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RESEARCH ARTICLE

Land use/cover change detection in the coastal zone of Safaga region, Red Sea, Egypt

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Abstract

Changes in land use and cover (LU/LC) are essential for sustainable development and managing natural resources. This study examines how remote sensing data and field observations can be used to analyze LU/LC in Safaga region, Red Sea, Egypt. This region drained by two watersheds (Wadi Safaga and Wadi Um Taghir) and including important marinas, mainly aluminum and phosphate in the Egypt's Red Sea. Its coastal zone is suffering from many anthropogenic and natural activities that result in severe environmental changes. The present study is aimed to detect environmental changes due to the anthropogenic activities in the coastal zone of Safaga. Multi-temporal Sentinel-2 data from the years 2016 and 2022 are processed and analyzed using GIS Image Analysis approach. The results showed that the study area experienced changes in terms of infrastructures, urbans and degradation of the Red Sea coast. Landfilling and pollution represent one of the most serious threats to the Red Sea environments. Field observations validated the multi-temporal changes. Overall, integration of remote sensing and GIS techniques are valuable for detecting spatio-temporal changes of coastal regions.

Keywords: Change detection; GIS; Land use/cover; Red Sea; Sentinel-2.

1. Introduction

The coastal region represents one of the most desired areas for urbanization and coastal development. Globally, coastal communities' density is about 3 times higher than human population inland (Martinez *et al.*, 2006; Barbier *et al.*, 2008). Furthermore, it is predicted that the coastal development of the world's shoreline will be rise to 91 % over coming three decades (Sale *et al.*, 2008). Consequently, severe environmental impacts of high magnitude influence the coastal ecosystems due to the anthropogenic activities (Martinez *et al.*, 2006) leading to degradation of these natural resources rapidly and severely all over the world (Barbier *et al.*, 2011; He *et al.*, 2014). The development of Safaga region is huge.

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It includes the city of Safaga with its infrastructure, the industrial (Aluminum and Phosphate) and civil ports, and the main highway (Hurghada- Quseir). Therefore, its coastal zone is suffering from many anthropogenic activities that led to environmental changes in the Red Sea environments (Mansour *et al.*, 2000; 2005; 2011). The present study is aimed to detect environmental changes due to the anthropogenic activities in the coastal zone of Safaga region.
Change detection which is "the process of identifying differences in the state of an object or phenomenon by observing it at different times" (Singh, 1989) is widely used in remote sensing approaches. Thus, remote sensing detects the amount of variation in the earth's surface using two or more satellite images of different times and covering the same geographic area (Mahdavi *et al.*, 2019; Seydi *et al.*, 2020). Therefore, multi-temporal data is used for change detection for

analyzing the temporal impacts and quantify the differences of phenomena (Hussain *et al.*, 2013), and enables to quantify the variations, determine the geographic location, and type of variations and evaluate the accuracy of change detection results (Macleod and Congalon, 1998; Coppin *et al.*, 2004; Hussain et al., 2013).

Remote sensing technique has high ability to detect and map changes in the coastal regions in fast and coast effective manner (El-Asmar, 2002; Chong, 2004; Li and Damen, 2010). Change detection by using remote sensing data is vital for proper management and sustainability of the natural resources (Hasanlou *et al.*, 2018; Seydi *et al.*, 2020).

Several studies have applied remote sensing data for detection environmental impacts associated with the anthropogenic and natural activities on the coastal region of the Egyptian Red Sea (Among them; El-Gamily *et al.*, 2001; Dewidar, 2002; Moufaddal, 2005; Kamh *et al.*, 2012; El-Asmar *et al.*, 2015; Madkour, 2015). An integrated approach of remote sensing, GIS, and field data will be integrated to detect environmental changes due to anthropogenic activities in the coastal zone of Safaga region.

2. Study area

The study area is situated in Safaga region in the Egyptian Red Sea coast (Figure 1). Sagfaga city occurs about 60 Km south of Hurghada and 82 Km north of Quseir. It represents one of the attractive areas in the Red Sea for tourism, urabnization, coastal development and industries. It contains the largest port on the Egyptian Red Sea coast. Safaga harbour (26˚ 43’ 42’’ N to 26˚ 44’ 22’’ N and 33˚ 56’ 20’’ E to 33˚ 56’ 05’’ E) is extremly important for the Egyptian international trading. The harbour includes terminal for passengers, coal, bauxite, quartz, orthoclase and cement transportation. Another harbour (Safaga minig port) for Phosphate shipment is also occur south of the main Aluminum harbour. The area is drained by two major watersheds namely W. Safaga and W. Um Taghir.

The area is characterized by dry climate, with long hot summers and short warm winters. It is located in semi-arid climate condition. It is characterized by prevailing arid conditions which are evident by the low amount of precipitation and the extremely high evaporation rate.

