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Monitoring the trends of aeolian desertified lands based on time-series remote sensing data in the Horqin Sandy Land, China

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A B S T R A C T

Aeolian desertification is one of the most significant environmental and socio-economic problems, represents a major component of land degradation, and seriously harms the ecological environment, leading to adverse impacts on human society. Monitoring aeolian desertification and identifying the driving factors behind it are crucial for developing prevention and management strategies to combat this issue. The objectives of this study were to monitor the trends of aeolian desertification in Horqin Sandy Land by using time-series MODIS-NDVI remote sensing data for the period of 2000–2013. A dimidiate pixel model was chosen to calculate the Vegetation Coverage Index (VCI), while a unary linear regression analysis was used for a temporal trend analysis of the Aeolian Desertification Index (ADI) and selected climate factors. The Sen's slope estimator and the Mann-Kendall statistical test were used to analyze the spatial trends of the ADI. (1) The temporal trend of ADI showed three stages: reversion during the period of 2000–2005 and 2009–2013, and development during the period of 2005–2009. For the five classes of ADI, the areas of non-aeolian desertified lands (N) showed an increasing trend and the slight (SL), moderate (M), serious (S), and very serious aeolian desertified lands (VS) showed decreasing trends, with the decline in areas of SL and M contributing to the reversion of aeolian desertification. (2) The spatial distribution showed that the VS was mainly distributed in the southwestern portion, and the S was mainly distributed around the VS portion. The SL and M formed a straight line from the southwest to the northeast, bisecting the two areas of S. The N was mainly distributed in the northwestern portion and the eastern edges of the study area. (3) The spatial trends showed that areas of decreasing and significantly decreasing ADI trends occupied 78.44%, while areas with increasing and significantly increasing ADI trends only occupied 21.56% of the study area over the period of 2000–2013, indicating that aeolian desertification in Horqin Sandy Land is decreasing overall and advancing in certain portions. (4) The driving factors of aeolian desertification were analyzed from the perspectives of two groups: climate and anthropogenic factors. We found that the desertification control measures and favorable climate condition have played key roles in the process of desertification reversion; and climate fluctuations, reclamation and livestock pressure have led to the desertification development. The results can provide meaningful information for the prevention and control of aeolian desertification in Horqin Sandy Land.

1. Introduction

At present, aeolian desertification represents one of the most serious environmental and socio-economic problems at the global scale, especially in arid, semi-arid, and dry sub humid areas of Africa, Central Asia, Australia, and Northern China (Liu and Wang, 2007). Aeolian desertification harms the ecological environment, natural resources, socio-economic factors and people's life in the desertified areas. According to statistics, the economic losses directly caused by aeolian desertification were 54 billion RMB a year in China (Wang and Zhu, 2001). Horqin Sandy Land is located in the eastern part of Inner Mongolia, a farming-pastoral region in Northern China. In the 20th century, the most significant landscape change of Horqin Sandy Land is a large area of land desertification (Wulantuya, 2002). As populations have increased and the boundaries of farming areas have moved northward continuously, large areas of former grasslands have been cultivated, and the steppe-woodland areas have been converted to a farming-pastoral type of landscape. In addition, much of the grassland vegetation has been seriously destroyed by livestock grazing and unsound land use, causing frequent sandstorm disasters (Wang and Ha, 2004). For these reasons, Horqin Sandy Land is often selected a site for the sandstorm source control project around the Beijing–Tianjin

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region of China (Duan et al., 2014). Therefore, prevention and control of aeolian desertification are critically important and urgent for Horqin Sandy Land.

Desertification monitoring is an important and effective way for combating desertification (Millennium Ecosystem Assessment, 2005). Remote sensing, digital image processing, and spatial analysis have proven to be useful technologies in both assessing and monitoring environmental change (Sun et al., 2005). Since the 1970s, many scholars have initiated a series of desertification studies using remote sensing, in which Landsat TM, ETM, MSS, MODIS, NOAA/AVHRR and SPOT images have been widely used for desertification monitoring (Lamprey, 1975; Reining, 1978; Peterson et al., 1987; FAO, 1984; Askolla and Hirscheider, 1990; Qi and Cai, 2007; Helldén and Tottrup, 2008; Yin et al., 2011; Reiche et al., 2012). In many studies, Landsat TM, ETM, and MSS were used to develop visual interpretation methods to monitor the desertification process. Based on field surveys and empirical judgments, remote sensing data has been interpreted to determine indicators of desertification. H.B. Wang et al. (2015) monitored the dynamic changes of aeolian desertification in the Qinghai Lake basin using Landsat TM imagery for 1987, 2000, 2009, and Landsat 8 images for 2014. Using TM and ETM images, changes in land desertification occurring each year during four periods (1990, 2001, 2007, and 2010) were monitored in the Ebinur Lake region, Xinjiang China by Zhang et al. (2015). Hu et al. (2012) analyzed the trends of aeolian desertification in the source region of the Yellow River, using MSS images for 1975, TM images for 1990, ETM + images for 2000 and TM images for 2005. Because Landsat images are multispectral in nature, provide remote sensing images of earlier years for its lager time span. By comparing a supervised classification with visual interpretation, the monitoring accuracy can often be improved. However, Landsat images can be easily affected by atmospheric factors, requiring an increased amount of data processing. This, coupled with additional analysis work required for visual interpretation often makes it difficult to examine the desertification process for long time-series data.

