  
 246 to the desert, especially on the West bank of Nile River. The main reasons about the environmental  
 247 problems in the temples area are related to the unplanned encroachment, bad sewage networks, and  
 248 Agricultural drainages.

249 **Table 3.** Total changes in the urban and agriculture areas (expressed in Km<sup>2</sup>) in Luxor area.

Class	Study area	1964 (KM2)	Change detection ± KM2	1984 (KM2)	Change detection ± KM2	2005 (KM2)	Change detection ± KM2	2016 (KM2)
Urban	Luxor	4.539	7.792	12.331	2.734	15.065	1.763	16.828

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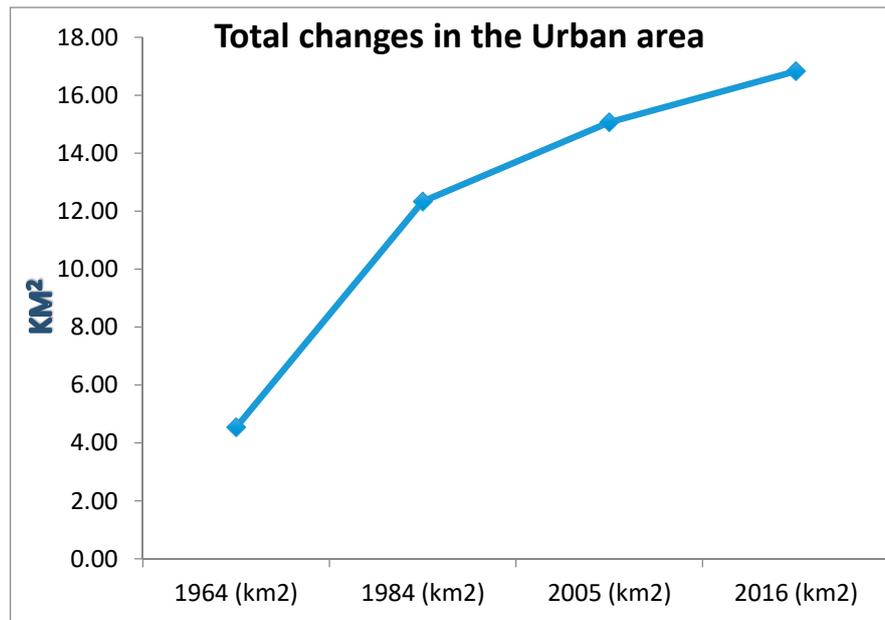


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**Fig.12.** Changes in the urban area between 1964 and 2016.



**Fig.13.** Total changes in the urban area by the graph.

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The accuracy assessment has been built by comparison between standard (Urban, agriculture, desert, water, and barren area) points which has been choice in Sentinel-2A image (high resolution 10 m) and the output in classifications in ENVI 5.1 (post classification, confusion matrix, and using ground truth ROIs). This method has been used to measure the classification truth in the classified images by overall accuracy (Dividing the total number of correct pixels (diagonal) by the total number of pixels in the error matrix) and Kappa Coefficient (Measure of agreement between the classification map and the reference data ).

Band combination techniques were used to identify the changes in the vegetation and built up indices between 1984 and 2016. The assessment included two indices BRBA (Band Rotation for Built up Area), and BSI (bare soil index). The result of this study, based on the classification of the BRBA indices showed that in Luxor there is a continuous increasing of urban areas. This can be seen in the 2016 from the classified image. In particular, urban areas and roads have been constructed after 1984 on the eastern, centre, as well as on the western sides of the area (Fig. 14) and in the southwest direction. Moreover, BSI indices showed the extension of agriculture area within the study area in the northwest direction. Built-up was generally very clear through in the vegetation from the BSI layout out in the 2016 date (Fig. 15).

