Geo-environmental risk assessment around Qayitbay castle, Rosetta, Egypt, using remote sensing and GIS techniques

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Abstract

In this paper, the environmental risks and their effects on preservation issues are investigated for the archaeological area at Rosetta (Rashid "North of Egypt"), where the most famous Islamic monuments are located. The history of Rosetta is passed over different periods of historical value according to the political and economic situations. The main problem that faces the historic buildings of Rosetta is the salt coming from the soil moisture, caused by saltwater intrusion from the Mediterranean Sea. Over the past twenty years, the Ottoman buildings became the subject of many restoration tasks but most of them have been re-damaged due to the increasing level of the groundwater and humidity. Multi-temporal Satellite images have been used to detect all the changes mainly linked to the expansion of urban, water, and agriculture areas. This unplanned change in land use strongly caused witnessed disturbance in the levels of groundwater which, in turn (and along with changes in temperature), caused the deterioration process affecting the Qayitbay castle. Innovative solutions are created to support the preservation of the castle using GIS and remote sensing techniques.

Keywords; Risk, Qayitbay Castle, Remote Sensing, GIS, Egypt

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الملخص

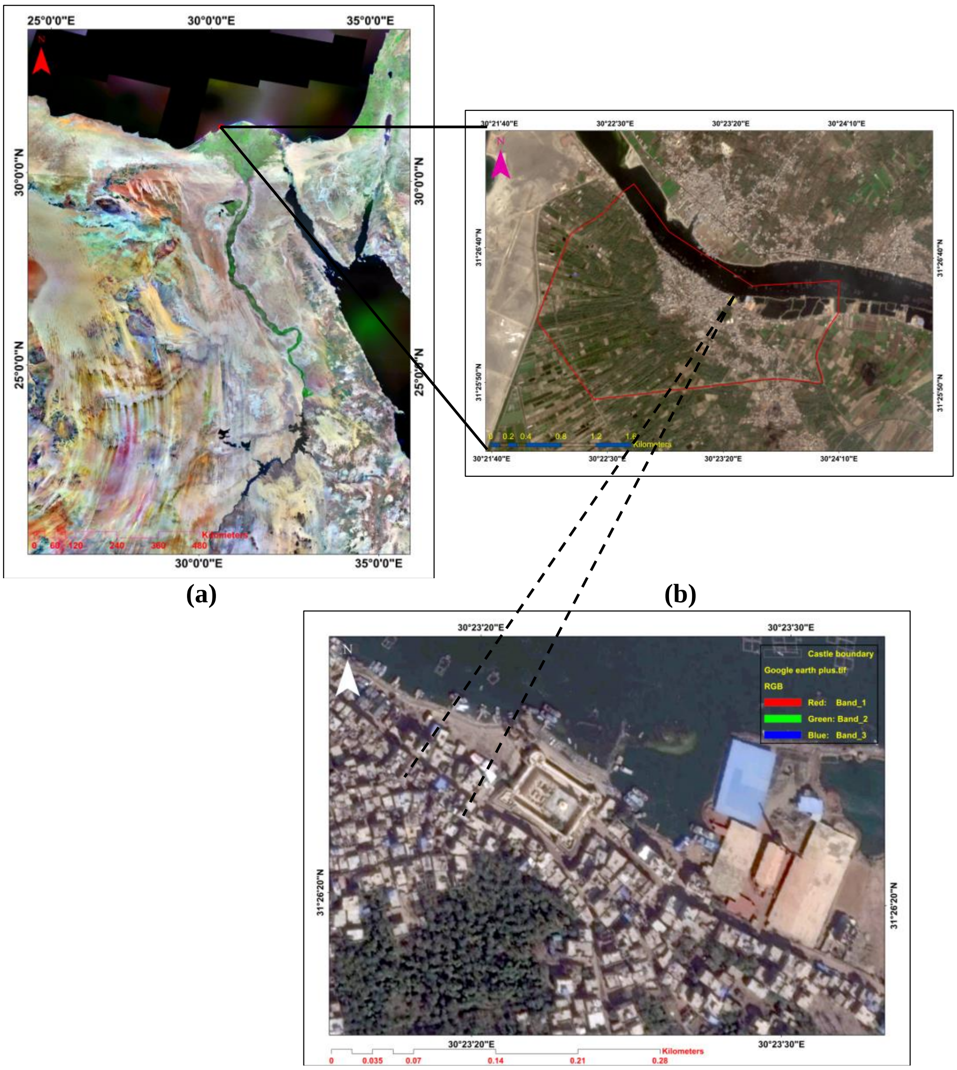
رشيد (Rosetta) والتى أشتهرت بحجر رشيد الذى عثر عليه فى قلعة رشيد عام 1799م. مرت مدينة رشيد عبر تاريخها بأوقات قوة وضعف حسب الأهمية الإقتصادية والسياسية، والموروث الثقافى للمدينة يوضح العصور التاريخية التى مرت بها، ولكن منازلها الأثرية تعتبر الأكثر أهمية بالإضافة إلى المساجد التى تعود للعصر العثمانى. وتعتبر المشكلة الرئيسية التى تتعرض لها أثار المدينة هى نسبة الأملاح المرتفعة الناتجة عن ارتفاع منسوب المياة الجوفية، وقد لاقت منازلها الأثرية اهتماما بالغاً لإعادة ترميمها فى العشرين سنة الأخيرة، ولكن للأسف لم يستمر الترميم كثيرا وعادة المنازل لحالتها الأولى نتيجة لاستمرار المشاكل البيئية فى المنطقة. لقد أصبح الإهتمام بالموروث الثقافى ضرورة ملحة هذه الآونة كنتيجة للآثار المترتبة على الاستخدام الآدمى وما ينتج عنه بالمناطق المحيطة بالأثار وأثر ذلك السلبى على المواقع الأثرية، وسوف نعرض بهذة الورقة البحثية المخاطر البيئية وأثرها على أحد المواقع الأثرية الهامة فى مدينة رشيد بشمال مصر والتى تتميز بإحتوائها على أهم الأثار الإسلامية بمصر وسوف نستخدم صور الأقمار الصناعية لرصد المشاكل البيئية حول قلعة قايتباى والتى ترتبط بالزحف العمرانى على الأثر وما ينتج عنه من ارتفاع منسوب المياه الجوفية. وسوف تعمل هذه التقنية العلمية الحديثة على تخليق مجموعة من الحلول المبتكرة للحد من المشاكل البيئية والحفاظ على هذا الموروث الثقافى الهام.

