Mapping Sand Dune Fields in Abu Dhabi Emirate Over the Period of 1992–2013 Using Landsat Data

N. Saleous, S. Issa and R. Saeed

Abstract Up to 90% of the United Arab Emirates' (UAE) surface is covered by sand dunes and intervening inter-dune belts. The country is severely affected by problems related to sand dunes movement and Aeolian deposits, recognized as a major contributor to desertification. This study discusses the use of publicly available Landsat TM and ETM+ data to detect sand dunes fields and enable monitoring of their movements in the Emirate of Abu Dhabi, UAE. The study focuses on developing a classification approach and applying it to historical Landsat data to produce consistent Land cover maps useable in subsequent change detection studies. Landsat scenes acquired over the period 1992–2013 are used to evaluate different multispectral classification approaches and determine the accuracy of resulting maps. The methodology uses several configurations of supervised classification techniques that include different band combinations to determine those that produce the highest accuracy in mapping the predominant land cover classes in the area. Results indicate that the tested configurations exhibit an unacceptable level of confusion in detecting the built-up class and that the use of surface reflectance as input to supervised classification yields adequate results for sand detection. All configurations also exhibit a certain level of confusion between sparse vegetation and other classes. The use of a vegetation index as a discriminator helps improve the classification accuracy.

Keywords Sand dunes · Classification approaches · Landsat · Monitoring · Vegetation index · Change analysis · UAE

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1 Introduction

A major part of the United Arab Emirates is covered by sand dunes and sand sheets. With the rapid growth that the country witnessed after the discovery of oil in 1968, major urbanization and farming projects were undertaken throughout the country some in the heart of the sand sea. Sand dunes and their movements present a serious sand encroachment threat to these structures. This study focuses on the mapping of sand dune fields and assessing their changes over the period 1992–2013 in the largest emirate of UAE using Landsat imagery. Availability of similar spatial and spectral characteristics of the Landsat TM and ETM+ sensors during the study period will ensure that they will provide consistent and reliable imagery that can be used in this study (Masek et al. 2001; Teillet et al. 2001).

Many previous studies explored the use of satellite imagery for detecting sand dunes and sand sheets. Different approaches to extract sand features were studied and evaluated. Some authors used enhancement and filtering techniques followed by digitizing sand fields (Janke 2002; Al-Dabi et al. 1997). Others used the spectral characteristics of sand to detect it through a multispectral classifications process (Hutchison 1982; Tuller 1987; Smith et al. 1990; Janke 2002).

Some of the approaches used in land cover classification suggest supplementing the spectral information with spatial information through the use of texture (Chang and Park 2006). Others suggest a transformation of input data through the use of Principal Component Analysis (PCA) to increase the classification accuracy (Rajesh 2008; Fung and LeDrew 1987).

In this study, we examine different approaches to create, detect, and map sand using Landsat imagery collected in three different years: 1992, 2002, and 2013. We apply the selected approach to create land cover and sand/non-sand maps over the study area for the three different dates. We assess their accuracy using higher resolution imagery and store them in vector format for use in change detection studies.

2 Study Area

The study area (Fig. 1) is located along the southern coast of the Arabian Gulf, between 22° 40″ and 25° North and 52° and 56° East. Approximately 85% of the Emirate is desert and can be divided into five different landforms: sand dunes (moving desert), inter-dune areas, coastal sabkhas, inland sabkhas, and exposed rock (Glennie 2001; Abu Dhabi Urban Planning Council 2007). Aeolian sand dunes are prominent in the UAE due to the country's climatological patterns, where the lack of rainfall and high summer temperatures, coupled with the scarcity of vegetation cover and strong wind patterns, all contribute to the suitable conditions that enhance sand dune movement (Glennie 2001; Al-Awadi 2004).

