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Albedo indicating land degradation around the Badain Jaran Desert for better land resources utilization

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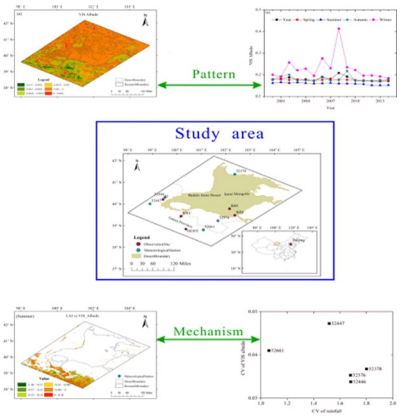
HIGHLIGHTS

- Distinct spatial pattern was found between hinterland and ecozone of desert.
- Increased LAI controlled the variation pattern of albedo at vegetation region.
- Increased precipitation contributed to the stability of natural system.
- Decreased albedo indicated the amelioration of desert environment from 2000 to 2014.

GRAPHICAL ABSTRACT



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ABSTRACT

Surface albedo is an easy access parameter in reflecting the status of both human disturbed soil and indirectly influenced area, whose characteristic is an important indicator in sustainable development under the background of global climate change. In this study, we employed meteorological data, MODIS 8-day BRDF/Albedo and LAI products from 2000 to 2014 to show the amelioration and mechanism around the Badain Jaran Desert. Results showed that the human-dominated afforestation activities significantly increased the leaf area index (LAI) in summer and autumn. Lower reflectance at visible band was sensed inside the desert compared with the ecozone and the lowest albedo at forested area. The contribution of soil and vegetation reflectance to surface albedo determined the linear sensitivity of albedo to LAI variation. Decreased albedo dominated the spatial-temporal pattern of the Badain Jaran Desert. This study suggested that surface albedo can be regarded as a useful index in indicating the change process and evaluating the sustainable development of biological management around the Badain Jaran Desert.

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1. Introduction

Land degradation refers to any form of deterioration of the land that affects the integrity of the ecosystem and causing the unsustainable utilization of land. In arid and semiarid area, unsustainable development mode usually related with such vegetation destructions as deforestation, over-grazing (Eckert et al., 2015; Li et al., 2016), which causing salinization and desertification severe environmental problems in North-Central China. Six major afforestation programs have been implemented to control the deterioration of environment. But the overemphasis on tree and shrub planting has result in complex ecological consequences, which likely to compromising the ability to achieve environmental policy goals (Cao et al., 2011). For example, unsuitable afforestation had caused severe water shortage (Wang et al., 2012) and accumulation of surface saline (Du et al., 2014; Custodio et al., 2016) through upward movement of soil water at environmentally fragile areas. These consequences worse the rhizosphere conditions not only at artificial forest ecosystem by enhanced salt stress but also at natural ecosystem through water flow out. The overall assessments on the land degradation process and the effects of human afforestation on regional sustainable development are the key to guiding human activity. Kosmas et al. (2014) suggested rain seasonality, slope gradient, plant cover, rate of land abandonment, land-use intensity, and the level of policy implementation from 70 candidate indicators as the most important indicators identified as affecting desertification risk. These factors are very useful in the oasis and the ecozone between oasis and desert, but have less reference value in the central area of desert where indirectly influenced by human activities.

The biophysical processes affected by human-induced impacts upon the land are the focus in ecological climatology. As the most important biophysical parameter, the surface albedo increasingly draws the scientific attention since its emergence in the study of albedo and desert synergy (Charney, 1975). Since surface albedo has close tie with surface characteristic, any change in desert can be reflected by albedo variation. Soil moisture and salty crust had been found statistical relationships with surface reflectance (Fujimaki et al., 2003; Zhang and Huang, 2004; Chudnovsky and Ben-Dor, 2008). The higher albedo caused by soil exposure becomes an important index in the detecting of desertification. A Decision Tree method proposed at Hogno Khaan protected area in Mongolia showed the trends of desertification based on the strong correlations between topsoil grain size index and albedo, the less representation of NDVI was also revealed (Lamchin et al., 2016). Another important trait of land degradation is the simplification of vegetation canopy structure, which is benefit for the increase of albedo (Kuusinen et al., 2016). And the easy availability makes albedo a perfect parameter in revealing the variation and whole situation of desert (Jackson et al., 1975; Lamchin et al., 2016).

