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ORIGINAL ARTICLE

Monitoring and analysis of aeolian desertification dynamics from 1975 to 2010 in the Heihe River Basin, northwestern China

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Abstract The Heihe River Basin is the second largest inland river basin in the arid region of northwestern China, and aeolian desertification is one of the most serious environmental issues it faces. Monitoring and analysis of the dynamics of aeolian desertification in this region could improve the understanding of its status and developmental trajectory, which is important for establishing effective and reasonable countermeasures. Based on a combination of multi-temporal Landsat images and GIS analysis, the temporal and spatial evolutions of aeolian desertification in the Heihe River Basin from 1975 to 2010 were reconstructed using visual interpretation methods. The driving force behind aeolian desertification and its sensitivity to climate change and human activities was clarified based on local meteorological and hydrographic data. The results showed that in 2010, aeolian desertified land covered 10,528.07 km^2 (8.2 %) of the study area and most aeolian desertification was classified as severe or extremely severe. The expansion of the area of aeolian desertified land was gradual from 1975 to 2000, but it then decreased rapidly from 2000 to 2010. Climatic variability showed similar trends to that of aeolian desertification during the study period; however, excessive and uncontrolled water use due to an increase in the cultivated area, agricultural irrigation, and construction of water conservancy facilities was the main cause of aeolian desertification. Political measures are the principal factors behind the alleviation of desertification, and its reversal can be the result of the implementation of integrated water management and comprehensive environmental protection and restoration projects.

Keywords Heihe River · Aeolian desertification · Trend analysis · Remote sensing

Introduction

Desertification is defined as a land degradation process that occurs in arid, semiarid, and dry subhumid regions. It can occur as a result of various factors, including climate change and unsustainable human activities (UNEP 1994; Gad and Abdel-Samie 2000; Wang and Zhu 2003; Huang and Siegert 2006) and has become a very important issue in the eco-environmental and socioeconomic fields (Abubakar 1997; Warren 2002; Verstraete Michel et al. 2009). For example, the United Nations Convention to Combat Desertification (UNCCD) states that throughout the world, more than 250 million people are directly affected by desertification, about one billion people in 110 countries are at risk of being affected by desertification (UNCCD 2008), and that dry land vulnerable to desertification covers 45 % of the Earth's land surface. This has created a situation that causes widespread poverty and population migration (Kenneth et al. 1995; Ali et al. 2002; Portnor and Safriel 2004).

Desertification is one of the most serious environmental and socioeconomic problems in northern China (Wang 2000) and the affected land area exceeds 3.9 × 10^5 km^2, which accounts for 4.1 % of the national land area and

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7.5 % of the global desertified area (Wang et al. 2003, 2004a). In China, desertification can be divided into three classes: water erosion, salinization, and aeolian desertification (Wang and Zhu 2003). Specifically, aeolian desertification is the most common and widely distributed type in northern China (Zhao et al. 2005). This is defined as "land degradation in arid, semiarid, and parts of dry subhumid areas, characterized by former non-desert areas being replaced by desert-like landscape to withstand drift activities, caused by excessive human activities under susceptible ecological conditions" (Zhu and Liu 1984). The land affected by this process is named aeolian desertified land (ADL) and since the middle of the twentieth century, the extent of ADL has increased rapidly (Zhu et al. 1989; Zhu and Wang 1990; Wang et al. 2003, 2004a). The occurrence and development of aeolian desertification causes serious harm to the ecological environment, natural resources, socioeconomic activities, and lives of the people in China's vast desert areas (Fullen and Mitchell 1994; Runnström 2000; Li et al. 2007; Zhang et al. 2012). Many scholars have studied the trend of land desertification in typical desertification areas using remote sensing methods (e.g., Starodubtsev and Truskavetskiy 2011; Hu et al. 2012, 2013; Wang et al. 2013; Duan et al. 2014; Song et al. 2014). In particular, Wang et al. (2011) monitored and assessed the dynamics of aeolian desertification using remote sensing and field surveys, and their results showed a reversal of desertification after 2000; however, desertification remains severe in northern China.

The Heihe River Basin is the second largest inland river basin in the arid region of northwestern China, encompassing a total river length of 821 km. The climate in the middle and lower reaches of the Heihe River Basin is one of extreme drought, and it is one of the major contradictions that the regional water supply has difficulty meeting the needs of the local economic development and ecological balance in this area (Bai et al. 2008; Zhang et al. 2011). Because of the uncontrolled development and use of water, land, and biotic resources, continued population growth and economic development has meant that the shortage of water has become the most important factor driving environmental degradation in the inland Heihe River Basin. The continued growth in demand for water in the upper and middle reaches of the Heihe River Basin has led to both a marked deterioration of the downstream ecosystem and a wide range of environmental problems including dried-up rivers and lakes, degraded grassland, desertification, and dust storms (Wang and Cheng 1998; Gong et al. 2002; Zhong et al. 2002; Shen and Kheoruenromne 2003; Cheng et al. 2006). In addition, aeolian desertification has become a serious environmental problem in this region, which has attracted increasing attention from government and scholars. Ecological construction and environmental protection in the Heihe River Basin are important aspects of development in western regions of China, not just for the environment and socioeconomic development within the catchment, but also with regard to the environmental quality across northwestern and northern China (Cheng 2002; Liu and Gan 2004; Cao et al. 2005). Therefore, the monitoring and assessment of the dynamics of aeolian desertification is very important for sustainable development within the Heihe River Basin.

