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ORIGINAL ARTICLE

Mohammad Hossein Rezaei Moghaddam
Mahdi Saghafi

A change-detection application on the evolution of Kahak playa (South Khorasan province, Iran)

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M. H. Rezaei Moghaddam (✉)
M. Saghafi
Department of Physical Geography,
Tabriz University, Tabriz, Iran
E-mail: rezmogh@Yahoo.com

Abstract Kahak salt playa in South Khorasan province of Iran, have special geomorphological characteristics by the presence of ephemeral saline lakes, wetlands, salt crusts, surface accumulations of salt and zones of patterned ground. Salt crusts in the soil surface are unique in the region and have laminated horizons in the playa soil. Soil-surface salt accumulations are dominated by NaCl and gypsum. It has been found that distribution of chemical soluble is not uniform across the playa landscape, and this result influences on the variety form of patterned ground. In this study, the percent changes in some of the chemical elements such as NaCl, gypsum and also brine extent have been calculated in the playa. Indicating changes in Kahak salt playa is the main aim of this study by using remote sensing and GIS techniques. In this paper, techniques such as spectral un-mixing, maximum likelihood classification, band rationing, fuzzy classification and correlation relationships are discussed. This contribution presents modeling of temporal and spatial changes of salinity and playa developing using combined approaches that incorporate different data-fusion and data-integration techniques for two periods of date. Furthermore, percent changes in the surface-patterned ground of the playa have been calculated using texture and pattern analysis of the PCA1. Results have revealed that, in the playa developing, chemical materials such as sodium, NaCl, gypsum and also brine extent are positively correlated with each other and the most increased changes are related to gypsum and the most decreased changes are related to the NaCl. Also changes in the amount of agricultural area in the playa-lakes margin, show low effects in the desertification process.

Keywords Remote sensing · Playa · Fuzzy classification · Chemical characteristics · Change detection · Kahak (Iran)

Introduction

Playas are typical closed depressions of desert areas. Playas, or terminal lakes, are essentially flat surfaces with minimal topographic relief; and they are particularly frequent in semiarid regions in the world (e.g., Goudie 1991). Apart from the tectonic origin (Sinha-Roy 1986; Roy 1999), their origin may be related to the individual or combined intervention of a wide variety of processes, including aeolian erosion (Cooke et al. 1993; Goudie and Wells 1995) and human activities. It is also suggested that during the late Pleistocene, excessive siltation at the river confluence (Ghosh 1964; Ghosh et al. 1977) and formation of sand dunes across the river channels (Agarwal 1957; Singhvi and Kar 1992) led to the formation of these shallow (1–3 m deep), closed basin playas. The physical and chemical evolutions of these playas are attributed to favorable geomorphological, tectonic and climatological conditions. These playas are economically important as some thousands of tons of salts are produced every year from their brine.

One of the problems in monitoring and preserving these playa-lakes is the scarcity of records about their hydrological conditions and associated environments in terms of ecological aspects. Only some punctual and unpublished ground records are available, but remotely sensed data can surrogate ground observations if spectral or other features of the satellite image allow reliable interpretation. Corroborating the ground data, even over a limited time span, can increase the evidential value of the satellite information, facilitating the detection of key factors that condition environmental preservation such as agriculture and irrigation.

Many articles have investigated playa-lakes in the regions where they are threatened by desiccation, and are located both in coastal and flood-plain environments (e.g., Al Saifi and Qary 1996; Kasishke and Bourgeau-Chavez 1997; Dwivedi et al. 1999; Rao et al. 1999; Baghdadi et al. 2001). Frequently, these researches aim to detect and delineate the water bodies and estimate their changes. For this purpose, some of these studies have used Landsat imagery, taking advantage of the analysis potential stemming from its spatial and temporal resolution, and the continuity of the image acquisition that began in 1972. There are examples of remote-sensing studies of playa-lakes, which show a great variety in the thematic approach and the surface area studied. As an example, Verdin (1996) discriminated ephemeral water bodies of between 1 and 150 ha in Nigeria. Drake and Bryant (1994) monitored the flooding ratio of Tunisian playa-lakes sized from 90 to 5,500 km^2 for studying the climatic changes on the playas hydrology. Later, Bryant and Rainey (2002) examined the response of these playas to seasonal changes, and the inundation process stages within the saline pan were recognized by changes in the surface-reflectance properties of the playa-lake bed. Changes in the water extent of playas and closed salt lakes have been estimated by remote sensing to assess changes in the regional climate (e.g., Schneider et al. 1985; Harris 1994; Bryant 1999; Birkett 2000). Nakayama et al. (1997) detected changes in the water area and volume of Central Asian lakes and related them to environmental parameters. In the absence of of historical data such as water levels, remote sensing provides a temporal perspective of the playa-lakes hydrology (Al-Khudhairy et al. 2002).

The aim of this research was to examine the application of satellites data to the study of sensitive playa in south eastern of Iran and to detect the future changes in the playa surface. Specific objectives of the study are: in the first section, change detection in the chemical formation of surface playa; in the second section, the study has been directed toward indicating the effects of these changes on the land use; in the third section, the study of patterned ground in the playa surface and investigate the chemical changes at the surface of playa as related to the patterned ground changes; in the fourth and final section, correlation between these changes and the rates of salinity and trends is discussed.

Therefore, it is important to understand the response of contemporary closed playa basins to the current short-term changes in desertification patterns and judge the effect of land use in the total changes of the playa. We have described the methods to obtain environmental variables of relevance to mapping and predicting the present desertification rate from satellite observations, and discuss areas that may benefit from recent advances in this area.

Geographical and geological setting

The site chosen for this study is a salt playa in south of Birjand township, south Khorasan province, of Iran. The playa is known as Kahak and is bounded by the

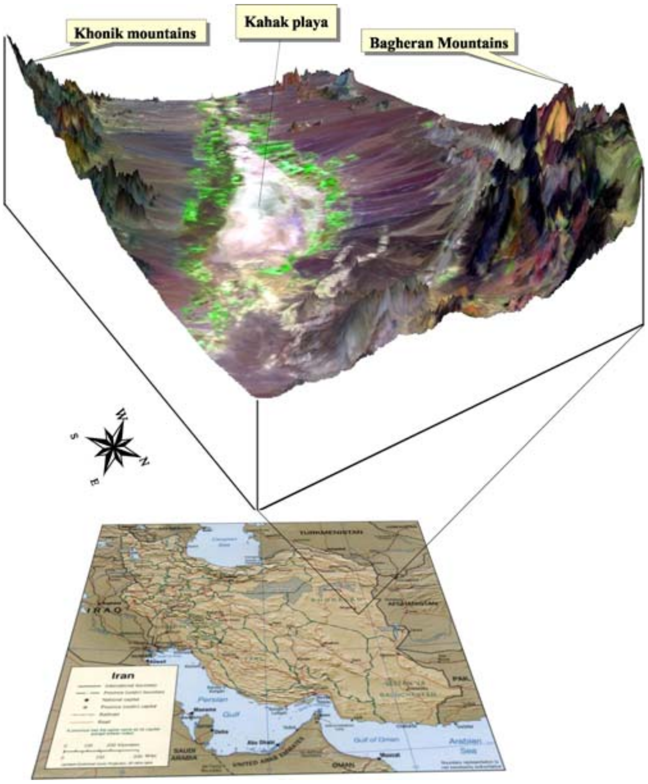


Fig. 1 The study area, the Kahak playa is located within the wind gaps between the Bagheran Mountains at an altitude of 2,720 m and Khonik Mountains having a maximum altitude of 2,503 m

