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*Corresponding author(s) email:
lamyaa@narss.sci.eg

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Development of Desertification Indicators for Desertification Monitoring from Landsat Images Using Python Programming

Lamyaa G. E. Taha [1*], Manar A. Basheer [1], Amany M. Mohamed [1]

1. *National Authority for Remote Sensing and Space Science (NARSS), Egypt*

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Abstract

Nowadays, desertification is one of the most serious environment socioeconomic issues and sand dune advances are a major threat that causes desertification. Wadi El-Rayan is one of the areas facing severe dune migration. Therefore, it's important to monitor desertification and study sand dune migration in this area. Image differencing for the years 2000 (Landsat ETM+) and 2019 (OLI images) and Bi-temporal layer stacking was performed. It was found that image differencing is a superior method to get changes of the study area compared to the visual method (Bi-temporal layer stacking). This research develops a quantitative technique for desertification assessment by developing indicators using Landsat images. Spatial distribution of the movement of sand dunes using some spectral indices (NDVI, BSI, LDI, and LST) was studied and a Python script was developed to calculate these indices. The results show that NDVI and BSI indices are the best indices in the identification and detection of vegetation. It was found that mobile sand dunes on the southern side of the lower Wadi El-Rayan Lake caused filling up of large part of the lower lake. The indices results show that sand movement decreased the size of the lower Wadi El-Rayan Lake and there are reclamation activities in the west of the lower lake. The results show that a good result could be achieved from the developed codes compared to ready-made software (ENVI 5).

1. Introduction

Desertification is one of the main defiance that is facing the activities of development in several areas worldwide (Ahmed, 2015). It is recognized as a serious ecological, environmental, and socio-economic threat to the world, and there is a pressing need to develop method to assess it at different scales (Lamchin et al., 2016) because it threaten the sustainability and reliability of economic growth and its monitoring is an indispensable requirement for reviewing and improving resource management (Afrasinei et al., 2017). Desertification has been defined as the land degradation in arid, semi-arid and dry sub-humid areas due to climate variation and/or human activity by the United Nations Convention to Combat Desertification (UNCCD, 1994). Desertification has been assessed by a lot of researchers using various strategies (Xu et al., 2009). The major causes of desertification are wind, overgrazing, logging, over drafting of groundwater, desert advance, climatic change, and diversion of water from rivers for human consumption and industrial use. All these phenomena, fundamentally driven by overpopulation (Elhag et al., 2014)

Desertification is any widespread environmental degradation that reduces productivity of dryland ecosystems by reducing plant cover, soil loss, loss of soil organic matter, increasing sand dunes, and increasing run-off. Desertification can lead to adverse health impacts including disease, food shortages, and Water scarcity . These impacts have been shown to be contributors to poverty, nutrition deficiencies, and mass migrations of affected populations. Various remote sensing techniques were developed to monitor desertification in arid and semiarid regions, that can be categorized into visual interpretation, Spectral Mixture Analysis (SMA) classification algorithms, spectral indices, and image transformation, such as the tasseled cap transformation (TCT) (Lamqadem et al., 2018). In 1984, the United Nations Environment Program (UNEP) reported that the desertification process could be assessed by modification in different natural, biological and socio-economic factors. The factors can be used to assess the sandy desertification, which can be categorized into several types such as erosion, sand dunes movement, and fragmentation of quicksand, the decrease of cultivated land, removal of the forest, and quality and quantity decrease of underground and surface water (Yao et al., 2007).

Sand dunes are one of the main impediments facing the extension of agriculture in the desert (Metwally et al., 2016). A sand dune is one feature of land degradation that takes place in dry and semi dry lands which consequently can lead to desertification (Fadhil, 2013). Wind direction and strength can change effectively sand dunes location, pattern or dimensions. Sand dune movements can be assessed through the comparison of multi-temporal satellite images (Els et al., 2015). Wind erosion and deposition in the western desert of Egypt have produced a sand dunes accumulations, some of which have been detected by traditional surveying methods, and which can now be used with remote sensing methods to determine net sand movement (Maxwell & Haynes Jr, 1992). High temperature with strong winds caused the accumulation of sand dunes. Sand dune movement is a hazardous phenomenon leads to soil erosion, breaking down the cultivated land, and soil becoming lacking the organic matter and nutrients and threats the man-made activities, developmental plans, existing land-use and land-cover, and the permanence of archaic sites (Els et al., 2015). This motivated several countries to plant windbreaks for stabilization of the sand dunes to diminish desertification and land degradation, especially in the arid and semiarid regions (Metwally et al., 2016).

Many researchers use fixation to face this natural hazardous. There are several sand dune stabilization strategies such as mechanical stabilization, or biological stabilization, presently biological strategies considered as the most common and most efficient strategies (Gómez et al., 2018). Yao et al. (2007) utilized multi-temporal Landsat imagery for tracking of dune migration and pattern identification on the northern Alxa plateau, Inner Mongolia, China (Els et al., 2015). Al-Dabi et al. (1998) used multi-temporal Landsat (TM) images for monitoring the changes in the dune patterns in northwest Kuwait. Monitoring of the rates of sand dune movements and changes can be helpful to conserve anthropogenic and natural resources (El-Magd et al., 2013). Al-Adhami (2001) has estimated sand dunes movement rate of different agricultural regions that facing sand encroachment in Efak district - Sumer (Qadisiyah province). Kadim et al. (2009) used remote sensing and geographical information system (GIS) for studying the desertification process in the Baiji area / northern of Iraq, an increase in desertification and sand dunes area. Remote sensing techniques played a remarkable function in the monitoring of desertification due to the limitations of classic ground surveys (Cui & Wenbo, 2008). Several indices have been generated to monitor sand movement in arid regions.

