Journal of Geography and Cartography (2021) Volume 4 Issue 2
doi:10.24294/jgc.v4i2.1311

Review Article

Research progress and prospect of coastal flood disaster risk assessment against global climate change

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ABSTRACT

The sea level rise under global climate change and coastal floods caused by extreme sea levels due to the high tide levels and storm surges have huge impacts on coastal society, economy, and natural environment. It has drawn great attention from global scientific researchers. This study examines the definitions and elements of coastal flooding in the general and narrow senses, and mainly focuses on the components of coastal flooding in the narrow sense. Based on the natural disaster system theory, the review systematically summarizes the progress of coastal flood research in China, and then discusses existing problems in present studies and provide future research directions with regard to this issue. It is proposed that future studies need to strengthen research on adapting to climate change in coastal areas, including studies on the risk of multi- hazards and uncertainties of hazard impacts under climate change, risk assessment of key exposure (critical infrastructure) in coastal hotspots, and cost-benefit analysis of adaptation and mitigation measures in coastal areas. Efforts to improve the resilience of coastal areas under climate change should be given more attention. The research community also should establish the mechanism of data sharing among disciplines to meet the needs of future risk assessments, so that coastal issues can be more comprehensively, systematically, and dynamically studied.

Keywords: Coastal Flood; Global Climate change; Storm Surge; Risk Assessment; Impact

ARTICLE INFO

Article history:
Received 6 July 2021
Accepted 29 August 2021
Available online 4 September 2021

1. Introduction

In the context of global warming, coastal flooding caused by sea level rise and extreme water level of high tide and storm surge has a great impact on coastal social economy and natural environment. From 1975 to 2016, 80% of the global flooding deaths happened in areas 100 km away from the coast[1]. In 2005, the Hurricane Katrina storm surge disaster chain in the United States burst the flood dike in New Orleans, causing economic losses of more than 96 billion US dollars[2]. In 2008, Cyclone Nargis swept across the delta of Myanmar, resulting in 138000 missing and dead[3]. In addition, typhoon Haiyan in the Philippines (2013), hurricane Sandy in New York (2012) and hurricane Harvey in Texas (2017) all caused huge casualties and economic losses. As the important gathering places for economy and populations, China's coastal areas are prone to be influenced by extreme weather and climate. With the rapid development of urbanization, the coastal population has expanded rapidly. The high-intensity human activities, urbanization and land reclamation have made great changes in China's coastal land use and cover[4]. From 1989 to 2014, coastal floods caused by storm surges in China has led to economic losses of about US $70.6 billion and about 4354 missing and deaths[5]. Under the initiative of "The Belt and Road", coastal areas continue to develop rapidly. it can be inferred that China's coastal exposure will continue to increase in the future and the coastal areas will still be badly influenced by the natural disasters. The increasingly frequent extreme disasters in coastal areas have attracted great attention of governments, organizations and academic circles. Land-Ocean Interactions in the Coastal Zone (LOICZ) established in the "Future Earth planning" has now developed into the "Future Earth Coast" (FEC), which aims to develop and integrate multidisciplinary analysis methods (natural science + economy + society) under the background of global change, and to promote the sustainable development of coastal areas and improve their adaptability to climate change. The EU has also carried out a number of large-scale scientific research projects on this subject (**Table 1**). China has also implemented a series of major projects on the comprehensive risk research of global change in coastal zones and coastal areas. According to the major science and technology special project of the Ministry of Science and Technology of People's republic of China during the 13th Five-year Plan, it shall assess the comprehensive risk of coastal zone and coastal area change, so as to generate the distribution map of disaster-causing factors, vulnerability distribution map of disaster-bearing body and comprehensive risk map of China's coastal zone and coastal area with spatial resolution better than 1 km under the global change during 50–100 years in the future. It has been a great challenge for China as well as other countries to alleviate the risk of natural disasters in coastal areas.

