

Abstract

In the context of global warming, extreme weather events and rising sea levels are increasingly threatening human societies. Over the past four decades, the rate of sea-level rise along China's coastline has accelerated; when compounded by rapid urbanization, coastal cities have been confronted with increasingly severe risks and challenges. As a coastal megacity with a dense population and developed economy, Shanghai has long been exposed to the impacts of ground subsidence and typhoon storm surges. In the future, these disaster factors will weaken coastal defense capabilities, exacerbate flood disasters and economic losses, and endanger sustainable development. Therefore, conducting comprehensive risk and economic-loss assessments under coupled disaster scenarios is crucial to strengthening Shanghai's disaster prevention capabilities and resilience. Considering ground deformation, sea level rise, and extreme storm surge events, this study employed a hydrodynamic model to simulate spatial extent and water depth of coastal flood inundation in Shanghai under different disaster scenarios in 2030, 2050 and 2100. Based on the simulation outputs, flood hazard indicators were derived. Subsequently, these indicators were integrated with building-level vulnerability and exposure indicators to establish a comprehensive risk assessment model (H-V-E model) for individual buildings in megacity. We applied this model to assess the risk of over 1.2 million buildings in Shanghai (excluding Chongming District). Additionally, this study estimated the potential direct economic losses caused by seawall overtopping and breaching under the various disaster scenarios. A multi-regional input-output model (MRIO) was further applied to assess the indirect economic damages of these disasters at the provincial level. The results indicate that under future complex disaster scenarios, the coastal areas of Shanghai face severe risks of coastal flood disasters, which may cause large economic losses.

Keywords: Ground subsidence; Sea level rise; Coastal flooding; Comprehensive risk assessment; Economic loss assessment;

1. Introduction

Coastal cities are situated at the interface between land and sea. Under the combined effects of natural and human activities, these regions are particularly vulnerable to severe coastal flooding. Shanghai is situated in the eastern coastal region of China, where storm surge disasters are frequent[1]. As one of China's most economically developed megacities, Shanghai is highly vulnerable to major flood events, which could result in enormous direct and indirect economic losses. In the future, under the combined influences of sea-level rise, storm surges, and weakened coastal defenses caused by land subsidence, the risk of coastal flooding and its economic losses will intensify, posing a serious threat to Shanghai's sustainable development. Therefore, this study focuses on the coupled disaster chain, innovatively conducting risk assessments at the individual-building level rather than the grid-cell scale, and applying a multi-regional input-output (MRIO) model[2] to assess indirect economic losses. We develop future disaster scenarios and employ the LISFLOOD-FP model, which is widely used for urban flood simulation[3], to simulate coastal flooding caused by seawall overtopping and breaching. Next, we construct a risk assessment index system based on three dimensions of hazard, vulnerability, and exposure, followed by a detailed assessment of individual buildings. Furthermore, we estimate potential direct economic losses using a loss function and assess indirect economic losses at the provincial level using the MRIO model.

2. Experiments and results

A. Ground Subsidence

In this study, we applied the SBAS algorithm to 141 ascending Sentinel-1A images acquired over Shanghai between 2017 and 2021 to derive the city's ground deformation velocity, as shown in Figure 1. This result will be used to construct future disaster scenarios and processed as one of the vulnerability indicators.