1. Introduction

Satellite images and GIS can be fruitfully used in archaeological investigations to support documentation, spatial analysis, risk management and modeling (Gupta and Devillers 2017). Integrated archaeological studies and approaches based on remote sensing techniques and systematic in situ surveys can introduce suitable picture cultural heritage evolution (Cerrillo-Cuenca 2017). The joint use of Geographical Information Systems (GIS) and remote sensing can help decision-makers support, sustainable development and enhance heritage preservation including emerging, coastal and underwater cultural remains (Agapiou et al., 2017). Over the last years, these techniques have empowered the Middle Eastern archaeologists to overcome some of practical limitations, for example, providing low-cost and high-resolution commercial satellite images. Recent applications of these techniques have advanced the archaeological documentation in rapidly urbanization, explored the mechanism behind illegal looting, and helped preservation strategies and excavation activities (Hritz 2014; Keay et al., 2014). Moreover, GIS predictive models are considered useful tools for archaeological research. These tools can (i) facilitate new discoveries by saving time and money, especially in large-scale areas; (ii) provide a decision support system useful to obtain information for defining survey priority (Danese et al., 2014; Papoutsa et al., 2014). Satellite remote sensing for cultural heritage can further develop, benefitting of larger consistent archives at increasing spatial resolution and temporal frequency. Satellite data provide useful information for assessing urban sprawl, that is a complex dynamical process (associated with landscape change driving forces such as the environment, geography, politics, and many others) that affects monuments at multiple spatial and temporal scales. GIS, satellite data along with the use of dynamic models are important tools very useful for the analysis, representation, and modeling of urban dynamics and their impact on cultural properties (Malfitana et al., 2015; Tapete and Cigna 2017; Akın et al., 2014; Verhoeven 2017.)

1.1 Study area

Rosetta City is located at the northeastern side of Behaira Governorate on the West Bank of Rosetta branch of the river Nile. It is situated at 31°24′N latitude and 30°24′E longitude. The architectural heritage of the city reveals the influence of various periods, but the most unique are archaeological houses and mosques from the Ottoman era. The city is famous for the discovery of the Rosetta stone, which helped in resolving the structure of the old Egyptian language. Rosetta is considered one of the most important cities in Egypt and is also famous for the Islamic monuments which dated to the Ottoman and Mamluk era (Bayoumy 1993; Anany 1987, 1991; GAUP 1993; EGASP1993). Today Rosetta is characterized by a particular suburban landscape made up of agricultural land and palm groves that gave special importance (Teresa et al., 2011) to the area for the numerous informal peddlers and many markets scattered throughout the streets of the monumental area (Badr et al., 2006) (Fig. 1a, b, and 1c).

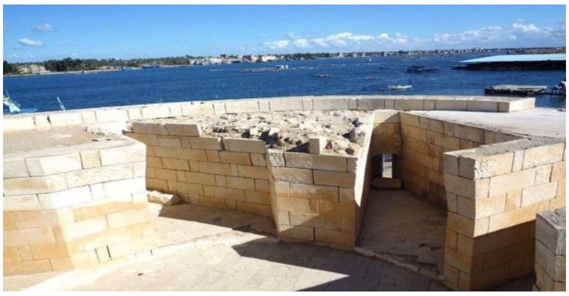


(c)

Fig. 1 Location of the study area (a) Landsat 7, (b) Sentinel 2A 2017 and (c) Google earth image 2017.

