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Spatiotemporal evolution of carbon sequestration vulnerability and its relationship with urbanization in China's coastal zone

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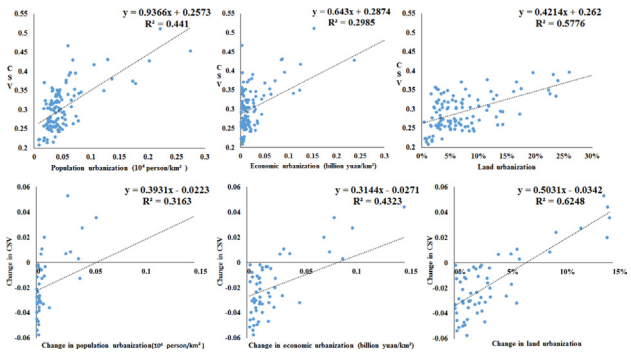
HIGHLIGHTS

- Carbon sequestration vulnerability (CSV) from 2000 to 2010 was evaluated.
- Land urbanization has better interpretation strength for CSV than other indexes.
- Land urbanization can better explain the change in CSV over the 10-year study period.
- CSV response to land urbanization was proven to be linearly increasing.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbon sequestration plays a vital role in maintaining the stability of global climate and the carbon cycle, but is undergoing significant changes due to urbanization. This study proposes the concept of carbon sequestration vulnerability (CSV), and explores the spatiotemporal evolution of CSV and its relationship between urbanization in China's coastal zone from 2000 to 2010. The study results provide a scientific basis for government management and policy-making. The results showed that the average amount of CSV in 2000 and 2010 was 0.301 and 0.279, respectively, in China's coastal zone and exhibited obvious spatial heterogeneity. Land urbanization had better interpretation strength for CSV than population and economic urbanization indexes, and could explain the 10-year change in CSV well in China's coastal zone. In China's coastal zone from 2000 to 2010, CSV response to land urbanization was proven to be positive and linearly increasing, and the slope of the linear relationship was 0.4214, cities with high land urbanization level have higher CSV; likewise, the change in land urbanization level had a significant positive and linear relationship with the change in CSV, and the slope of the linear relationship was 0.5031. When the city's land urbanization level increased by <6.8% over ten years, the CSV declined, and conversely, the CSV rose. For the goal of reduce CSV of cities, government and policy-makers should focus on land urbanization and it is possible to realize the goal by controlling land urbanization below 6.8% every ten years.

1. Introduction

Urbanization has become a remarkable characteristic of social development (Li et al., 2012; Zhao et al., 2016; Allington et al., 2017). The

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population shifts from rural to urban areas have caused rapid increases in the number of people living in cities (Tian and Qiao, 2014). In addition, urban construction lands have been converted from croplands and forests (Burke et al., 1991; Wang et al., 2012). By changing land use and land cover, urbanization has affected the flows of materials, energy, and information, and altered regional ecosystem services provided for humans (Rees and Wackernagel, 2008; Peng et al., 2017).

Carbon sequestration is the process of capturing, collecting, and storing carbon into carbon pools (IPCC et al., 2005; Li and Tang, 2006). As an important ecosystem service, carbon sequestration plays a crucial role in global warming and changes in the global carbon cycle (Zhang et al., 2016). The urbanization process has resulted in the loss of carbon sequestration capacity (Tian and Qiao, 2014). Besides, urbanization has brought increasing pressure on ecosystems with abundant green vegetation, such as forests, grasslands, agricultural land, and wetlands, which play an important role in carbon sequestration (Millennium Ecosystem Assessment, 2005; de Groot et al., 2012; Gao et al., 2013). Therefore, it is necessary to determine the extent to which carbon sequestration service may be affected by urbanization.

"Vulnerability" is a basic concept in assessing the environmental response to external impacts (Adger, 2006; Toro et al., 2012), and has been widely explored in interdisciplinary research (Qiu et al., 2015). Taking the concept of ecological vulnerability as a reference (Wu et al., 2018), carbon sequestration vulnerability (CSV) can be described through such characteristics as weak stability, weak anti-interference ability, and low recovery capability when an ecosystem with carbon sequestration service is suffering external disturbances. Compared to CSV assessment, the vulnerability assessment of ecosystem services (ES) is more common (Shen et al., 2016; He et al., 2018). However, only a few studies have demonstrated that urbanization has an impact on the vulnerability of ES. For example, Qiu et al. (2015) assessed the vulnerability of ES driven by urbanization, and found that the vulnerability degree of ES provisioning was intensified in China's eastern provinces. However, few studies have explored CSV and its relationship with urbanization. How large exactly is the impact of urbanization on CSV? This question has not been answered sufficiently.

