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ORIGINAL ARTICLE

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Land-use change and its environmental impact in the Heihe River Basin, arid northwestern China

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Abstract Rapid land-use change has taken place in many arid and semi-arid regions of China over the last decade as the result of demand for food for its growing population. The Heihe River Basin, a typical inland river basin of temperate arid zone in northwestern China, was investigated to assess land-use change dynamics by the combined use of satellite remote sensing and geographical information systems (GIS), and to explore the interaction between these changes and the environment. Images were classified into six land-use types: cropland, forestland, grassland, water, urban or built-up land, and barren land. The objectives were to assess and analyze landscape change of land use/cover in Heihe River Basin over 15 years from 1987 to 2002. The results show that (1) grassland and barren land increase greatly by 22.3, and 268.2 km^2, respectively, but water area decreased rapidly by 247.2 km^2 in the upper reaches of Heihe River Basin; (2) cropland and urban or built-up land increased greatly by 174.9, and 64.6 km^2, respectively, but grassland decreased rapidly by 210.3 km^2 in the middle reaches of Heihe River Basin; and (3) barren land increased largely by 397.4 km^2, but grassland degraded seriously and water area decreased obviously by 313.3, and 21.7 km^2, respectively in the lower reaches of Heihe River Basin. These results show that significant changes in land-use occur within the whole basin over the study period and cause severe environmental degradation, such as water environmental changes (including surface water runoff change, decline of groundwater table and degeneration of surface water and groundwater quality), land desertification and salinization, and vegetation degeneracy.

Keywords Land use change · Environmental change · Heihe River Basin · Arid northwestern China

Introduction

Changes in land use and land cover are among the most important human alterations affecting the surface of the earth (Lambin et al. 2001). Land use represents the most substantial human alteration of the Earth system in the past 300 years (Vitousek et al. 1997). Between one-third and one-half of the land surface has been transformed (Vitousek et al. 1997; Ramankutty et al. 2002). Land-use changes in China are being powered by demand for food for its growing population.

The Heihe River Basin is in arid inland of northwestern China. Because of economic expansion and population increases in the whole basin, land-use-related ecological degradation has been very intensive as to constitute a severe threat to regional sustainable development (Qin et al. 2002; Qi and Wang 2003; Luo et al. 2005; Qi and Luo 2005). Many studies have focused on

desertification processes or oasis landscape changes in the Heihe River Basin to understand desertification-related ecological problems (Luo et al. 2005; Lu et al. 2003; Jiao et al. 2003). Land-use change and its environmental impacts in the Heihe River Basin have received little attention, even though land use and land cover changes there are partly studied (Meng et al. 2003).

The aim of this study is to detect changes in land-use and to assess its impacts on the environment in the Heihe River Basin. It attempts to document land cover changes since 1985 using two sets of multispectral thematic mapper (TM) images (1987 and 2002) to detect trends in land-use in the late 1980s and early 2000s. This study is specifically concerned with the analysis of the assessment of related environmental impacts and socioeconomic consequences. Land-use change was the result of physical and anthropogenic factors.

Study area

The Heihe River Basin, in the middle of the Hexi Corridor of Gansu Province, lies in 98°–101° 30′ E and 38°–42° N, and is a typically larger inland river basin in the arid zone of Northwest China, covering an area of approximately 130,000 km^2. Its upper reaches source from the boundary district of Gansu Province and Qinghai Province; its middle reaches totally lie in Gansu Province and its lower reaches end at the desert in the western part of Inner Mongolia Autonomous Region (Gao and Li 1991). There are three major regional distinctions in this basin, namely, the upper reaches of Heihe River Basin, administratively in Qinghai Province, the middle reaches of Heihe River Basin, administratively in Gansu Province, and the lower reaches of Heihe River Basin, administratively in Gansu Province and Inner Mongolia Autonomous Region (Fig. 1).

Geographically, from south to north, they are the southern Qilian Mountains, including the upper reaches of Heihe River Basin, the middle Hexi Corridor including the middle reaches and the northern Alxa High-plain including the lower reaches. According to Chen and Qu (1992), the southern Qilian Mountains are characterized by a remarkable vertical zonality. The water source area mainly concentrates on their upper and middle zones with an elevation ranging from 2,000 to 5,500 m a. s. l., and a mean annual precipitation increasing from about 250 mm in the low-mountain or hill zone to about 500 mm in the high-mountain zone. The middle section of the Hexi Corridor Region, which is between the Qilian Mountains and the Beishan Mountains, has an elevation from >2,000 to 1,000 m. The mean annual precipitation ranges from 250 mm in the south of the Heihe River Basin to less than 100 mm in the north. The northern Alxa High-plain was mainly covered by bare Gobi with a mean elevation of about 1,000 m where the mean annual precipitation is even less than 50 mm.

