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Urban growth and environmental impacts in Jing-Jin-Ji, the Yangtze, River Delta and the Pearl River Delta

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ABSTRACT

This study investigates land cover changes, magnitude and speed of urbanization and evaluates possible impacts on the environment by the concepts of landscape metrics and ecosystem services in China's three largest and most important urban agglomerations: Jing-Jin-Ji, the Yangtze River Delta and the Pearl River Delta. Based on the classifications of six Landsat TM and HJ-1A/B remotely sensed space-borne optical satellite image mosaics with a superior random forest decision tree ensemble classifier, a total increase in urban land of about 28,000 km^2 could be detected alongside a simultaneous decrease in natural land cover classes and cropland. Two urbanization indices describing both speed and magnitude of urbanization were derived and ecosystem services were calculated with a valuation scheme adapted to the Chinese market based on the classification results from 1990 and 2010 for the predominant land cover classes affected by urbanization: forest, cropland, wetlands, water and aquaculture. The speed and relative urban growth in Jing-Jin-Ji was highest, followed by the Yangtze River Delta and Pearl River Delta, resulting in a continuously fragmented landscape and substantial decreases in ecosystem service values of approximately 18.5 billion CNY with coastal wetlands and agriculture being the largest contributors. The results indicate both similarities and differences in urban–regional development trends implicating adverse effects on the natural and rural landscape, not only in the rural–urban fringe, but also in the cities' important hinterlands as a result of rapid urbanization in China.

1. Introduction

Alongside the continuous rise in global population, a simultaneous growth of urban areas is omnipresent. The increase in world population and the need for living space and search for employment results in migration from rural areas to cities and since 2008, more than half of the world's population resides in urban areas (United Nations, 2008). Over the past 30 years, China has experienced rapid urbanization and an immense growth in population as a consequence of economic and political reforms in 1978. Nowadays, urbanization is still proceeding at staggering speed. According to the National Bureau of Statistics of China, the total population in China has risen from 987 million at the end of 1980 to 1.341 billion in 2010. In order to adequately address the challenges for urban planning and a sustainable future development resulting from such a drastic increase in population, effective analytical methods to monitor the unprecedented growth of Chinese cities and techniques to evaluate the effect of urbanization upon the natural environment are crucial. The overall objective of this research is to investigate urban land cover changes and the resulting effects of urban growth on the environment by quantification of ecosystem services solely by remotely sensed data in form of multitemporal optical Landsat TM and HJ1-A/B image analysis. There are numerous studies on satellite monitoring of urbanization and different aspects of the impacts of urban growth at different scales over China. The following overview presents the most important and recent works on urbanization in China both at national and regional level.

2. Remote sensing efforts and urbanization in china

A summary of optical remote sensing capabilities and efforts in monitoring China's environmental changes not exclusively limited to the effects of urbanization but generally was performed by Gong et al. (2012). Driving forces, environmental change, materials transport and transformation, concentration and abundance change, exposure and infection change of human and ecosystems and the resulting impacts were categorized. Furthermore, the potential of remotely monitoring these changes was assessed and studies on environmental change efforts over China with remote sensing reviewed. A comprehensive evaluation of China's urbanization and effects on both resources and the environment was performed

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by Chen et al. (2010). Profound urbanization effects on resources, energy and an increased pressure on the environment could be reported. The extent of urban expansion for the whole of China for 1990, 2000 and 2010 was recently determined by Wang et al. (2012b). Optical Landsat TM/ETM+ data were used to delineate built-up from natural land cover classes. It was found that urban areas increased exponentially more than twice. Similar to the findings in this study, urban expansion is found occurring mainly at the expense of cropland. Urban expansion proceeded faster in the second decade. The changes in surface cover greenness in China were analyzed by Liu and Gong (2012) from 2000 to 2010. Interestingly enough and contradictory to the expectation of a decrease in vegetation cover for reasons of urbanization and desertification, Normalized Difference Vegetation Index (NDVI) values were found increasing over the whole of China. In some areas though, i.e. Jiangsu and Shanghai, a decrease in greenness could be observed as a resulting effect of urbanization. In addition to urbanization monitoring using optical data, Synthetic Aperture Radar (SAR) data have also been evaluated for urban land cover mapping and change detection in China with promising results (Ban and Yousif, 2012; Gamba and Aldrighi, 2012; Ban and Jacob, 2013; Yousif and Ban, 2013).

Chan and Shimou (1999) assess two issues having affected Chinese urbanization since the late 1970s. Firstly, the relationship between economic development and the protection of arable land is investigated and secondly, the quest for coordinated development in both rural and urban areas is discussed. Furthermore, a sustainable metropolitan development strategy is proposed. Lin (2002) gives a comprehensive overview of the growth and structural change of Chinese cities throughout different stages of urbanization, dating back to 1949. Another review that summarizes the achievements but also deficiencies of urban transformation in China from 1949 to 2000 was published by Ma (2002). Deng et al. (2008) investigate the driving forces and extent of urban expansion in China from the late 1980s to 2000 by analysis of remote sensing and socioeconomic data. Recently, Chen et al. (2013) investigated the development of urbanization and economic growth in China from 1960 to 2010. Their main findings were that China's urbanization process has progressed faster than the economic growth since 2004. It is advised that China should rethink under-urbanization and it is countermeasures in its development strategy. Continuous urbanization should focus on a qualitative rather than a quantitative development. The negative effects on health as a result of the transition from a rural to an urban society are summarized in Gong et al. (2012) and resulting impacts of urbanization in terms of changes in ecosystem service values was investigated in e.g. Zhao et al. (2004), Wang et al. (2006), Hu et al. (2008) or Liu et al. (2011).

