

Article

Cultural Heritage Management Using Remote Sensing Data and GIS Techniques around the Archaeological Area of Ancient Jeddah in Jeddah City, Saudi Arabia

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Abstract: Historic Jeddah is located on the eastern shore of the Red Sea. Historic Jeddah was designated as a UNESCO world heritage site in 2014. The new urban development for the city of Jeddah has resulted in different spatial patterns. The southern part of Jeddah city falls within the moderate zone, because this area is well developed in regard to infrastructure with rainstorm and sewage networks. The middle area of the city falls within high vulnerability risk due to its high population, shallow water depth, flat slopes, and various incomplete network services (i.e., leakage from septic tanks and water pipes). The western and northwestern parts of the city are subject to very high pollution risk, due to the highly permeable area with coralline formation, very shallow water depth, and depressions. Unfortunately, historic Jeddah has been affected by the unplanned development and shallow water depth. Most of the construction and decoration of the ancient buildings are suffering from deterioration. The paper aims to detect the environmental changes, assessing the geo-environmental status, and creating some of the innovative solutions while using the integration between remote sensing and GIS techniques. The combination of SRTM, Corona 1966, Spot 1986, Landsat 1987, Orbview 2003, and Sentinel2A 2017 data will help in monitoring the changes around the study area. The Bands combination and the spatial statistical analysis are considered to be the most effective methods in the examination of the new built-up indices. GIS techniques and some models would be suggested as solutions to protect the archaeological area, according to UNESCO recommendations.

Keywords: supervised classification; heritage management; satellite imagery; spatial statistical

1. Introduction

In 1962, the UNESCO recommended two concepts that would guide the World Heritage List (WHL) nomination, which was the preservation and protection of natural and rural landscapes. Furthermore, in 1972, they issued a unique international instrument to protect and recognize cultural and natural heritages [1]. Large numbers of heritage sites around the world are fragile properties, and they are faced with different risk [2]. Cultural heritage is always under pressure from a variety of problems [3,4]. Natural disasters, urban development, pollution, looting, inappropriate site management, and conflict are just some examples of the risk that faced these sites [5,6]. In more details, the threats can be natural or

anthropogenic. Natural risk can be divided into two categories: catastrophic and sudden occurrences, such as a flood or an earthquake, which have an immediate impact on heritage sites, and continuous threats with cumulative and slow effects, such as erosion and material decay. On the other hand, anthropogenic risks result from a number of different human activities, including development and inappropriate management, the lack of maintenance, and neglect [7]. The monitoring and maintenance of an archaeological site and its landscape are fundamental management responsibilities [8–10]. Maintenance is a routine activity, whose absence constitutes one of the greatest and least recognized threats to long-term preservation. Monitoring is to provide information regarding the condition of the heritage place, or the quality of the visitor experience, or the effectiveness of management itself, in order to make certain that necessary actions should follow [11]. The first step in creating a NHR (National Heritage Register) and SMR (Site and Monuments Record) is a literature survey to gather the accumulated knowledge on the sites that were already surveyed and excavated. The next step is a nationwide archaeological survey. The NHR is a primary and reliable source of information for archaeologists, heritage managers, policy-makers, tourist organizations, researchers, developers, planners, community groups, and the general public [12]. Remote sensing is one of the main foundations of archaeological data, underpinning knowledge and understanding of the historic environment and the Aerial Archaeology provides up to date expert statements on the methodologies, achievements, and the potential of remote sensing with a particular focus on archaeological heritage management [13]. In fact, the early applications of satellite for studies on past human activities while using the Thematic Mapper (TM) were attempted, starting from the 1980s [14,15].

1.1. Study Area

Jeddah city is situated on the west coast of Saudi Arabia (21.4858° N, 39.1925° E), with its mapped area occupying a stretch of land along the shoreline of the Red Sea, 60 km long and 40 km wide. The urban boundary of the city is approximately 1765 km² and the total area is about 5460 km². The city has a hot and dry desert climate with high humidity and it receives an annual average rainfall of about 54 mm [16]. Jeddah is presented as the second biggest city and the most significant commercial center in Saudi Arabia [17]. Our study focused on a total area of about 67.14 km² around the ancient Jeddah that presented about 0.66 km² (Figure 1a,b).

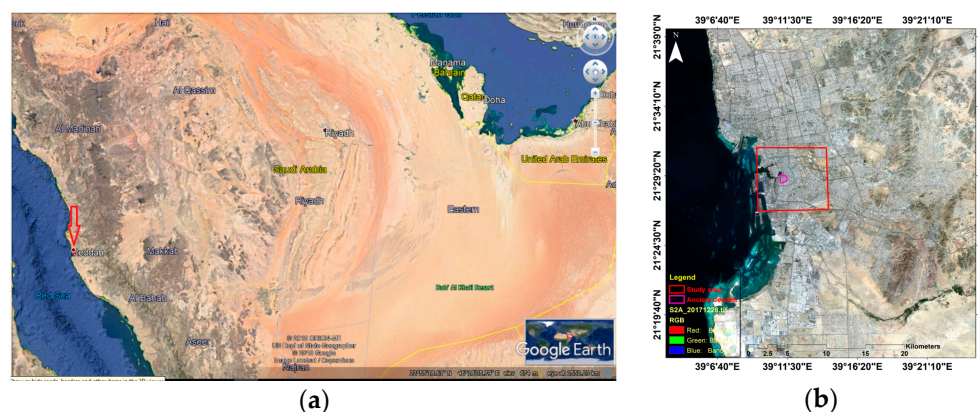
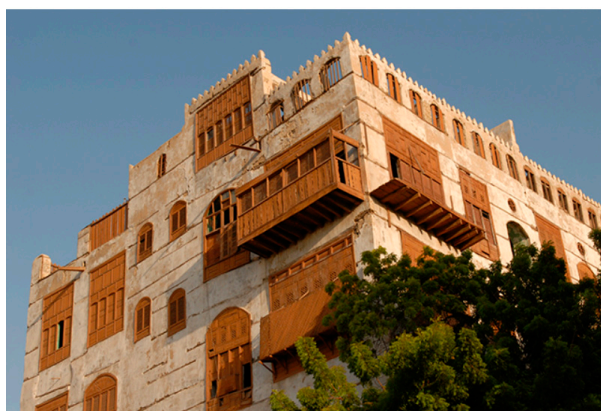


Figure 1. Shows the study area of Jeddah: (a) the Jeddah city by Google Earth; (b) Ancient Jeddah (the study area) by Sentinel2A 2017 (RGB 4, 3, 2).

