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Analysis of Maritime Accidents in China's Coastal Waters Based on GIS Technology

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ABSTRACT
China's coastal waters represent one of the globe's most busy shipping zones, handling over 90% of the nation's foreign trade volume. However, the complex marine environment (e.g., typhoons, dense fog, intricate sea conditions) coupled with intense vessel traffic density leads to frequent maritime accidents. These incidents not only cause casualties and economic losses but may also trigger ecological issues such as marine pollution. To investigate the spatiotemporal patterns of maritime accidents along the China coast, this study collected data on 154 maritime accidents occurring between 2015 and 2025. Utilizing the ArcGIS platform and integrating environmental data such as ocean currents and typhoons, spatiotemporal visualization and spatial correlation analysis were conducted. The results indicate that: (1) Accidents exhibit significant spatiotemporal clustering, frequently occurring in the southeastern coastal regions and peaking during the summer months (June-August); (2) Collision and grounding accidents are closely correlated with typhoon tracks and ocean current activities; (3) Stranding accidents occur more frequently in narrow channels during winter, characterized by fog and low visibility. The research confirms the effectiveness of GIS technology in revealing the complex relationships between maritime accidents and environmental factors, providing a scientific basis for precise risk prevention and control in coastal shipping.

KEYWORDS
Maritime accidents; GIS technology; Spatiotemporal distribution; Risk prevention and control

1 Introduction

With the surge in shipping density along China's coast, risk prevention and control of maritime accidents have become critical issues. China's rising position in the global trade landscape has led to explosive growth in shipping density within its coastal waters, with massive numbers of vessels navigating between busy ports and complex channels [1-2]. Behind this prosperity, risks of maritime accidents loom large, intertwining factors such as collisions, strandings, fires, and even environmental pollution, posing severe challenges to maritime safety, property security, and marine ecology. Particularly noteworthy is the increased frequency of extreme weather events (e.g., typhoons, storm surges) induced by climate change, further amplifying navigational uncertainties [3]. Concurrently, geopolitical conflicts leading to risks of international shipping route blockades (e.g., lessons from the Suez Canal incident) could systematically impact China's resource security supply [2,4]. Against this backdrop, Geographic Information Systems (GIS), leveraging their superior spatial analysis capabilities, are becoming core technological supports for risk modeling and prevention systems [5-6].

The core advantage of GIS lies in its powerful spatial processing and multi-source data integration capabilities [7-8]. It can accurately plot discrete accident points onto electronic navigational charts, intuitively revealing the spatial distribution patterns and hotspot areas of accidents. More crucially, GIS can integrate and process various key spatiotemporal data: AIS (Automatic Identification System) data reflecting real-time vessel dynamics and density; precise chart information including water depth, obstructions, and channel boundaries; and complex marine environmental elements (wind, waves, currents, fog) and meteorological conditions affecting navigation safety. Through core techniques such as spatial overlay analysis (e.g., identifying spatial relationships between accident points and shallow waters/reef areas), buffer analysis (e.g., assessing risks around port facilities and sensitive ecological zones), and density analysis (e.g., depicting correlations between accident hotspots and dense traffic flow areas) [6,9], GIS can delve into the intrinsic links between accidents and various environmental and traffic factors. For instance, precisely identifying shallow areas as high-risk zones for stranding accidents, or warning of exponentially rising collision risks when encountering low visibility conditions in high-density traffic waters.

However, traditional GIS models still lack sufficient capability to quantify human errors in vessel operations (e.g., improper handling, delayed emergency response) and emerging risks like cyber-attacks (e.g., intrusion into vessel control systems) [10-11], necessitating integration with dynamic risk assessment frameworks [12]. Existing research often exhibits significant data limitations, relying on single data sources (e.g., AIS or accident reports) and lacking integration of multi-source data like meteorology and hydrology [5,7]. While previous studies have revealed the spatiotemporal distribution, typological characteristics, and causation patterns of accidents, they often lack the spatial visualization and risk modeling supported by GIS technology [15-16]. Research focusing on the international maritime security situation (particularly pirate threats) [17-18] has proposed vessel self-protection measures and emergency response mechanisms, providing logical support for GIS application in coastal risk prevention and control, yet often falls short in achieving risk visualization and coordinated response.

