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Dynamic monitoring of aeolian desertification based on multiple indicators in Horqin Sandy Land, China

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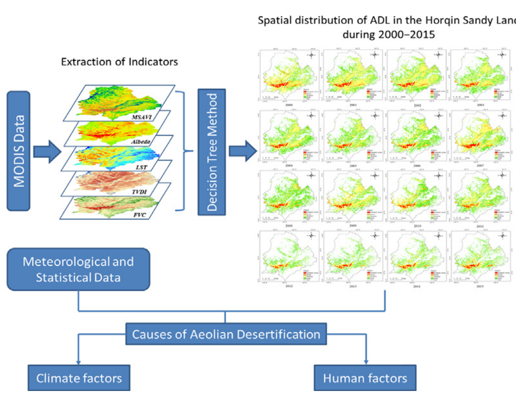
HIGHLIGHTS

- Auto-extraction method of aeolian desertified land based on multiple indicators.
- The time series dataset of aeolian desertified land was extracted from 2000 to 2015.
- Aeolian desertified land decreased significantly at a rate of 2388.60 $km^2\ y^{-1}$.
- Climate and human factors both responsible for aeolian desertification reversal.

GRAPHICAL ABSTRACT



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ABSTRACT

Aeolian desertification has become one of the most serious environmental and socioeconomic problems facing the world today. Quantitative remote sensing technology is an important means to achieve the development trends of aeolian desertified land (ADL). To compensate for the shortcomings in the time scale of Landsat Thematic Mapper and other high-spatial-resolution remote sensing data, this study introduces Moderate Resolution Imaging Spectroradiometer time series data and products to invert the monitoring indicators of ADL. The QUEST (quick, unbiased, and efficient statistical tree) classification method was used to establish the extraction model of ADL based on multiple indicators. The ADL time series dataset was extracted from 2000 to 2015, and the characteristics of ADL and its spatial-temporal dynamics were analyzed. These results were combined with meteorological data and socioeconomic statistics to discuss the main factors influencing ADL. The results showed that, by the end of 2015, the total area of ADL was 32,633 km^2, accounting for 26.02% of the study area. The slight, moderate, severe, and extremely severe ADL accounted for 51.39%, 34.11%, 10.31%, and 4.20%, respectively. The total area of ADL decreased significantly at a rate of 2388.60 $km^2\ y^{-1}$ from 2000 to 2015. The decreasing area was dominated by the slight and moderate ADL. The reversal of ADL exhibited significant correlations with an increase of annual precipitation and a decrease of annual maximum wind velocity ($p < 0.01$). The impact of annual maximum wind velocity on ADL is more important than annual precipitation. Increases in population density and the number of livestock did not promote the development of ADL. A series of ecological protection projects and policies created advantageous conditions for the reversal of ADL. This research provides a new method for monitoring ADL and useful information for controlling and managing aeolian desertification in this region.

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1. Introduction

Desertification can be defined as a land degradation process that occurs in arid, semi-arid, and dry subhumid regions as a result of various factors, including climate change and unsustainable human activities (UNCCD, 2004; UNEP, 1994). It is composed of aeolian desertification, water erosion, salinization, and freeze or thawing according to the chemical and physical processes of soil degradation. Aeolian desertification is one of the main types of desertification that occurs in northern China (Wang and Zhu, 2003), which is one of the most serious environmental problems, especially in arid, semi-arid, and dry subhumid zones (Helldén, 2008; Kassas, 1995; UNCED, 1992; Wang et al., 2015). The occurrence and development of aeolian desertification cause serious harms to the environment, natural resources, social economy, and people's lives (Oswald and Harris, 2016; Song et al., 2015; Zhao et al., 2014). The expansion of aeolian desertification has converted land areas from non-desertified land as large as a midsize county each year, and the economic loss directly attributed to aeolian desertification was approximately 54 billion RMB per year in China (Ge et al., 2016; Wang and Zhu, 2001). These losses seriously restricted the regional socioeconomic sustainable development and affected nearly 300 million people in northern China (Li et al., 2007; Wang et al., 2004; Zhu and Wang, 1993). Therefore, the Chinese government has supported many studies in the field of aeolian desertification and conducted a series of projects over the past 40 years. However, after many years of effort, the aeolian desertification situation remains severe with the possibility that restoration gains could be thwarted. This makes it necessary to continue to strengthen comprehensive research on aeolian desertification.