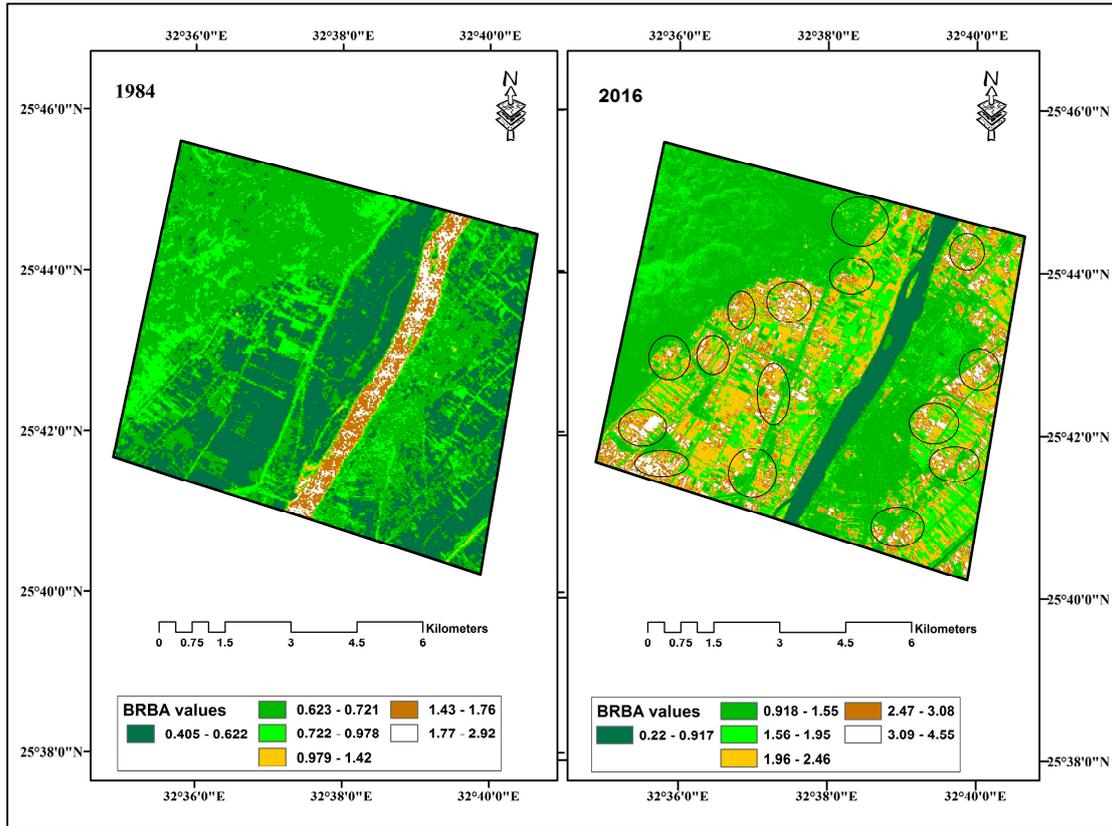


Fig.14. The changes in BRBA indices in the area between 1984 and 2016.

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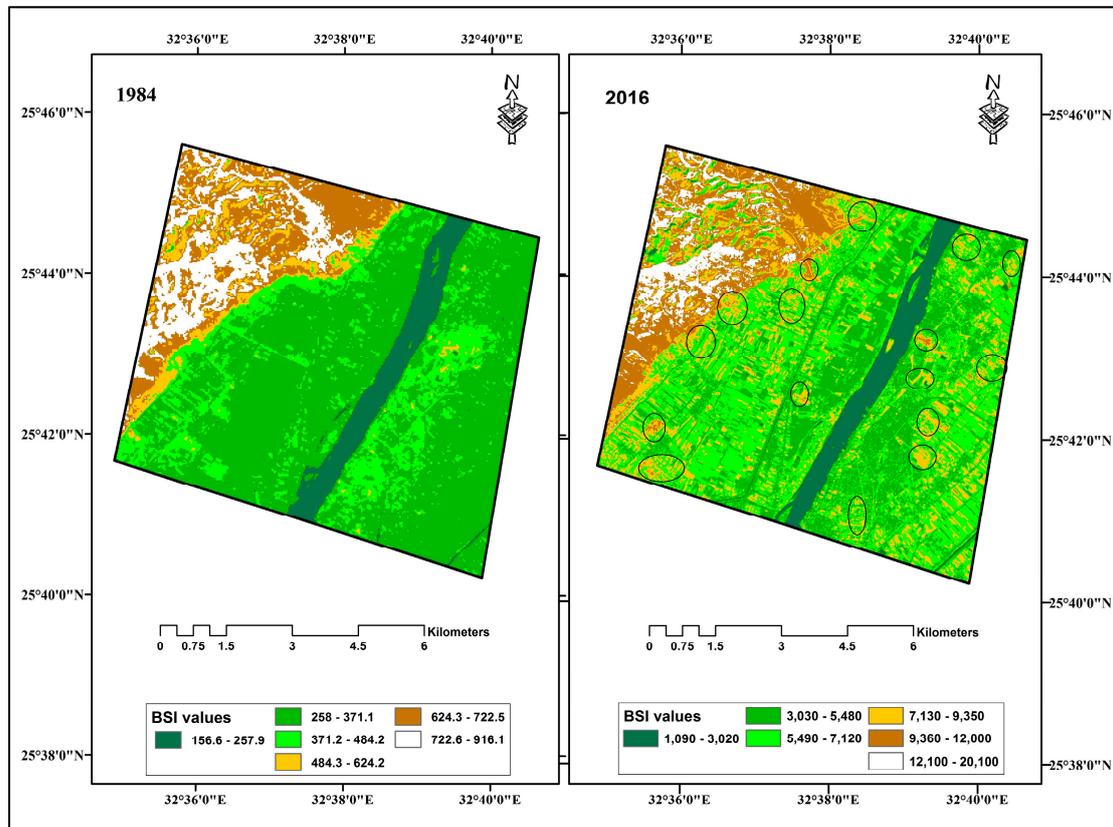