Many change detection methods and their developed versions have been explored in the last two decades to identify differences in a certain feature or phenomenon. Several spectral indices are proposed in the existing literature for the assessment desertification. The most important physical indicators of land degradation are the state of vegetation and soil (Hill et al., 1996). Vegetation cover is an essential indicator of desertification in dry areas and can be utilized to assess desertification processes (Joseph et al., 2018). Dulaimi (2015) also found that NDVI is an important indicator in monitoring desertification and sand dunes. (Gonçalves et al., 2014) used Normalized Difference Built Up Index (NDBI), in order to separate the built-up areas from the other areas and Used Normalized Difference Water Index (MNDWI) as it can efficiently suppress from the water information the noise coming from built-up land, vegetation and soil. BAI (2017) used NDBaI (Normalized Difference Bareness Index) to Recognize different types of bare area The primary bare area are area there no vegetation cover existed due to physiographic factors such as climate, hydrology; the humus bare lands were mainly influenced by anthropogenic disturbance such as heavily farming and urban construction and Normalized difference soil salinity index (NDSI) to suppressing the vegetation and highlight the saline zones. Fadhil (2013) proposed Normalized difference sand index “NDSI” to identify and highlight the existence of the sand dunes and

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the drifting sands in the study area and used Tasseled cap wetness indicator "TCW" to determine the amount of moisture being held by the vegetation or soil, thus termed wetness, as well as to other indicators point to the vegetation and the brightness of soil.

The temperature measured at the border between earth's surface and the immediate atmosphere is known as LST (Joseph et al., 2018; Valiente et al., 2010). LST is a great factor in the detection of dryness, desertification, and different environmental issues. This research studies the movement of sand, sand accumulations located in the Fayoum and Wadi El Rayan (1,759 km^2). Desertification Indicators from Landsat Images were developed using Python programming for desertification monitoring. The two Landsat satellite images of the years 2000, 2019 were compared using Bi-temporal layer stacking and image differencing. Monitoring, mapping, and assessing the sand dune encroachment have been studied using indicators

2. Study area and data sources

Wadi El-Rayan (Figure 1) is a natural depression in the western desert of Egypt. It located in the southwest of Fayoum Governorate, Egypt. This depression was declared a Protected Area by Prime Minister. Two man-made lakes connected by a channel were constructed at two dissimilar levels. The first lake area is around 53 km^2 at 10 m below the sea level, while the second is 110 km^2 at 18 m below the sea level. Wadi El Rayan lakes have a variety of surrounding habitats. It includes about 4,575 feddans of reclamation lands and 1300 feddans of fish farms. Gabal Madwera, nearby the second lake, contains extended dune formations. The most important threat to the protection of Wadi El-Rayan is the expansion of uncontrolled economic activities such as large-scale land reclamation projects, aquaculture, fishing, oil extraction, and tourism. The greatest threats to the surrounding area come from a land-claim project which intends to cultivate 15,000 feddans of the desert, right in the center of Wadi El Rayan Protected Area.

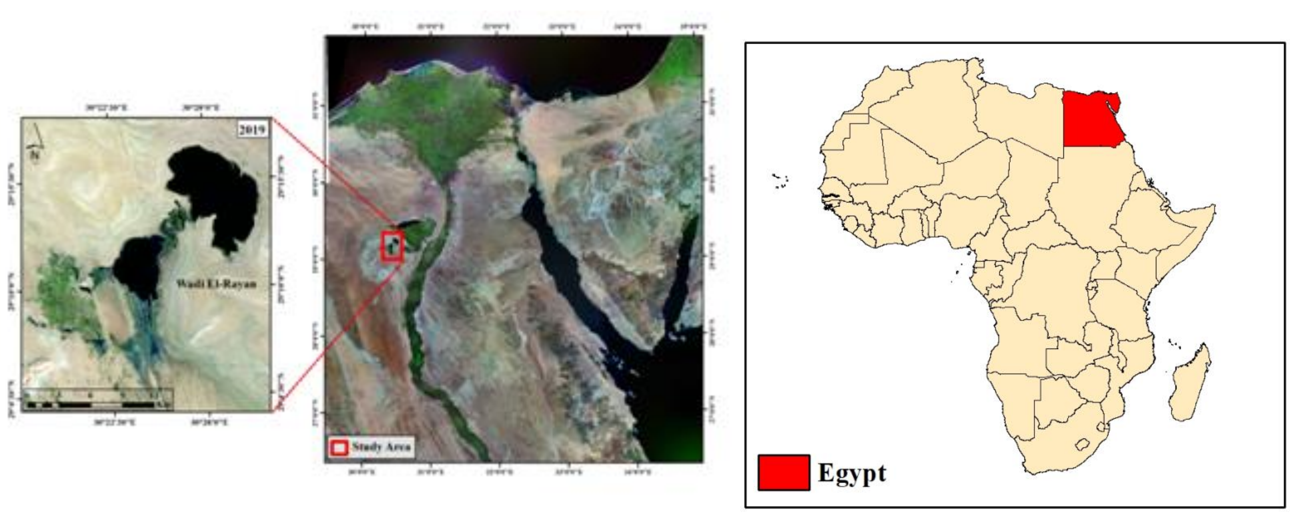

Figure 1. Study Area.

3. Data and Methods

This researches used several data sources, there are Landsat 7 (ETM+) and Landsat 8 OLI image datasets for the years 2000 and 2019 (20/2/2000 and 16/2/2019) were acquired from the USGS Earth Explorer (http://earthexplorer.usgs.gov/); and topographic maps scale 1:50 000.

There are several methods have been done specifically downloading multitemporal Landsat has been performed; geometric corrections has been performed; atmospheric correction has been performed; change detection using two methods (Bi-temporal layer stacking and Image differencing) has been performed; and a Python script was developed to calculate NDVI, BSI, and LDI also NDVI, BSI, and LDI was calculated using ENVI 5 software. The methodology that adapted for this study can be seen at Figure 2.

