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Determining the influencing distance of dam construction and reservoir impoundment on land use: A case study of Manwan Dam, Lancang River

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ABSTRACT

Based on Landsat MSS and TM images from 1974, 1988, and 2004, we conducted a case study of the Manwan Dam along the Lancang (Mekong) River to determine the influencing distance of dam construction and reservoir impoundment on land use. Spatio-temporal variation in land use was analyzed within 14 adjacent buffer zones around the dam site (concentric rings) and in upstream and downstream areas along the riverway (linear tract). Grassland increased with the greatest dynamic degree in the 1974–1988 period, whereas water area increased extensively in the 1988–2004 period. The integrated dynamic degrees of forestland were low in both periods. The integrated land use dynamics in the 14 concentric rings showed that the impact of dam construction extended to a threshold distance of 5000–6000 m from the dam site during the 1974–1988 period and to 2000–3000 m during the 1988–2004 period. The transformational patch density in the 14 linear buffer zones indicated that the impact of reservoir impoundment on land use conversion exhibited a threshold distance of 3000 m from the riverway. The impact intensity of dam construction in the concentric rings and linear buffer zones tended to decline with increasing distance from the dam site or riverway. The impacts of dam construction and reservoir impoundment were larger in upstream locations than in downstream ones. Our results enhance our understanding of the threshold of dam construction and may guide the management of dam construction on a regional landscape level.

1. Introduction

Approximately 70% of the world's rivers are modified by large dams and reservoirs constructed for hydropower generation, seasonal flood control, irrigation, and drinking water (Kjaerland, 2007; Kummu and Varis, 2007). However, dam and reservoir impoundments have significant effects on the environment (Coker, 2000; Bombino et al., 2006; Benjankar et al., 2012). Dams can reduce river connectivity, fragment watersheds, and degrade adjacent land resources (Tiemann et al., 2004; Hu et al., 2008; Lü et al., 2012). Impoundments and reservoirs not only change hydrological regimes, sediment regimes and chemical, biological, and physical characteristics of water bodies (Ligon et al., 1995; Poff and Hart, 2002; Hu et al., 2008; Zhao et al., 2012b), but also flood large areas of land.

Land use dynamics are among the most sensitive indicators of the interactions between the natural environment and human activities (Zhang et al., 2010). Land use dynamics research is often performed to assess natural landscape status, to evaluate anthropogenic influences at different spatial and temporal scales, and to provide recommendations for future management (Munsi et al., 2010). As a high-impact form of habitat disturbance, hydropower development can induce a chain reaction in land use dynamics (Zhao et al., 2010). Thus, understanding how hydropower development affects land cover is important for guiding hydropower project development and regional land use management.

Remote sensing (RS) is a valuable tool for monitoring, mapping, and inventorying various resources (Zhang et al., 2010; Benjankar et al., 2012) because of its high spatial and temporal resolution and the consistency of information available for regional analysis. The combined use of RS with geographic information systems (GIS) has proven useful for the timely assessment of land use dynamics (Geneletti and Gorte, 2003; Wang et al., 2010). Many studies have investigated land use dynamics associated with dam construction and reservoir impoundment using RS and GIS techniques (Rautela et al., 2002; Verbunt et al., 2005; Zhou et al., 2008, 2010; Ouyang et al., 2010). These studies focused primarily on land use and its influences at the regional scale (Rautela et al., 2002; Porter-Bolland et al., 2007; Raumann and Cablk, 2008; Zhou et al., 2008, 2010; Lü et al., 2012). However, few studies have attempted to identify

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the influencing extent of dam construction or to distinguish the impacts of dam construction from those of reservoir impoundment (i.e., after dam completion). Buffer analysis has recently been used as an effective GIS-based method to assess the spatial extent of urban sprawl, road network construction and other activities (Zeng et al., 2005; Liu et al., 2006, 2008; Xu et al., 2007) but has not much previously been applied to assess the impact of dam construction.

For the current study, buffer zones characterised by several variables (e.g., distance to dam site, distance to riverway) were generated to assess land use dynamics. To quantitatively analyse how dam construction and reservoir impoundment affect land use, a single land use dynamics index, an integrated land use dynamics index, and the number of transformational patches (patches transformed from other land use types between two periods) were calculated for the entire study area and each buffer zone. This study was conducted in an area of great scientific interest (Lancang-Mekong Basin, Yunnan Province, southwest China), where 14 cascade hydropower stations are planned within the mainstream, with several dams already constructed. Construction of the first of the 14 cascade dams, Manwan Dam, began in 1986, with river closure occurring in December 1987 and operation of the first generator beginning in 1993. Adjacent land use has been significantly affected by the construction of the Manwan Dam (Zhou et al., 2008, 2010); however we still have know little regarding the spatial influencing distance of dam construction and how impacts vary over time (i.e., between dam construction and reservoir impoundment) and space (i.e., between upstream and downstream areas).