1.2 Description of the castle

The Castle of Qaitbayat at Rashid is one of the most important military fortifications established by the Mamluk Sultan Al-Ashraf Abu Al-Nasr Qaitbay, one of the Circassia Mamluks after accomplishing of the construction of his famous castle in Alexandria in (884 AH / 1479 AD) (Lane P and Stanley 1901). The castle was built to firmly control the inlet of Rashid and to repel the crusades that attacked the coasts of the Mamluk state in Egypt (Hamwi 1914). Named after the Coptic name (Rachit), the name which some historians refer it back to the Pharaonic name (Rikhito) or (Rakhit). The Arabs turned it into a "Rachid ,(" while the foreigners called it "Rosetta," or the small rose where trees and orchards surrounding it from everywhere (Gardiner 1947). The site (on the coast of the Mediterranean Sea and the Nile near Alexandria) has had a military significance since the Pharaonic era and through the era of Muhammad Ali, except for the Ottoman period in which the importance of the city was mainly linked to commercial activities. The castle construction was designed similar to the inner fortress at Qaitbay Castle in Alexandria. It is a square-shaped building with four round towers (Denon 1807). The castle is composed of a rectangular external wall supported by four corner towers in the form of a three-quarters circle. These towers are internally linked with each other by ribbed vaults. At the head of each entrance is placed an embrasure which was originally designed for archery. This was the first level of defense. As for the second level of defense, that is an internal passage which contained embrasures for archery. The third and last defensive level of the fences is the fence’s walkway, which included shields overlooking the outside. The corner towers included two levels of defense: the ground level consisting of a number of embrasures, and the second level, which was above the shallow dome and covered the first level also included a set of embrasures. The castle has a monumental entrance ripped by vaults. The ripped vaults contain a rectangle named Sultan Qaitbay, reading as follows: "Proud for our sire, the sultan, the king Abulnasr al-Ashraf Qaitbay, Pride and Victory" in three lines. The entrance hole is slightly behind the entrance’s vault and is rectangular ripped by a straight vault. The space between the entrance hole and the ripped entrance contains a set of ratchets. The entrance’s alidades are made of stone carrying pharaonic inscriptions. The interior design of the castle includes two elements: the main tower, which is a rectangular area divided into two parts by a row of grating columns topped with decades and the entire area covered with cross vaults. The windows of the tower take the form of the embrasure, and the ground of these windows is inward. The main tower includes a door opening in the northeast corner leading to a collection of accessories, storage rooms, and weapon. The other element is the mosque which is not dating back to the Qaitbay era since the old mosque was demolished and an Ottoman mosque was built instead which was also demolished and a mosque was built in a later era (Darwish 1991). When the French succeeded in entering the castle of Qaitbay in 1799, they called the castle "St. Julian Fort". They made many changes to the castle (Herold 1986), which led to the blurring of many of the old features. In the towers of the North West and South West, they blocked the three outlets of the embrasures in the red brick. Then, they established two small embrasures in each tower for gun-firing. In each embrasure six-gun openings were made for guns and two vents were established in the celling. They also closed the corridors of the embrasures to become mute. A bathroom for the French leader Bushar, who was supervising the process of the castle’s restoration, was established at the big tower which was assigned to soldier’s residence. Finally, the towers in the ground floor of the castle were reinforced with red bricks. During the excavation of the foundations of the castle, a stone was found with inscriptions in an old wall that had to be demolished to lay the foundation of the "Castle of St. Julian". This stone is later known as the Rosetta stone. This stone was the forerunner of Champollion and its predecessor to the ancient Egyptian language. Now it is preserved In the British Museum in London (Forster 1922). It is 115 cm long and 73 cm wide, and its top plate and its angles from the north and the right are missing some parts. Some scientists believe that it was circular in the above, as is known in the Ptolemaic period. This stone of black basalt is written in three languages from top to bottom hieroglyphics, demotic and Greek (Champollion 1950). His history dates back to March 27, 196 BC. M in the days of King Ptolemy V, who ruled Egypt between 203 to 181 BC. The theme of writing about it is that after the death of Ptolemy III 221 BC. The Ptolemaic state began to talk about what Ptolemy IV did when he died in 204 BC. An internal sedition led to the extermination of many of the footmen until the Romans intervened and established the foundations of Ptolemy V and destroyed the strife. A great celebration was held in Memphis to thank and pledge allegiance to the king and the inscription of the stone in the presence of the chief priests and writers and it was necessary to put it in the temples of First to third-degree next to the king statue (Cary 1932) (Fig. 2a, b, c, and d).


(a)


(b)


(c)

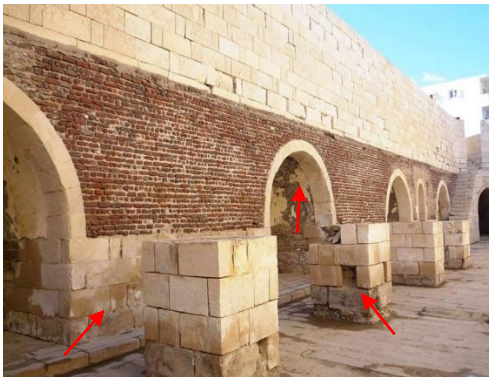

(d)

Fig. 2 The main view of Qayitbay Castle (a, b, c, and d)

1.3 The geo-environmental aspects of the study area

The Nile Delta is very heavily populated, with population densities up to 1,600 inhabitants per square kilometer. Most of a 50 km inland strip along the coast is less than 2 m above sea-level (Zeydan 2005). Erosion of the protective sand belt is a serious problem and has accelerated since the construction of the Aswan dam. On the other hand, rising of the sea level would destroy weak parts of the sand belt (El-Ramady et al., 2013). The study area is generally covered by extensive exposures of sedimentary succession ranging from the Late Cretaceous to Quaternary, The geomorphological status clarified into four forms (Dawoud et al., 2005), young and old alluvial plains, fanglomerates, and sand dunes (Abdel Baki 1983; Rizzini et al.

1978; El Menayar 1999; Atwia et al. 2006). The collected data from the groundwater wells indicates that most important regional aquifer is the Quaternary aquifer. This aquifer system is overlaid by a clay cap which is considered as semi-confining layer with a thickness of up to 20 m. With a thickness ranges between 10 m in the south up to 30 m in the north. This layer vanishes at the western desert fringes. The groundwater salinity is about 800 ppm in the South and it reaches about 359000 ppm in the north due to the effect of seawater intrusion (El Bouraie et al., 2011). The geo-electrical investigation studies show that the salinity of groundwater in the North increases with clear depth (RIGW/IWACO 1998; Elsorady 2012). The archaeological deterioration caused by the groundwater recharge which taking place in the Nile Delta area. (Willems and Dahms 2017) (Fig. 2a, b, c, and d).