To sum up, the research on coastal flood disaster risk assessment under global climate change is a frontier issue of international scientific research, which is of great significance to meet the needs of national and regional development, formulate disaster reduction strategies and implement the sustainable development of coastal zone. However, there is no widely recognized definition, genetic elements, mechanism and dynamics, as well as other relevant concepts for coastal flood risk at present, which will influence the research directions and results of coastal flood risk., Therefore, from the perspective of

Table 1. Non-exhaustive list of EU funded research projects about coastal flood under climate change

Project and execution time	**Name of Projects**	**Goal**
DINAS-COAST (2001–2004)	Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea Level Rise	Integrating multidisciplinary knowledge (coastal geomorphology, ecology, economics, environmental geography and computer science); modeling and developing assessment models to help decision-makers analyze the impact of climate change and sea-level rise
XtremRisK (2008–2012)	Integrated Flood Risk Analysis for Extreme Storm Surges	Carrying out risk analysis for coastal flood disaster caused by extreme water level in open coastal and estuarine areas
THESEUS (2009–2013)	Innovative Technologies for Safe European Coasts in a Changing Climate	Providing a comprehensive assessment method for coastal flood and coastal erosion combined with multidisciplinary knowledge, from three specific directions: risk assessment, coping strategies and application to develop innovative adaptive measures for maintaining the sustainable development of coastal zone
RISES-AM (2013–2016)	Responses to Coastal Climate Change: Innovative Strategies for High End Scenarios — Adaptation and Mitigation	Developing innovative mitigation and adaptation measures to address extreme scenarios in coastal areas under climate change
SPP 1889 (2016–2019)	Regional Sea Level Change and Society	Carrying out cross research on climate related sea-level change through comprehensive and interdisciplinary integration means, while considering the interaction of human and environment as well as the socio-economic development of coastal areas

regional disaster, this paper summarizes the research progress and existing problems of coastal flood at home and abroad, so as to provide reference for better clarifying the research direction and refining the research problems and related research.

2. Definition of coastal flood

At present, the academic circles at home and abroad have not unified the definition for coastal flood, mainly discussing from it broad sense and narrow sense.

In the broad sense, the coastal flood refers to the flood occurring in coastal areas (**Figure 1**). In addition to influence of the extreme water level caused by sea level rise, astronomical spring tide and storm surge, it may also be affected by the comprehensive action of riverine flood and urban water logging caused by heavy precipitation. Its main disaster-causing factors may include over-fortified land-based flood, extreme precipitation and extreme seawater level. In the EU THESEUS project, Zheng *et al*.[6] and Zscheischler *et al*.[7] adopted the concept of coastal flood in broad sense. The research on coastal flood in broad sense is mostly in large estuarine urban areas, where urban waterlogging occurs frequently. Such areas will not only be threatened by marine factors, but also affected by land-based flood, coupled with extreme precipitation events and a high proportion of impermeable layer in complex urban system. Shanghai is a typical representative.

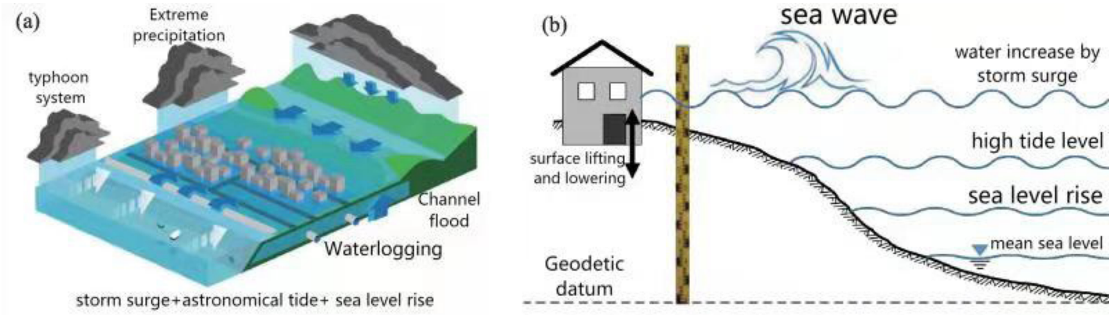

Figure 1. Coastal flooding in the broad sense (a) and the narrow sense (b).

Note: The schematic diagram of coastal flood in a broad sense is provided by Dr. Thomas Wahl of the University of Central Florida.

