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ASSESSING AND MONITORING LAND DEGRADATION DUE TO SALINIZATION IN TURKMENISTAN AND EXAMINING NEW PHYTOREMEDIATION METHODS

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ABSTRACT

Takyrs and solonchaks are typical soil/geomorphological ground features in the interdune depressions of the Central Asian deserts. These areas have recently attracted attention of the local as well as foreign scientists due to the possibility of takyr surfaces to produce runoff. Both the clay-enriched takyrs' surface and the white salty crust of the solonchaks appear in similar bright tones in the satellite images and therefore hardly distinguishable. A special image processing procedure, based on seasonal change detection, was developed in order to discriminate between these two surfaces. Advantage was taken from the seasonal dynamics of the solonchaks. During the wet season, after rainfall, the soluble salts are leached down-profile and the surface color is turned into dark tones. Implementing the suggested procedure reveals that significant change occurs only in the solonchaks' surfaces whereas the majority of other soil surfaces show only a minor change.

1. Introduction

The Karakum ("Black Sands") Desert, the southernmost of the Central Asian deserts, is located south of the Aral Sea and east of the Caspian Sea, and spreads from 37° N to 42° N and from 56° E to 64° E. The southern part of the Central Karakum Desert is characterized by the so-called "ridge-takyr complex" with sub-meridional sand dunes and dense clay surfaces (takyrs) in the interdune depressions (figure 1).

The term "takyr" is borrowed from the Turkic group of languages and means "barren land", "nothing". Takyrs were first found and described in the deserts of Central Asia, but they are also present in other arid areas under similar geographic and climatic conditions (Ganssen, 1968). Turkmenistan is the richest in takyrs among the Central Asian states. Estimations of the total takyrs' area vary between 31,000 km^2 (Babaev and Vitkovskaya, 1985) and 40,000 km^2 (Lavrov, 1984). There is much confusion about this term, since quite different definitions and concepts are used: it can be defined as a pedological category as well as a geomorphological one. Moreover, it can be

studied from the hydrological perspective since these surfaces have been traditionally used by local dwellers as indigenous water harvesting systems.

Pedologists define takyrs as a type of primitive desert soil, where typical processes of soil formation are reduced due to the aridity of the climate (Ganssen, 1968; Mainguet, 1999). They develop on various parent materials but are always characterized by high content (more than 80%) of clay and silt particles in the soil surface (Lavrov, 1984). Takyrs in the geomorphological sense, throughout the arid regions of the world, are generally referred to as clay pans, or playas if their surface is saline (Briere, 2000). Although these landforms are strongly conditioned by local parameters, there are a number of common characteristics. Takyrs occupy the lowest parts of the land, subsurface ephemeral water bodies are frequently present, and their surfaces are vegetation-free (Thomas, 1997, p. 295 - 296). Due to their fine texture and smooth surface, takyrs usually appear very bright on the satellite images.

The continental hydrologically closed salinized depressions are called "solonchaks" in the Soviet and post-Soviet literature. The main and principal difference between takyrs and solonchaks is that solonchaks are connected to the shallow ground water table, whilst takyrs are cut off from the ground water. The capillary fringe of the water table intersects the soil surface. In this case the water fluxes carry with them salts from the salinized ground water horizons to the surface where they crystallize and accumulate. As a result, white crusts that may be a few centimeters thick form. Solonchaks are broadly known as halorthids in the USDA soil classification system (Cook et al., 1993) or simply saltpans. Since they are extremely saline surfaces that cannot be used for water supply or any other use, it is of interest to discriminate between takyrs and solonchaks. In view of the large areas and the difficult terrain it appears that remote sensing techniques would be the best tool. However, since both are usually appear as very bright spots on satellite images and, as can be observed in figure 1, it is quite difficult to tell them apart.

