Geospatial Information Technology and Coastal Zone Science Research Postprint

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Abstract

In recent years, geospatial information technologies—including remote sensing, Geographic Information Systems (GIS), and Global Positioning Systems (GPS)—have developed rapidly, providing highly favorable technical support and development opportunities for coastal zone scientific research, and playing an increasingly important role in practical coastal zone applications. This article briefly enumerates the applications of geospatial information technology in coastal zone resource surveys, ecological environment monitoring, disaster management, and comprehensive assessment, and discusses its current application status and prospects. Based on China' s substantial current reserves of geospatial information technology, it is recommended to conduct foundational research on geospatial big data to support the informatization, quantification, and systematization of coastal zone scientific research, and to develop operational and intelligent applications to further directly demonstrate the value of geospatial information technology.

Full Text

Geospatial Information Technology and Coastal Zone Scientific Research

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Abstract

In recent years, geospatial information technologies (GITs), including remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS), have developed rapidly, providing powerful technological support and excellent development opportunities for coastal zone scientific research while playing an increasingly important role in practical coastal applications. This article briefly reviews applications of GITs in coastal zone resource surveys, ecological environment monitoring, disaster management, and comprehensive assessment, and discusses their current status and future prospects. Based on China' s substantial technical reserves in GITs, we recommend initiating fundamental research on geospatial big data to support the informatization, quantification, and systematization of coastal zone research, and to develop operational and intelligent applications that fully demonstrate the value of geospatial information technologies.

Keywords: remote sensing, geographic information system, global positioning system, coastal zone, applications
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Coastal zones serve as transitional areas between land and sea, characterized by pronounced land-sea interactions and unique properties that combine both terrestrial and marine features. With advantageous geographical locations, convenient transportation, abundant resources, and pleasant environments, coastal zones have become preferred regions for ocean development, economic growth, trade, and cultural exchange. Globally, although coastal zones account for less than 10% of the Earth's land area, they host extremely frequent human activities, with two-thirds of metropolitan areas exceeding 1.6 million inhabitants located in these regions [1]. China' s coastal zone encompasses economically developed and commercially active provinces and municipalities including Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hong Kong, Macao, and Taiwan. However, coastal zones are also ecologically fragile and sensitive areas. Intensive human activities exert tremendous pressure, leading to ecological degradation and environmental damage in some regions. Given the socioeconomic importance, geographical advantages, and ecological vulnerability of coastal zones, their sustainable development has become a global focus.

Geospatial information technology broadly comprises remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS)—commonly known as "3S" technology. Emerging as high-tech innovations in the 1960s–70s, 3S technologies have served as effective tools for data acquisition and analysis, playing important roles in coastal zone scientific research and production management. Remote sensing is an Earth observation technology offering broad coverage, strong timeliness, high accuracy, and cost-effectiveness, with unparalleled superiority in large-scale, massive data acquisition. GIS provides a comprehensive means for collecting, integrating, editing, processing, analyzing, managing, and applying geospatial data. Compared with traditional databases, GIS can better integrate geospatial and non-spatial information to analyze and represent spatial positions, attributes, and interrelationships of actual features. GPS is a new-generation system providing real-time three-dimensional navigation, positioning, velocity measurement, and timing services, characterized by all-weather operation, high precision, automation, and high efficiency, and has been widely integrated into daily life and military activities. In recent years, GITs have been extensively applied in coastal zone monitoring, analysis, investigation, and research, including coastal resource development and conservation, environmental monitoring and integrated management, becoming indispensable technical tools for sustainable coastal development research.

1.1 Coastal Resource Development and Conservation

Coastal zones possess abundant biological, energy, tourism, and port transportation resources, making them exceptional areas for human settlement and socioeconomic development. However, with limited resources and unlimited human demands, rational development and conservation constitute the key to maximizing resource utilization. Major maritime nations such as the United States, United Kingdom, and Australia have applied 3S technologies to virtually all large-scale nearshore resource surveys, ecological conservation, and development planning. Australia' s eastern coast, renowned as the "Gold Coast," features extremely rich coastal ecosystems. To comprehensively understand its complex ecological structure and material composition and achieve scientific management, local scholars have dedicated efforts to coastal resource surveys. In recent years, these investigations have increasingly employed remote sensing rather than traditional field surveys, monitoring nearshore seagrass species composition and coverage, retrieving biomass [2-4], detecting coral reef distributions [5], and assessing mangrove leaf area indices using remote sensing [6]. Additionally, GIS-based analysis of resource changes and future trend prediction has matured, providing scientific foundations for management decisions regarding resource development or conservation. In Hawaii, researchers developed a public-participation GIS to collect various data on coral reef utilization from the public and map usage patterns, enabling effective development and conservation management of coral reef resources [7].