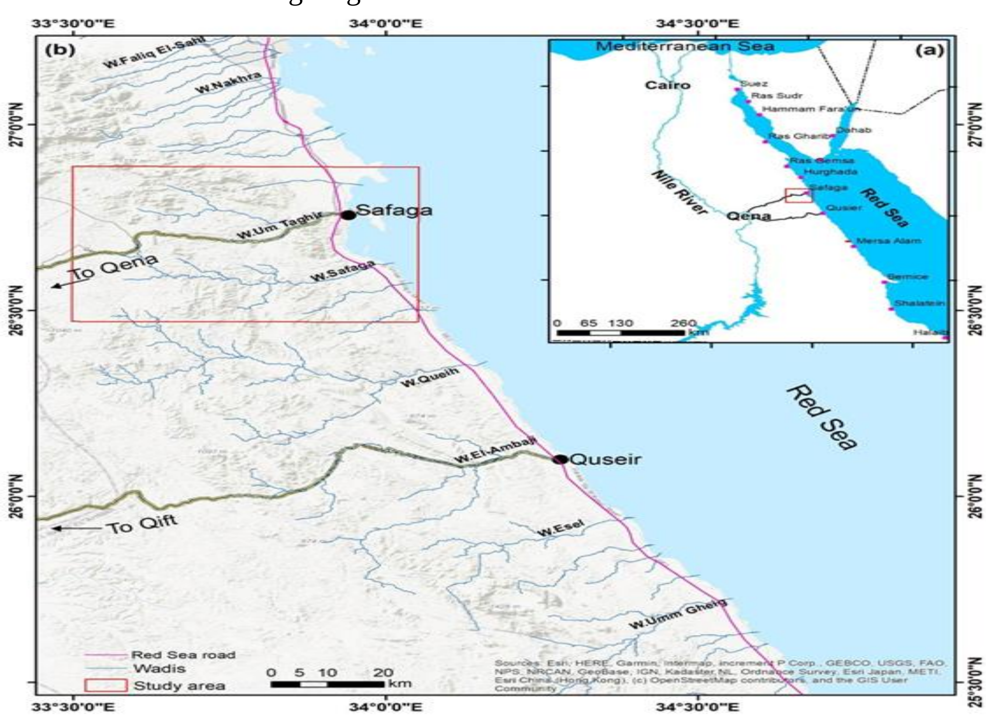

Figure1. Location map of the study area.

3. Data and methods

The present study utilized remote sensing data and field observations to detect environmental changes in the coastal zone of Safaga region. Remote sensing is the technology of gathering information about objects from a distance without direct contact with them depending on reflected and emitted electromagnetic radiation (Schowengerdt, 2006). It is unique technique that has ability to gather, process, analyze and interpret big dataset of temporal and spatial resolution depending on sensors, measurements and images obtained from satellites and aircrafts (Mohamed and Elmahdy, 2017; Nasr *et al.,* 2020). So, it is more effective for coastal zone monitoring and change detection than the traditional techniques (Martin, 1986; El-Raey *et al.,* 1995; Dewidar, 2002). Remote sensing data enables us to determine the impact of anthropogenic activities in the coastal zone of Safaga region.

SRTM is a source of elevation of the earth’s surface (Farr *et al.,* 2007) that represents the appropriate spatial resolution of global open digital elevation models with approximately 30 m spatial resolution (Radočaj *et al.,* 2020). It is based on the radar interferometry technology, which compares two radar pictures taken from slightly different angles but of the same geographic area in order to process elevation data (Radoaj *et al.,* 2020). The X-band radar system (X-SAR) and the C-band radar system (SIR-C) are two interferometric synthetic aperture radars (InSAR) that are advanced (Liu *et al.,* 2020). The first SRTM C-band system (30 m and 90 m resolution) was released in 2003, with the greatest SRTM resolution (30 m or 1 arc-second) being available solely in the United States and the SRTM 90 m resolution (3 arc-second) being available in other places outside of the United States (Liu *et al.,* 2020).

In recent years, there has been a significant increase in the availability of timely and free satellite remote sensing data. The capacity for monitoring land cover change at high spatial resolution has increased significantly with the launch of the Copernicus Sentinel satellites by the European Space Agency (ESA). Compared to Landsat 8 and 9, Sentinel-2 offers multispectral (MS) imagery with a finer spatial and temporal resolution. Sentinel-2 can map even little changes due to its 10 m spatial resolution. Sentinel-2 has a better chance than Landsat of capturing an image without any clouds because of its 5-day temporal resolution. Therefore, two date scenes that acquired on 12th December 2016 and 21st November 2022 are used to map change detection.

4. Results and discussion

The study area's elevation ranges from 0 m to 1400 m (a.s.l), according to the findings of the DEM-SRTM analysis (Figure 2). Model's elevation values and the drainage channel networks that were automatically retrieved for the current study refer to the substantial runoff toward the east (DEM). This is revealing a broad headwater area and the uplift reached its peak at its western end. Due to a lack of average rainfall, as shown by the Tropical Rainfall Measuring Mission (TRMM) data, the amount of precipitation ranged from 0.014 to 0.024 mm/day from 1998 to 2012. (Figure 3).

With the use of ArcGIS' spatial analyst tool, the changes in LU/LC are detected between two Sentine-2 images of 2016 and 2022 (Figure 4). In this method, the zero value indicates that there are no differences between the two scenes, and the more the positive value deviates from zero, the more differences there are between the dates. (Figure 4) shows areas of positive change highlighted in dark blue, whereas areas of negative change highlighted in high dark brown. Changes in infrastructures, urbans, and degradation of the Red Sea coast due to the anthropogenic activities are detected.