(a)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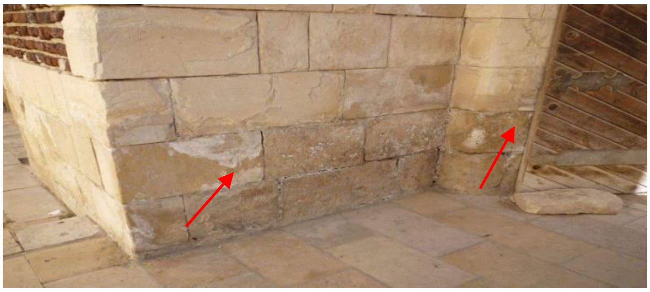

(d)

Fig. 3 The deteriorations features in the Castle body according to the continuously rising level in the groundwater table in the study area, (a) Wall erosion, (b) high rate of moisture, (c) growth of vegetation and (d) wall salinization.

2. Data collection and Methodology

2.1 Data collection

The present study is based on low and high-resolution satellite imagery downloaded from the USGS Earth Explorer and Global Land Cover Facility (GLCF); (SRTM, Corona1970, Landsat TM 1984, and Sentinel-2A 2017). In this study, some of the control points were collected around the Castle using GPS (Table. 1).

Table. 1 The satellite images properties for the study area

Number	satellite	Sensor	Resolution (M)	Acquisition date	Source
1	Corona	KH-4B	1,8 m	1970	USGS
2	Landsat 4	TM	30 m	1984	GLCF
3	Sentinel-2A	2A	10 m	2017	USGS

2.2 Methodology

The processing of satellite images is done in ArcGIS 10.1 and ENVI 5.1 software. The images are studied and analyzed to detect the changes in the urban expansion occurred from 1970 to 2017 around the castle. The dark subtract, geometric correction, unsupervised classification, supervised classification, and post supervised classifications techniques are carried out using ENVI and ArcGIS software. Built-up and vegetation indices techniques have been derived using the built-up and vegetation expressions. Besides, studying the natural and chemical properties of the study area aquifers, the following figure shows a strategy of studying the extent of the danger groundwater levels around the castle. Deriving the soil properties are bearing the effects and sources of salts threaten the susceptible to geomorphological hazards. A new scientific strategy will support the preserving and protection plan for the castle area.

3. Results and discussions

Digital Elevation Model report for the watershed has been carried out by SWAT model. The elevations statistics are reported in meters. The Minimum elevation reported about -13m and the Maximum elevation reported about +13. On the other hand, the Mean elevation reported about 2.37m, and the standard deviation reported about 2.99. According to the SRTM Dem and SWAT tool, the castle is situated in 3m elevation (Table. 2) (Fig. 4).

Table.2 Elevation report for the watershed and elevations statistics reported in meters.

Elevation (M)	Area Below Elevation %	Area Watershed %
-13	0.02	.02
-12	0.03	.01
-11	0.04	.01
-10	0.08	.04
-9	0.1	.02
-8	0.15	.05
-7	0.39	.24
-6	0.7	.31
-5	1.42	.72
-4	2.44	1.01
-3	4.56	2.12
-2	8.59	4.03
-1	16.91	8.32
0	28.62	11.71
1	40.01	11.39
2	50.24	10.23
3	62.2	11.96
4	73.67	11.47
5	84.24	10.57
6	92.28	8.04
7	96.8	4.51
8	99.07	2.28
9	99.76	.69
10	99.91	.15
11	99.97	.05
12	99.99	.02
13	100	.01

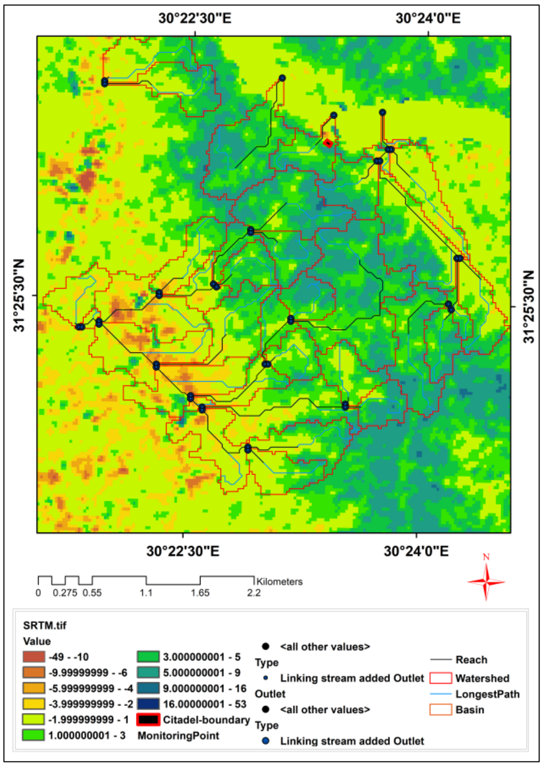
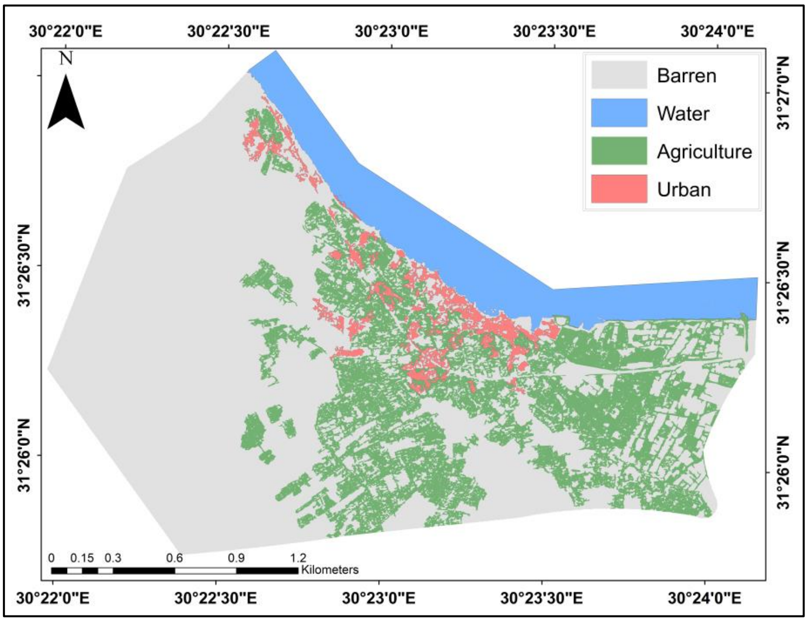