Data and methods

To detect changes in land-use during a 15-year period (1987–2002) using remote-sensing data, a new set of land-use categories was developed by modifying the US Geological Survey Land-use/Land Cover Classification System (Chen 2002) applicable to the study area, including six classes (cropland, forestland, grassland, urban and/or built-up land, water, and barren land) and taking full account of these field investigations. The chosen classes were also based on amenability to accurate identification from the available imagery and ancillary interpretation resources.

Two datasets for the years 1987 and 2002 were used. These datasets were obtained from the interpretation of composite Landsat 5 images of bands 4, 3 and 2 (R, G, B) (Ma et al. 1996), obtaining the Landsat™ data from the Institute of Remote Sensing Application (IRSA), Chinese Academy of Sciences. The area measurements of these types in the study were made using the statistics function of GIS according to the details of the satellite image processing methodology and procedures (Li et al. 2004; Zuo et al. 2005).

To identify and assess environmental impacts by land-use change, the field investigation was carried out along three routes passing through most of the study area. The first route, along the upper stream of the Heihe River, aimed at investigating the status of deforestation and water erosion of Qilian Mountains; the second one was along the middle stream and the trunk canals aimed at investigating the status of water shortage, land salinization and sandy desertification; and the third one, along the lower stream in the Ejina Oasis, aimed at investigating the status of desertification. Some available census data (The Gansu Forest Survey and Design Institute 2000; The Agriculture Programming Office of Zhangye District 1997; The Agriculture Programming Office of Jiuquan District 1997) were collected.

Results and discussion

Land use change

The classification results show that five land-use categories changed significantly in the study area during the 15-year period: cropland, forestland, urban or built-up land, grassland, and water area (Figs. 2, 3). Specifically, the total area of cropland increased from 5,178.0 km^2 in 1987 to 5,357.8 km^2 in 2002, forestland area increased

