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# Land use/land cover change along the Eastern Coast of the UAE and its impact on flooding risk

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## ABSTRACT

This study was conducted to investigate the spatiotemporal changes of land use/land cover (LULC) along the eastern coast of the United Arab Emirates (UAE) over a 20-year period using an integration of remote sensing and Geographic Information Systems techniques. The impact of land use change on flooding potential was also investigated through hydrologic model simulations. Landsat images of the years 1996, 2006 and 2016 were processed and analyzed. Change detection was carried out to assess changes in the built-up areas. Furthermore, the impact of urbanization on flooding was assessed using a hydrologic model in two major watersheds of Fujairah Emirate. It was observed that for the period 1996–2006 the vegetation and the built-up areas had increased at a rate of 11.23% and 24.56%, respectively. For the period 2006–2016, this expansion more than doubled in terms of the vegetation class (27.51%) and slightly increased for the built-up class (28.98%). The change detection analysis revealed that urbanization has mostly occurred along the coastal boundary. Hydrologic model simulations quantified the role of urbanization in increasing the flooding potential. The increase depends on watershed characteristics and the rate of change in urbanization and the magnitude of the rainfall event.

## ARTICLE HISTORY

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## KEYWORDS

Land use land cover;  
remote sensing; GIS; flood  
risk assessment; UAE

## 1. Introduction

Studies have claimed that there is only a limited portion of the earth's surface which is still in its original state (Bhatta 2010). Due to anthropogenic activities, the Earth's surface is being significantly altered in some manner and man's presence on the

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Earth and his use of land has had a profound effect upon the natural environment, thus resulting in an observable pattern in the land use/land cover (LULC) change over time (Leh et al. 2013; Rawat and Kumar 2015). These radical changes in LULC have attracted the attention of researchers to assess the drastic effects of these changes on different aspects of urban planning and the environment, including strategic land management, air quality standards, and flood risk reduction (Panahi et al. 2010; Superczynski and Christopher 2011; Kaul and Sopan 2012; Apollonio et al. 2016; Batunacun et al. 2018; Al Abdouli et al. 2019). The information obtained from studying and detecting LULC change can help policy makers and managers better understand the underlying relation of human-induced factors with the environment (Usman et al. 2015; Liaqat et al. 2017).

The LULC of the UAE has changed tremendously in the past few decades. Since the discovery of oil in the Arabian Gulf region in the 1960s, the Gulf Cooperation Council (GCC) countries, and in particular the UAE and Qatar, have experienced continuous growth in terms of their economies and populations (Al-Nakeeb et al. 2015). This growth resulted in huge urbanization that turned the desert into an expansive urban development consisting of residential, commercial, industrial, sports and tourism projects that are supported by intricate infrastructures. Urban sprawl in the UAE is the driving force behind a number of urban environmental issues such as the decrease in air quality and the increase in local temperature. Therefore, understanding how, why, where and what impact LULC changes are having, is very crucial and useful. This is particularly significant inasmuch that it will equip planning policy makers with the necessary information they need in order to plan for growth that is more coordinated and controlled.

Land cover classifications serve an important role in physical and social sciences research on topics such as urbanization and soil mapping. LULC change has also become a central component in the current strategies for managing natural resources and monitoring environmental changes (Harika et al. 2012; Batunacun et al. 2018), particularly in vulnerable areas such as coastal zones. One of the major influences of the rapid pace of economic and population growth, especially in developing countries, is the change in LULC. Identifying and understanding these radical changes are crucial for the assessment of their drastic effects along the coastal areas. Assessing LULC change, particularly how rapid urbanization is affecting coastal areas, would contribute to managing natural resources and monitoring environmental changes. In addition, it would help policy makers to identify priorities, as well as helping them in making informed decisions.

Coastal zones of the world are highly productive, constituting a vital component in maintaining climate and ecosystems. Detection and assessment of terrain features along the coasts is an important task as variations of shoreline ecosystems have a direct impact on economic and industrial growth as well as land management (Alesheikh et al. 2007; Masria et al. 2015). The monitoring and mapping of coastal zones is a challenging task for sustainable development and environment protection (Muttitanon and Tripathi 2005).

In the past, LULC change had been studied using *in situ* data, however, such data is limited in spatial and temporal coverage. Moreover, collection of field data has

often meant duplication of efforts or that the data collected for a specific purpose was of little or no use for a similar purpose (Anderson et al. 1976). It is also difficult, if not impossible, to collect data from inaccessible areas. Thus, data collection is time consuming and often costly. Therefore, such data is not reliable for efficient planning and decision-making (Weng et al. 2004; Weng 2009). These problems can be addressed using remote sensing data that offer a supplement to local measurements, providing comprehensive coverage of large areas. Such data are reliable and regularly updated (Chen et al. 2013; Mujabar and Chandrasekar 2013; Mohammady et al. 2015). LULC datasets are generally generated from available satellite data such as Landsat using state of the art classification methods including supervised, unsupervised, cross-correlation analysis, object-oriented and neural networks (Yuan et al. 2005; Adepoju et al. 2006; El Gammal et al. 2010; Rawat and Kumar 2015).

