Landscapes in the Horqin Sandy Land: Patterns and Processes

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Abstract: The Horqin Sandy Land (HSL) falls in the interlocking agricultural and pastoral zones in northern China. The sandy area experiences wind and water erosion and the evolution of lakes and landcover is closely related to changes to the sandy land surface. This study applied geomorphological analysis and mathematical and statistical analyses to multiple sources of remote sensing data to study the characteristics and changes in landforms, lakes, and lan cover patterns in the area. The results showed that the area of sandy land in the HSL has decreased over the last 40 years at an average rate of -0.31%, whereas the areas of fixed and semi-fixed sand dunes, such as scrub dunes and parabolic dunes, are increasing. The area of lakes and the number of patches have decreased, there was increased clustering of lakes, and the changes to the landscape appear to be stabilizing. There was an increase in vegetation growth, with mean annual average Normalized Difference Vegetation Index (NDVI) of between 1.42–2.06. There was an obvious increase in NDVI, mainly in the southeastern part of the study area. The study provides a basis for the sustainable development of the ecological environment in the HSL.

1 INTRODUCTION

Landscape evolution is an important field in geography and ecology and refers to changes in the structure and function of land surface processes at various spatial and temporal scales driven by natural and human factors (Wu, 2013; Elhag, 2017; Fan et al., 2018). The use of remote sensing data sources and geographic information system (GIS) spatial analysis methods within the study of landscape evolution can reveal the processes and patterns of land surface evolution, which is of importance in regional sustainable development. Many past studies have focused on the dynamic changes in sandy land at different spatial and temporal scales and using different landscape classification systems (Zuo et al., 2009; Li et al., 2008; Wu and Ci, 2001). Among current processes driving the evolution of sandy land, lakes play an important role in maintaining the wind-water balance and wetland landscape ecology (Gao et al., 2020; Zhao and Feng, 2020; Zhu et al., 2010). Consequently, there have been studies in China and abroad on lakes in sandy land areas, mostly focusing on lake area dynamics, hydrological characteristics, and the impact of climate change. For example, a study by Bai et al. on changes to the lake area in the Otindag Sandy Land area over the past 45 years determined that lake shrinkage was mostly concentrated in the sandy hinterland (Bai et al., 2016). Dong et al. explored the underlying mechanism of recharge of the Alashan Desert Lake Group (Dong et al., 2016). Past studies have gained some understanding on the coupling relationship between wind-sand activities and vegetation conditions, including on changes to vegetation cover, the movement of sand grains, wind erosion speed, and wind profile height (El-Wahab et al., 2018; Zhang, 2012). However, there has been relatively less focus on the relationship between the changes in and interactions between these three landscapes (Chen et al., 2006). Past studies on the wind- and sand-driven landscapes in the HSL have mostly focused on the spatial and temporal changes to the sandy area, assessment of the degree of desertification, the evolution of landscape patterns, and drivers of landscape change (Li et al., 2017; Bai et al., 2017; Duan et al., 2012; Duan et al., 2014). Past studies of lakes in sandy areas have mostly focused on the dynamic changes in lake numbers and their influences on climate (Chang et al., 2013; Jia et al., 2014). However, studies on the interactions between sandy areas and vegetation and between sandy areas lake based on long timeseries data remain limited. Therefore, the current study

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conducted long-term remote sensing monitoring of the sandy land and lake group dynamics of the HSL based on multiple sources of satellite data. The aim of the present study was to identify the characteristics of the evolution of sandy land, lake and landcover patterns in this area over the last 40 years to explore the relationships between sandy patterns and lake and vegetation. The results of the present study can provide a scientific basis for the study of regional landscape responses in the context of global environmental change.

2 OVERVIEW OF THE STUDY AREA AND RESEARCH METHODS

2.1 Overview of the Study Area

The HSL is located at the edge of the monsoon zone and is a typical agro-pastoral area in northern China. The distribution area of HSL is about 42.3 thousand square kilometers and falls between 118°31′–124°18′ E, 42°31′–44°50′N. The climate of the region is characterized by a transition from the warm temperate zone to the temperate zone and semi-humid zone to semi-arid zone. The frost-free period of the area is 140–160 d, the annual average temperature is 5.2–6.4 °C, annual precipitation is 343–500 mm, annual sunshine hours are 2 900–3 100 h. The zonal soil is mainly dark brown loam, chestnut calcium soil, and black kiln soil, whereas the non-zonal soil is mainly sandy soil, meadow soil, and saline-alkaline soil. The zonal vegetation transitions from typical grassland to forest grassland. The HSL contains sand dunes, inter-dune depressions, and swamp bubbles. Several sand monopolies and inter-monopoly depressions occur from the rear banner of the left wing of the HSL to the Changling. The inter-monopoly depressions are distributed with ancient riverbeds, lakes or deans running from east to west.