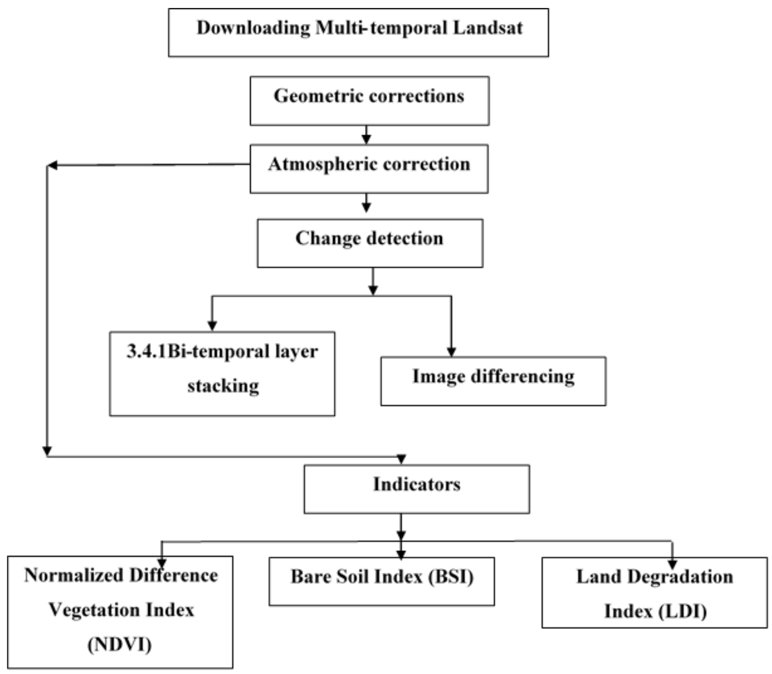

Figure 2. Methodology Adopted for This Study.

3.1. Pre-processing of Landsat Satellite Images

Radiometric correction, geometric correction, and atmospheric correction were performed for Landsat 7 (ETM+) and Landsat 8 (OLI) image datasets for the years 2000 and 2019. All images processing were applied using ENVI, ERDAS imagine, and ArcMap software.

3.2. Change detection

Change detection used for detecting changes of two multispectral satellite images at two dates (Bakr & Afifi, 2019). Several change detection techniques have been used for decades. In this study, two change detection techniques were employed Bi-temporal layer stacking and image differencing. Bi-Temporal Layer Stacking (BTLS) process originated from Write Function Memory Insertion (WFMI) methods (Jensen, 2005). WFMI is a visual change detection method, in which one band from each satellite image are displayed in specific colors (typically red, green and blue). Mohamed & Verstraeten (2012) applied WFMI to Landsat images to identify the sand dune movements. Figure 4 illustrates BI-temporal layer stacking (BTLS) showing sand increase and decrease. Image differencing used for subtracting the image at a certain date from another (Jensen, 2005). Figure 3 depicts Image differencing between NIR band of the two years 2000 and 2019. Change detection of the lake water body was performed through digitization of the lake boundaries in the two years 2000 and 2019. Figure 5 depicts the boundaries of Wadi El-Rayan Lakes in 2000 and 2019.

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Figure 3. BI-temporal layer stacking (BTLS) showing sand increase and decrease (layout by ARCGIS10.1).

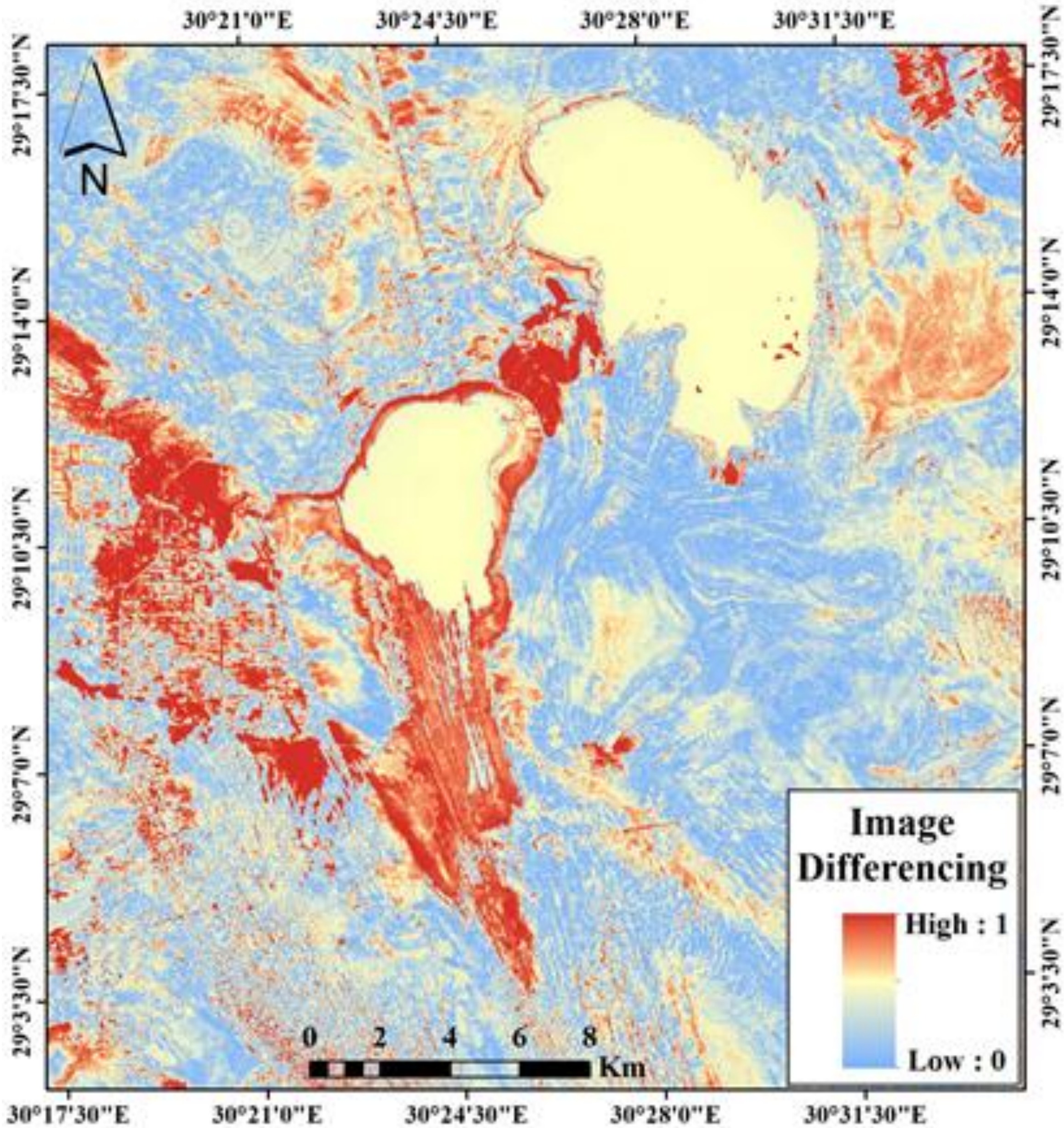

Figure 4. Image differencing between NIR band of the two years 2000 and 2019 (layout by ARCGIS10.1).