Remote sensing data acquired by sensors onboard different satellite platforms has been applied successfully in many land cover classification and land use change detection studies (Hereher et al. 2012). Petchprayoon et al. (2010) studied the impacts of LULC change, particularly urbanization, in the Yom River's discharge behaviour using Landsat data of Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) in integration with remote sensing and GIS techniques. The research revealed that, the area was subjected to urbanization and that was mainly at the expense of agricultural area. The researchers also observed that the river discharge had slightly increased with changes in LULC, especially an increase in urban areas and a decrease in forested areas. Abd and Alnajjar (2013) studied LULC change that occurred in Johor, Malaysia between 1995 and 2011 using Landsat data of TM and ETM+. The analysis showed that urban area had increased, while the vegetative area had decreased. Chen et al. (2013) investigated the spatiotemporal changes in Honduran mangrove forests using Landsat imagery during the periods 1985–1996, 1996–2002 and 2002–2013. They concluded that from 1985 to 2013, approximately 11.90% of the mangrove forests were lost to other uses, especially shrimp farming. The greatest loss (~7.30%) was observed during 1985–1996 due to the substantial development of shrimp culture adopted in the 1980s. They also examined the trends of land cover change and predicted that the area of mangrove forests will be reduced by 1200 ha between 2013 and 2020.

Similarly, Dewan and Yamaguchi (2009) and Yagoub and Kolan (2006) studied LULC change along the coastal zone of Greater Dhaka, Bangladesh, between 1975 and 2003 and Abu Dhabi between 1972 and 2000, respectively. The results of Dhaka's study revealed that substantial growth of built-up areas over the study period, which resulted in a significant decrease in the area of water bodies, cultivated land, vegetation and wetlands. The study of Abu Dhabi coast revealed that the area of mangrove, represented by a single species, *Avicennia marina*, had been drastically reduced due to different anthropogenic activities including reclamation and dredging. Siddiqui and Maajid (2004) evaluated coastal changes between 1973 and 1998 in Pakistan using Landsat Multispectral Scanner (MSS) and TM data. The authors concluded that the Korangi-Phitti Creek area along Bundal and Buddo Islands had experienced significant geomorphological changes during the study period due to land accretion and erosion. Tan et al. (2011) assessed the LULC change over Penang, Malaysia using

Landsat images for the years 1991 and 2007. The analysis revealed that during the study period forest area decreased by 25.76% and the urban and grassland areas increased by 20.75% and 70.60%, respectively. Amin et al. (2012) used Landsat MSS 1976, ETM 2001, 1990 and IKONOS 2007 data to monitor LULC over Srinagar city in Kashmir Valley for a period of 31 years (1976–2007). They found that the built-up areas have increased, while forest area and open spaces have decreased. Landsat 5 TM and Landsat 8 OLI data for the years 1992, 2003 and 2014 were applied by Liping et al. (2018) to monitor and predict LULC change over Jiangle, China. The study results have shown that the urban and forest areas have increased.

Hereher et al. (2012) have used Landsat and Moderate Resolution Imaging Spectroradiometer (MODIS) data in studying LULC change of Hail, Saudi Arabia. The study concluded that the geomorphology of Hail area is dominated by plains and sand dunes and the cultivated areas had increased significantly (~15 times) from 1972 to 2010. Ghanavati et al. (2008) used TM and ETM + data to monitor geomorphologic changes of Hendijan River Delta, southwestern Iran. The results of this study showed that the Hendijan River channel had migrated several times over the past few decades and, as a result, several meanders and ox-bow lakes were formed. Hegde and Akshaya (2015) studied the accretion and erosion pattern along the Karnataka coast. The results of this study indicated that an overall average accretion of 1.1 m/yr and erosion of 1.0 m/yr along the Karnataka coast.

Prajapati (2016) analyzed LULC change for possible land and forest management strategies in Chakia, Tahsil India. The study used Indian Remote Sensing satellites IRS-P6 and LISS-III for preparation of the thematic map of LULC and the changing pattern during a 10-year period (2004–2014). The results showed that larger parts of forest and fallow lands were converted into cultivated lands. Batunacun et al. (2018) have used Landsat MSS, TM, ETM + and OLI data for the years 1975, 1990, 2000, 2005 and 2015 and Huan Jing-1 (HJ-1) scenes for the year 2009 to study land degradation in Xilingol, China. The research found that in spite of notable restoration successes in the past, grassland degradation continued to be the main ecological and environmental problem.

Land use change in a watershed has a direct relationship with the amount of runoff generated from a given rainfall event. Brath et al. (2006) found that land use change and urbanization had significant effect on the peak discharge of medium size watershed in the Apennines mountains of Italy. However, the effect was insignificant for extreme events (return period of 200 years and above). Saghafian et al. (2008) observed the discharge from several watersheds for the 1967–1997 period and found that the change in discharge varied among watersheds depending on the magnitude of land use change. A modelling study by Mao and Cherkauer (2009) showed that conversion of forests into grassland and row crop agriculture significantly decreased evaporation and increased runoff in the Great Lakes region of the United States while the reverse effect happened when prairie grassland were converted to crop agriculture. Sheng and Wilson (2009) observed that development increased runoff and peak discharge for several watersheds in Los Angeles area, with the rate of flood discharge increase with population density depending heavily on the distribution of the impervious surface and character of the storm water conveyance system. Statistical analysis

of flood events over small catchments in Slovakia revealed that flood event frequency increased with the increasing total area of land cover changes in a catchment (Solin et al. 2011)