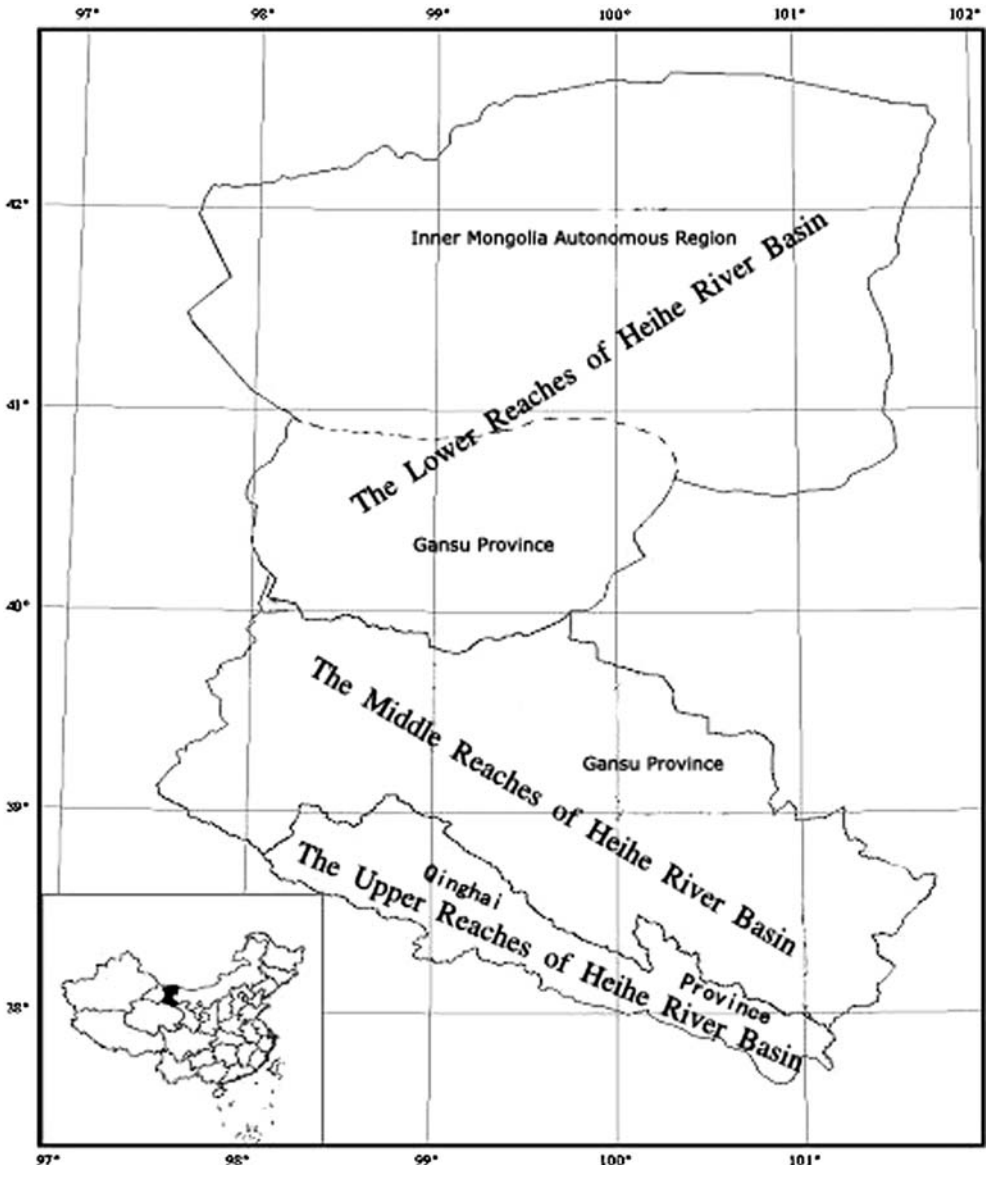

Fig. 1 Geographic and administrative location of the Heihe River Basin

from 6,422.1 km^2 in 1987 to 6,450.4 km^2 in 2002, and urban or built-up land area increased from 115,179.5 km^2 in 1987 to 115,791.4 km^2 in 2002. However, the largest net change in terms of acreage (501.3 km^2) was of grasslands, which decreased from 27,710.6 km^2 in 1987 to 27,209.3 km^2 in 2002, and water area decreased from 1,645.7 km^2 in 1987 to 1,386.4 km^2 in 2002, net decreasing by 279.3 km^2.

During the period from 1987 to 2002, the spatial change in the land-use within regional distinction of Heihe River Basin indicates a dynamic variation of land-use development. Figures 2 and 3 present the spatial change of five types of land-use during this period. The significant decrease of grassland occurred in the middle reaches and the lower reaches of Heihe River Basin, where its maximum decreases were 210.3 and 313.3 km^2, respectively. Moreover, the significant decrease of water area occurred in the upper reaches of Heihe River Basin, with a maximum decrease of 247.2 km^2. On the other hand, the significant increase of barren land occurred in the upper reaches and the lower reaches of Heihe River Basin, where its maximum increases were 268.2 and 397.4 km^2, respectively; and the significant increase of cropland occurred in the middle reaches of Heihe River Basin with a maximum increase of 174.9 km^2, where a smaller increase of urban or built-up land also occurred. The urban or built-up land increased by 64.6 km^2. The grassland increased by 22.3 km^2 in the upper reaches of Heihe River Basin and a smaller increase of forestland occurred in the middle reaches. However, the water area

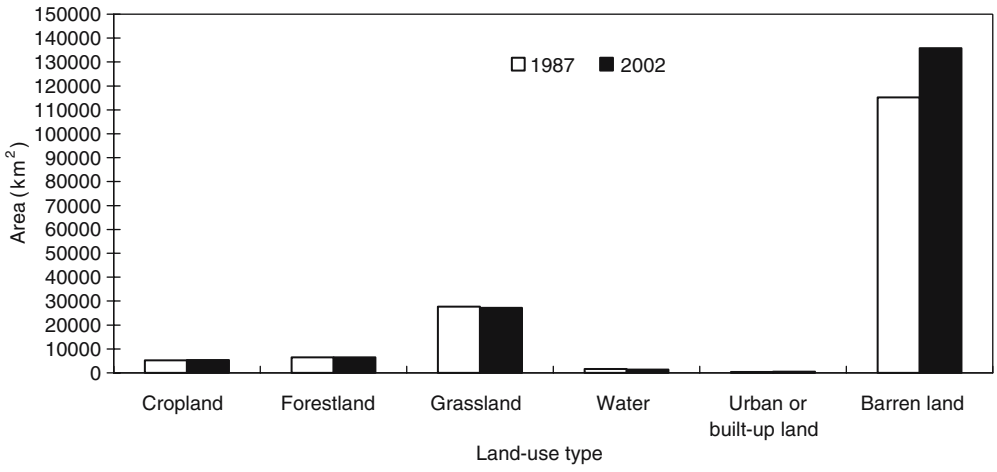

Fig. 2 Dynamic patterns of area change of land-use type in the Heihe River Basin of arid northwestern China

and barren land decreased by 21.7 km^2 in the lower reaches and 53.7 km^2 in the middle reaches of Heihe River Basin.