2.2 Data Source and Pre-processing

The multispectral remote sensing data used in the present study included Landsat Multi-Spectral Scanner (MSS) multispectral images (spatial resolution of 80 m) for 1980, Landsat Thematic Mapper (TM) multispectral images (spatial resolution of 30 m) for 1990, 2000, 2010, and 2020, Landsat Operational Land Imager (OLI) multispectral images (spatial resolution of 30 m). The topographic map and coordinates of typical features measured by a real-time kinematic global positioning system were used as control points to geometrically finetune the data for each synthesis band, and the error was minimized to within one pixel. Histogram matching and stitching were performed on the contemporaneous data, following which the images were cropped according to the boundary of the study area. The wind-driven sandy land types were divided into nine categories: (1) wind erosion pits; (2) scrub dunes; (3) gently undulating dunes; (4) beam-well dunes; (5) parabolic dunes; (6) flat dunes; (7) sand monopolies; (8) crescent-shaped dunes and; (9) dune chains. Lakes were divided into several categories, including natural lakes, artificial reservoirs, and ponds.

2.3 Research Methodology

2.3.1 Interpretation of Remote Sensing Image Data

Manual visual interpretation for object-oriented segmentation was used to improve the accuracy of classification. GPS-guided field observation was conducted to interpret areas not yet defined, and the interpretation was verified using the random point method with an accuracy of 91.02%.

2.3.2 Maximum Value Synthesis Method

The Maximum Value Composites (MVC) were used to obtain the maximum monthly NDVI for the analysis of regional vegetation cover and spatiotemporal characteristics of NDVI variation. The vegetation index reflects a certain period of time within the remote sensing data under an optimal state for interpretation, which can effectively reduce errors resulting from aerosols, cloud shadows, and perspective, thereby improving the precision of the vegetation index.

2.3.3 Mean Value Method

The present study adopted the mean value method (MVM) to statistically analyze the mean value of NDVI in the study area. The MVM is an index reflecting the central trend of a dataset and is used to calculate the mean NDVI of vegetation in the study area over a certain period. The MVM can reduce disturbance from outliers resulting from the angle of solar altitude and extreme climate conditions, thereby improving the accuracy of the vegetation index.

3 RESULTS AND ANALYSIS

3.1 Evolution of Sandy Land in the HSL

The wind-driven sandy land in the HSL is mainly distributed on the alluvial plains along the dry tributary streams of the Xiliao River. The sand dune types of the Horqin Sand Area tend to become simpler from west to east and from south to north. The area of wind-driven sandy land has been decreasing continuously over the last 40 years, with a net decrease in the sand area of 5,194.33 km^2 and an annual rate of change of −0.31%. There were general increases in the areas of crescent-shaped dunes and dune chains from 1980 to 2020, with a net increase in area of 165.51 km^2. There was an average annual growth rate in the areas of crescent-shaped dunes and dune chains of 1.47% from 1980 to 2000, followed by a declining trend from 2000 to 2020 with an average annual rate of change of −1.17%. The area of scrub dunes showing fluctuating increases, with a total increase in area of 331.53 km^2, with most of the increases occurring over the last 10 years at a growth rate of 0.37%. The area of beam nest dunes continued to decrease, with a net decrease of 5,194.43 km^2. The area of flat sandy land fluctuated, although there was a rapid decreasing trend in the area of flat sandy land over the last 10 years. The area of parabolic dunes showed a fluctuating increasing trend. The areas of gently undulating sandy land and sandy monopoly land both showed fluctuating decreasing trends, with net decreases of 6.35% and 11.28%, respectively. The area of wind erosion pits did not change significantly. In general, the area of the wind-driven sandy land of HSL decreased over the last 40 years, while the area of fixed and semi-fixed dunes such as scrub dune land and parabolic dunes increased, indicating that the mobility of the Horqin Sand Area weakened and showed a trend of moving from desertification to oasis.

3.2 Evolution of the Lake

The overall area of lake Complex showed a decreasing trend over the last 40 years. The area increased by 239.87 km^2 from 1980 to 1990, with an annual rate of change of 3.91%. The area began to decrease from 1990, decreasing by 6.78 km^2 by 2000. The area decreased by 247.99 km^2 from 2000 to 2010, with an annual rate of change of −3.8%. The decreasing trend in the lakes complex gradually stabilized from 2010 to 2020, with an annual rate of change of −2.90%. The number of patches of lake groups showed a continuous increasing trend from 1980 to 2000, with a total increase of 314. The increasing trend was most significant from 1980 to 1990, with an annual rate of change of 6.62% and reaching a maximum value of 623 in 2000. However, the change in number of patches of lake groups was not synchronized with the change in lake area, indicating increased fragmentation of the lake during this period. The change in the number of lakes from 2000 to 2020 was consistent with the change in area, showing a rapid decline with an annual rate of change of −4.60%.

3.3 Evolution of the Vegetation Landscape

The overall NDVI trend in the HSL during the growing season from 1982 to 2020 was one of fluctuating increase, with an increase in area of 23.05% and an average annual growth rate of 0.59% (Figure 1). NDVI showed a fluctuating increasing trend from 1982 to 1992, with an increase of 16.43% and an average annual rate of increase of 1.64%. NDVI showed a fluctuating decreasing trend from 1992 to 2007, with a decrease of 17.46% and an average annual rate of decrease of 1.16%. A significant increasing trend in NDVI was evident from 2007 to 2020, with an increase of 28.31% and an average annual rate of increase of 2.18%. NDVI reached a maximum in 2017 of 2.0639.