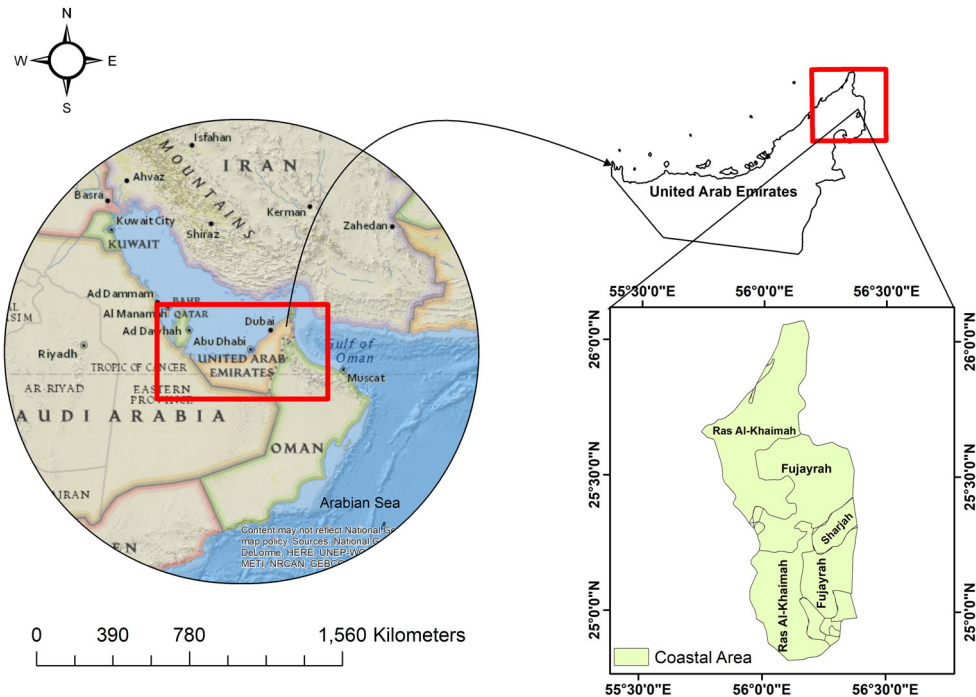
Sharif et al. (2016) showed that a 15% increase in the urbanization of the watershed in Al-Aysen, Riyadh, resulted in about 30% boost in the peak discharge for the 5-year return period event. An increase of 115% was simulated when the watershed became fully urbanized for the 5-year return period event. The increase noted to be higher in the lower return period events than the higher return period events. Muñoz et al. (2018) concluded that the 3% increase in the imperviousness of Houston Metropolitan Statistical Area resulted in the increase of peak flow by ~5% and 15% increase of inundated area. This clearly demonstrates that a minor change in land use can be amplified, exposing the area to devastating consequences of flooding. Although, population and economic growth are the main forcing agents for land use change, Low-impact Development (LID) and Best Management Practice (BMP) strategies should be followed to reduce the adverse flooding that comes with development.

Over the last few decades, the LULC of the United Arab Emirates (UAE) has considerably changed. Therefore, there is an urgent need to map the resulting changes and to understand the trend of LULC change in the different parts of the country to aid in any future land development planning, flood control, and resource management. In this study, we investigate LULC change that has taken place in the eastern coastal areas of the UAE over a period spanning from 1996 to 2016. The specific objectives of this study are to: (1) classify land use and land cover of the east coast of the UAE using multi-temporal Landsat images; (2) determine how land use has changed in the east coast of the UAE over a period of 20 years; (3) examine the reliability of maximum likelihood supervised classification method for image classification in the context of the present study, and (4) assess the potential impact of land use change on flood risk.

## 2. Study area

The study was carried out in the east coast of the United Arab Emirates (UAE). The UAE is located in the arid southeast part of the Arabian Peninsula. The Arabian Peninsula is one of the harshest places on earth with regard to climatological conditions. The region is characterized by very scarce rainfall and extremely high summer temperatures and high evaporation rates. These conditions make the Peninsula a hostile environment for the people, fauna and vegetation (Boer 1997; Ouarda et al. 2014). The East Coast of the United Arab Emirates is a small section lying between two regions of Oman, the Musandam Peninsula and the region surrounding Muscat, the capital of Oman. Most of it is located within the boundaries of Fujairah Emirate – the fifth largest emirate of the seven emirates that constitute the UAE (Figure 1). Fujairah is the only emirate located on the Gulf of Oman at the eastern end of the country rather than on the Arabian Gulf. It is also the sole emirate that is surrounded by mountains rather than desert.





**Figure 1.** A map showing the study area (UAE Eastern Coastal Zone). Source: Author

### 3. Materials and methods

#### 3.1. Data

To investigate the LULC change of the east coast of the UAE, different LULC cover types were delineated from remotely sensed data. Landsat satellite (5, 7 and 8) images of spectral band 3 (0.63–0.69  $\mu\text{m}$ ), 4 (0.78–0.90  $\mu\text{m}$ ) and 5 (1.55–1.75  $\mu\text{m}$ ) of Thematic Mapper (TM); band 3 (0.63–0.69  $\mu\text{m}$ ) and band 4 (0.77–0.90  $\mu\text{m}$ ) and band 5 (1.55–1.75  $\mu\text{m}$ ) for ETM+, and band 3 (0.533–0.590  $\mu\text{m}$ ), band 4 (0.636–0.673  $\mu\text{m}$ ) and band 5 (0.851–0.879  $\mu\text{m}$ ) of Operational Land Imager (OLI), sensors acquired in February 1996, 2006 and 2016 were obtained from the United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (<https://earthexplorer.usgs.gov>). We chose images of 1 month (February) because there are no significant seasonal variations of LULC and in particular vegetation due to the prevailing harsh climatic conditions of the region.

The images were used to produce a time series of LULC change on a 10-year period. The whole area was covered by four scenes of Landsat (path/row 159/42, 159/43, 160/42, 160/43). The spatial resolution of the images was 30 m. The selected images were free of signal error from the sensor and were cloud free. The ground truthing points were collected from field data and high-resolution images for classification and discrimination among different classes. Other datasets were integrated with remotely sensed data including city and district boundaries obtained from Abu Dhabi municipality and the Central Bureau of Statistics. To improve the accuracy of the classification, some field visits were carried out in areas where there was a problem distinguishing between farms and parks and between built-up and sandy areas due to similarities in spectral signatures.