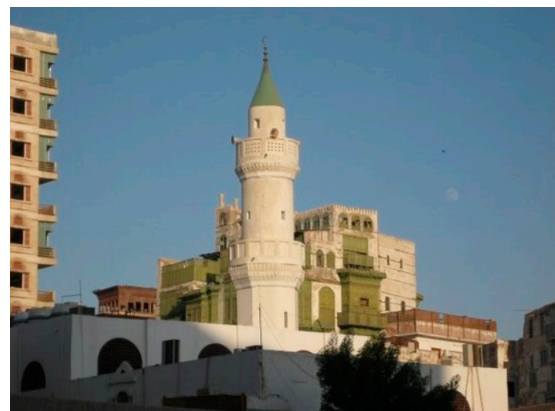
1.2. Archaeological View

In the Kingdom of Saudi Arabia and also in the Middle East region, the city of Jeddah is considered to be one of the most important historical cities [18]. Historical Jeddah is a historical city that is known locally as Jeddah the town in the center of Jeddah, which is one of the ancient historical cities that has its great position religiously, geographically, and historically [19]. Jeddah has a significant

geographical position and it is a port for the population of Mecca. It was characterized by its extensive trade and remarkable wealth. The flourishing trade was based on the activities of the Persian merchant community who settled there [20]. It was occupied by the Persian Emperor in the middle of the sixth century B.C. and was subjected to the Habashi (Ethiopian) occupation and the Portuguese threats and attacks in about 948 AH/1541 AD due to its crucial port in the marine trade [21]. Jeddah has witnessed great historical transformation since it was first cared for by the Third Rashid Caliph Othman bin Affan and it became a port of Mecca instead of the port of Shuaiba that was used by the commercial vessels of the Roman in the trade with Mecca [22–24]. The importance of Jeddah in the Mamluk era is obviously shown in the concerns of the Mamluk rulers to protect the two Holy Mosques and the securing of pilgrimage routes, in addition to Jeddah being a vital and important commercial port [25]. The city has been under Ottoman control since it had a vital and strategic position as an important naval station for the supply of water and fishing vessels. Since then, Jeddah has gained its historic Islamic significance, which has made it one of the most important cities on the Red Sea coast and a gateway to the two Holy Mosques [26]. The urban heritage of Jeddah is reflected in its historic neighborhoods or lanes, as it was called in ancient times [27]. Its architectural heritage characterizes the historical depth of the city of Jeddah, which includes a special collection of important historical and heritage buildings. The historical wall of Jeddah, which surrounded the city, is one of the most important historical monuments that characterized the city of Jeddah, whose parts of it still exist that were built in about 911 AH/1505 AD during the reign of the Mamluk Sultan Qansoh Ghuri [28]. In addition to the fence, a military garrison was built to protect the wall and the city from the external threats that were posed by the Portuguese threats and attacks. The fence contains six doors in order to protect the Holy Land and the Red Sea area [29]. Each door has 16 arms and a new door was added at the beginning of this century, and the wall was removed in 1947 [30]. The architectural designs of homes and houses, in Jeddah represent a special architectural character. They are part of the architectural style of the Hijaz region, which is characterized by strength, durability, and hardness. The houses were mostly constructed of skeletal stone [31]. The wooden parts, especially the doors, were decorated with various and different decorative elements, such as animal, plant, and engineering firms. On these decorative patterns were obviously foreign art effects from Europe, Egypt, Syria, and India [32,33]. Some of the archeological buildings of the city still exist, such as Al-Jamjoom House, Al-Baashen House, Al-Shaikh, Al Qabal, Al-Shafi'i Mosque, Al-Mazloum, Al-Banaja, and Al-Zahid. Additionally, many historical khans (e.g., Khan Indians, Khan Kasbah, Khan Aldalalin, and Khan At-tarin [34]). Furthermore, what attracts the attention of the beholder to this ancient city is the existence of many Islamic historical mosques, e.g., the Great Mosque and the Mosque of Uthman ibn Affan [35,36] (Figure 2a–d).



(a)



(b)

Figure 2. Cont.

