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EVOLUTION AND PREDICTION OF URBAN FLOOD RISK UNDER LANDUSE CHANGE SCENARIOS: A CASE STUDY OF TIANJIN DOWNTOWN

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Abstract. The process of urbanization has resulted in alterations to land use patterns and catchment characteristics, which have in turn led to an increase in the frequency of urban flooding. The prediction of future land use in urban areas and the exploration of the evolution of urban flood risk under scenarios of land use change can provide a reference basis for the improvement of urban disaster prevention and mitigation planning and sustainable development. In this study, the Future Land Use Simulation (FLUS) model is employed for the purpose of predicting the land use pattern in 2030. The Maximum Entropy (MaxEnt) model and the risk evaluation indicator system are integrated to identify the principal influencing indicators and their impact on the urban flood risk. Furthermore, the urban flood risk pattern and its evolution under the scenario of land use change are analyzed with Tianjin Downtown as a case study. The results of the study indicate that: (1) The characteristics of land use change in Tianjin are dominated by a decrease in arable land and an increase in construction land. It is predicted that the area of arable land in Tianjin will decrease by about 2.51%, the area of urban construction land will increase by about 3.61%, and the impermeable rate of the urban subsurface will continue to increase from 2020 to 2030. (2) Indicators such as population density, land use type, and precipitation have a high contribution to the distribution of flood risk in Tianjin, while indicators such as imperviousness and green space coverage have a higher importance. (3) The proportion of high-risk area in Tianjin in 2010, 2020 and 2030 is 8.77%, 9.69% and 10.81% respectively. It can be predicted that the area of high-risk area will gradually increase with the expansion of urban construction land in the future. The high-risk areas are mainly concentrated in the central urban areas along the Haihe River. By 2030, the proportion of high-risk areas in Heping District, Hedong District, and Hebei District will exceed 50%. The results of this study provide a foundation for theoretical considerations regarding urban disaster early warning and land use resilience optimization.

1 INTRODUCTION

The acceleration of urbanization has profoundly altered land use patterns and watershed hydrological characteristics, leading to frequent urban flooding disasters [1]. Studies indicate that the expansion of impervious surfaces, reduction of green spaces, and lagging drainage systems significantly increase surface runoff and confluence speed, posing a greater flood risk to cities. In this context, predicting future land use dynamics and their potential impact on flood risk is crucial for optimizing disaster prevention planning and achieving sustainable urban development.

Existing research often focuses on risk assessment at a single time point, lacking coupled analysis of land use changes and the spatiotemporal evolution of flood risk. Traditional hydrological models can simulate hydrological processes but struggle to quantify the derivative effects of land use changes [2]. Therefore, this study innovatively couples the Future Land Use Simulation (FLUS) model with the Maximum Entropy (MaxEnt) model to construct a multi-scale risk assessment framework. The FLUS model can accurately predict the land use pattern for 2030, while the MaxEnt model, combined with a risk assessment index system, identifies the spatial impact mechanisms of key driving factors (such as population density, imperviousness, and precipitation intensity) on flood risk.

This study focuses on Tianjin Downtown, using multi-source remote sensing data and socio-economic driving factors. The FLUS model is employed to predict the spatial pattern of land use in 2030. Combined with key indicators such as historical precipitation intensity, terrain elevation, and impervious surface ratio, the MaxEnt model quantifies the contribution of each factor to urban flood risk, revealing the spatiotemporal relationship between land use changes and flood risk. The research results provide scientific support for optimizing the drainage network layout and formulating resilient urban planning in Tianjin, offering valuable insights for reducing flood disaster losses and achieving sustainable urban development.

2 MATERIALS AND METHODS

2.1 Overview of the study area

Tianjin Downtown is the political, economic, and cultural core of Tianjin, consisting of six administrative districts: Heping, Hexi, Nankai, Hedong, Hebei, and Hongqiao, as well as parts of Dongli, Jinnan, Xiqing, and Beichen districts. Tianjin Downtown serves as the central area for the coordinated development of the Beijing-Tianjin-Hebei region, characterized by highly intensive land use. Urban construction land is densely distributed, with a significant proportion of impervious surfaces (such as roads and buildings), while green spaces and open areas are relatively limited [3]. The area features a low-lying terrain, with the Haihe River and its tributaries running through the city, forming a typical dense river network. However, the drainage system's design standards do not match the rapid urbanization process, making some areas prone to waterlogging during heavy rainfall (Figure 1).

