Assessing Coastal Land Dynamics Along UAE Shoreline Using GIS and Remote Sensing Techniques

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Abstract. The coastal areas geomorphological characteristic is greatly active, where land accretion and erosion is a continuous phenomenon with different degrees. The temporal change in coastline location is an important sign of coastal development and it can provide quantitative and descriptive information on beach dynamics. To investigate coastal variability trends, when field-based surveys are inaccessible or absent, historical remote sensing data and GIS analysis can be effective techniques. This study focuses on the United Arab Emirates (UAE) coastline that stretches for more than 1,000 km to cover the entire coastal area of the country. Multi-temporal Landsat satellite images cover more than 45 years had been used to assess the coastal land dynamics by first delineate land areas from existing water bodies accurately using GIS and remote sensing approaches. Then, quantify coastline variability by measuring erosion and accretion rates, using the statistical operations within Digital Shoreline Analysis Software (DSAS) that include, Net Shoreline Movement (NSM), Linear Regression Rate (LRR), and End Point Rate (EPR). Finally, compare and analyse these rates with the associate causes for a better understanding of the coast area dynamic nature. The study results can be a feasible management tool to help coastal planners and policymakers to consider the identified coastal dynamic trends before starting any urban development.

Key Words: Remote Sensing, Geographic Information system (GIS), Net Shoreline Movement (NSM), Linear Regression Rate (LRR), and End Point Rate (EPR).

1. Introduction
Coastal areas are low elevated lands located at 10 m (or less) above sea level, these areas represent the shift region between the land and water [1] and hold more than 10% of the world’s population [2], where the oceanographic and geomorphological elements result in a continuous morphological dynamic progress such as erosion and accretion [3], [4]. Coastal land erosion is the removal of the material from the coastline, the materials deposition through erosion results in land accretion at a different place [5]. Coastal land suffers from erosions due to urbanization and the construction of coastal infrastructure considered as a serious hazard around the world [6], and are more likely to become gradually vulnerable to sea-level rise [7] and life-intimidating disasters such as tsunamis and hurricanes [8]. Rapid and effective techniques are vital to understanding the active nature of the coasts. Field surveys along with aerial photogrammetry had been used to address and study this phenomenon, these techniques considered costly and time-consuming, however Geographic information science (GIS) and
remote sensing offer the chance to observe and analyze the dynamic processes of coastal areas in a cost-effective method [9]. Most usually engaging coastline detection methods are subjective to visual analysis and manual digitalization of images. On the other hand, the availability of multi-spectral, multi-temporal, and multi-resolution satellite images along with light detection and ranging (LiDAR), and synthetic aperture radar (SAR) provides an efficient approach to semi-automate the monitoring process of large areas with a minimum in situ coastal information. Since the 1970s, several studies had been conducted to understand the dynamic environment of coastal areas using GIS and remote sensing [10-14]. Numerical models had been used to address the morphological dynamic progresses such as erosion and accretion [15], where empirical surveys had been conducted to measure the erosion [16]. Field surveys have been combined with Dynamic Computer Modelling (DCM) and Decision Support Systems (DSS), to measure erosion and accretion rates along shorelines. GIS has been used to delineate and vectorize coastline for further analysis of erosion and accretion rates to enable measuring and evaluating temporal rates of change for a better understanding of the possible processes that affect coastlines. A multi-temporal study for 60 years has been conducted to address the geomorphic variations along the Nile river, results addressed the changing of erosion rates after building the Aswan dam [17]. KOMPSAT-3 and aerial images cover more than 35 years had been used to detect erosion processes along Korea beaches after constructing a dam in that area [18]. Landsat images have been widely used for coastline dynamics monitoring at large scales [19]. Moreover, [20] used Landsat images along 16 years to address coastline changes along Mannar gulf, results warned about the possibility of losing Van Island within less than three decades. On the other hand, [21] predicted a rate of 4 m/year erosion within the next 50 years, using aerial and multiple satellite images such as (WorldView-2, IKONOS, and GeoEye-10. Considering all different studies, the geomorphology of coastal areas is expected to suffer from accretion and erosion processes.

The study’s main objective is to use remote sensing technology along with GIS to observe, analyze and quantify UAE coastline changes for more than 45 years, to provide a multi-temporal statistical analysis for coastline erosion and accretion rates. This study can provide basic information for disaster monitoring and mitigation that can be caused by climate change or by urbanization. The paper begins with introducing the study area, and the used datasets. Then, in section 3, it provides a detailed methodological framework of pre-processing the satellite images, land-water boundary delineation. Section 4, describes historical shoreline analysis, and the detection of land dynamics. Section 5, explains the results, and finally, section 6 concludes the study.