Topography data used to build the hydrologic model were extracted from ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) product. ASTER is a project that is jointly funded by the Japan and the United States National Aeronautics and Space Administration (NASA). The product covers the entire Globe and is available in  $1 \times 1^\circ$  tiles with a resolution of 30 m.

### **3.2. Methods**

#### **3.2.1. Land use analysis**

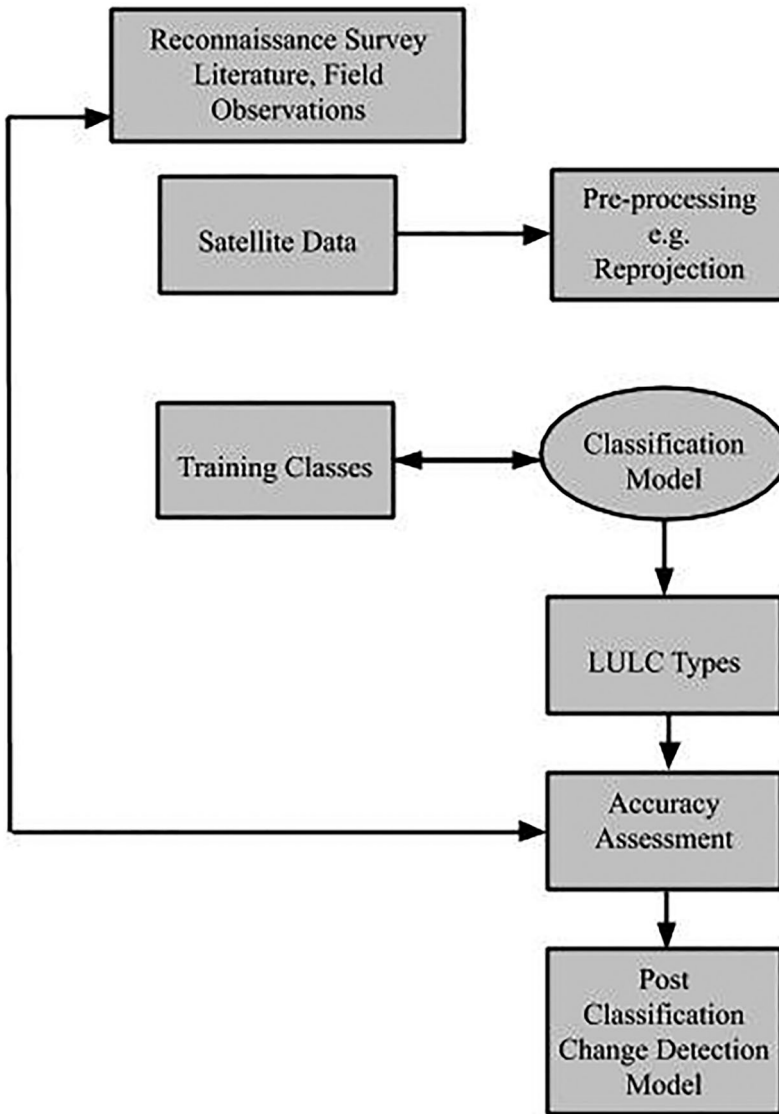
In this study, Environment for Visualizing Images (ENVI) and ArcGIS software were used to process the satellite images. Figure 2 shows the functional flow of the methodology used for LULC change analysis. The reliability of quantitative information of Landsat data relies on atmospheric correction (Liang et al. 2001). Standard Landsat equations and scaling factors (USGS 2014) were used for the rescaling of Landsat 8 OLI to the Top of Atmosphere (TOA) reflectance. All datasets were re-projected to WGS84/UTM Zone 40N, corrected for atmospheric conditions and geometric errors. Then parts of Landsat scenes that cover the study area were mosaicked. For LULC classification, remote sensing computer processing techniques (supervised classification) and visual interpretation were applied to classify the images into five LULC categories including vegetation, built-up areas, mountains, sandy areas and water.

Training classes were selected using existing information obtained from field surveys, Statistical Center of Abu Dhabi (SCAD 2016) reports, high spatial resolution data, and previous land use maps. Afterwards, a spectral signature file was created for each of the defined land cover classes using each training class. The maximum likelihood algorithm was employed to classify the study area into the five LULC types using the developed spectral signatures because of its robustness and easy availability in almost all image-processing software (Lu and Weng 2007), and the assumption of normally distributed data was met. However, the maximum likelihood method requires more computations per pixel than other techniques such as parallelepiped or minimum distance classification algorithms (Beitzel et al. 2005). Additionally, normalized spectral mixture analysis was applied to observe the impact of mixed pixels in the classified map (Lu and Weng 2005). Mode file developed by De Jong et al. (1999) was applied to remove the isolated pixels and replace them with the nearby majority class pixels. The classified images were converted to ArcGIS files format for change detection analysis. The raster calculation application was used for analyzing LULC changes from 1996 to 2016 and for identifying areas where rapid changes occurred in the study area.