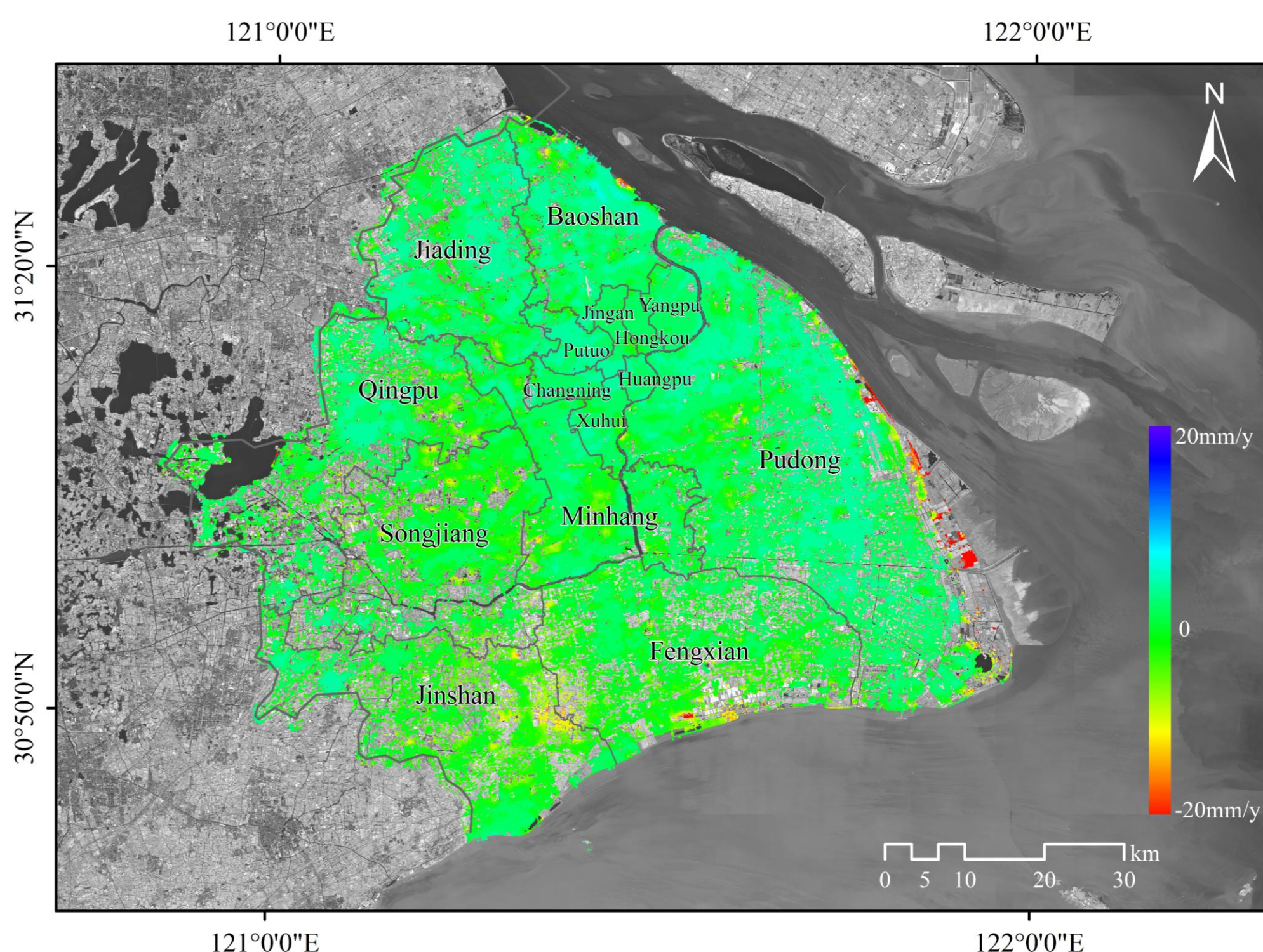


Figure 1. Maps of vertical deformation velocity of Shanghai from 2017 to 2021

B. Coastal Flooding Simulation

Considering ground subsidence, sea-level rise, and extreme storm surge events (Typhoon 9711), we computed the water-level boundary conditions for various future scenarios. Then we used the LISFLOOD-FP model to simulate the extent and depth of coastal flood inundation in Shanghai caused by overtopping and seawall breaching under the SSP1-1.9, SSP2-4.5, and SSP5-8.5 scenarios in 2030, 2050, and 2100. Figures 2 and 3 present the projected extents and depths of future coastal flooding under the SSP1-1.9 and SSP5-8.5 scenarios.