In the narrow sense, coastal flood generally refers to the flood caused by sea level rise, storm surge and extreme water level aroused by astronomical spring tide under climate change in coastal areas. This is also a commonly used concept in IPCC series reports. It is based on the analysis of inundation results of the extreme water level and sea level rise during the return period[8]. The study of coastal flood in broad sense involves many disaster-causing factors, and the research problem is complex. Currently, coastal flood mentioned by most international studies refers to coastal flood in a narrow sense, which is a flood disaster caused by the instability of the marine system, such as tropical cyclone storm surge, with water source coming from the ocean[9,10]. Therefore, this paper focuses on the research progress of coastal flood risk assessment in a narrow sense under climate change.

3. Analysis of disaster-causing factors of coastal flood

The disaster-causing factors of coastal flood in a narrow sense can be divided into two parts: relative sea level change representing tendency and extreme water level change representing extremity. In the 1960s, the study of extreme water level mainly considered the results of the superposition of storm surge water increase and high tide level caused by tropical cyclones, and developed a series of storm surge numerical models[11], but the consideration of sea level rise at this stage is very limited. Since the 1980s, climate change and sea level rise have attracted attention, and a series of studies have emerged to predict future sea level rise[12]. The two studies were relatively independent in the early stage. At the end of the 20th century, relevant scholars realized that compared with the inundation of static water level caused by the slow rise of sea level, the disaster consequences caused by extreme high water level of superimposed extreme climate events will lead to more serious situations, and it is urgently necessary to carry out further research by combining the two factors[13]. Hoozemans *et al*.[14] and Baarse[15] preliminarily constructed the assessment method to access the impact of extreme water level during sea level rise and established the basic database, which gave the preliminary results of impact assessment on a global scale. Nicholls *et al*.[16], Klein *et al*.[17] and Nicholls[9] continuously improved the assessment method and carried out global coastal flood risk assessment research, which has become one of the main achievements cited in the Coastal Zone Chapter of the third and fourth report of IPCC. The main disaster-causing factors of coastal flood in a narrow sense can be defined by formula (1):

$$\triangle WL=\triangle SL_G+\triangle SL_{RM}+\triangle SL_{RG}+\triangle SLM_H+\triangle SLM_N+\eta_{NTR}+\eta_W \quad (1)$$

where $\triangle WL$ is the change of total water level; $\triangle SL_G$ is the global mean sea level change; $\triangle SL_{RM}$ is the regional sea level difference caused by climate and ocean factors; $\triangle SL_{RG}$ is the sea level difference caused by the change of regional earth gravity field; $\triangle SLM_N$ and $\triangle SLM_H$ respectively represent the changes of surface rise and fall caused by natural and human factors. The surface rise and fall of natural factors include neotectonic movement, glacier equilibrium adjustment and sediment compaction / integration. Most of the surface rise and fall caused by human factors are underground liquid extraction and other factors[13]. The abovementioned five factors usually change with the sea level. η_{NTR} is storm surge or surge as translated by Chinese scholars[18], but internationally it is expressed as non-tidal residual (NTR), referring to that the total water level minus the astronomical tide. Astronomical tide can obtain the part of tidal variation through harmonic analysis[19]; η_W is the increase of water by waves, but the observation device of general tide gauge station can not capture the change of sea water level caused by short-period waves. Tsunamis can also cause extreme water levels, but the extreme water level height caused by tsunamis is far beyond the measurement range of tide gauge stations, which is usually combined with seismic research. Therefore, in the current coastal flood research, most studies mainly focus on the extreme water level combination of astronomical tide and storm surge, as well as the global absolute sea level change and regional relative sea level change.

The research on extreme water level mainly focuses on its historical variation law and influencing factors, as well as the simulation and evaluation of the risk of extreme water level. Domestic and foreign scholars have studied the historical long-term variation law of extreme water level, and found that the extreme water level of most tide stations in the world shows an increasing trend, but after subtracting the average sea level change from the extreme water level, it is found that this increasing trend decreases significantly. Therefore, it is considered that most of the changes of extreme water level are caused by sea level change[20–22]. Some studies have also pointed out that the increase

