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Examining impacts of the Belo Monte hydroelectric dam construction on land-cover changes using multitemporal Landsat imagery

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ABSTRACT

Many hydroelectric dams in the Brazilian Amazon have been constructed, but how dam construction influences land-cover change has not been fully examined. For our research, we selected Belo Monte hydroelectric dam, the third-largest dam in the world, to explore its impacts on major land-cover change. Multitemporal Landsat images between 2006 and 2017 were used. The maximum likelihood classifier was used to classify these Landsat images into primary forest, secondary forest, agropasture, man-made bare land, natural bare land, and water. The land-cover change was examined using the post-classification comparison approach based on different stages of dam construction, and was further examined along the upstream and downstream river buffer. The results indicate that overall classification accuracies of 89.7% and 92.3% were obtained for the 2011 and 2015 land-cover classification results, respectively. Primary forest decreased continuously from 47.8% in 2006 to 35.3% in 2017. Different stages of dam construction had various impacts, that is, before dam construction, deforestation and agropasture expansion were the major land-cover change categories; during dam construction, the increased area of man-made bare lands, the canal construction zone, and the increased area of natural bare lands downstream were obvious, in addition to deforestation and agropasture dynamics; when dam construction was complete, water bodies increased considerably upstream and decreased downstream. These big changes in water bodies may have long-term impacts on ecosystem functions and environments. This research provides new insights on the impacts of dam construction on land-cover changes, which is valuable for making better decisions about water and land resources.

1. Introduction

Since the 1970s, economic development, industrialization, and demographic growth have resulted in increasing demand for energy. This developmental pathway has led to strategies that give priority to the expansion of electric energy production (Bermann, 2001; Moretto, Gomes, Roquetti, & Jordão, 2012). As happened earlier in the USA and Europe, the strategy in Brazil gave importance to the construction of hydroelectric dams (Moran, 2016), and with priority given to the region with the highest hydroelectric potential: The Amazon. The region has a high potential for production of energy estimated at 77 GW (Brasil, 2007) and is considered the frontier for hydropower development with 352 dams planned, of which 96 will be hydroelectric and 256 will be smaller ones capable of generating energy (Aneel, 2017). The Belo Monte dam on Xingu River is the largest one in the Amazon.

Studies conducted in the 1970s projected the construction of up to six large dams that would have created flooded areas covering 17,610 km^2 (Sevá, 2005). The negative impacts associated with these projects, especially the flooding of territories of 37 indigenous groups, led to social mobilization opposing the construction of dams, with national and international attention brought to bear (Fearnside, 2015, 2017). These considerations, as well as difficulties in financing such dams in the 1990s (Moretto et al., 2012), kept the project from going forward. In the first decade of the 21st century, the project came back to

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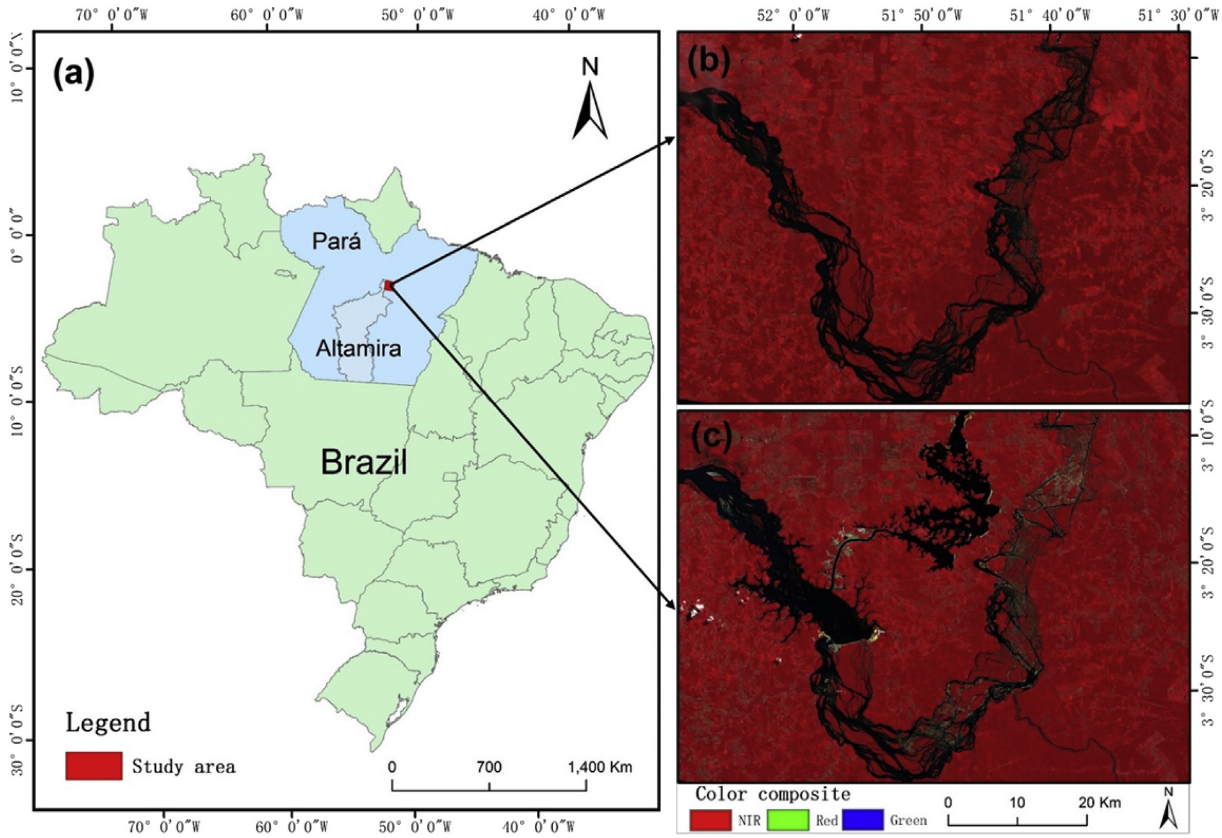

