Typhoon Compound Disaster Risk Assessment and Coping Strategies for Haikou City

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Abstract: This study takes Haikou, a typical tropical coastal city, as its research object. Using the H-E-V framework and multi-source geospatial data, it assesses typhoon compound disaster risks. Results show significant spatial differentiation, with an overall "high along coast, low inland" pattern. Based on the assessment, spatial planning strategies are proposed across macro, meso, and micro levels to inform disaster prevention and climate-adaptive governance for high-density coastal cities.

1 Introduction

Global climate change and rapid urbanization have increased extreme weather events, particularly typhoons threatening coastal cities. Enhancing urban climate resilience is now a national strategic priority. Focusing on Haikou, this study develops a framework for assessing "wind-heat-waterlogging" compound disasters, simulates their spatial risk patterns, identifies high-risk areas, and translates findings into spatial optimization strategies, providing theoretical support for disaster-resilient planning in high-density coastal cities.

2 Research Status

Domestic research has advanced in indicator systems and methodologies. A mainstream framework evaluates risk from hazard factors, exposure, and vulnerability. Yin et al. established a comprehensive indicator system with 14 metrics (Yin et al.,2013)[1]. Methods like AHP and fuzzy comprehensive evaluation are widely used; Zhou Xiaomei et al. applied AHP to create a system including disaster-forming environment, hazards, and exposure(Zhou Xiaomei et al.,2018)[2]. To improve accuracy, combined approaches are explored, such as Gu Xiaoli et al.'s model integrating fuzzy algorithms and AHP(Xiaoli et al.,2018)[3].

International research focuses on hurricane model development, establishing robust assessment systems. Rumpf et al. built a loss model using event-based simulations, historical data, and insurance records(Rumpf et al.,2009)[4]. Murakami et al. proposed the simultaneous excess duration concept, employing coupled atmosphere-ocean-wave models to assess complex hurricane risks(Murakami et al.,2015)[5].

3 Study Methods

3.1 Study Area

Haikou is located in northern Hainan Island, bordering the Qiongzhou Strait. Frequently affected by typhoons, its unique geographical and climatic conditions, combined with intensive urban development, make it an ideal case for studying typhoon compound disaster risks.

3.2 Evaluation Framework and Indicators

This study employs the Natural Disaster Risk Index method and adopts the UNDRR's H-E-V framework: Risk = H × E × V. Using AHP, an evaluation model was constructed with target, criterion, and indicator layers. Pairwise comparison matrices determined indicator weights, as shown in Table 1.

Table 1 Indicator Layer Weight Assignment Table.

Criterion Layer	
Primary Indicator	Weight
Hazard	0.338
Exposure	0.320
Vulnerability	0.342

3.3 Data Sources and Preprocessing

Hazard indicators were derived from multiple sources. Typhoon disaster data were obtained from the CMA-STI best track dataset (1949–2024) maintained by the Tropical Cyclone Data Center of the China Meteorological Administration. Waterlogging hazard data included 30 m resolution SRTM DEM and GlobeLand30 (2020 edition) land use data from Geospatial Data Cloud. Design rainfall was calculated using Haikou's storm intensity formula,

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resulting in a total rainfall of 152 mm for a 50-year return period and 120-minute duration. High-temperature hazard simulation utilized Landsat 8/9 Collection 2 Level 2 data from USGS Earth Explorer to retrieve summer land surface temperature (LST) for the period 2020–2025.

Exposure indicators included population density from WorldPop (2020), key facility density from OpenStreetMap POIs, and building density from the GHS-BUILT-S dataset (2025). Vulnerability indicators were derived as follows: proportions of elderly and child populations were based on multi-age group population density data at the township/street level in China; GDP distribution as a proxy for socioeconomic level came from corrected long-sequence nighttime light data (2020); building quality data were sourced from the 2024 National Multi-Attribute Building Distribution Vector Dataset; and cultivated land area was obtained from Hainan Province's 30 m land cover data.

4 Risk Assessment Results and Spatial Analysis

4.1 Hazard Assessment

For typhoon hazard, an assessment model integrating path frequency, duration, and wind speed was built using line density, point density, and interpolation methods (Wang, R.,2023)[6]. High-risk areas were identified in the middle reaches of the Nandu River and southern areas near Penglai Town (Figure 1). Sub-high-risk areas include the northern Xiuying Port coast and the ring area south of Dongzhai Bay. Spatial mismatches between high wind intensity and frequency zones, often adjacent to green spaces, reveal hazard complexity.