The rate of extreme water level is significantly higher than the average sea level growth[23]. The extreme water level along the coast of China showed a significant growth trend, increasing at a rate of 2.0–14.1 mm/a from 1954 to 2012[24,25]. Sea level change not only plays an important role in the long-term change of extreme water level, but also leads to the increase of extreme water level frequency. Early studies have shown that the return period of extreme water level will change greatly due to slight changes in sea level[26]. Other studies at home and abroad have reached similar conclusions[27–29]. In addition to sea level changes, extreme water levels are also affected by typhoon, storm surge, wind field and atmospheric circulation index[30]. Besides studying the historical variation law of extreme water level and its influencing factors, there are also a large number of studies to evaluate the risk of extreme water level. Extreme water level risk assessment is the basis of risk assessment research. It mainly adopts two methods, namely statistical model and numerical simulation. Mature storm surge numerical models have been established internationally, such as SLOSH, ADCIRC, DELFTD, MIKE21 and GCOM-2D/3D models[31]. Dutch scholars have developed the world's first set of storm surge and extreme water level data set based on hydrodynamic model[32]. At present, with regard to the study of extreme water level in China's coastal areas, the station data of tide gauge stations are mostly used to calculate the surge height under different return periods due to the sparse distribution of coastal stations and short time series and carried out risk assessment on this basis[33–35].Sea level changes are often divided into absolute sea level changes caused by changes in the overall quality of marine water bodies and specific volume effects and relative sea level changes relative to a datum (such as geodetic datum or historical average sea level)[36]. The common methods for predicting the future sea level change trend are divided into two categories: one is to analyze the historical observation data by using statistical model methods such as singular spectrum analysis, grey model, Empirical Mode Decomposition (EMD), autoregressive model and wavelet analysis, and then find out their laws and extrapolate them[37]. The second is to use the global coupling model to simulate and analyze the sea level change under different greenhouse gas emission scenarios in the future[38]. Using the extrapolation of statistical model to predict future changes is greatly affected by the length and quality of data series, and assuming that the future sea level change system is in a stable state, its change law remains unchanged, so it can not reflect the actual situation of marine system changes caused by climate change. In contrast, the research on global sea level change based on large-scale numerical model is the mainstream of current research and the main method adopted in IPCC series reports[39–41]. In the IPCC AR5 report, various emission scenarios in the future are simulated based on the CMIP5 global climate model[42]. At present, the coupled numerical model has the problems of imperfect description of the global climate change process simulation, many uncertain factors in the model and insufficient accuracy of the model. A large number of scholars around the world are trying to improve the physical mechanism of model simulation and improve the resolution of sea-level rise data products, so as to make the simulation process more reasonable and the quality and accuracy of data products higher.

Table 2 shows the relevant cases of existing (narrow sense) coastal flood risk assessment and the factors considered. Most studies consider the change of mean sea level, the superposition of astronomical spring tide and NTR, but due to the small amount of wave observation data and the great technical difficulty of simulation, it is less considered in the relevant risk assessment. Less consideration is given to regional sea level differences, more consideration is given to the ground rise and fall of natural factors, but less consideration is given to the ground rise and fall caused by human factors. It is worthy of attention that the above research is a linear superposition of sea level rise and extreme water level, without considering the coupling mechanism of the two. Lin *et al*.[43] made a breakthrough in the research on this issue. Based on the physical mechanism, a numerical model was used to analyze the change of storm surge water level in New York under the scenario of sea level rise. However, because the research involves a large number of numerical operations, it is difficult and requires the cooperative efforts of multiple disciplines and units, and there are few relevant research results. Therefore, the linear superposition of sea lev-

Table 2. Non-exhaustive examples of coastal flooding assessment

Literature	Content	Sea level composition					
		△ SL_G	△ SL_{RM}	△ SL_{RG}	△ SL_{M^N}	△ SL_{M^H}	△ SS
Lowe *et al.*, 2009	National level(Britain)	√	√		√		√
Rosenzweig, 2010	City (New York)	√			√		√
Hanson *et al.*, 2011	Global (city)	√			√	√	√
Parris *et al.*, 2012	National level (America)	√	√		√		√
Wang *et al.*, 2012	City (Shanghai, China)	√			√	√	√
Kebede *et al.*, 2012	City (capital of Tanzania)	√			√		√

Note: △ SS is the part of extreme water level relative to mean sea level.

el rise and extreme water level is still used in most of the current relevant studies.