In the present study, the main objective was to reconstruct the temporal and spatial evolutions of aeolian desertification from 1975 to 2010 in the Heihe River Basin based on a systematic analysis of Landsat MSS, TM, and ETM images. Local meteorological and hydrographic data were analyzed to clarify the driving force behind aeolian desertification and its sensitivity to climate change and human activities. Aeolian desertification was identified through visual interpretation of false-color composite images from five periods (1975, 1990, 2000, 2005, and 2010).

Materials and methods

Study area

The Heihe River Basin is one of three large inland river basins in the Hexi Corridor region of northwestern China (Fig. 1). The river originates in the summit glaciers of the Qilian Mountains, flows northwestward through the Hexi Corridor in Gansu Province, diverges into some ten branches in the Ejina Oasis, and finally enters East Juyan Lake and West Juyan Lake in the Ejina Banner of Inner Mongolia. The basin lies within the geographical coordinates of 37.70–42.75°N, 97.40–102.15°E, covering an area of approximately 128,615 km^2. The climate is characterized as arid because the area is located in the inner Asian–European continent. Geographically, there are three major different geomorphological units. From south to north, these are the southern Qilian Mountains, middle-stream oasis, and northern Alax High Plain. The southern Qilian Mountains, which have elevations varying between 2000 and 5500 m and mean annual precipitation that increases from about 250 mm in the low-mountain or hill zone to about 500 mm in the high-mountain zone, represent the formation area of the water resource that supplies the Heihe River. The middle-stream oasis area is a part of the Hexi Corridor with elevations between 1000 and 2000 m, where the mean annual precipitation decreases from 250 to $<$100 mm from south to north. The middle-stream oasis is the main area of water consumption, primarily because of intense agricultural irrigation. The northern Alax High Plain is mainly covered by Gobi desert with elevations of about 1000 m. Here, the mean annual precipitation is

