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Spatiotemporal Analysis of the Bohai Sea Coastline Based on GIS and Remote Sensing

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Abstract. In recent years, the Bohai coastline has undergone significant changes. Due to sea reclamation and harbor construction driven by industrialization, the coastline has expanded significantly, bay areas have shrunk, and the types of coastal land use experienced huge changes. These alterations pose threats to the stability of coastal ecosystems. Remote sensing plays a crucial role in monitoring the spatiotemporal changes of coastlines, providing high-resolution images that are indispensable for coastal analysis. Based on remote sensing and GIS methods, this paper will analyze the spatiotemporal changes of the coastline from 1986 to 2016, identifying the drivers behind these changes. The study focuses on three main factors: coastline change, bay area change and land-use type change. It finds an increase of 1102.77 km in coastline length, a decrease of 1824 km² in the bay area, and a gradual replacement of natural shorelines with artificial ones and constructed lands, leading to severe degradation of coastal mudflat wetlands. These changes have resulted in impaired ecosystem services, habitat loss, and reduced biodiversity, threatening the stability of the coastal ecosystem.

Keywords: Remote sensing; GIS; Bohai sea coastline; Spatiotemporal analysis.

1. Introduction

In the last 40 years, due to natural and human factors such as climate change, land reclamation, and port construction, significant changes have occurred along the coastline of the Bohai Sea [1]. Changes in coastline had great research significance due to their strong connection to the stability of coastal ecosystems and coastal economic activities. Coastal analysis can reveal information about coastal erosion, changes in coastal land use, and alterations in mudflats and wetlands, providing a scientific basis for ecological conservation studies. This process aids in mitigating the negative impacts of climate change and human activities on coastal ecology.

Coastline morphology data has two main sources of collection, which are In-situ measurement and remote sensing measurement. In-situ measurement relies on field works that yield the most accurate data, but it is only feasible in small areas, which is unpractical in large-scale and long-time span coastline observation [2]. Remote sensing offers significant advantages such as extensive coverage area and the ability to obtain high spatiotemporal resolution data. It effectively overcomes various constraints that might be encountered in field surveys of coastlines. As a result, remote sensing has been widely applied in monitoring the spatiotemporal changes of coastlines. Scholars have extensively researched the spatiotemporal changes of coastlines using remote sensing technologies. Currently, the remote sensing images used for extracting coastlines are obtained through satellite optical remote sensing, microwave remote sensing, or LiDAR (Light Detection and Ranging) remote sensing [3]. The primary data sources used for extracting coastline remote sensing data include the Landsat satellite, SAR satellite, and Gaofen satellite series. Specifically, Landsat satellite imagery is often used to analyze coastline changes over large areas and long time spans due to its extensive temporal data series. Its relatively low resolution is insufficient for precise mapping and monitoring. High-resolution satellite imagery offers fewer error images, but its use in large-scale spatial-temporal studies is limited. Characteristics such as high cost and limited scale determine its limitations in coastline analysis.

This paper will focus on analyzing the Bohai Sea's key coastal areas over the last 30 years. Utilizing remote sensing and Geographic Information System (GIS), it examines trends in coastline and coastal land use changes, sourced from Landsat satellite data. Furthermore, the study will delve into the underlying causes of coastline alterations, investigating the spatiotemporal dynamics driving these changes. It also aims to uncover the primary effects of coastline modifications on ecosystem stability. Ultimately, this research will offer scientific insights to inform the formulation of sustainable coastal development strategies.

2. Data and Method

2.1. The Study Area

The Bohai Sea, an inland sea of China, is bordered by Liaoning, Hebei, Tianjin, and Shandong—three provinces and one municipality to the north, west, and south, respectively. It is located between latitudes 37°07' to 40°56' N and longitudes 117°33' to 122°08' E and serves as a vital economic development zone and maritime trade route for the country. The Bohai Sea is divided into five parts: the Liaodong Bay, Bohai Bay, Laizhou Bay, the Central Shallow Sea Basin, and the Bohai Strait. The coastline of the Bohai Sea hosts major ports such as Dalian, Tianjin, Yingkou, Qinhuangdao, Tangshan, Huanghua, Weifang, and Longkou ports. Most of these port areas have been artificially constructed on shallow beaches through dredging and land reclamation [4].

