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Original Articles

Relating historical vegetation cover to aridity patterns in the greater desert region of northern China: Implications to planned and existing restoration projects

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A R T I C L E I N F O

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A B S T R A C T

Desert regions of northern China have often been reported with climate change signals. Thus, assessments of dryness in space and time have become critical for the development of climate change. Earlier studies have identified long-term patterns of dryness in northern China, but they have usually been of limited value to land-management planning as they ignored local-to-regional-scale climate features. To identify cause-and-effect relationship between aridity and vegetation cover, changes in aridity and vegetation cover were tracked with the assistance of a chronological series of surfaces based on the mapping of aridity and normalized difference vegetation index (NDVI) and convergent cross mapping. By tracking regional-scale variation in precipitation, air temperature, aridity from 1961 to 2013 (53 years), and vegetation cover dynamics from 1982 to 2013 (32 years), we show that precipitation increased in approximately 70% of the greater desert region, including in the Ulanbuh, Tengger, Badain Jaran, Qaidam, Kumtag, Gurbantunggut, and Taklimakan Deserts. This increase was statistically strongest for the Gurbantunggut and Taklimakan Deserts. Our results indicate that air temperature rose in nearly all deserts in northern China at about 2.5 times greater than the global rate. NDVI largely increased in oases of the western desert region and the Mu Us Desert over the 1982–2013. For the most parts, aridity had a moderate control on NDVI, with no indication of vegetation feedback at an 8-km resolution. The wetting trend observed in the western desert regions (increasing aridity index, i.e., AI) coincided with an increase in NDVI; most regional increases in NDVI ranged between 0 and $0.0005\,yr^{-1}$. In contrast, continued drying in the eastern desert regions (decreasing AI) was mostly associated with a decline in NDVI $< 0.0005\,yr^{-1}$. Knowledge regarding drying and wetting trends regionally is critical for the proper planning and management of land resources. In order to avoid the excessive re-vegetation, pattern changes in drying/wetting should be taken into account in balancing re-vegetation projects with the domestic needs for water in vulnerable desert environments.

1. Introduction

In recent decades, many studies have demonstrated the fact of climate change (IPCC, 2013) and its impacts on water resources (e.g., Raghavan et al., 2012; Deng et al., 2015; Pumo et al., 2016), ecological environment (e.g., Chen et al., 2013; Yang et al., 2015), human settlement (e.g., Dumenu and Obeng, 2016), and human health (e.g., Moore et al., 2008; Abaya et al., 2011; Wu et al., 2016). Continued global climate change may have a profound impact by accelerating hydrological processes and by increasing the unpredictability of related eco–hydrometeorological variables (Gan, 2000; Ma et al., 2004; Jentsch and Beierkuhnlein, 2008), possibly leading to a re-definition of desert-dryness patterns globally.

Desert regions of northern (N) China cover nearly one-fifth of the country's land base. Drylands have been severely affected by changes in climate (Fullen and Mitchell, 1994; Liu and Diamond, 2005; Wang et al., 2013). Extended periods of dryness serve to alter local-to-regional biogeochemical cycles and key ecosystem functions and services and, in the process, enhance regional desertification (Delgado-Baquerizo et al., 2013). Knowledge regarding drying and wetting trends regionally is

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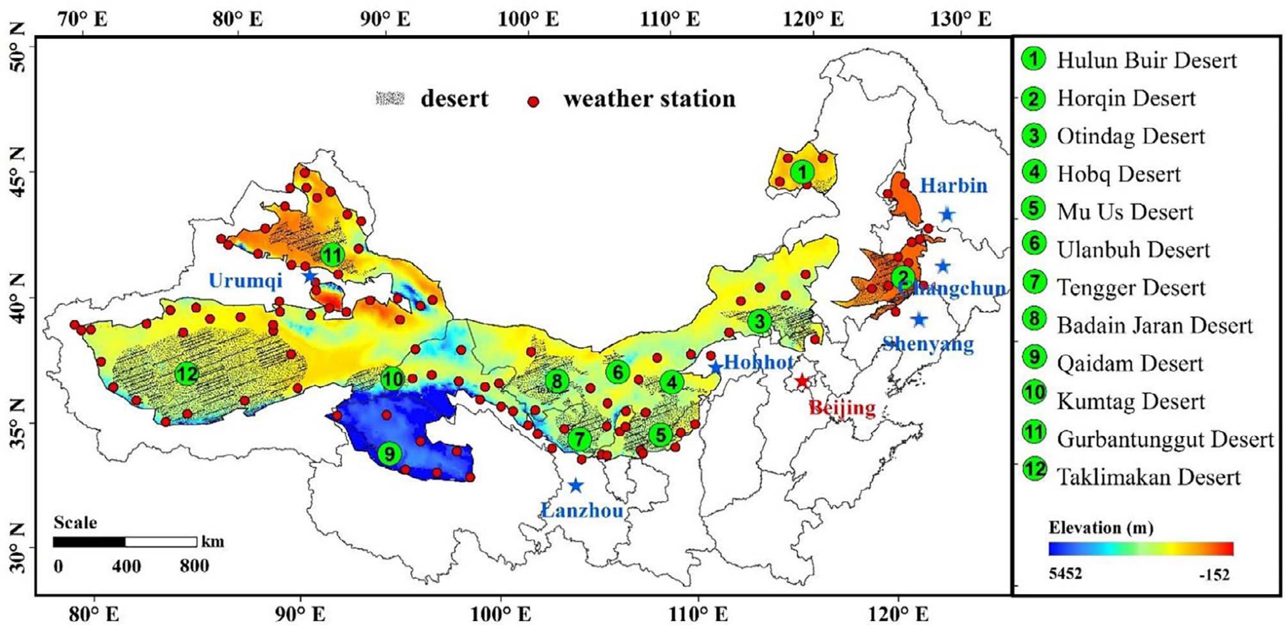

