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Vegetation response to 30 years hydropower cascade exploitation in upper stream of Yellow River

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ABSTRACT

The accumulated response of vegetation successive dam constructions and operations is an important concern, but the systematic assessment of impacts induced by cascade hydropower exploitation over long periods are seriously lacking. Using remote sensing data, the variations in grassland, the principal land cover in the upper catchment of the Yellow River, were investigated for eight dams constructed during the period 1977–2006. Two different scales—watershed scale and on-site area—were used to compare the changes in grassland and water area. Correlation coefficients from regression analyses showed that grassland area had more significant interactions with hydropower exploitation indicators in on-site scale than in watershed scale. The hydropower exploitation indicators had a more complex correlation with water area in watershed scale than in on-site scale. Consequently, observations of grassland area responses to successive hydropower exploitations were focused on the on-site region. The Normalized Difference Vegetation Index (NDVI) and the standardized NDVI, which can be used to analyze inter-annual climatic differences, were applied to identify the most heavily influenced vegetation zones. For different hydrological and micro-climatic conditions, the vegetation zones around reservoirs and along the main stream of Yellow River were analyzed, respectively. Two NDVI spatial principles at varied distances from the water demonstrated that the vegetation NDVI was recovering from 1994 to 2006. For distance of less than 10 km from water, the vegetation around reservoirs was better as the higher NDVI in 2006 than in 1977. The inter-annual NDVI comparison demonstrated that the critically affected vegetation zone was concentrated at distances of 0.1–0.4 and 1–6 km from the water. In on-site region, the grassland was further analyzed with elevation and aspect information, which indicated that grassland in sunny aspects was much disturbed. Detailed information about grassland response with water distance and the degradation characteristics provide the comprehensive assessment by cascade hydropower exploitation.

1. Introduction

More than 40,000 dams have been constructed on the world's rivers, nearly 29,000 of which are located in China. These dams can provide extensive economic benefits, but they also disturb fluvial processes in the rivers and the terrestrial status of the associated watersheds. In many of the world's rivers eco-environmental aggradations have taken place [1,2].

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The Yellow River in China has experienced a dramatically decreasing trend in water resource discharge since the construction and operation of large reservoirs. Most of these dams and reservoirs have been built in the river's upstream catchment area during the last several decades [3]. Not only is the land cover in the upper stream portion of the Yellow River affected by the construction of eight successive dams, but also recovery is difficult. This regional vegetation is extremely fragile as the result of typical continental season climate. Understanding the long-term variation in the vegetation recovery process, and its principles, resulting from hydropower cascade exploitation (HCE) can help explain the spatial extent and the degree of influence from human activities. Equally important, it can help in predicting the impact of future HCE plans and assist in preventing environmental degradation from such projects.

Dams are constructed for diverse purposes, including seasonal flood control, generation of hydroelectric power, and improvement in the supply of water resources. Although dams can provide various economic benefits, they can also be the source of negative impacts on the natural environment [4,5]. Hydropower dam constructions affect the status of the regional land cover, which was the result of flooding and alteration of river. After dams are constructed and under operation, irrigation conditions improve and water table depths increase, leading to more convenient access to groundwater. As a result, farmland areas will increase and cropping patterns will shift [6]. In most cases, communities in close proximity to large dams are displaced or affected by explorations of hydropower resources [7]. As a consequence of hydrological and socio-economic developments associated with dam construction, watershed land cover changes occur. However, during the environmental impact assessment and management process, the principal problem is to determine an appropriate definition of the assessment region.

In this paper, the affected land cover characteristics are examined over two regions; a watershed region and the other by an on-site region. Thus, land cover characteristics are analyzed from the perspective of two different scales. Using a standard hydrological concept, the watershed region delineates the geographic area from which the run-off water flows into the portion of the Yellow River under study. The on-site region of the HCE delineates a smaller region which is defined in a more complicated manner. The first step is to construct a buffer zone of 25 km along each side of the riverbank, a designation that covers almost all construction fields associated with real hydropower engineering. In the second step, the main portion of the Yellow River watershed is identified. For example, when a mountain intrudes into the 25 km buffer zone in such a way that the water on the side of the mountain away from the river does not drain directly into the river and construction activities do not occur there, the mountainous portion is excluded from consideration. Finally, the on-site region of the HCE is defined as the intersection of the areas determined in steps one and two.

Whether or not hydropower explorations should be continued has become an increasingly important topic and is widely debated in developing countries, as well as developed countries [8]. For the most part, these discussions have been about the impact identifications and assessments for single dam constructions. Pamo and Tchamba studied land changes resulting from dams and its impact on animals [9]. Gordon and Ross studied dam operation effects on land use and riparian vegetation [10]. However, there is a widespread lack of detailed data to support systematic assessments of HCE induced impacts.

With the advance of remote sensing (RS) and Geographic Information System (GIS) technologies, the study of land cover variation, and its principles, resulting from HCE has become feasible and reliable. Many studies have demonstrated that remotely sensed data can provide both actual and spatially distributed information for land cover variation monitoring and analysis, especially on a watershed scale over long time periods [11,12]. Such analyses are difficult to monitor by conventional techniques [13]. The Landsat MSS data has been widely applied to multi-temporal land cover analyses because it has been available for quite some time. The later launched Landsat TM can also provide high spatial resolution and frequent time-series data for a wide variety of environmental applications, ranging from regional land use analyses to vegetation simulation [14]. With the Normalized Difference Vegetation Index (NDVI), the temporal–spatial variation principle of vegetation status can be achieved. Fabio successfully used the NOAA-AVHRR, Landsat TM, and ETM+ images to produce a long-term NDVI data series for coniferous and broadleaved forestland assessment in Tuscany (Central Italy) [15]. The GIS tools treat the information extracted from remotely sensed data and the analytical results can be used as the primary base for regional environmental impact identification and management [16,17].

Land cover variation is one of the most obvious impacts resulting from dam construction. Temporal changes in land cover have been studied with the aid of satellite images. However, no studies are available that identify the range of land cover affected by HCE over a long time period. This article presents the temporal–spatial variation principle of land cover in the Longliu Section in the upper stream of the Yellow River during the period 1977–2006. In this period eight reservoirs were built along the river; these constructions were the most critical cause of regional land cover transformation. The objectives of this paper are summarized as follows:

(1) Define the area directly influenced from dam construction and operation by comparing the correlation of HCE indicators with grassland and water areas in the on-site and watershed regions.
(2) Determine grassland (the dominant land cover) degradation characteristics within the on-site region at different elevations and their relationship with HCE.
(3) Demonstrate the differences in spatial principles of on-site vegetation NDVI variation by the data in last 30 years. These observations are based on the water distance along the riverbank and around reservoirs, thereby identifying the detailed impacted zone from HCE.