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Changes in the area and pattern of farmland in China's eastern Loess Plateau

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ABSTRACT

The aim of this study was to analyze the changes in the area and pattern of farmland in Ningwu County of China's eastern Loess Plateau, using multi-temporal Landsat data, for the periods 1990–2000 and 2000–2010. It was found that (1) the increase in area of farmland from 1990 to 2000 has been a direct result of the rapid population increase in the area; (2) the decrease in area of farmland from 2000 to 2010 has been caused primarily by the implementation of the governmental project involving conversion of sloping farmland into woodland or grassland project since 2000, and the simultaneous rapid expansion of construction land; (3) the expanded areas of farmland have been mainly located on hillsides during 1990–2000, which has resulted in the farmland becoming more fragmented and dispersed, and consequently, the shapes of the farmland patches have become more irregular and complex during this period; (4) the decrease in sloping farmland has been the main reason for forcing the shapes of farmland patches to become more regular and simplified during the period 2000–2010.

1. Introduction

In the last few decades, dramatic conversions among various land use patterns have occurred due to population growth, food scarcity, urbanization, and shifts in regional land use policy [1–5]. These changes have had major impacts on regional water cycles, biogeochemical cycles, biological diversity, terrestrial ecosystem productivity, and climate change [6,7]. As a result, the study of land use and land cover change (LUCC) has become a major focus of global change research since the 1990s [8–11]. Numerous studies have been performed to understand the current status, trends, driving forces, and environmental impacts of LUCC [12–16]. The goal is to ultimately achieve sustainable land utilization based on the insights provided by these studies [8,17].

In China's rural areas, farmland represents the most important of land use types. Since the Chinese government initiated a project named ‘Convert sloping farmland into woodland or grassland’ in the Loess Plateau in 2000, tremendous LUCC has occurred in regions such as northern Shaanxi Province and eastern Gansu Province [18–20]. The resulting decrease in farmland cover has been considered an important beneficial result of the project [21–23]. However, accelerated construction of residential, commercial, and industrial buildings as well as transportation facilities, highways, and railways as a result of rapid economic growth and population increases have also greatly affected farmland landscapes through the conversion of farmland to construction land [24–26]. Shanxi Province lies in the eastern part of the Loess Plateau, in the central reaches of the Yellow River and the upper reaches of the Haihe River. The project to convert sloping farmland into woodland or grassland in this region has been supported financially by the Chinese government, but little research on the resulting LUCC processes, especially the farmland change process, has been conducted.

The changes in the area and pattern of land can be characterized by status and trend that are closely related and reflects the land-change dynamics and if a land type has a positive or negative change, respectively. Luo et al. [3] have developed a set of quantitative models for characterizing the status and trend of land change and successfully apply the models to a case area located in the China's Sangong River Basin. In the present research, we used Ningwu County of China's Shanxi Province as a case study to explore the change in area and pattern of farmland during the last two decades by integrating remote sensing and GIS techniques based on the models developed by Luo et al. [3]. Our overall objectives were to understand the changes in the area and pattern of farmland and the driving forces responsible for such changes.

2. Materials

2.1. Study area

Ningwu County is located in northern Shanxi Province, from 111°50′E to 112°37′E and from 38°31′N to 39°09′N. It covers about 1941 km^2, with an average elevation of 2000 m (Fig. 1). The elevation increases from the center of the study area to the southeast and northwest, and the lowest elevations extend from the southwest to the northeast through the central part of the study area. The county is bounded on the east by the Yunzhong Mountains, on the west by the Guanchen and Luya mountains, and on the southwest and north by the Lvliang and Hongtao mountains, respectively.

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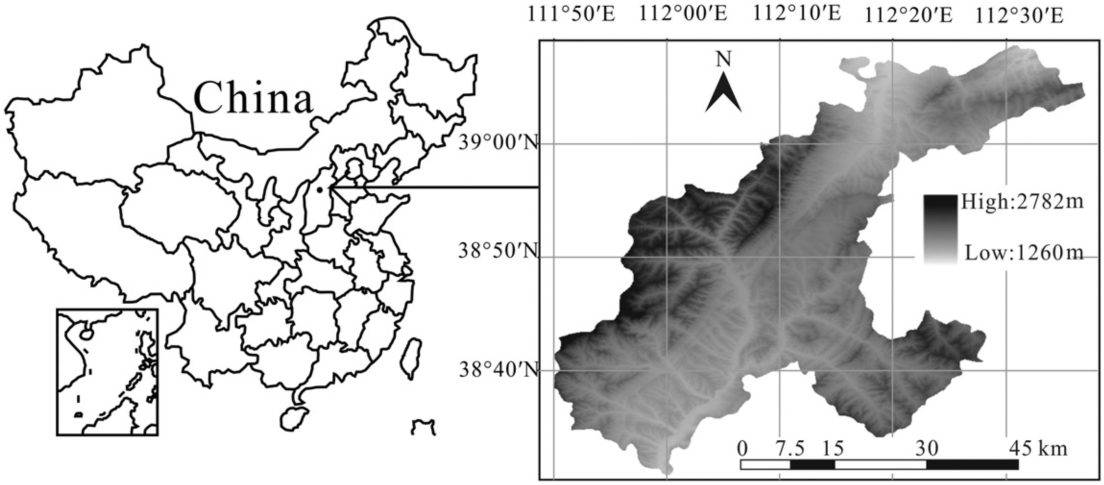

Fig. 1. Location of the study area, and topographic map.