2.2. Data source and processing

The data sources of this research study are primarily from the Landsat series satellite. Landsat TM and OLI series remote sensing data from 1986 to 2016 were used. In the processing of remote sensing images, the ENVI platform is used as the primary tool. This platform is capable of performing geometric precision correction, coordinate system and projection conversion, band combination, and radiometric enhancement on satellite remote sensing images.

2.3. Method of extracting the coastline

In remote sensing terminology, a coastline is usually derived from instantaneous water—the land-water boundary at the time of remote sensing imaging. Based on the instantaneous coastline and a digital elevation model (DEM), a more stable coastline called a corrected coastline can be obtained to estimate the mean high waterline [5]. The methods of extracting coastline information by remote sensing can be divided into visual and automatic interpretation. Visual interpretation is more accurate, but it is vulnerable to the subjective factors of operators. Automatic interpretation, due to its high efficiency and reusability, has become the most popular method of extracting coastline information [6].

Coastlines can be categorized into natural and artificial characteristics [7]. During the extraction process, artificial coastlines are easier to identify and can be visually interpreted using remote sensing images with the help of the ArcGIS platform. In contrast, natural coastlines usually require a human-computer interactive interpretation method [4]. The process begins with data collection using high-resolution remote sensing images. Next, automated algorithms are applied to preliminarily identify the coastline areas. Subsequently, by combining manual interpretation and automated results, the final coastline dataset is generated. Lastly, field verification or interpretation validation using high-accuracy data is necessary.

3. Results and Discussion

3.1. Spatiotemporal variation of coastline length

Based on research data from Zhang Lei et. al [4], the trend of coastline length changes in the Bohai Sea can be deduced. From 1986 to 2016, the Bohai coastline increased by 1102.77 km, with a growth

rate of 47.2%, and showed an annual increasing trend (Fig. 1). The Bohai Sea region is finely divided into five coastal segments based on administrative divisions: Liaoning Province, Tianjin City, Northern Hebei Province, Southern Hebei Province, and Shandong Province [7]. The period from 2006 to 2016 was the peak of coastline growth in the Bohai Sea, with an overall growth rate of 22.9%, which is higher than the 9.2% of 1986-1996 and 9.6% of 1996-2006. Specifically, Liaoning Province and Shandong Province had growth rates of 21.1% and 17.8% respectively during 2006-2016, close to the Bohai region's average of 22.9%. Tianjin City and Southern Hebei had the highest growth rates at 77.6% and 70.6%, respectively, above the regional average. Northern Hebei had a growth rate of 7.9%, below the average.

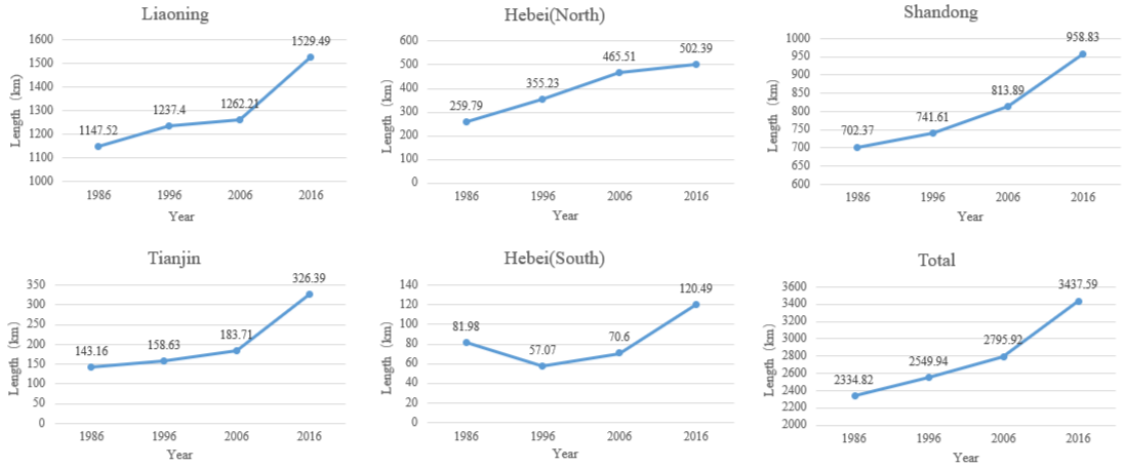

Fig. 1 Coastline Variation of Each Observation Zone in Circum-Bohai Sea Region

3.2. Spatiotemporal variation of bay area

Bohai Bay, a semi-enclosed bay located in the western part of the Bohai Sea, is one of the three major bays of the Bohai Sea (Liaodong Bay, Bohai Bay, and Laizhou Bay). The area of Bohai Bay has shown a decreasing trend, with the rate of reduction accelerating over time (Fig. 2). Between 1984 and 2015, the area of Bohai Bay decreased by a total of 1824 km², at an overall reduction rate of 16%. The period from 2005 to 2010 saw the fastest rate of decrease at 6%.