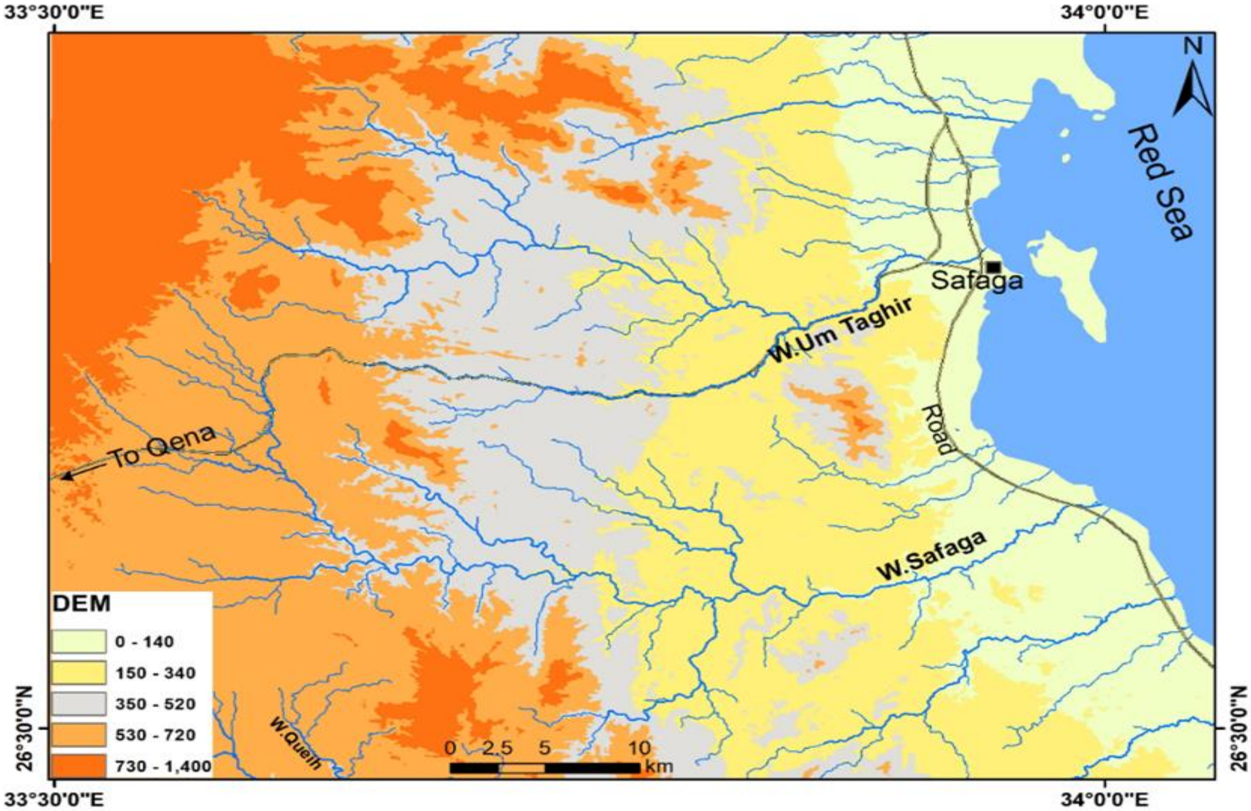

Figure 2. SRTM DEM data of the study area overlain by stream-networks.