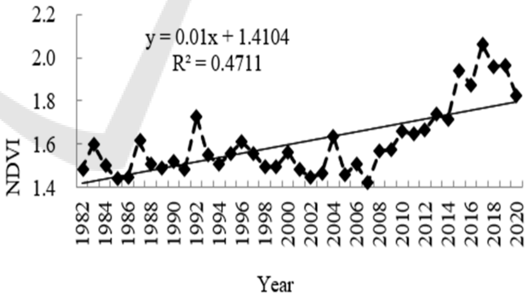

Figure 1: Interannual trends of NDVI in HSL.

The NDVI during the vegetation growing season decreased from east to west, with an annual average exceeding 0.25 in most areas over the last 39 years and good vegetation conditions. The annual average NDVI in the southwestern part of the sandy area ranged from 0.15 to 0.25, and vegetation conditions were slightly worse. The multi-year mean NDVIs for Shuangliao City, Kangping County, and southeastern Horqin Left Wing Back Banner were high, ranging from 0.35 to 0.49, whereas the multi-year mean NDVI for Wengniut Banner and western

Naiman Banner were relatively low, ranging from 0.15 to 0.26.

4 DISCUSSION

The changes to HSL over the last 40 years were characterized by a decrease in the total area of the wind-driven sandy landscape and an increase in fixed and semi-fixed sand dunes, such as scrub dunes. These changes are consistent with a transition from desert toward oasis and are supported by the findings of Yue et al. (Yue et al., 2017). Lake complexes in sandy areas are important components of desert ecosystems and play an important role in maintaining ecological stability and development (Ma et al., 2016). However, lake complexes themselves have poor stability, and the areas and numbers of lake complexes vary greatly on interannual and seasonal scales due to the influences of climate and human activities (Duan et al., 2012).

The HSL is in a dynamic equilibrium, which maintains its developmental stability under the interactions of wind and water erosion. Moisture is the most dominant factor governing plant growth and survival. Improved moisture conditions and lush vegetation growth around the lake complex have an important influence on the structure of the regional sand flow field and wind-driven sand transport, which in turn determines the evolution of the sandy landscape within a certain buffer zone around the lake complex (Smith et al., 2017; Bai et al., 2016). However, such areas are also mostly surrounded by lakes and fields, resulting in the transformation from natural to artificial landscapes and in the shrinkage of the lake area. In addition, the construction of reservoirs in the upper reaches of rivers, inevitably affect downstream runoff and change the water and sand conditions of rivers. A reduction in river flow can result in the river running dry and the exposure of rocks on the riverbed. These rocks can act as sources of sand for the development of riverbank dunes (Liu and Coulthard; 2015). A decrease in surface water results in a decrease in the water table. The water table in lumps and sand swamps will also decrease, resulting in decreases in moisture-loving plants, the establishment of drought-tolerant plants, the death of trees, lower vegetation cover, dune activation, and the continued expansion of desertification (Telfer et al., 2017). The processes driving the evolution of both landforms and landscape patterns can be represented by spatial attribute information.

The overall trend of a fluctuating increase in NDVI in the HSL during the vegetation growing season is consistent with the results of studies on NDVI trends at different scales, such as in eastern China (Liu et al., 2015; Han, 2007). In particular, NDVI showed significant increasing and decreasing trends before and after 1992, respectively, generally consistent with the findings of Piao et al. for the Eurasian region (Piao et al., 2003). The vegetation cover of the HSL showed an general increasing trend up until 2000, after which the influences of the national policies for returning farmland to forests and grasses, natural forest protection, and sand control projects, accelerated the process of a transition from desertification to oasis.

5 CONCLUSIONS

The wind-driven sandy land area of the HSL has experienced a decrease over the last 40 years, with a net decrease of 5,194.33 km^2 and an annual rate of change of 0.31%. The wind-driven sandy land area decreased, the area of fixed and semi-fixed dunes such as scrub dunes and parabolic dunes increased, and the mobility of the sands decreased.

The area and number of lakes in the HSL showed fluctuating and decreasing trends, decreasing by 60.05 km^2 and 68 individual lakes respectively. The lake showed an overall stabilizing evolution. However, the lake remains in a dynamic evolutionary process and plays an important role in the spatial and temporal evolution of the land surface of the HSL.

The vegetation growth in the HSL showed an overall increasing trend from 1982 to 2020 and the multi-year mean NDVI values fluctuated between 1.4235–2.0639. There were obvious phases of change, among which vegetation cover increased significantly from 1985 to 1992 and from 2007 to 2019, with annual growth rates of 4.06% and 4.53%, respectively. Although the area in which there were increases in NDVI was large, the increase in NDVI was small and spatially variable, with areas of high and low NDVI mainly distributed in the southeast and northwest, respectively.

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