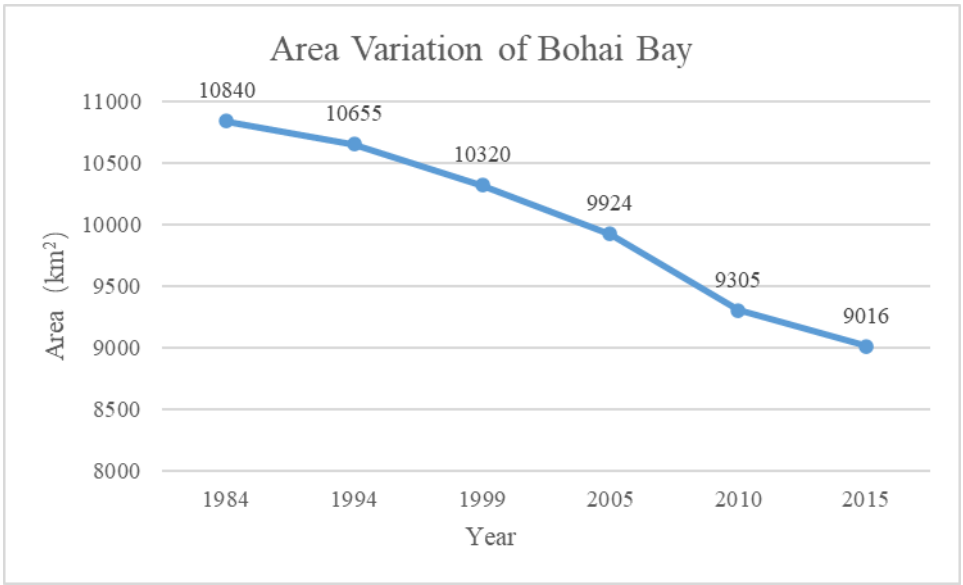

Fig. 2 Area Variation of Bohai Bay

3.3. Spatiotemporal variation of land-use type

Based on the research data from Wei Fan et, al [8], changes in the nature of coastlines and land use types in the Bohai Sea region have been determined. As shown in Fig. 3 (a), the artificial shoreline in the Bohai Sea region exhibits a continuously increasing trend, while the natural shoreline continues to decrease. The area of land reclamation shows a positive correlation with the length of the coastline and the length of artificial shorelines, and a negative correlation with the length of natural shorelines. This indicates a close relationship between coastline changes and land reclamation activities. In terms of changes in coastal land use types (Fig. 3 b), it is evident that the areas of salt pans, aquaculture, construction sites, and agricultural lands are positively correlated with the growth of the coastline. Unused lands are negatively correlated with coastline growth. Land reclamation activities are a significant driver of coastline changes, with human activities such as salt production, aquaculture, and port construction causing substantial changes in coastal land use types, thereby leading to an increase in the length of artificial shorelines.