Impacts on the environment

In northwestern China, a river basin can be regarded as a whole ecosystem where meteoric water, surface water and groundwater can be transferred into one another and form a complete water cycle, and any changes in their links will greatly influence the system (Gao and Li 1991). Compared with ecosystems in other climatic regions, ecosystems in arid and semiarid regions are disproportionately prone to ecological damage from inappropriate forms of land use. According to these field investigations and data analysis, different types of land-use change, from better ecological conditions to worse ones, corresponded to degrees of environmental degradation severity in the Heihe River Basin.

The first, forestland, grassland and barren land mainly cover the mountainous region area of the upper reaches of Heihe River Basin (Fig. 3a). Because of the significant increase of barren land, this gives great disadvantages to soil conservation. Water being a limiting factor in plant growth, decreases in the water resources of the upper reaches have resulted in concomitant decreases in the number of plant species, along with their density, coverage and yield or biomass despite having larger areas of grassland and forestland. For example, the forest cover was reduced from 22.4% in the early 1950s to only 12.4% in the 1990s and the grassland degradation features such as lower grass yields, grassland desertification and lowered carrying capacity have become commonplace (Wang et al. 2003).

The second, cropland, grassland, and urban or built-up land mainly cover the region of the middle reaches of Heihe River Basin (Fig. 3b). With the continuous increase in population and livestock (Qi and Luo 2005), the area of cropland and built-up land has risen but the grassland area has decreased significantly during the study period. These changes have caused sandy desertification development exhibiting spatial and temporal differentiation in the Zhangye Region of Gansu Province (Luo et al. 2005) and the changes of regional groundwater resources in the Heihe River Basin. For example, the impacts on the recharge were 2.602×10^8 and 0.218×10^8 m^3/a in the former (1969–1985) and latter (1986–2000) 15 years and those on the discharge were 2.035×10^8 and 4.91×10^8 m^3/a, influenced by the land-use change (Wang et al. 2005). Water environmental degradation owing to land-use changes and human activities was described in detail by Qi and Luo (2005).

The third, in the lower reaches of Heihe River Basin, grassland and barren land are the main land-use types (Fig. 3c). Owing to the significant decrease of water area, grassland and natural desert forests became seriously degraded. The area of *Populus euphratica*, *Elaeagnus angustifolia* L., and *Tamarix chinensis* Lour. forest in the Ejina Delta of the lower reaches of Heihe River, decreased by 1,924 km^2 from 1982 to 1994, an average decrease of 137.4 km^2 $year^{-1}$ (Wang et al. 2003), thus resulting in the degradation of natural vegetation and oasis desertification in the lower reaches (Fig. 4). Land salinization is another important manifestation of land degradation resulting from land-use change in the downstream region of Heihe River. In 1995, there was 6,641 km^2 of salinized lands in Erjina County, accounting for 49.5% of total degraded lands in the whole county.

Conclusions

In the recent 15 years, widespread changes in land use and land cover have taken place in the Heihe River