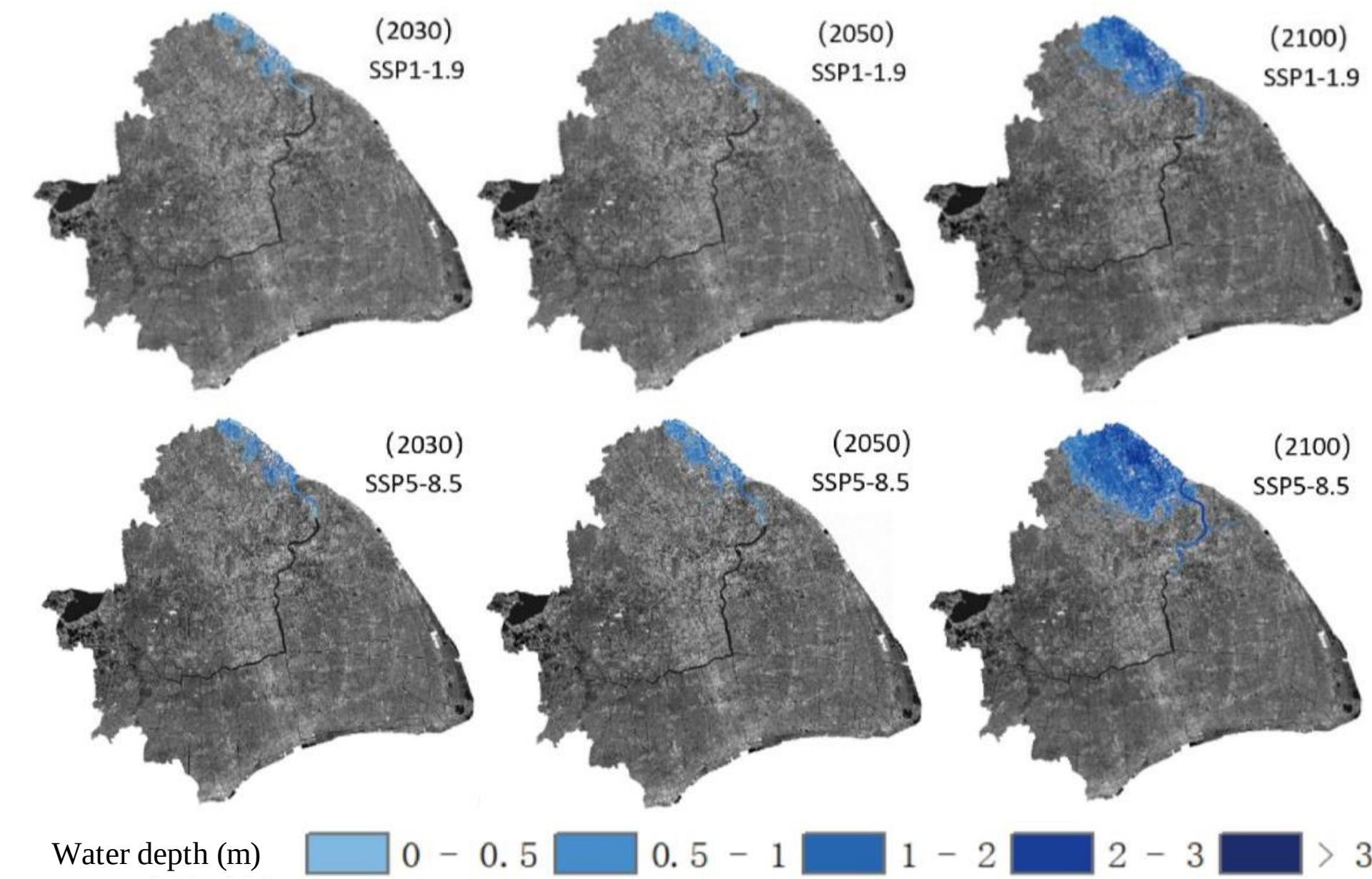


Figure 2. Projected coastal flood inundation extent and depth from overtopping under future disaster scenarios