The coastal zone is an important carbon source/sink site of an ecosystem (Regnier et al., 2013). On the one hand, because of its unique natural resources and geographical characteristics, China's coastal zone has become an area of intense human activities with rapid urbanization, economic growth, and high density population (Wang et al., 2012). However, the coastal zone is a typical ecologically vulnerable area with weak carbon sequestration capacity. A large amount of ecological space in China's coastal zone has been exploited, and coastal wetlands are continuing to disappear (Wang et al., 2012; Zhou et al., 2016). Therefore, it is necessary to clarify the relationship between urbanization and CSV in China's coastal zone to provide a scientific basis for government management and policy-making.

The objective of this study was to explore the spatial and temporal heterogeneity of CSV and its relationship with urbanization in China's coastal zone. First, we evaluated the CSV in China's coastal zone from 2000 to 2010. Then, we used population, economic, land urbanization indicators to detect urbanization levels from 2000 to 2010. Finally, we quantified the relationships between population urbanization, economic urbanization, land urbanization and CSV, and examines which urbanization indicators best explain CSV and provide scientific advice on policies.

2. Materials and methods

2.1. Study area and data sources

In principle, the coastal zone extends from the coastline a certain distance on both the land and sea sides, and typically is considered to encompass all area from the continental shelf to the beginning of the lowland interior in the continent. According to a comprehensive survey of coastal and tidal-flat resources of China in 1980, the coastal zone was defined as the coastline extending 10 km inland and extending 15 m isobaths to the sea (Du, 2005). However, this study focused on the area extending from the coastline to the land, referred to in previous studies as China's coastal zone (Di et al., 2014; Zhou et al., 2016). Thus, the study area was identified as a 10-km wide zone within the coastal zone (i.e., from the coastline to the land side), while maintaining the integrity of administrative boundaries within the prefecture level. The study area is in the eastern part of the Eurasian continent, on the west coast of the Pacific Ocean, (107°29′–125°40′E, 20°13′–42°06′N). The area encompasses 479,019 km^2 and includes 59 cities (excluding Hong Kong and Macao, as shown in Fig. 1) and accounts for 4.97% of China's territory. Benefitting from unique natural resources and geographical characteristics, the coastal zone study area has become the most important economic region in China, carrying 21.14% of the population and 39.90% of the total economy while comprising <5% of the area of the whole country (NBSC, 2014).

China's coastal zone belongs to the typical East Asian monsoon climate zone and contains several climatic variations from north to south. Taking Hangzhou Bay as a boundary, in the north, the landscape is dominated by staggered plains, mountains and hills. In the south, the landscape is dominated by low hills and plateaus, and the plains are mainly distributed in the estuarine delta near the coast. Furthermore, there are many coastal islands in the area. The main types of land use in the coastal zone are farmland, forest land, and construction land, of which forest land is dominant in the south and farmland is mostly located in the north (Di et al., 2014).

In this study, ten types of data were used. The detailed data resources are listed in Table 1. "Urban land" in the High-resolution Multi-temporal Global Urban Land Dataset refers to 'impervious surface' based on Landsat images for the 1990–2010 period with a five-year interval (X. Liu et al., 2018). The land use type of land use-land cover (LULC) data included six main types: forests, grasslands, agricultural land, construction land, unused land, and waters. The normalized

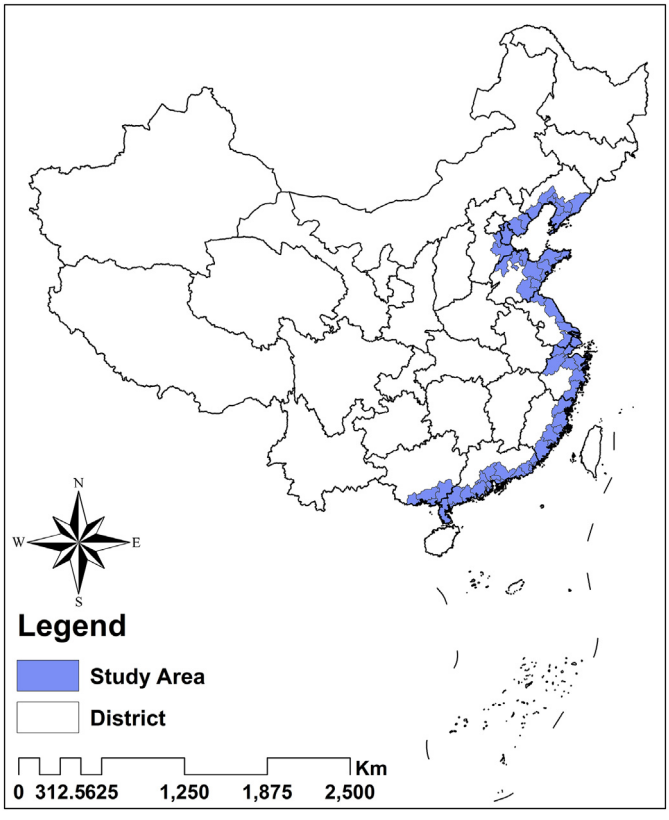

Fig. 1. The location of China's coastal zone.