

Using Satellite Imagery and GIS in the Mapping of Coastal Landscapes in an Arid Environment: Khor Al Bazam, Western Abu Dhabi, United Arab Emirates

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ABSTRACT: A geographic information system (GIS) has been developed to map assess the coastline to the west of Abu Dhabi, United Arab Emirates. The study area, Khor Al Bazam, is an embayment prone to environmental hazards natural changes. The eastern portion of the bay has been classified and mapped for its bathymetric geologic features using digital image processing techniques. Past beach ridges, sabkha flats, algal mats, black mangroves, associated with the Khor Al Bazam, were identified on Landsat Thematic Mapper (TM) scenes of the region. The images were evaluated using a hybrid combination of band ratioing, iterative-statistical clustering, and principal components analysis to produce classification maps. The findings of this research reveal that seven land cover features, in the uplands, four bathymetric features, in the coastal waters, can be identified in the Landsat data sets.

Using digital image processing algorithms and techniques it was possible to enhance the imagery in such a way that features nearly undetectable in visual examination were discernible after classification, i.e. oolitic ridges and black mangroves. The functionality of combining raw TM bands with principal components and band ratios in a hybrid spectral analysis is demonstrated by this research. Also, the arid climate of the study area makes it ideal to use in this case because of the low levels of atmospheric constituents and water vapor, associated with the region. Atmospheric 'noise' usually limits the usage of principal components analysis and band ratioing because the degradation of the signal associated with the noise is usually enhanced by the two statistical analyses.

This project has revealed some interesting findings that must be explored by further research in this study area and other regions of the Arabian Gulf. Some improved digital image processing techniques have been tested and can be potentially useful in additional analysis of the region, especially in helping to identify areas that are sensitive to environmental stresses, i.e. algal mats, corals, and black mangroves. Certain upland and bathymetric features 'fell-out' nicely in feature space analysis and could easily be classified, while others had to be rigorously identified using advanced statistical image processing techniques.

INTRODUCTION

The effective management of coastal resources is increasingly being recognized as both an important and complicated operation (Trotter, 1991; Welch et al., 1992). The expanding knowledge that coastal resources are diminishing has created the need to compile inventories and information systems that will be able to supply the answers needed to manage these fragile resources (Kempka et al., 1991; Ji et al., 1992b). A GIS provides a technology that can accumulate, as well as administer, coastal resource

information (Ehlers et al., 1991; Jensen et al., 1991; Williams Lyon, 1991; Johannessen et al., 1993; Palicki, 1993). Information that includes growth of coastal cities, land suitability for commercial industries, monitoring of dredging activities, ports and shipping practices, wetland accretion and subsidence, and evaluation of wildlife habitats. GISs are presently being incorporated into numerous fields of study, which include environmental sensitivity mapping, geological exploration, natural resource inventory, and urban development.

Though great strides have been made in GIS database manipulation, storage, and querying, the cost of operating a GIS still remains high. It is the cost of obtaining and interpreting the original input data that remains the largest single cost in the GIS database creation. Nonetheless, using remotely sensed data (aerial photography and satellite imagery) as an information source for a coastal management GIS has become the standard. Digital imagery, not only creates the possibility of lowering the initial data cost, but also gives the GIS a reliable input. For the most part, remotely sensed data is 1) sufficiently accurate, 2) uniformly standard over large areas, and 3) able to offer varying spatial and spectral resolutions. However, this does not imply that the integration of digital imagery into a GIS is a simple task. The digital imagery and a GIS represents two different levels of generalization (i.e. raster imagery and vector GIS).

For this project, we explore the use of GIS in coastal resource management. We identify different coastal phenomena that can be mapped and analyzed using satellite imagery and GIS.

KHOR AL BAZAM

The Khor Al Bazam (Figure 1) is part of the prograding coastal system that forms the southwestern shore of the Arabian Gulf. Located west of Abu Dhabi, it is 130 km long and 8 to 16 km wide. The eastern end (the main study area) is intertidal and terminates in a network of shoals and channels.

The west end is relatively deep (25 m) and is connected to the Arabian Gulf. The bay offers a series of dynamic ecological habitats, including algal mats, coral reefs, and black mangroves that are home to numerous species of fish and shrimp (Sabock & Gurr, 1969).