#### **3.2.2. Assessment of classification accuracy**

The accuracy assessment is a process to examine the perfection between the real physical situation and the classified images (Campbell and Wynne 2011). It explains the degree of difference between reference and classified data. The accuracy of the classified images of 1996, 2006 and 2016 was evaluated using the ground data. An error matrix was developed to evaluate the accuracy of the classified images. The standard criteria for training and accuracy assessment of classified images were followed using ground values, i.e. 70% of data were used for image classification and the





**Figure 2.** Functional flow of methodology used for LULC change detection. Source: Author

remaining 30% of ground data were used for accuracy assessment. The overall accuracy and Kappa coefficient were used to assess the accuracy of the classification. They are the most extensively used methods for accuracy assessment (Bogoliubova and Tymków 2014). The overall accuracy ( $O_a$ ) is the ratio of the total number of pixels correctly classified ( $t_c$ ) to the total number of pixels used for accuracy assessment ( $n_c$ ).

$$O_a = \frac{\sum t_c}{\sum n_c} \quad (1)$$

On the other hand, Kappa coefficient measures the percentage improvement in the classification over the completely random classification and it can be defined as:

$$K_c = NA^\bullet - B^\bullet/N^2 - B^\bullet \quad (2)$$

where  $K_c$  denotes the Kappa coefficient,  $N$  is the number of samples,  $A$  shows the correctly classified pixels from each class and  $B$  is the product of the total classified pixels and ground data pixels of each class.

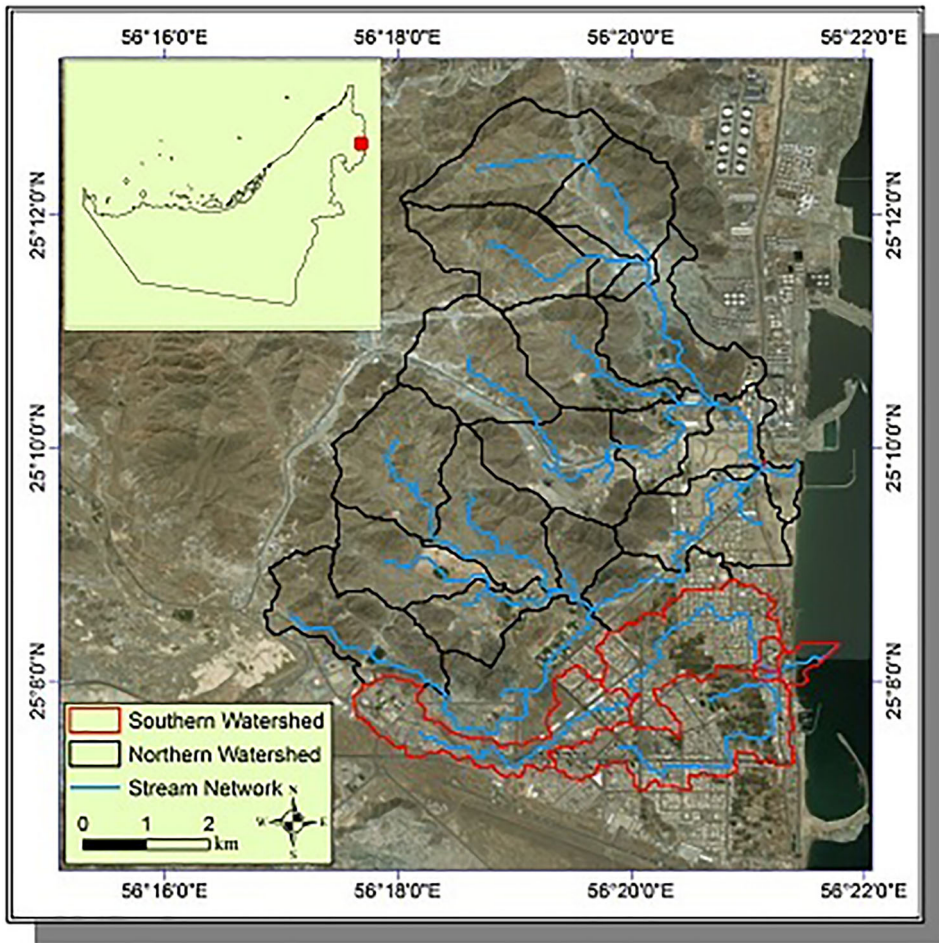
### 3.2.3. Hydrologic impact of urbanization

The degree of urbanization in a catchment has a major impact on the runoff response to given rainfall storm. Increased urbanization leads to more runoff volumes, higher flooding depths and elevated peak discharges. The impact of land use change is quantified through hydrologic model simulation of the generated runoff and the peak discharge for sub-catchments in the study area for different land use change scenarios. These scenarios represent the past and future possible urbanization rates in the study area. Hydrologic simulations were run with urbanization fractions ranging from 0% to 100% of the total catchment area, with the built area assumed to spread from the city centres in all directions. For each scenario, the hydrologic parameters were recalculated for each sub-catchment assumed to be experiencing land use change. Runoff hydrographs were simulated under different storm scenarios and degrees of urbanization to quantify the differences in runoff volume and discharge resulting from potential urban sprawl.

### 3.2.4. Hydrologic model setup

In this study, the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model was used for hydrologic modelling. HEC-HMS is a semi-distributed, sub-basin-based modelling system developed by the U.S. Army Corps of Engineering to simulate the hydrology of a watershed (USACE and HEC 2016). The model includes several sub-models to simulate different components of the runoff generation process with the choice of different infiltrations, unit hydrograph and flood routing methods. HEC-HMS is widely used because of its simplicity and the small number of parameters, which makes calibration relatively easier. The Soil Conservation Service (SCS) (currently the Natural Resources Conservation Service (NRCS)) curve number (CN) method (SCS 1986) is the main parameter used for estimating the infiltration capacity and runoff for various combinations of soil and land use/cover types. Several studies have demonstrated that the CN method can be applied in different environments and is able to produce reasonable results comparable to those of more complex models despite its simplicity (e.g. Ponce and Hawkins 1996; Shrestha 2003).