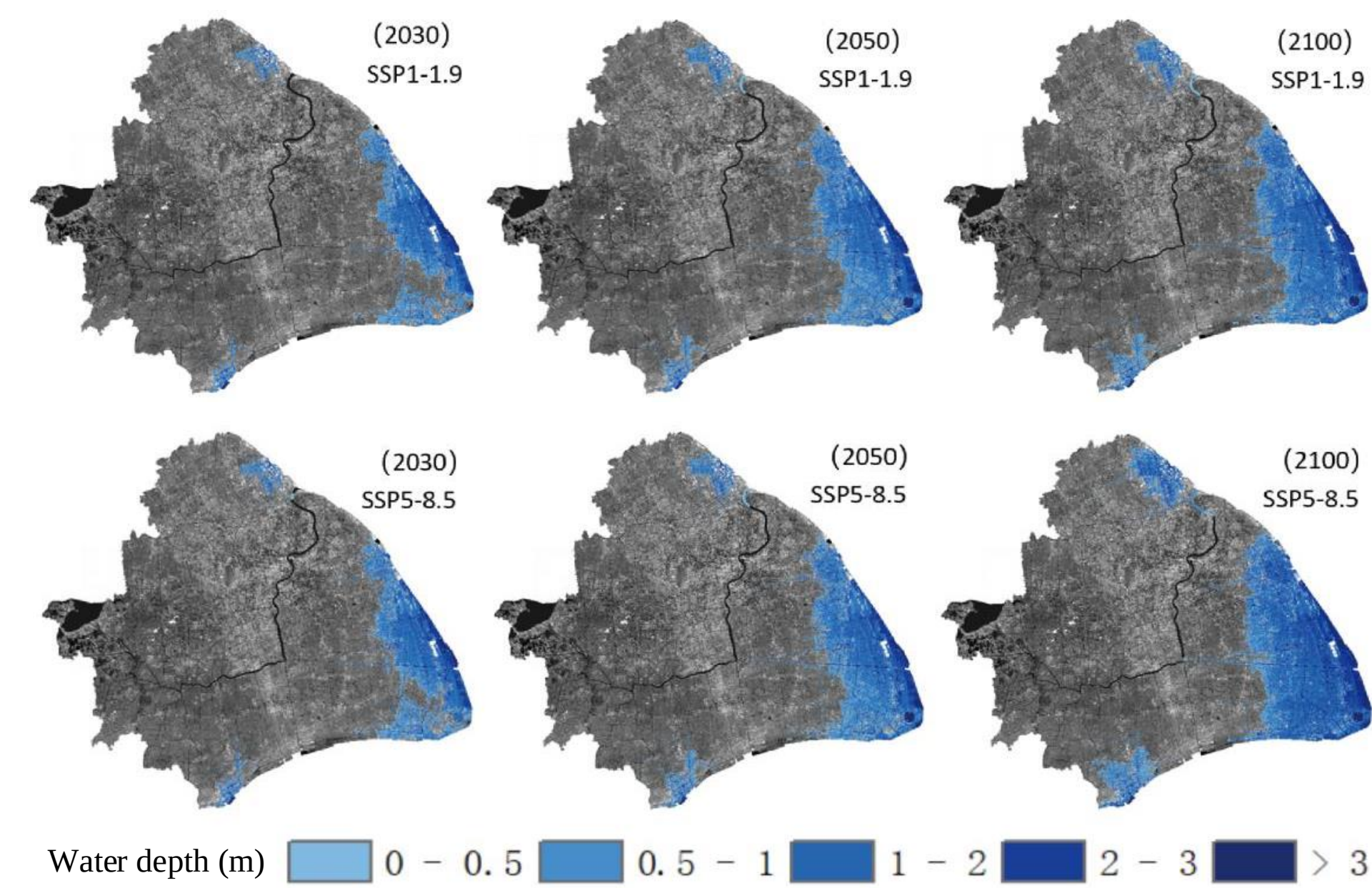


Figure 3. Projected coastal flood inundation extent and depth from breaching under future disaster scenarios

C. Assessment of Flood Risk

Based on flood simulation results, the hazard index was obtained. Subsequently, by integrating socio-economic data such as building height, year built, building function, structural deformation, Gross floor area, population, and GDP, we obtained the vulnerability and exposure indicators of each building, thereby completing the comprehensive risk assessment index system. The structure of the risk assessment index system is illustrated in Figure 4. Finally, we applied this system to assess risk for approximately 1.2 million buildings in Shanghai, with the results presented in Figure 5.