Kendall and Skipwith (1968; 1969a; 1969b) and Alsharhan and Kendall (in press) have studied and mapped in great detail the geological history of the area. They have revealed that the sediments of the region include skeletal grains, non-skeletal grains, carbonate mud, non-carbonate minerals and organic material. The lithofacies include: 1) corals, 2) oolitic sands, 3) pellet aggregates, 4) muds, 5) molluscan



Figure 1. The Khor Al Bazam study area western Abu Dhabi as imaged by the Landsat-7 ETM+ sensor. Imagery acquired on 11 July 1999. ETM+ Bands 4,2,1 (RGB) are shown.

sands, 6) algal mats, and 7) evaporites. They have related the composition and location of these sediments and facies to several physical phenomena of which include wave energy, currents, winds and fluvial processes.

Arid coastal environments, like the Khor Al Bazam, are ideal to study using remote sensing and GIS technologies (Smith and Baker, 1981; Lindell et al., 1991; Khan et al., 1992; Murali and Lulla, 1992; Bierwirth et al., 1993; Narumalani et al., 1993). Due to low amounts of water vapor, clouds, and other aerosols over these parts of the world, outgoing radiance received by sensors are usually of high quality (Jensen, 1996). Geologic geomorphic features are readily distinguished from one another under these conditions (Mekarnia and Chorowicz, 1992). In addition, the relatively nutrient-poor surface waters associated with the region (Jones et al., 1978) allow for good penetration of radiant energy into and out of the water column. Thus, intertidal and subtidal shallow-water shelf areas can be examined using the visible portion of the electromagnetic spectrum (Ji et al., 1992a; Khan et al., 1992; Mekarnia and Chorowicz, 1992).

DATA SOURCES

Sediment samples, along transects, from each of the facies were collected by Dr. Gregory Whittle of the UAE Desert Marine Environment Research Center in 1993 and 1994. The samples have been analyzed to establish field verification for the Khor Al Bazam. Ancillary data, consisting of sediment and facies maps, developed by Kendall and others (1963 to present) were also used as information for the region. Such data allowed the remotely sensed data to be calibrated and better utilized to assess what the surface environment is like.

The research group obtained three Landsat satellite scenes, of the study area, for years 1972, 1989, and 1999. The TM scene for Abu Dhabi (Path 161, Row 43), acquired on 29 June 1989, will receive most of the attention in this paper. The 1972 Multispectral Scanner (MSS) scene and the 1999 Enhanced Thematic Mapper Plus (ETM+) scene were recently acquired and have yet to be processed to the same level as the 1989 scene. Also, the field data collected by Dr. Whittle coincide more appropriately with the 1989 data. For the classification analysis, a 1500 x 1500 pixel (45 x 45 km) subset of the full 1989 scene was created as a study area.

RECTIFICATION OF REMOTELY SENSED DATA

The Landsat TM subscene was rectified to a Universal Transverse Mercator map projection so it could be used effectively as a planimetric base map. Ground Control Points (GCPs) were identified on the image measurable on 1:50,000 and 1:25,000 scale ADCO (Abu Dhabi Company) maps. The image grid and the map coordinates were registered to yield a first-order coordinate transformation equation having a root-mean-square-error (RMSE) of ± 1 pixel (± 30 m). The Landsat MSS and Landsat ETM+ scenes were then registered to the 1989 Landsat TM image.

ANALYSIS OF THE 1989 TM DATA

The first step was to generate a band ratio of TM4/TM3 to separate upland and water information (binary mask generation). This created two different images to analyze; an 'upland' image showing the algal mats and surface features inland, and a 'bathymetric' image showing the shallow water environments. The scenes were then statistically analyzed to yield clusters of land and water information. An iterative-statistical algorithm was used in conjunction with band ratios and vegetation indices on the upland portion of the imagery, while principal components analysis, in combination with an iterative-statistical algorithm was used to analyze the water information. A maximum likelihood classifier was used in both the upland and bathymetric cases to define the spectral clusters. When satisfactory results were not obtained, further iterations were made by modifying the statistical parameters, bands, or logic.