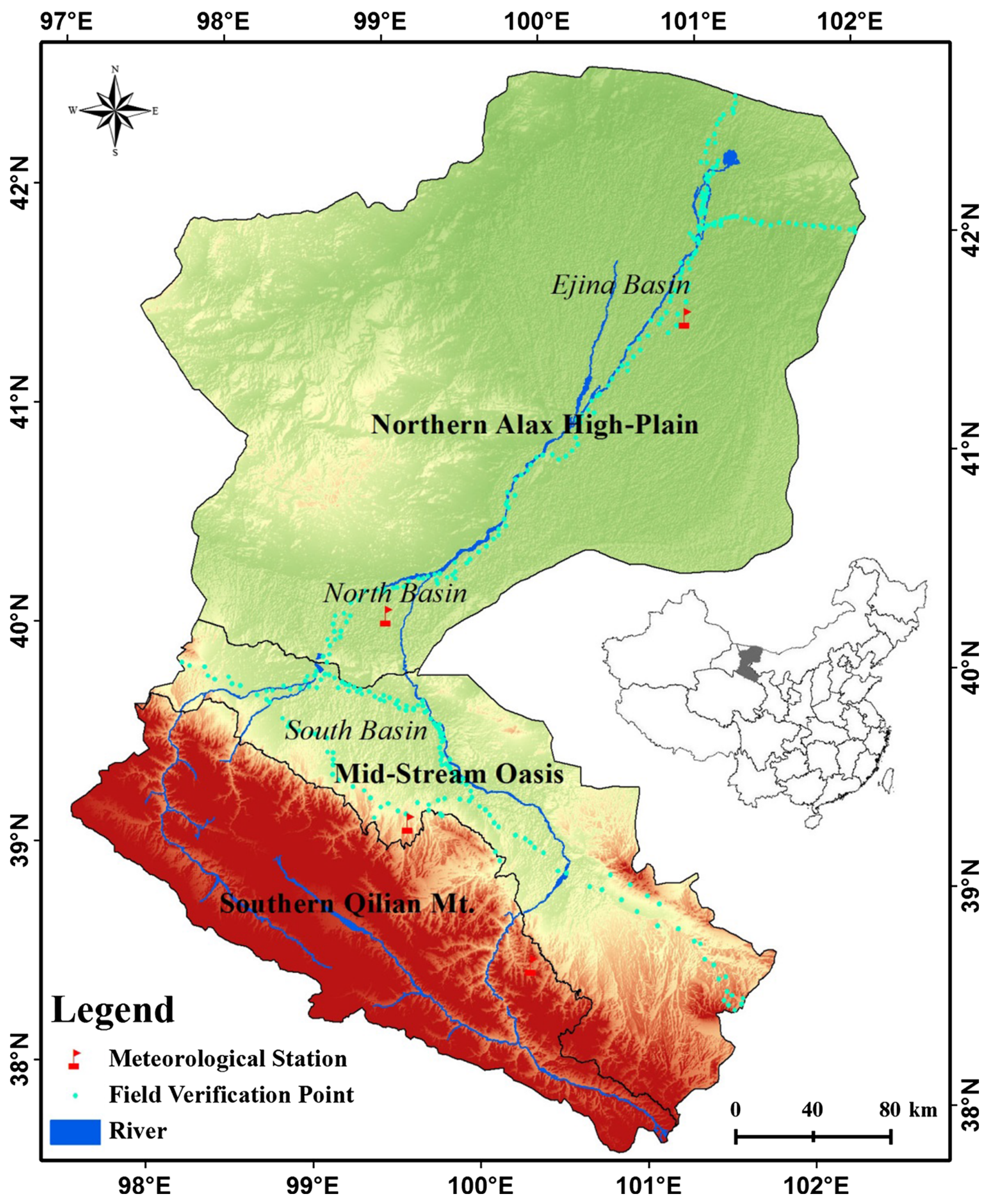


Fig. 1 Location of the study area

<50 mm, but annual potential evaporation is >3000 mm (Li et al. 2001; Ma and Veroustraete 2006). The soil type of the Heihe River Basin includes not only gray-brown desert soil and gray desert soil, but also includes several non-zonal soil, such as anthropogenic-alluvial soil, saline soil, meadow soil, marsh soil, and aeolian soil (Meng et al. 2004).

Data and processing

The Landsat satellite series represents the longest temporal record of space-based land observations (Williams et al. 2006). The remote sensing images used to derive the ADL database for our study comprised Landsat MSS, TM, and ETM images with spatial resolutions of 80 m (MSS) and 30 m (TM and ETM). The data used in 1990, 2005, and 2010 were TM images, and those used in 2000 were ETM images. MSS images were mainly acquired in 1975. All images were obtained from June to September in the respective years, because vegetation typically reaches its maximum extent during the region's growing season. Because of the large area of the study region, it was difficult to acquire cloud-free images that encompassed the entire area within a given year. Therefore, some images from earlier or later years were chosen as replacements for images that could not be obtained in the target years. All images used in this study were obtained from the US Geological Survey (http://glovis.usgs.gov).

Using the Image Analyst function of the Module GIS Environment (MGE) software (Intergraph Corp., Huntsville, Alabama), false-color image was obtained by stacking the near-infrared, red, and green bands. Then, the ETM images, acquired in 2000, were georeferenced and orthorectified using 30–40 ground control points (GCPs) derived from a 1:100,000-scale topographic map developed by the Chinese Mapping Agency in the early 1980s. The mean location error after georectification was less than 1.5 pixels. The 1990 TM images were matched with the 2000 ETM images by means of an image-to-image matching method. During the image-matching process, 40–50 GCPs both in 1990 and in 2000 were selected randomly to cover most of the area represented by the two sets of images. The root mean-square error of the geometrical rectification between the two images was less than one pixel, which is sufficient for multi-temporal comparisons. The same method was used to process the 2005 and 2010 TM images and the 1975 MSS images, and similar results were obtained. In addition, interpretation marks of ADL were developed by establishing the relationship between the features of different degrees of ADL and aeolian desertification type from the remote sensing images using a portable GPS.

An average of 14 Landsat images were used from each year to develop the ADL database on a spatial scale of 1:100,000 by means of visual interpretation and digitization using the freehand drawing tools of the MGE software. In addition to the MSS, TM, and ETM images, ancillary materials such as regional land-use maps, topographic maps, climatic zone data, vegetation maps, and field survey reports were collected to assist in the labeling of the map patches during the interpretation process. After the manual visual interpretation process was completed, the increases or decreases in ADL (i.e., desertification and rehabilitation of land, respectively) from 1975 to 2010 could be obtained by detecting changes in the aeolian desertification degree from the time series database. After the ADL database was corrected and rechecked, the interpretation results were verified by a field survey performed in August 2011, which used 334 field verification points to assess its accuracy. Overall, the accuracy was greater than 95 %, which satisfied the research requirements.

Meteorological data (1970–2010), including precipitation, temperature, and wind velocity, were collected from the China Central Meteorological Bureau for four weather stations taken as representative of the arid climate of the study region: Ejina Banner in Alax League of Inner Mongolia, and Zhangye, Gaotai, and Dinxin in the Hexi Corridor of Gansu Province (Fig. 1). Hydrological data were also acquired from hydrological stations and some estimates made for small brooks with no monitoring stations to calculate the inflow of water resources into the South Basin (including the Corridor Plain and Jiuquan Basin), North Basin (Jinta and Dinxin basins), and Ejina Basin since the 1950s.