Bagheran Mountains in the north and east and Khonik mountains in the south and west. The study area is located at 32°23′–32°39′E and 59°01′–59°34′N (Fig. 1). The playa surface is usually free of water, although parts do occasionally flood (to a depth of several centimeters) annually. This is the largest of a series of playas that lie at the southern edge of the Bagheran Mountains in the south Khorasan province, Iran. The area has a cold arid climate. Rainfall displays high inter-annual and seasonal variability, annual precipitation is 150 mm. From May to September, the natural drying process of playa takes place and only sporadic inflow of water occurs as a result of slight raining. The mean maximum temperature in the region ranges between 20 and 43°C. The playa area is up to 17 km^2, and the catchments area of the basin is approximately 2,500 km^2.

Gaz River, which is one of the sub-basins of the Birjand Salt River drainage basin, is the only integrated drainage network, which presently flows from the Mokhtaran plain and confluences with the Birjand Salt River into the Lute desert. However, the presence of a number of palaeo-channels throughout the desert suggests the existence of a former fluvial system in the region. The lack of proper drainage led to the accumulation of rainwater in the various large and small natural depressions (playas), which later became saline during higher-evaporation periods in the region. Due to the relatively higher precipitation, seasonal rivers and streams feed the playas. During the rainy periods, these streams carry detrital fractions and dissolved constituents into the playas. The level of soil salinity is related to the balance between the deposition of salt through evaporation and the dilution effect of precipitation.

The Kahak playa is located within the wind gaps between the Bagheran Mountains at an altitude of 2,720 m and Khonik Mountains having a maximum altitude of 2,503 m. It is the most extensive and economically, most important playa of the region. The playa is elongated in NW–SE direction, 43 km in length and 1–3 km in width and an altitude of about 1,490 m (Fig. 1).

The geological and geochemical observations in the region indicate the presence of metamorphic rocks of varying lithologies, intrusions of pegmatites and volcanics rocks (Geological survey of Iran 1992) (Fig. 2a, b). Rocks of several groups belonging to the Cretaceous and Tertiary constitute the Bagheran mountain system. The Cretaceous rocks include peridotite, colored mélange and shale-sandstone in the north and north east of the area, and the Tertiary rocks include tuff-marl-conglomerate in the south and south west of the study area (Geological survey of Iran 1992) (Fig. 2a, b). Widespread volcanic events at the end of the Mesozoic are marked by the isolated exposures of the Bagheran igneous suite. This igneous suite consists of basalt and rhyolite.

Several landforms and superficial deposits are identified in the area including stepped sequences of fluvial terraces, aeolian accumulations, debris-covered slopes, talus flatirons, blowouts and playas. Some of these landforms and deposits record changes in the surface processes induced by climatic variations in Quaternary.

Methodology

Data sources and image interpretation

This study uses two Landsat TM and ETM+ images with a time span of 14 years, from 1988 to 2002. Both represent the summer season. Table 1 shows the dates and specifications of the images.

The first step in the image study was the satellite-images corrections. After checking the uniformity of the atmosphere over the scenes, a simple haze compensation procedure (Richards and Jia 1999) was applied to minimize the influence of the path-radiance effects (Lillesand and Kieffer 2000). This study focused on the plain area of the playa-drainage basin. Therefore, we extracted the plain area from drainage basin of the playa by GPS and topographic maps with 1:25,000 scales and automatic method by DEM and GIS (Brabyan 1998). Automating the landform classification is an interesting challenge. It produces classifications having a good resemblance to manual methods (Brabyan 1998).

Playa basins are actively filling with sediments dominated by the evaporate minerals such as gypsum and halite. The evaporation of these minerals from the surface of the playa, together with the movement of the surface water and the effect of sandstorm activity, plays a key role in the formation and temporal variability types of patterns such as patterned grounds at the playa surface. It is possible to classify the surface of playas. We extracted information from images to identify chemical and pattern-ground characteristics and their associated faces in the surface of the playa. Using visual analysis and supervised classification, the outlines of the salty area and the types of land use along with maximum likelihood classification are extracted with RGB 741 combined image from two periods. Chemical characteristics of the superficial playa by material mapping indexes such as: halite, gypsum, dray grass and water extent are extracted (ERDAS 2002). Using texture and pattern analysis of the PCA1, the surface-pattern ground of the playa was calculated. The first-principle components analysis image (PCA 1) is a weighted positive sum of all the original bands; it represents a panchromatic view of the area containing 88% of the data variance. It is dominated by topography, expressed as highlights and shadows that are highly correlated in all six original TM bands.

Fig. 2 **a** Geological map of the Kahak drainage basin. **b** Geological cross-sections that represent the arrangement of rocks along lines across geological map (adapted from Geological survey of Iran 1992)