UPLAND CLASSIFICATION

When examining satellite data it is often necessary to use band ratioing as a means of highlighting certain features. In many geologic studies, band ratioing has proven to be a very useful utility (Sabins, 1997). In this research, band ratioing was utilized to highlight three land covers (halite, black mangroves, and Tertiary hills) that could not be delineated using normal single band classification algorithms. Scaled TM4/TM3 not only allowed for the creation of a land/water mask but also broke-out the mangrove patches very nicely. This band-ratio allowed for classification, via thresholding, of the mangroves with no additional classification necessary. Scaled band ratios of TM7/TM4 TM5/TM3 allowed for good separation of halite and Tertiary hills, respectively. The latter two band ratios (after thresholding and scaling) when combined with

the statistical clustering of the raw TM Bands (TM2, TM3, TM4, TM5, and TM7) provided a hybrid classification (Figure 2).

WATER CLASSIFICATION

When studying water depth and bottom structures, Principal Components Analysis (PCA), of the visible bands of TM, has been shown to be a significant support to other classifiers (Singh and Harrison, 1985; Chavez and Kwarteng, 1989; Khan et al., 1992). Other algorithms also used to study bathymetric features are discussed in Al-Hinai et al. (1987), Tassan and d'Alcalá (1992), Nanu and

Robertson (1993). Of the many algorithms discussed in the literature, for determining bathymetric properties from Landsat TM data, PCA appears to be the best alternative when *in situ* field measurements were not performed during sensor overpass (Spitzer and Dirks, 1987; Van Hengel and Spitzer, 1991; Ji et al., 1992a).

PCA is a statistical technique that transforms a multivariate data set consisting of inter-correlated variables into a data set consisting of variables that are uncorrelated linear combinations of the original variables (Ingebritsen and Lyon, 1985). For remote sensing investigations, principal component transformation is based on the analysis of the