Aeolian desertification evaluation system and indicators

The classification system for ADL is an objective reflection of the extent of land degradation in regions where desertification has occurred. In the Heihe River Basin, vegetation condition has been tightly associated with ecological environment quality. Because of uncontrolled development and use of water and land, the destruction of the natural vegetation cover has led to severe wind erosion accompanied by the development or expansion of moving sand dunes and sand sheets. Therefore, patchy vegetation cover and sand sheets are the main landscape characteristics of ADL and provide good visual indicators of environmental changes and the severity of aeolian desertification (Mainguet and Da Silva 1998; Diouf and Lambin 2001; Yan et al. 2007). According to classification criteria proposed in previous studies (Zhu and Liu 1984; Feng 1985; Dong et al. 1995; Wu 2001) and the interpretation of Landsat images, the proportions of the areas covered by shifting sand dunes (sand sheets), wind-eroded areas, and vegetation were selected as the main indices for describing the severity of aeolian desertification. Aeolian desertification intensity was classified into four levels—extremely severe, severe, moderate, and slight—and details of these classification indices are provided in Table 1.

Results and discussion

Status and spatial distribution of aeolian desertified land

Figure 2 shows the spatial distribution of ADL in the Heihe River Basin in 2010. The overall location of the ADL did not change greatly from 1975 to 2010, but the severity of aeolian desertification in subsets of this area did change over time. The areas of ADL were distributed mainly in three regions of the basin: areas adjacent to the middle-stream oasis in the Hexi Corridor, areas around Ejina Oasis and sparse vegetation along the Heihe River in the northern Alax High Plain, and areas of the western edge of the Badain Jaran Desert. Extremely severe and severe desertified land was concentrated and mainly distributed in the Jinta, Gaotai, and Ejina basins. Slight and moderate desertified land was fragmented and mainly distributed in the Jiuquan, Shandan, and Minle areas. The desertified land in the Hexi Corridor jeopardizes the stability and development of these important agricultural areas.

In 2010, the total area of ADL was 10,528.07 km^2, which accounted for 8.2 % of the entire area. The areas of desertified land according to the categories of slight, moderate, severe, and extremely severe were 754.77, 1263.28,

Table 1 Indices used for the classification of aeolian desertified land in the study area

Degradation intensity	Area of mobile sands or of wind erosion (% of area)	Vegetation cover (% of area)	Representative factors
Extremely severe	>50	<10	Mobile sand ridges, dunes, and sand sheets cover the whole area. Blowouts are widely distributed. Only sparse xerophytic herbs grow between dunes
Severe	25–50	10–30	Sand sheets and coppice dunes are common. There are some wind-scoured depressions and residual mounds. There is sparse vegetation
Moderate	5–25	30–60	Semi-anchored dunes cover most of the area and some scattered mobile sand dunes or sand sheets are present around the semi-anchored dunes. Blowouts or sand sheets are sparsely distributed. The vegetation areas contain scattered areas of sand sheets, sand dunes, or blowouts.
Slight	<5	>60	Only small, sparse, scattered patches of mobile sand or blowouts are present; most of the area still resembles the original landscape. The whole area is covered by vegetation, but some areas suffer from degradation resulting from a lack of water or from human activity

3552.03, and 4957.99 km^2, respectively (Table 2), which accounted for 7.2, 12.0, 33.7, and 47.1 % of the total ADL within the study area, respectively. Extremely severe desertified land was the most widely distributed type and the areas of ADL gradually decreased from extremely severe to slight.

Aeolian desertification trends from 1975 to 2010

Analyzing the trends of aeolian desertification can help reveal the mechanisms responsible for its development and the relationship between the driving forces and the resulting changes. During the 25 years from 1975 to 2000, the area of ADL in the Heihe River Basin increased, but then it gradually decreased from 2000 to 2010 (Table 3). The total area of ADL in 1975, 1990, 2000, 2005, and 2010 was 10,660.16, 10,840.76, 11,014.79, 10,632.25, and 10,528.07 km^2, respectively, which accounted for 8.3, 8.4, 8.6, 8.3, and 8.2 % of the total area, respectively. From 1975 to 1990, the area of ADL expanded, representing a linear increase of 12.04 km^2 y^{-1}. The area under severe aeolian desertification increased rapidly, whereas other types showed a decreasing trend during this period.

The area of ADL increased quicker from 1990 to 2000 than from 1975 to 1990, showing a linear increase of 17.40 km^2 y^{-1}. Apart from the slight desertified land, the other classes of ADL increased during this period, i.e., by 1.8 % for extremely severe, 2.9 % for severe, and 4.3 % for moderate. Because of the increase in area of moderate, severe, and extremely severe aeolian desertification, the area of slight desertified land decreased by 14.8 %.