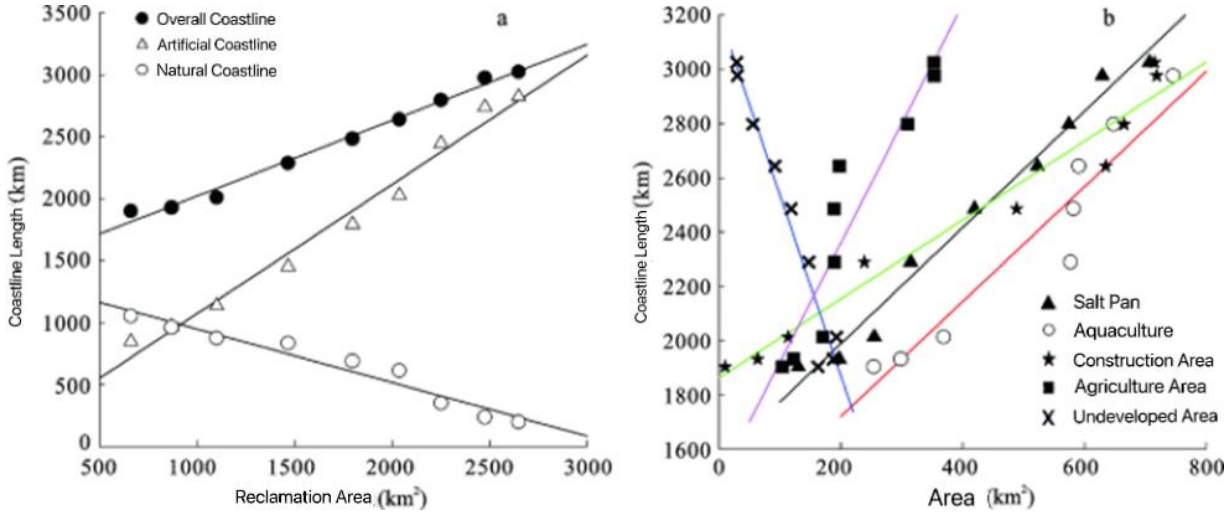

Fig. 3 Land-use Type Variation of Bohai Sea Coastline

3.4. Analysis of Spatiotemporal Variation

The changes in coastline length are closely related to human exploitation and the development of coastal tidal flat resources. The main reasons for the increase in coastline length are land reclamation, aquaculture, and the construction of ports and docks. Originally natural and relatively straight coastlines have become protruding polygons, resulting in an increase in coastline length. Since the 21st century, driven by the need for coastal economic development, large-scale port construction and industrial park developments have been the primary causes of the increase in artificial shoreline length and land reclamation. Post-2006, a period of rapid growth, industrial parks and ports such as Tangshan Caofeidian Port, Tianjin Binhai New Area, Tianjin North Port, Tianjin South Port, and Cangzhou Huanghua Port have driven massive urbanization and infrastructure construction along the coast, closely related to changes in coastline length and bay area. It can be said that changes in the intensity of human activities are the main reason for the changes in the coastline around the Bohai Sea.

3.5. Influence of coastline change on the environment and economic activities

The changes in the coastline of the Bohai Sea have significantly impacted the region's ecosystem. As the coastline expands and land reclamation activities increase, natural habitats are transformed into artificial structures, posing a direct threat to biodiversity. Land reclamation encroaches upon coastal tidal flats, estuarine deltas, and wetlands, leading to a sharp decline in the value of ecosystem services and the loss of their functions, such as fish spawning migrations and the habitats of migratory birds, resulting in the drastic reduction or even near extinction of wetland species populations [9]. Land reclamation activities reduce the water exchange capacity and self-purification ability of pollutants

in the sea. Activities like aquaculture, port docks, and portside industries increase the discharge of pollutants into the sea, continuously deteriorating the Bohai Sea environment, notably increasing the content of heavy metals like Cu, Cd, and Pb in sediments [10]. Studies indicate that the land reclamation project at Caofeidian causes an annual loss in ecosystem services such as biodiversity, climate regulation, and air and water quality adjustment, totaling 47.36 million yuan [11]. Furthermore, land reclamation damages the Bohai Sea ecosystem and biodiversity, affecting nearshore fisheries. The decline in water quality leads to the degradation of coastal fishery resources, impacting the economy and livelihood of fishermen [12].

4. Summary

This paper comprehensively utilizes remote sensing technology and GIS tools to analyze the dynamic changes in the coastline of the Bohai Sea region over the past 30 years and its impact on coastal land use. The results reveal a significant expansion trend in the coastline, primarily driven by human activities such as land reclamation and port construction. These changes have profound effects on the ecosystem, including decreased biodiversity and increased coastal pollution. Therefore, the future emphasis should be on establishing ecological reserves to protect coastal tidal flats, wetlands, and deltas. Strict implementation of ecological redline policies is necessary, along with improved supervision of land reclamation by relevant departments, and implementation of total area control over wetlands. Efforts should be made to restore and rebuild the environment and ecology of reclaimed areas and their surrounding seas, focusing on natural restoration supplemented by artificial means, to recover natural coastlines and coastal tidal flats. Intensified management of reclaimed areas should optimize coastal land use efficiency and prevent the disorderly expansion of economic and construction lands and artificial coastlines.

In the future, remote sensing technology and GIS will play a significant role in the ecological restoration of coastlines. Leveraging their networked, information-based, and multi-platform characteristics, they will enhance the construction of monitoring systems for coastal zones and marine foundations. By doing so, a shared platform integrating technology, remote sensing data, and policy can be established, providing support for scientifically planning future land reclamation activities to minimize their impact on the natural environment.

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