Fig. 4 Watershed delineation by SWAT tool in ArcGIS for the study area.

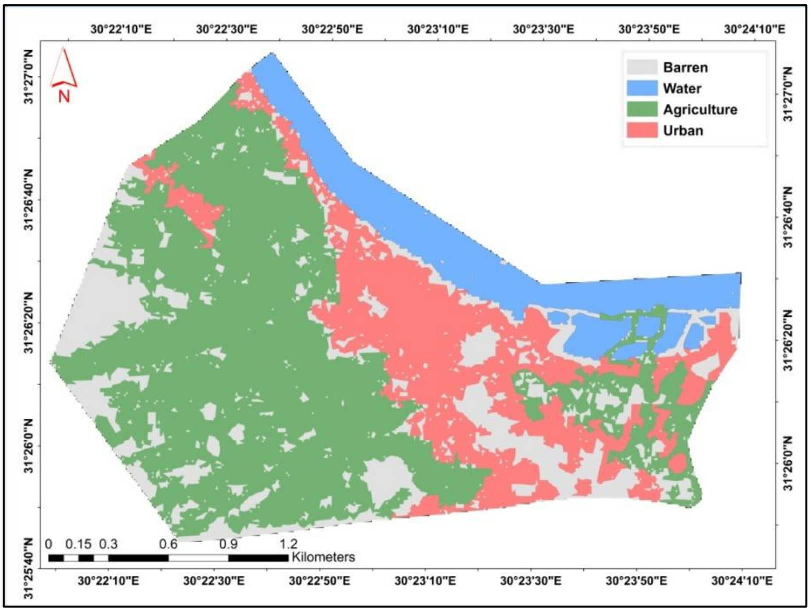
The change detection was mainly focused on the detection of urban, agriculture, barren area, and water bodies changes using images acquired in the same season of the different years investigated (see Table 3). The classified images were used to calculate the differences occurred in the span of data in the area under investigation. In order to calculate the accuracy assessment of the studied change areas, the classified change images were compared to their corresponding reference data using overall accuracy and the traditional Kappa statistic. The classification accuracy was estimated from in situ test points that were collected as the control points (400 points; 100 points related to agricultural area, water bodies area, urban area, and barren land area) using both the Kappa coefficient and overall accuracy. Results showed that, in the year 1984, the kappa coefficient was 0.74 and the overall accuracy was 79.51 percent. On the other hand, the kappa coefficient increased to be 0.895 and the overall accuracy was of 96.92 percent in 2017. In more detail, the analysis of Corona, Sentinel-2A imagery revealed that the urban area increased around .88 km2 from 1970 to 2017. However, the vegetation area increased around 1.18 km2 from 1970 to 2017. In the same direction, the water area increased also around .06 km2 from 1970 to 2017. But, of course, the barren area decreased around 2.12 km2 from 1970 to 2017 (see Fig. 5a, b, and c). These changes highlighted that agriculture, water, and urban sprawling increased exhibiting the main direction in the changes chronology. The biggest change in the study area was observed in the agriculture area. The main phenomenon in the encroachment is the increment in built-up area, including the waterbodies area (Fig. 6).

Table. 3 The total layer changes in the study area by ±Km2 between 1970 and 2017.

Layer / Year	Urban	Barren	Water	Agriculture
1970	0.17 Km^2	3.05 Km^2	0.57 Km^2	1.17 Km^2
2017	1.05 Km^2	0.93 Km^2	0.63 Km^2	2.35 Km^2
The changes ± KM^2	+0.88 Km^2	-2.12 Km^2	+0.06 Km^2	+1.18 Km^2



(a)