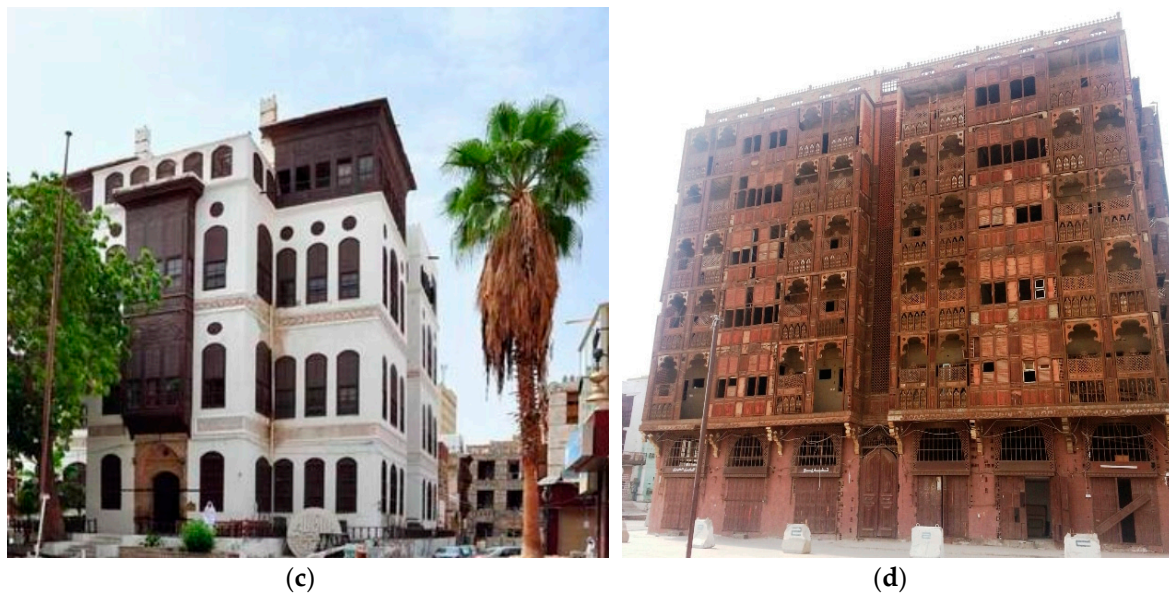


Figure 2. Some of the archaeological buildings in Ancient Jeddah: (a) House of Nassif; (b) Othman bin Affan Mosque; (c) Bayt Ba'Ishan; and, (d) Merchant house [37].

1.3. Problem Definition

Until now, the ancient City of Jeddah still contains traditional urban fabric, along with many historic landmarks and mosques, old paths, and bazaars or Souks; thus, providing a living example of a historic city in Islamic societies [38]. Most of these historic buildings have no database, which considers serious problems should they need to be repaired or rebuilt in the case of potential collapse or erosion due to human activities or environmental risk [39]. Recently, the growth of the city has been rapid and diverse. Unfortunately, these development activities were accompanied by environmental degradation, and the air quality progressively deteriorated. Therefore, both stationary and mobile sources affect Jeddah's environment. While most of the industrial zones (e.g., the oil refinery) were originally built in nonresidential areas, with the urban development that ensued, they have now come to be in the middle of highly populated areas, and some of Jeddah's residential areas are particularly affected by several concrete factories [40]. On the other hand, the subsoil conditions of the city included; the western part of the city is underlain by marine silt and clay, sand, coral limestone, and coral sand. North of Jeddah presents the coastal plain that is underlain for the most part by coral limestone. However, there are places particularly in the south where the plain is underlain, for the most part, by marine silt, clay, and sand. The eastern part of the city essentially consists of in situ weathered sheet wash deposits that were derived from older rock outcropping further to the east. The degree of weathering decreases eastwards [41]. According to the study of Al-Sefry et al. 2006, urban development influenced the groundwater regime beneath these areas. Leakages from different water sources lead to groundwater table level fluctuations and the groundwater level rises. Various types of leakages during the period from 1996 to 2002 caused the groundwater level to rise, on average, at about ± 0.12 m. The extent of groundwater rise coverage locations has increased in 2002 more than 1998, which covers about 61% (910 km²) of the total area, being about 56% in 1998. Hence, there has been about a 1.25% yearly increase, which corresponds to 18.75 km². Consequently, in some coastal-close areas, the depth to water level is less than 2.5 m [42]. There are high concentrations of salt in the groundwater and the concentration of the salts increases towards the west. The chloride and sulphate content of the groundwater ranges from 400–7000 mg/l and 250–3900 mg/l, respectively [43]. This bad geo-environmental status besides the geological situation put the archaeological buildings at risk (Figure 3a,b).

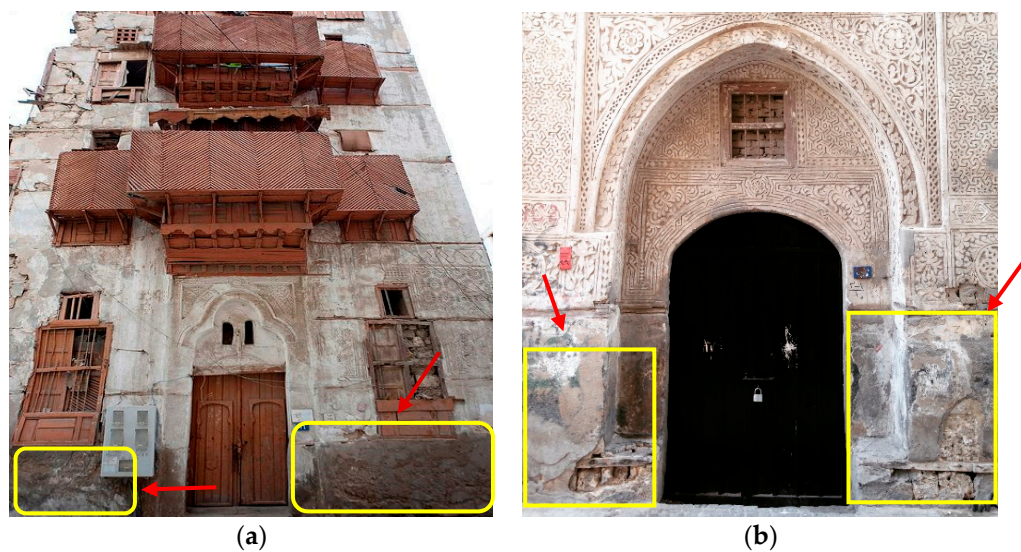


Figure 3. Some of the deterioration in some of the archaeological buildings in Ancient Jeddah as a result of the high level in the groundwater: (a,b) Traditional houses near the entrance to Souq al-Alawi in the al-Balad district [44].