The topography data, at 30-m resolution, were obtained from the Global Digital Elevation Model (DEM) data based on ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) instrument (Farr et al. 2007). The watershed modelling system (WMS) software (EMRL 2019) was used for processing the model input data. The software automates the watershed delineation and parameter calculation from digital elevation data. The sub-catchments in the study area were delineated in such a way that they cover a significant portion of the developed area in the Emirate of Fujairah (Figure 3). To account for the variability of topography, a total of

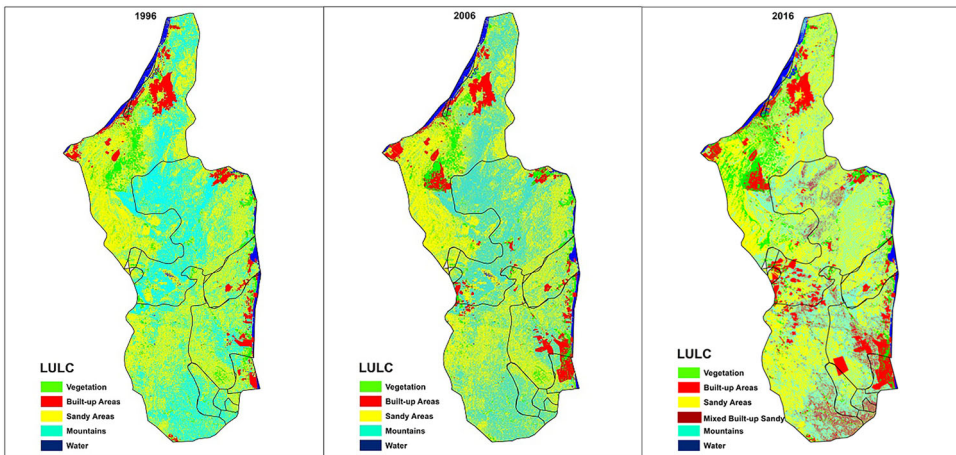


**Figure 3.** The location map of the Northern and Southern Watersheds of Fujairah. Source: Author

25 sub-catchments were found to be appropriate. The stream network was generated by implementing a drainage area threshold of  $0.5 \text{ km}^2$ . The sub-catchments were grouped into two watersheds, each draining into the coast as shown in Figure 3. The southern watershed ( $\sim 10 \text{ km}^2$ ) is dominantly urbanized at the current time, however, for the northern watershed ( $\sim 44 \text{ km}^2$ ) the developed area currently makes less than 10% of the total area.

The rainfall input used was based on the 24-h design for the UAE east coast obtained from the literature (Sherif et al. 2014). The estimated maximum 24-h rainfall values corresponding to return periods 100, 25 and 5 years are 218, 156 and 83 mm, respectively. The 6-min distribution of the 24-h storm was based on the Natural Resources Conservation Service (NRCS) Type II storm.

The CN of the sub-watersheds was estimated from the land use and hydrologic soil groups. Land use/cover data were obtained from remote sensing imagery as described above. Soil and geologic data were obtained from previous studies in the region (e.g. Elmahdy et al. 2015). Soil properties and parameters were derived from



**Figure 4.** Land cover and Land use classes of the UAE eastern coasts for the years 1996, 2006 and 2016. Source: Author

the digital soil map of the world (FAO 1998). WMS automatically computes the sub-catchment curve numbers from the soil type and land use maps and parameters. The CN values for different sub-catchments ranged between 60 and 85. Impervious area fractions for urban sub-catchments were estimated from aerial photography maps. The Muskingum-Cunge routing method and the standard Natural Resources Conservation Service (NRCS) lag method were used to route the hydrograph estimated by HEC-HMS at the outlet of each sub-catchment.

## 4. Results and discussion

The eastern coast of the UAE is confronted with environmental changes in the form of seawater intrusion, loss of landforms and aquifer contamination due to rapid changes in land use and land cover induced by economic activities and population growth (SCAD 2016) and other human activities.

### 4.1. LULC change

The spatial distribution of major LULC classes in the study area is shown in [Figure 4](#). Five major classes, i.e. vegetation, built-up areas, sandy areas, mountains and water, for the years 1996 and 2006 were delineated through the interpretation of the satellite images, in addition mixed built-up and sands class was demarcated for 2016 due to its appearance on the image of 2016 compared to the images of 1996 and 2006. The aerial extent ( $\text{km}^2$ ) and coverage in percentage of each class for the three study years are shown in [Table 1](#). The results show that vegetation areas were increased from 215.87 to 243.19  $\text{km}^2$  at a rate of (11.23%) during 1996–2006 and increased by 243.20  $\text{km}^2$  (27.51%) during the period 2006 to 2016. Based on the UAE Economic Vision 2030, the Abu Dhabi Food Control Authority (ADFCA) plans to partially fulfill the food demand of the country's growing population by increasing

**Table 1.** Area (km<sup>2</sup>) and the amount of change (%) in LULC of the eastern coast of the UAE over the period 1996–2016.