2. Study area

This study focus on the United Arab Emirates (UAE) that covers more than 83,000 KM2, located at the western part of Asia at the northeast end of the Arabian Plate, bordering Saudi Arabia to the south and west and Oman to the east, UAE also shares nautical borders with Iran to the north and Qatar to the west [22], figure1. Over the last 40 years, UAE had experienced rapid and active growth, resulted in densely populated coastal land. UAE population have been doubled since 2005 to be more than 9 million as in 2018 [23]. Most of the UAE’s population lives close to the coastline. UAE consists of seven emirates, where each one has its coastal area. Within this study UAE coastline has been divided into four zones, figure1, to cover the whole UAE coastline that stretches for more than 1000 km. land dynamics assessment procedures cover the period from 1972 to 2019, have been developed to group coastal areas into categorized classes: land accretion, land erosion, and stable or unaffected lands.
3. Materials and methods
The study methodology consists of a three-stage procedure. First data acquisition, correction, and enhancement. Second coastline delineation. Finally, coastline statistical analysis.

3.1. Data acquisition and pre-processing
To deliberate the temporal variations in UAE coastal dynamic nature, satellite images for more than 47 years, downloaded from earth explorer United States Geological Survey (USGS) table 1, had been used to first build mosaics for all UAE coastal area, and then divide UAE into four zones for more accurate analysis and assessment. Landsat Multispectral Scanner System (MSS) sensor aboard Landsat 1, and Landsat 5 had been used for the years of 1972, 1986. On the other hand, high-resolution multi-spectral Landsat 7 images, with Landsat Enhanced Thematic Mapper Plus (ETM+) sensor had been used to cover the year of 2002. Finally, Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) sensors aboard Landsat 8 had been used to acquire high resolution and multispertal images of 2019. To precisely and accurately extract needed information from remote sensing data, the atmosphere effect must be removed. Therefore, Landsat images atmospherically corrected using ENVI, and the Dark Object Subtraction method used to remove the haze component.

| Satellite     | Year | Sensor                           | Resolution | Projection              |
|---------------|------|----------------------------------|------------|-------------------------|
| Landsat 1     | 1972 | Multispectral Scanner System (MSS) | 60m        | WGS 84 UTM Zone 43 N & 42 N |
| Landsat 5     | 1986 | Multispectral Scanner (MMS)      | 30m        | WGS 84 UTM Zone 43 N & 42 N |
| Landsat 7     | 2002 | Enhanced Thematic Mapper (ETM+)  | 30m        | WGS 84 UTM Zone 43 N & 42 N |
| Landsat 8     | 2019 | Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) | 30m | WGS 84 UTM Zone 43 N & 42 N |
3.2. Coastline extraction: delineation of land-water boundary
In this study, Multi-Resolution Segmentation (MRS) algorithm, using large-scale value was used for the generation of image objects from the satellite images. Green, NIR, and SWIR1 waveband along with the object textural attributes (within eCognition software) were used to the isolated coastal area from water in the satellite images. The isolated coastlines were exported into shape-files (within ArcGIS). To validate the generated coastlines, each one was manual checked using the traditional visual interpretation technique, by manual digitizing and topology building for accurate and precise coastline production.

3.3. Historical coastline analysis
The ArcGIS extension Digital Shoreline Analysis System (DSAS), established as a cooperative work by USGS and the TPMC Environmental Services, helps analysts to quantify coastline rates-of-change locations using a multi-temporal vector coastline data within GIS setting [24]. It automatically produces perpendicular transect-lines on a pre-defined baseline and through all the used multi-temporal coastlines at a specific spacing distance specified by the analyst. After that, each transect-coastline intersection with the baseline used to measure rate-of-change statistics. The coastline movement away from the baseline towards the sea called accretion (with positive statistical amount), and any shift towards the land called erosion (with negative mount) measured at each transect. In this research, different transects were created at a 500 m and 1500 m (according to the zone area) spacing distance perpendicular to the baseline. This study fulfills three statistical operations to quantify coastline variability, which includes Linear Regression Rate (LRR), Net Shoreline Movement(NSM), and End Point Rate (EPR). NSM is the total distance between the first and the last coastline measured at each transect, EPR calculated by dividing NSM on the time interval between the images.