Fig.15. The changes in BSI indices in the area between 1984 and 2016.

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279 Many environmental studies have been carried out in Luxor area [61-72]. Most of these  
280 references focused on hydrology, geology, and climate setting for monitoring the environmental  
281 status around the archaeological areas, which are necessary, but performed using the classical  
282 methods.

283 Today, satellite images as sentinel 2 are systematically available free of charge for large  
284 coverage, and can be used for accurate mapping as well as for documenting and analyzing the  
285 historical and contemporary human activities around cultural heritage sites [73].

286 Luxor is an obligatory place for the tourist to Egypt for its incredible wealth of antiquities; the  
287 natural beauty and the Nile River. The local village life presents in the town and throughout the  
288 river valley and its dry, sunny weather, particularly in the winter. Antiquities and monuments date  
289 back to early pharaonic dynasties (3000 B.C) in addition to later Roman, Coptic and Islamic periods.  
290 Among others, Luxor's main landmarks includes 'world heritage' sites such as the royal tombs of the  
291 Kings' Valley, Queens' Valley and the Tombs of the Nobles. It also includes master pieces such as the  
292 Colossi of Memnon, Karnak Temple (the most imposing Pharaonic temple in all of Egypt) and Luxor  
293 temple. They represent some of the finest examples of mankind's early civilization and rank among  
294 its greatest cultural achievements. It has therefore always fascinated travelers from all over the  
295 world. Tourism in Luxor has been a major economic activity of most of its population, as it is the  
296 source of various jobs and business opportunities. The local economy is therefore largely depended  
297 on tourism. Besides the importance of Luxor city as a tourism spot and the increasing in the  
298 population numbers in Luxor city, most of the urban encroachment has been focused on the  
299 archaeological areas.

300 Unplanned wastewater and drinking-water networks are inevitable results of the randomly  
301 urban crawling around the monuments temples. In this paper, we propose the use of historical  
302 archives along with recent satellite acquisitions, in order to recover the past information and set up a  
303 systematic monitoring of ongoing changes using current satellite acquisitions. The analysis is  
304 focused around the four temples of Luxor city (Egypt). Results of this study have been developed  
305 taking advantages of GIS and RS based on the utilization of a variety of environmental factors.

306 In particular, the analysis of Corona 1964, Landsat TM 1984, Quickbird 2005, and Sentinel2 2016  
307 in Luxor city revealed that urban areas increased about 63.4% from 1964 and 1984, about 22.3% from  
308 1984 and 2005 and finally about 14.3% from 2005 and 2016. It is observed that the highest level in the  
309 urban increasing was between 1964 and 1984; this curve went down from 1984 and 2005, and more  
310 again from 2005 and 2016.

311

#### 312 4. Recommendation

313 The information on the changes ongoing in the investigated area obtained from the  
314 multitemporal analysis can fruitfully support the smart management of the archaeological areas in  
315 particular providing insights for the definition of zonations, as usually required by UNESCO for the  
316 preservation of heritage. The following recommendations highlight the operational role that the  
317 remote sensing may have to fruitfully support management and decision process. According to the  
318 periodic 2017 UNESCO reports (see for example (<http://whc.unesco.org/en/soc/3597> and  
319 <http://whc.unesco.org/en/soc/751>) on the status of this archaeological area, the main factors affecting  
320 the archaeological property are the following:

- 321 • Deliberate destruction of heritage
- 322 • Flooding
- 323 • Housing
- 324 • Impacts of tourism / visitor / recreation
- 325 • Land conversion
- 326 • Management activities
- 327 • Management systems/ management plan

- 328 • Water (rain/water table)  
329 • Other Threats:

330 The UNESCO reports of the previous years reported among the others the following factors,  
331 which considered to adversely affect the property:

- 332 • Rising underground water level  
333 • Risks of flooding (Valleys of Kings and Queens)  
334 • Absence of a comprehensive Management Plan  
335 • Major infrastructure and development projects taking place or scheduled  
336 • Uncontrolled urban development  
337 • Housing and agricultural encroachment on the West Bank of the Nile

338 Following the suggestions of the Strategy for Risk Reduction at World Heritage Properties,  
339 presented and approved by the World Heritage Committee during its 31st session in 2007, priority  
340 actions, have to be structured around the needs to strengthen the protection of World Heritage and,  
341 at the same time, contribute to its sustainable development. Considering this approach, on the basis  
342 of the results obtained from the satellite investigations and the ancillary information we propose the  
343 following recommendations:

344

345 I.) Current space technologies could be incorporated in traditional technologies for improving  
346 environmental analysis, following Lasaponara et. al [74-78] and the approaches proposed by  
347 UNESCO in the Man and Biosphere Program (MAB); that is based on the application of the concept  
348 of “biosphere reserves “

349 II.) In Luxor, the risk mitigation can be performed using a “Zonation System” that applies  
350 different management policies to different zones {50 meter}. The archaeological area is to be  
351 surrounded by three areas, as suggested by UNESCO. The first area for monitoring; the second for  
352 the research, experiment, education and training; the third area for tourism and recreation area (Fig  
353 16). The proposed zonation is based on the consideration that for the Hatshepsut temple the areas  
354 identified have to cope with the need to.

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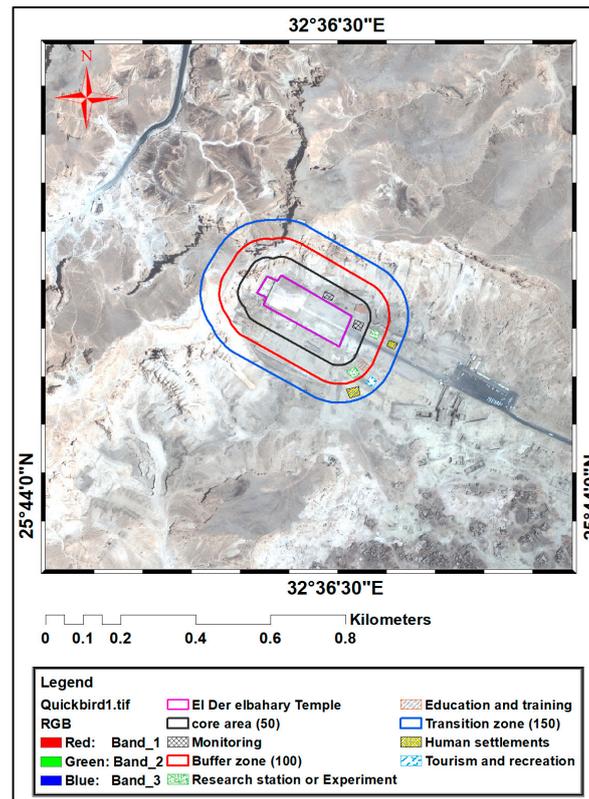


Fig.16. Proposed zonation areas around Hatshepsut temple by Quick bird satellite image 2005 (RGB).

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III. ) As a result of the bad environmental status around the archaeological area of Luxor, it becomes very necessary to choose some suitable places to dig some trenches in order to collect the ground water, including the wastewater originated by the urban uncontrolled expansion (to cope with the needs highlighted in the UNESCO reports). Figure 17 shows the location of the trenches connected with pumps defined considering ancillary information and the slope of the area, also depicted in Figure 17. Considering the slope and topographical features of the area, these trenches, connected with pumps, should be located at a depth around 9 m. Moreover, these wastewaters will be transferred to a water recycling station which finally will move them to the nearest canal, to purify water made them suitable for irrigation.

IV.) In the next future, additional investigations based on GIS-modeling methodology will also be addressed to the identification the alternative sites for urban areas and agricultural activities to minimize their adverse impact on the cultural properties. Potential feasible sites will be identified on the basis of external impact factors such as Roads, DEM, archaeological area, Agriculture land, and Urban (see Fig. 17,18), management purposes, following the UNESCO recommendations.

