The 3rd International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/3/20230379

Review of modelling approaches for flood risk assessment in Chinese coastal cities

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Abstract. Floods are thought of to be the foremost frequent natural disaster, and the flood risk assessment is the evaluation of inundation and the damage suffered when subjected to floods of different frequencies, based on conditions such as the natural environment, flood characteristics and the socio-economic situation of the study area. Climate change, sea level rise, ground subsidence and rapid urbanization are expected to increase the risk of coastal urban flooding. Inundation scenarios based on hydrological and hydrodynamic models of future extreme storm floods are now becoming an effective method for studying future trends in flooding. This paper reviews several models for simulating floods and their advantages and disadvantages, focusing on coastal areas of China, to provide a basis for scientific understanding and effective adaptation to future flood risks. Flood hazard elimination is predicated on hydrological and hydraulic modelling, ground information assortment and remote sensing. This article analyses the capabilities and limitations of the current tools used for flood hazard assessment and simultaneously demonstrates that the scientific understanding and effective methods can be used to eliminate the risk of future floods.

Keywords: flood risk assessment, model, coastal areas.

1. Introduction

Numerous coastal cities around the world are currently facing severe flood risks from climate change, sea level rise, ground subsidence and rapid urbanization. As China's urbanization process accelerates, the impermeable surface area of cities has increased significantly, resulting in the rapid discharge of rainwater during rainfall and the frequent occurrence of urban flooding.

Flooding in China's inland cities is mainly due to the inadequate capacity of the drainage network system, whose rainfall is less affected by typhoons and other catastrophic weather, and whose flooding is even negligibly affected by changes in water levels in the city's internal rivers [1]. There are two major differences between coastal flooding and inland flooding. Firstly, the coastal region is mainly affected by the coastal climate, with constant rain and typhoons in summer and autumn, which causes concentrated and intense rainfall. Secondly, the huge instantaneous rainfall causes cities to experience rapid increases in river levels and overflow from water storage facilities, which can further prevent cities from discharging the flood waters [2].

Flood prevention and mitigation work are often divided into engineering and non-engineering measures, wherever engineering measures principally embrace the development of dams, and reservoirs, whereas non-engineering measures include flood warning systems and flood risk assessment systems,

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DOI: 10.54254/2755-2721/3/20230379

in which the flood risk assessment system is crucial [3]. With the change of flood control concept from flood control to flood management, numerical flood simulation has become an important tool for flood risk mapping, flood risk analysis, flood damage assessment and a scientific basis for flood management

In addition, within the absence of extra adaptation measures, the chance of coastal flooding is predicted to rise within the future because of two main factors. Firstly, global climate change and sea level rise are predicted to extend the frequency and severity of flood events, and second, the amount of potential receptors like infrastructure, socio-economic assets, and population is increasing within the coastal area [4].

2. The previous measures to eliminate the costal flood risk

In order to manage coastal flood risk and develop effective and long mitigation measures, it's necessary to understand not solely the extent of the various flood elements, like flash floods, marine storms and property development, similarly as their associated consequences, they conjointly have to be compelled to be understood in relevance one another. This input is vital once considering area-wide analyses, because it permits coastal managers to spot and find out the foremost crucial areas in danger as a result of the various flood elements. This analysis allows a lot of elaborate assessments to be conducted and to concentrate resources on these locations.

Risk refers to the prospect of loss of life or property, or disruption of economic activity, as a results of a particular event during a given space and reference amount. Risk may be a combination of hazard and vulnerability[5]. Hazard assessment maps delineate flood hazard areas in river basins based on local knowledge, hydrometeorological, geomorphological and socio-economic data [6]. In the area of flood inundation analysis and flood damage estimation, scientists have synthesized the current methods of assessing economic, human and building losses in flood risk assessment, generating a derivation of flood vulnerability curves and further deriving vulnerability formulas to be widely used [7]. A full version of the model for flood loss assessment in stream catchments, consisting of a physical distributed hydrological model and a distributed loss assessment model, was introduced in detail by researchers and eventually applied to a medium sized catchment in Japan[8]. The GIS-based multi-criteria flood risk assessment model was developed by foreign scholars in 2003, where uncertainties in the criteria and their impacts were investigated and the impact of flooding on spatial distribution was assessed by the model development [9]. S. Lang focuses on flood risk assessment based on the weather change and quantifies vulnerability by dividing it into spatial units to facilitate decision-making[10].

For the Shanghai region, researchers modelled and assessed the combined effects of future rising ocean levels, surface settlement and tidal turbulence on selected combined flood scenarios[11]. A number of Chinese scholars have been gradually focusing on disaster risk assessment research since 1980, mainly focusing on single-hazard risk assessment studies, and have achieved a certain amount of progress. Chinese scientists explored the model of integrated natural disaster risk assessment and management in Chinese coastal cities, which culminates in a proposal to strengthen the research on natural hazards in the context of risk assessment and empirical proof in China.

Global warming has a huge impact on future flood hazards. There is also concern that persistent growing and development of the floodplains will interfere for environmental systems and ecosystems processing, emphasizing that as a contributor to flooding problems, human behavior is a factor. Approximately 196 million people in 90 countries have been exposed to catastrophic floods, with 170,000 people dead from floods worldwide between 1980 and 2010. Floods are the most common of all environmental hazards, which claim a large number of lives each year and have a detrimental impact on millions of people across the world.