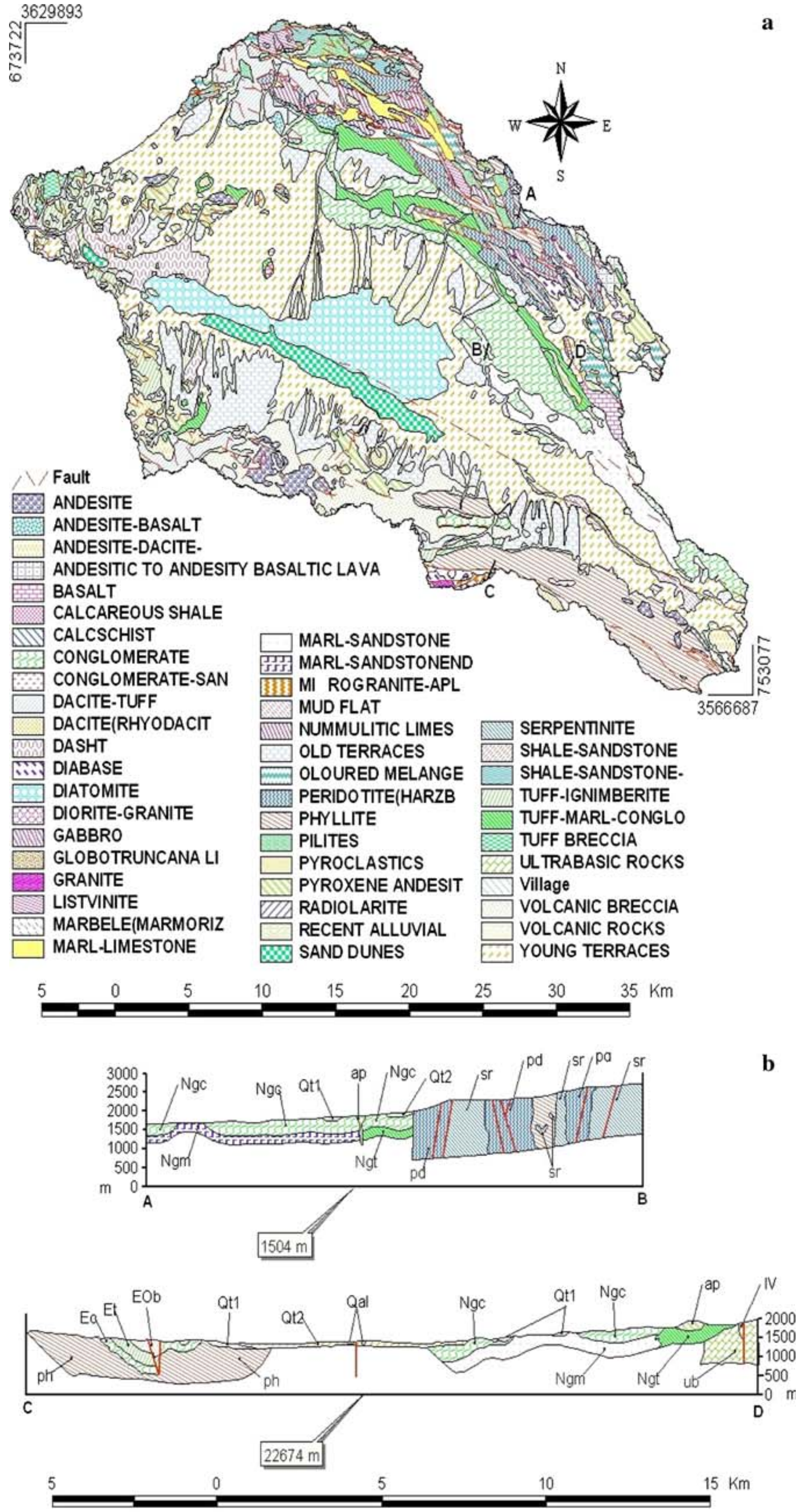


Table 1 Specifications of used images

Satellite	Scene ID	Date	Resolution	Instrument
Landsat 4	2231036-01 WRS = 159/03700	September 1988	28.5	TM10
Landsat 5	2231036-01 WRS = 159/03700	September 2002	28.5	ETM+

Change detection

Change detection is the process of identifying the differences in the state of an object, a surface or a process by observing it at different times (Singh 1989). Methods of change detection in remote sensing typically analyze sequential images of the same area, and involve the detection and display of the change in the image space. When performing change detection, it is important to consider: (1) sensor systems; (2) environmental characteristics and (3) geodetic control.

Many change techniques have been developed, but no single algorithm is suitable for all cases (Lu et al. 2004). There are several digital change-detection algorithms or techniques, which have been developed and used over the years to estimate changes using remote-sensing (in most cases satellite) data. These techniques are based on various mathematical and or statistical relationships, principles and assumptions. Singh (1989) provides an early review which includes simple image differencing and thresholding, principle components analysis (PCA) and change vector analysis. These are mostly linear methods, which estimate change on the basis of a linear combination of the input-image spectral bands. Some of the methods are based on the application of statistical properties of the image to extract the change component based on the assumption that the variability caused by real change is different from the other sources of variance in the images (e.g., PCA). Image classification, either in the form of comparison of independent classifications from two dates or as multi-date classification, is frequently used for change detection. Recently, numerous methods have been developed and applied because there is a growing interest in the change detection as a way to monitor the environment is growing (e.g., see Eastman and Fulk 1993; Lambin and Strahler 1994; Gopal and Woodcock 1994). However, few change-detection studies could meet such stringent criteria even under controlled experiments. Extremely wet or dry conditions on one or more of the dates can result in serious change-detection problems. Therefore, when remotely sensed data is being selected for use in change detection, it is very important to look at precipitation records (Dobson et al. 1995). Consequently, it is necessary to adapt the available data in order to extract the best possible information from the given resources.

There are a number of image processing methods that can be used for the change detection, the two used in this study are image differencing, which was used to compare the material mapping results. Image differencing is performed by subtracting the DN (digital number) values of one date for a given band from the DN values of the same pixel for the same band of another date. Previous researchers indicated that image differencing provided lower change-detection errors when compared against other approaches (Hall 1995). A series of threshold values based on standard deviation from the mean is then applied to the new image to determine the changed pixels from the unchanged ones.

The technique of post classification, which involves comparison of two independently classified images was used to determine the land-use changes. As the two images are classified separately, normalizing the images for atmospheric and sensor differences is minimized. It is the best way to achieve categorical change information (Cook and Iverson 1991). However, the accuracy of the change map is dependent on the accuracies of the individual classifications. Errors in classification of either image can lead to a large number of false indications of change (Singh 1989).

Collection of secondary data

Monitoring salinity changes from the past to the present faces the difficulty that, in general, there is no ground-truth information available for the past situations. Thus, validating historical remote-sensing data involves uncertainties. To overcome this difficulty, fusion of multi-source remote-sensing data and their integration with field and laboratory data have been advocated. Therefore, documents and maps containing chemical properties and land-uses data related to the study area were collected in order to: (a) obtain information on the chemical properties of playa-lakes in the study area; (b) collect existing data to feed the accuracy assessments database from three types of documents, namely maps with accompanying explanations area data, field observation and ground sampling by GPS and documents with soil-profile descriptions and analysis point data with attributes.

In this study, accuracy assessment was based on comparisons of the area extent of the classes in the derived thematic map (e.g., km^2 or % cover of the region mapped) relative to their extent in some ground or other reference data set.

Fuzzy algorithm

The theory of fuzzy logic was first raised by the mathematician Lotfi Zadeh (1965). This theory is a response to the insufficiency of Boolean algebra to many problems of the real world. While Boolean mathematics only recognizes “0” and “1,” most of the information in the real world is imprecise, and one of humans’ greatest abilities is to effectively process imprecise and “fuzzy” information. When the knowledge is intricate and little is known about the relationship between variables, Fuzzy expert systems are useful to gather disperse information and to accumulate certainty about some facts.