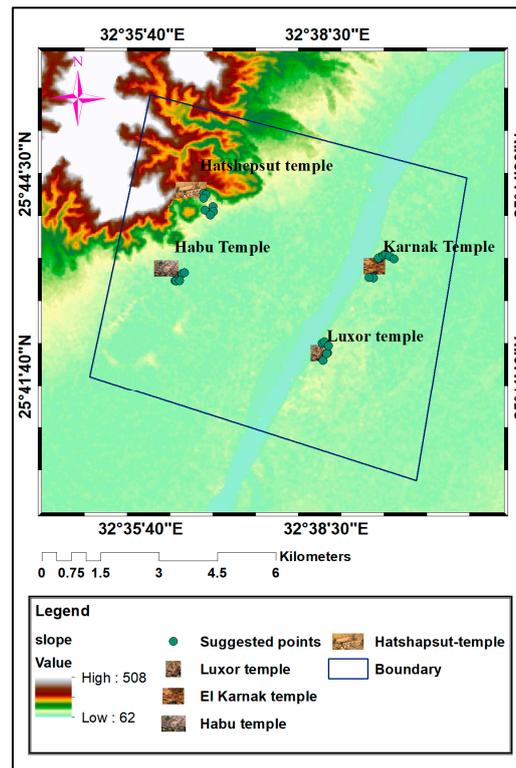


Fig.17. Proposed Points for the recommended trenches around the temples.

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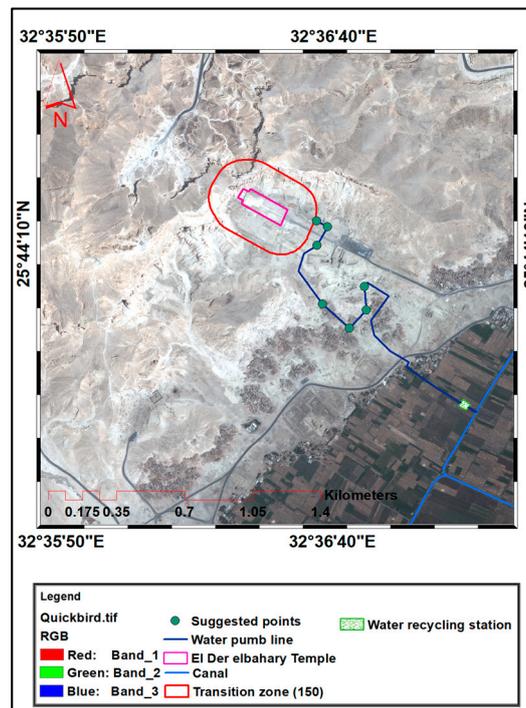


Fig.18. Proposed GIS-modeling around Hatshepsut temple by Quick bird satellite image 2005 (RGB).

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## 381 5. Conclusion

382 Recent improvements in earth observation technologies offer advanced technical characteristics  
383 which enable new applications specifically for the documentation, enhancement, risk monitoring  
384 and preservation of cultural heritage. In particular, the most recent space missions as the ESA

385 sentinel are specifically concerned with risk estimation and management, systematically acquired  
386 for the entire globe.

387 This study presents the possibility of using these modern technological tools in terms of design  
388 and planning a smart and sustainable use of cultural heritage resources. The aims of our  
389 investigations were focused on the estimation of the effect of urban crawling around some Temples  
390 of Luxor city which is considerably affected by continuous changes. The survey study has shown  
391 that most of the environmental problems around the archaeological areas have been coming from  
392 the high level of the groundwater depth and the essential reason is the unplanned urban  
393 encroachment. Results from our analysis conducted using data acquired in 1964, 1984, 2005 and 2016  
394 showed the spatial dimension of the changes in urban and agricultural areas which appeared clearly  
395 in the images of classification and extracted indices. On the basis of the analysis, we carried out  
396 mitigation actions which were also identified and suggested. A "Zonation System" has been  
397 proposed and mapped in order to support the preservation strategies that can take benefits from  
398 different management policies devised for the different identified zones.

399 Sustainable management and exploitation as well as conservation and mitigation strategies are  
400 mandatory to reduce decay phenomena, threats and human actions that may accelerate decay  
401 dynamics or produce significant deterioration and/or alteration of cultural heritage and "its  
402 environment". In this context, remote sensing technologies can offer useful data to timely update  
403 information and documentation as well as reliable tools for systematic monitoring of cultural  
404 properties. The tremendous availability of advanced remote sensing data has opened today new  
405 challenges and prospective unthinkable several years ago. In particular, for archaeological sites and  
406 landscape remote sensing can provide useful data not only for probing the subsurface to unveil sites  
407 and artefacts, but also for the management, valorisation and preservation, for detecting changes as  
408 well as for assessing degradation and emerging threats.

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