2. Materials and Methods

2.1. Materials

Different sets of data have been integrated to study the effect of the rising of the groundwater levels on the archaeological site. The material of the satellite images are dependent on the one band (Corona, Spot, and Orbview) and multispectral bands (Landsat and Sentinel2A). The collected data in this study included the SRTM, Corona 1966, Spot 1986, Landsat 1987, Orb-view 2003, and Sentinel2A 2017 (Table 1). In this study, various remote sensing data have been used to detect the changes in the urban layer around the study area. Another technique has been carried out while using the band indices to detect the changes between 1987 and 2017, according to the new built-up areas. The supervised classification, remote sensing Indices (built-up indices), and spatial statistical analysis methods have been used in this study. The Digital Elevation Model (two-dimensional (2D)) and SWAT model have been extracted from SRTM radar data. The layer stacking, dark subtract, geometric correction, unsupervised classification, supervised classification, and post supervised classifications techniques are carried out while using ArcGIS 10.4.1, SNAP 6.0, and ENVI 5.1 software.

Table 1. Data collection and satellite images properties.

Number	Satellite	Sensor	Resolution (M)	Acquisition Date	Source
1	Corona	KH-4A	1.8 m	20 March 1966	USGS
2	Spot	1	10 m	24 March 1986	USGS
3	Landsat	TM	30	20 December 1987	USGS
3	Orbview	3	1.2 m	22 December 2003	USGS
4	Sentinel	2A	10 m	28 December 2017	USGS

2.2. Methods

2.2.1. Pre-Processing

The layer stacking, dark subtract, geometric correction, and unsupervised classification have been carried out for the collected data (Corona, Landsat, and Senti-nel2A). The unsupervised classification has been carried out for Corona, Spot, Orbview, and Sentinel-2A. The collected data have been divided into ten classes. Five classes have been chosen by the re-classes tool in ArcGIS software.

2.2.2. Supervised Classification

The supervised classification technique, herein adopted, was based on the maximum likelihood and on training sets (signatures) that previous field knowledge provided. All of the images are a multi-spectral data, but Corona, Spot, and Orbview are one band data. The supervised layers for all of the images have been transformed into digital shapefiles in the ArcGIS software to process the measurements. Finally, the changes in the areas have been measured to detect the changes between 1966 and 2017 for the urban layers.

2.2.3. Spatial Statistical Analysis (Spatial Distribution Analyzing by Getis-Ord and Hot Spot)

In fact, Getis and Ord created the family of G statistics, which were used to study the evidence of identifiable spatial analysis patterns. These global statistics are usually too general in a way that local patterns are likely to be neutralized over a vast area and become undetected. While the level of spatial in the fact is dependency may significantly vary across space suggests that the capacity to monitored and pinpoint the spatial heterogeneity is more desirable. Subsequently, Local Moran's I was developed by decomposing Global Moran's I to compensate for such limitations and frequently used in many hot spot analyses [45]. Getis-Ord G_i^* statistic here is denoted as Equations (1) and (2) [46,47].

$$\text{Getis - Ord } G_i^* = \frac{\sum_{j=1}^n w_{i,j} x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^n w_{i,j}^2 - (\sum_{j=1}^n w_{i,j})^2}{n-1}}} \quad (1)$$

$$S = \sqrt{\frac{\sum_{j=1}^n x_i^2}{n} - (\bar{X})^2} \quad \bar{X} = \frac{\sum_{j=1}^n x_i}{n} \quad (2)$$

In Formula (2), X_j represents the value of attributes to features J , W_{ij} is spatial weight between i and j features, and (n) is the number of features: G_i is kind of Z score [48].

2.2.4. Remote Sensing Indices (Built-Up Indices)

The band-designations of the two sensors (Landsat Thematic Mapper (TM) and Sentinel-2) have various proprieties (Tables 2 and 3) [49,50]. The Sentinel-2A satellites have a single multi-spectral instrument, with 13 spectral channels in the visible/near-infrared and short wave infrared spectral range. Accordingly, the bands resampling method was an important step in Sentinel image before the starting in the indices preprocessing to have similar properties of Sentinel2A and TM satellite image 3.

Table 2. Band-designations for the used bands in Landsat Thematic Mapper (TM).

Landsat 4 Thematic Mapper (TM) Bands	Wavelength (Micrometers)	Resolution (m)
Band 2—Green	0.52–0.60	30
Band 3—Red	0.63–0.69	30
Band 4—Near Infrared (NIR)	0.76–0.90	30
Band 5—Shortwave Infrared (SWIR) 1	1.55–1.75	30
Band 7—Shortwave Infrared (SWIR) 2	2.08–2.35	120* (30)

Table 3. Band-designations for the used bands in Sentinel-2A.

Sentinel-2 Bands	Central Wavelength (μm)	Bandwidth (nm)	Resolution (m)
Band 3—Green	559.8	36	10
Band 4—Red	664.6	31	10
Band 8—NIR	832.8	106	10
Band 11—SWIR1	1613.7	91	20
Band 12—SWIR2	2202.4	175	20

In this study, three kinds of urban indices have been extracted from the TM and Sentinel2A satellite images. The first method is NDBI (Normalized Difference Built Index), which is produced by the following equation [51] to clear the changes in the built-up areas (Equations (3)–(5)).

$$NDBI = \frac{SWIR1 - NIR}{SWIR1 + NIR} \quad (3)$$

$$NDBI = \frac{band11 - band8}{band11 + band8} \text{ Sen} \quad (4)$$

$$NDBI = \frac{band5 - band4}{band5 + band4} \text{ TM} \quad (5)$$

The second method, a normalized difference soil index (NDSI), was carried out using the combination of SWIR2 and Green bands in TM and Sentinel2A data [52] (Equations (6)–(8)).

$$NDSI = \frac{SWIR2 - Green}{SWIR2 + Green} \quad (6)$$

$$NDSI = \frac{band12 - band3}{band12 + band3} \text{ Sen} \quad (7)$$

$$NDSI = \frac{band7 - band2}{band7 + band2} \text{ TM} \quad (8)$$

The third method is the modified normalized water index proposed (MNDWI). This method is developed by [53]. This method is extracted according to the green and SWIR1 bands in TM and Sentinel2A satellite images (Equations (9)–(11)).

