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Changing landscape in the Three Gorges Reservoir Area of Yangtze River from 1977 to 2005: Land use/land cover, vegetation cover changes estimated using multi-source satellite data

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ABSTRACT

The eco-environment in the Three Gorges Reservoir Area (TGRA) in China has received much attention due to the construction of the Three Gorges Hydropower Station. Land use/land cover changes (LUCC) are a major cause of ecological environmental changes. In this paper, the spatial landscape dynamics from 1978 to 2005 in this area are monitored and recent changes are analyzed, using the Landsat TM (MSS) images of 1978, 1988, 1995, 2000 and 2005. Vegetation cover fractions for a vegetation cover analysis are retrieved from MODIS/Terra imagery from 2000 to 2006, being the period before and after the rising water level of the reservoir. Several analytical indices have been used to analyze spatial and temporal changes. Results indicate that cropland, woodland, and grassland areas reduced continuously over the past 30 years, while river and built-up area increased by 2.79% and 4.45% from 2000 to 2005, respectively. The built-up area increased at the cost of decreased cropland, woodland and grassland. The vegetation cover fraction increased slightly. We conclude that significant changes in land use/land cover have occurred in the Three Gorges Reservoir Area. The main cause is a continuous economic and urban/rural development, followed by environmental management policies after construction of the Three Gorges Dam.

1. Introduction

In recent years, to satisfy the hydrological energy and water resources consumption demand from the rapid development of economy and society, many large-scale water conservation projects have been undertaken at the global level. These major projects have brought certain economic benefits, but have also had adverse effects on the ecological environment. For example, the influence of Egypt's Aswan High Dam, on water and soil quality, human health 20 years after its completion (White, 1988; Moussa et al., 2001); the influence of the Itaipu Project located along the border river between Brazil and Paraguay, on vegetation, animals, water quality and soil pollution (Murphy, 1976; Strand et al., 2007). Therefore, for many years using new technologies to monitor the impacts of these activities on the ecological environment has been a focus of attention around the world (Ivits et al., 2009; Liao, 2004; Liu et al., 2002; Veldkamp and Lambin, 2001).

As the largest water conservation project in the world, China's Three Gorges Project has attracted worldwide attention. This attention has not been only for its comprehensive social and economic benefits such as flood prevention, hydropower generation, and shipping capacity, but also for the potential security impacts on the natural environment, potential geological disasters, as well as on the biological diversity imposed on the surrounding reservoir area. Specifically, the major impacts include land cover changes caused by population migration, potential water pollution and soil erosion following the construction of the Three Gorges Dam and the immigration towns, etc. The Chinese Government and the environmental management professionals have long been aware of these problems, and have gradually formulated and implemented a series of relevant policies (Luo and Shen, 1994; Tullos, 2009).

Among these impacts, land use/land cover change (LUCC), as well as the vegetation cover change, have been well recognized as some of the most important indicators for global and regional environmental changes (Meyer and Turner, 1994; Lindquist et al., 2008). Therefore, quantifying the LUCC and vegetation cover change is crucial for assessing the effect of land management policies and environment protection decisions (Opoku, 2007).

Many studies have been carried out about land use mapping, change detection, as well as vegetation monitoring using multi-temporal satellite data for regional ecological and environmental

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change research (Veldkamp and Lambin, 2001; Peng et al., 2006; Pouliot et al., 2009; Berberoglu and Akin, 2009). Various techniques have been successfully used in the land use/land cover classification and change detection, e.g., pixel based classification (Foody, 1996; Duda et al., 2001), object oriented classification (Geneletti and Gorte, 2003; Elmqvist et al., 2008), artificial neural network classification (Kanellopoulos et al., 1992; Liu et al., 2004), post-classification comparison change detection (Serra et al., 2003), and visual interpretation (Liu et al., 2005). For vegetation monitoring, some biophysical parameters, e.g., vegetation leaf area index (LAI), fraction of photosynthetically active radiation (fPAR), and vegetation cover fraction, have been recommended for monitoring its long-term changes (Ganguly et al., 2008; North, 2002; Sun et al., 2008; Mostovoy et al., 2008). For vegetation changes estimation over large areas, the retrieval of the fraction of vegetation cover (FVC) from remotely sensed data has been an effective method (Carlson and Ripley, 1997; Zhang et al., 2006).

In this paper, the multi-temporal satellite dataset in the Three Gorges Reservoir Area has been analyzed to understand LUCC as a consequence of driving factors. Our study focused on the following two aspects: (1) to estimate LUCC from 1977 to 2005 in the TGRA, and to obtain vegetation cover changes from 2000 to 2006, being the time before and after the water line rising of the reservoir, and (2) to incorporate and analyze landscape changes in the TGRA using these estimated results.

The remaining sections of this paper are organized as follows. Section 2 introduces the background of the study area. Section 3 describes the data and method used in this article. In Section 4, the LUCC and vegetation change results are presented, followed by a discussion of the results in Section 5. The conclusions of this research are given in Section 6.