Liu et al. (2012) analyzed regional differences of urban expansion in China from the late 1980s to 2008 at a 1-km resolution at provincial, regional and natural scales and found steadily increasing urban areas. Largest increases could be observed from 2000 to 2008. Regarding previous work over the three regions analyzed in this research, studies of urban expansion and changing landscape patterns in the PRD were performed by e.g. Li and Yeh (1998, 2004), Lin (2001), Seto et al. (2002), Seto and Fragkias (2005), Yu and Ng (2007) or Güneralp and Seto (2008). Urbanization studies in Beijing and in the JJJ region were carried out by e.g. Deng and Huang (2004), Tan et al. (2005), Xie et al. (2007) or Guo et al. (2009). Ban and Yousif (2012) investigated effective urban change detection methods in rapidly growing urban environments such as Beijing and Shanghai. The YRD and Shanghai as its biggest metropolitan area were analyzed in terms of landscape and urban pattern changes, urban growth and its effects upon the environment by, e.g. Ren et al. (2003), Zhang et al. (2004, 2009, 2011), Xie et al. (2006), Zhao et al. (2006), Deng et al. (2009), Hu et al. (2009), Zhang and Ban (2010), Tian et al. (2011), and Kim and Rowe (2012). The impact of urbanization on regional climate in Jing-Jin-Ji (JJJ), the Pearl River Delta (PRD) and the Yangtze River Delta (YRD) was analyzed by Wang et al. (2012a). Spatial and temporal changes of surface air temperature, heat stress index, surface energy budget and precipitation due to urbanization could be confirmed.

All studies mentioned above all pursue a particular objective and are most often either targeting the entirety of China or investigate only one of the regions under consideration. Even if the analyses concern urbanization and its effects in particular, variations in data, temporal and spatial resolutions, time frame analyzed and methodologies exist, rendering comparative studies difficult. Amongst all the above mentioned studies, no comprehensive analysis of the three largest agglomerations (JJJ, YRD and PRD) with the same methodology, same data and the same comparable environmental impacts could be found that may enable regional comparisons and could eventually contribute to a more sustainable development, giving impetus to this study. The main contributions of this research are the presentation of an analytical framework to investigate urbanization processes and potential environmental impacts on a large scale, the combined use of landscape metrics and ecosystem services as environmental impact indicators and a comparison of the divergences, similarities and character of urban and landscape development of China's three most important regions.

3. Study area and data description

The study areas of Jing-Jin-Ji (JJJ) with the Bohai Economic Rim, the Yangtze River Delta (YRD) and the Pearl River Delta (PRD) are the largest areas of urban agglomeration and can be regarded as the most important centres of Chinese trade, commerce, manufacture and industry. The location of the study areas is presented in Fig. 1. In 2010, the study areas' combined population accounted for 27% of the total in China and the regions' gross domestic product (GDP) represented 43% of the national GDP. JJJ as China's northernmost metropolitan region with its major cities of Beijing and Tianjin is located in Hebei province and stretches from the municipalities of Beijing and Tianjin towards the Bohai Sea. The region is rich in natural mineral resources, especially coal, iron and petroleum. The climate is humid continental and characterized by hot, humid summers and cold winters. The study area comprises roughly 185,000 km^2.

The PRD is located in southern mainland China adjacent to the South China Sea and is considered one of the country's chief economic regions and manufacturing centres. The study area covers about 42,500 km^2 in Guangdong province, one of the most densely populated provinces with the largest absolute population in China. Major cities in the region are Guangzhou and Shenzhen and the special administrative region of Hong Kong. The climate is humid subtropical. According to Ma (2008) the region's biggest advantage and threat at the same time is the extremely high degree of foreign investment.

The study area of the YRD covers an area of about 118,000 km^2 at the Chinese East coast bordering the East Chinese Sea. The region is characterized by a marine monsoon subtropical climate with cool dry winters and hot, humid summers. The YRD is part of the densely populated Jiangsu province in the north and Zhejiang province in the south with Shanghai municipality centrally located at the coast. The region's biggest advantages lie in a well-established infrastructural network regarding both high-speed roads and harbour areas (Ma, 2008).

38 Landsat 5 GLS1990 and 12 HJ-1A/B scenes dating from 2010 were selected for monitoring bidecadal land cover change over the large study areas covering nearly 350,000 km^2 in total. The images lie predominately in the vegetation period. However, there are some variations in acquisition dates for both the Landsat images