Abstract

Using MODIS Time-Series satellite data for land cover change analysis in the Southern Aral Sea Basin, Uzbekistan

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Introduction

The desiccation of the Aral Sea since the 1960s is considered to be one of the most severe man-made ecological disasters in history. With the recession of the once fourth largest sea of the world, a huge new saline desert emerged on the former seabed, which is called the "Aral Kum" (Breckle et al., 2001). Since 1960, the shrinking Aral Sea left more than 50.000 sqkm of exposed sea bed (Micklin, 2007), that features a wide variety of different landscape and soil types. This new terrestrial ecosystem is changing rapidly with time, as the Aral Sea keeps on shrinking. The major part of the desiccated sea bed is considered as highly unstable landscape (Dukhovny et al., 2008). Especially salt affected areas (e.g. a wide variety of Solonchaks and Takyrs) provide a large source for salt- and dust storms in the region (Razakov & Kosnazarov, 1996; Singer et al., 2003). This study used MODIS time series for classification and post-classification change detection of the land cover in the study area. The objectives of this study were to: (1) develop a method for map and monitor land cover changes through MODIS time series classification and post-classification change detection; (2) assess the accuracy of the classification and change detection; (3) analyze land cover change pattern and relate them to ecosystem dynamics in the southern Aral Kum.

Study Area

The study area is located in the southern Aral Kum within the autonomous Republic of Karakalpakstan (Uzbekistan), an area of approximately $15x10^3$ sqkm. The lower reaches of the Amu Darya delta is often referred to as Southern Prearalie. It includes a diversity of all major land cover classes of the Southern Aral Sea Basin, e.g. bare areas, sand-dunes, shrublands, reeds and salt affected soils (e.g. Solonchaks and Takyrs). About 65% of the area is composed of former sea bed sediments. Within the last nine years (2000-2009), the landscape has changed dramatically since the Aral Sea and small lakes covered 19.33% (approx. 2,889 sqkm) of the study area in 2000, and have decreased to 0.7% (approx. 105 sqkm) until 2008.

Data and Methods

The MOD09 8-day Surface Reflectance Data of the MODIS-Terra satellite (Moderate Resolution Imaging Spectroradiometer) was chosen as primary data source. All 7 spectral bands, centered at 648 nm, 858 nm, 470 nm, 555 nm, 1,240 nm, 1,640 nm, and 2,130 nm respectively, were processed to obtain the full spectral range and improve class separability. The almost daily availability of MODIS satellite images since the year 2000 enables recording landscape dynamics in a very high temporal resolution. Ground-Truth data for classification of satellite images were collected during field surveys in the study area in 2007, 2008 and 2009 in accordance to the FAO LCCS (Land Cover Classification System), whereas more than 200 ground truth sampling points were collected, including photos of the sampling sides, vegetation mapping and important soil characteristics. Detailed sampling was performed on 49 independent sites, representing a variety of the most important soil/ surface types.

A quality assessment of the input data was performed, using the TiSeG software (Time Series Generator) (Colditz et al., 2008). Additional input information for the classification procedure was provided through the calculation of the NDVI (Normalized Differentiated Vegetation Index) and band ratio of MODIS bands 3 and 1, which proved valuable for discriminating salt affected areas. The resulting dataset includes nine 8-day time series (seven MODIS bands and the two indices) per year. In order to reduce the high dimensionality and data noise of the dataset, metrics (basic statistics such as mean and standard deviation, minimum and maximum) were calculated. Decision trees were found to be the most suitable method for classifying the high dimensional time series data, and have successfully been applied in other studies (DeFries et al., 1995; Hansen et al., 2000). The classification of the time series was conducted with the QUEST algorithm (Quick Unbiased Efficient Statistical Tree) (Loh & Shih 1997), which is implemented in the software add-on “RuleGEN 1.02” running in the standard image processing environment “ENVI” (ITT Visual Information Solutions).

Although a wide variety of classes were mapped in the field, six final classes were chosen to be most suitable for classification, regarding their thematic importance and spectral separability.

The classification results were used to perform a post-classification change-detection analysis for the time steps 2000-2004, 2004-2008 and 2000-2008. The approach used in this study provides “from-to” change information and the kind of landscape transformation that have occurred. The land-cover change areas between the different classes were then calculated.