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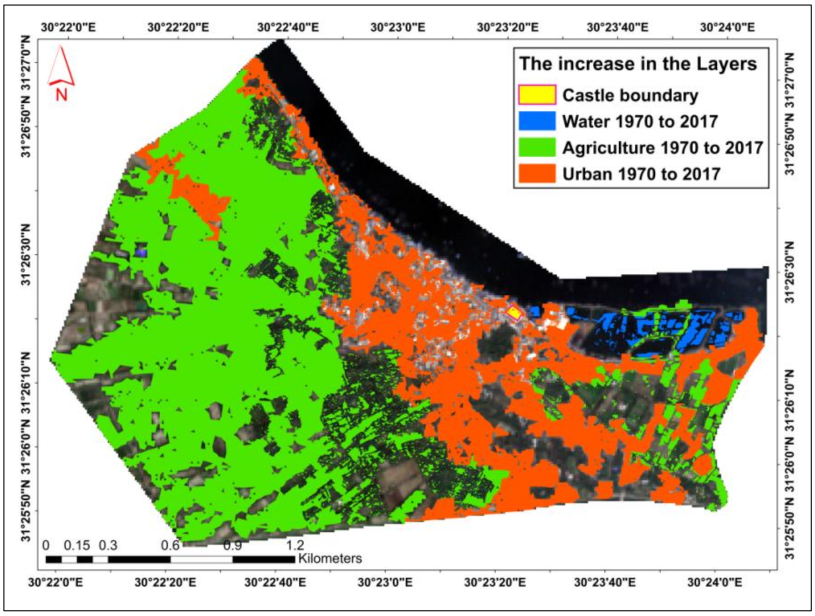


(c)

Fig. 5 The supervised classification of the satellite image in 1970 (a), the supervised classification of the satellite image in 2017 (b), and the total changes in the layers between 1970 and 2017 (c.(

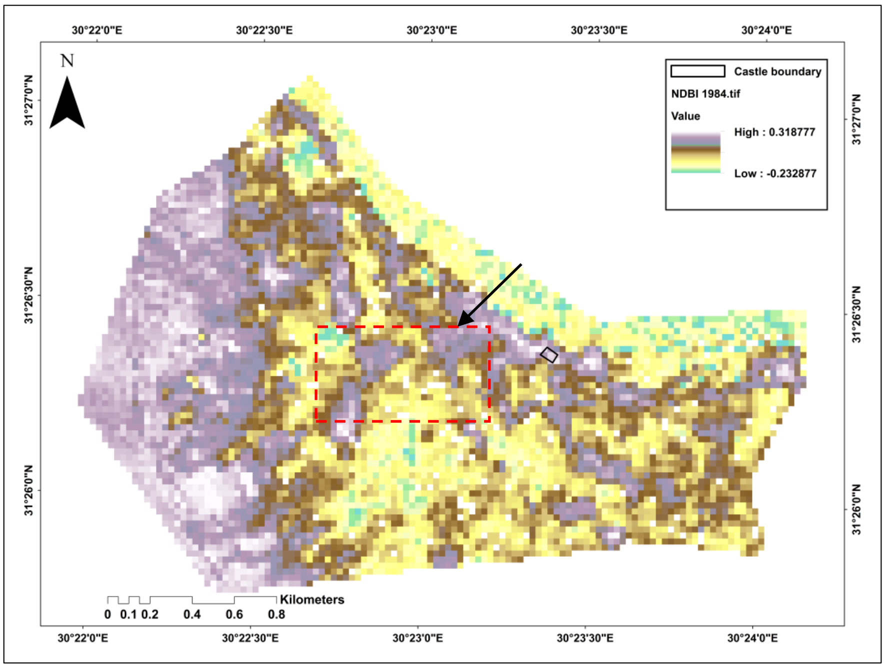
Fig. 6 The total changes in the studied layers by graph between 1970 and 2017.
To improve the analysis, the Normalised Difference Built-Up Index (NDBI) has been also used because it is able to enhance the new built-up areas. Urban land classifications are largely based on the use of this specific index, i.e. a mathematical combination of diverse spectral channels, for improving the identification of the built-up and bare land in the study areas according the formula (Badlani et al., 2017);

NDBI = (SWIR - NIR) / (SWIR + NIR) (1)

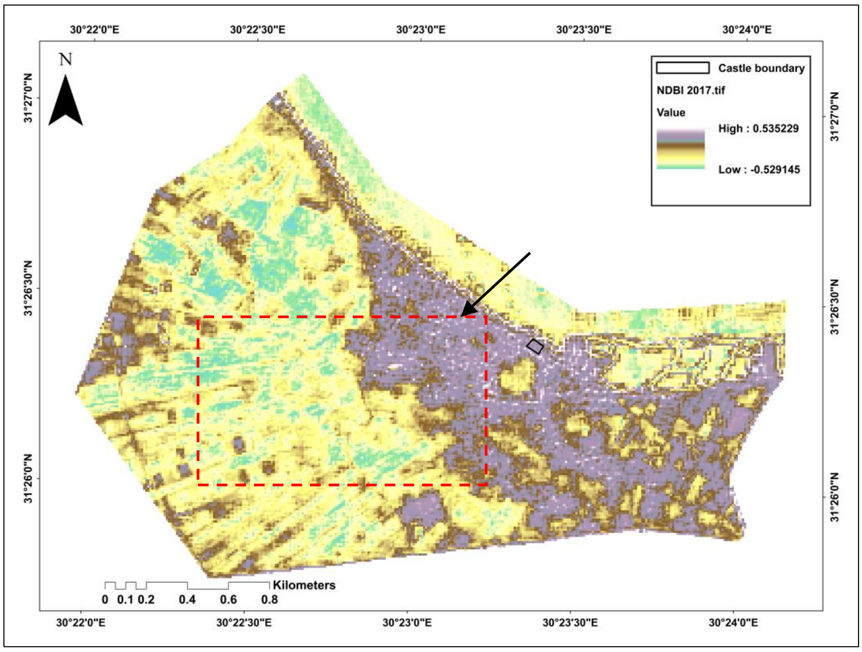
Where, band 5 in Landsat 4 presented the Shortwave Infrared (SWIR) 1, while band 11 in Sentinel2 has the properties of the Shortwave Infrared (SWIR) 1. On the other hand, band 5 in Landsat 4 presented the Near Infrared (NIR), while band 11 in Sentinel2 presented the Near Infrared (NIR). The computation of the MNDWI (Modified Normalised Difference Water Index) will produce three results: (i) the water will have greater positive values; (ii) the built-up land will have negative values, and (iii) the soil and vegetation will still have negative values as soil reflects. The greater enhancement of water in the MNDWI-image will result in more accurate extraction of open water features as the built-up land, soil and vegetation all negative values, as in formula (XU 2006)