The rationale of the proposed approach is based on the assumption that after rainfall or flooding the rate of drying of takyrs and solonchaks is probably different. Immediately after the rainfall event both surfaces appear as dark areas, because the surface is wet and the albedo much lower and the salts on the surface of the solonchak are dissolved. The solonchaks lie in depressions and after rainfall event water will not drain easily and they will probably remain flooded for some time. Thereafter the evaporation proceeds at a low rate due to the presence of salts. The net result is that the surface of the solonchaks appears dark for a considerable time after a rainfall event. The surface of the takyr changes to a darker tone as well when wet, but returns to its former brighter appearance within a shorter period of time due to the fact that the runoff flows into the surrounding dunes and allows the surface to dry out quicker. Remotely sensed images taken during the period of time when the solonchak is still wet and the takyr drying out could be used to differentiate between them.

2. Material and methods

The study is based on the analysis of two Landsat-TM images centered at coordinates 38°53' N and 59°09' E. The first image of 28 August 1987 (denoted hereby as image 0887) was acquired during the peak of the dry period of the year and represents the phase during which salts cover the solonchaks' surfaces. The other image of 15 October 1987 (denoted as image 1087) was taken shortly after 20 mm of rainfall were recorded in the nearby Karrykul Meteorological Station. This is probably the phase during which the surface of the solonchak was flooded.

Prior to the main analysis of the satellite data, typical preprocessing operations of the Landsat-TM images, including radiometric, atmospheric, and geometric procedures were carried out on the data in order to improve the image quality and thereby the accuracy of the analysis. The radiometric correction procedure was adapted from Markham and Barker (1986). A simple first-order atmospheric correction was performed by the histogram adjustment technique (Jensen 1986). Dark-pixels over a large water reservoir

located west of Ashgabat were used as an estimate of the path radiance for the entire scene. Finally, the images were geometrically registered to the Universal Transverse Mercator (UTM) projection. These preprocessing operations as well as data analysis were implemented with the ERDAS-Imagine software.

3. Analysis and results

The availability of image data sets from two different hydrological seasons made it possible to test our hypothesis of a change in spectral signatures due to differential drying out. In the current study, a pre-classification change detection procedure was carried out, the results of which are supposed to lead to a classification. The aim of the analysis, based on the 0887 and 1087 images, was to identify solonchaks by the intensity of change in their reflectance between the dry and the wet states, which sets them apart from their surroundings.

We analyzed a subset of approximately 12x14 km, located northwest of Karrykul livestock breeding settlement on the border between the solonchak belt and the ridge-takyr complex, which was extracted from the geometrically corrected images 0887 and 1087 (figure 2a, b, respectively). It comprises several solonchaks, a few takyrs, and dune ridges in-between. The reflectance values of the single bands of the subsets were then transferred into brightness values (Ω) by summing up the reflectance values of each band (X_n), using the following equation:

$$\Omega = \sqrt{X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2 + X_7^2} \qquad (1)$$

The brightness images are shown in figure 2c, d. An brightness difference subset (figure 2e) was created by subtracting the earlier from the later subset, which shows the change in brightness between a dry and a wet states during 1987. As expected, the solonchaks are clearly marked by a decrease in brightness values, whereas the change in these values on takyrs and sand dunes is around zero. Subsequently, the absolute brightness difference

values were transformed into relative values, so to bring out the percentage change of brightness taking the dry phase brightness as a basis. Finally, the resulting image was classified by a supervised classification procedure (minimum distance) into solonchaks and other surface types. In order to remove presumably misclassified pixels - individual pixels scattered throughout a solonchak classified as other surface types - and isolated pixels, a majority filter was applied on the classified output: a 5x5 pixel moving window was passed through the classified data set, which changed the identity of the center pixel into that of the majority of pixels in the window, thus smoothing the image by modifying the class assignment of pixels isolated by the classifier in their spatial context (Lillesand and Kiefer, 1999). The final result is presented in figure 2f.

Quantified evaluation of the suggested procedure is revealed in figure 3. It shows the number of pixels as a function of the percentage change in reflectance values. The solonchak pixels stand out by decreases in their brightness values of 60 per cent whereas the majority of other soil features' pixels show only minor brightness changes.