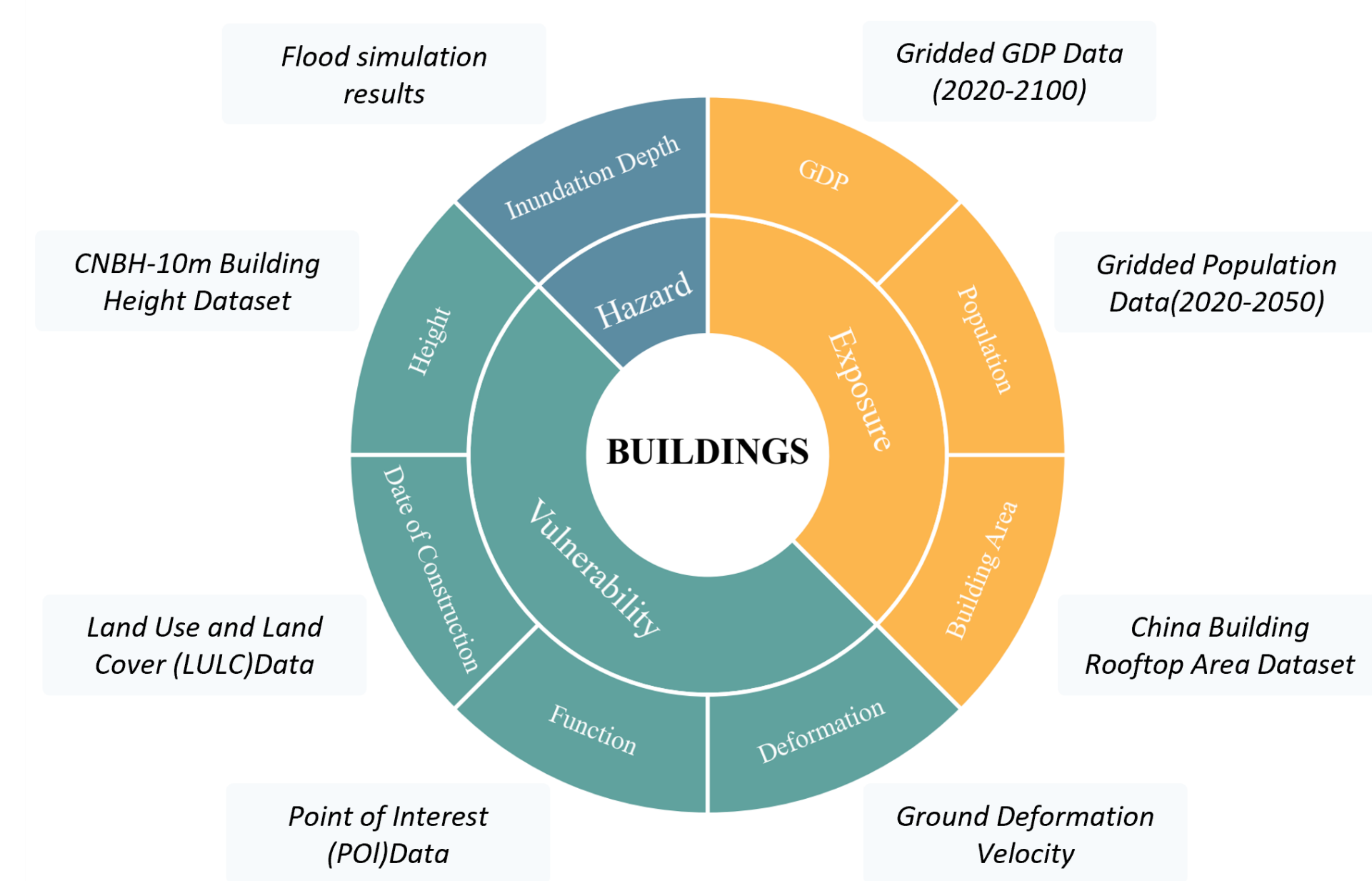


Figure 4. Index system for comprehensive risk assessment of buildings

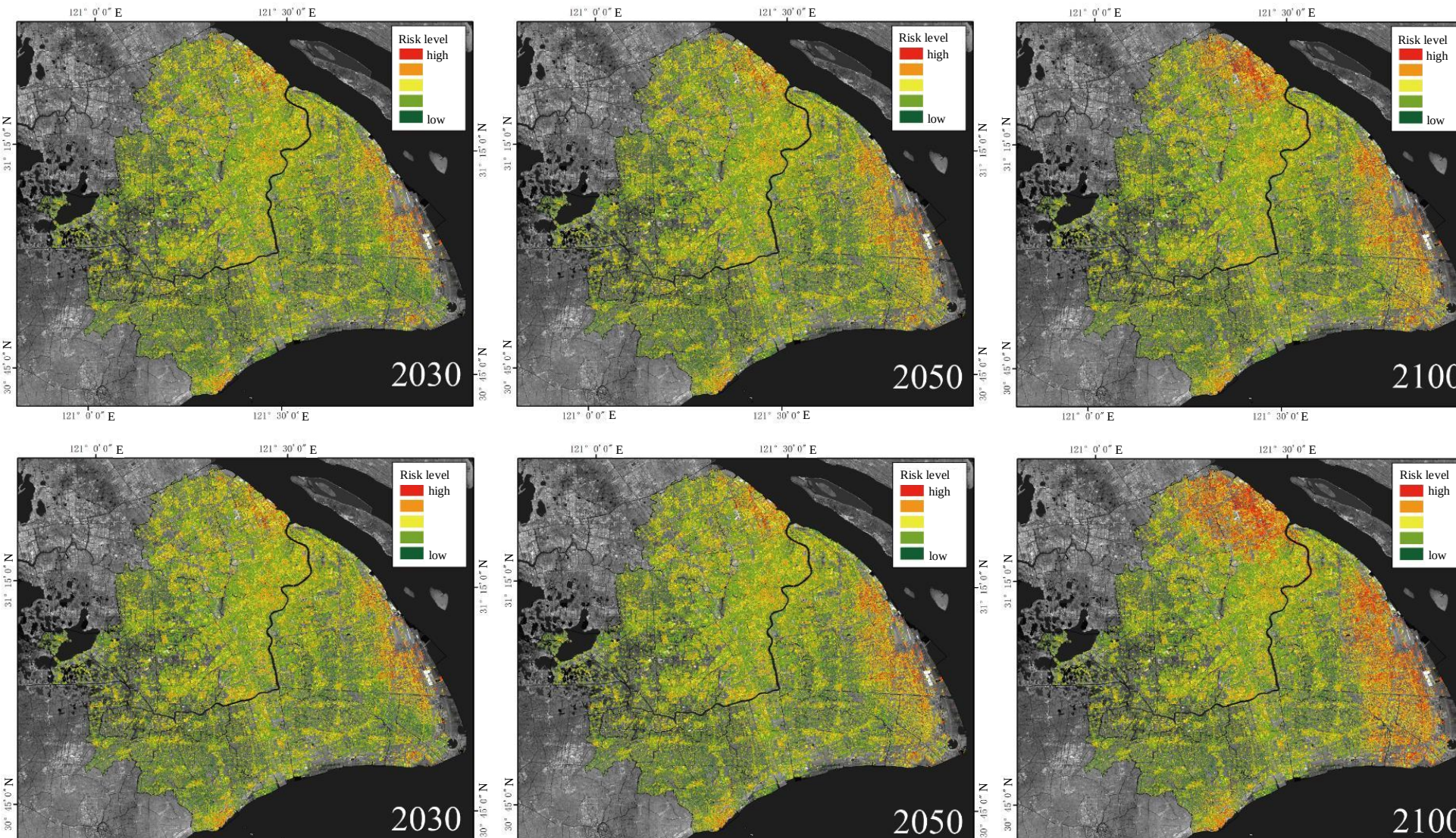


Figure 5. Comprehensive risk assessment results of buildings in Shanghai in 2030, 2050 and 2100 under the SSP1-1.9 and SSP5-8.5 scenarios

D. Assessment of Economic Losses

In this study, a flood loss function was defined to calculate potential direct economic losses caused by seawall overtopping and