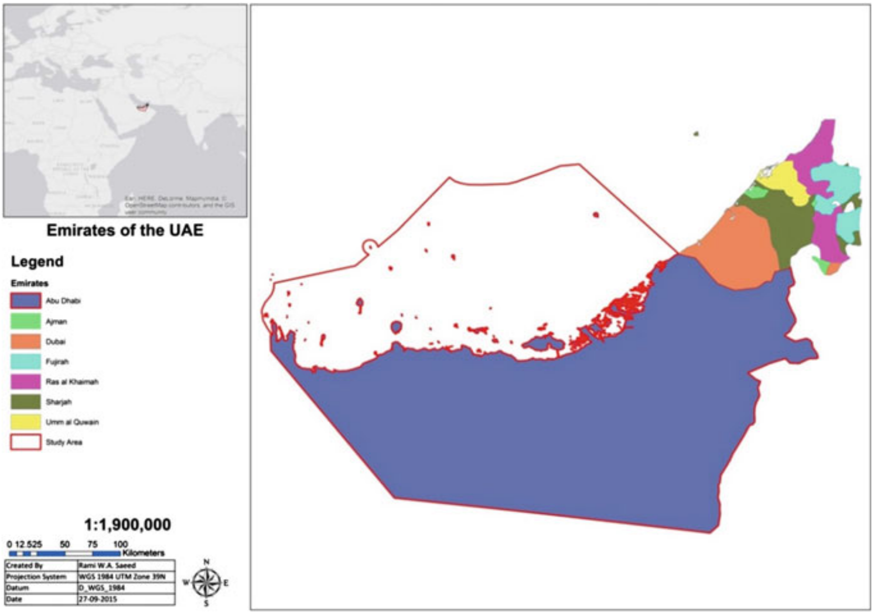

Fig. 1 Map of the UAE with the study area delineated by the *red border*

The Emirate's climate is harsh with mainly two seasons. One is the hot summer (May–September) with rare rainfall where temperatures reach 48 °C; humidity ranges between 80 and 90% and sandstorms regularly strike between May and early July. The other is a mild winter where the temperature reaches 24 °C, where fog becomes more frequent, and little rainfall occurs more between November and February.

3 Methodology

3.1 Data

Six Landsat scenes defined by paths 160–162 and rows 43–44 of the WRS-2 frame are required to cover the selected study area. A set of these scenes for each of the study dates 1992, 2002, and 2013, are acquired from the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) Climate Data Record (CDR) repository at the United States Geological Survey (USGS) (Masek et al. 2006). Their characteristics are summarized in Table 1. The radiometrically corrected surface reflectance product included in the collected data set are processed using Exelis Visual Information System ENVI 5.3 image processing software to extract and build a time series of the sand class in the study area.

Table 1 Characteristics of acquired Landsat scenes

<table>
<tr><th rowspan="2">Row</th><th colspan="3">Path
Date</th><th rowspan="2">Resolution</th><th rowspan="2">Parameter</th><th rowspan="2">Sensor
Platform</th></tr>
<tr><th>162</th><th>161</th><th>160</th></tr>
<tr><td rowspan="3">43</td><td>04-06-1992</td><td>05-06-1992</td><td>14-06-1992</td><td rowspan="6">30 meters</td><td rowspan="6">CDR
Surface
Reflectance</td><td rowspan="2">TM
Landsat
4</td></tr>
<tr><td>03-07-2002</td><td>10-07-2002</td><td>12-07-2002</td></tr>
<tr><td>01-08-2013</td><td>25-07-2013</td><td>18-07-2013</td><td rowspan="2">ETM+
Landsat
7</td></tr>
<tr><td rowspan="3">44</td><td>04-06-1992</td><td>05-06-1992</td><td>14-06-1992</td></tr>
<tr><td>03-07-2002</td><td>10-07-2002</td><td>12-07-2002</td><td rowspan="2">OLI
Landsat
8</td></tr>
<tr><td>01-08-2013</td><td>25-07-2013</td><td>18-07-2013</td></tr>
<tr><td>Datum
Projection</td><td>WGS 1984
UTM Zone 39 N</td><td>WGS 1984
UTM Zone 39 N</td><td>WGS 1984
UTM Zone 40 N</td><td></td><td></td><td></td></tr>
</table>

Table 2 Characteristics of secondary data used in the study

Data type	Date	Spatial resolution (m)	Purpose
Rapid eye	2013	5	Accuracy assessment
IKONOS	2003	1	Accuracy assessment
SPOT panchromatic	1986	10	Accuracy assessment
Abu Dhabi Emirate boundary shapefile	2013	–	Delimit study area

Additionally, a set of secondary data is needed in the study to delimit the study area and to perform accuracy assessment of the created land cover maps. They are listed in Table 2.