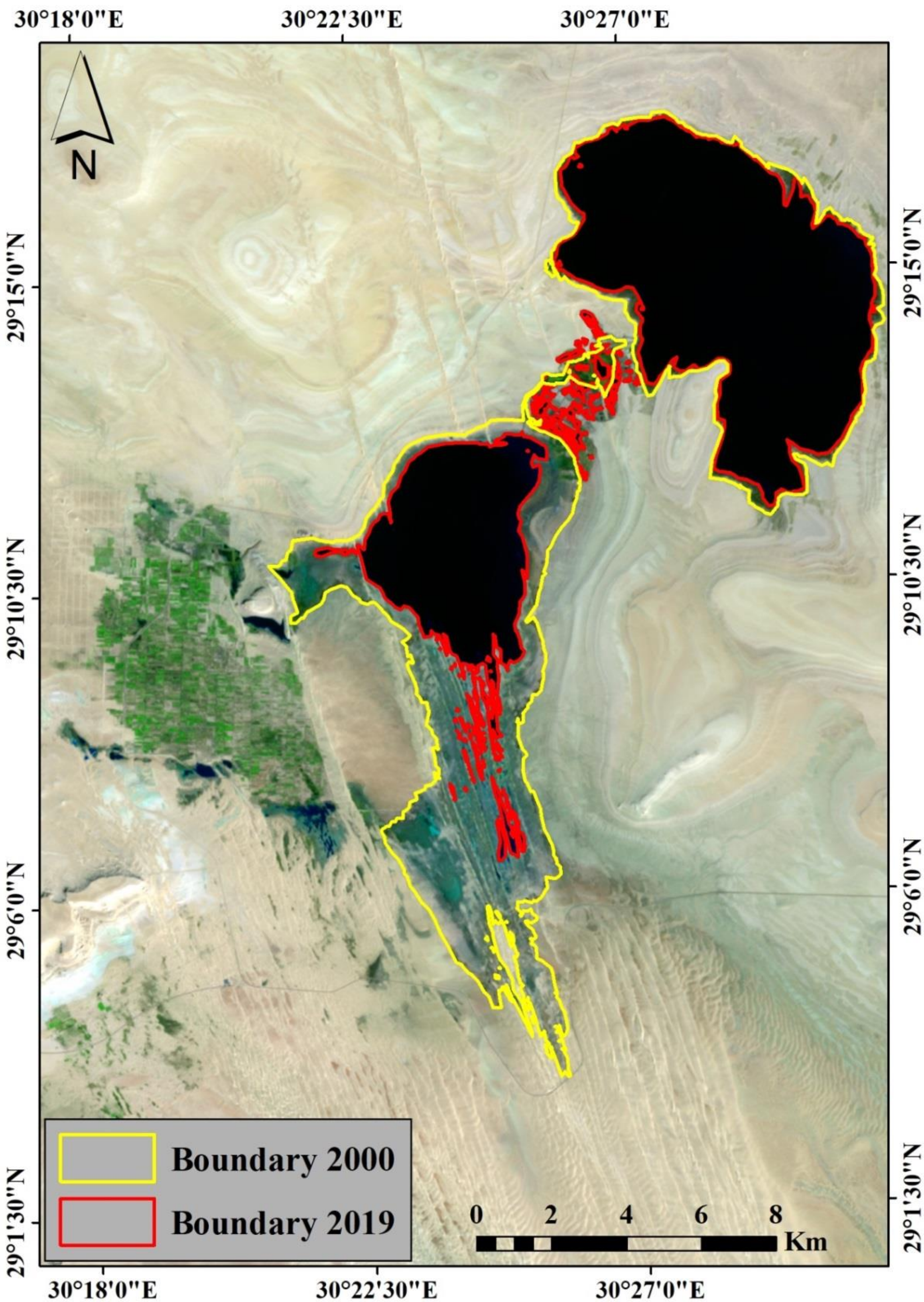

Figure 5. Boundaries of Wadi El-Rayan Lake in 2000 and 2019.

3.3. LST calculation

Land surface temperature (LST) was extracted from thermal bands. Figure 6 depicts LST of the years 2000, 2019 and changes between the two years. The thermal band 6 of Landsat ETM+ 2000 with 60 m resolution and thermal bands 10 of Landsat OLI 2019 with 100 m resolution were used for calculation of more accurate LST. LST calculation was performed according to Anandababu et al., (2018) equations as follow:

Land Surface Temperature (LST):

$$LST = (BT / 1) + W * (BT / 14380) * \ln (E)$$

Where:

BT = Top of atmosphere brightness temperature (°C)