$$MNDWI = \frac{Green - SWIR1}{Green + SWIR1} \quad (9)$$

$$MNDWI = \frac{band3 - band7}{band3 + band7} \text{ Sen} \quad (10)$$

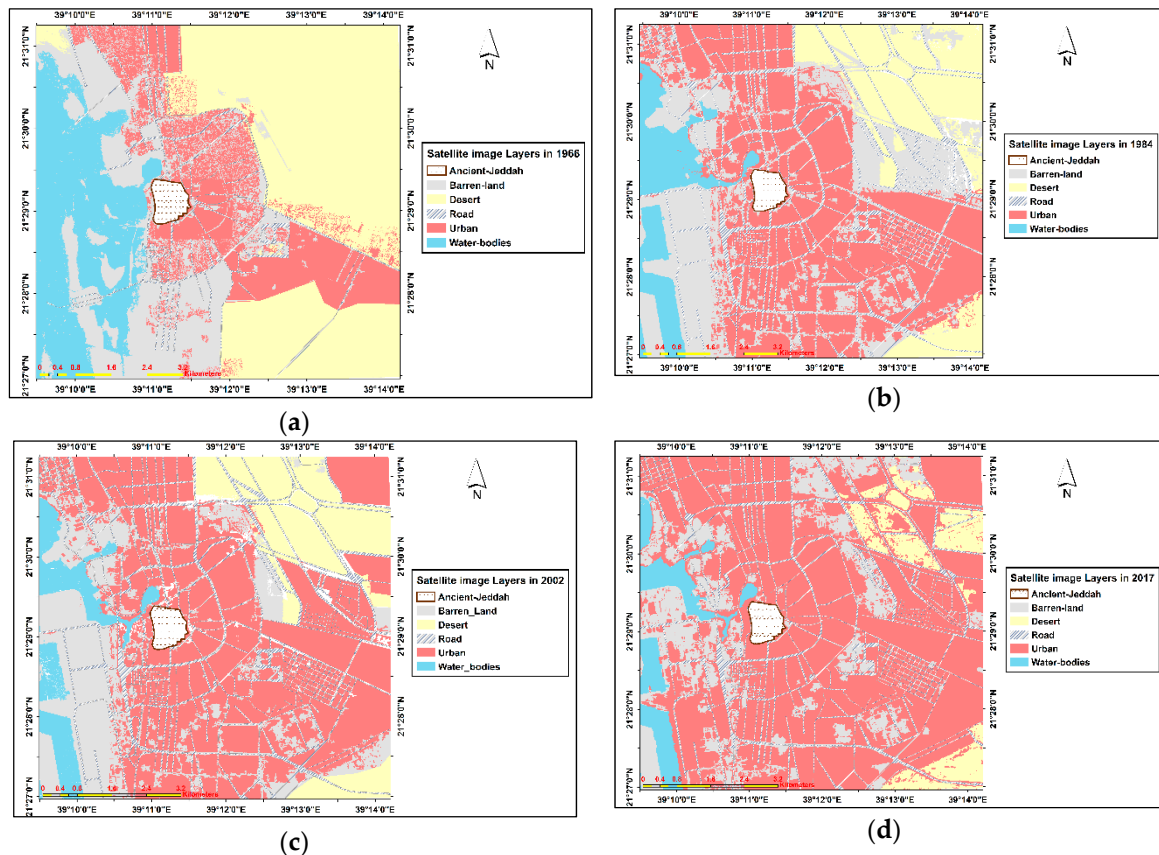
$$MNDWI = \frac{band2 - band5}{band2 + band5} \text{ TM} \quad (11)$$

3. Results and Discussion

According to the results of the supervised analysis in Corona (1966), Spot (1986), Orbview (2003), and Sentinel 2A (2017) (Table 4) imageries (Figure 4a–d) that were acquired for Jeddah area revealed that urban areas increased by about 15.07 km² between 1966 and 1986, and about 4.82 km² between 1986 and 2003, and finally about 8.96 km² between 2003 and 2017. While, the results showed that the barren land is increased by about 5.93 km² between 1966 and 1986 and decreased by about 1.82 km² between 1986 and 2003, and finally decreased by about 3.96 km² between 2003 and 2017. On the other hand, the desert area is decreased about 14.51 km² between 1966 and 1986, and by about 2.36 km² between 1986 and 2003, and finally about 4.20 km² between 2003 and 2017. Finally, the waterbodies are decreased about 6.49 km² between 1966 and 1986, and about 0.64 km² between 1986 and 2003, and finally about 0.80 km² between 2003 and 2017 (Figure 5). Generally, the changes have been extracted by the differences that were revealed from unsupervised and supervised classification applied to the scenes that were acquired at different times for the study area. The results obtained from the classification images of the four dates are used to calculate the area of change related to different land covers. The results proved that the urban area has continued to increase between 1966 and 2017 (Figure 6).

Table 4. Total changes in the urban, barren land, desert, and water areas (expressed in km²) in the Jeddah area.

Class	1966 (km ²)	Change Detection \pm km ²	1986 (km ²)	Change Detection \pm km ²	2003 (km ²)	Change Detection \pm km ²	2017 (km ²)
Urban	12.5	15.07	27.57	4.82	32.39	8.96	41.35
Barren Land	14.5	5.93	20.43	−1.82	18.61	−3.96	14.65
Desert	25.45	−14.51	10.94	−2.36	8.58	−4.2	4.38
Waterbodies	11.55	−6.49	5.06	−0.64	4.42	−0.8	3.62

**Figure 4.** The results of the supervised classification for the study area: (a) Barren, Desert, Road, Urban and Waterbodies in 1966; (b) Barren, Desert, Road, Urban and Waterbodies in 1986; (c) Barren, Desert, Road, Urban and Waterbodies in 2003; and, (d) Barren, Desert, Road, Urban, and Waterbodies in 2017.