3.2 Methods

The approach used in this study is summarized in Fig. 2. It includes mosaicking individual Landsat scenes for each study year and creating surface reflectance subsets of the study area that are subsequently used in the multispectral classification process. The approach also defines a classification scheme including

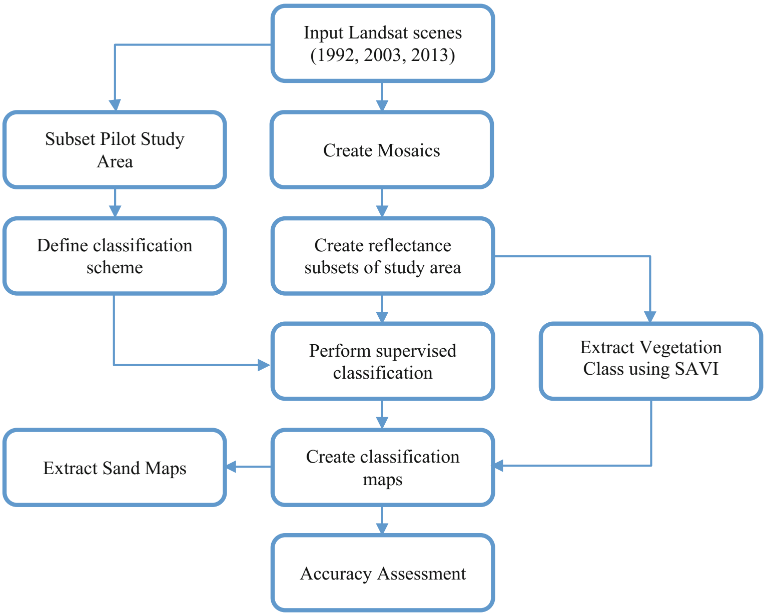

Fig. 2 Methodology flowchart

important land cover classes in the study area that can be adequately derived from the available dataset. It calls for the selection of a smaller pilot study area where multiple configurations of inputs are used to identify detectable spectral clusters.

To improve the overall accuracy of the classification, we extract the vegetation class using a vegetation index approach prior to performing supervised classification using the surface reflectance mosaics of the study area. As a result, land cover maps are created for the three study years, and their accuracy is assessed using the confusion matrix technique. Finally, sand maps that can be used in analyzing sand changes are extracted (Fig. 2).

3.3 Extraction of Vegetation Class

Since in arid regions, vegetation is usually sparse and can be spectrally confused with other cover types at Landsat spatial resolution, we opt to extract the vegetation class separately using a vegetation index approach. Given the sparse nature of vegetation with exposed soil-understory, we select the Soil Adjusted Vegetation Index (SAVI) to help identify vegetated areas. SAVI is calculated from the Red and Near-Infrared surface reflectance using the formula given in Eq. (1) (Huete 1988).

$$\text{SAVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED} + L} * (1 + L), \tag{1}$$

where L is the factor that highlights the difference between vegetation and soil and is set 0.5.

The analysis of the produced SAVI maps for the three study periods leads to determine the vegetation threshold to be 0.35. All pixels where SAVI is greater than 0.35 are labeled vegetation and are excluded from the subsequent classification process.

3.4 Classification Scheme

The classification scheme used in this study is based on a modified Level 1 Anderson scheme. Classes in the original scheme that do not occur in UAE are removed from the scheme. They are rangeland, forest land, tundra and perennial snow, and ice. As mentioned earlier, vegetation class (agricultural land) is extracted separately and is excluded from the classification process.

Due to the limited spatial resolution of Landsat data coupled with the heterogeneity of certain land cover classes such as the urban class, it cannot be detected accurately. To minimize detection errors, we test several configurations of input parameters to the clustering algorithms over a pilot study area to ensure that the selected classes can be identified using Landsat data. The pilot study area is limited to one Landsat scene that includes all desired classes. The test set of inputs are: (1) Texture entropy, (2) surface reflectance and texture, (3) surface reflectance and (4) three first components of the PCA. The results of the clustering using the ISODATA algorithm are presented in Fig. 3. Other than the texture entropy, the different input configuration yielded a substantial number of different clusters: 31 clusters in the case of surface reflectance, 41 clusters in the case of surface reflectance + texture and 295 clusters in the case of PCA. However, merging the clusters into information classes produces the same number of detectable classes for all three configurations such as in the example presented in Fig. 4. The classes that can be identified are: sand, vegetation (as derived from the vegetation index), water (deep water), intertidal zone (shallow water), wet soils and sabkhas, and exposed bedrock. The urban class is consistently confused with wet soils or exposed bedrock classes. Since the main focus of this study is sand, the errors in the detection of the urban class can be tolerated.

Since the different input configurations yield comparable detectable information classes, the configuration using the surface reflectance only is used in the classification process. A class separability analysis confirmed that the selected classes are spectrally identifiable.