Since 2000, the overall trend of aeolian desertification has been one of rapid decrease. From 2000 to 2005, ADL decreased by 382.54 km^2 with a linear decrease of 76.51 km^2 y^{-1}. However, the area of slight ADL increased by 11.2 %, whereas the areas of moderate and severe ADL decreased by 15.1 and 6.9 %, respectively. Furthermore, extremely severe ADL also expanded slightly during this time, because the severe drought event in northern China in 2000 aggravated desertification in some regions. The decrease in the area of ADL was slower from 2005 to 2010 than from 2000 to 2005, with a linear annual decrement of 20.84 km^2 y^{-1}. Moreover, the severity of aeolian desertification also continued to decrease.

From 1975 to 2010, the total area of ADL decreased by 132.09 km^2 and the severity of aeolian desertification also reduced. The area with moderate aeolian desertification decreased markedly with a decrement of 232.90 km^2, whereas the area of severe and extremely severe desertified land decreased only slightly. Because of the reduction in the severity of aeolian desertification, the area with slight aeolian desertification increased by 126.23 km^2. Overall, the decrease in the area of moderate desertified land has been the principal reason for the reversal of aeolian desertification.

Driving forces behind desertification

Natural factors and human activities can both influence aeolian desertification on the regional scale (Nicholas and Paula 2000; Wang et al. 2004b). In this study, the principal driving forces behind aeolian desertification were divided into three major categories: climate, human activities, and political measures.

Climate

Climate is an important factor driving aeolian desertification through the influence of changes in temperature,

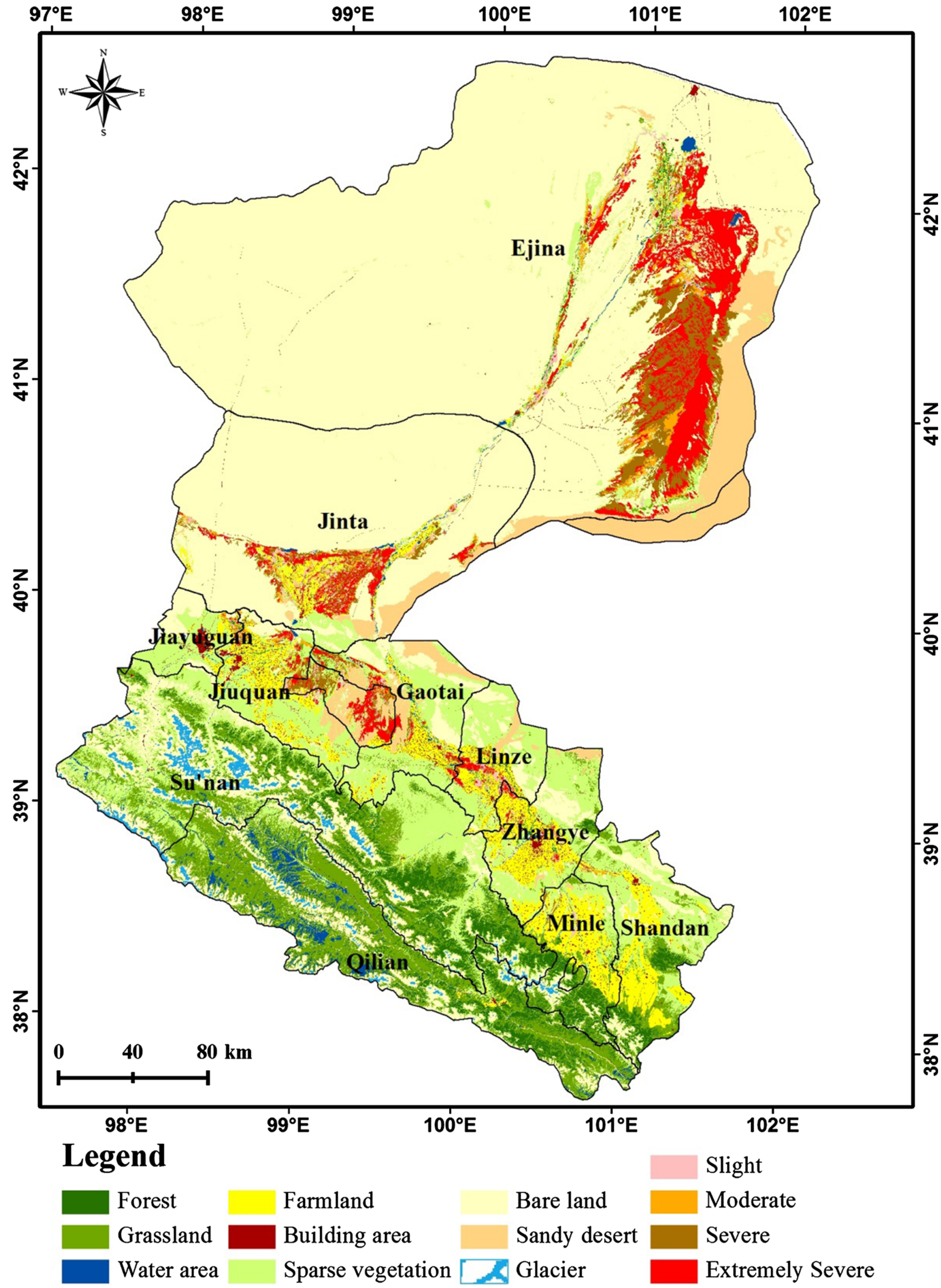


Fig. 2 Spatial distribution of aeolian desertified land in the Heihe River Basin in 2010