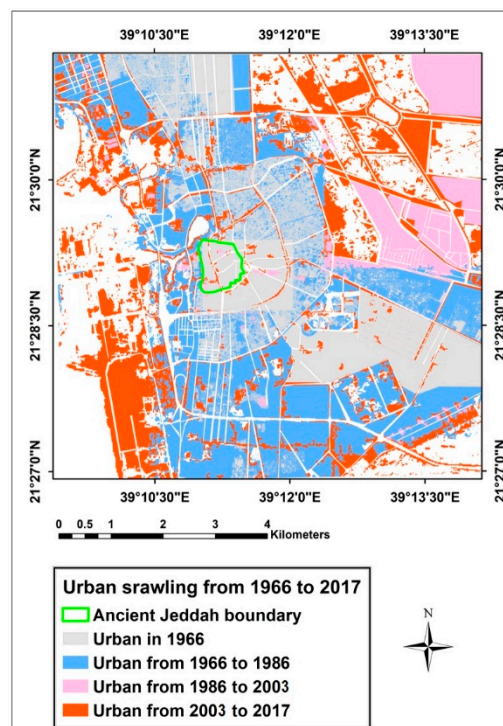


Figure 5. The total changes in the four studied layers (Barren, Desert, Road, Urban, and Waterbodies) in the study area between 1966, 1986, 2003, and 2017.

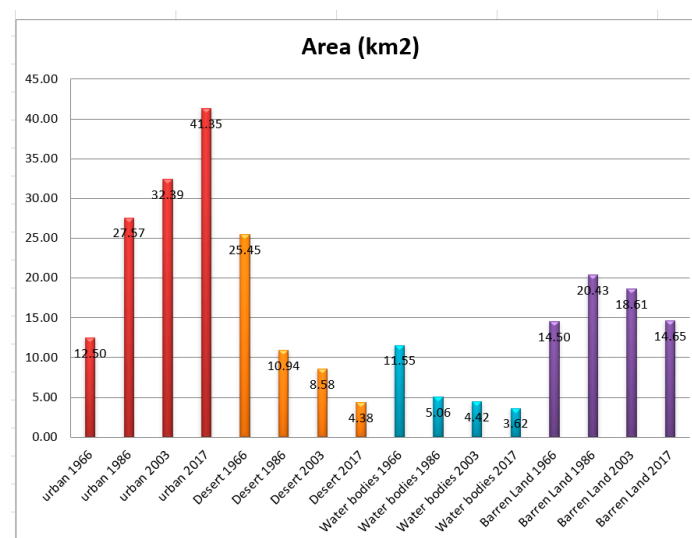


Figure 6. Shows graph for the total changes in the four studied layers (Barren, Desert, Road, Urban, and Waterbodies) in the study area between 1966, 1986, 2003, and 2017.

The HotSpots spatial distribution analysis has been used for calculating the distributions in the urban pattern of the urban area. This method calculates the value of the Z score, P-value, and a code that indicates the type of cluster for the urban feature. The value of Z score and P value show the significance of the calculated index. The Z scores indicate the place of particular value in a dataset relative to the mean, standardized with respect to the standard deviation. The P value indicates whether the result is statistically significant; the results of hot spot index analysis are proved that the urban areas have continued to increase between 1966 and 2017 (Figure 7a–d).

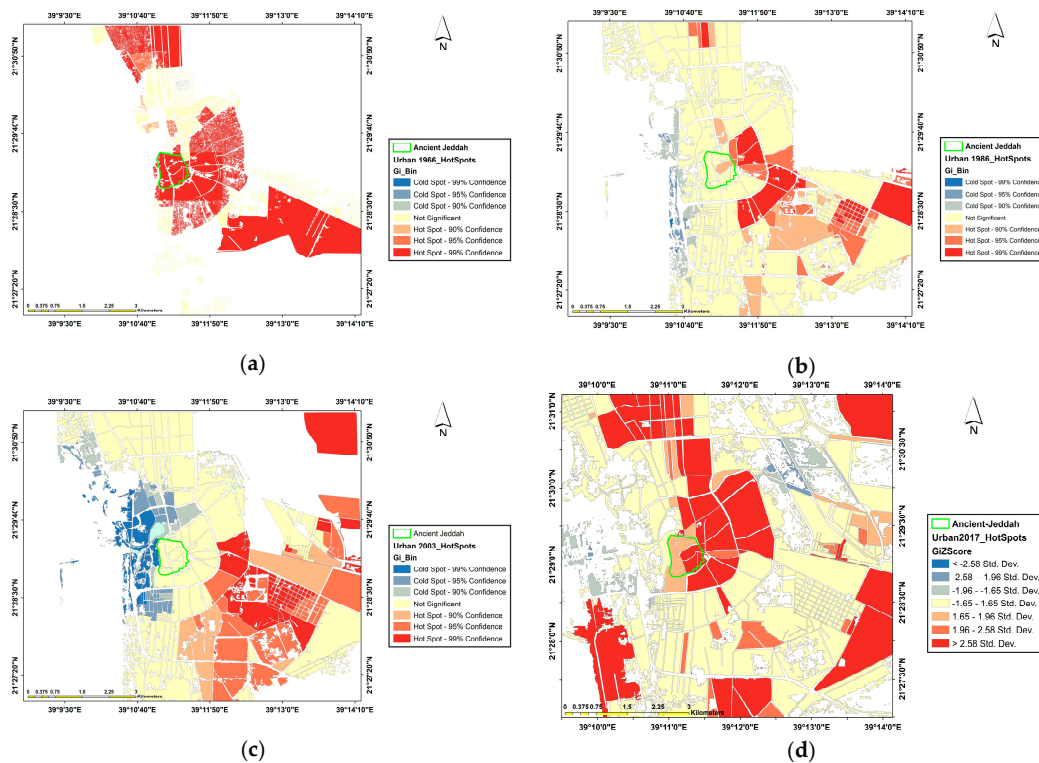


Figure 7. Shows the total changes in the urban layer by The HotSpots spatial distribution analysis between: (a) 1966; (b) 1986; (c) 2003; and, (d) 2017.