MNDWI = (Green – MIR or SWIR2) / (Green + MIR or SWIR2) (2)

The result of the built-up (Fig. 7a, and b) and vegetation indices (Fig. 8a, and b), pointed out that the changes occurred between 1984 and 2017 were actually enormous. Significant changes in the built-up area focused around the study area in the north-eastern side as well as also changes in the agriculture area (in appositive degree)

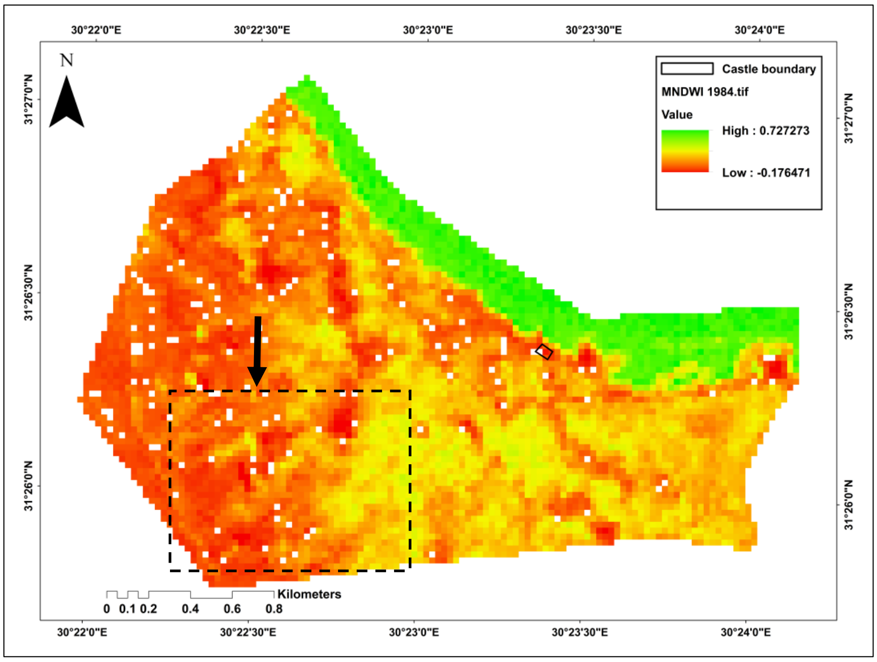


(a)

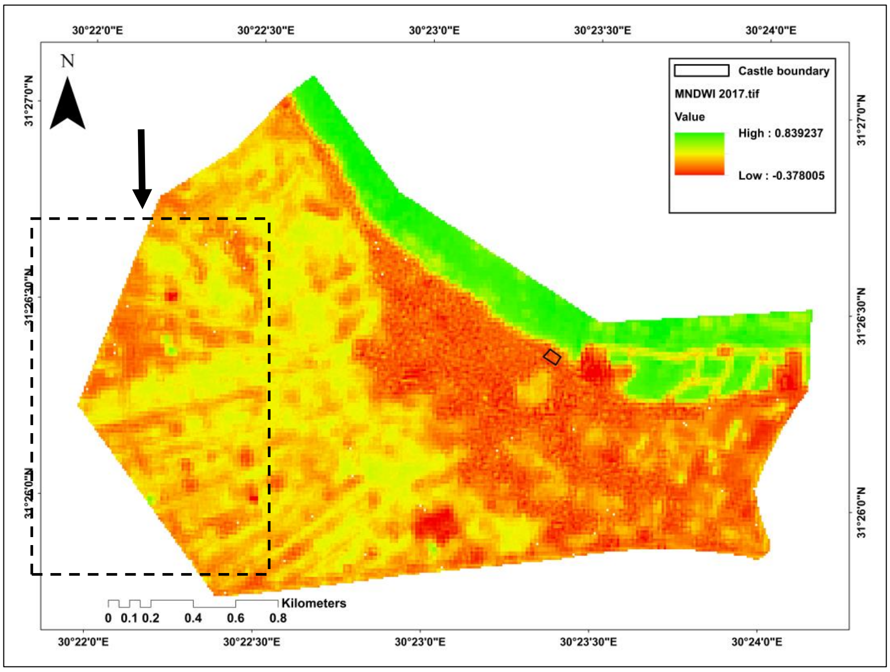


(b)

Fig. 7 The NDBI classification for the study area in 1984 (a), and the NDBI for the study area in 2017 (b)



(a)