Over the past few decades, fuzzy logic has been used in a wide range of problem domains. Although the fuzzy logic is a relatively young theory, the areas of applications are very wide: process control, management and decision making, operations research, economies, pattern recognition and classification. In the last years, fuzzy logic was implemented successfully in various GIS processes. The most important implementations were made in the fields of classification, analysis, data collection and in remote sensing. Examples in ecological research include the use of fuzzy logic for classification of ecological data (e.g., Boyce 1998; Eyre et al. 2003), land use and land cover (e.g., Burrough 2001) and for mapping transitional areas (Armitage et al. 2000; Townsend and Walsh 2001).

Fuzzy sets are inexactly defined classes that characterize an attribute or a phenomenon that for various reasons does not have sharply defined boundaries (Burrough and McDonnell 1998). Fuzzy methodology has become an invaluable tool when dealing with spatial uncertainty in ecology (see review by Hunsaker et al. 2001). Moreover, it is a critical issue for spatial analysis and modeling since both GIS and remote sensing create approximate representations of geographical objects (Foody 2002).

A fuzzy set is a set whose elements have degrees of membership. An element of a fuzzy set can be a full member (100% membership) or a partial member (between 0 and 100% membership). That is, the membership value assigned to an element is no longer restricted to just two values, but can be 0, 1 or any value in between.

Mathematical function, which defines the degree of an element’s membership in a fuzzy set, is called membership function. The natural description of problems, in linguistic terms, rather than in terms of relationships between precise numerical values is the major advantage of this theory.

Spectral information for certain classes is used in order to classify Landsat change images by fuzzy logic in this study. In final step, superficial information of playa that was created with this imagery, is used in the fuzzy classification model for determination of area with critical changes. Fuzzy classification produces a series of images where the membership of each pixel is determined based on spectral similarity to training sites and user confidence of homogeneity of training sites (*z* score).

This model contains four fuzzy sets with A_1, A_2, A_3, A_4 indices, and $A_1 \cap A_2 \cap A_3 \cap A_4$ membership functions by $\mu_{Ai}(x)$ as follows:

$$\mu_{\bigcap A_i}(x)(1 \le i \le 4) = \mu_{A_1}(x) \wedge \mu_{A_2}(x) \wedge \mu_{A^3}(x) \cdots \wedge \mu_{A^6}(x)$$

and

$$\mu_{A_i}(x) \wedge \mu_{A_i}(x)(1 \le i,\ j \le 4) = \begin{cases} \mu_{A_i}(x) & \mu_{A_i}(x) \le \mu_{A_j}(x) \\ \mu_{A_j}(x) & \mu_{A_j}(x) > \mu_{A_j}(x) \end{cases}$$

then

$$\bigcap A_i(1 \le i \le 4) = \min\left\{\mu_{A_1}(x), \mu_{A_2}(x), \ldots, \mu_{A_6}(x)\right\}$$

Classification of changes is done considering following equations:

decreased if $\mu_{A_i}(x)(1 \le i \le 4) \in [0, 0.25]$

increased if $\mu_{A_i}(x)(1 \le i \le 4) \in [0.75, 1]$

some decreased if $\mu_{A_i}(x)(1 \le i \le 4) \in [0.25, 0.5]$

some increased if $\mu_{A_i}(x)(1 \le i \le 4) \in [0.5, 0.75]$

Result

Analysis of chemical changes

Many chemical elements are present in the playa. In this study, some of the chemical elements such as NaCl, sodium, gypsum and also water extent in the playa were calculated with the aim of satellite data for two periods. Chemical changes of playa are a result of many factors such as: climatic changes and changes in the land uses of the study area. By mapping this material for two periods, we obtained changes map by image-differencing method of change detection (Fig. 3).

For determination of changes between chemical element maps of two periods, we consider 10% rate for classification of area within the five classes. Therefore, area with up to 10% of increased changes is classified as high increased changes area, area with 0–10% of increased changes as some increased area, area with up to 10% decreased changes as high decreased area, and area with 0–10% decreased changes as some decreased area and unchanged area (Fig. 4).

On the modern playa landscape, salt occurs on tracts of land ranging in area from a few tens of square meters to a few tens of hectares. The largest salt flats are on 0–2% slopes, but salt also occurs as smaller patches alongside or within the banks of streams. All of the salt

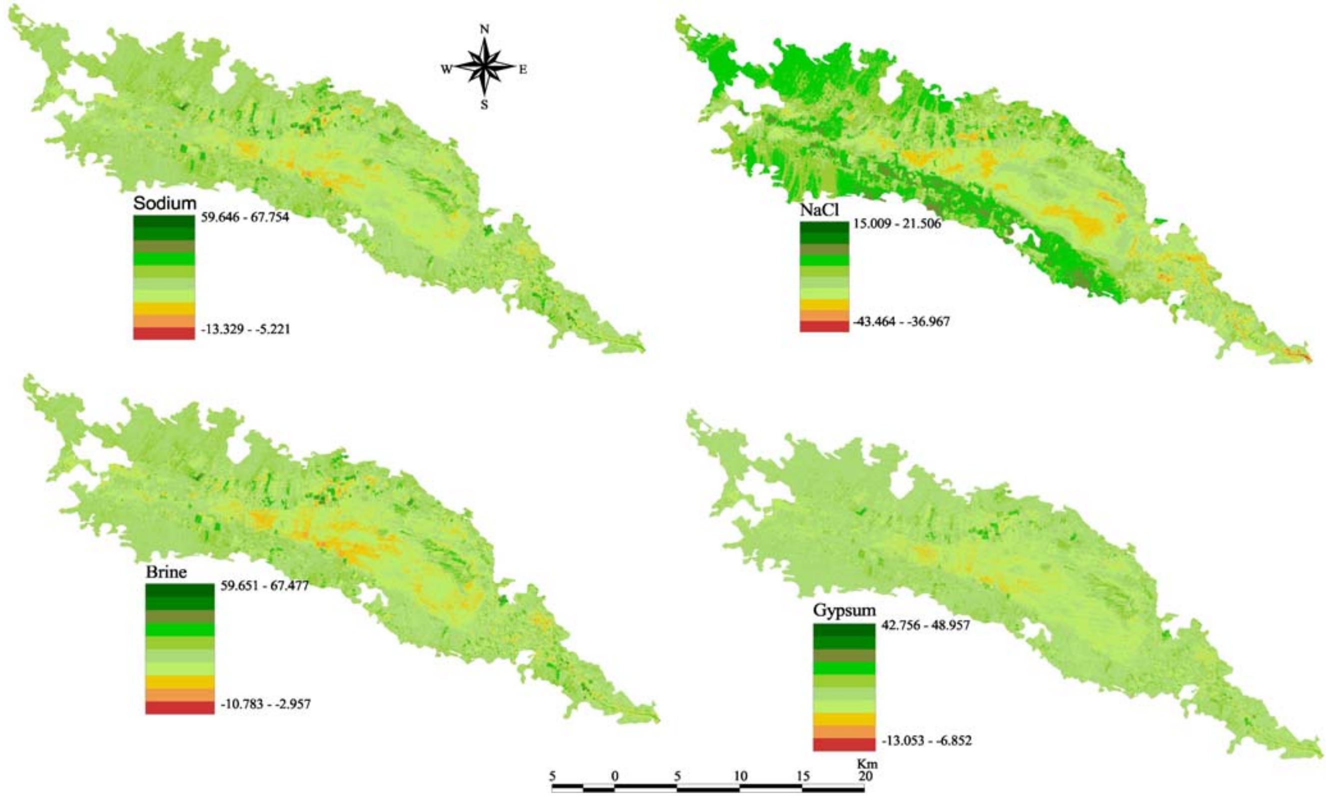


Fig. 3 Changes in the chemical elements calculated for the study area from two period images

lands in the playa have been altered directly and indirectly, by land-use practices and climate changes. In the Kahak playa-lake, climate variability plays a substantial and interactive role in the chemical properties changes.