LULC Type	1996 (km <sup>2</sup> )	Study area (%)	2006 (km <sup>2</sup> )	Study area (%)	2016 (km <sup>2</sup> )	Study area (%)	1996–2016	
							Amount change (km <sup>2</sup> )	Percentage growth (%)
Vegetation	215.87	04.33	243.19	05.12	335.52	07.06	119.65	35.66
Built-up areas	217.92	04.37	288.90	06.08	406.83	08.56	117.60	46.43
Sandy Areas	2383.98	47.81	2080.37	43.79	1938.78	40.78	−2048.46	−22.96
Mountains	2073.71	41.59	2043.60	43.02	1728.30	36.36	−1738.19	−19.99
Water	94.94	01.90	94.58	01.99	87.41	01.84	240.58	−08.61

Negative sign indicates decrease in area between two time spans.

the local agricultural production and decreasing reliance on imported products. Hence, such increase of the vegetation areas was in line with the green desert policy of the UAE government (AGEDI 2016). Similarly, tremendous development in the infrastructure sector was observed in the form of built-up areas which significantly increased from 217.92 to 288.90 km<sup>2</sup> (24.56%) during 1996–2006 and from 288.90 to 406.83 km<sup>2</sup> (28.98%) between 2006 and 2016. The built-up areas were expanding mostly along the eastern coastlines and towards the southwest and northwest direction. This expansion proves that urban and infrastructure development constitutes a pillar of the national agenda of the UAE Government's economic plan – UAE Vision 2021.

As built-up areas increased consequentially, sandy areas decreased as shown in Figure 4 and Table 1. Sandy areas declined at a rate of 14.59% and 7.30% between 1996 and 2006, from 2006 to 2016, respectively and the overall rate of decline was 22.96%. This decrease was due to conversion of certain sandy areas to built-up areas and infrastructure development, as well as parts of some areas being used for agriculture and urban landscape features (e.g. roadside vegetation and parks). In a similar way, mountainous areas were also decreasing, especially during 2006–2016. This was mainly due to the large amount of mining and crushing activities which were being carried out in these areas due to the recent boom in the construction sector in Dubai and Abu Dhabi Emirates.

#### 4.2. Classification accuracy assessment

Classification accuracy of the developed LULC change maps using supervised classification was assessed. The overall accuracy describes the percentage of correctly classified pixels. The overall accuracies of the classified maps of the years 1996, 2006 and 2016 ranged from 73% to 78%, with Kappa coefficient values ranging from 68% to 71% (Table 2). There are no specific criteria to check the accuracy of classified maps because of the nature of LULC which varies according to different regional conditions and also due to lack of availability of ground values. In case one uses a semi-automated approach, Goodin et al. (2015) and Jiang et al. (2012) argue that the values of classification ranging between 61% and 80% can be in good agreement with the actual LULC. Similar results were reported in some previous studies on LULC change



**Table 2.** Accuracy assessment of classified images based on the error matrix for 1996, 2006 and 2016 images.

LULC type	Producer accuracy 1996	User accuracy 1996	Producer accuracy 2006	User accuracy 2006	Producer accuracy 2016	User accuracy 2016
Vegetation	83%	83%	92%	85%	83%	88%
Built-up areas	71%	71%	75%	75%	82%	70%
Sandy Area	75%	75%	80%	80%	74%	82%
Mountains	70%	70%	75%	82%	72%	73%
Water	95%	98%	91%	95%	90%	93%
Overall accuracy	75%		80%		78%	
Kappa coefficient	69%		72%		71%	

(Zhang et al., 2009; Im et al. 2015; Wilson et al. 2016; Batunacun et al. 2018; Hailu et al. 2018).

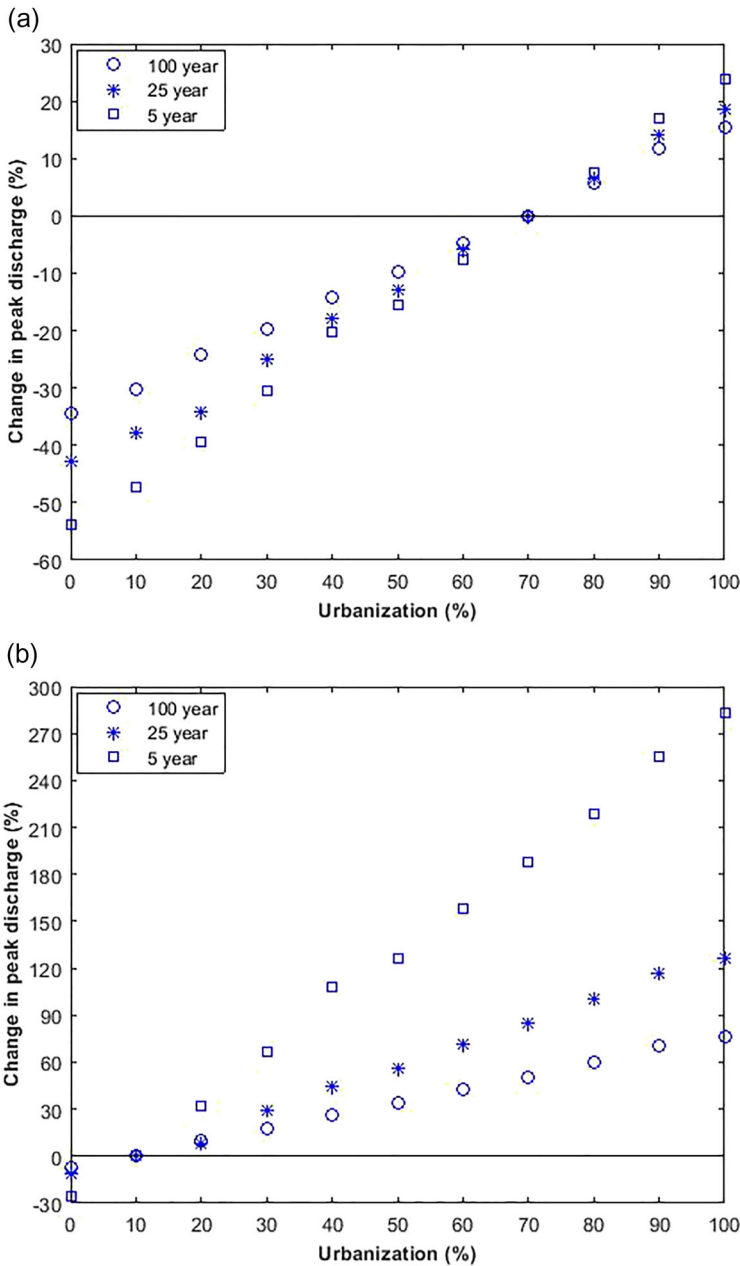
### 4.3. Impact of urbanization on flood potential