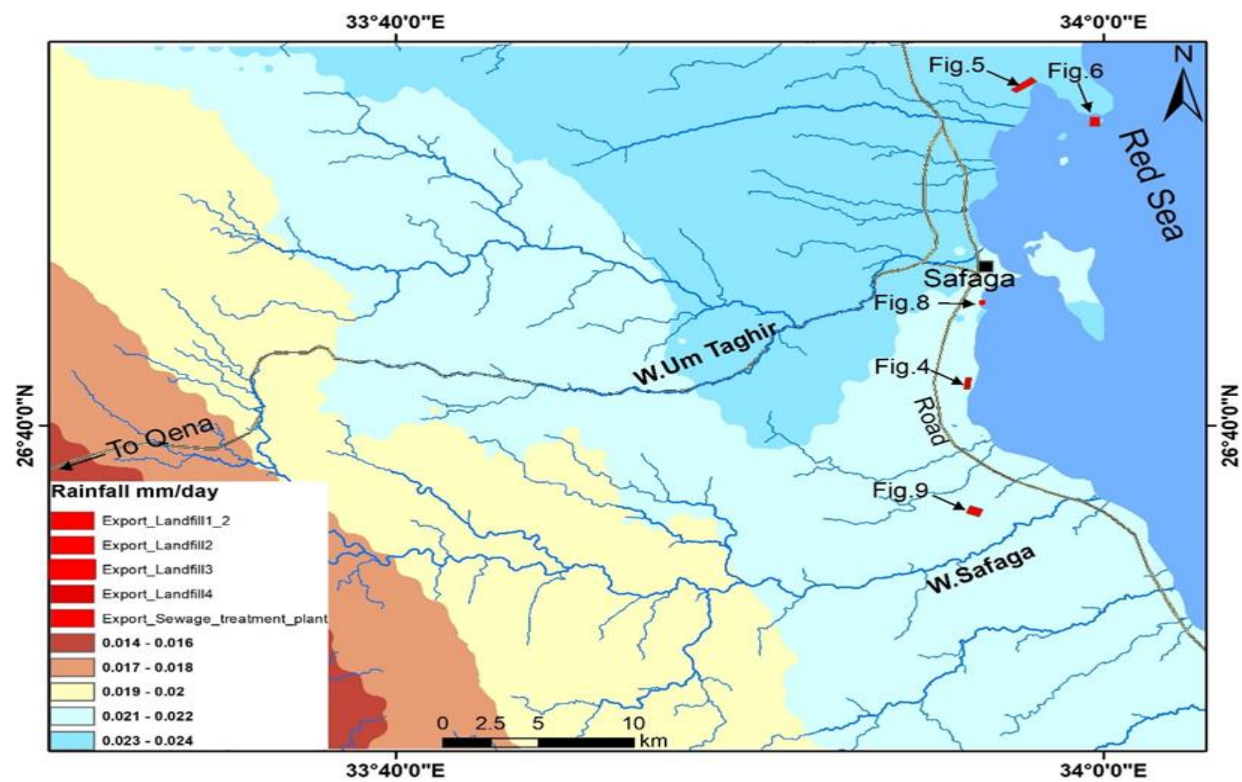

Figure 3. Spatial distribution of TRMM data of Safaga area (average Jan 1, 98 to May 31, 2012) and locations of detected environmental changes.

Based on alaysis of Sentinel-2 data which is characterized by visible and infrared wavelengths is effective for monitoring and mapping shoreline (DeWitt *et al.,* 2002) because the coastal and marine ecosystems; land, vegetation and water interact with electromagnetic radiation in different manner as land and vegetation reflect the infrared wavelength strongly while the water absorbs it effectively (Alesheikh *et al.*, 2007; Van and Binh, 2008).

Safaga maritime seaport and Safaga mining port represent a major problem in the coastal zone of Safag region that already led to pollution and destructions to the Red Sea environments either from shipping or landfilling and dredging operations (Mansour *et al.,* 2000; 2005; 2011). Now there is development and enlargement for Safaga mining port that results in shoreline change due to large amounts of landfilling and dredging. Figure (4a) is sentinel-2 image (2016) showing the shoreline before modification while figure (4b) is sentinel-2 image (2022) showing the shoreline change due to landfilling during development and enlargement of Safaga mining port. Figure (4c) is a change detection image showing the change of shoreline between 2016 to 2022 with large amounts of landfilling that appear in brown color. Figure (4d) is high resolution GeoEye-1 image (2022) support the landfilling process that extended in Safaga mining port. Field observations (Figure 4e) validated the results of remote sensing data.