W = Wavelength of emitted radiance

E = Land Surface Emissivity

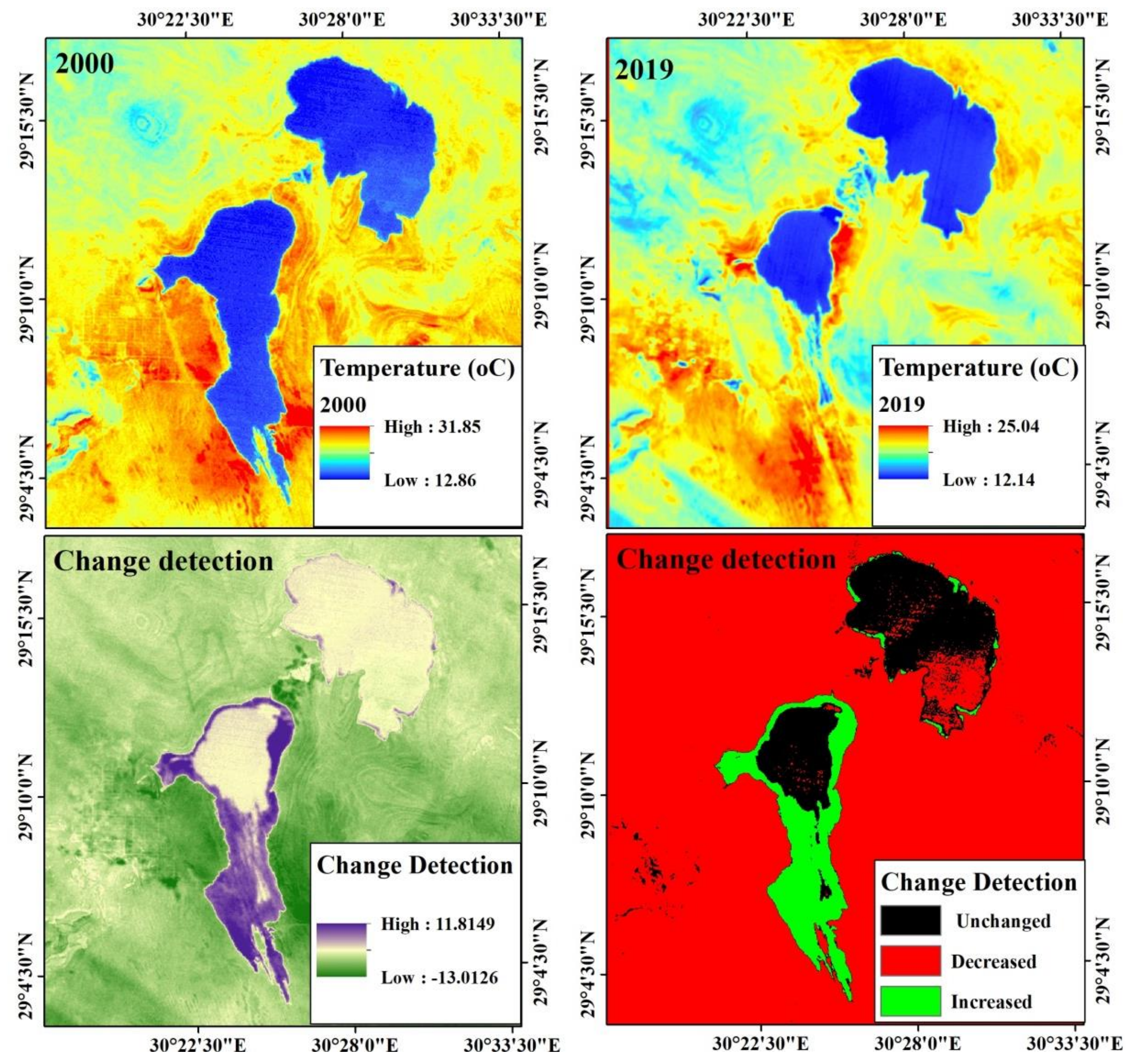

Figure 6. LST of the years 2000, 2019 and changes between the two years (layout by ARCGIS10.1).

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3.4. Indicators

Four indicators were calculated from Landsat images for desertification monitoring. A Python script was developed to calculate NDVI, BSI, and LDI. Besides, images were analyzed and processed by ENVI 5 software. All the images indices were calculated by using the formula (1), (2), and (3).

3.5. Normalized Difference Vegetation Index (NDVI)

NDVI represents the relation between the spectral reflectance and vegetation cover. The main feature of desertification is the lower land productivity. Changes in vegetation index represent the changes in land productivity (Cui & Wenbo, 2008). For the quantification of vegetation biomass for desertification, NDVI was measured according to equation (1). Changes in the index between the two years were also calculated.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

(1) (Suliman & Farhood, 2015)

Anyamba & Tucker (2005) indicated that NDVI <0.1 reflect desert, areas between 0.1 and 0.2 reflect semi-desert, areas between 0.2 – 0.4 reflect shrub and grassland, while NDVI >0.5 reflect forests. Besides, Helldén & Tottrup (2008) considered areas with long-term mean monthly NDVI values between 0.1 and 0.5 as subject to desertification. Differencing vegetation index image comparing vegetation index information derived from different dates (Jensen, 2005). Figure 7 illustrates NDVI of the years 2000, 2019 and changes between the two years.