4. Summary

Although both takyrs and solonchaks are soil/geomorphological ground features of interdune depressions that commonly exist adjacently in the Central Asian deserts, they differ from each other in many properties and by their ability to be used. For centuries the takyrs have been used as catchment areas for runoff harvesting as well as for a limited agriculture along their margins. The caravan routes were passing through them. In these senses, the solonchaks are considered to be ineffective lands. In order to produce a proper classification of the area by satellite image processing means, it should be possible to discriminate between takyrs and solonchaks, however both produce the same brightness values when the surfaces are dry. Taking advantage of the differential drying rates of both surfaces we were able to easily map the solonchaks.

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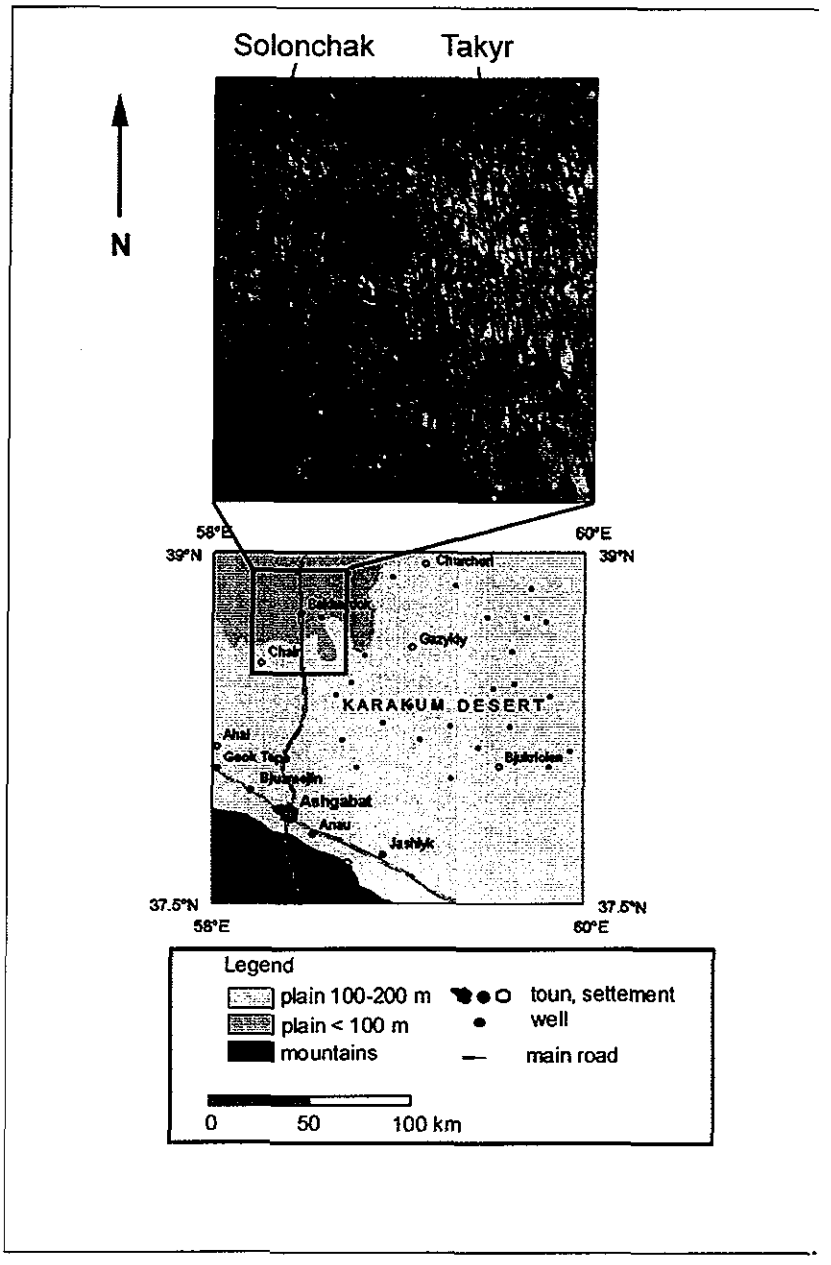

Figure 1: (a) Physical map of Turkmenistan showing the location of the Central Karakum desert; (b) Landsat-TM false color composite of image 0887 (RGB = bands 4,3,2).