precipitation, and wind velocity. In this study, air temperature, precipitation, and wind velocity data, recorded at four meteorological stations, were averaged to analyze changes in the climatic trend of the region during the study period. Over the study period, the mean air temperature in the study area showed a significant increasing trend (Fig. 3a) with a mean of 0.04 °C a^{-1}. Increased air temperature can result in a more arid climate, which would favor the development of aeolian desertification. Precipitation increased slightly during the same period by about 0.16 mm a^{-1} (Fig. 3b). The mean annual increment of temperature (0.04 °C a^{-1}) corresponds to a potential evapotranspiration increase of about 3 mm y^{-1} (Wang et al. 2013). Because the increase in precipitation was lower than the increase in evaporative demand, the climate trended toward enhanced aridity during the study period. Therefore, these simultaneous changes in temperature and precipitation favored aeolian desertification by creating greater stress on vegetation. However, mean annual wind velocity underwent an overall significant decrease with a

Table 2 Desertified land area and ratio of the Heihe River Basin in different decades (km^2, %)

Decade	Slight		Moderate		Severe		Extremely severe		Total
	Area	Ratio (%)	Area	Ratio (%)	Area	Ratio (%)	Area	Ratio (%)	
1975	628.54	5.9	1496.18	14.0	3556.59	33.4	4978.85	46.7	10,660.16
1990	597.23	5.5	1445.95	13.3	3861.54	35.6	4936.03	45.5	10,840.76
2000	508.86	4.6	1508.18	13.7	3973.37	36.1	5024.39	45.6	11,014.79
2005	566.10	5.3	1279.71	12.0	3697.23	34.8	5089.21	47.9	10,632.25
2010	754.77	7.2	1263.28	12.0	3552.03	33.7	4957.99	47.1	10,528.07

Table 3 Trends in desertification from 1975 to 2010 in the Heihe River Basin

Period	Slight		Moderate		Severe		Extremely severe		Total change	Mean annual change
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	km^2 y^{-1}
1975–1990	−31.31	−5.0	−50.23	−3.4	304.95	8.6	−42.82	−0.9	180.60	12.04
1990–2000	−88.37	−14.8	62.23	4.3	111.83	2.9	88.36	1.8	174.03	17.40
2000–2005	57.24	11.3	−228.47	−15.1	−276.14	−6.9	64.82	1.3	−382.54	−76.51
2005–2010	188.67	33.3	−16.43	−1.3	−145.20	−3.9	−131.22	−2.6	−104.18	−20.84

ratio of 0.022 m s^{-1} a^{-1} (Fig. 3c). Because there is a cubic relationship between the wind's erosive capacity and wind velocity, such a decrease could reduce the wind's erosive power. The annual mean wind velocity showed a significant decreasing trend from 1971 to 1995, but then a slight increasing trend after 1995. At the same time, aeolian desertification showed the opposite trend. However, it is difficult to evaluate the impact of wind velocity on aeolian desertification. Furthermore, because of the enhanced irrigation in the middle reaches of the Heihe River Basin, necessary to combat the effects of rising temperature due to global warming, ecological water consumption has reduced, resulting in increased land desertification. Overall, the observed climate change is prone to exacerbate the development of aeolian desertification with a similar trend to that observed in the different aeolian desertification monitoring phases from 1975 to 2010.

Human activities

The area of ADL is distributed mainly along the middle and lower reaches of the Heihe River Basin and in the grass steppes around the deserts. The main factor driving desertification is uncontrolled human activities, including over-reclamation, overgrazing, and excessive use of water resources. The oasis in the middle reaches of the basin is the major grain production base in Gansu Province and even in China. According to previous studies, the cultivated area in the oasis increased rapidly from 1975 to 2010 (the total cultivated area in 1975, 1990, 2000, 2005, and 2010 was 4605.10, 4758.23, 5184.48, 5618.22, and 5794.89 km^2, respectively), which could be attributed to the implementation of the "Grain Production Base Policy" in the 1970s. Because intense irrigation is the principal agricultural water use, the water consumption of the entire basin is concentrated in the middle region. Because of economic development, the ever-increasing demand for water in the middle reaches of the Heihe River Basin has led to a marked deterioration in downstream ecosystems. According to hydrological observations, the surface water resources flowing out of Yingluoxia, which also means the water resources flowing into the South Basin, have remained at the multi-year average, but with a slight increase since the 1980s. Beyond the middle reaches, the surface water resources flowing into the North Basin (Jinta and Dingxin basins) showed a gradual decline, followed by a drastic reduction in the 1990s. This suggests that development and utilization of water resources has increased gradually in the plain area of the Hexi Corridor (Figs. 4, 5). Because of the limitations of natural and social conditions, the North Basin water consumption has been relatively stable with only a slight increase. Affected by the amount of water discharged, the final consumption of the water resources in Ejina Basin has shown a downward trend, which has led to lakes and rivers drying up, aeolian desertification, and ecological degradation. Furthermore, reservoirs, ponds, and other water projects in the Heihe River Basin have adjusted the amount of spatiotemporal