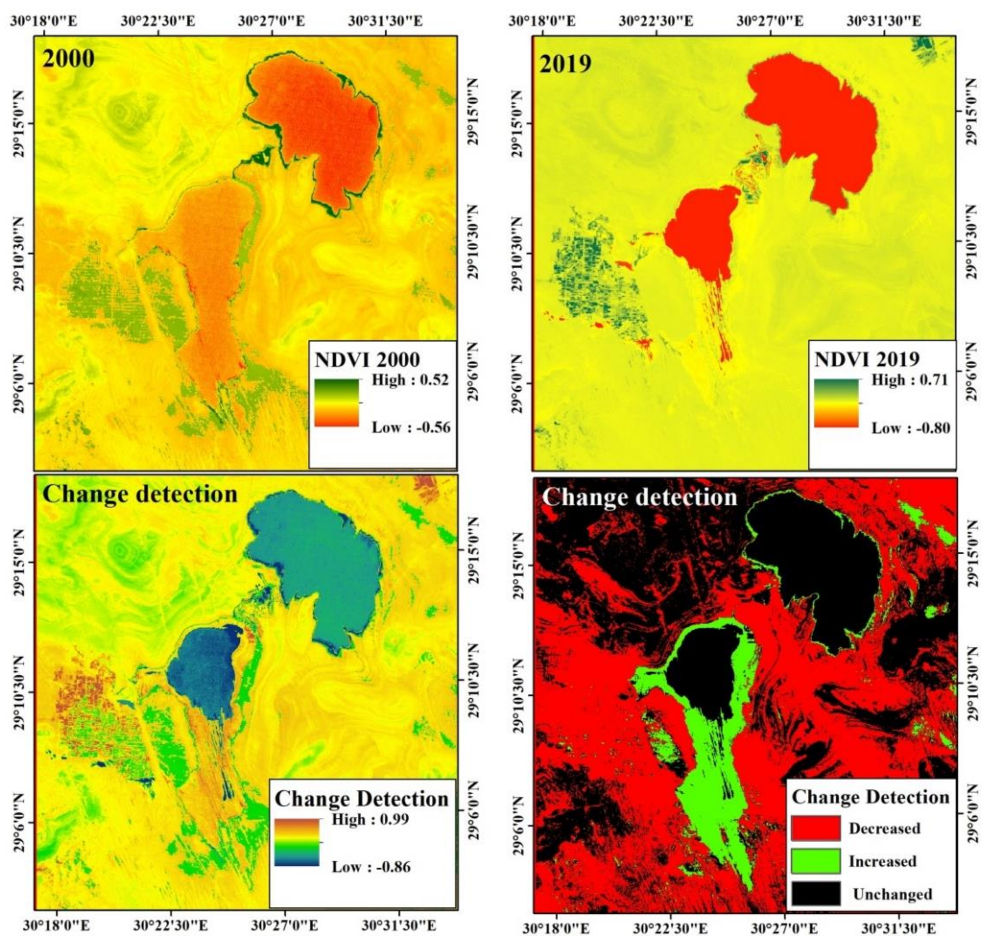

Figure 7. NDVI of the years 2000, 2019 and changes between the two years (layout by ARCGIS10.1)

3.6. Bare Soil Index (BSI)

The bare soil Index (BSI) with the highest values found in areas with high salt accumulation, and it was the lowest value in agricultural areas. Bare Soil Index (BSI) used by (Munkhdulam et al., 2018) as the following equation:

$$BSI = \frac{(SWIR + Red) - (NIR+BLUE)}{(SWIR + Red) + (NIR+BLUE)} * 100+100 \quad (2)$$

Were the Red and SWIR and NIR and BLUE representing short wave infra-red, near infra-red, and blue bands, respectively (Suliman & Farhood, 2015). Changes in the index between the two years were also calculated. Figure 8 depicts BSI of 2000, 2019 and changes in bare soil index.

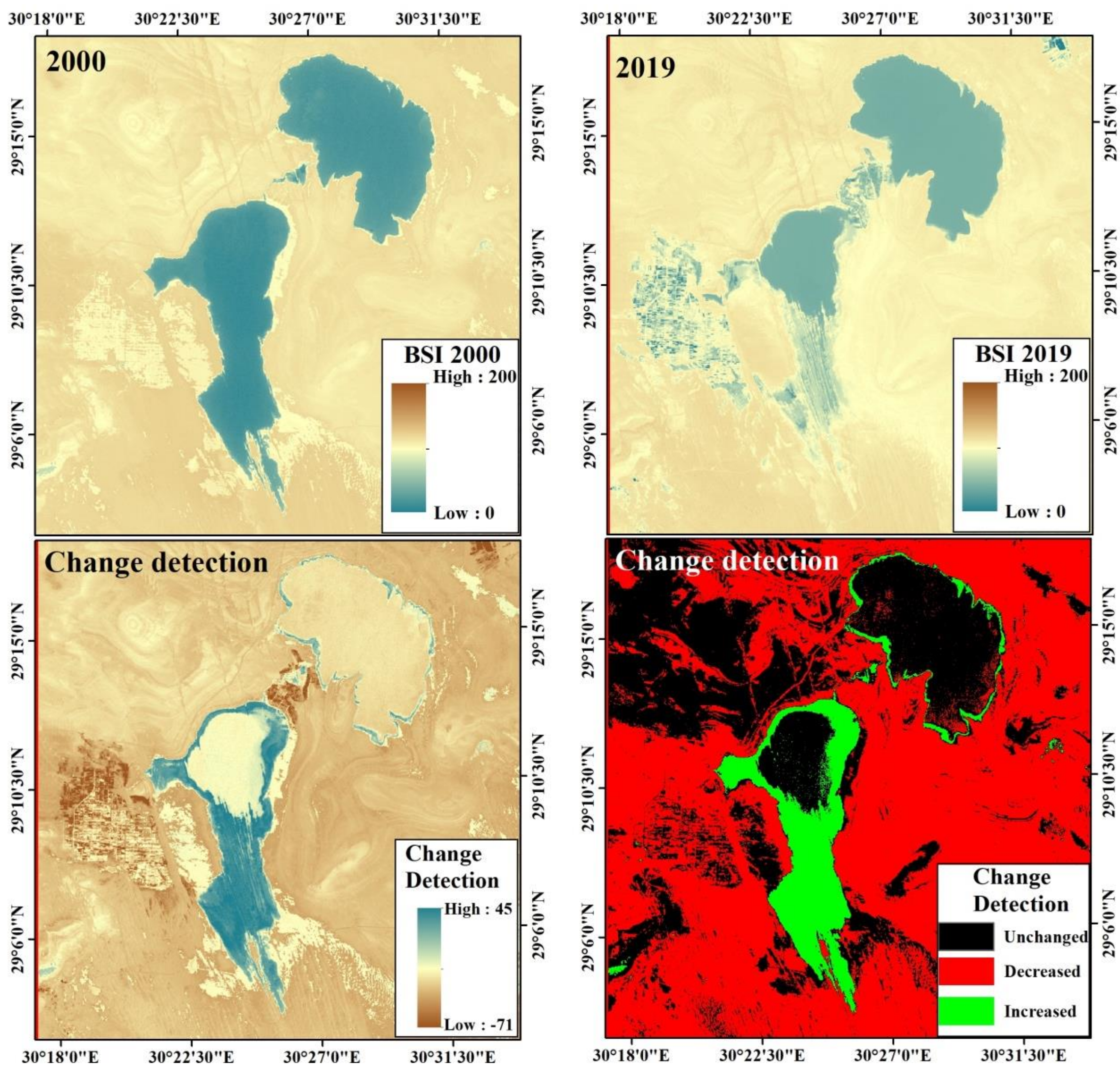

Figure 8. Bare soil index (BSI) of 2000, 2019 and changes in bare soil index (layout by ARCGIS10.1).

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3.7. Land Degradation Index (LDI)

Zhao & Meng (2010) used LDI according to the following equation:

$$\mathbf{LDI}=\frac{(255-(\mathbf{Green}+\mathbf{Red}))}{(255+(\mathbf{Green}+\mathbf{Red}))} \quad (3)$$

Green and Red bands respectively, and 255 is a higher value for the two sensors TM and ETM + and that of the sensor OLI is 65535 (Suliman & Farhood, 2015). Figure 9 illustrates the land degradation index (LDI) of years 2000, 2019 and changes in LDI. Table (1) shows land degradation degrees, according to the ranges of LDI (Zhao & Meng, 2010; Suliman & Farhood, 2015).