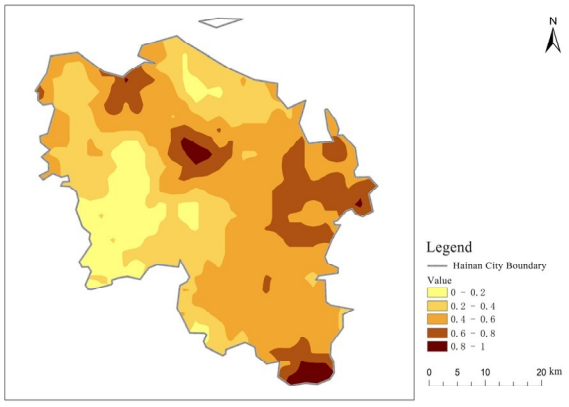

Figure 1 Typhoon Hazard Level Distribution Map.

For waterlogging hazard, the SCS-CN model and DEM simulated runoff under a 50-year rainfall scenario(Ma, L. et al.,2022)[7]. High-risk areas concentrate in natural convergence corridors like river valleys and their intersections with dense urban areas (Figure 2). Drainage capacity and micro-topography are key determinants in built-up areas, while central and northern regions face higher risk due to larger catchments and flatter terrain.

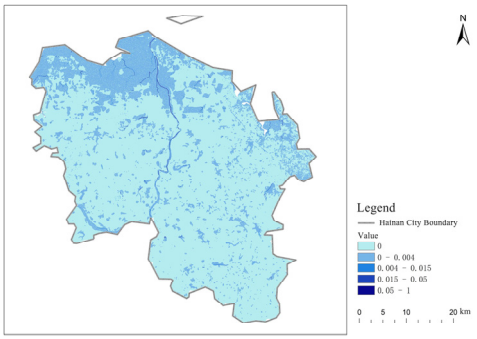

Figure 2 Waterlogging Hazard Level Distribution Map.

For heat risk, LST was retrieved via atmospheric correction, revealing a clear urban heat island effect with a "high core, low periphery" pattern (Figure 3)(Tang, H. et al.,2025)[8]. High-risk areas coincide with dense construction and low vegetation cover; low-risk areas correspond to large water bodies and vegetated zones, serving as ecological cold sources.

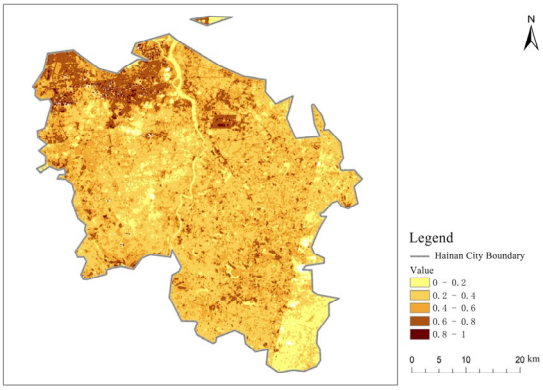

Figure 3 Extreme Heat Hazard Level Distribution Map.

Comprehensive analysis shows significant spatial coupling and differentiation of hazards (Figure 4 and Table 2). The central urban area in the lower Nandu River basin and Xiuying Port face multi-hazard threats. Secondary hazard areas, primarily typhoon-affected, include the middle Nandu River reaches, southern Haikou near Penglai, and areas south of Dongzhai Bay. The central city is dominated by waterlogging and heat risks from intensive development. The southwestern hilly region, with higher elevation and good vegetation cover, shows low levels across all hazards.

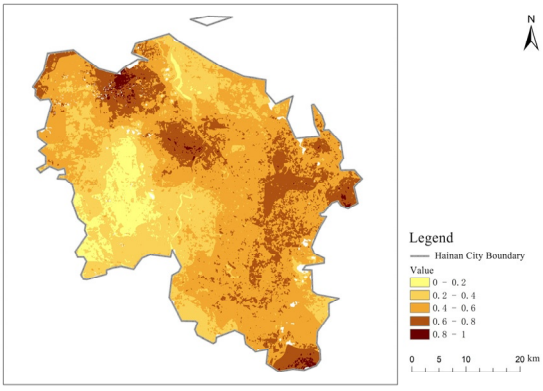

Figure 4 Hazard Index Distribution Map.