In recent years, with urban expansion and population concentration, land use types have rapidly shifted from agricultural to construction land, leading to a continuous increase in surface hardening rates. This has weakened the natural infiltration capacity of rainwater and intensified surface runoff pressure [4]. At the same time, the combined effects of frequent extreme precipitation events and rising sea levels have further amplified the risk of waterlogging.

Flooding disasters in the downtown area are mostly concentrated in low-lying areas along the Haihe River and around transportation hubs with dense underground space development. These areas are prone to forming water accumulation points during heavy rainstorms, threatening urban operational safety and residents' lives.

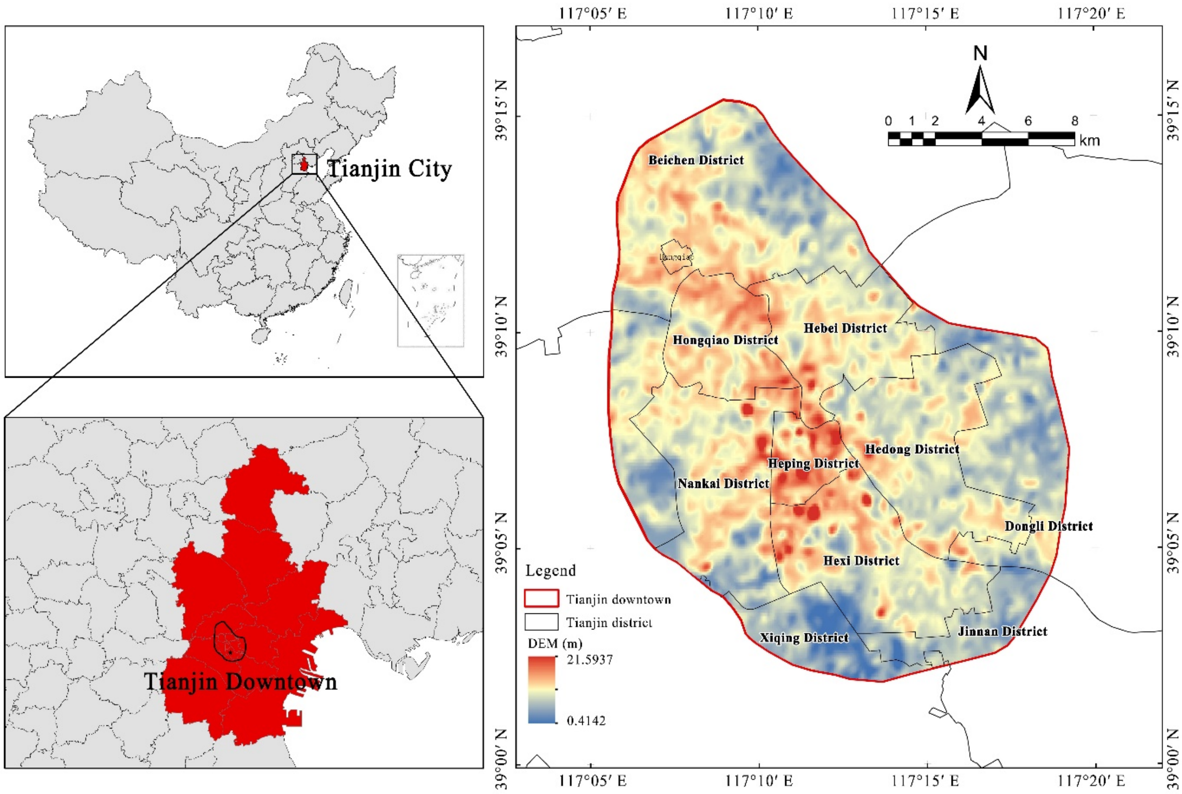


Figure 1: Overview of the study area

2.2 Research methods

2.2.1 FLUS model

The FLUS model, which combines system dynamics and cellular automata mechanisms, incorporates artificial neural network algorithms and a roulette selection mechanism. It effectively addresses land use scenario simulation and analysis driven by various natural, social, and economic factors, offering high simulation accuracy and reliability [4]. Land use changes are typically influenced by multiple factors. Natural conditions such as topography, geomorphology, hydrology, and meteorology determine the basic spatial pattern of land use. In contrast, socioeconomic factors, spatial location conditions, and planning policies significantly impact the evolution of land use patterns. This study uses land use data from Tianjin Downtown from 2010 to 2020, selecting normalized factors such as GDP, population, distance to roads, vegetation coverage, and elevation as driving variables. The FLUS model is used to simulate land use patterns for 2020 and 2030. The 2020 simulation results are used for model validation, confirming the model's reliability in land use scenario prediction.