breaching under the various disaster scenarios. Figure 6 shows the losses in different industries. A multi-regional input-output model was further applied to assess the indirect economic damages of these disasters at the provincial level. Figures 7 and 8 show the indirect economic losses to each province caused by overtopping and breaching respectively.

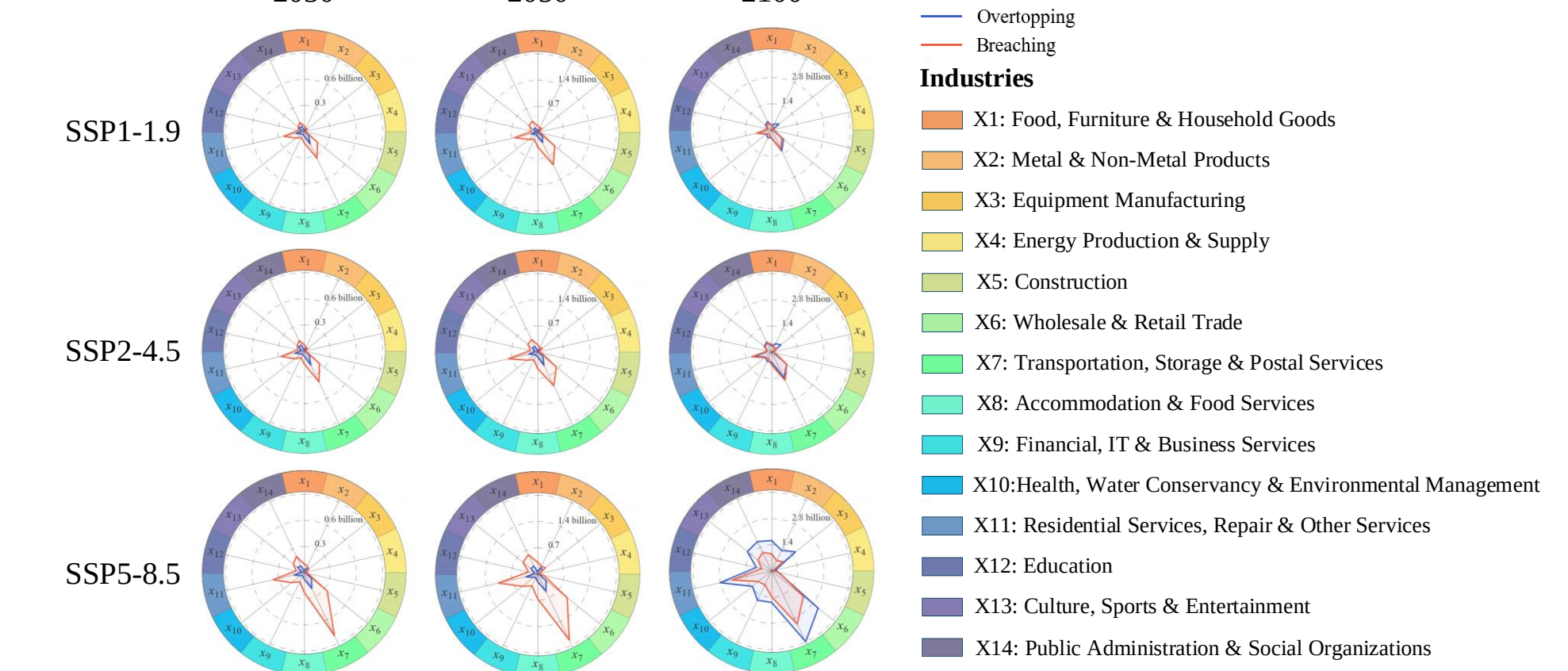


Figure 6. Statistics of direct economic losses (by industry)