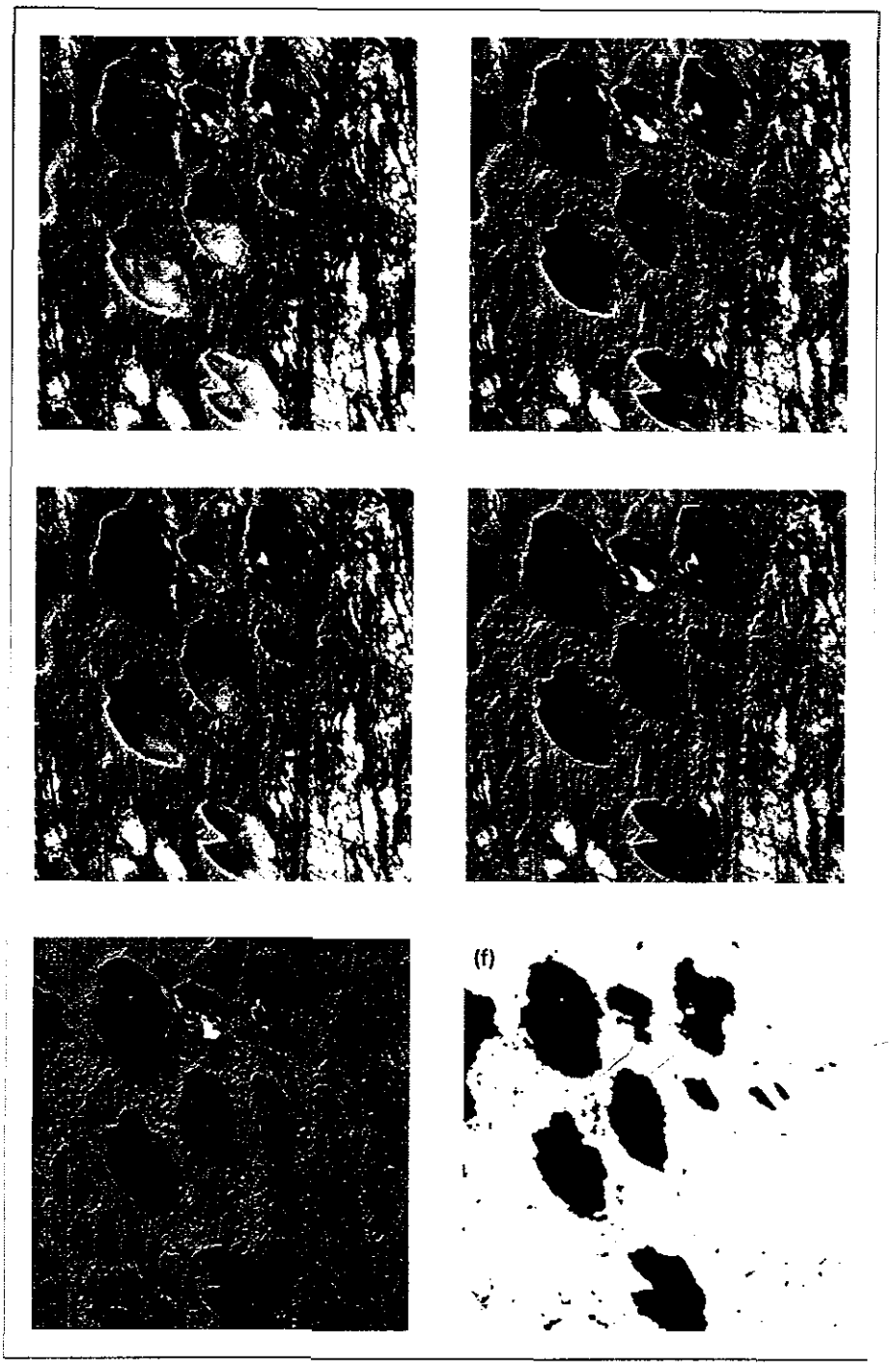

Figure 2: Change detection procedure to identify surface changes caused by seasonal salt dynamics: (a) False color composite (RGB = bands 4,3,2) image 0887; (b) False color composite (RGB = bands 4,3,2) image 1087; (c) Albedo image 0887; (d) Albedo image 1087; (e) Albedo