The purpose of this paper is to address the following questions: (1) How do dam construction and reservoir impoundment impact the intensity and extent of land use dynamics? (2) What are the effects of reservoir impoundment in upstream and downstream areas? Answering these questions will enhance our understanding of the impacts of dam construction and reservoir impoundment on sustainable development in this region.

2. Materials and methods

2.1. Study area and data management

The Lancang River, the largest international river in Asia, originates from the eastern Tibetan Plateau in China (Liu et al., 2008). It has a main channel drop of 5000 m along its entire, 4880 km from the headwater to the mouth at the South China Sea (Fu and He, 2007; Fu et al., 2008). Average yearly rainfall ranges from approximately 250 mm in the northwest to 500 mm in the southeast (Jacobs, 2002; Hu et al., 2009). Its unique geographic features and hydraulic properties provide many advantages for hydropower cascade development in the area (He et al., 2005, 2006; Baumann and Stevanella, 2012). The Lancang Cascade, a controversial hydropower project within China's Yunnan Province on the Lancang River, has 14 dams planned for the upstream area, four of which (Manwan, Dachaoshan, Jinghong, and Xiaowan) are already completed. Manwan Dam, located in the middle reach of the Lancang River, was the first dam completed (Fig. 1) (He et al., 2004). The dam is 132 m high 418 m long and has a total installed capacity of 150×10^4 kW. The Manwan Reservoir area is 23.6 km^2, which is 2.8 times larger than before dam completion, with a backwater of 70 km extends to the Xiaowan Dam upstream. The average water surface area of the reservoir is two times that of the natural channel. The total reservoir capacity is 1.06×10^9 m^3 at the target pool level of 994 m, and the effective capacity is 257×10^6 m^3, which is dependent upon seasonal discharge regulation (He et al., 2004; Fu and He, 2007; Zhao et al., 2010, 2012a).

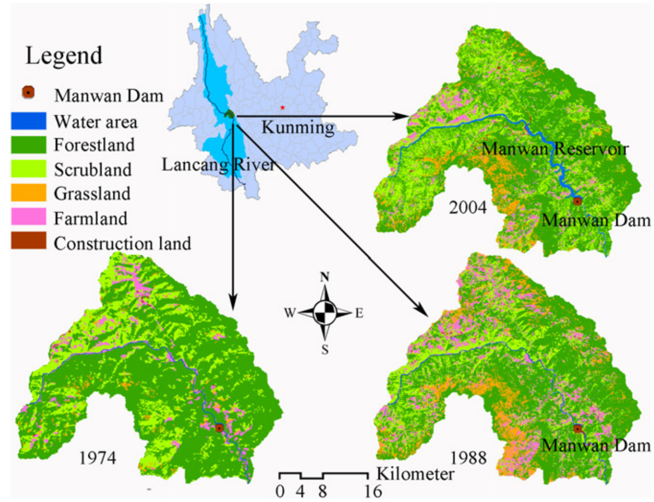

Fig. 1. Location of the study area.

In this study, the study area boundary was extracted as a watershed using the soil and water assessment tool (SWAT) with digital elevation model (DEM, 1:50,000) (Xie and Cui, 2011). In the watershed, the upper control point was located 500 m downstream from the Xiaowan Dam at the end of the backwater and the lower control point was located 12 km downstream from the Manwan Dam (Fig. 1). The areas upstream and downstream from the dam site are connected both spatially and temporally; however, they experience largely independent impacts of dam construction and impoundment. Therefore, land use changes in the areas 10 km upstream and downstream from the dam site were also compared.

To analyze spatio-temporal changes in land use and to assess the effects of dam construction and reservoir impoundment, we used three RS data scenes from satellite images, all calibrated for atmospheric and geometric correction: a Landsat MSS image from January 1974 (before dam construction) and a Landsat TM image from February 1988 (during dam construction) and a Landsat TM image from February 2004 (after dam construction). A supervised classification that combined field survey data with existing land use maps was performed on these Landsat images using ERDAS 8.5, yielding six classes of land use maps (Fig. 1): (1) water area, (2) forestland, (3) scrubland, (4) grassland, (5) farmland, and (6) construction land. Classifications were validated using ground truth data, with each land use map reaching at least 90% accuracy, meeting our research requirement.

2.2. Determining the extent of the buffer

An appropriate buffer can clearly reveal land use dynamics within each zone, whereas a buffer that is too long or short may prevent an accurate assessment of the effects of disturbances (Zeng et al., 2005; Ouyang et al., 2010). Therefore, two measures of distance (mean Euclidean distance (MED) and area-weighted mean Euclidean distance (AWMED)) were used in ArcGIS (McGarigal et al., 2002; Xu et al., 2007). These two measures are useful for understanding the temporal and spatial relationships between the riverway and transformational patches (patches that changed from one land use type to another), as well as for determining the extent of the buffer. MED is defined as the mean Euclidean distance from all transformational patches to the riverway. AWMED is a measure of the mean distance from the transformational patches of all land