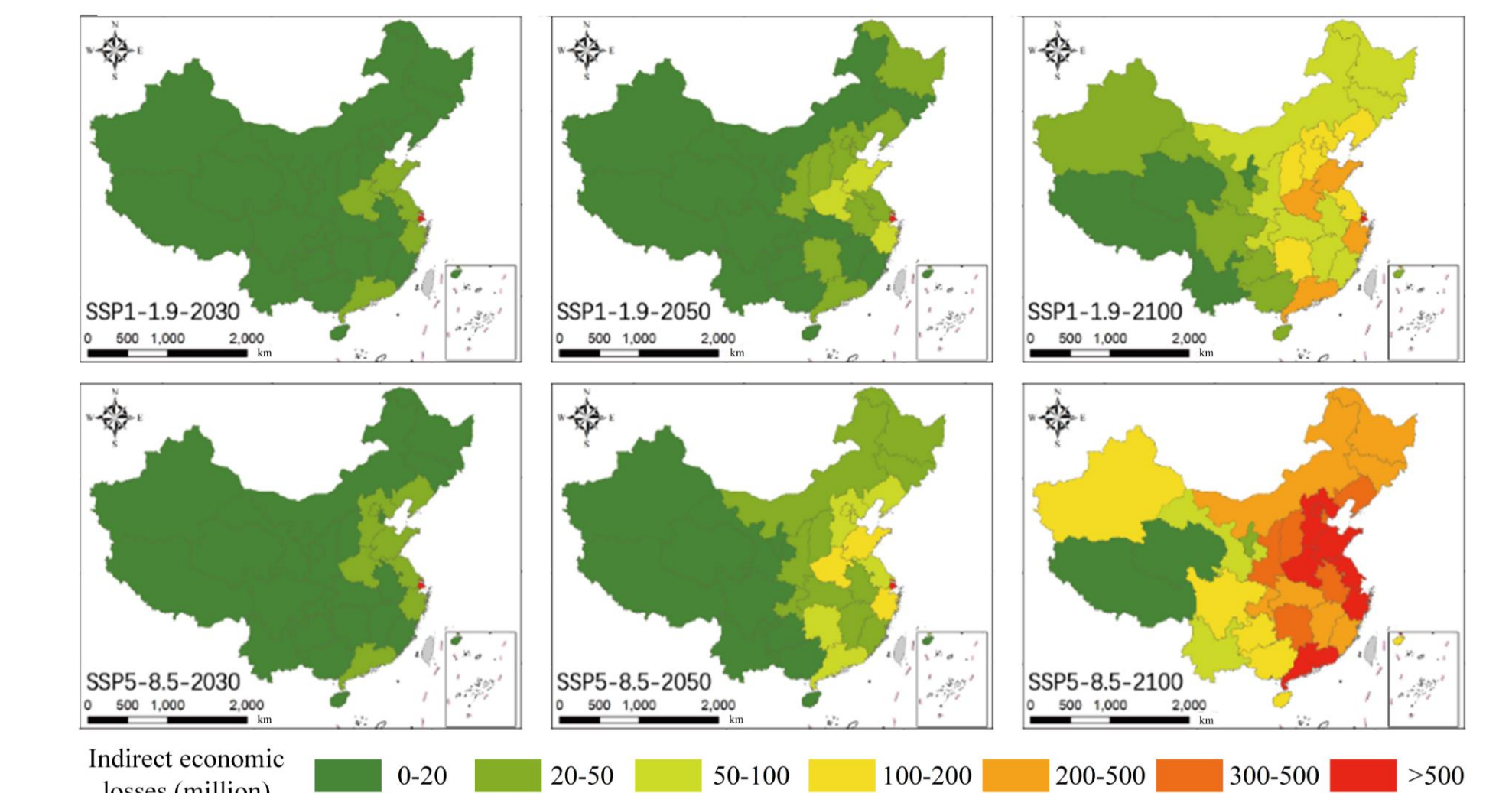


Figure 7. Distribution map of provincial indirect economic losses of coastal flood caused by overtopping under different scenarios