Table 1. Land degradation degrees, according to the ranges of LDI

The degree of degradation	Not degraded light deterioration	Moderate	Severe	Very severe
Ranges of LDI	More than 90	60-90	30-60	Less than 30

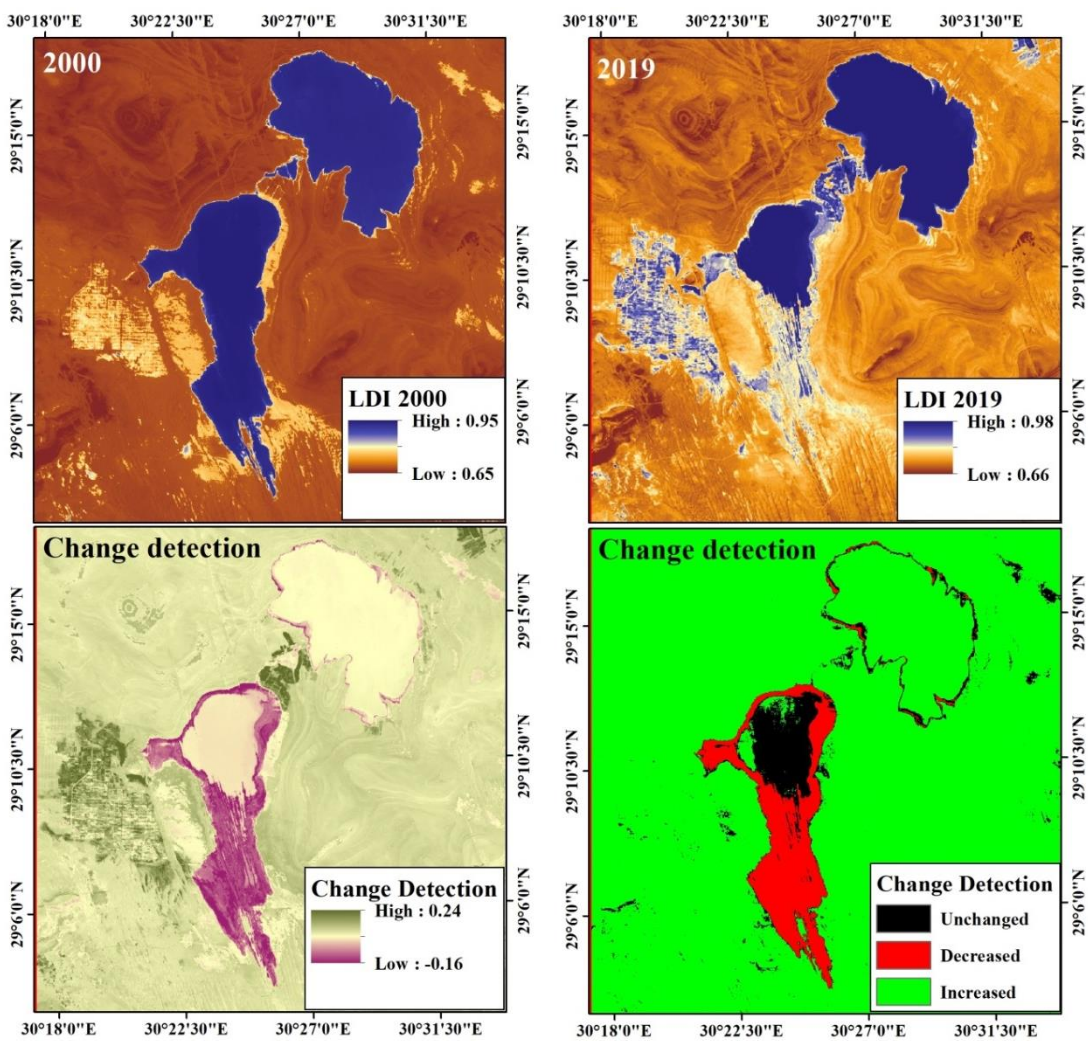

Figure 9. Land degradation index (LDI) of years 2000, 2019 and changes in LDI

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Developed Python code was used for extraction of the previous desertification indices; NDVI, BSI, LDI, and LST then image differencing for each index. Figure 10 shows the workflow of the developed indices in Python.