The most increased changes are related to gypsum and the most decreased changes are related to the NaCl in the study area. This means declined rates for the area that contain NaCl and inclined rates for area that contain gypsum in the 14-years period (Fig. 4).

Analysis of land-use changes

There are different types of land uses in the playa marginal. Land uses in the marginal playa-lakes were classified by spectrally corrected images and using a supervised classification approach with a maximum likelihood classifier.

Thematic maps resulting from the land-use classified images are shown in Figs. 5 and 6.

In the period of 1988–2002, there was net increase of 5,061 ha in total agricultural land in playa-lakes margin, including all of the changes in cropland, natural pastures and planted pastures. These results indicate a basin-wide annual net increase of ~15% in total agricultural area during the period. Using the major land-use categories extracted in the imagery data between 1988 and 2002, we can break down playa-lakes margin land-use changes to three components: changes in salinity area; water extent; and bare soil. Results indicate that the total cropland

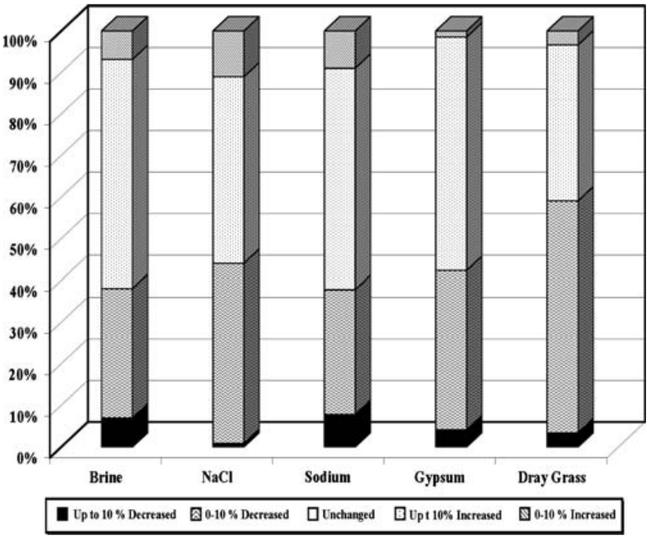


Fig. 4 Changes in the chemical elements and their effects on the vegetation area at the playa surface. The most increased changes are related to gypsum and the most decreased changes are related to the NaCl. Overall increases on the vegetation cover have effected in large decrease of the chemical element in the study area

within the playa-lakes margin grew by 21%, though cropland was lost in some areas and gained in others (Fig. 7).

The increase in total agricultural area during the period was driven by a major expansion in the area of agriculture type one, by a total of 562 ha, nearly everywhere in the playa-lakes margin during this period (Fig. 7). Much of this gain in agriculture type was offset by a decrease in brine during the period (Fig. 7).

As a result, changes in the amount of agricultural area in the playa-lakes margin, show low effects in the desertification process, while changes in overall salinity in the playa-lakes are directly tied to patterns of vegetation- clearing and climate change. Our estimates of total agriculture change between 1988 and 2002 include cropland increase, loss of natural pasture and increase in planted pasture (Fig. 8).

One way of the result evaluation was through the accuracy assessment. The classification results are compared to the raw image data and the report is created. This process is done during the random sample selection (Table 2).

Analysis of pattern ground changes

An image-texture analysis was used to detect variation in pattern structure as imaged in the PCA1 data. Texture analysis is a common method for delineating surface features that cause localized variations in pixel brightness. On the other hand, changes in the chemical properties of the playa-lake result in morphological and pattern ground variations. For this purpose, we used texture and pattern analysis and determined the variety of texture for two-period PCA1 images and calculated the differences between them.

Texture analysis of the study area comprised types of pattern ground, undisturbed, and vegetated regions.

Fig. 5 Land use in the study area (1988)

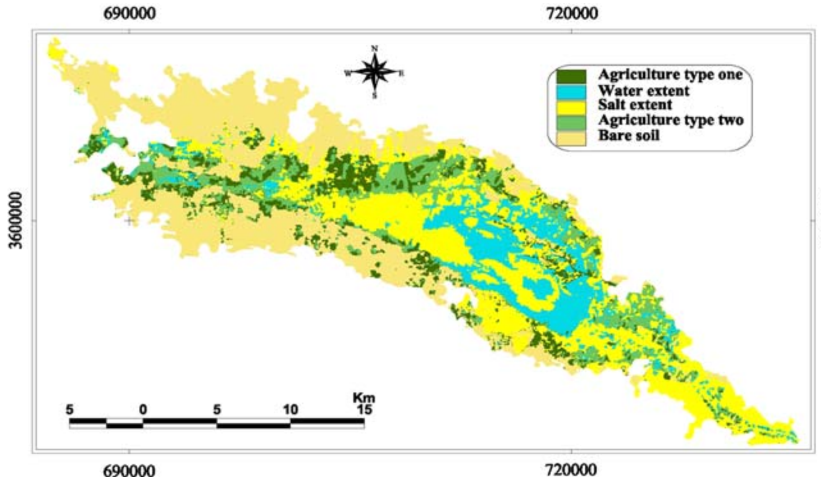
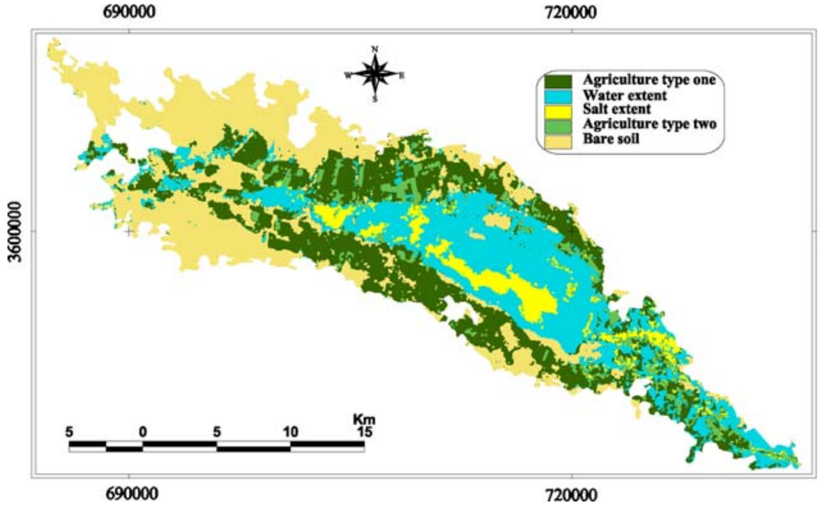