2.2.2 MaxEnt model

The MaxEnt model is based on the maximum entropy principle proposed by Jaynes [5]. It calculates the contribution of each environmental factor to the distribution of samples using the geographical coordinates of sample points and the environmental variables of the distribution area, thereby simulating the potential distribution of the target event within the study area. This paper applies the MaxEnt model to predict the distribution of flood disasters in Tianjin Downtown, selecting 118 flood-prone points as sample points and normalizing 15 flood risk factors. After standardizing the data using the SDM Toolbox tool in the ArcGIS extension module, the data is input into the MaxEnt model. Land use types are assigned values based on their runoff and flood-prone characteristics, with construction land, farmland, grassland, forest land, and water bodies assigned values of 1 to 5, respectively, for unified processing. In the preliminary environmental settings of the model, a cross-validation method is used for model validation, with the maximum number of iterations set to 1000. The average of 10 repeated runs is taken as the final result to ensure the stability and reliability of the model.

2.3 Data sources

This study obtained a total of 510 flood-prone points in Tianjin Downtown from the "Tianjin Sponge City Construction Special Plan (2016-2030)," the Tianjin Water Authority, and the Baidu Flood Map. From these, 118 repeatedly occurring flood points were selected as research samples to ensure their representativeness. To scientifically simulate future land use changes and assess urban flood risk, the study collected and organized various data, including natural conditions, social capabilities, infrastructure, and built environment, using site-measured data, remote sensing imagery, and statistical survey data, as detailed in Table 1. Finally, all data were resampled using ArcGIS to a uniform resolution of 30-meter grids (Figure 2).

Table 1: Data sources

Dimension	Indicator	Attribute	Data Source
Natural Condition	Precipitation	1km grid	National Science & Technology Infrastructure of China (http://gre.geodata.cn)
	Elevation	30m grid	Geospatial Data Cloud (http://www.gscloud.cn)
	Slope	30m grid	ArcGIS analysis
	Roughness	30m grid	
	Relief	30m grid	
Social Capital	Population density	1km grid	LandScan population dataset (https://landscan.ornl.gov)
	GDP	1km grid	Real GDP data [7]
Infrastructure	Road density	30m grid	Gaode map
	Overpass distance	30m grid	
	Rain pipe density	30m grid	Rainwater System Planning of Tianjin Downtown (2020-2035)
Built environment	Land use	30m grid	Annual Land Cover Data of China
	Building density	30m grid	Gaode map
	Impervious surface	30m grid	ENVI remote sensing analysis
	Green space	30m grid	
	Water	30m grid	