4. Study on disaster breeding environment and disaster bearing body

Natural and human disaster breeding environments such as topography, coastal engineering and land subsidence have an important impact on the disaster formation process of coastal flood in coastal areas. With the deepening of research, in recent years, scholars have paid more and more attention to the impact of actual fortification level and land subsidence on the process of coastal flood disaster[44] the data on coastal fortification level is very limited. At present, relevant evaluation studies at home and abroad simplify the fortification level according to per capita GDP, or directly ignore fortification[45]. However, in reality, there is a certain degree of fortification in populated areas and major coastal cities. In China's coastal areas, in order to resist coastal extreme meteorological and marine disasters such as coastal erosion, coastal floods and catastrophic waves, a series of protective measures have been established to protect coastal population security and economic activities. Research shows that more than 60% of the coastlines in China have been protected by seawalls[46,47]. If fortification is not considered, the risk assessment result will be too high. In addition, there is a serious land subsidence problem in the global coastal Delta and major cities[48], which reduces the land elevation and accelerates the rise of relative sea level, thus reducing the fortification capacity. Therefore, more and more attention is paid to the impact of land rise and fall caused by natural and human factors in risk assessment[49]. Previous studies have considered this disaster breeding environment in the risk of disaster causing factors, pointing out that land subsidence changes the relative sea level rise height and amplifies the risk[50]. In China's coastal cities, land subsidence caused by human factors has been very serious[51], but the research on land subsidence in risk assessment is very limited.

In recent years, scholars at home and abroad have evaluated the impact of extreme water level on social economy and natural environment under sea level change for disaster bearing bodies such as population, economy, agriculture and wetland. Nicholls[9] and Spencer *et al*.[52] assessed the impact of coastal floods and wetland losses; Hanson *et al*.[53] assessed the population and asset risks of 136 port cities in the world under the once-in-a-century coastal flood event in the future; Jongman *et al*.[54] calculated the asset exposure in 2010 and 2050 under the once-in-a-century river type and coastal flood events; Hallegatte *et al*.[55] assessed the exposure, loss and risk of 136 major coastal cities under future coastal floods and ranked them in risk; Hinkel *et al*.[10] analyzed the population and asset risks under future global coastal floods and emphasized the importance of adaptive measures; Vousdoukas *et al*.[56] analyzed the contribution rate of various climate scenarios and socio-economic scenarios to coastal flood risk change. The disaster bearing body is not static, but dynamic. For example, the elderly population will continue to increase in the future, the floating population in coastal cities has seasonal characteristics, the land use type is changing, and the coastal exposure may continue to increase. Although there are risk assessments combining various climate scenarios and socio-economic scenarios in the future, such studies mostly focus on population and economic aggregate, such as those by Hinkel *et al*.[10] and Vousdoukas *et al*.[56], and the dynamic research of other disaster bearing bodies is very limited. In addition, there are few studies on key exposures affecting disaster losses, especially important coastal key infrastructure including power facilities, transportation hubs, shelters, material reserve bases, sluices and guard facilities[57,58]. The destruction of key infrastructure will lead to the systematic and cascade paralysis of regional infrastructure functions, and then lead to other indirect losses. At present, there are few studies on the evaluation of indirect losses and the impact evaluation of system dynamic network functions.