Table 2 Hazard Assessment Distribution Table.

Risk Level	Area (km²)	Percentage (%)
Extremely High Risk	91.91	2.94%
High Risk	438.98	14.04%
Moderate Risk	1264.41	40.37%
Low Risk	663.96	21.23%
Extremely Low Risk	669.57	21.41

4.2 Exposure Assessment

Exposure risk assesses the spatial density and value of elements at risk. Results show highly uneven distribution, with a "single-core, clustered" pattern in the main urban area where population, buildings, and critical infrastructure are highly concentrated (Figure 5 and Table 3). Medium exposure occurs in urban expansion zones and fringes; low exposure corresponds to southern ecological forests, nature reserves, and farmland/water bodies.

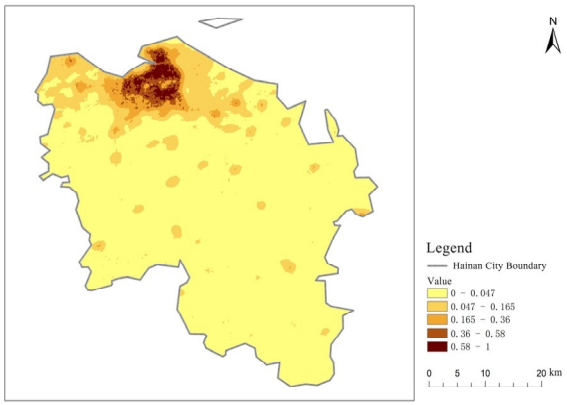

Figure 5 Exposure Index Distribution Map.

Table 3 Exposure Assessment Distribution Table.

Risk Level	Area (km²)	Percentage (%)
Extremely High Risk	99.44	3.18%
High Risk	89.02	2.85%
Moderate Risk	343.89	11.00%
Low Risk	338.35	10.82%
Extremely Low Risk	2256.12	72.15

4.3 Vulnerability Assessment

Vulnerability measures susceptibility and recovery capacity. The spatial pattern is a complex "mosaic" (Figure 6 and Table 4). High vulnerability clusters in old urban areas, historical neighborhoods, and some urban-rural fringes, characterized by aging populations, lower economic levels, and poor building quality. In contrast, core commercial and new development zones, despite high exposure, show medium/low vulnerability due to younger populations, better construction standards, and stronger economic resilience. Secondary high-vulnerability areas outside the main urban area relate to agriculture-dependent economies.

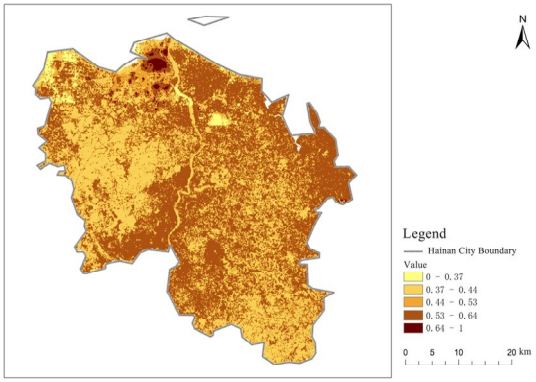

Figure 6 Vulnerability Index Distribution Map.

Table 4 Vulnerability Assessment Distribution Table.

Risk Level	Area (km²)	Percentage (%)
Extremely High Risk	103.36	3.31%
High Risk	1636.93	52.35%
Moderate Risk	150.15	4.8%
Low Risk	1026.28	32.82%
Extremely Low Risk	210.10	6.72%

4.4 Comprehensive Risk Assessment

A comprehensive risk index was generated by weighted overlay of normalized H, E, V rasters using AHP weights, classified into five levels (Figure 7 and Table 5). High and relatively high risks concentrate in Haikou's old urban core. This area is typhoon-affected, has low-lying terrain, aging drainage, high exposure density, and prominent social vulnerability, amplifying potential impacts. The central urban area's high risk is driven mainly by high exposure and vulnerability, not maximal typhoon hazard, whereas medium risk south of Dongzhai Bay stems from high hazard and vulnerability. This provides a scientific basis for targeted resilience strategies.