4. Results

4.1. Overall accretion and erosion
This research measures the changes in morphological changes of areas at four coastal zones, along with 47 years. The statistical analysis shows that both the erosion and accretion rates were minor at zones 1 and 4 of the coast, with an annual average of 3% and 1% respectively. The differences in the amount of annual average land added were highest at zone 3. A general demonstration of the rates of erosion and accretion along all the zones can be found in figure 2. Table 2, describes the total accretion and erosion rates along the study time period. In general, the transects for the whole study area shows a minimum changeability with an erosion rate as high as 10.01 m/year. While the highest accretion rate was 10.2 m/year. Over 47 years, the highest average erosion pattern was found in zone 3 equals to 39%, and the highest average accretion pattern was found in zone 2 which was 76%. Zone 2 coastline erosion rate reached the highest value of EPR (~10.5 m/year), and the accretion rate reached the highest value of EPR (18 m/year) at zone 4, figure 3. Coastline present the highest changeability in NSM with an overall accretion of 340 m; however, the highest amount of landward shift (350 m) was located in zone 2. Within the study area, erosion and accretion rates did not greatly change, this indicates that the UAE coastal area is almost stable with a minor change.
Figure 2. Overall change in erosion and accretion rates along study zones.
Table 2. Accretion and erosion in different UAE coastal zone.

| Zones | Emirates covered | Max. erosion | Avg. of all erosional rates | Max. value accretion | Avg. of all accretion rates | Average rate |
|-------|------------------|--------------|-----------------------------|----------------------|-----------------------------|--------------|
| Zone1 | Fujairah          | -9.21        | -2.37                       | 5.85                 | 1.3                         | -0.3         |
| Zone2 | Umm Al Quwain, Ras Alkhaimah | -10.01       | -2.11                       | 9.29                 | 1.5                         | -0.76        |
| Zone3 | Ajman, Sharjah, Dubai | -9.06        | -1.63                       | 10.2                 | 1.96                        | 0.39         |
| Zone4 | Abu Dhabi         | -7           | -1.6                        | 8.69                 | 1.2                         | -0.1         |

4.2. Zone wise erosion and accretion

The Highest average erosion rate was identified at zone 2, which includes: Umm Al Quwain, Ras Alkhaimah. While the highest average accretion rate was identified at zone 3, which represents Dubai, Ajman, and Sharjah emirates. However, Zone 1, and Zone 3 coastline erosion rate had the same value of EPR (-9 m/year), with a bit different in the accretion rate observed as an EPR value of (15 and 5.5 m/year) at zone 3, and 1, respectively, figure 3. It is observed that the rate of erosion (9, 10 m/year respectively) was higher than the rate of accretion (5, 9 m/year) during the study period at both zones 1, and 2. Zones 3, and 4 show a slightly higher accretion rate (10, 8 m/year respectively) than erosion (9, 7 m/year, respectively) during the study time period, Table 2. Zone 1 shows the highest seaward shoreline movement at around 5 km from north equals to 180m, whereas the highest landward shoreline movement at 12 km from the north equals to 300 m, figure 4. The highest erosion amount happened in the central part of zone 2, starting from 70 km to the south, and the highest accretion at zone 2 appears at 209 km south, figure 4. At zone 3 the maximum accretion occurred in the southern part of the center at 115, 135, and 140 km, figure 4. Finally, at zone 4 the accretion rate reaches its highest at 220 km, while the erosion rate reaches its highest at 510 km to the south, figure 4.
Figure 3. EPR statistical change rate measurements.
Coastal erosion is an important issue that affects many coasts all over the world. Actually, coastline location is an indication of the sediment budget, and any changes may show natural or anthropogenic processes along the coast. During the last decade, coastline delineation and statistical quantification have been really enhanced with the availability of new satellites, and the advanced developments in the processing, and analysis techniques. The use of remote sensing approaches and the availability of historical data can overcome the absence of in situ field surveys. Therefore, multi-temporal monitoring and analysis of coastlines are vital to understanding its dynamic processes.

This study offers a quantitative statistical analysis of UAE coastline variability between 1972 and 2019. Multi-temporal remote sensing images and GIS techniques had been used to calculate and detect the overall erosion (76%) and accretion (39%) locations. The study shows different results on the spatial scale, where maximum coastal erosion was measured at zone 2. While maximum accretion was measured at zone 4. Overall the study reveals the stable nature of the UAE coastal area, where the erosion and accretion rates did not greatly change over the past four decades. However, this methodology is very important to understand the active coastal geomorphology and can be considered be an effective management tool to help coastal urban planners and officials to think through the observed coastal dynamic movements before planning urban development and extensions.

6. References
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