The study area is located in a semiarid region of northern China, and is dominated by a continental monsoon climate. The average annual temperature is about 6.2 °C, with a minimum mean monthly temperature of −9.9 °C in January and a maximum of 20.1 °C in July. The average annual precipitation is about 600 mm, about 80% of which falls during the primary growing season from June to September. The average annual pan evaporation rate is about 1700 mm. There are two cropping seasons annually, with the main crops being wheat, millet, broom corn millet, and potatoes.

2.2. Data sources and processing

We used three sets of remote sensing images in this study, including Landsat ETM+ images acquired on 24 July 2000 and Landsat TM images acquired on 22 August 1990 and 12 July 2010, all with a 30-m spatial resolution. The study area is entirely contained with path 125 and row 33 for Landsat TM/ETM+ images. In addition to these data, we used topographic maps at a scale of 1:50,000 surveyed by the Chinese Mapping Agency in the early 1980s, as well as vegetation map (1:1,000,000) and soil map (1:1,000,000) provided by several Chinese government agencies [27,28], in order to obtain ancillary materials to assist our classification of the land use types during the visual interpretation process.

We performed geometric corrections using version 9.1 of the ERDAS Imagine software (ERDAS, Norcross, GA). The ETM+ images acquired in 2000 were georeferenced using ground control points derived from the topographic maps. The mean positional errors for georectification of the TM and ETM+ images were controlled to less than 1.5 pixels in mountainous regions and less than 1 pixel in flat regions, which are acceptable levels of precision for large-scale surveys. The TM images from 1990 and 2010 were matched with the geometrically corrected ETM+ images from 2000 by means of an image-to-image matching method provided by the ERDAS Imagine software.

To accurately classify the land cover, we investigated the study area at the beginning of our research by taking a series of photographs of each type of land cover and recording each photograph's geographic coordinates using a global positioning system (GPS) receiver, and then finding the corresponding land cover in the remote sensing images at those geographic coordinates to build an interpretation symbol database for use in subsequent image interpretation. In addition, we digitized the topographic maps at a scale of 1:50,000 to provide vector data, after which we transformed the vegetation and soil maps into the same projection mode and coordinate system, so that they could be overlaid on the other images to provide assistance with image interpretation.

The polygons with different land use types in the images acquired in 2000 were labeled according to their cover class. Once the digital map of the land coverage in 2000 was complete, the polygons were copied and the segments that required modification were changed based on the 2010 and 1990 images; these were updated by adding, deleting, or modifying lines in order to reflect LUCC from 1990 to 2000 and from 2000 to 2010. The visual interpretation process was completed using version 9.1 of ArcMap software (ESRI, Redlands, CA).

Using the resource and environment database established by the Chinese Academy of Sciences, we classified the land use types in the study area into six classes: farmland, woodland, grassland, water body, construction land, and unused land. Descriptions of these land use types are presented in Table S1 (supplementary information), and their distribution in each of the three years is shown in Fig. S1 (supplementary information). The interpretation results for the study area were validated in the field in August 2011. Subsequent corrections were made after field validation to ensure that the classification accuracy was higher than 95%.

To define the mutual conversion(s) between farmland and other land use types that occurred in the study area from 1990 to 2000 and from 2000 to 2010, we used the Overlay Tool in the ArcInfo 8.3 GIS software (ESRI) to compute the geometric intersection of areas of each land use type in the three periods based on the land use maps from each year. The output coverage file was converted into shapefile format. The cross-tabulation table was calculated using the PivotTable Wizard in Microsoft Excel, and was output as a transition matrix.

3. Methods

3.1. Methods for farmland area change

The status and trend in land change to farmland can be defined as

$$C_{s-i} = \frac{\Delta U_{in-i} - \Delta U_{out-i}}{\Delta U_{in-i} + \Delta U_{out-i}}, \Delta U_{\mathrm{in}} + \Delta U_{\mathrm{out}} \neq 0 \text{and} -1 \leq C_{s-i} \leq 1 \tag{1}$$

$$C_s = \frac{\sum_i^n (\Delta U_{\mathrm{in}-i} - \Delta U_{\mathrm{out}-i})}{\sum_i^n (\Delta U_{\mathrm{in}-i} + \Delta U_{\mathrm{out}-i})}, \sum_i^n (\Delta U_{\mathrm{in}-i} + \Delta U_{\mathrm{out}-i}) \neq 0 \text{ and} -1 \leq C_s \leq 1 \tag{2}$$

where C_{s-i} is defined to characterize the status and trend in mutual conversion between farmland and land use type *i*, and C_s is defined to characterize the total status and trends in mutual conversion between farmland and other all land use types. $\Delta U_{\mathrm{out}\text{-}i}$ (≥0) represents the area of farmland lost or converted to land use type *i* over the period and $\Delta U_{\mathrm{in}\text{-}i}$ (≥0) denotes the total land area gained by or converted to farmland from land use type *i*. Note that Eq. (1) is not applicable if $\Delta U_{\mathrm{in}\text{-}i} + \Delta U_{\mathrm{out}\text{-}i} = 0$,