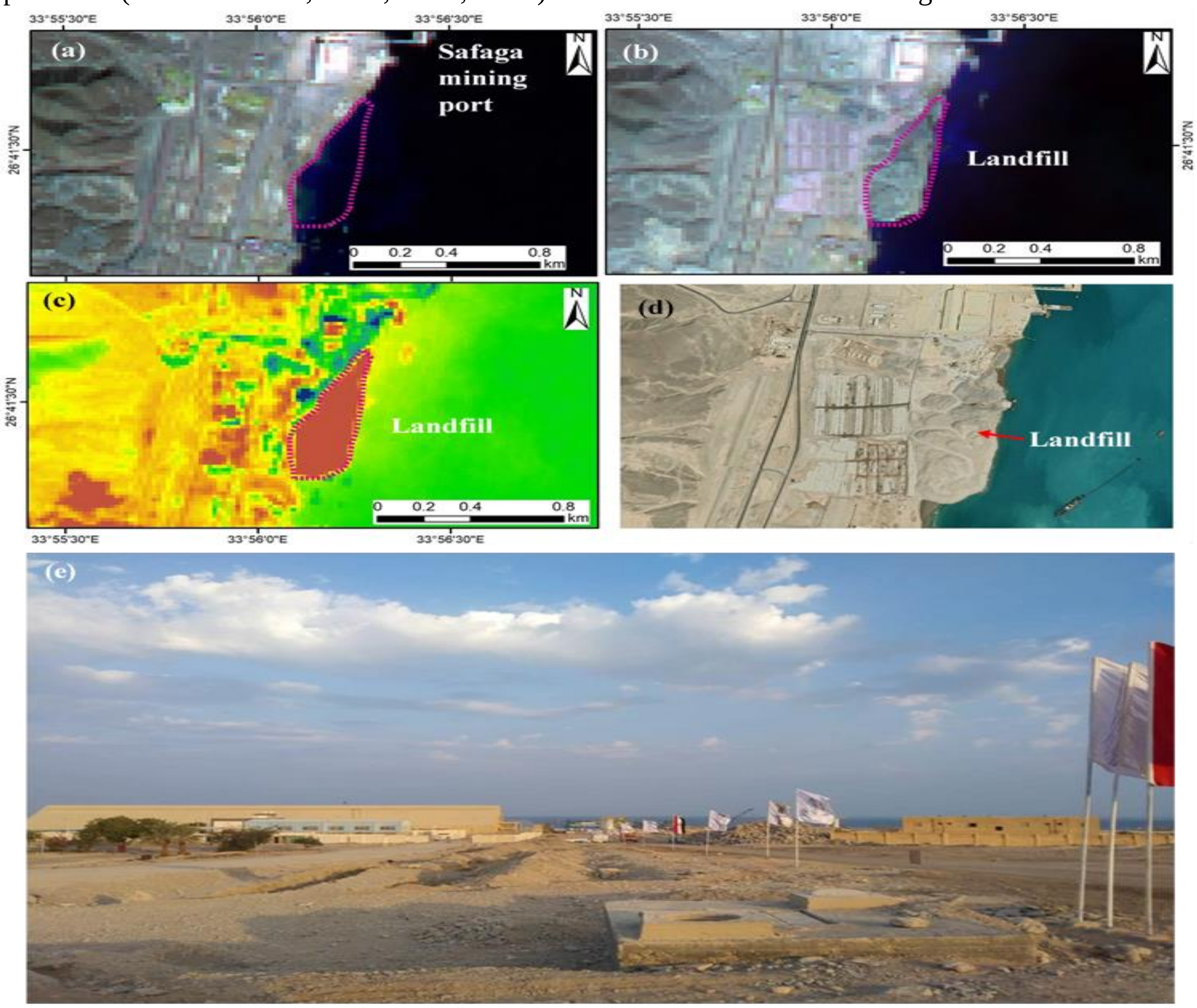

Figure 4. (a) Sentinel-2 of 2016; (b) Sentinel-2 of 2022; (c) change detection image between 2016 and 2022; the dashed pink polygon represents the landfill area; (d) is Geo Eye 1 image of 2022 showing development and enlargement of Safaga mining port that results in shoreline change due to large amounts of landfilling.

The coastal zone of Safaga represents one of the most desired regions of tourism in the Egyptian Red Sea but, tourism and recreation activities threat the coastal zone. Pollution from human activities is one of the most negative impacts in the marine environments (Mansour *et al.*, 2000, 2005 and 2011). Moreover, the coastal zone suffers from destruction, landfilling and dredging operations that is associated with resorts construction (Figure 5, 6 and 7). Sentinel-2 image (2016) of the Red Sea environments particularly (Figure 5a) showing the shoreline before modification while sentinel-2 image (2022) showing the shoreline change due to landfilling that is associated with resorts construction (Figure 5b). Change detection analysis image showing the change of shoreline from 2016 to 2022 (Figure 5c). In this image, large amounts of landfilling due to resorts construction are detected in brown color, however, the infrastructures of resorts and vegetations appear in blue. These changes are clearly detected in high resolution GeoEye-1 image (2022) (Figure 5d).