The HEC-HMS model was run with urbanized fractions ranging from 0% to 100% to represent the past and future possible urban growth conditions in the two watersheds and quantify the impact on the flooding caused by storms of different return periods. The southern and northern watersheds of Al Fujairah display a contrast of the current degree of urbanization (2016 land use). While the former is dominantly urbanized (at 70%), the latter has only about 10% of its area classified as urban. The current fractions of the urban area represent the reference urbanization levels for the two watersheds. The change in peak discharge (%) relative to the computed discharge with the current conditions for different levels of urbanization for the 5-year, 25-year and 100-year storms is shown in Figure 5 for the two watersheds.

The hydrologic simulations show that flooding caused by more frequent rainfall events (with a smaller return period) is exacerbated more by urbanization than by large storm events. This can be seen more clearly in the northern watershed, which might see a 290% increase in the discharge caused by the 5-year storms if fully urbanized. The already urbanized Southern watershed can still see a 26% increase in flooding caused by the 5-year storm if and when it becomes 100% urbanized. On the other hand, the results also show that the current level of urbanization of the southern watershed increased the pre-development peak discharge by about 222%, 175% and 150% for the 5-year, 25-year and 100-year storms, respectively. These results agree with the Brath et al. (2006) findings that watershed response was less sensitive to extreme events.

Urbanization, in general, will not only increase the peak discharge, but will also increase the runoff volume and the extent of the flooded area within a catchment. For urban areas, this means that more streets and built areas will be flooded. The impact will also depend on the terrain. For steep areas, the flooding will last for a shorter time, but water velocities will be high. This can result in sweeping away of vehicles on the streets and cause destruction by the force of the water. Stagnant water on mild slopes will also pose other dangers, including water contamination. These findings were supported by several studies demonstrating that increasing urban activities in flood plain areas will increase peak discharge, decrease the time to peak, and





**Figure 5.** The impact of urbanization in flooding potential of the two watersheds in Fujairah (a) southern and (b) northern watersheds, expressed as the per cent change in peak discharge as a function of the watershed level of urbanization relative to the current level of 70% and 10%, respectively, for the 5-year, 25-year and 100-year storms.

increase runoff volume (e.g. Suarez et al. 2005; Nirupama and Simonovic 2007; Saghafian et al. 2008; Huong and Pathirana 2013).

The 5-year event is more sensitive to the urbanization level (percentage of the impervious fraction) because the water losses (mainly infiltration) represent a large fraction of the rainfall. Changes to the extent of impervious portion will affect these

losses and consequently affect the runoff volume and peak discharge. The sensitivity increase will be even higher for the more frequent storms (i.e. return period less than 5 years). This frequent event will start to cause more problems as urbanization increase. This analysis highlights the direct impact of land use changes on watershed hydrologic response and is crucial step in planning, management, mitigation of flood hazards and sustainable development as has been discuss in several other studies (e.g. Neuvel and van den Brink 2009; Audisio and Turconi 2011; Špitalar et al. 2014; Ran and Nedovic-Budic 2016).

## 5. Conclusion

This study investigated the spatiotemporal dynamics of land use and land cover changes in the Eastern coast of the UAE from 1996 to 2016 using multispectral satellite data. Identifying and understanding these radical changes are crucial for the assessment of their drastic effects along the coastal areas. Land use/land cover change was evaluated using Landsat data in integration with supervised classification techniques. Five major classes were identified and delineated (vegetation, built-up areas, mountains, sandy areas and water). The results revealed that vegetation and built-up areas are continuously increasing at a rate of 11.23% and 28.98% for 1996–2006 period and 24.56% and 27.52% for the 2006–2016 period. During the study period, the built-up areas changed by 46.43% (from 217.925 km<sup>2</sup> in 1996 to 406.830 km<sup>2</sup> in 2016) and vegetation areas also exhibited an expansion by 35.66% (215.872 km<sup>2</sup> in 1996 to 335.520 km<sup>2</sup> in 2016). The accuracy assessment of the classified images proved the reliability of the applied classification scheme. It was also found that most of newly built-up areas were expanding along the coastline as well as along the southwest and northwest directions. The change detection analysis showed that the increase in built-up areas had caused a sharp decrease in the mountainous and desert areas. This was mainly due to crushing and mining, which can cause environmental problems in the future.

The study examined flood hazards associated with rapid urbanization in the study area. Remote sensing data and GIS techniques were used to prepare inputs for a hydrologic model. The impact of urbanization on flood peak discharge was studied for storms of different return periods under different urbanization scenarios. The simulations demonstrated that urbanization can significantly exacerbate flooding caused by a given storm due to obstruction of natural drainage and decreased infiltration. The impact of urbanization is significantly higher for small and moderate rainfall events than for larger events indicating that flooding caused by more frequent rainfall events will be more problematic as urbanization continues.

The outcomes of this study are not only helpful in understanding land changes along the eastern coast of the UAE for the purpose of policy making and planning but also in identifying areas where ecological systems are threatened. Since urbanization is inevitable with the growth in economy and population, it is crucial to implement Low-impact development (LID) and Best Management Practices (BMPs) strategies in order to reduce the impacts of urbanization on runoff.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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