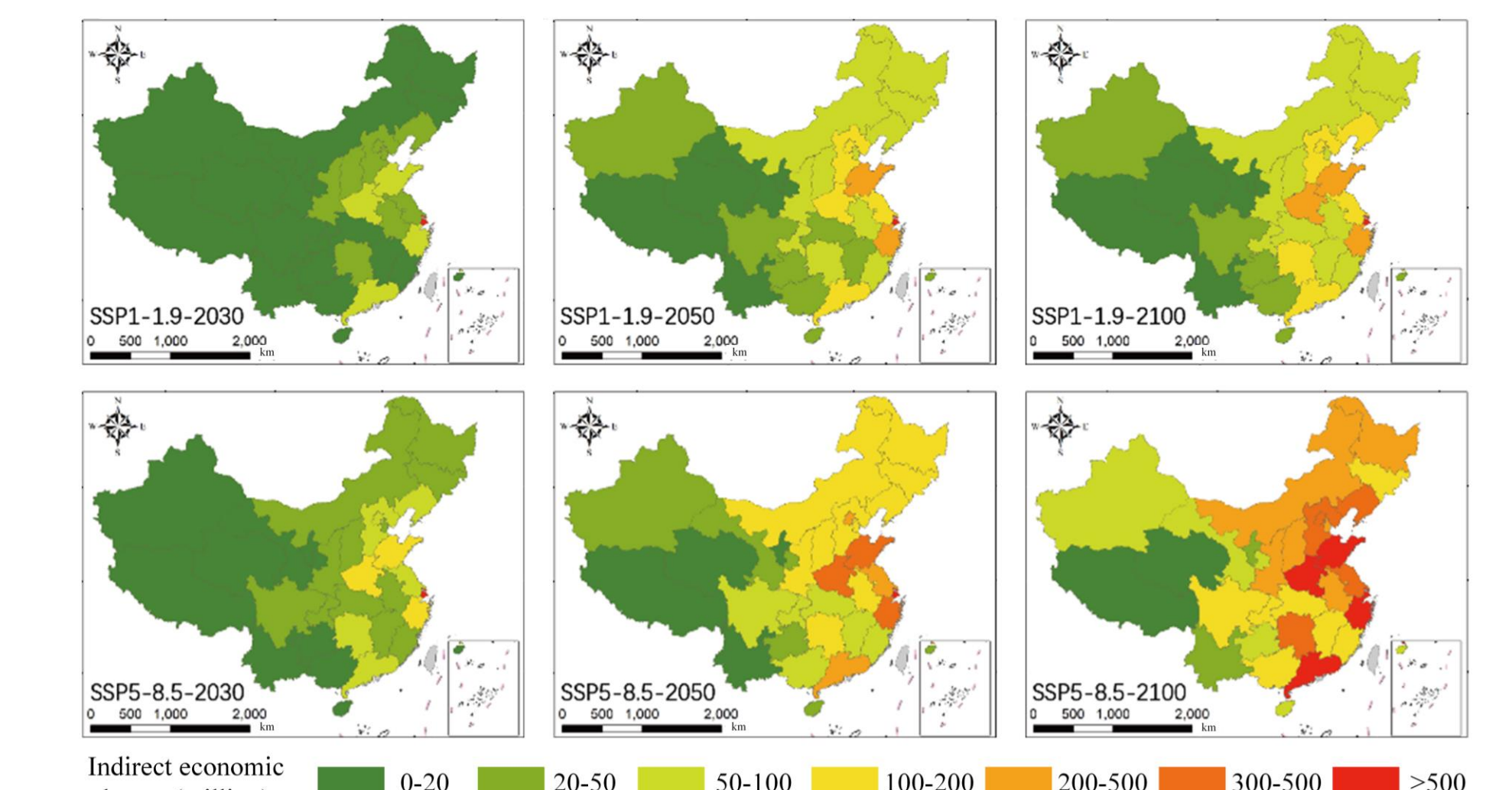


Figure 8. Distribution map of provincial indirect economic losses of coastal flood caused by breaching under different scenarios

3. Conclusion

This poster presents the study's core content, with the principal findings as follows: The results derived from InSAR demonstrate that ground subsidence has mainly occurred in the coastal areas of Shanghai in recent years, notably in eastern Pudong and some areas near the seawalls. Considering different future disaster scenarios, the LISFLOOD-FP model was used to simulate flooding. The results indicate that the potential inundated area caused by overtopping ranges from 56.4 km² (SSP1-1.9 in 2030) to 392.55 km² (SSP5-8.5 in 2100), while the potential inundated area caused by seawall breaching ranges from 442.79 km² (SSP1-1.9 in 2030) to 1059.71 km² (SSP5-8.5 in 2100). Based on the H-E-V framework, a risk assessment index system was constructed. Based on the above results and related data, we completed a detailed risk assessment for about 1.2 million buildings in Shanghai. The results indicate that high-risk buildings are clustered along the coast, particularly in the northeastern and eastern coastal zones. Finally, the economic loss assessment was conducted using the loss function and input-output model. In 2100, the maximum direct economic losses caused by overtopping and breaching are estimated at RMB 24.274 billion and RMB 16.03 billion, respectively, while the indirect economic loss could reach RMB 48.47 billion and RMB 33.294 billion. Under future disaster scenarios, industries such as Transportation, storage and postal services are expected to suffer substantial losses, while Shanghai, Shandong, Zhejiang, and other eastern provinces are projected to incur high indirect economic losses.

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