Fig. 6 Land use in the study area (2002)



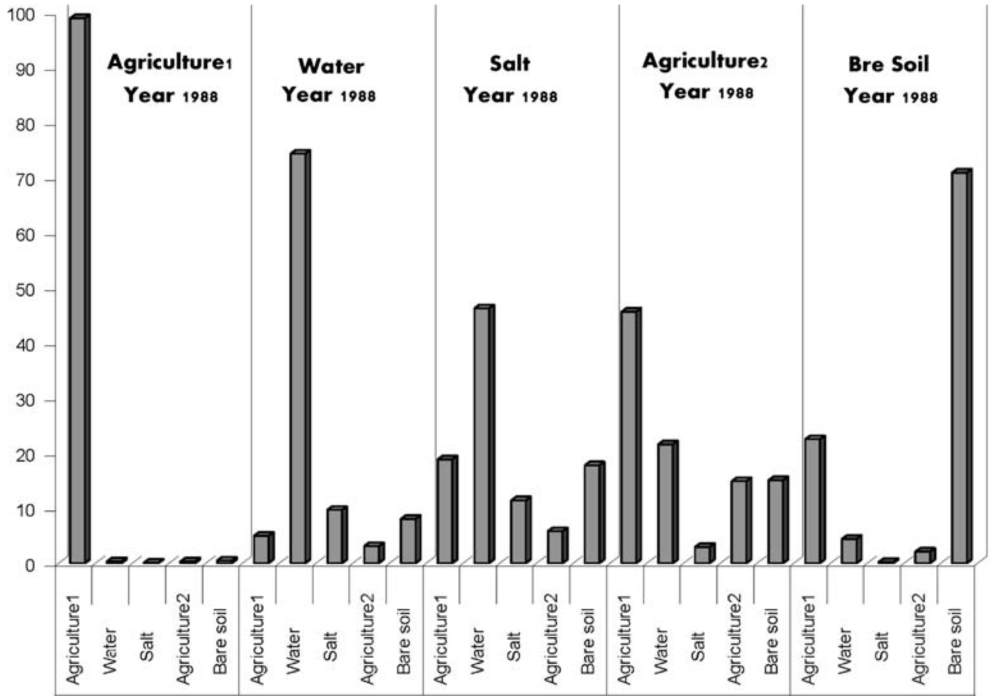


Fig. 7 Land-use changes in 14 periods. The chart shows transformation of changes in land use

These different types of area have distinct spatial edge frequencies or texture that can be used as the input into classification algorithms (Gong and Howarth 1990). Playa areas typically have significant texture resulting from chemical formation, whereas homogeneous areas such as agricultural fields have little ton texture.

Four distinctive features characterize the playa surface. They are: (1) salt flats and patches of salty ground, where salt accumulates at the surface; the salt flats may be divided into polygonal plates, which can grow and buckle as the salt crystallizes; (2) ephemeral to semi-permanent wetlands, which are generally rimmed by salt flats; (3) zones of brine; (4) zones of bare soil around saline lakes. Study of crack and polygon formation was carried out on the playa surface. Vertical desiccation cracks and soil polygons 4–12 cm wide appear on the salt flats (Fig. 9), particularly in the summer. There are distinguishing patterns in playa surface in salt-flat soils,

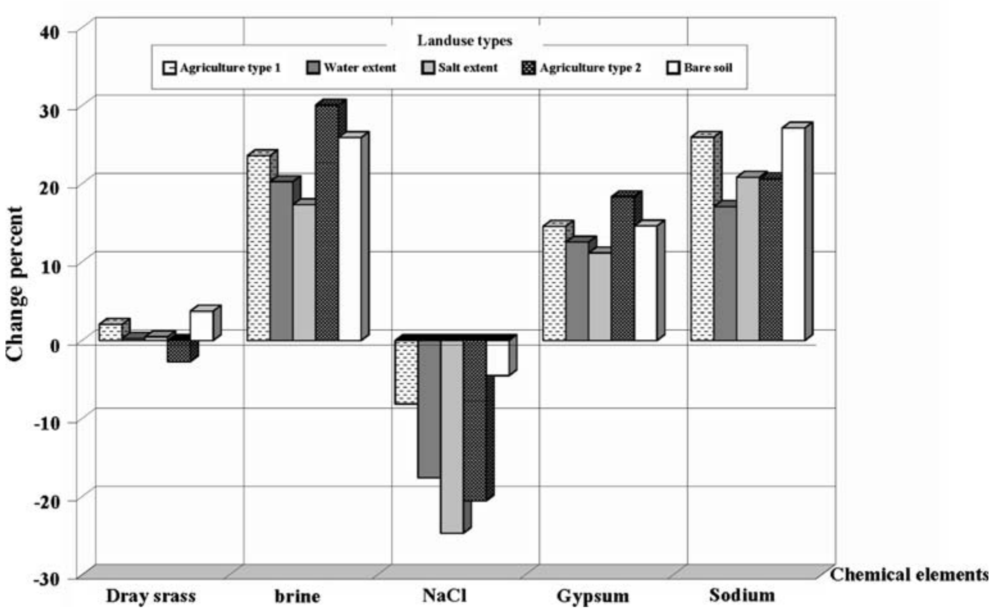


Fig. 8 Desertification effects on land uses and land cover of the study area. The chart shows decreased effect for NaCl and increased effect for gypsum and sodium

Table 2 Error matrix for land-use and land-cover status in 2002

	Agriculture type one	Agriculture type two	Bare soil	Brine	NaCl	Sodium	Gypsum	Dry grass
Agriculture type one	42							
Agriculture type two		48						
Bare soil			35					
Brine				27				
NaCl					23			
Sodium						22		
Gypsum							36	
Dry grass								44
Total sample	50	50	40	30	30	34	42	52
Accuracy	84%	96%	87%	90%	76%	64%	85%	84%

Actual status designed by column heading and measured status by row designation

Overall accuracy = 277/328 = 84%

Overall kappa statistics = 0.6735

which can change significantly across as little as 2 m moving outward from bare salt-flat surfaces to vegetated salt-flat margins. However, the early observation reveals that they have appeared in approximately the same locations. Thus, despite the severe effects of land use and chemical-formation change at the land surface, the spatial pattern of this polygonal feature has not changed. Maximum elevated polygon margins are about 4 cm. Individual salt flats in the playa surface range from 0.2 to 36 ha in area, but vary considerably in area from year to year.

