Mapping and monitoring sand dune patterns in northwest Kuwait using Landsat TM images

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ABSTRACT: Satellite images of northwest Kuwait reveal a prominent northwest-southeast-trending sand dune corridor that is intersected by northeast-southwest trending escarpments and ridges. A set of multi-date Landsat TM images (pre-war and post-war) was co-registered and used for monitoring temporal and spatial changes in the sand dune patterns. Diverse image enhancement techniques, including edge enhancement filters and contrast stretches, were utilized to delineate the sand dune field as a whole, as well as to map individual dunes. Preliminary results show a dramatic change in the amount and distribution pattern of dunes, especially between the years 1989 and 1992. The increased rate in dune formation and migration is mainly attributed to the effects of the Gulf War on Kuwait's desert surface.

KEYWORDS: Al-Huwaimiliyah, change detection, dune migration, Jal Al-Liyah, sand dune field.

1 INTRODUCTION

The area of Jal Al-Liyah is located in the north-northwest of Kuwait, between N 29°30' to N 30°5', E 47°30' to E 47°5', and encloses a major dune field (Al-Huwaimiliyah) that trends from northwest to southeast. The dune field approximately covers 220 km². This area was selected to map and monitor changes in the formation and migration of dunes, based on satellite images. The major natural factor controlling the formation of the dunes is the wind blowing constantly from southwest of Iraq. As the wind travels from Iraq to Kuwait, it carries large quantities of sediments, which are deposited downwind, causing the formation of a large dune field in Kuwait (El-Baz, 1994). The main eolian actions are dust storms, which carry fine-grained particles in suspension, and sandstorms, which are active winds loaded with sand particles (Khalaf & Al-Ajmi, 1993). These two types of storms are the main agents of sediment transportation from south Iraq to northwest Kuwait.

This natural system of deflation and deposition of aeolian sediments has recently been disturbed by human intervention to the environment. Two major factors that are accelerating the rate of sediment transport and, thus, increasing the formation of the dunes, are the disruption of the desert pavement due to the Gulf war (El-Baz & Al-Ajmi, 1993; El-Baz
et al., 1994) and the draining of the marches in southern Iraq. As a result of the migration of dunes and the increased transport of suspended material, roads, farms, and oil installations are being obstructed, and health problems may affect the population. Consequently, there is a need for mapping and monitoring these environmental changes so that remedial actions can be taken. This paper presents a methodology to detect dune pattern changes over a relatively short time period of nine years, and examines their possible causes.

2 MATERIALS AND METHODS

Four Landsat Thematic Mapper (TM) images of 1985, 1989, 1992 and 1994 were co-registered and used for this study. The bands, selected for processing the image corresponding to the area of Jal Al-Liyah, were Band 2 (green), Band 4 (near infra-red, NIR), and Band 7 (short-wave infra-red, SWIR). The reason for selecting these bands was that they show high reflectance variability of the desert surface. Color-composite images were produced by combining these bands as RGB. A window of 1250 pixels by 1050 lines was extracted from the full TM scene, covering only the dune field area, and the following enhancement procedures were applied.

Figure 1. Landsat TM images (Band 4) showing Al-Huwaimiliyah dune field in four years.
2.1 Contrast stretching

The first step was to improve the brightness contrast of the raw image, in order to stretch the dark areas, and increase the contrast between the different bands. This was performed by applying either a histogram normalization and/or an exponential stretch to the image, depending on which one produced a better color contrast image.

2.2 High-pass filtering

The second step was to apply an edge detection filter to the raw image to sharpen the image. This type of enhancement, called high-pass filtering, is used to enhance the spatial information contained in the image, especially those of linear features. The filtered image is added back to the contrast stretched image and, as a result, the dune pattern as well as escarpments and ridges stand out much clearer and brighter (Fig. 1).
3 MAPPING OF INDIVIDUAL DUNES

Using the processed images as background files, dunes or groups of dunes were mapped using a technique called on-screen-digitizing. An x-mark is placed on features representing individual dunes or closely grouped dunes based on criteria such as their shape and spectral brightness values. A vector file (Fig. 2) is created that contains the location and number of digitized dunes. Dunes are excluded if they are smaller than the pixel resolution (30 m for TM images), hidden by topographic shadows, or next to a major road.