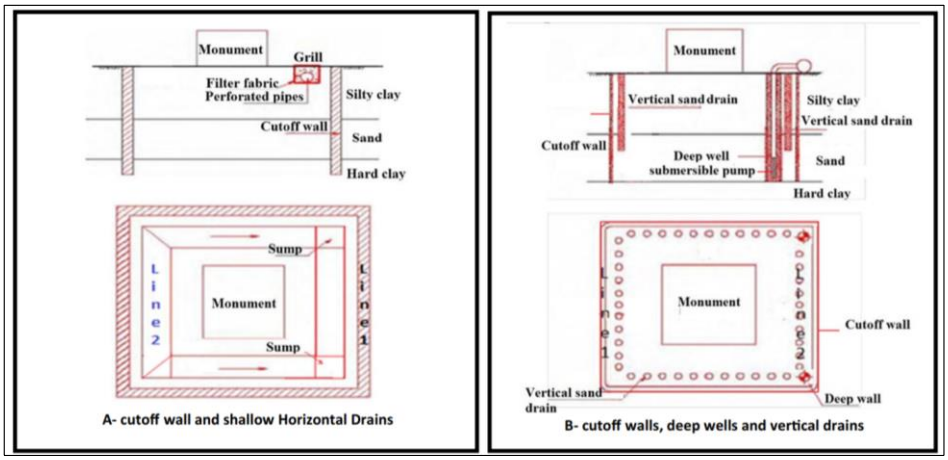


(b)

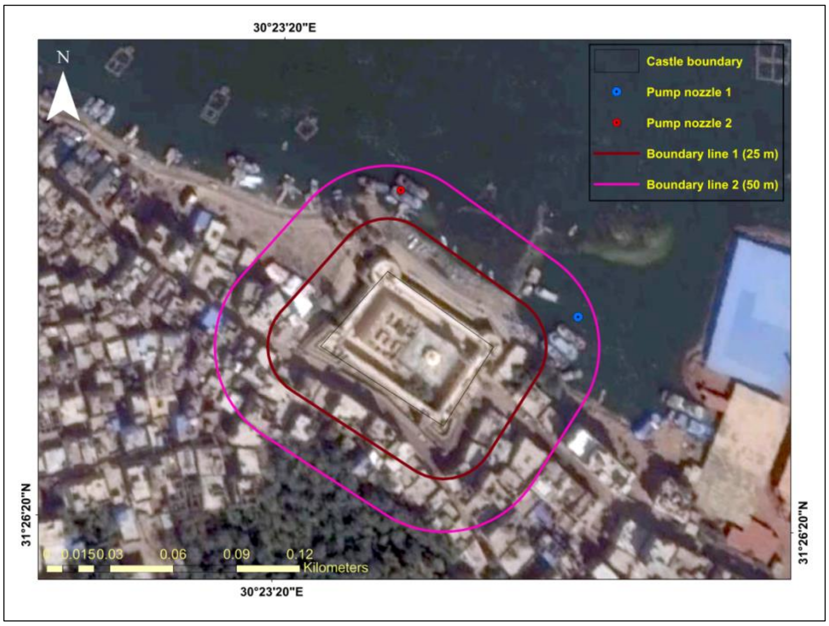
Fig. 8 The MNDWI classification for the study area in 1984 (a), and the MNDWI for the study area in 2017 (b)

4. Recommendations

Although many attempts to solve the erosion and sedimentation problem were performed in the study area, the problems still existing (Teresa et al., 2011, Masria et al., 2015). According to (Abdel-Warith 2007), an engineering system can be used as an effective method for groundwater lowering. A cut-off walls (in the suggested boundary line 1) can be built using diaphragm wall equipment and filled with plastic concrete. This cut-off wall is to prevent groundwater from entering the soil below the monument. In order to control surface water, a system of horizontal drains (in the suggested boundary line 2), should be installed at the intended final groundwater level with sloping from the southwest to the northeast and covered with a steel screen. Horizontal perforated pipes can discharge water to corner sumps in the northeast side, from which water can be pumped out of the site to the nearest drain and then to the Rosetta branch. The second method depends on the cut-off wall similar to the first example (in the suggested boundary line 1), in addition to deep wells that exist in the corners of the east side with submersible pumps to pump the groundwater from the sand aquifer to relieve the pressure on the bottom of the upper clay layer. While the suggested (boundary line 2), to collect the groundwater, is designed with sloping from the southwest to the northeast. The submersible pumps in the deep wells in the east corners would be operated intermittently to keep the lowered groundwater level at the target elevation, with minimal influence on the monument. Discharge water can be sent to the Rosetta branch. This system would have a low construction cost (Lasaponara et al., 2015a, 2016b, 2017c, Elfadaly et al., 2017a, 2017b, 2017c) (Fig. 9a, b, and c).



(a) (b)



(c)

Fig. 9 An engineering system for groundwater lowering in the study area (a, b, and c)

5. Conclusion

Like most of the Egyptian monuments, the castle of Qayitbay suffers from underground water. The problem is increased by the poor drainage system, urban sprawling, agriculture encroachment, and seawater rising around the castle. Change detection analysis showed the differences between images of the same area at different times. Suggestions and Solutions established a suitable engineering system groundwater lowering in the study area. The case studied presented in this paper shows the feasibility of integrating aerial images, which can be used as the basis for helping in detect and create a suitable solution to keep the archaeological area. The collected data allowed a detailed analysis on the environmental status through the past and immediate time. The results of this study highlighted the importance of using new scientific tools and techniques in the archaeological geo-prospection. This new technique is not only important from the scientific viewpoint but in providing information that can be used in development-planning, helping to keep this prodigious archaeological area.

Acknowledgments

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