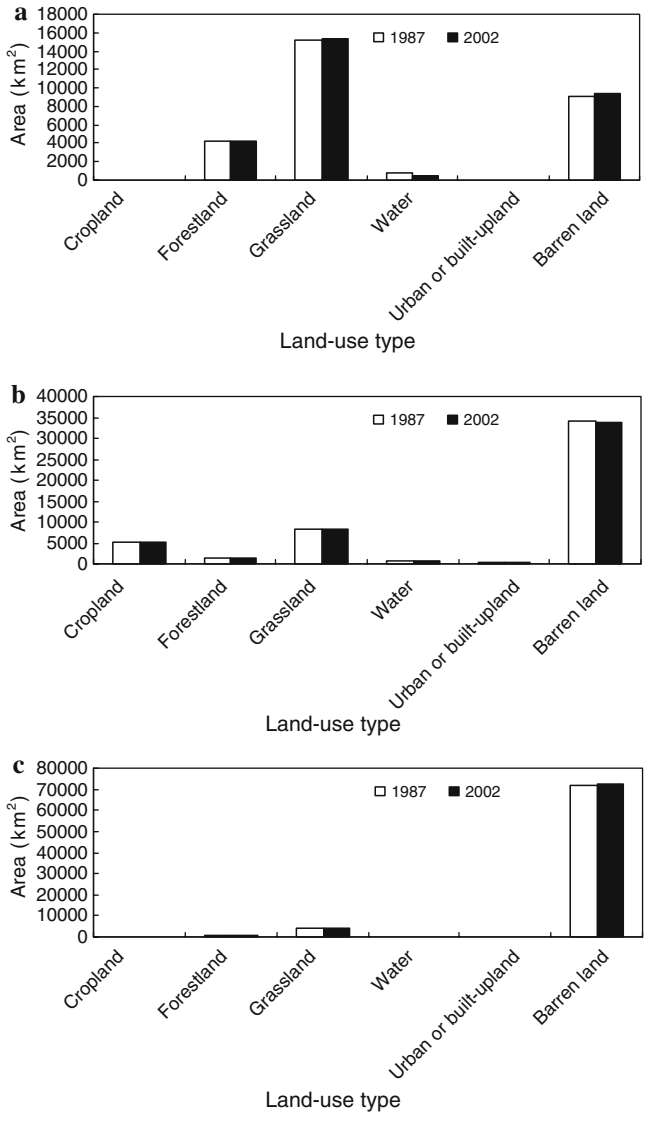

Fig. 3 Dynamic patterns of area change of land-use type in each part of the whole basin. **a** the upper reaches of Heihe River, **b** the middle reaches of Heihe River, **c** the lower reaches of Heihe River

Basin, arid northwestern China (Figs. 2, 3). Grassland and barren land increased by 22.3, and 268.2 km^2, respectively, in the upper reaches, cropland and urban or built-up land increased by 174.9, and 64.6 km^2, respectively, in the middle reaches, and barren land increased by 397.4 km^2 in the lower reaches of Heihe River Basin. By comparison, water area decreased by 247.2 km^2 in the upper reaches, grassland decreased by 210.3 km^2 in the middle reaches, and seriously degraded grassland

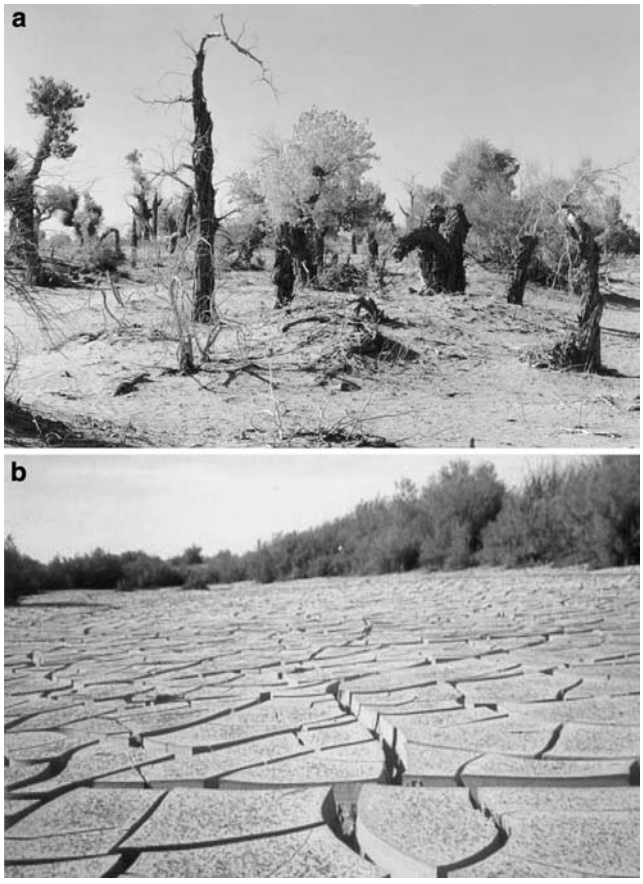

Fig. 4 Degeneration of natural vegetation and oasis desertification in the Heihe River Basin

and water area decreased by 313.3, and 21.7 km^2, respectively, in the lower reaches of Heihe River Basin. As a result of land-use changes and human activities, severe environmental degradation occurred in the whole basin from 1987 to 2002, such as water environmental changes, land desertification and salinization, and vegetation degeneracy, which had, in turn, impacted on the regional sustainable development. Therefore, more attention had to be paid to the effect of land development on ecological environment in land use planning and management in the future.

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