As a major macroalgae farming country, China' s coastal macroalgae cultivation area and production have increased annually. Traditional information acquisition methods, such as querying statistical records or field visits, often yield inaccurate and untimely data. Lu et al. [8] utilized high-resolution imagery to automatically extract nearshore aquaculture areas in Fujian, while Gao et al. [9] successfully investigated spatiotemporal changes in mariculture patterns in Shandong Bay using Landsat data. Our research group employed China' s newly launched Gaofen-2 satellite (4 m resolution) to monitor macroalgae cultivation (Figure 1 [Figure 1: see original paper]), achieving 97% accuracy in cultivation area identification. However, such research remains in its infancy, with small study areas and limited macroalgae species monitored. Our group is currently developing a remote sensing-based automatic macroalgae identification system according to spectral and phenological characteristics of different species, integrating geospatial information technologies to rapidly and accurately obtain macroalgae distribution areas and estimate yields, thereby providing technical support for effective management and sustainable development of the macroalgae aquaculture industry.

1.2 Coastal Ecological Environment Monitoring

Dense populations and intense human activities in coastal zones create enormous pressure on ecological environments, causing or exacerbating problems such as invasive species, red tides, oil spills, and organic and heavy metal pollution. In nearshore terrestrial areas, Wang et al. [21] used Landsat and SPOT imagery to accurately monitor species distribution in Yueqing Bay, Zhejiang Province from 1993 to 2014 (Figure 2 [Figure 2: see original paper]), analyzing growth status and dynamic patterns of the invasive species *Spartina alterniflora* to provide means and strategies for its control. For the major oil spill incident in the Gulf of Mexico, Nelson et al. [11] utilized GIS and blowout/spill occurrence models to analyze spatiotemporal oil spill variations, assess vulnerability and potential risks in the Gulf, and support response efforts. Heavy metal pollution has become a primary environmental issue in coastal zones. Keshavarzi et al. [12] integrated geospatial information technologies to analyze heavy metal concentrations and spatial distributions in sediments of Chabahar Bay, clarifying various pollution sources. These cases demonstrate that GITs can effectively monitor the occurrence and evolution of ecological environmental problems, analyze and predict their trends, reveal mechanisms and influencing factors, and provide technical means and scientific foundations for ecological restoration, environmental protection, and efficient management.

Chlorophyll, colored dissolved organic matter, and suspended solids can reflect seawater health status and forecast red tide occurrences. Wen [10] used synchronous remote sensing spectral information and measured water quality data to develop a suspended matter remote sensing model for the Fuzhou section of the Min River, analyzing spatiotemporal variation patterns and their causes. Pan Delu's team at the Second Institute of Oceanography, State Oceanic Administration [23,26], achieved breakthroughs in "Key Technologies and Applications of Remote Sensing for Complex Nearshore Waters" in China, developing not only remote sensing retrieval models for colored substances like chlorophyll but also for non-photochemical substances such as nitrogen, phosphorus, and organic carbon. These advances enable high-precision water quality classification and have promoted the development of operational marine water quality remote sensing monitoring in China.

1.3 Coastal Land Use and Landscape Change

Frequent human activities in coastal zones cause dramatic land use changes. Geospatial information technologies can visually display land use conditions in different periods, providing scientific foundations for analyzing regional economic development speed and trends, formulating national development strategies, and supporting government policy guidance. Government agencies can establish coastal zone management systems using GITs to monitor land use, analyze development intensity, and assess environmental and ecological security [13], providing bases for rational land use planning formulation and adjustment. Furthermore, land use changes alter landscape patterns, making understanding land use dynamics essential for regional landscape pattern research. Taking coastal reclamation dynamics in Cixi City on the southern bank of Hangzhou Bay as an example, Landsat imagery acquired on July 19, 2004 (Figure 3 [Figure 3: see original paper]), combined with historical records from local chronicles and ground surveys, was used to trace reclamation activities over the past 1,000 years, revealing dynamic changes and patterns that facilitate systematic studies of socioeconomic, resource, environmental, and climatic factors across different historical periods.

1.4 Coastal Disaster Management

With dense populations and developed economies, coastal zones suffer severe casualties and property losses from frequent disasters such as tsunamis, earthquakes, and storm surges. To mitigate disaster impacts, monitoring, assessment, forecasting, early warning, and emergency response have become essential components of coastal zone management. Integrating 3S technologies to establish coastal disaster management and decision-making systems enables historical disaster queries, studies of spatiotemporal disaster patterns, timed and targeted monitoring, early warning and risk assessment, and decision support to minimize disaster losses [14]. For example, GIS' s powerful data integration, spatial analysis, and mapping capabilities support disaster emergency management [15], while 3S technologies have been used to study long-term erosion hazards in major Mediterranean river deltas and assess disaster risks in coastal zones [16], informing engineering construction in low-risk areas, avoiding human activities in high-risk zones, and preparing measures for high-intensity disasters. Geospatial information technologies play indispensable roles in predicting coastal disasters and reducing disaster losses.