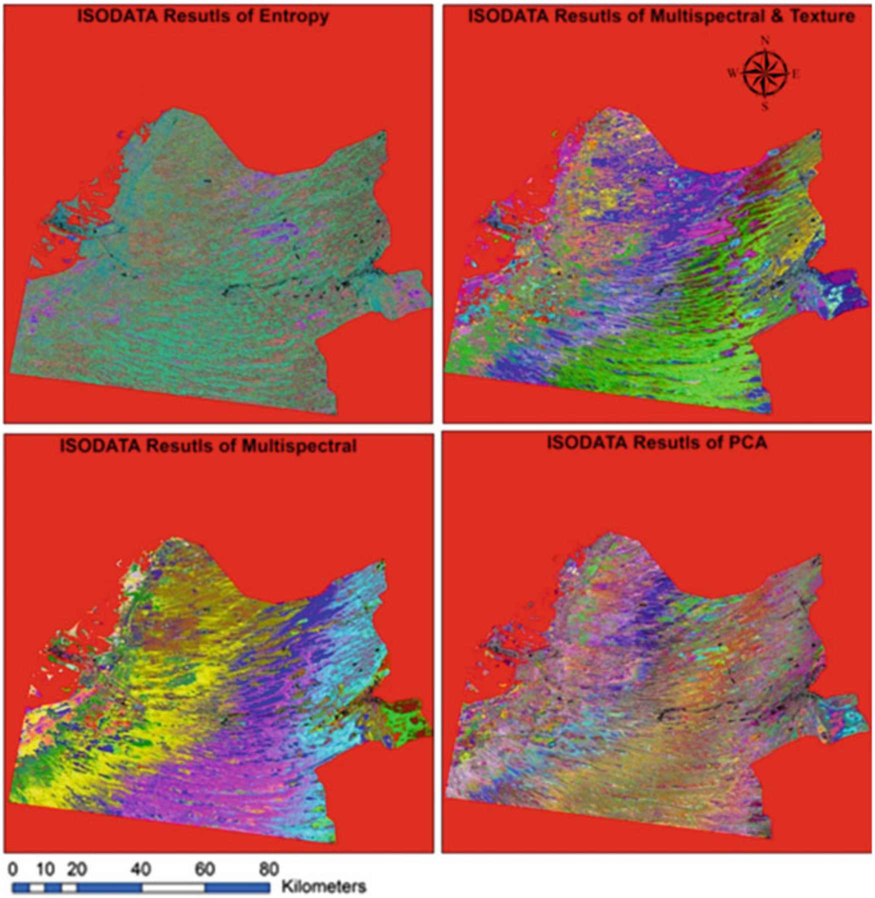

Fig. 3 Results of the clustering algorithm using the four input configurations

3.5 Classification and Accuracy Assessment

Once the classification scheme defined and the vegetation class extracted and excluded through a masking process, a supervised classification approach using the surface reflectance as input is applied to map the remaining classes: sand, intertidal zone, wet soil/sabkha, and exposed bedrock. The supervised classification process uses 142 training sites that we selected randomly across the different classes. Speckles and random errors in the classified maps are then removed using clumping and sieving filter.