Validation was performed by using an independent sample of validation points to assess classification accuracy. Validation points from 2008 were measured directly in the field, whereas for 2000 and 2004, validation points were randomly generated and evaluated visually using Landsat 5 TM imagery and NDVI temporal signatures.

Results

The overall accuracies of the classifications for 2000, 2004 and 2008 were 82.8%, 81.5% and 78.9%, respectively. Based on the individual classification accuracy of the three time steps, the RMS (Root Mean Square) was calculated in order to assess the accuracy of the change detection maps, which was 81.95% for 2000-2004 and 80.58% for 2004-2008.

To further evaluate the results of land cover conversions, change matrices of land cover change for three intervals, 2000-2004, 2004-2008 and 2000-2008 were created. The proportion of water surface in the study area has diminished from 19.33% in 2000 to below 1% in 2008. Only some small natural and artificial lakes remain such as the lakes Ribachie, Dzhyltyrbas and Sudochie, which have been preserved from desiccation by artificial embankments. In the same time salt affected soils (e.g. Solonchaks and Takyrs) and salt crusts increased from 15.62% in 2000 to 29.61%. The results from the change matrix and the change map indicate that increase of salt affected area is directly related to the shrinking of the Aral Sea water body. The salt crusts can be found within a narrow stripe directly adjacent to the sea body. The total area of salt crust has doubled between 2000 and 2008 (2.15% and 4.80% respectively). In the same time, a major part of salt affected area was further converted to bare area (such as sand sheets, dune fields or low-saline soils. Of the 2,783 sqkm of water decrease between 2000 and 2008 only a small proportion (6.19%) was transformed into shrubland. The change map shows the pattern of conversion of water. Shrubland is the most dominating land cover class, covering 30.07%, 25.62% and 37.81% in, respectively, 2000, 2004 and 2008. Reeds cover rather small areas showing highest values in 2004. The results from the change matrix indicate that increases of reeds come from conversion of shrubland into reed and vice versa, mostly due to changes in the inundation situation of remaining wetland areas in the Amu Darya delta.

Interpretation and Discussion

The recession of the Aral Sea results in a quick build up of extensive salt crust directly adjacent to the sea. Almost all of these salt crusts converted into a series of different Solonchak types (contained in the class salt affected soils) and then, in some parts of the study area, further into bare areas between 2000 and 2008. Lowering of groundwater table is one reason for the transformation of hydromorphic Solonchaks into automorphic Solonchaks and subsequently transformation into sandy desert soils (Rafikov, 1999; Dukhovny et al., 2008). A significant proportion of the emerged soil remained devoid of vegetation and became a salt desert. Only a small part of the salt desert in the study area, near to the former Amu Darja´s river mouth was converted to shrubland and reeds between 2000 and 2008. Salt affected area and salt crusts provide considerable source for salt- and dust storms (Singer, 2003) and features a highly unstable landscape (Dukhovny et al., 2008). Shrublands and reeds show high interdependence, which can be explained by the presence of shrub-reed mixtures in the tidal areas of permanent and temporarily flooded wetlands. Wetlands, dominated by mixture of reed species (e.g. *Phragmites* sp.) and shrubs (e.g. Saxaul) can convert into shrubland in dry years because of completely drying up of wetlands and bogs. During wet periods, this process can reverse completely.

Conclusion

The results demonstrate that MODIS time series classification is a valuable tool to produce accurate landscape classification and landscape change maps and statistics. The results from post-classification change detection revealed that: (1) most of increase in salt crusts and salt soils was because of diminishing of the Aral Sea; (2) no significant vegetation cover emerged on the former sea bed since 2000 in the study area; (3) shrublands and reeds show high interdependence; (4) the source area for potential dust- and salt storms has increased. The results quantify the land cover change patterns in the study area. MODIS time series provide an accurate, yet cost-efficient means to map and analyze changes in land cover, not only in the southern Aral Kum, but as well as on the regional scale covering the whole of the former Aral Sea extent and the adjacent regions in Karakalpakstan and Kazakhstan. The methodology and the resulting geoinformation products are highly suitable for an integration into existing landscape information systems.

Literature

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