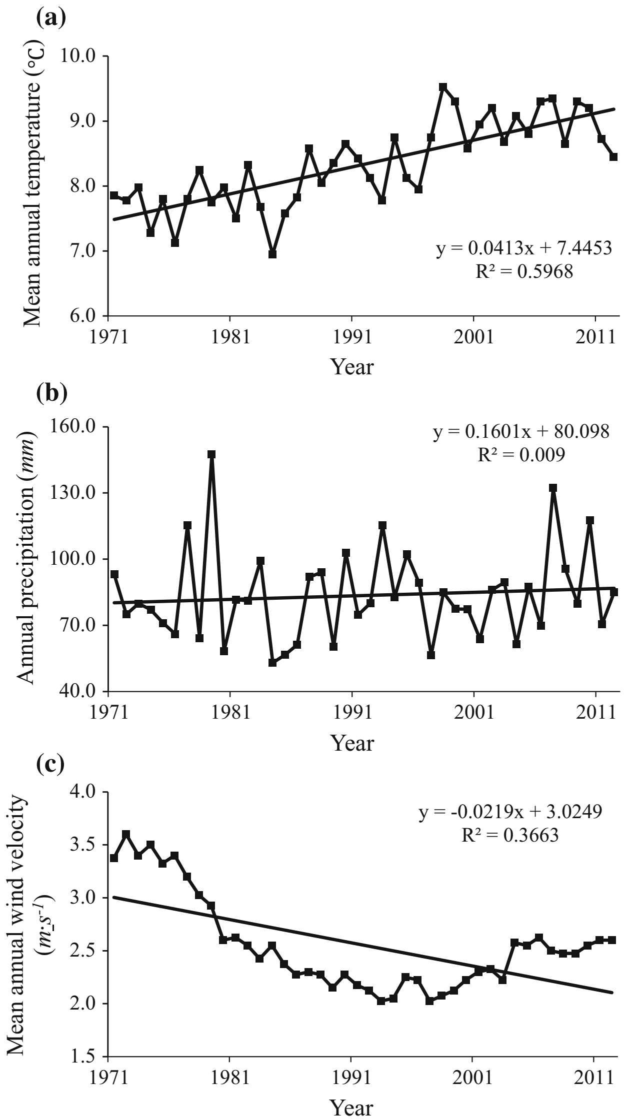


Fig. 3 **a** Mean annual temperature and its trend from 1971 to 2012 in the study area. **b** Annual precipitation and its trend from 1971 to 2012 in the study area. **c** Mean annual wind velocity and its trend from 1971 to 2012 in the study area

water redistribution to solve agricultural drought problems. However, the redistribution of water inevitably leads to the spatiotemporal redistribution of surface runoff under natural conditions. In addition, after the completion of a water-saving irrigation project, the groundwater recharge source was blocked by a waterproof canal. Following the loss of its water supply, vegetation nourished by groundwater gradually disappeared and aeolian desertification expanded in the middle and lower reaches of the Heihe River Basin before 2000.

Rapid population increase is another important factor responsible for aeolian desertification in the Heihe River Basin. According to statistics, the population of the Heihe River Basin was 1340,000 in 2000, which is about three times that of 1950 (Li et al. 2005). Overgrazing is widespread throughout the entire basin and overload rates of up to 163.7 % (Wang et al. 2002; Meng et al. 2005) far exceed the local recommended carrying capacity. Overuse of land, attributed to population growth and increased livestock, has led to the degradation of natural vegetation, which has destroyed the surface layer of the soil that protects against wind erosion, thereby exacerbating and accelerating aeolian desertification.

Political measures

To rehabilitate the deteriorated ecological environment and combat desertification, national and local governments have implemented a series of ecological environmental protection and restoration projects, which include the "Heihe River Water Allocation Plan" and "Grain for Green Project", prohibiting grazing in areas of degraded grassland, closed breeding, and artificial planting of trees and grass. These measures have reversed desertification in some areas from 2000 to 2010.

Conclusions

Aeolian desertification is a major environmental issue in the Heihe River Basin. Monitoring and analyzing the desertification dynamics in this region could improve the understanding of the status and development trajectory of desertification, which is fundamental for regional ecological and environmental rehabilitation. The results of desertification monitoring, based on a combination of multi-temporal Landsat images and GIS analysis, showed that the total area of ADL within the study area in 2010 was 10,528.07 km^2, which accounted for 8.2 % of the entire area. Most of the desertified land was classified as severe or extremely severe. The area of ADL expanded gradually from 1975 to 2000 with a linear increase of 14.2 km^2 y^{-1}, but then decreased rapidly from 2000 to 2010, especially between 2000 and 2005.