Historically, the Horqin Sandy Land was a lush forest and grassland landscape as well as a traditional grazing area. The ecology of the area was seriously damaged, however, because of the influence of climate factors, such as drought and wind; soil factors, such as a sandy substrate with low organic content; and excessive reclamation, overgrazing, and unsustainable human economic activities. This damage has been especially pronounced over the past century. The sparse forest sandy grassland gradually degenerates into a sandy landscape with frequent sandstorms, scattered sand dunes, and semifixed dunes. This has resulted in this region becoming an agropastoral area (Wu et al., 2003). The Horqin Sandy Land is one of the most ecologically fragile areas in China. It is close to the densely populated and economically developed regions in northeast and North China. Because of its unique geographical location, it affects the economic and social development of the region as well as the environmental quality of the Beijing-Tianjin-Tangshan region. The problem of aeolian desertification in the Horqin Sandy Land has been a widespread concern among the government, public, and academia since the 1950s. For nearly 50 years, scientific researchers have conducted work focused on the cause, process, and comprehensive improvement of aeolian desertification and they have published hundreds of academic papers and monographs (Ge et al., 2016; Li et al., 2017; Wang et al., 2016, 2017). Some fundamental and vital components of understanding, including the time series of aeolian desertification in the Horqin Sandy Land, still have not been fully elucidated.

The combination of remote sensing (RS) technology and geographic information systems (GIS) provides an effective method for monitoring aeolian desertification (Lambin, 2001). At present, most of the published work has focused on the analysis of dynamic changes in aeolian desertification via comparison of RS data in different periods that have a certain time interval. Taking Landsat Multi-spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) images as the data source, a human-computer interactive visual interpretation method was used to extract the information of aeolian desertification. Hu et al. (2015) monitored the spatiotemporal changes of aeolian desertification of the Zoige Basin five times over the course of 35 years (1975, 1990, 2000, 2005 and 2010). Xue et al. (2013) evaluated the evolution and status of aeolian desertification between 1975 and 2010 in the northwestern Shanxi Plateau by using MSS and TM images (acquired in 1975, 1991, 2000, 2006, and 2010). On the other hand, based on the same data source, computer automatic classification method also is used widely to extract and monitor the aeolian desertification. Qi et al. (2012) monitored the temporal and spatial dynamics of desertification by using the supervised classification method from 1986 to 2003 in the agropastoral transitional zone of northern Shaanxi Province, China. Salih et al. (2017) adopted spectral mixture analysis, object-based oriented classification, and change vector analysis methods to describe the status and rate of land degradation and desertification processes by using multi-temporal imagery of TM and ETM+ respectively. Although these methods have high precision, they are difficult to monitor the dynamics of aeolian desertification at a large scale and over long time series because of the large time scale of the process and the influence of artificial factors. With recent improvements in RS satellite technology, the application of low and moderate spatial resolution RS data can meet the requirements necessary to produce a time series of aeolian desertification. For example, the Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), and Systeme Probatoire d'Observation de la Terre (SPOT) can be used widely to monitor the aeolian desertification. Many researchers have begun to employ special indices to extract the information of aeolian desertification (Badreldin et al., 2014; Li et al., 2016). Eckert et al. (2015) detected land degradation and regeneration in Mongolia by using MODIS Normalized Difference Vegetation Index (NDVI) time series and found that NDVI time series trend analysis was suitable for identifying land degradation and regeneration. Feng et al. (2016) developed the Normalized Difference Desertification Index (NDDI) to analyze the spatial-temporal change of aeolian desertification and its possible influencing factors in northern China. Ma et al. (2011) constructed the desertification-monitoring model based on the Albedo-NDVI feature space, which can effectively achieve the automatic identification of desertified land. Related indicators or indices used in these studies can well represent the spatial and temporal changes of land desertification. However, most of these studies used a single indicator or constructed the feature space through the relationship among several indicators to describe the process of aeolian desertification. Because the causes and existing conditions of aeolian desertification are complicated, it is difficult to extract and evaluate the aeolian desertification comprehensively and accurately by using a single indicator, which cannot fully reflect the comprehensive situation of aeolian desertification due to the inherent uncertainty. To fill the gaps produced by utilizing a single spectral fingerprint, some researchers proposed methods suitable for large-scale monitoring of aeolian desertification based on a combination of multiple indices or indicators (Han et al., 2013; Lamchin et al., 2016; Liu et al., 2007; Ma et al., 2007; Mamatsawut et al., 2008). These studies have shown that this method not only can guarantee the monitoring accuracy but also can meet the requirements of time series. The combination of multiple indicators has become the latest development trend for aeolian desertification long-term monitoring and assessment (Jiang and Lin, 2018; Zucca et al., 2012). In addition, the analysis of aeolian desertified land (ADL) time series can reflect changes of ADL in drought or wet years and can also distinguish the impact of human activities and climate change more precisely.

The objective of this research is to use MODIS data and its products as the monitoring indicators to extract the time series data of aeolian desertification. These indicators include Fractional Vegetation Cover (FVC), Modified Soil Adjusted Vegetation Index (MSAVI), Albedo, Land Surface Temperature (LST), and Modified Temperature Vegetation Drought Index (MTVDI). FVC and MSAVI reflect the ecological status of ADL, and the other three indicators reflect the physical properties of ADL. All of these indicators can reflect the characteristics of different types of ADL and also can be obtained by quantitative RS inversion. By constructing a monitoring system of