Vulnerability of disaster bearing body refers to the possibility of socio-economic system and ecosystem being hit by disaster-causing factors. The most common are physical vulnerability and social vulnerability[59]. The physical vulnerability of disaster bearing body focuses on the physical characteristics of disaster causing factors and the response of disaster bearing body. Physical vulnerability analysis uses quantitative analysis to obtain the relationship between loss and disaster causing factors and give quantitative risk assessment results based on disaster data, field investigation data, insurance data, model simulation and other means[60]. By constructing the functional relationship between the inundation depth and the loss of coastal disaster bearing bodies (population, houses, seawalls, etc.), the vulnerability loss matrix or vulnerability curve can be constructed to determine the loss rate of disaster bearing bodies under different disaster intensity[61]. A large number of studies on flood disaster vulnerability curves have been carried out abroad. For example, the United States, Britain and the Netherlands have established loss curves for different building types[62,63]. Domestically, more detailed research has also been carried out in some areas such as Shanghai[64]. Due to the high requirements of physical vulnerability research on historical disaster data and the need for a large number of field research, the current disaster data are less open or of low quality and difficult access to data, and the research on vulnerability curve between water depth and loss is very limited, so it is difficult to construct a universal and practical physical vulnerability curve. This makes the current research more dependent on the international physical vulnerability curve. Social vulnerability can be understood as the sensitivity of the social system to the impact of disaster causing events and the adaptability to deal with disaster events[64]. The evaluation method usually adopts the index system method. By establishing the index evaluation system and giving weight to the factors by means of expert scoring method and factor analysis, the social vulnerability level is divided. Drawing on these methods, some progress has been made in the social vulnerability assessment of different scales and different research areas in China's coastal areas, such as the coastal municipal level[65,66] and coastal counties[67] carried out social vulnerability assessment. However, the selection and establishment of evaluation indicators and the weight giving methods are different, which are influencing and subjective. Besides, the index system method obtains unitless scalar or relative value, which can be used to identify high vulnerability areas or vulnerability change trends, but the quantitative relationship between it and the loss is not clear, so it is difficult to be applied to quantitative risk assessment.

For the coastal zone system, a large number of scholars have also carried out research on the comprehensive vulnerability and vulnerability of coastal zone disaster bearing bodies, and established vulnerability assessment models, such as PSR model (Pressure-State-Response-Framework), DPSIR model (Driving force-Pressure-State-Impact-Response) and SPRC (Source-Pathways-Receptor-Consequence)[68,69]. Based on the above conceptual model, relevant scholars have established a comprehensive vulnerability rating model of coastal zone, which is generally the index system method[70–74], but the vulnerability obtained from the above research is also a scalar result, which is difficult to be connected with quantitative risk assessment.

5. Coastal flood risk assessment method and model

After determining the factors to be considered in coastal flood, how to determine the inundation range of coastal flood under extreme water level has become the most key problem in risk analysis[75]. At present, the means to determine the coastal flood inundation range can be summarized into two categories: one is the elevation-area method based on GIS, and the other is the numerical model based on hydrodynamic evolution.

The most commonly used method in current research is the evaluation model based on GIS, which is widely used in large-scale coastal flood Research[76–78]. However, the defect of this method is that it does not consider the duration of extreme water level and ground roughness. Not all areas under a specific water level are affected areas, so it is easy to overestimate the risk; the advantage is that it can quickly divide high-risk areas, especially for the impact under various climate scenarios in the future, and can provide global and national decision-makers with information on macro disaster risk prevention in coastal zone. Numerical models based on hydrodynamic evolution, such as large storm surge numerical models such as ADCIRC and DELFD 3D, can better simulate the processes of storm surge water increase and floodplain, but it is difficult to be applied to large-scale coastal flood disaster risk assessment. The main reasons are: i) The data required by the model is huge and complex; ii) The solving process is complex and time-consuming; iii) The intensity of disaster causing factors is well simulated, but other factors such as the vulnerability of disaster bearing body in risk assessment are not considered enough. With the improvement of terrain data accuracy, such as LiDAR elevation data of 5m and below, the two-dimensional flood model based on GIS grid data is more widely used, such as LisFlood[79], JFLOW[80] and Floodmap[81,82], etc. This kind of two-dimensional flood model simplifies the physical process, greatly improves the solution efficiency, and performs well in small-scale research[83]. In order to improve the extreme water level simulation, simplify the solution process and improve efficiency, some scholars use the relevant storm surge products developed by other research teams, which are generally based on the large-scale storm surge numerical model and targeted at some specific areas, such as the extreme water level height under various return periods, as the input of the flood plain process on land; then, the two-dimensional flood model based on GIS grid data is used as the evolution of flood process[84]. However, this method is also difficult to be applied to large-scale coastal flood risk assessment, mainly due to the high requirements for the accuracy of basic data, and in terms of large-scale, the amount of basic data is huge and difficult to obtain.

