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Impact of the construction of a large dam on riparian vegetation cover at different elevation zones as observed from remotely sensed data

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ABSTRACT

The impact of the construction of a large dam on riparian vegetation cover can be multifold. How the riparian vegetation cover changes at different elevation zones in response to the construction of a large dam and the subsequent impound of reservoir water is still an open question. In this study, we used satellite remote sensing data integrated with geographic information system (GIS) to monitor vegetation cover change at different riparian elevation zones on a large spatial scale, taking the Three Gorges Dam in China as an example. Due to the large scale of this newly formed reservoir, it is expected to impact the riparian vegetation canopy both directly and indirectly. We chose to monitor vegetation cover changes along the 100 km riparian stretch of river directly upstream of the Three Gorges Dam site, over the construction period of eleven years (2000–2010), using MODIS vegetation indices products, digital elevation model (DEM) data from ASTER, and the time series water level data of the Three Gorges reservoir as the data sources. Results show that non-vegetated area increased in the inundated zone (below 175 m), as expected; area of densely vegetated land cover increased within the elevation zone of 175–775 m and no change in vegetation cover was observed above 775 m in elevation. Regression analysis between the vegetation index data and the reservoir water level shows that increasing water levels have had a negative impact on vegetation cover below 175 m, a positive impact on vegetation cover is limited to the region between 175 and 775 m, and no significant impact was observed above 775 m. MODIS EVI product is less sensitive in mapping non-vegetated land cover change, but more sensitive in mapping vegetated land cover change, caused by the reservoir water level variation; both products are similar in effectively tracking a trend between land cover change in each elevation zone with time or with reservoir water level.

Introduction

As the global demand for energy, especially renewable energy increases, a surge in large dam projects for hydropower production is expected since hydropower is one of the most economic energy resources and is renewable through hydrological cycle along with its other benefits such as water supply, irrigation, flood control, navigation, and recreation (International Hydropower Association, 2000; DOE, 2004). In the case of large dams, it is imperative to understand the interactions between the uncertainty around and the significance of environmental impacts due to such large dams, because changes in terrestrial ecosystems can affect climate, soils, vegetation, water resources and biodiversity; which are all closely linked to the sustainability of socio-economic development (He et al., 2003; Tullos, 2009).

China has an extensive history of water resource development and is home to almost half (22,000 out of an estimated 45,000) of the world's large dams (Fuggle et al., 2000). The Three Gorges Project is the largest water conservancy project ever undertaken, with a total reservoir storage capacity of 39.3 billion m^3 (Hayashi et al., 2008). The Three Gorges Dam, with a length of 2335 m and a height of 185 m, is the largest dam ever built in China (Fu et al., 2010). It is a multi-purpose hydro-development project designed to yield comprehensive benefits in flood control, power generation, and navigation (Wang, 2002). The project first began to impound water in 2003 and came to completion when the desired maximum reservoir water level of 175 m was reached in 2009. At a water level of 175 m with a storage capacity of 39.3 billion m^3, the Three Gorges reservoir has a surface water area of over 1080 km^2. The Three Gorges Project has great potential for hydro-electrical power generation and flood control (Liu et al., 2004), but its possible impact

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on the environment and socio-economy needs to be quantified. Because building up of reservoirs will inevitably result in significant loss of upstream terrestrial habitat through inundation, riparian and terrestrial ecosystems will be more or less disturbed (Railsback et al., 1991). Similar situations have existed with the construction of the Bhakra and Hirakud Dams in India, Volta Dam in Ghana, Kariba Dam in Zambia and the Aswan Dam in Egypt. However, a wide range of problems exist, such as reservoir sedimentation, environmental degradation, migration and resettlement (Sahin and Kurum, 2002; Gao and Mao, 2009). The construction of the Three Gorges Dam is expected to have a great influence on all ecosystems involved (Subklew et al., 2010) and the impact on environment is expected to be multifold. The purpose of this study is to investigate and quantify the impact of the construction of the Three Gorges dam on the riparian vegetation cover at different elevation zones using long-term remotely sensed data.

Many large ecosystems associated with large dam reservoirs are difficult to monitor because they are in remote or poorly accessible areas. The traditional ground-based method used at the regional-scale is very difficult to implement due to costs, labor and time involved. Satellite remote sensing techniques provide a useful and the most economical means for the monitoring of vegetation productivity and terrestrial ecosystems, due to the availability of high spatial and temporal resolutions. Moreover, satellites provide consistent repeat images of the same area at different times, allowing for timely and consistent estimates of changes in vegetation dynamics and productivity, and subsequently trends of change in the vegetation cover over a long time scale and on a large spatial scale (Zeng et al., 2008; Bellone et al., 2009; Sun et al., 2009). The capacity to monitor any on-going changes is critical to efforts toward balancing sustainable resource management and responsible habitat conservation. These changes will have characteristic spatial, spectral, and temporal patterns that can be observed in multiple acquisitions of satellite data over time (Hayes and Cohen, 2007).