The satellite-based indices, herein considered NDBI (Normalized Difference Built Index), NDSI (Normalized difference soil index), and MNDWI (Modified normalized water index proposed), show that, for all indices, NDBI between 1987 and 2017 (Figure 8a,b), NDSI between 1987 and 2017 (Figure 9a,b), and MNDWI between 1987 and 2017 (Figure 10a,b); low values are associated with waterbodies areas and high values are associated with both desert areas and built-up areas for all indices. Furthermore, the results of all the indices proved that the urban areas have a continuous increase in space between 1987 and 2017.

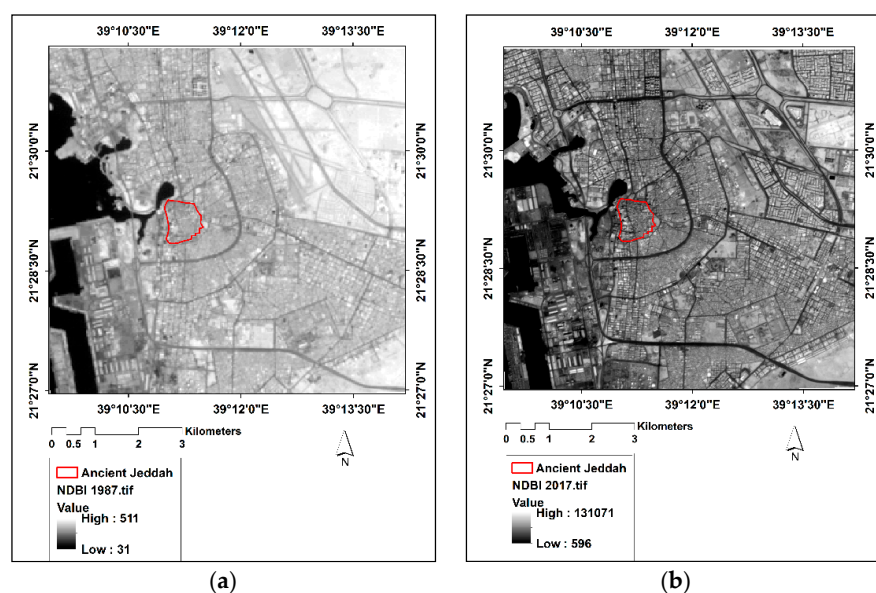


Figure 8. The changes in the studied layers (urban, barren land, desert and water bodies) using NDBI index between: (a) 1987; and, (b) 2017.

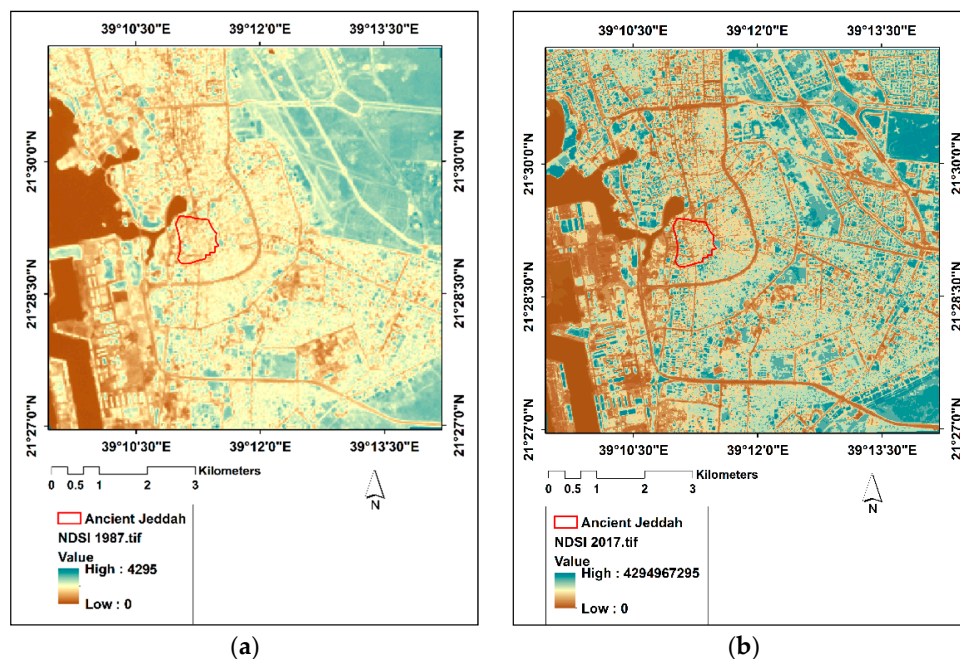


Figure 9. The changes in the studied layers (urban, barren land, desert and water bodies) using NDSI index between: (a) 1987; and, (b) 2017.