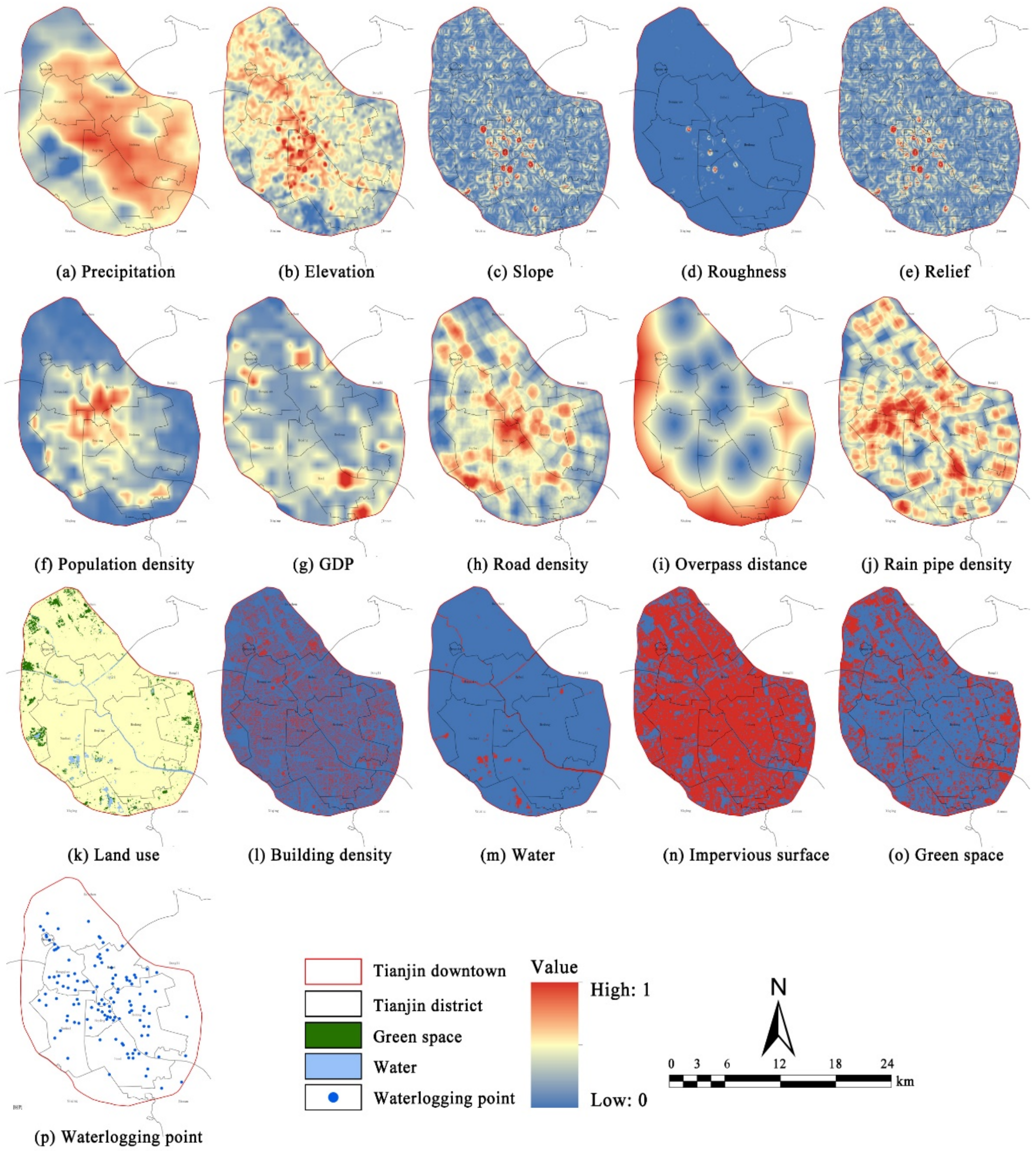


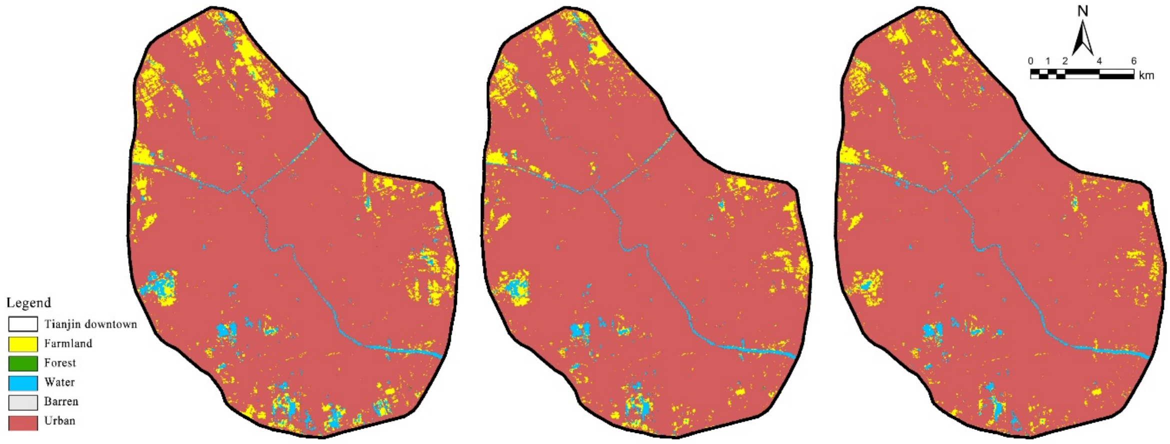
Figure 2: Data on the study indicators

3 RESULTS AND ANALYSIS

3.1 Land use scenario simulation and prediction

The FLUS model was used to simulate land use patterns for 2020 and 2030, as shown in Figure 3. The figure indicates significant changes in the land use patterns of Tianjin Downtown in recent years, with urban construction land continuously expanding, farmland being significantly encroached upon, and forested areas steadily decreasing. According to the statistical results of the pixel proportion of each land use type, between 2010 and 2020, Tianjin's farmland area decreased by approximately 2.64%, while construction land increased by about

3.43%. It is predicted that between 2020 and 2030, Tianjin's farmland area will decrease by about 2.51%, and construction land will grow by approximately 3.61%. Overall, the land use pattern is developing towards an increase in impervious surfaces, which to some extent raises the potential risk of flooding in Tianjin Downtown.