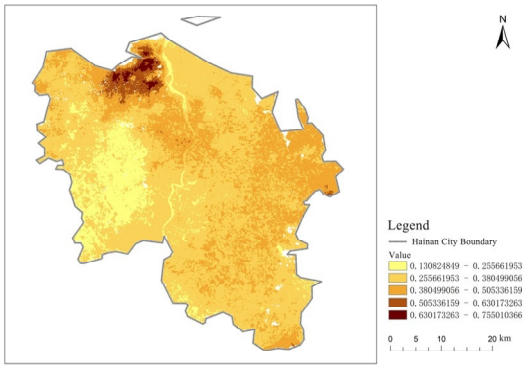

Figure 7 Comprehensive Risk Level Distribution Map.

Table 5 Comprehensive Risk Distribution Table.

Risk Level	Area (km²)	Percentage (%)
Extremely High Risk	108.37	3.47%
High Risk	231.99	7.42%
Moderate Risk	714.93	22.86%
Low Risk	1691.46	54.10%
Extremely Low Risk	380.07	12.16%

5 Spatial Planning Strategies

To address the compound risks of typhoons, waterlogging, and extreme heat in Haikou, a multi-scale resilient spatial system should be established.

At the macro level, the city is classified into three management zones based on comprehensive risk assessment: a red-line control zone in high-risk eastern and northern coastal areas, where development intensity is strictly limited and dual-purpose facilities for both daily and emergency use are promoted; a yellow improvement zone in the central urban area, focusing on restoring ventilation corridors and establishing resilient service stations; and a green conservation zone in low-risk southern ecological areas, emphasizing nature-based ecological restoration to enhance coastal buffering capacity. An integrated blue-green infrastructure network should also be established, including primary ventilation corridors no less than 500 meters wide along prevailing wind directions (Figure8, Figure9), linking ecological cooling sources such as the Dongzhai Harbor Mangrove Reserve and southern forest parks to improve systemic buffering capacity.

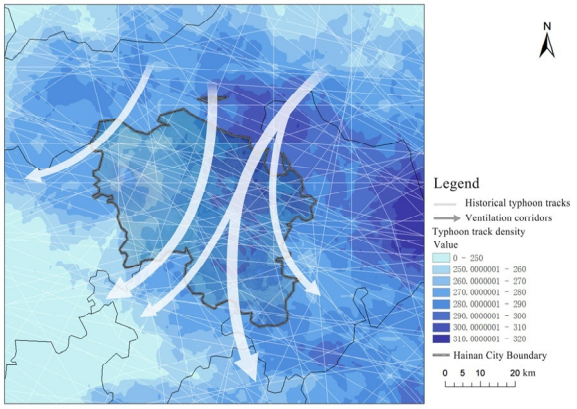

Figure 8 Haikou City Primary Ventilation Corridor Plan.

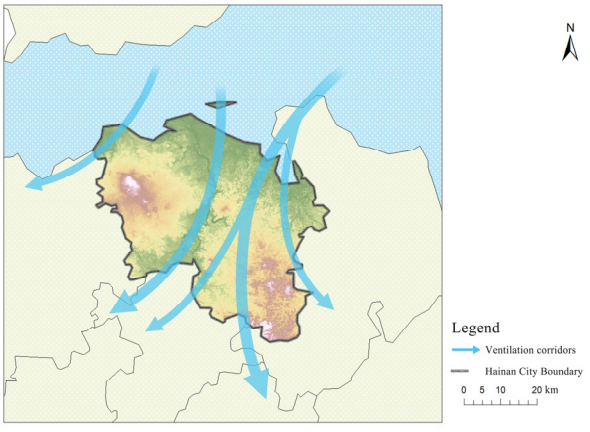

Figure 9 Haikou City Primary Ventilation Corridor Plan.

At the meso level, a stormwater management network combining blue, green, and gray infrastructure should be developed, with resilient sponge corridors constructed in areas like the middle and lower reaches of the Nandu River to improve waterlogging resilience. A hierarchical ventilation system should be established, with secondary wind channels along main roads, green spaces, and rivers to guide cool air into high-density built-up areas.

At the micro level, a wind-guiding system should be formed through block morphology regulation, dividing areas into corridor, buffer, and stable zones to coordinate typhoon wind management while maintaining urban functions. In high-vulnerability neighborhoods of old urban areas, organic renewal should emphasize pocket parks, vertical greening, and energy-efficient building retrofits to enhance intrinsic community resilience and climate adaptability.

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