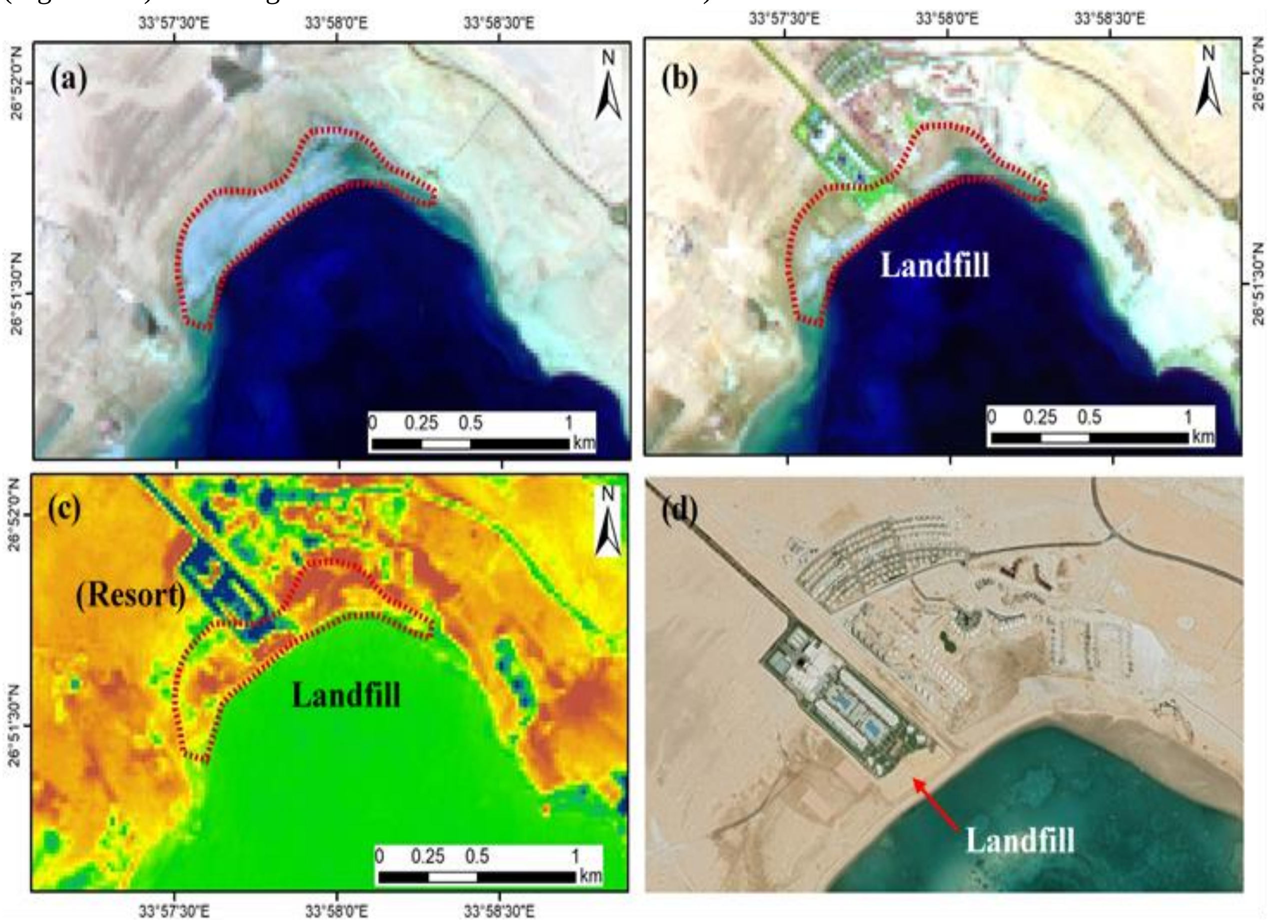

Figure 5. (a) Sentinel-2 of 2016; (b) Sentinel-2 of 2022; (c) change detection image between 2016 and 2022; the dashed red polygon represents the landfill area; (d) GeoEye-1 image of 2022 showing the shoreline change due to landfilling operations that is associated with tourism activities.

North of Safaga city, sentinel-2 image of 2016 displays the landfilling of the shoreline (Figure 6a) that increased in 2022 (Figure 6b) due to tourism and recreation activities. Figure (6c) is a change detection image that is processed between to images (2016 to 2022) using GIS tool. The landfill due to tourism activities of the shoreline recognized along the island. Further analysis using high resolution GeoEye-1 image (2022) (Figure 6d) validate the landfilling operations.

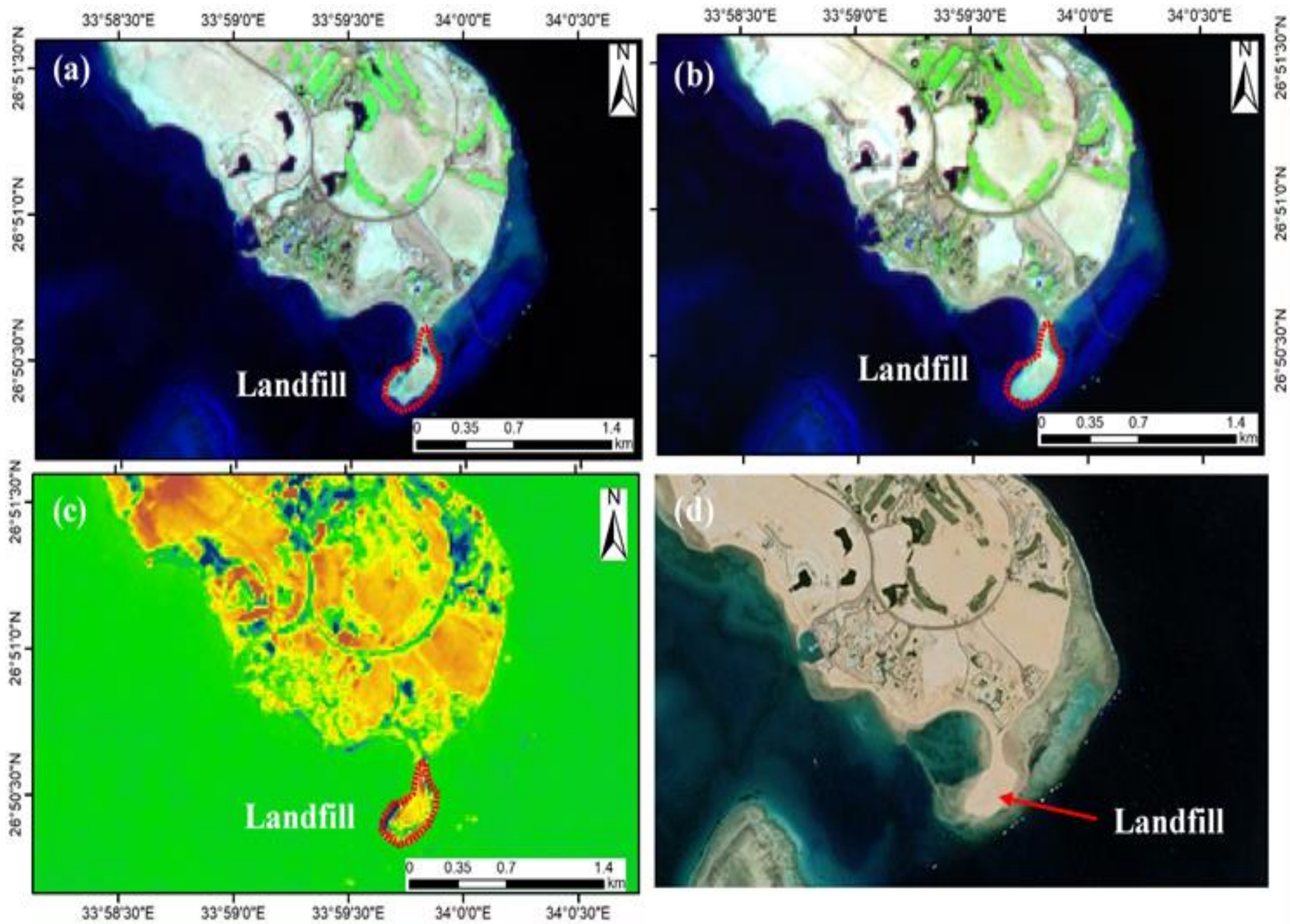

Figure 6. (a) Sentinel-2 of 2016; (b) Sentinel-2 of 2022; (c) change detection image between 2016 and 2022; the dashed red polygon represents the landfill area; (d) GeoEye-1 image of 2022 showing shoreline change and landfilling operations associated with tourism activities.