The Badain Jaran Desert is the second largest dunefield in China (Dong et al., 2004; Zhu, 2011). Influenced by climate drought, wind and human activity, the desertification area is spreading by 15–20 m year^{-1} toward to Tengger Desert direction (Fan et al., 2016). The rapid expansion had promoted the implementation of biological projects, which planting vegetation in the ecotone between oasis and desert to stop the desertification (Ao, 2010). These measures have greatly improved the comfort ability of local environment in short term. But the giant water demand of tree should be considered for long term ecological consequence, especially the indirect influence on the ecosystems in the ecozone and central area of desert. So the overall evaluation of the change process of the Badain Jaran Desert is the key step in guiding the reasonable match of desert resource as land, water, plant, salt and so on. This paper analyzed the spatial-temporal characteristics and mechanism of surface albedo variance using Moderate Resolution Imaging Spectroradiometer (MODIS) from 2000 to 2014. The connections to leaf area index (LAI) and precipitation were also analyzed to explore the change mechanism of albedo. The whole changing situation in the Badain Jaran Desert was revealed by surface albedo to guide human afforestation activity for sustainable utilization of resource.

2. Materials and methods

2.1. Study area

The study area is located around the Badain Jaran Desert, where at the border of Gansu province and Inner Mongolia, Northwest China (Fig. 1). The Badain Jaran Desert belongs to the continental climate in the temperate zone, with windy and dry winter and spring, and warm and comparatively rain-rich summer followed by a short and cool autumn. The annual mean air temperature is 7–8 °C. The annual mean precipitation is 40–120 mm, with 120 mm in the southeast and <40 mm in the northwest. The Badain Jaran Desert is one of the main sand sources of sandstorm and Yellow River sediment. The Chinese government has put great effort in biological measures to overcome the ecological problems. One afforestation program, planning >900 km^2 forest area between the Badain Jaran Desert and Tengger Desert, was implemented since 2010 (Ao, 2010). The Grain for Green Project, executed from 1999 to 2010 and restarted since 2014 (Cao et al., 2011), has greatly increased the vegetation coverage on the land surface. The significant change trait at the heartland of desert was the diminishing trend of lake area, and the change of underground water supply source is thought to be the main influence factor (Zhang et al., 2012, 2013).

2.2. Data and analysis

We employed version 005 (v005) MCD43A1 8-day BRDF/Albedo and MCD15A2 8-day LAI/FPAR products with a 500 by 500 m spatial resolution to analyze the spatial-temporal characteristics and driving factors of surface albedo (NASA LP DAAC, 2015a, 2015b). The black-sky dataset for the time periods spanning 2000 to 2014 was selected to represent the surface reflectance at VISible (VIS albedo: 0.3–0.7 μm), Near-InfraRed (NIR albedo: 0.7–5.0 μm), and SHOrtwave (SHO albedo: 0.3–5.0 μm) spectral bands. The MCD43A1 product agreed well with ground-based albedo measurements and finer spatial resolution airborne data, the root mean square errors are <0.03 during the periods of vegetation dormancy and snow cover (Wang et al., 2014).

Around the Badain Jaran Desert, 5 meteorological stations, including Guaizi Lake (ID: 52378) and Alxa left Banner (52576) in Inner Mongolia, Dingxin (52446), Jinta (52447), and Shandan (52661) in Gansu province, were selected to study trend and its relationships with albedo (Fig. 1). These 5 stations have different distances to the desert, Guaizi Lake is the nearest station to the desert, Jinta and Shandan stations are far away from the desert, and the distances of Alxa left Banner and Dingxin to the desert are in middle. These 5 meteorological stations showed that the precipitation was increased by 3.45, 1.83, 2.48, 1.38, 1.85 mm/year for Guaizi Lake, Alxa left Banner, Dingxin, Jinta, and Shandan station, respectively, which is benefit to the growth of xerophilous plant. Because of the discontinuity of selected stations in the space and differences of precipitation between stations, the coefficient of variation (CV) was calculated as the ratio of the standard deviation to the mean in order to dig into the internal logic between albedo and precipitation.

The remote sensing data (e.g. albedo, LAI) was resampled to spatial resolution of 0.01° * 0.01° using the Python code of Arcpy Resample_management. The Pearson's correlation and paired *t*-test analysis were proceeding by R code at where the pixels with <3 missing data. The significant and very significant level represents the *p* value in regression analysis <0.05 and 0.01, respectively. The pictures were generated in ArcGIS and OriginPro 8 software.

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