(a) 2010 (b) 2020 (c) 2030

Figure 3: Results of land-use simulation

3.2 Flood risk assessment and prediction

Land use data were used as change factors to assess and predict flood risk in Tianjin Downtown for the years 2010, 2020, and 2030. According to the ROC curve validation results from ten simulations in 2020, as shown in Figure 4, the model's average AUC is 0.876, which exceeds 0.7. This indicates that the risk prediction model employed in this study has a strong predictive capability for flood events, demonstrating high accuracy and reliability.

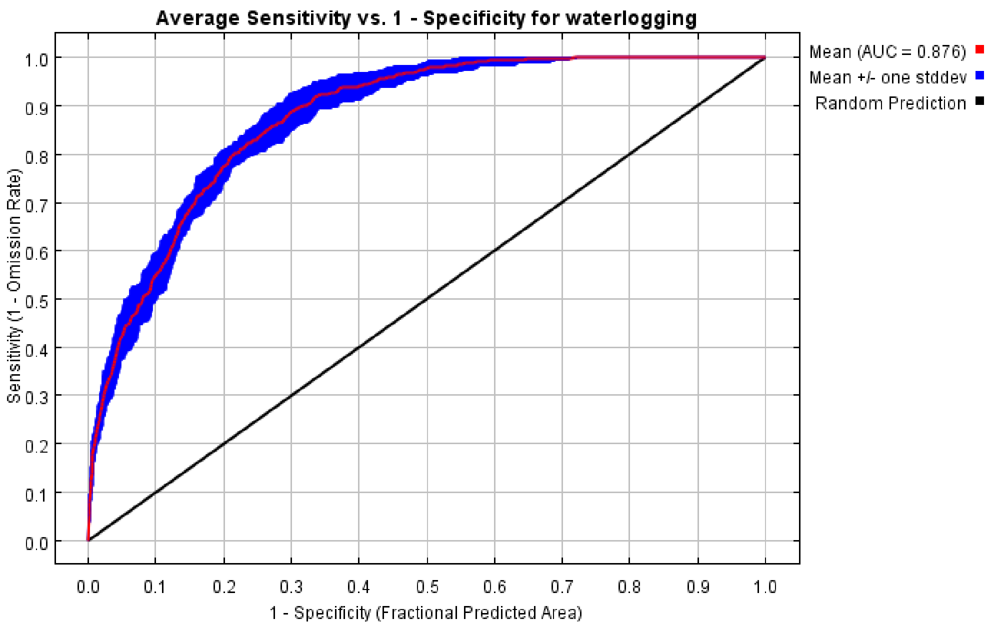
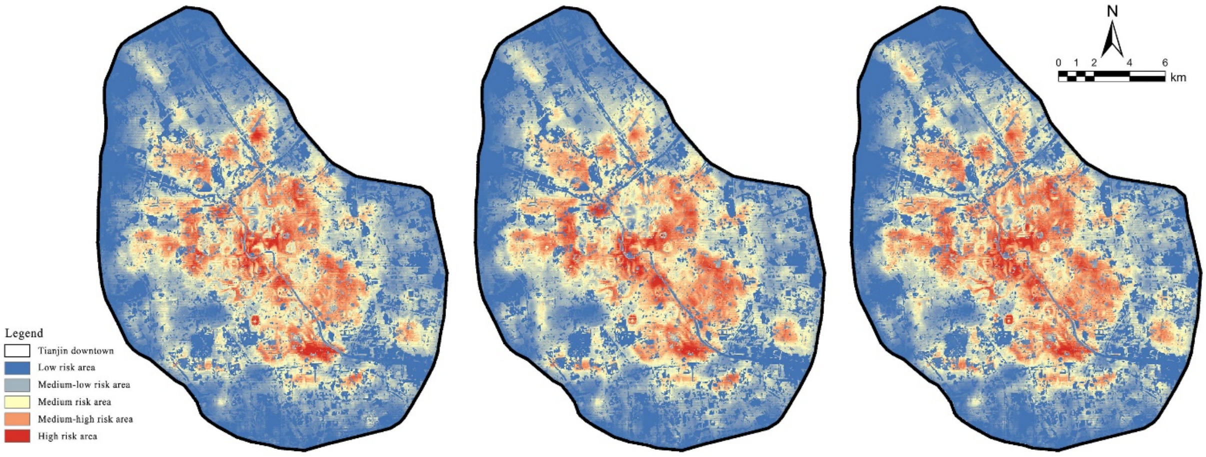