Because abundant sources of remote sensing images are available, MODIS, NOAA/AVHRR and SPOT images have been widely used for desertification monitoring and long time-series monitoring. Several studies have extracted special indices such as net primary productivity (NPP), normalized difference vegetation index (NDVI), soil-adjusted vegetation index (SAVI), land surface temperature (LST), albedo, temperature vegetation dryness index (TDVI), topsoil grain size index (TGSI), or integrative indices as desertification indicators. The soil-adjusted vegetation index (SAVI) was used as an indicator to monitor desertification change in Egypt by Badreldin and Goossens (2013). Based on the relationship between LST and SAVI, Badreldin et al. (2014) established MODIS-based disturbance index indicators, indicating mitigation strategy effects on desertification change in the Sinai Peninsula. NDVI, TGSI and albedo were selected as indicators for desertification monitoring in the Hogno Khaan nature reserve, China by Lamchin et al. (2016). Xu et al. (2009) assessed the desertification in the Ordos Plateau by using Landsat MSS and TM/ETM + data on a regional scale, using NDVI, MSDI, and land surface albedo as assessment indicators of desertification. Zhou et al. (2013) used change trends of actual NPP, potential NPP and HNPP (human appropriation of NPP, the difference between potential NPP and actual NPP) to analyze desertification from 2001 to 2010 in Heihe River Basin, China. An ordinary least-squares method was used to estimate the trends of potential NPP, actual NPP, and HNPP.

Vegetation is one of the important indicators for desertification monitoring. Thus, studies of time-series analysis of vegetation dynamic changes can present a reference for desertification monitoring. Guo et al. (2014) analyzed the changes in EVI by using MODIS time-series data from 2001 to 2012 in Qinghai Lake Basin, China, using simple linear regression analysis to simulate the trend of EVI. Fensholt and Proud (2012) evaluated global long-term vegetation trends by comparing GIMMS and MODIS global NDVI time-series data and linear trend regression slopes for expressing the NDVI trends.

The least squares method is commonly used to estimate the slope magnitude for analyzing trends in vegetation or desertification changes. However, problems with time-series data, missing data, outliers, and data distribution patterns may affect the monitoring results. Sen's slope estimator, proposed by Sen in 1968, is a non-parametric estimation algorithm for linear trends that is able to avoid the influence of missing data, outliers, and distribution patterns of time-series data on analysis results (Sen, 1968 and Hirsch et al., 1982). The slope of the data set estimated using Sen's slope is only one aspect of the analysis. A statistical test is also required to determine if the trends are significant. The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in time-series analysis (Partal and Kahya, 2006; Tabari et al., 2011), and Sen's slope estimator and the Mann-Kendall statistical test have been widely used in hydro-meteorological time-series analysis (Modarres and Silva, 2007; Chen and Grasby, 2009; Shadmani et al., 2012; Gocic and Trajkovic, 2013), but application in desertification trend analysis is rare.

Desertification monitoring in Horqin Sandy Land has been investigated by several authors. Hou et al. (2006) analyzed the spatiotemporal dynamic landscape changes of mobile and semi-fixed sandy lands in the past 50 years. Using ETM images for 2000 and TM images for 2005 and 2010 as data sources, the distribution of aeolian desertification areas, and their dynamic changes were analyzed by means of human-computer interactive interpretation (Duan et al., 2014). Li et al. (2007) monitored the dynamic changes of aeolian desertification by visual interpretation for 2000 and 2005. Du et al. (2009) used MODIS NDVI data to evaluate the degree of desertification for 2000 and 2007. Based on field investigation and conclusions based on previous research, Honggeer (2007) used modern historical documents, a topographic map from 1935, an aeolian desertification map from 1975, and TM images of 2000 and 2005 to analyze the spatiotemporal changes of aeolian desertification of Horqin Sandy Land in the last hundred years.

However, these studies have been mainly based on remote sensing images that cover only a few years. There are relatively few studies monitoring the spatiotemporal trends of aeolian desertification and their driving factors after 2000. In addition, few studies exist on the use of time-series remote sensing data for aeolian desertification monitoring. Monitoring aeolian desertification for each year is very effective for identifying the driving factors and facilitating real-time control and management of aeolian desertification. Hence, the objectives of this study are: (1) to use time-series remote sensing datasets as the data source, (2) to monitor the spatiotemporal trends of aeolian desertified lands in Horqin Sandy Land from 2000 to 2013, and (3) to determine the driving factors of aeolian desertification in Horqin Sandy Land. The intention of this study is to provide meaningful information for the prevention and control of desertification in Horqin Sandy Land.

2. Materials and methods

2.1. Study area

Horqin Sandy Land (117°49′–123°42′E, 41°41′–46°05′N) is located in the western part of Northeast China (Fig. 1), in the transition zone from the Mongolian plateau to the Northeast plain. The boundaries of Horqin Sandy Land are in the west the Qilaotu Mountain of Yanshan Mountain Ridge, in the east the western part of Songliao Plain, in the south the Nuruer Tiger Mountain, and in the north the southern margins of the Great Hinggan Mountains. The sandy land covers about 12.51 km^2 and includes the administrative regions of Tongliao City (Horqin District, Kailu County, Huolin Gol City, Jarud Banner, Hure Banner, Naiman Banner, Horqin Left Wing Middle Banner and Horqin Left Wing Rear Banner), part of Chifeng City (Barlin Right Banner, Barlin Left Banner, Aohan Banner, Ar Horqin Banner and Ongniud