Assessment of correlation in temporal variations

There are many possible sources that contribute solutes in saline environments. These include seawater, dissolution of rocks, ground water, geothermal water (mainly in rift sequences), surface water (floods), rain and aeolian processes (dust).

Throughout the history of the brine, including the stages of accumulating salts from the above-mentioned sources and the salinity increase, there are several processes that can change the chemistry of saline environments.

Fig. 9 Patterns ground in the playa surface in salt-flat soils

(1) Precipitation of salts; this is the major sink for solutes in many evaporite systems. (2) Dissolution–precipitation processes; throughout the flow path, water can interact with the surrounding rocks and dissolve and precipitate, depending on the degree of saturation for the particular mineral. (3) Ion exchange; it is suggested by many scientists to be important in controlling solute ratios in water. It should be noted that this process is probably less effective in highly saline brine because the specific ion capacity of the clay is small relative to the ions in the brine. (4) Redox reaction; it is associated with organic matter, can be responsible for changes in chemistry especially at the interface between fresh and saline water bodies. One of the best-described redox processes in such a system is reduction of sulfate to sulfide.

Evaporation is the main process forcing solute evolution of brines in most sabkhas, playas, lakes and other open water systems in arid areas. Removal of water by evaporation increases the concentration of the solutes, to the point when precipitation of minerals occurs. As solute concentrations increase in the brine, mineral precipitation occurs which removes some of each of the reacting solutes. The solute of the lowest concentration in this precipitation reaction will decrease in concentration, while the remaining solutes increase in concentration as evaporation proceeds. For example, if water contained greater equivalents of chloride than sodium, the sodium would ultimately become limited because the precipitation of NaCl removes both chloride and sodium. Sodium concentration would approach zero as the chloride concentration continued to increase due to evaporation. In this model, the initial solute ratio in the source water entering the evaporation process defines the chemical divides and the unique path along which the brine will evolve. That is, for a closed system, the milliequivalents per liter of the cations and anions in the input water and the equilibrium constants of the evaporite minerals are the only factors that control the solute evolution of the brine.

In order to understand the inter-relationship between the change maps, the entire data set of playa was standardized with the transformation function, $z = ((x - m)/s)$ (where x is the value of the variable, m is the mean and s is the standard deviation), to overcome the non-Gaussian nature (Ramkumar et al. 2002) (Table 3).

Unlike the increase in planted pasture and cropland, losses in natural pasture were probably not closely related to playa development. Though some natural pastures may have been converted into cropland, we assumed that the loss of natural pasture estimated during this period was due to the abandonment of formerly used lands to degraded pasture. Therefore, when estimating these rates, we focused strictly on the relationship between changes in cropland, planted pasture and deforestation. To estimate the change in cropland and planted pasture within the adjusted study area, we extracted the change in these quantities for all states. Our methods estimate that of the land deforested in this region between 1988 and 2002, 14.5 ha were still actively used as either cropland or pasture in 2002.

Monitoring the pattern ground related to changes in chemical properties is crucial for detecting environmental alterations or other changes in the playa. Although discrimination pattern ground is possible in the field, their accurate location and spatial determination are feasible by remote sensing, as we have done for the period 1988 and 2002 for the Kahak playa. Table 3 shows the correlations of the surface-topography pattern and homogeneity changes with chemical-formation changes in the surface of the playa form the studied images. Results show that pattern-texture changes are positively correlated to the chemical-formation changes, whereas it shows a negative correlation with the NDVI-changes map. Changes in the rate of sodium correlated highly with changes in the texture and pattern-change analysis of the playa.

In the playa, developing chemical materials, such as sodium, NaCl, gypsum and also brine water are positively correlated with each other. These observations indicate strong positive correlation for the gypsum, brine water and sodium changes. Relations of NaCl changes with other chemicals show less correlation (Table 3). These observations indicate different sources for the constituent geochemical variables. The source changes of gypsum, brine water and sodium is different from that of NaCl.

Discussions

Salinity-hazard prediction

The monitoring procedure based on fuzzy logic highlights areas where major changes in salinity and or alkalinity have taken place in the current situation and in the past (Figs. 10, 11). This retrospective monitoring shows trends, which can be extended into the future, within given possibility ranges. Such an attempt of change prediction has been done for the playa. Areas, which have undergone significant changes in the recent past, are considered as particularly prone to potential increase in salinity and therefore present a severe hazard of salinization. The degree of probability for such an evolution to occur can be attached to the mapped areas, as was done for a region in Russia (Krapilskaya and Sadov 1987).

Other methods for predicting the areas at risk of dryland salinity use a combination of multi-temporal satellite imagery, information derived from large-scale DEMs, and subjective probability. Evans and Caccetta (2000) used decision trees based on the relationships between salinity risk and variables describing landscape features to reproduce expert opinions about the future extent of salinity in a certain area, whereas Florinsky et al. (2000) assumed that the build-up of salts at macro topographic scale occurs in depressions.

Table 3 Correlation matrix showing the changes between the maps

Mean changes per maps:								
	1.82	14.04	23.57	0.37	−10.88	9.24	12.76	23.24
Std. Changes per maps:								
	4.30	3.86	6.65	23.82	8.15	6.58	58.03	6.60
Maps	Grass	Gypsum	H_2O	Homogeneity	NaCl	NDVI	Pattern	Sodium
Grass	1.00	−0.27	−0.12	0.08	0.47	0.03	0.01	−0.13
Gypsum	−0.27	1.00	0.89	−0.05	0.12	−0.08	0.05	0.86
H_2O	−0.12	0.89	1.00	−0.06	0.26	0.06	0.07	0.99
Homogeneity	0.08	−0.05	−0.06	1.00	−0.17	−0.11	0.25	−0.05
NaCl	0.47	0.12	0.26	−0.17	1.00	0.04	0.05	0.21
NDVI	0.03	−0.08	0.06	−0.11	0.04	1.00	−0.02	0.10
Pattern	0.01	0.05	0.07	0.25	0.05	−0.02	1.00	0.07
Sodium	−0.13	0.86	0.99	−0.05	0.21	0.10	0.07	1.00