Figure 4: ROC curve of MaxEnt model

3.2.1 Distribution of flood risk

Using the MaxEnt model, flood risk in Tianjin Downtown was analyzed under land use patterns for 2010, 2020, and 2030. The natural breaks method categorized flood risk into five levels: low, moderately low, medium, moderately high, and high risk. ArcGIS was used to map the flood risk zones (Figure 5), and the area proportion of each risk level in Tianjin was calculated.

Overall, from 2010 to 2030, the flood risk zoning pattern has not changed significantly. High-risk areas are mainly distributed along the Haihe River in Tianjin's downtown, with the largest proportions in Heping, Nankai, and Hexi districts. The area proportions of high-risk zones for the three periods are 8.77%, 9.69%, and 10.81%, respectively, showing a slow upward trend. In general, high-risk and moderately high-risk areas overlap significantly with the city center and core development regions, gradually increasing as urban construction land expands.



(a) 2010 (b) 2020 (c) 2030

Figure 5: Simulation results of flood risk distribution

3.2.2 Flood impact indicators

The MaxEnt model provides the contribution rates and importance rankings of various indicators for flood risk in Tianjin Downtown (Table 2). The contribution rate refers to the degree to which each factor contributes to the model's results, representing the proportion of each factor's contribution to the final outcome. Importance indicates which factors have a more significant impact on the results within the model.

The results show that population density has the highest contribution rate to flood risk, while green space has the greatest importance. Additionally, land use, impervious surface rate, and precipitation each contribute over 9%, while impervious surfaces, terrain variability, distance to elevated structures, and population density all have importance over 7%.

These findings indicate that population, underlying surfaces, and precipitation significantly influence urban flood risk, collectively affecting and controlling its distribution.

Table 2: Contribution and importance of each indicator

Indicators	Percent contribution	Permutation importance
Population density	21.8	7.8
Land use	14.8	4.6

Impervious surface	14.2	18.8
Precipitation	9.2	5.5
Green space	7	20
Overpass distance	6	7.9
Road density	5.3	3.6
Rain pipe density	4.1	3.6
Water	3.9	7.1
Roughness	3.8	2.7
Building density	3.3	1
Relief	2.1	8
GDP	2	2.7
Slope	1.9	6.3
Elevation	0.6	0.3

4 CONCLUSIONS

This study, based on the FLUS model and the MaxEnt model, explores the relationship between land use changes and urban flood risk during urbanization, using Tianjin's central urban area as a case study. The conclusions are as follows:

Characteristics of Land Use Change: The area of arable land in Tianjin continues to decrease (projected to decline by 2.51% from 2020 to 2030), while construction land is rapidly expanding (increasing by 3.61% in the same period). The urban impervious surface rate is rising, exacerbating surface runoff and flood risk.

Key Drivers of Flood Risk: Population density, land use types (such as the proportion of construction land), and precipitation are core driving factors of flood risk distribution. The proportion of impervious surfaces and green space coverage are more sensitive to spatial variations in risk.

Evolution of High-Risk Areas: From 2010 to 2030, the proportion of high-risk areas in Tianjin increased from 8.77% to 10.81%. In central urban areas (e.g., Heping, Hedong, and Hebei districts), high-risk areas will account for over 50%, with risk hotspots concentrated in low-altitude areas along the Haihe River.

Planning Implications: The findings provide a theoretical basis for building urban disaster warning systems and optimizing land use resilience. It is recommended to control the expansion of construction land, increase sponge city facilities (such as permeable pavements and rain gardens), and protect green spaces along riverbanks to mitigate flood risk.

This study validates the effectiveness of multi-model coupling in disaster risk assessment and offers scientific support for sustainable planning in high-density urban areas.

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