difference image 1087 – 0887; (f) Classified and smoothed albedo difference image

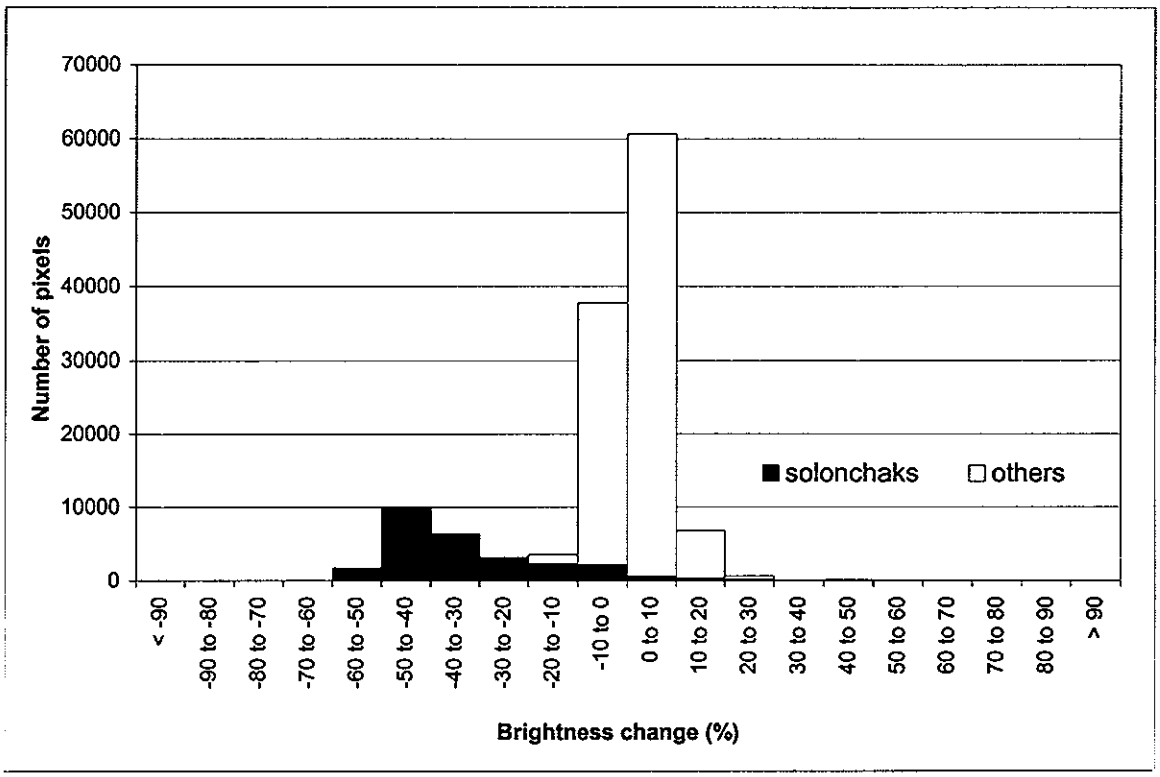

Figure 3: Albedo change histogram: The solonchak pixels stand out by decreases in their albedo of up to 60%, whereas the majority of other soil surface pixels show only minor albedo