In conclusion, in large-scale, such as global scale or national level, the impact assessment of coastal floods on coastal areas under global climate change depends more on the elevation area method based on GIS model. In addition to the general GIS assessment models, **Table 3** summarizes the existing coastal flood impact assessment models and their main parameters. Such evaluation model integrates multi-disciplinary knowledge and considers the dynamic feedback of natural environment and socio-economic environment to a certain extent. It can provide more effective information for decision makers and stakeholders and improve the evaluation efficiency.

6. Problems in domestic related researches

Through research at home and abroad, it is found that the coastal flood disaster risk assessment in European and American developed countries under various climate scenarios has been relatively in-depth, and coastal flood risk assessment has been carried out at the national level, such as Germany[85], the United States[86], Canada[87] and the United King-

Table 3. Key attributes of coastal flood impact models

Model	Scale	Spatial resolution	Time scale	Input data	Output data	Literature
Inundation model (e.g. GIS)	Local, regional and global	Changeable	User defined	Elevation, sea level rise scenario, socio-economic data	Map of potential inundation area and affected population	Rowley *et al.*, 2007
SLAMM (Sea Level Affecting Marshes Model)	Local and regional	10–100 m	5–25 a time step	Elevation map, wetland cover, development footprint and seawall location	Map of potential inundation area and affected population	Galbraith *et al.*, 2003
DIVA (Dynamic Interactive Vulnerability Assessment)	National, regional and global	Coastline segmentation (12000 sections in the world, with an average of 70 km per section)	1–5 a, up to 100 a	Elevation, geomorphic type, coastal population, land use, administrative boundary, GDP	Coastal floods are expected to affect population, wetland change, loss and adaptation costs, and land loss	Hinkel *et al.*, 2009
LIS Coast (Large scale Integrated Sea-level and Coastal Assessment Tool)	European Region	The coastline is segmented with different lengths	Variable, user defined	Elevation, meteorological data, population, *etc.*	Expected population and economic loss, etc.	Vousdoukas *et al.*, 2018

dom[88]. However, China has not yet had relevant assessment reports at the national level. Compared with foreign countries, domestic coastal flood related research on sea-level rise and extreme water level superposition started late, and at present, most of them focus on the risk of disaster causing factors, and there are more research on the prediction of sea-level rise at the regional scale under the future climate scenario, whereas there are less disaster risk assessment in China's coastal areas under different climate scenarios in the future. Most of the existing domestic relevant studies are aimed at a certain region, such as the Pearl River Delta[18] and Shanghai[68]. It is very limited to carry out coastal flood risk assessment of sea level rise and extreme water level superposition at the national level. At the same time, there are few data products independently developed and disclosed in China, and the statistical caliber of socio-economic data and disaster data is inconsistent and of year-missing situations, which has become a major bottleneck in the current research.

(1) Lack of hazard factor coupling risk study. In most relevant studies, it is assumed that the mean sea level rise and the storm surge system leading to the extreme water level are relatively independent and of a linear superposition relation; and it is assumed that the system is stable, without considering the change resulted by global climate change to the overall storm surge system or regional volatility. Global climate change may lead to corresponding changes in the overall marine system, so it is necessary to be vigilant against the emergence of extreme scenarios (high end scenario) and "Grey Swan"[89,90], and attach importance to the inconsistency and stability process. In coastal and estuarine areas, due to the effect of nearshore topography and the superposition of multiple water sources, it is prone to the superposition of multiple disasters, which may make the disaster degree higher than the impact of only a single extreme seawater level. That is the focus of international attention[7]. Foreign countries have carried out joint probability distribution to study the nonlinear effect of superposition of various coastal flood disaster causing factors, such as combining river runoff flood with coastal flood[91], or combining coastal flood with extreme precipitation[92]. At present, the domestic related research is relatively weak, which awaits a breakthrough in the future.

(2) Lack of interdisciplinary integration and consideration of disaster breeding environment and human factors. From the perspective of disaster system, the change of coastal flood disaster risk is affected by many factors of nature and human society, but current research involves a few factors and ignores multi-scenario and human factors. Although experts in various fields have conducted research from the perspectives of oceanography, geology and geography, there is a lack of systematic research integrating various disciplines[93]. At present, most of the relevant studies in China are carried out from the perspective of global climate change. Coastal disaster risk assessment is usually carried out based on a certain climate model or emission scenario. There is a lack of consideration of land surface system and human economic system. The consideration of coastal fortification, land subsidence control and other factors in the assessment is very limited. There are fewer studies considering both future climate scenario change and socio-economic scenario change. Although there have been simulation studies on China's future population and economy[94,95], but the two have not been combined in the current evaluation study.