Figure 7. Field photo showing landfilling of shoreline due to resort construction.

The overpopulation pushes for increasing the urbanization and infrastructures of Safaga city but the unplanned and unsustainable anthropogenic activities threat the coastal region and the ecosystems (Figures 8 and 9). Figure (8a) is a sentinel-2 image (2022) showing coastal urbanization in Safaga city and shoreline change due to landfilling operations as revealed in high resolution GeoEye-1 image (2022) (Figure 8b) and field photos (Figure 8c and d).

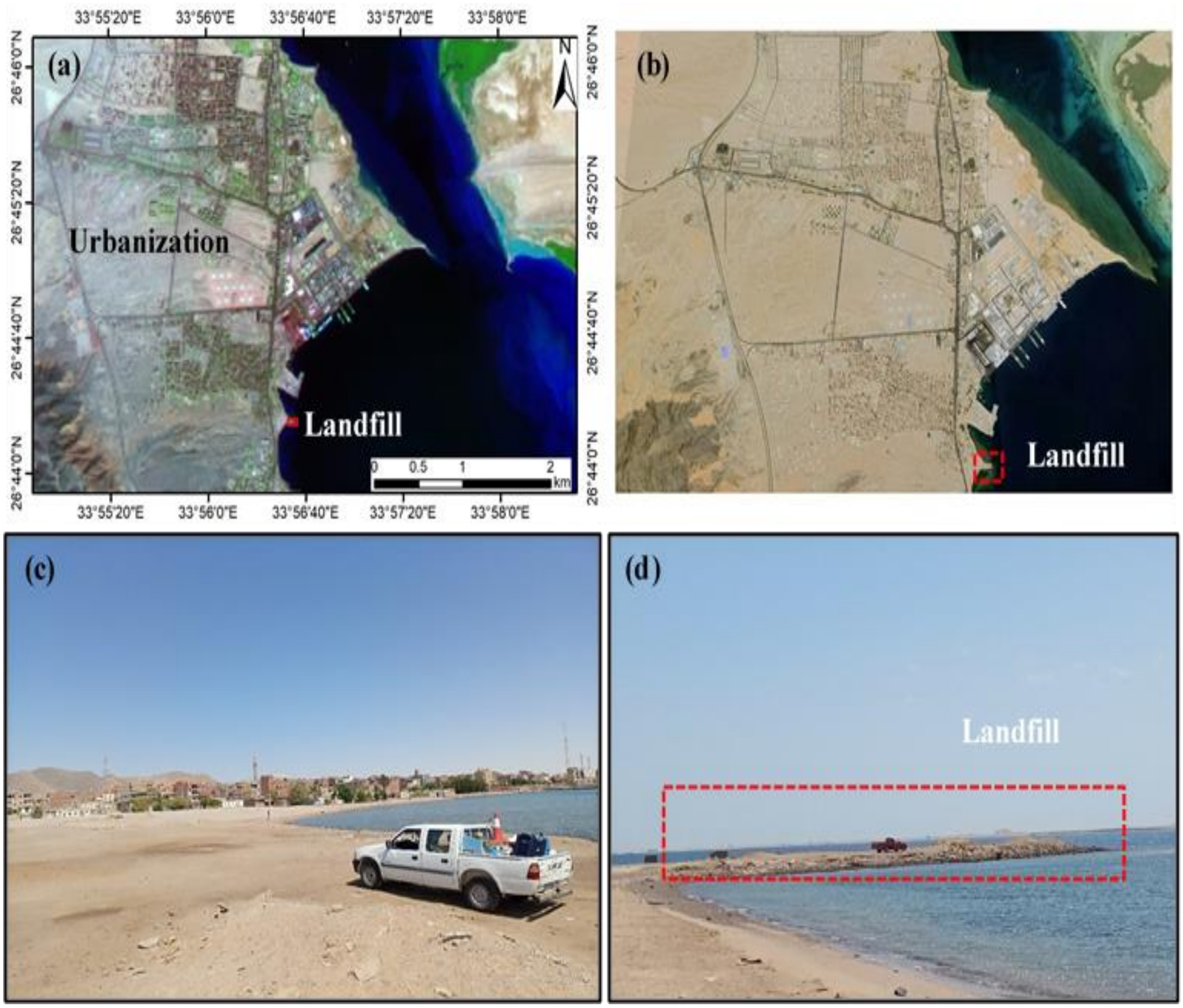

Figure 8. (a) Sentinel-2 of 2016; (b) Geo Eye 1 image of 2022 showing urbanization in the coastal zone of Safaga and shoreline change due to landfilling operations; (c) field photo showing coastal urbanization in Safaga city; (d) field photo showing landfilling operations in the coastal zone of Safaga; the dashed red polygon represents the landfill area.

Sentinel-2 image (2016) (Figures 9a) showing the sewage treatment plant of Safaga that modified as revealed in sentinel-2 image (2022) (Figure 9b). Processing of the two images allowed revealing changes in vegetation, sewage treatment plant, and infrastructures at Wadi Safaga as detected in blue color (Figure 9c). A high resolution GeoEye-1 image (2022) exhibiting sewage treatment plant of Safaga in front of wadi Safaga (9d) and a new-constructed dam as indicated by red arrow (F igures 9 b, c, and d). This plant represents a threat to the Red Sea environments in Safaga and possible source of pollution as it occurs in the front of wadi Safaga which probably during flooding will carry large amount of sewage to the coastal area and the sea.