Aeolian desertification is affected by both climatic variations and human activities. Although climatic change has shown similar change to the trend of aeolian desertification (evidenced by the increased aridity of the past 35 years), aeolian desertification within the study area still presented a reversed trend after 2000. Furthermore, because of the enhanced irrigation in the middle reaches of the Heihe River Basin, necessary to combat the effects of rising temperature due to global warming, ecological water consumption has reduced, resulting in increased

Fig. 4 Changes of water consumption in the three water cycle zones in the middle and lower reaches of the Heihe River Basin since the 1950s

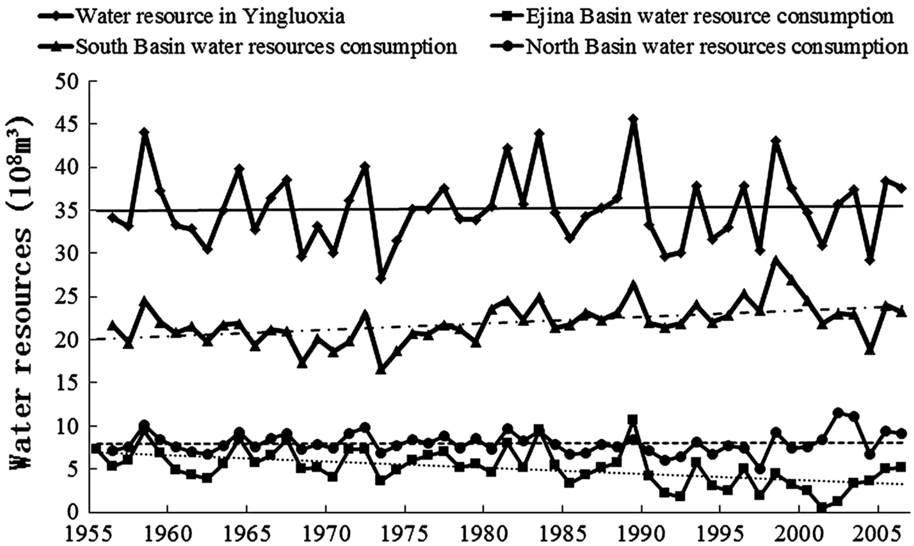
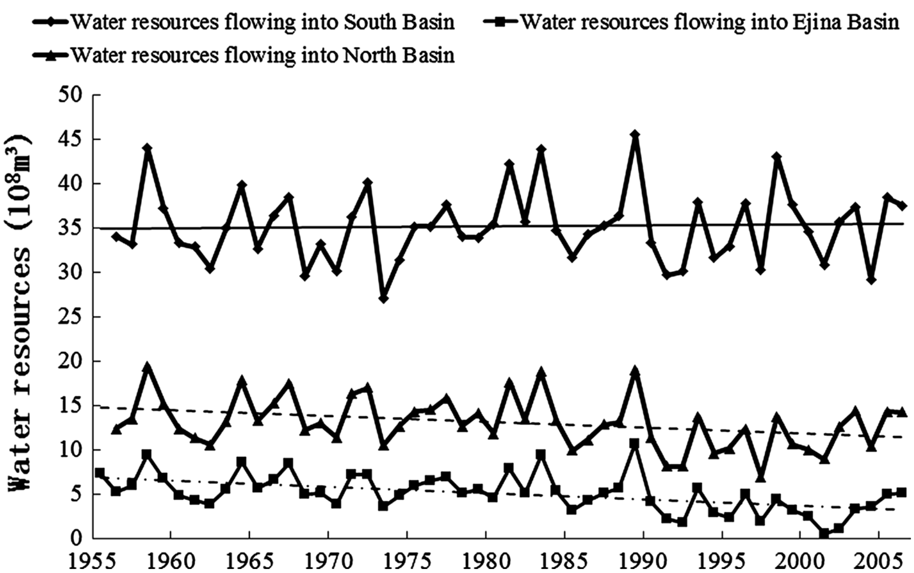


Fig. 5 Changes of water resources in the three water cycle zones in the middle and lower reaches of the Heihe River Basin since the 1950s



land desertification. The variability of climate has had some impact on aeolian desertification, but human activities such as the uncontrolled use of water resources, unsustainable use of land for agriculture, and overgrazing have been the major driving factor behind aeolian desertification. Political measures are the principal reason for the alleviation of aeolian desertification. The reversal of the trend of desertification since 2000 has been the result of the implementation of integrated water management, comprehensive environmental protection, and restoration projects designed to combat desertification. The fight against desertification is a long and difficult process, and desertification remains a threat to the ecological environment and economic development of the Heihe River Basin. Therefore, it is suggested that political measures that mitigate and control the effects of desertification should be implemented for the long term.

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