Subsequently, the vector files are used in a geographic information system (GIS) to create dune density maps. A grid is superimposed on the vector data, and the number of x-marks (dunes) per unit area is calculated for each grid-box. Based on these numbers, an interpolation program generates a continuous surface of dune distribution variation (Fig. 3). The variation of dune densities is shown here by a range of grey tones. The

![Dune Density Maps](image-url)

Figure 3. Dune density maps showing high densities in black and low densities in light grey.
darker tones mean high density of dunes and the lighter tones mean low density. This way, the shape of the overall dune field and the relative concentration of dunes can be shown in a visually appealing manner.

4 MONITORING DUNE PATTERN CHANGE

The dune field of Al-Huwaimiliyah encloses mainly barchan dunes, which are crescent-shaped features with their horns pointing downwind in a southeast direction. Barchan dunes are usually formed as a result of a fixed wind direction. In this case, sand particles are transported from southern Iraq and deposited in northern Kuwait where they accumulate as sand dunes (El-Baz, 1994).

The sand dunes accumulate in an area that is characterized by a sequence of parallel ridges and basins. These geomorphic features are the remnants of a delta, which formed by an ancient river system (El-Baz, 1994). The finer particles were subsequently eroded, forming the present basins, and coarser particles (gravels) of the river bed were left over as ridges made up of gypcrete and caliche.

This geomorphic setting causes an interesting interplay between fluvial and eolian features. Where the sand dune corridor intersects the linear pattern of subparallel ridges and depressions, a change in dune field pattern is observed as a result of a change in topography as the sand dunes pass through rugged terrain. This phenomenon can be observed in Figures 2 and 3, which show the distribution of dunes in four years, namely, 1985 and 1989 (pre-war), and 1992 and 1994 (post-war). A change in sand accumulation is clearly occurring over this time period. Figure 3 shows a migration of high density peaks from NW to SE, and a general increase in dune densities, especially after the Gulf War.

The overall shape of the dune field has also changed dramatically. While in 1985 the sand dunes were mainly concentrated in the northwestern corner of the dune field with some isolated clusters further downwind, by 1994, the dune field had already become one consolidated body of sand accumulations. The width of the dune field increased and high dune density peaks are well distributed over the entire field. Within the dune field, a few clear spots remain, mostly due to changes in topography. These spots reveal the underlying material, which consists of residual gravels from the ancient river bed.

A graphical representation of the number of dunes per year (Fig. 4) and the areal extent of the dune field per year (Fig. 5) supports the aforementioned observation of a sharp increase in new dune formation shortly after the war. While the rate of dune formation is 31 dunes per year for the pre-war images (1985-1989), this rate suddenly increases to 321 dunes per year (between 1989 and 1992), and continues to be high for the post-war images (1992-1994), with a rate of 296 new dunes per year. The area covered by the dune field also increases from 123.5 km² (in 1985) and 150.8 km² (in 1989) to 220.2 km² (in 1992) and 222.7 km² (in 1994). These numbers indicate an areal increase of about 70 km² between the pre-war image of 1989 and the post-war image of 1992.
Figure 4. Diagram showing number of dunes per year.

Figure 5. Diagram showing area of dune field per year.
CONCLUSIONS

Landsat TM images are ideal for mapping dune patterns and monitoring dune migration. This is true because the images are vertical and their spectral reflectance allows the identification of sand-covered areas.

The present study illustrates the value of satellite images in establishing changes to the desert environment of Kuwait due to the Gulf War. Based on the results, it is recommended that monitoring of sand dune formation and accumulation should continue using Landsat TM images.

REFERENCES