Fig. 1. Location of the study area (a) and color composites in 2011 (b) and 2016 (c) with Landsat spectral bands NIR, red, and green mapped in RGB. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

life as a response to concerns with deficits in energy production due to lower precipitation and lower energy production in existing dams—and a lack of planning and investment in the energy sector (Fearnside, 2003; Hage, 2012). Up to 2002, the energy matrix of Brazil depended on hydropower for 80% of energy production (Aneel, 2002), a situation of high risk due to a lack of diversified energy sources.

To speed up construction of Belo Monte, the Brazilian government and the construction companies redesigned the project to reduce the size of the area to be flooded to avoid flooding indigenous areas. This redesign increased the power production and made the project the third largest in the world in terms of energy production, i.e., 11 GW. The magnitude of the project—the largest infrastructure project undertaken by the government during the first decade of the 21st century—provoked the largest resettlement of people and greatest negative environmental impacts (Maia, Guerra, & Calvi, 2017). It led to rapid population increase (Moran, 2016), expansion of the urban area, and changes in the landscape (Feng et al., 2017).

The impacts of dam construction on population displacement, fisheries, biodiversity loss, and ecosystem functions and services have long been recognized (Fearnside, 2014, 2016, 2017). Chen, Powers, de Carvalho, and Mora (2015) examined the impacts of the Tucuruí Dam in the State of Pará, Brazil, on deforestation and degradation, but the impacts may be much more extensive and intensive in Belo Monte, and would include other land covers too. Studying the effects of Belo Monte dam on the surrounding environment is highly relevant given the scale and importance of the project for the local area, and because it is just one of many hydropower dams planned for the Amazon region. Understanding the land-cover transformations is also relevant to discussions of climate change, and to debates over the impacts that dams have on land-cover change. There has been a notable lack of assessments of the areas transformed by the building of dams and filling of reservoirs. In the past, construction companies have routinely underestimated the areas flooded by dams and the land-cover changes resulting therefrom. It is important to understand how different stages of dam construction—before, during, and after influence land-cover change.

The unique characteristic of remotely sensed data in data collection and representation of land surfaces has made it the primary data source for land-use/cover classification and change detection in the past four decades. A large number of studies have been conducted to explore the approaches to improve land-cover classification (see the review paper by Lu & Weng, 2007) and change detection accuracies (see the review papers by Lu, Mausel, Brondízio, & Moran, 2004, 2014). Although many classifiers such as maximum likelihood classifier (MLC), minimum distance, decision tree, and artificial neural network are available (M. Li, Zang, Zhang, Li, & Wu, 2014; Lu & Weng, 2007; Salah, 2017), MLC is often used for land-cover classification because it can provide similar or even more accurate classification results, especially when only spectral bands are used (G. Li, Lu, Moran, & Hetrick, 2011, 2012; Lu, Li, Moran, Dutra, & Batistella, 2011, 2012). Considering remote sensing–based change detection techniques, most of the algorithms such as principal component analysis, image differencing, and regression can only detect binary change and non-change information (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004; Erasu, 2017; Lu et al., 2004; Singh, 1989). However, in reality, we need to know the detailed "from-to" land-cover change trajectories (Lu, Li, & Moran, 2014). The post-classification comparison is commonly used for detecting land-cover trajectories (Han, Zhang, & Zhou, 2018; Lu, Li, Moran, & Hetrick, 2013; Tewkesbury, Comber, Tate, Lamb, & Fisher, 2015; Zhu, 2017). The key is to develop accurate land-cover classification result for each date.

Considering the stages of dam construction in this research, remote sensing data availability, and the characteristics of landscape under investigation, multitemporal Landsat images from 2006 to 2017 were selected to examine land-cover distribution and dynamic changes. The