This study aims to construct a multi-source database (accident data, AIS data, marine environmental data) and comprehensively utilize GIS spatial analysis (e.g., kernel density estimation, overlay analysis) and statistical methods to quantitatively reveal the spatiotemporal distribution patterns of different categories of maritime accidents along the China coast. It will specifically investigate the spatial coupling relationships and mechanisms between these accidents and key environmental drivers such as typhoons and ocean currents, thereby addressing the current research gap in multi-dimensional, visual analysis of risk causation.

2 Data and methods

2.1 Data sources

Based on official data from the Maritime Safety Administration of the People's Republic of China (MSA), maritime accident data of various types occurring along the China coast over a ten-year period from 2015 to 2025 were collected. According to incomplete statistics, 154 cases of maritime accidents in China's coastal waters were ultimately collected. Due to the large spatiotemporal span, publicly available information is limited, and detailed information for some accidents could not be obtained. However, basic information such as the time, location, casualties, and category of each accident is generally clear. The case information in these statistics is relatively complete, and the sample is highly representative, serving as a data foundation for studying the spatiotemporal characteristics and patterns of maritime accidents along the China coast.

2.2 Analytical methods

ArcGIS was used for visualizing the accident data. Maritime accidents along the China coast from the past decade were categorized into the following four types for statistics, as shown in Table 1.

Table 1 Classification of maritime accident types

Category Name	Explanation
Category 1: Grounding	Refers to maritime traffic accidents where a vessel, during navigation and due to various reasons (e.g., navigational errors, severe weather, complex sea conditions), makes contact with submerged reefs, resulting vessel damage, cargo loss, or even casualties.
Category 2: Collision	Accidents where vessels contact or strike each other at sea or with other maritime structures (e.g., offshore installations). May be caused by improper vessel handling, negligence in lookout, violation of navigation rules, etc.
Category 3: Stranding	Accidents where a vessel, due to improper handling, positional errors, or influence by natural factors like wind, waves, or tides, rests its draft part on shoals, riverbeds, or other underwater obstructions, preventing normal navigation.
Category 4: Other Accidents	Encompasses all traffic accidents at sea, other than grounding, collision, and stranding, that cause damage or adverse effects to vessels, personnel, cargo, or the marine environment. Examples include vessel fires, loss of control due to mechanical failure, encounters with sudden maritime disasters (e.g., tsunami, not directly manifesting as grounding/collision/stranding).

Based on this four-category classification, the data were visualized in ArcGIS with overlay analysis to display the spatial distribution of accidents. This study also analyzed the influence of geographical factors on maritime accidents, presenting ocean current conditions and recent typhoon tracks in ArcGIS for combined analysis.

3 Results

3.1 Ocean current and typhoon factors

(1) In this study, China coastal ocean currents are divided into three parts for analysis: East China Sea region: As the most complex ocean current activity, it is affected by the superposition of multiple key currents, including Kuroshio, Warm

Current and Yangtze River Diluted Water. Ocean currents in this region are not only affected by warm currents in the open sea, but also easily coupled with tidal dynamics when typhoons pass through, forming a special "typhoon-tidal residual flow field ", and the direction and intensity of the flow field change sharply in the short term. The current is dominated by monsoon . It flows northeastward driven by southwest monsoon in summer, and southwest driven by northeast monsoon in winter . Although the overall current field is more stable than that of the East China Sea, the fluctuation of current velocity during monsoon transition period will still affect coastal shipping.(For example, Qiongzhou Strait and Pearl River Estuary route) .