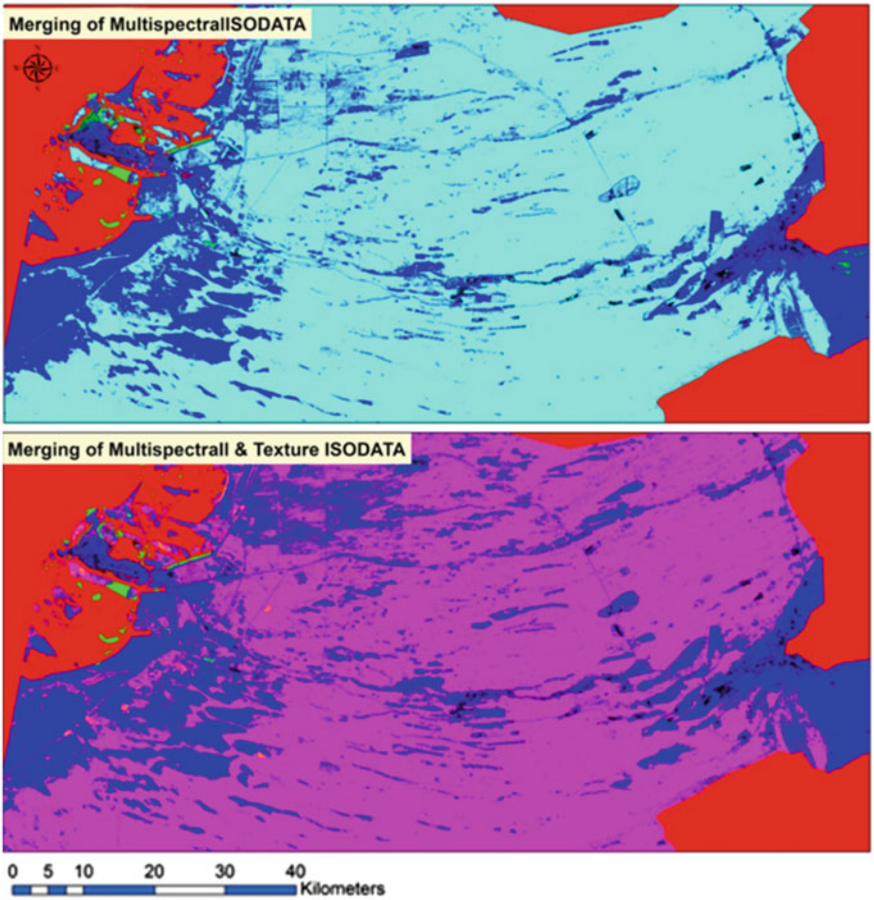

Fig. 4 Results of merging the clusters for the surface reflectance and surface reflectance + texture cases

To assess the classification accuracy, confusion matrices for the three study years are created from a set of 94 assessment invariant sites. The sites are selected using a stratified random sampling to ensure all classes are covered. The invariant sites are selected using the available higher resolution imagery: 2013—5 m RapidEye; 2003—1 m IKONOS and 1986—10 m SPOT. Ensuring that the selected sites consistently represent the same land cover classes for these three dates gives us confidence in their invariability allowing us to use them in the assessment of three land cover maps we produce.

4 Results and Discussion

4.1 Land Cover and Sand/Non-sand Maps for Years 1992, 2002, and 2013

The results of the classification process are presented in Fig. 5. Land cover maps for the years 1992, 2002, and 2013 show the distribution of the different land cover classes in the emirate. It is worth noting though that due to the limitations of the input data, the urban/built-up class is assigned to either wet soil/sabkha class or exposed bedrock class making the distribution of these classes inaccurate. However, since the main objective is to map sand dunes. The extracted classes are merged into two categories: sand and non-sand. The resulting sand/non-sand maps are also presented in Fig. 5. Table 3 summarizes the size of each one of the classes