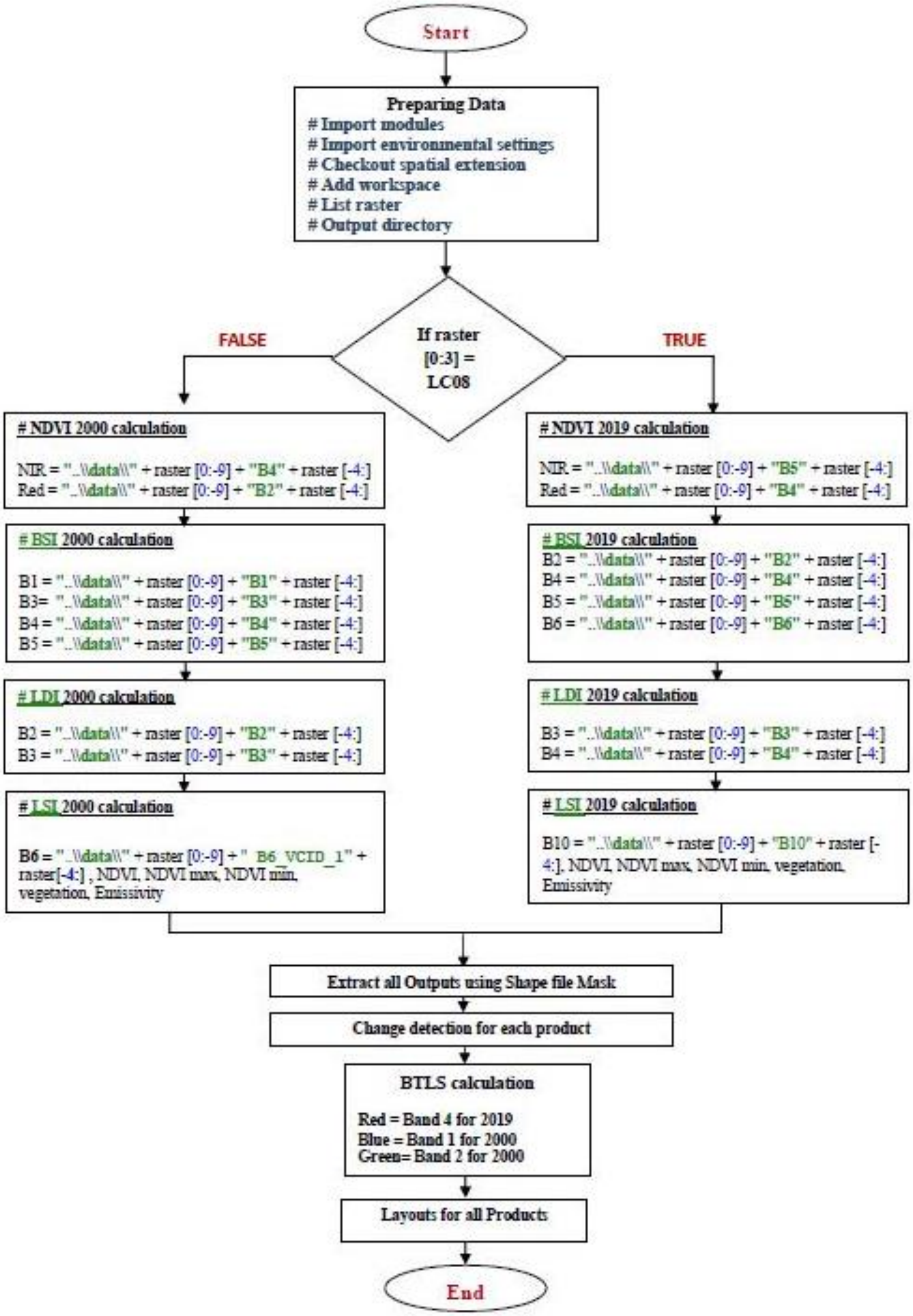

Figure 10. Workflow of the developed indices in Python.

4. Results and Discussion

A Python script was developed to calculate NDVI, BSI and LDI indices. The results show that NDVI and BSI indices are the best indices used for the identification and detection of vegetation. The highest Normalized Difference Vegetation Index values were 0.52 and 0.71 for the years 2000 and 2019 respectively. Based on the visual interpretation of figure 5, it was found that the area of Wadi El-Rayan Lake decreases in the year 2019 due to sand movement and the accumulation of sands that filled up a large part of the lower lake. Also, the filled part of the lake has a lower NDVI (orange and yellow color) which means desertification in this area. Also, it was observed that NDVI values increased (dark green color) in the west of the lower lake which means vegetation increased in this area (reclamation activity). Based on figure 6 there is a reduction in the lower lake.

By comparing BSI in the years 2000 and 2019, based on figure 8, it is clear that the highest calculated value of BSI index was 107 and 114 for the years 2000 and 2019 respectively. The lowest value was zero for the years 2000 and 2019. When these values close to zero this indicates the abundance of vegetation and when it increased that indicates that the soil is bare. It was found that the filled part of the lake has higher BSI values in 2019 (brown color) which means desertification in this area. Also, it was observed that BSI value is zero in 2019 (blue color) in the west of the filled part of the lake which means vegetation increased in the west of the filled part of Wadi El-Rayan lake.

By comparing the land degradation index (LDI) in the year 2000 and 2019, based on figure 9, it is clear that the highest value of LDI was 95% and 98% for the years 2000 and 2019 respectively. The blue color in 2019 in the filled part of the lake indicates light deterioration in the filled part of the lake.

By comparing the land surface temperature (LST) values in the year 2000 and 2019, based on figure 6, it is clear that the highest value of LST was 31.85 ^{o}C and 25.04 ^{o}C for the years 2000 and 2019 respectively. The lowest value of the index was 12.86 ^{o}C and 12.14 ^{o}C for the years 2000 and 2019. It was found that the filled part of the lake has higher LST values in 2019 (yellow and red color) compared to blue color (lower LST) in 2000 which means that the temperature becomes higher from 2000 to 2019 due to desertification and sand movement.

The results show that a good result could be achieved from the developed codes compared to ready-made software (ENVI 5). It was found that image differencing is a superior method to get changes in the study area compared to the visual method (Bi-temporal layer stacking).

5. Conclusions and Recommendation

Desertification is one of the main defiance that is facing the activities of development in many areas worldwide. This research focused on assessing desertification using remote sensing. Landsat ETM+ and OLI were used in the monitoring of desertification dynamics by calculation of LST, NDVI, BSI, and LDI. It was found that image differencing is a superior method to get changes in the study area compared to the visual method (Bi-temporal layer stacking). A Python script was developed to calculate NDVI, BSI, and LDI. The results show that NDVI index and BSI index are the best indices in the identification and detection of vegetation. NDVI was used for analyzing vegetation quality which indicated that regions around the lake had higher NDVI values which matched with vigorous vegetation recognized during the field survey. Bare soil index (BSI) and land degradation index (LDI) were applied, it was found that (BSI) is zero around the lake this means the abundance of vegetation, BSI higher value in the filled part of the lake this revealed that the soil is bare.

Land degradation index is higher in the year 2019 in the filled part of the lake indicates light deterioration in the filled part of the lake. The results of indices show that sand movement decreased the size of the lower lake and there is a reclamation activity surround the lake. The results also show that a good result could be achieved from the developed codes compared to ready-made software. It was found that mobile sand dunes on the southern side of the lower lake caused filling up of large part of the lower lake. The desertification process from 2000 to

2019 was prompted by climate change. Finding indicators that are unambiguously related to certain land degradation processes or to desertification in general is important. Assessments based on combination of these indicators have been found effective, but they are not sufficient to provide an accurate assessment for the whole desertification process. It is recommended to use indices (NDVI, BSI, and LDI) for assessment of desertification in other regions. It is recommended to use other indices such as the Soil Adjusted Vegetation Index (SAVI).

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