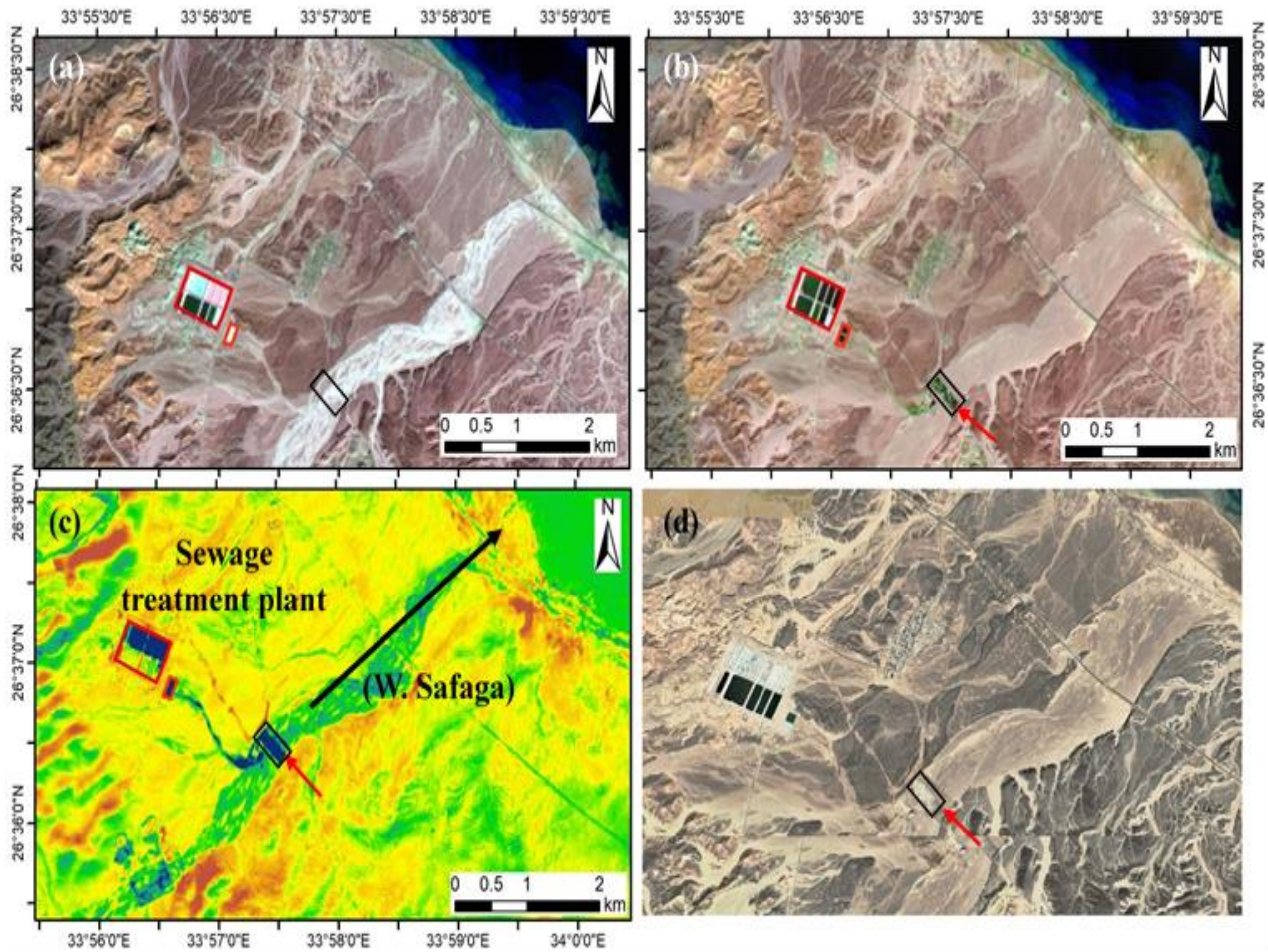

Figure 9. (a) Sentinel-2 of 2016; (b) Sentinel-2 of 2022; (c) change detection image between 2016 and 2022; the red polygon represents sewage treatment plant; the black arrow showing the flow direction of wadi Safaga; (d) GeoEye-1 image showing sewage treatment plant of Safaga in front of wadi Safaga.

5. Conclusions

The present study is aimed to detect environmental changes in Land use/Land cover (LU/LC) due to the anthropogenic activities in the coastal zone of Safaga region. For this target, two dates of Sentinel-2 scenes were processed and analyzed using GIS techniques. The results showed that the coastal zone of Safaga region experienced changes and suffered from damages due to the anthropogenic activities. Landfilling, unplanned new constructions represent the most serious threats to the Red Sea environments. Field observations confirmed the multi-temporal remote sensing changes.

Authors' Contributions

All authors are contributed in this research.

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Institutional Review Board Statement

All Institutional Review Board Statements are confirmed and approved.

Data Availability Statement

Data presented in this study are available on fair request from the respective author.

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable.

Conflicts of Interest

The authors disclosed no conflict of interest starting from the conduct of the study, data analysis, and writing until the publication of this research work.

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