Since the Three Gorges dam was built in a topographically rough region, how elevation will constrain the scale on which the dam will impact the riparian vegetation is still an open question. We hypothesize that local steep topography may act as a barrier to the transport of moisture in the atmosphere of the microclimate regime surrounding the reservoir. To test this hypothesis, we subdivide the riparian region along the Yangtze river around the Three Gorges dam into multiple elevation zones and track the vegetation cover changes with time at each zone. The objectives of this study are: (1) to map the dam's impact on the spatial and temporal vegetation coverage at each elevation zone using remotely sensed vegetation indices data at a regional scale in the Three Gorges Dam riparian region; and (2) to investigate the change of vegetative canopy at each elevation zone in response to dynamic reservoir water levels.

Study area

The Three Gorges Dam region in this study is the area from Baidicheng in Fengjie prefecture, Chongqing city, to Sandouping in Yichang prefecture, Hubei province (Hayashi et al., 2008). With a total length of 6300 km, the Yangtze River, the third longest river in the world, originates in the Tibet Plateau and flows eastward to the East China Sea. As the river flows east through the Daba mountains, it encounters a series of narrow constrictions at the Three Gorges of Qutang, Wu, and Xiling. The Three Gorges Dam was constructed at Sandouping in Yichang prefecture, Hubei province, located downstream from the Xiling Gorge. The area inundated by the reservoir pool stretches from Yichang of Hubei Province upstream to Jiangjin City of Chongqing Municipality, a distance of 600 km and covering an area of 57,900 km^2, including 9777 km^2 of previously cultivated land (Ponseti and López-Pujol, 2006). As a result of the dam construction, the average width of the upstream waterway increased from 0.6 to 1.6 km (Wu et al., 2006). The reservoir has a mean depth of about 70 m and a maximum depth near the dam of approximately 175 m. As the topographic profiles are narrow and deep, the reservoir will retain the long narrow belt shape of the original river section and will be a typical river channel-type reservoir. The Three Gorges region has a humid subtropical climate with a frost free season of 300–340 days. The mean annual temperature is 16.5–19.0 °C. Annual precipitation averages approximately 1100 mm, 80% of which is received from April to October (Chen, 1993). The Three Gorges area is a mountainous region with 95% of the area consisting of hills and mountains and only 4.3% being flatland (Chen and Wang, 2010). Elevations vary greatly in the study area, with the lowest elevations at approximately 60 m above sea level (asl) along the Yangtze River and the highest elevations averaging 2000 m (asl), with several mountain peaks reaching approximately 3000 m (asl). Natural vegetation along the main channel of the Yangtze River consists mostly of shrublands and grasslands (Jiang et al., 2005. Also please see Fig. 11).

This study focuses on the 100 km riparian stretch of river upstream of the Three Gorges Dam site within the Yangtze River catchment watershed boundary (Fig. 1). The straight line which makes up the western boundary of the study area indicates the 100 km mark upstream from the dam site. This 100 km riparian stretch of river was chosen as the study area because it includes the main body of the reservoir immediately above the dam, extensive reaches of newly flooded river corridor and tributaries as well as a wide range of elevations above the maximum reservoir level. The size of the study area allows for an appropriate portrait of how the environment is reacting to the new reservoir storage levels at a regional scale.

Data sources

The data sources for this study include: 16-day 250 m vegetation indices satellite imagery data of Moderate Resolution Imaging Spectroradiometer (MODIS) on board Terra satellite; digital elevation model (DEM) data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and the Three Gorges Reservoir water level data collected by China Three Gorges Corporation.

MODIS vegetation index products

MODIS is one of the main instruments on board the Terra satellite launched in December 1999 and Aqua satellite launched in 2004. MODIS has a total of 36 bands, including 7 land bands. Out of the 7 land bands, two bands have a spatial resolution of 250 m and the rest have a spatial resolution of 500 m. The two 250 m bands were included to detect anthropogenic-driven land cover changes that commonly occur at or near this spatial scale (Townshend and Justice, 1988). Hansen et al. (2002) discovered that land cover changes associated with anthropogenic and natural causes can be well detected in the MODIS 250 m imagery. Wessels et al. (2004) and Wardlow et al. (2007) both found that general land cover patterns (e.g., agricultural, deciduous/evergreen forest, and grassland) could be successfully mapped with the MODIS 250 m data. MODIS has a total of 44 data products that hold the promise of becoming the most important data source for land cover characterization and operational monitoring at regional and global scales (Hayes et al., 2008). The land products from MODIS are designed to support long-term global change research and natural resource application (Justice et al., 2002).