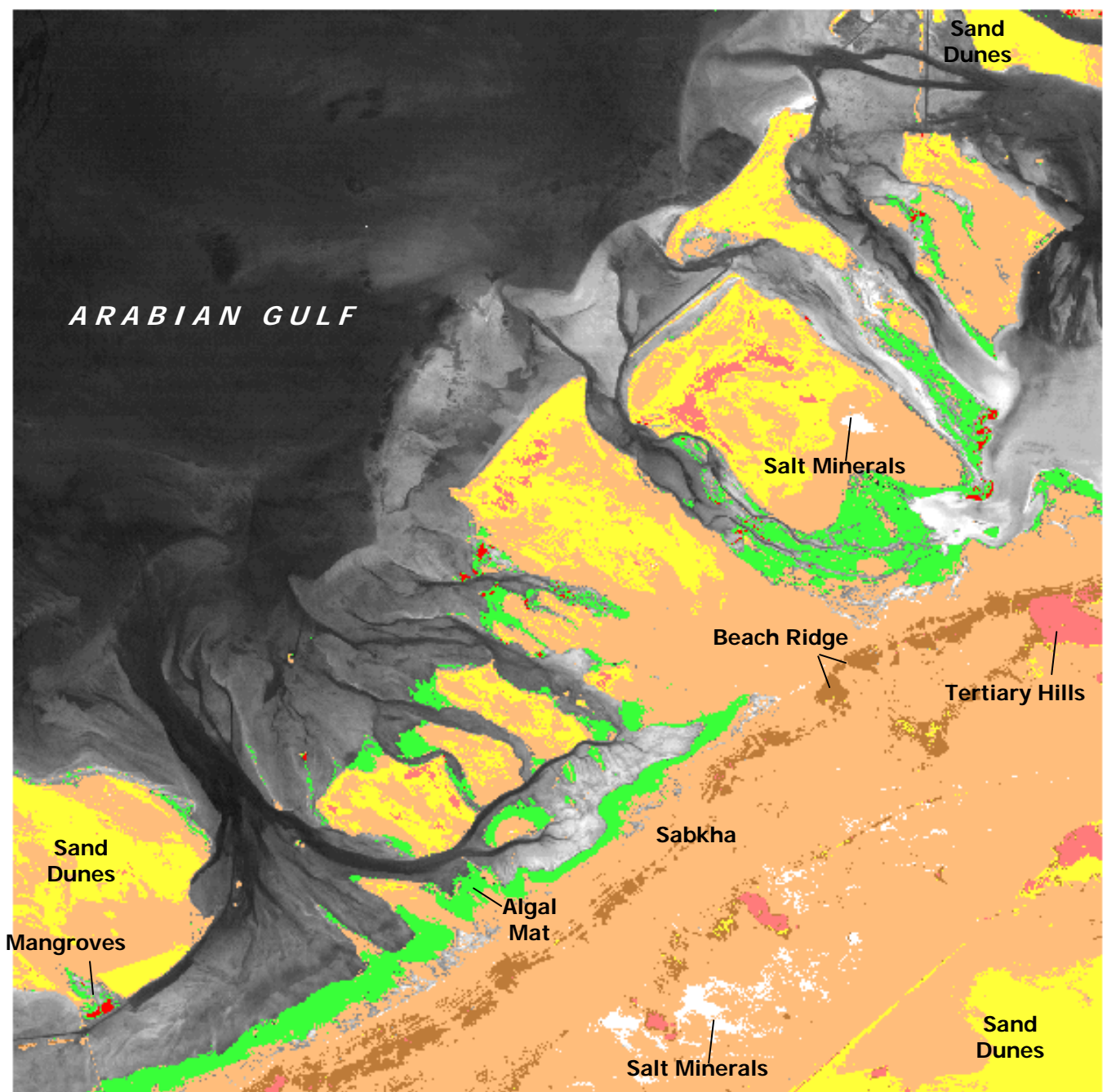


Figure 2. Upland land cover map of the Khor Al Bazam subset used for hybrid classification treatment.