(2) This study selects typhoons that have significant impact on the coast from 2015 to 2025, analyzes the generation source, movement track and main impact range of typhoons, reflecting the spatial law and risk coverage characteristics of typhoon activities . Typical typhoons mostly originate from the tropical northwest Pacific Ocean, and move mainly along the "northwest direction" after generation, forming two core paths: One is the "west-by-north track," which approaches and lands on the southeast coast of China via the sea east of the Philippines; the other is the "north-by- west track," which moves to the south-central East China Sea of China and the sea area near the Yangtze River estuary.

The typhoon track mainly covers the southeast coast of China, and the core affected areas include the south-central East China Sea and the northeast South China Sea, which are highly overlapped with the high-risk areas of subsequent maritime accidents; a few typhoons will penetrate deep into the Yellow Sea, although the frequency is relatively low, they will trigger short-term extreme sea conditions in this region . Typhoon track dense area is located near the southeast coast, completely overlapping with collision and reef accident hot spot area, reflecting the direct threat of typhoon to shipping safety. The huge waves and strong currents caused by typhoon will significantly increase the difficulty of ship operation .

3.2 Accident spatial distribution

The accidents showed a remarkable law of "southeast coastal agglomeration" -more than 80% of the accidents concentrated in the southeast coast of China (East China Sea and North South China Sea) . This area is not only the sea area with the highest shipping density, but also the area with the most active environmental factors such as typhoons and ocean currents."High shipping density + complex environment" leads to accident clustering. Collision accidents (accounting for about 40%): highly concentrated in the central and southern parts of the East China Sea . The ship flow in this area is large, and the "wave-current interaction" caused by typhoon-ocean current coupling will reduce the maneuverability of ships, resulting in difficulties in collision avoidance. Grounding accidents (accounting for about 25%): It is mainly distributed in two types of areas: one is the shallow water area near the Yellow Sea, where ships are prone to grounding due to errors in draft judgment due to deep water and large tidal changes; the other is the narrow channel along the southeast coast, where low visibility in foggy winter days will aggravate the risk of grounding. Reef accidents (accounting for about 15%): Sporadically distributed in islands and reefs concentrated areas, such as Zhoushan Archipelago in the East China Sea and Wanshan Archipelago in the northern South China Sea, the accident points are completely consistent with the spatial distribution of underwater reefs and reefs, and are mostly caused by ship deviation from the navigation channel or navigation errors . Other accidents (accounting for about 20%, including fire and mechanical failure): concentrated in the port periphery and busy route nodes, due to high equipment load and frequent personnel operation when ships are docked, accidents such as fire and main engine failure are easy to occur .

4 Discussion

4.1 Temporal pattern analysis

4.1.1 Seasonal dimension

From the temporal distribution of ocean currents and typhoons, summer (June - August) is the high-incidence season for typhoons, and ocean current activity is also relatively active. During this season, the frequency of collision and grounding accidents is relatively high. The synergistic effect of typhoons and ocean currents poses multiple threats to vessel navigation safety. Research finds that the refraction of tropical cyclone-generated waves by ocean currents can form wave height beams extending to the 100-meter isobath, where areas of high and low waves alternate, significantly increasing vessel handling difficulty [13].

In winter (December - February), influenced by cold air, coastal waters are often foggy and affected by cold waves, resulting in low visibility and difficult lookout for vessels. Stranding accidents show a certain high-incidence trend during this season, especially in areas with narrow channels and significant water depth variations, where vessels are prone to strand due to misjudgment.

4.1.2 Monthly dimension

From July to September each year, typhoon activity is most frequent, coinciding with the busy period of marine transportation and high vessel traffic density. During this time, the number of collision and other accidents increases significantly. The increase in collisions is due to the high number of vessels and poor maneuverability in typhoon conditions, making avoidance difficult. Other accidents are often related to damage to vessel equipment by typhoons and crew operational errors in severe weather.