(3) Lack of research on adaptive measures and resilience in coastal areas. Using quantitative cost-benefit analysis to evaluate the adaptability and mitigation measures of various coastal engineering or non-engineering to prevent, respond to or mitigate climate change and disaster risk is the current popular research trend[44,96]. In addition to fortification, there are other adaptive measures in coastal areas to deal with global climate change, which can be summarized into three categories: protection, retreat and accommodation; according to the nature of the project, it can be divided into engineering measures and non- engineering measures[97]. However, the current research on adaptive measures in China's coastal areas is in the preliminary stage[98]. Moreover, most studies began to shift from the perspective of vulnerability to the perspective of resilience, which

has increasingly attracted attention in coastal zone research[96]. Resilience research is to explore the internal stress, recovery, adaptation and transformation ability of the system under a multidisciplinary framework, emphasizing the independent resistance of the system to external interference[99]. But, the research on the resilience of China's coastal areas is also very limited.

7. Outlook

Based on the above shortcomings, this paper puts forward the following prospects to strengthen the research on coastal areas to deal with the risk of global climate change.

(1) Strengthen the research on the coupling risk and uncertainty of multiple disaster causing factors under climate change. In the future, it is necessary to strengthen the impact of global sea level rise on the tropical cyclone system and the interaction of coastal zone system. Based on the physical mechanism, a numerical model is used to simulate the changes of tropical cyclone system and extreme water level under global sea level rise. Strengthen the research on the disaster mechanism of disaster chain and disaster group, and analyze the nonlinear effect of multi disaster factor coupling with statistical model or dynamic model. Strengthen the research on the uncertainty of disaster causing factors, generate a large number of random data sets of typhoon track and intensity by random simulation, and calculate and analyze the uncertainty in the simulation by numerical model. Based on the in-depth research on the risk of coastal disaster causing factors, we will independently develop disaster causing factor products and related evaluation software for the whole coast of China, strengthen independent model research, better serve marine engineering and provide information for stakeholders.

(2) Enhance risk assessment research on key coastal areas and key exposures (key infrastructure). In the future, we should pay close attention to the investigation and hidden danger investigation of key coastal areas and key exposures, focus on the highly vulnerable population (such as the elderly population and floating population), and investigate the key infrastructure that may have a significant impact (such as dams, power facilities and transportation hubs). Typical areas can be selected to try to predict and study the disaster bearing bodies in the future, establish corresponding vulnerability curves for key exposures such as different land use types and infrastructure, and carry out comprehensive population and economic risk assessment.

(3) Improve the cost-benefit evaluation of global climate change risk adaptation and mitigation measures. At present, the research on the impact of a variety of adaptive and mitigation measures on the coastal environment is very limited, especially the measures such as embankment construction and land reclamation. In the future, deepen the research on the comprehensive impact of engineering measures such as fortification and reclamation on the coastal zone environment against global climate change. For the coastal zone system, in the face of future global climate change and extreme disaster events, how to improve the resilience of coastal areas and better adapt to global change will become increasingly important.

(4) Enlarge data openness and conduct interdisciplinary research. It is suggested that relevant departments should strengthen the openness of data required for scientific research projects, strengthen the collection and statistics of basic socio-economic data, formulate statistical norms and standards, and establish a more effective social information collection system and a more complete data database. With the rapid development of network technology, using big data for research is also a major trend in the future. Hence, it is crucial to optimize the basic data sharing mechanism among multiple disciplines, adopt interdisciplinary means, and apply the emerging means of other disciplines (such as economics, sociology and system dynamics) to the coastal areas, so as to study the coastal zone problems more comprehensively, systematically and dynamically.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

The present study was supported by National Key Research and Development Program of China, No. 2016YFA0602404 and 2017YFE0100700; Shanghai Sailing Program, No. 19YF1413700; abd China Postdoctoral Science Foundation, No. 2019M651429.

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