1.5 Integrated Coastal Zone Management

Integrated coastal zone management encompasses planning, development, monitoring, conservation, and assessment. NOAA funded 29 coastal (and lake) states to establish coastal zone management databases 20 years ago, completing basic information and network platform construction that supports operational integrated coastal management, real-time information transmission, and publication [17]. China established its National Marine Information System in 1997, integrating marine development, application, network technology, and communication technology with marine economic, resource, environmental, spatial, literature, and legal information, capable of graphics, image, and text display, but without forming a complete integrated coastal monitoring system. RS provides more macroscopic and comprehensive coastal baseline information, while GIS can overlay land and marine data to provide scientific support for coastal functional zoning. Comprehensive RS and GIS applications bring new vitality to coastal ecosystem construction and promote integrated coastal zone management. Chen et al. [18] assessed the health status of terrestrial ecosystems along the Zhejiang coast from 1998–2007 by calculating vegetation indices from remote sensing and establishing three indicators (vigor, organization, and resilience) within a pressure-state-response framework. Miao et al. [19] used multi-temporal remote sensing imagery to classify and statistically analyze Bohai Bay coastal development activities over the past 20 years, estimating and analyzing ecosystem service value changes based on existing quantification research results.

2 Future Research and Development of Coastal Geospatial Information Technology

2.1 Future Research Directions and Frontiers

With complex natural conditions and frequent socioeconomic activities, sustainable development in coastal zones will remain a global priority. As the optimal means for massive coastal data acquisition, RS, combined with GIS as a powerful tool for storage, management, and analysis, and GPS as a rapid, accurate positioning and navigation technology integrating sea, land, and air, the development and comprehensive application of these three technologies are crucial for advancing coastal zone scientific research and establishing efficient integrated management systems in China.

(1) Remote Sensing: Technology Integration and Application Orientation. Hyperspectral remote sensing can detect finer and more specific coastal features to obtain spatiotemporal changes of target objects. Microwave remote sensing enables all-weather coastal monitoring. LiDAR, using airborne laser transmission and reception devices to emit high-power pulsed lasers at controlled wavelengths for underwater detection, is a new technology integrating optics, mechanics, and electronics, and an effective means for coastal topographic surveying [20]. However, due to laser signal energy attenuation in seawater, especially China’ s coastal waters with high suspended sediment concentrations causing stronger random interference, successful applications remain limited. Overcoming this challenge to enhance shoreline and ecological environment monitoring represents a future research direction. UAV remote sensing, with its low cost, high mobility, flexibility, and cloud resistance, demonstrates clear advantages and promising application prospects.

(2) Geographic Information Systems: Visual Interaction and Technol-

ogy Popularization. Currently, GIS possesses powerful data storage, editing, analysis, management, and application functions. Future development should support more data fusion types to achieve more comprehensive representation and comparison of coastal geographic spatial features and their evolution; develop and support more advanced and convenient public data analysis methods to enhance user-friendliness and operability for simpler, more effective, and faster coastal management; and develop more network-based, highly interactive GIS to facilitate collection, updating, and sharing of coastal natural and socioeconomic data, promoting public participation in coastal management [21-23].

(3) Global Positioning Systems: Integration with RS and GIS for Technological Leadership. Before 2025, China may launch over 70 Earth observation satellites [24], including land and environment satellites, ocean satellites, and meteorological satellites, creating enormous market opportunities and application prospects. China has independently developed multiple high-performance GIS software packages and trained numerous GIS professionals. The Beidou satellite navigation and positioning system can provide quality services comparable to American GPS. China' s drones occupy the vast majority of the global market share, becoming leaders in civilian drones. Features such as fixed hovering, automatic return, GPS positioning and navigation, 3D map reconstruction, and real-time image transmission provide low-cost, efficient, and practical technologies and means.

We are currently in the "big data" era. Li and Cheng [25] excellently elaborated on the research status and significance of big data and proposed development strategies. Big data implies tremendous social, economic, and scientific research value. In geoscience fields including coastal zones, big data has long existed —maps and documents accumulated over thousands of years, countless aerial images and photographs obtained over the past century, and massive remote sensing images from various satellites over the last 50 years constitute what we may call "geospatial big data," of which we currently utilize only a small fraction. Big data generally cannot be perceived, acquired, managed, processed, or served within tolerable timeframes using traditional IT technologies and software/hardware tools, and geospatial big data poses even greater challenges. How to reasonably filter and integrate these data, conduct comprehensive analysis and utilization, and serve the purposes of understanding coastal zone patterns, protecting, utilizing, and improving coastal zones represents not only the data value we pursue but will also better lead coastal science and engineering research and promote sustainable socioeconomic development in coastal regions.

2.2 Recommendations for China' s Development in This Field

China is currently implementing its maritime strategy and building the "21st Century Maritime Silk Road." Coastal zones in special geographical locations serve as essential links and harbors for this initiative. Simultaneously, China faces enormous challenges including maritime rights and interests maintenance, effective resource development and conservation, and ecological and environmental security. Geospatial information technologies can provide technical support for addressing these issues. However, solving these problems requires professionals, integration of ground-based and historical data, conventional and emerging technologies and methods, and particularly promotion of data standardization and sharing. Standardizing data from relevant departments, unifying data standards, and enabling public access and utilization will more effectively advance coastal zone scientific research and better solve practical problems we face.

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