Fig. 1. Distribution of meteorological stations and deserts across N China.

critical for proper planning and management of land and state resources, including their allocation and deployment, to ensure the sustainable development of vulnerable desert environments.

Previous studies have indicated that increasing precipitation and subsequent wetting in northwest (NW) China during the past 50 years represents a major climate signal anticipated to persists into the future (Wang et al., 2007; Xu et al., 2010; Huo et al., 2013; Li et al., 2013a,b, 2016). Some drylands in northern (N) China have been reported to have undergone some expansion in the last 50 years with their boundaries extending eastward to NE China by about 2° of longitude and southward to the middle-to-lower reaches of the Yellow River by about 1° of latitude (Li et al., 2015). This expansion has led to water scarcity and land degradation in many parts of the affected region. Differences in wetting and drying patterns across China are clearly not uniform, potentially placing many existing and planned re-vegetation projects in N China at risk of failure.

Earlier studies addressing the variation and long-term patterns of aridity in China are generally unsuitable for ecological-restoration-project planning because of their coarse spatiotemporal resolutions. Precipitation, air temperature, and aridity patterns over large areas vary in both space and time as a result of differences in climatic regimes induced by differences in geographic placement, synoptic-scale weather patterns, topography, prevailing wind directions, proximity to sources of moisture, and other controlling features. Under the background of climate change, it is largely undetermined if spatial variation in related eco–hydrometeorological variables for ecological-restoration-project development in N China, particularly at sub-regional scales (e.g., < 10-km resolution), has changed over the past 50 years.

To investigate this problem, we analysed the changes in precipitation, air temperature, aridity, and vegetation dynamics in the deserts of N China. Changes in vegetation cover and aridity (assessed by means of the aridity index, i.e., AI) are tracked with the assistance of a chronological series of surfaces based on the mapping of normalized difference vegetation index (NDVI) and AI. The analysis is based on meteorological and NDVI data from 1961 to 2013 and 1982 to 2013, respectively. The objectives of the study were to (1) understand the role of regional change in climate in effecting vegetation cover dynamics in the greater desert regions of N China, and (2) relate their probable impact on existing and planned ecological-restoration projects. Our specific aims were to (1) quantify trends in spatiotemporal variation in precipitation and air temperature and reveal pattern changes in surface aridity, and (2) track spatiotemporal changes in vegetation dynamics vis-à-vis plant vigor (greenness) and plant-cover expansion and contraction in corroborating our assessments of climate-change impacts in N China.

2. Materials and methods

2.1. Study regions

Desert regions of N China (75°–125°E longitude, 35°–50°N latitude) cover approximately 1.72×10^6 km^2 (State Forestry Administration, 2015a), accounting for about 17.9% of the total land area of China. The land area forms a discontinuous arc-shaped desert belt from the western Tarim Basin to western Songnen Plain. It traverses the NW-, N-, and northeast (NE)-regions of China with a length of 4500 km from east to west and a width of 600 km from south to north, including most of Xinjiang, Inner Mongolia, Ningxia, N Gansu, Hebei, Heilongjiang, Jilin, Liaoning, and a part of Qinghai and Shaanxi provinces (Zhu and Liu, 1981; Li et al., 2013a,b, 2014). According to the climate type classification suggested by Hulme (1996) and Middleton and Thomas (1997), these areas are characterized by different climate types, from hyper-arid (AI < 0.05), arid (0.05 ≤ AI < 0.2), to semiarid (0.2 ≤ AI < 0.5). The deserts span two vegetation zones, namely steppes (grasslands) in the east and temperate deserts in the west of the Helan Mountain Range (106° E longitude). Harsh natural conditions (e.g., drought, wind erosion, sparse vegetation, and infertile soils), combined with anthropogenic undertakings (e.g., over-grazing by free-ranging sheep and goats, excess land reclamation, and irrational exploitation of water resources), have resulted in serious land degradation and desertification in many parts of this region. To improve environmental conditions, the Chinese government's "Grain for Green" program (1999-present) was responsible for re-planting vast areas of N China. By the end of 2014, 1.59×10^5 km^2 of N China had been converted into forests and grassland (State Forestry Administration, 2015b).

2.2. Data source and processing

By means of desert (Zhu et al., 1980) and sand-covered desert classification maps of China, at a 1:100,000 scale (http://westdc.