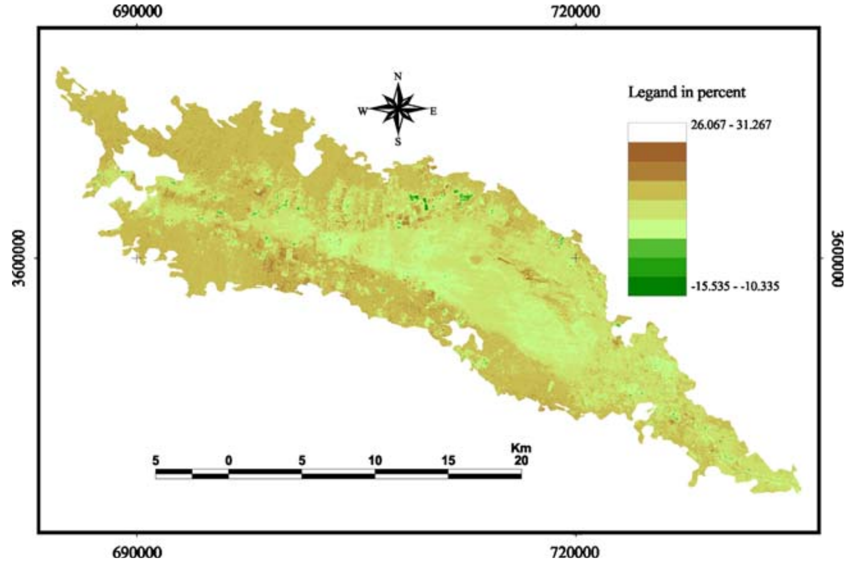


Fig. 10 Fuzzy classification of overall averaged changes and their area

During the analysis of classification results, quality assessment was erformed by comparing overall accuracy and kappa coefficient . In general, an overall accuracy in the order of 0.84 was obtained (Table 2).

Origin and interpretation of surface salt accumulations

The range of depth to water table in playa-lakes corresponds closely to 22–145 cm; average of 93 cm measured, under-groundwater supplied surface salt efflorescences in agricultural lands. Evaporate mineral covers large areas of the playa and lower slopes of the depression. Different types of salt accumulation occur at present in the Kahak playa, mainly NaCl and gypsum, which grow below the sediment surface in brine-soaked sediments of the playa formations. Precipitation would occur at the level where NaCl or gypsum becomes supersaturated. The first results from evaporation from the shallow water table, show a precipitation principally of gypsum and NaCl in the topsoil; this will be referred to as evaporation salinity.

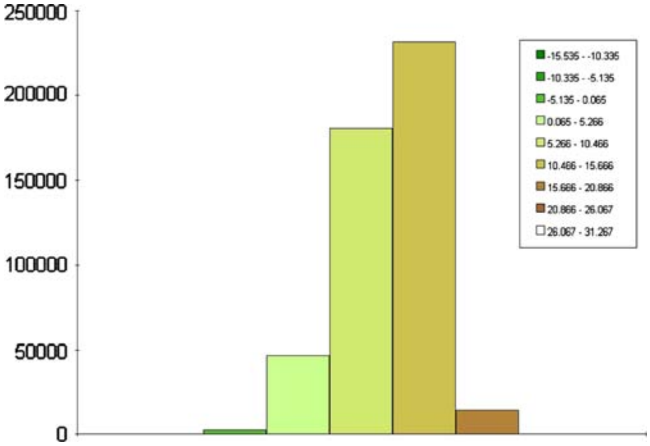


Fig. 11 Percent of changes extracted from fuzzy classification for the 14 years (in pixel)

Salt efflorescences in plain soils is a result of leaching on high-landscape positions, followed by lateral movement of the resulting solute-enriched groundwater, and, finally, by precipitation of salts at the soil surface in low-lying areas via surface evaporation of groundwater, which moved upward by capillary action. This and other occurrences of salt efflorescence on the land surface appear to be associated with land use, particularly intensive irrigation.

Concentrations of sodium, gypsum, sulfate and NaCl were the highest in playa sites and decreased significantly toward the upland. Variation in chemical properties and solute content of playa-lakes in this environment is largely controlled by precipitation runoff and evaporation.

Salt efflorescence on agricultural lands provides irrefutable evidence for the persistent generation of salt crusts by capillary movement and the evaporation of groundwater at the land surface, rather than from the evaporation of standing surface waters.

The presence of highly soluble NaCl on the surface is a further characteristic of per ascensum evaporite crystallization; otherwise, leaching would tend to produce a zone of NaCl crystallization beneath the soil surface near the permanent water table.

Salt features in the playa are similar to salt-cemented crusts, but in the Kahak playa they are thin, appearing in clay soils, in a very small land area, which are formed by evaporation of waters introduced by capillary rise. Moreover, the geomorphic role played by a playa appears to be minimal, although it does appear to survive multiple rainfall events. Other authors, e.g., Glennie and Evans (1976), and Watson (1979) have noted inland salt crusts up to 75-cm thick cemented by various soluble salts, including NaCl, sodium sulfate and gypsum in other regions. These crusts are typically more long-lived features found in semiarid to arid regions. They are formed by a variety of processes, including evaporation of lacustrine waters, lateral flow of groundwater and the descent of meteoric waters, as well as the capillary rise of groundwater (Watson 1979; Sonnenfeld 1989).

Overall, from 1988 to the 2002, the playa landscape changed significantly and the desertified land has expanded rapidly. The saline areas of the playa are increased during this period, which are about 62.6875 ha at the present (Fig. 8). In 2002, both shifting and fixed salinity rates are dominant.

Based on this study, a conclusion can be reached that the status of playa development in the study area is expanding rapidly in most areas, and rehabilitation has occurred in some areas only. The government and researchers should pay more attention to this fact. Adverse natural conditions and human activities are responsible for the playa expansion in the Kahak playa.

Conclusions

In order to determine the changes to the Kahak playa during a 14 years period, several standard, commonly used image-analysis techniques were considered. This research successfully shows that the change-detection techniques can be applied to playa environments. Analysis of the change data provides information to assess landscape-level changes in playa-formation extent and composition. It also affords information on causal agents that have the greatest impact throughout the project area. The change data also benefits the existing programs. Incorporating the change data into the field observations of the area enhances the ability to correctly map the changes in environmental landscapes. More investigations are required to define thresholds between change classes representing quantitative changes in salinity and wetland reduction and growth. Although the numbers representing acres of detected change have not been verified exactly by an accuracy assessment, correlations exist between the detected changes such as sodium, NaCl, gypsum, water extent, dry grass, NDVI and pattern-ground indexes such as topography homogeneity and pattern.

Remote sensing has provided a great mean to study various ecosystems of the earth including playa environment by providing low-cost and time-consuming data. One major and widespread use of remotely sensed data has been easier, faster and cost-effective investigation of various types of changes in different environments. Over the years, remote sensing has been used as a tool to map large areas. Moreover, remote sensing in the form of aerial photography served the purpose of identification, delineation and measurement of spatial extent of environmental landscapes successfully. With regular passages of remote sensing vehicles (aircraft and/or satellites) over a locality, land information in the form of multi-date, multi-spectral images can be obtained within a constant period of time. Changes in surface environmental conditions can therefore be monitored using space-borne digital imageries. Yet, its use is very limited for studies of different aspects of all types of playas, specifically, arid and semiarid playas, which usually have smaller aerial extent and complex mixture of vegetation species. Availability of Landsat TM data solved this problem to some extent. With a spatial resolution of 30 m, it becomes possible to study relatively smaller areas.

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