From March to May, temperatures rise, and sea conditions in coastal waters are relatively stable. However, as spring is the peak season for fishery production, fishing vessel activity is frequent. In channel areas shared by fishing vessels and merchant ships, collision accidents also occur, though the overall frequency is lower than in summer.

4.2 Spatial pattern analysis

We found that typhoons and ocean currents are primarily concentrated and relatively active in the southeastern coastal areas of China.

The East China Sea is influenced by multiple current systems, leading to more complex typhoon-current interactions and resulting in most collision accidents.

The Yellow Sea, due to its semi-enclosed nature and shallow water characteristics, exhibits unique current field changes induced by typhoons. The coupling of tidal dynamics in shallow seas with typhoon forcing can produce special residual current fields [20], leading to various types of maritime accidents.

4.3 Direct impact of ocean currents and typhoons on maritime transport

Extreme waves generated by typhoons are one of the main factors threatening vessel safety. Research on super typhoon "Lekima" showed that considering wave-current interaction, the maximum significant wave height nearshore could increase by 6%-15% [14]. Coupled models revealed that waves significantly alter current direction during typhoons, with changes up to 20° in some areas, posing serious challenges to vessel stability [19]. Changes in ocean currents can exacerbate navigation risks during typhoons. During the interaction between typhoon "Matthew" and the Gulf Stream, waves underwent a transition from following currents (wave elongation) to negative current gradients (wave steepening and dissipation). Such rapid changes make it difficult for vessels to adapt [21]. Along the China coast, current changes during typhoon "Muifa" were closely related to tides and wind fields. This multi-scale dynamic coupling increases the uncertainty of the navigation environment. Particularly in nearshore areas, typhoon-induced current field changes superimposed with topographic effects can form complex eddies and shear currents [22], further increasing vessel handling difficulty.

5 Conclusion

(1) Main findings: This study, based on GIS technology, systematically organized and conducted spatial visualization analysis of maritime accident data along the China coast from 2015 to 2025, revealing the spatiotemporal distribution patterns of accidents and their close relationship with marine environmental factors (particularly typhoons and ocean currents). The research indicates that maritime accidents along the China coast exhibit significant spatiotemporal clustering characteristics, frequently occurring in the southeastern coastal waters with busy shipping and complex hydro-meteorological conditions. The accident types are highly correlated with season, month, and sea area environment. The coupling effect of typhoons and ocean currents significantly increases the difficulty of vessel handling and course keeping by altering the navigation environment (wave fields, current fields, visibility, etc.), serving as an important external cause for accidents such as collisions, groundings, and strandings.

(2) Theoretical/Practical significance: Through GIS spatial visualization and overlay analysis, this study spatially correlated abstract accident data with environmental factors (typhoons, ocean currents), achieving visual expression of risk and compensating for the shortcomings of traditional methods in mining spatial correlations. Practically, the research results can provide maritime regulatory authorities with high-precision, visual risk distribution maps; they can also offer scientific basis for shipping companies to optimize route planning and develop seasonal risk prevention and control plans, holding significant application value for enhancing the safety level and risk prevention capability of coastal shipping in China.

(3) Limitations of this study: As this study primarily focused on the relationship between natural environmental factors and accidents, it did not systematically quantify the impact of human and organizational factors such as human operational errors (e.g., negligence in lookout, misjudgment), vessel equipment status, and company safety management levels. Furthermore, the collected public accident data still has certain limitations in terms of detail completeness and

consistency; some accidents with incomplete information and minor accidents might not have been included in the statistics, potentially affecting the comprehensiveness of the analysis results.

(4) Suggestions for future research: Future studies could further integrate multi-source information such as AIS dynamic data, vessel attribute data, and crew operational behavior to construct a comprehensive dynamic risk assessment model encompassing "natural-human-vessel" factors. Simultaneously, introducing methods like machine learning could enhance the predictive ability for accident risks in complex environments. Additionally, expanding the research area to conduct comparative studies between different sea areas could deepen the understanding of regionally differentiated risk mechanisms.

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