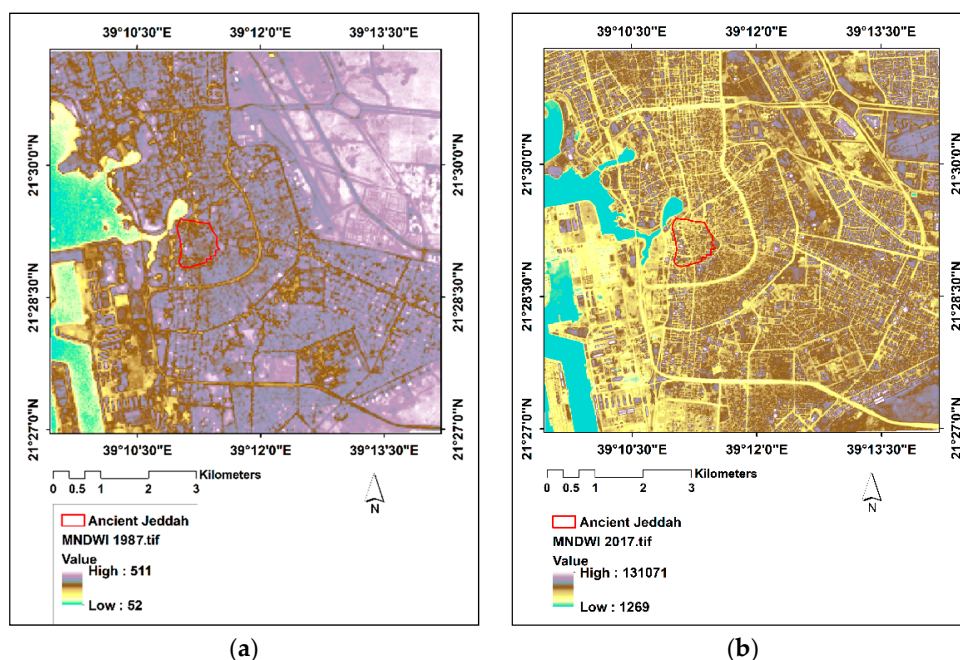


Figure 10. The changes in the studied layers (urban, barren land, desert and water bodies) using MNDWI index between: (a) 1987; and, (b) 2017.

4. Recommendation

The World Heritage system requires States Parties to engage in the management of cultural heritage properties in two different and significant stages. In the first stage, a State Party must first demonstrate, as a part of the inscription process, how it will manage the Outstanding Universal Value of the property by responding to issues that were raised in the nomination format and by demonstrating the existence of a management plan that is adequate for protecting the property. The second stage, after inscription, is that a State Party must respect its commitment to safeguarding the Outstanding

Universal Value of the property through effective long-term management [54,55]. In this study, the 2D Elevation model and the watershed has been carried out by the SWAT model in ArcMap. According to the SRTM Dem and SWAT tool, the study area is situated between 5m and 13m elevation. It is observed that the direction of the inclination is from the east to the west side. Additionally, the study area is situated close to two streams, and this situation gave the indicator that one of the reasons of rising the groundwater level in the site of the ancient Jeddah (Figure 11a). According to the result of the SWAT model, the proposed model is created to protect the heritage site from the risk of the flooding that can happen. This proposed is created, depending on building three dams over the streams according to the direction of the stream and the elevation of the study area (Figure 11b).

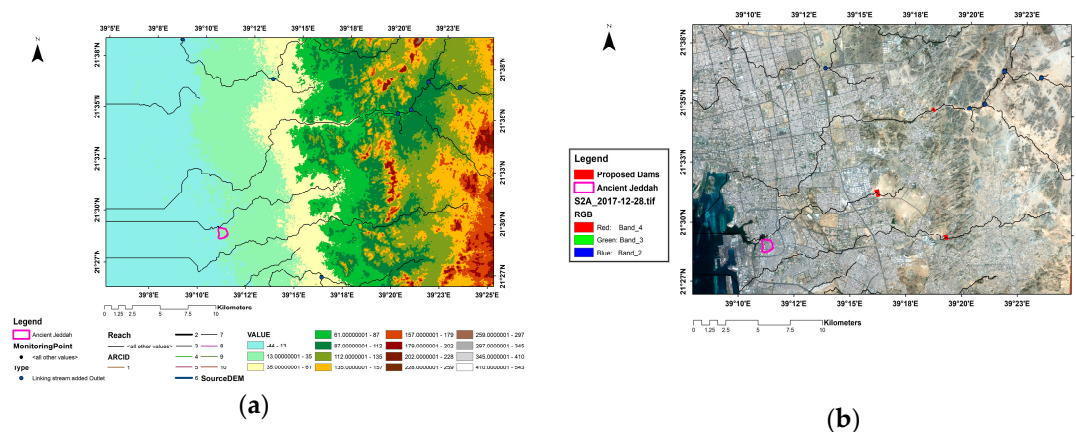


Figure 11. SWAT model for the study area shows: (a) the streams and two-dimensional (2D) elevation model; (b) proposed model (three suggested dams) for protecting the study area from any expected flooding.

Here, in order to preserve and protect the core area, the buffer zone is planned according to sustainable development criteria, adding value to the core itself [56]. This buffer zone is circled around the ancient Jeddah with 100m that should be empty from any kind of buildings. The suggested buffer zone will decrease the geo-environmental risk around the studied heritage area (Figure 12).

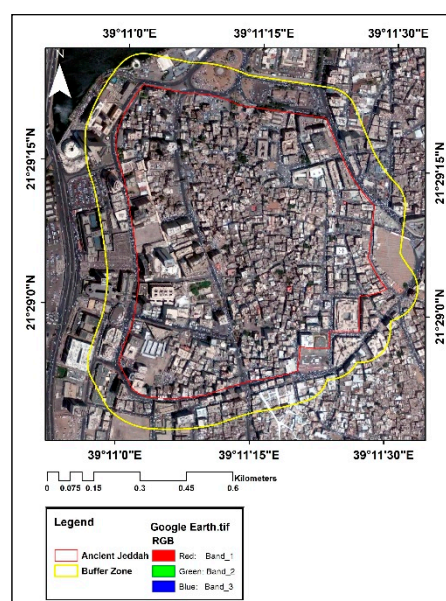


Figure 12. Shows suggested a buffer zone around the boundary of ancient Jeddah is created according to UNESCO recommendations to protect the study area.

5. Conclusions

This study presents the possibility of using remote sensing images in terms of design and planning a smart and sustainable cultural heritage management. The aims of our investigations were focused on the estimation of the effect of urban sprawling around Ancient Jeddah, which is considerably affected by geo-environmental risk, according to the land use/cover changes between 1966 and 2017. The analysis of multi-temporal satellite data processed using GIS, SNAP, and Envi software provided invaluable information and provided some of the innovative solutions for risk mitigation.

Author Contributions: The research article included two main contributions: GIS analysis and satellite data interpretation. The GIS analysis was carried out by A.E. Satellite data interpretation was processed by R.L. Writing of the manuscript was done through cooperation between A.E., A.S.e. and R.L. The last version of the article was revised by R.L. All authors have read and agreed to the published version of the manuscript.

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