2. Study area

The Three Gorges Reservoir Area (TGRA) is located between latitude 28°56′N–31°44′N and longitude 106°16′E–111°28′E, covering the lower section of the upper reaches of the Yangtze River, with an area of 58,000 km^2 and with a population of almost 20 million (Meng et al., 2005). It consists of 21 counties or cities of Chongqing municipalities and Hubei province (see Fig. 1), with various geographic conditions, 74% of the region is mountainous, 4.3% of the region is plain area and 21.7% hilly area (Peng et al., 2004). The climate in the TGRA is a subtropical monsoon climate, and vegetation in this area is abundant and diverse.

The construction period of the Three Gorges Project lasted from 1993 to 2009 with the final water level at 175 m, the total storage capacity of the reservoir being 39.3 billion m^3. The water level was 135 m in June 2003. With its continuous rising, 1.13 million immigrants will be resettled. For instance, from 2000 to 2004, about 96,000 immigrants from the Chongqing reservoir region along the upper reach of the Three Gorges Reservoir Area have been moved and settled outside the region. As the water in the reservoir increased up to 175 m height, about 240 km^2 citrus and farmland will be submerged.

Along with the rapid population growth and economic development in this region since 1980s, the ecological environment has changed rapidly because of excessive cultivation and over-felling, e.g., the woodland area and the diversity of vegetation reduced quickly (Zhou et al., 2004). As a consequence, soil erosion in certain parts of the TGRA is becoming more and more serious.

To protect and reverse the deterioration of the ecological environment of the Yangtze River Valley, several policies and management projects have been carried out in this region. For example, the Shelterbelt Construction Project in the upper reaches of Yangtze River was started by the central government in 1989 (State Forestry Administration, 2006). This project included tree planting, aerial planting, closing hillsides to facilitate afforestation and raising seedlings, through which, a net increase of 9.6 percentage points of the forest cover was gained by the end of 2000, the close of the first phase of the Shelterbelt Construction Project. After that, the second phase construction of shelter forest system was carried out. At the same time, to strengthen the ecological and environmental construction in the TGRA and the surrounding area, the State Council approved the "Greenbelt Around the Three Gorges Reservoir Construction Project Planning" in July 2004 with the construction period from 2004 to 2007. The work includes the implementation of returning farmland to forest, planting tree on barren hills and wasteland, closing hillsides to facilitate afforestation and construction of basic farmland, and other measures to protect the existing forest resources, and create a water conservation forest and soil conservation forests, ensuring the ecological safety of the Three Gorges Reservoir. The project involved 26 districts and counties and 204 townships of Hubei and Chongqing, with the area of returning farmland to forest and grass being 488.7 km^2, afforestation of barren hills and wasteland being 119.3 km^2, closing hillsides to facilitate afforestation being 120.0 km^2, and

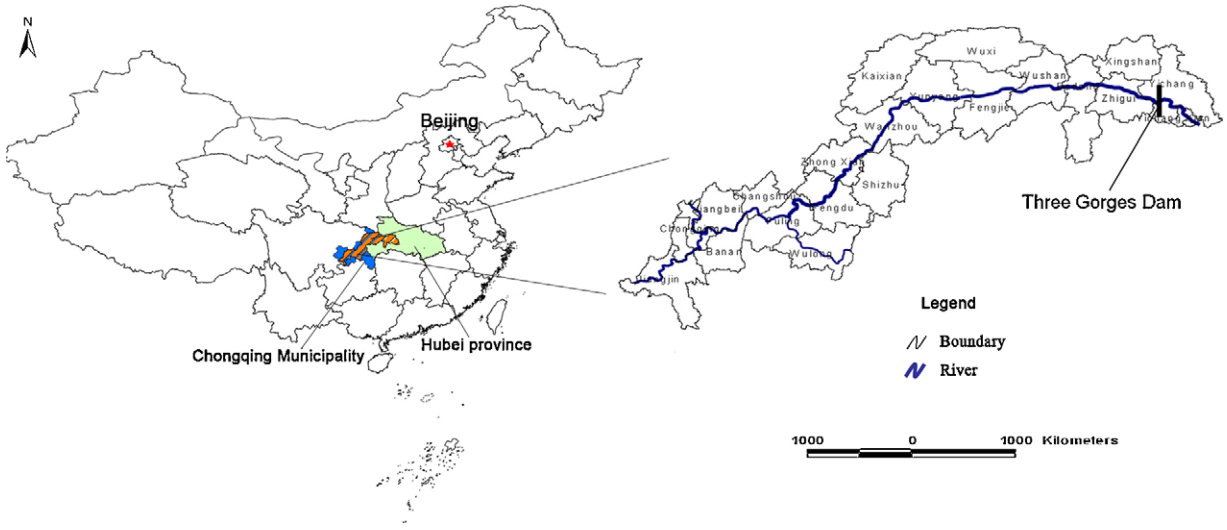

Fig. 1. Location of the study area.