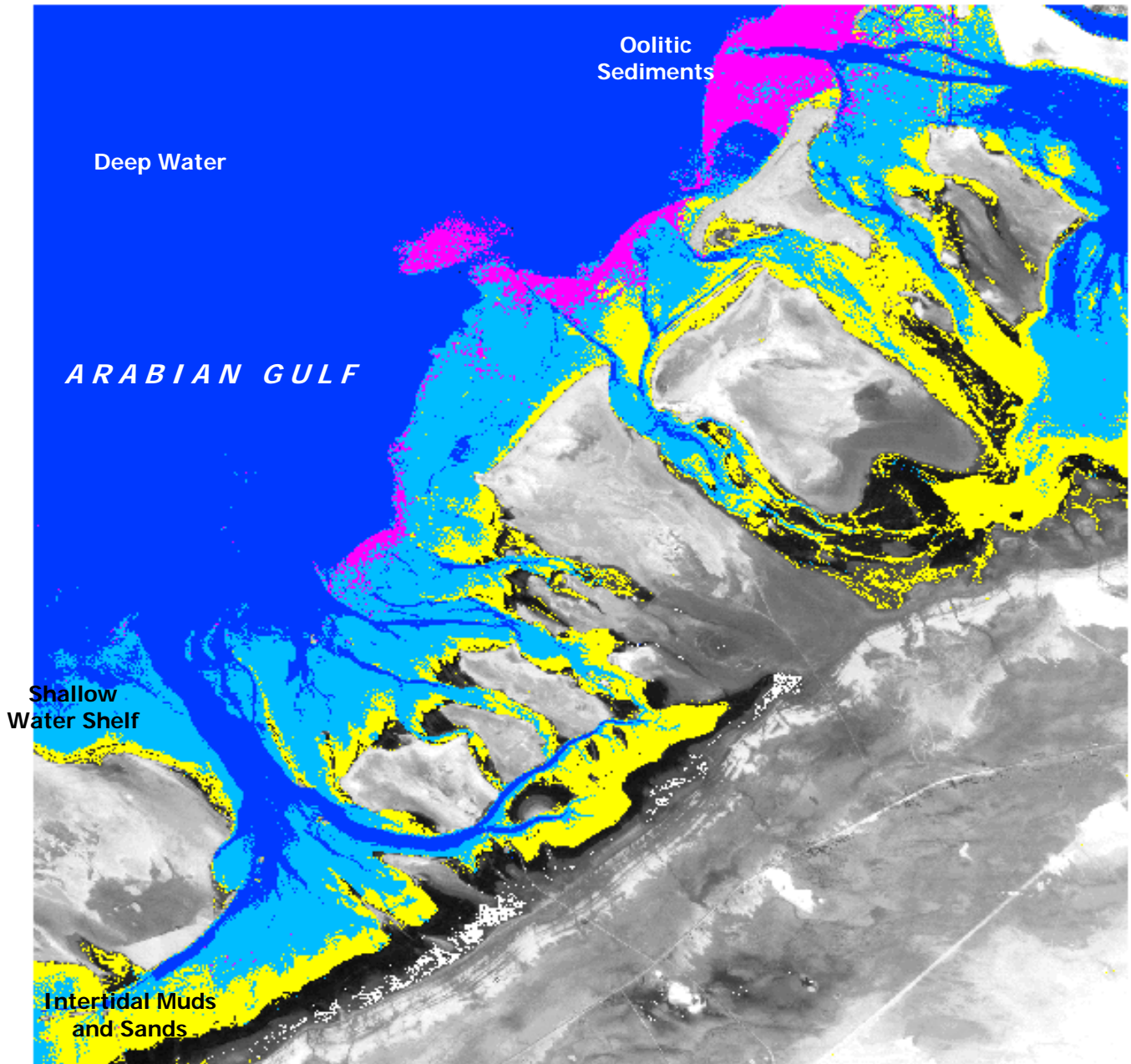


Figure 3. Bathymetric feature map of the Khor Al Bazam subset used for hybrid classification treatment

relationship between the different bands rotates the axes to produce a set of image bands, uncorrelated with each other (Jensen, 1996 provides an outstanding discussion on this technique). TM1 TM2 were used in a PCA for this research. The first component (PC1) contained the variance related to water depth, while the second component (PC2), orthogonal to the first, contained the variance associated with bottom structure. The two PCs were then combined in a hybrid routine, with TM3, to yield a shallow water environment classification (Figure 3). Khan et al. have made similar findings, to the ones presented, in 1992.

RESULTS AND OBSERVATIONS

The functionality of combining raw TM bands with principal components band ratios in hybrid spectral analysis is demonstrated by this research. It is a methodology that is seldom used by remote sensing scientists. The arid climate of the study area makes it ideal to use in this case because of the low levels of atmospheric constituents and water vapor, associated with the region.

RESULTS OF HYBRID CLASSIFICATION OF UPLAND FEATURES

In many instances it is useful to describe remotely sensed data in terms of where it resides in feature space (Jensen, 1996). Algal mats absorb most of the energy in the visible and infrared regions of the electromagnetic spectrum, thus they were found at the lower end of the feature space. Tertiary hills and beach ridge have high visible and infrared reflectances, thus were found on the upper end of feature space. Salt minerals, such as halite, were easily identified, as were the upland sand dunes. Carbonate flats, exposed during low tide, were also identified as upland (tidal flat) in feature space, but later recoded into a bathymetric category. Mangroves, as mentioned previously, were identified in a separate analysis using band-ratioing.

RESULTS OF HYBRID CLASSIFICATION OF BATHYMETRIC FEATURES

The visible bands, because of their water penetration, and the two principal components, generated from TM Bs 1 2, were used in this part of the analysis. From the statistical clustering, four bottom water features were identifiable in feature space. Deep-water shallow water environments were easily discerned in the analysis, as each broke out where they were expected to (lower end of feature space diagram). Carbonate flats were also broken out of the feature space diagram. They had a very high reflectance in both the red and blue portions of the electromagnetic spectrum (TM Bands 3 and 1, respectively).

One interesting feature of the bathymetric analysis was the appearance and identification of the oolitic ridges that exist off the coastline of Abu Dhabi. They 'fell-out' distinctively in feature space, which made their classification quite easy. Their uncomplicated identification was most likely due to the inclusion of the second principal component in the statistical clustering. The ridges are a highlighted bottom structure in that component.

CONCLUSIONS AND FUTURE RESEARCH

This project has revealed some interesting findings that must be explored by further research in this study area and other regions of the Arabian Gulf. Some new digital image processing techniques have been tested and can be potentially useful in additional analysis of the region, especially in helping to identify areas that are environmentally sensitive, i.e., algal mats, corals, and black mangroves. Certain upland and bathymetric features 'fell-out' nicely in

feature space analysis, and could easily be classified, while others had to be rigorously identified using advanced statistical image processing techniques. Unfortunately, coral reefs could not be identified from the procedures utilized. Additional investigations using texture analysis will be attempted by the authors in the near future.

The Khor Al Bazam was an exceptional arid environment to study using remote sensing technologies because of its minimal amounts of water vapor and atmospheric constituents. If further collection of field transects and water bathymetry can be accomplished, a detailed map of the region can be performed which can be assessed for its accuracy. Since the findings appear to be similar to other studies from within the Arabian Gulf region, the accuracy of the classifications should be high (Al Hinai et al., 1987; Jensen et al., 1993).

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