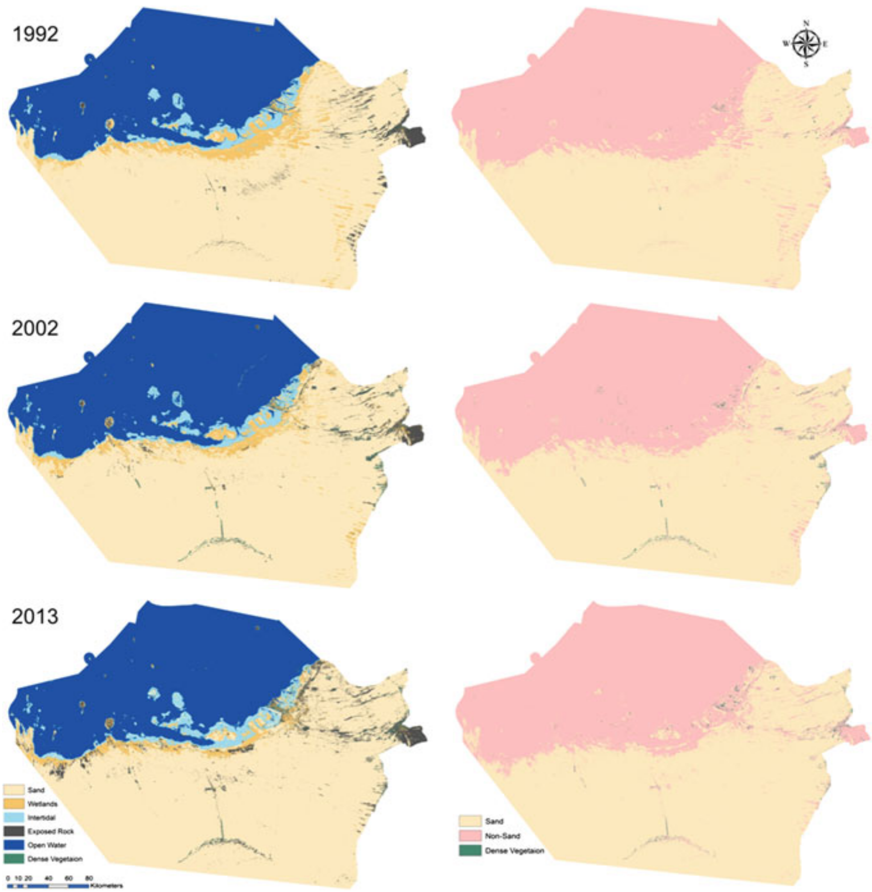

Fig. 5 1992, 2002, and 2013 land cover and sand maps

Table 3 Size of the sand/non-sand classes for 1992, 2002, and 2013

Class	1992 (km^2)	2002 (km^2)	2013 (km^2)
Vegetation	147	518	440
Wet soil	5168	4341	2651
Intertidal	3069	2788	3175
Exposed bedrock	1874	1864	3821
Water	32,172	32,873	32,678
Non-sand (excluding water)	10,258	9,511	10,087
Sand	52,186	52,732	52,848

Table 4 Confusion matrix for 1992

Class	Sand	Wet soil	Intertidal	Exposed bedrock	Open water	Vegetation	Total
Sand	90.98	0	0	23.02	0	0	64.23
Wet soil	2.88	100	0	25.68	0	0	17.56
Intertidal	0	0	100	0	0	0	1.76
Exposed bedrock	6.14	0	0	51.30	0	0	10.56
Open water	0	0	0	0	100	0	4.59
Vegetation	0	0	0	0	0	100	1.29

for the three time periods. It highlights the changes in the size of the sand class that can be attributed to different factors including sand encroachment, urban growth, the establishment of farms and dredging. However, a more thorough change detection study, planned as an extension of the current study, is needed to assess the magnitude, extent, and nature of the change. Land cover maps created in this study have been vectorized and saved in a geodatabase for use in such change detection analysis.

4.2 Accuracy Assessment

The classification accuracy was assessed using a confusion matrix approach. The matrices for the three time periods were constructed using the assessments sites selected as described in the methods section. The three confusion matrices are presented in Tables 4, 5 and 6. The results indicate that the overall accuracy of the classification is 87% for the 1992 map, 89% for the 2002 map, and 91% for the 2013 map. However, sand has been mapped with a higher accuracy for all three years.

Table 5 Confusion matrix for 2002

Class	Sand	Wet soil	Intertidal	Exposed bedrock	Open water	Vegetation	Total
Sand	99.06	9.76	0	44.60	0	0	73.89
Wet soil	0.94	80.59	0	16.95	0	0	12.68
Intertidal	0	9.43	100	0	0	0	2.94
Exposed bedrock	0	0.18	0	38.44	0	0	4.52
Open water	0	0	0	0	100	0	4.65
Vegetation	0	0	0	0	0	100	1.31

Table 6 Confusion matrix for 2013

Class	Sand	Wet soil	Intertidal	Exposed bedrock	Open water	Vegetation	Total
Sand	99.75	0	0	56.15	0	0	74.38
Wet soil	0.06	85.67	0.85	0.12	0	0	10.63
Intertidal	0	9.97	99.15	0	0	0	2.99
Exposed bedrock	0.19	4.37	0	43.73	0	0	6.10
Open water	0	0	0	0	100	0	4.60
Vegetation	0	0	0	0	0	100	1.30

5 Conclusion and Recommendations

Publicly available Landsat data were used successfully to map sand in the Emirate of Abu Dhabi for three periods spanning over two decades. The sand mapping approach used in this study relied on a robust supervised classification technique. The use of radiometrically corrected surface reflectance as input allowed the use of a consistent set of training sites across the three periods and paved the way to extend the study to other periods. Similarly, a set of invariant classification assessment sites was selected using high-resolution imagery. The levels of accuracy achieved in mapping the sand and non-sand classes make the produced maps useful for change detection and change trajectory studies. To that effect, the produced classification maps were vectorized and stored in a geodatabase to facilitate its use in a GIS environment. This research should be continued to derive, analyze sand change trajectories, and develop a model for its movement.

A major issue encountered in this study was related to the limitations of the moderate spatial resolution Landsat data in identifying accurately heterogeneous classes, such as urban areas. It is recommended to explore the use of higher resolution imagery to address this shortcoming.

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