The frequency and intensity of flood disasters due to global warming is increasing, therefore it is important to study the modelling approach for coastal cities flood risk in this research topic.Flood risk assessment is central to managing flood risk, and it's essential to possess a completely outlined flood situation that has all processes which will occur throughout an occurrence. Understanding and assessing these processes needs meteorologic, topographical and land use knowledge in addition as historical observations. Ground surveys, remote sensing analysis and hydraulic modelling are the newest methods

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implemented for evaluating flood risk[3]. These typical instruments exhibit a number of restrictions associated specifically with their specific properties or the circumstances of their use. Both space and time averaging are a challenge for instrument-acquired data, in terms of the maintenance and the expense of data manipulation of representative networks. Remote sensing has the potential to conquer several of these deficiencies. Nevertheless, there are additional issues, which may affect the spatial coverage of the area under consideration, such as weather conditions affecting the physiographic quality of satellite images, the possible absence of images overlaying the research region, or the manipulation of the processing artefacts used in this data exploitation. In the case of hydrological modelling, the quality and quantity of inputs can have a significant impact in terms of the accuracy of the results[12]. The purpose of this article is to overview current coastal flood hazard assessment practice and providing the preliminary perspectives on potential applications in current practice.

3. Methodology

Hydrological modelling and remote sensing. These approaches are used for description of scenarios, generation of input data such as rainfall data, flow rates, geomorphology information or terrain utilization types and the outcomes of the outputs include hydraulic depth, delineation of flooding, flow rates, inundation times or compositions of flow rates and water depths. Flood risk assessments can be carried out by deterministic or probabilistic methods and the results are then expressed as the probability of a flood of a particular size or strength occurring over an interval of time. The reliability of the results is highly dependent on the availability and quality of the data, as well as the scale of the analysis and well-understood limitations of the methods used. Accordingly, each technique has advantages and disadvantages that are relevant to the surrounding context .

The geographical information system (GIS) and remote sensing technologies provide an extensive spectrum of techniques for identifying areas affected by flooding and predicting areas likely to be inundated due to high river levels. In recent years, remote sensing, in combination with GIS, appears to have become an important tool for flood monitoring.

The most popular numerical hydrodynamic simulation software are Delft 3D, MIKE, GIS, TUTFLOW and SOBEK models. Although these software varies in terms of functional implementation, computing algorithms and modelling methods, they are all widely used and validated by industry experts and have a high degree of credibility.

There are two main characteristics of the flooding model for coastal cities in China. One is that overflow from large water storage facilities intensifies urban flooding. The second is that some rivers in coastal areas are directly entering the sea, and the flow direction of the rivers reaching the sea is in a state of dynamic change. If heavy rainfall occurs at high tidal levels, the water in urban rivers cannot be discharged smoothly, which will block the water from the urban drainage network and enhance urban flooding. Therefore, it is necessary to add large water storage measures such as rivers and reservoirs as basic elements of the modelling based on the inland drainage network model. Moreover, the downstream boundary of the model needs to be used as the tidal process line at the inlet to include the effect of tidal water levels on flooding.

4. Data collection

To characterise the ocean flooding, fluctuations and sea levels have been drawn from the hindcast SIMAR-44 database, which was produced from multi-resolution atmospheric, marine-level and wave modelling carried out in the HIPOCAS project. The data selected in this study covers meteorological tide level time series, deep-water specific wave heights Hm0, mean period Tm, peak period Tp and three-hourly mean wave directions for the period 1 January 1958 to 31 December 2001. In order to obtain topography of the surface and thereby measures the slope of the coast, a digital elevation model (ICGC 2015) with 95 m cell size was used. In addition, to determine the physical geomorphological features for assessing flash flood risk, maximum greenness information was used to characterize vegetation abundance and soil textures developed by the European Soil Data Centre (EC 2015) at a scope resolution of 191 km unit size. To characterize the climate change-induced sea level rise, the RCP

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8.5 scenario presented in the Fifth Assessment Report (IPCC 2015) was chosen. Moreover, detailed information about land-use maps in matrix format developed by the Centre for Applied Research in Ecology and Forestry (CREAF) used to estimate the impact and establish accurate receptor exposure. The map was obtained by analyzing photographically interpretive aerial photographs at a scale of 1:2500 and a pixel resolution of 0.25m. Furthermore, many socio-economic factors have been accounted in the analysis of the data.

5. Model

Existing flood models are of great research interest and most of the models discussed now focus on dimensional classification. Existing flood models can be categorized by dimension into 1D, 2D and 3D flood models. The main one-dimensional flood models are MIKE11 and HECRAS, which are the simplest and most computationally efficient of all flood models. These models identify the series of cross-sections of rivers and floodplains perpendicular to the direction of flow and use traditional field measurements for parameters to replace distributed topographic and friction data. One-dimensional models have the advantage of having limited data requirements, but the simplicity of one-dimensional models results from the neglect of flood mechanics and therefore they are unable to simulate urban flooding in developing countries.

Two-dimensional models are represented by SOBEK and MIKE21. The advance of remote sensing technology, especially with high-resolution and high-precision input data, such as LiDAR and SAR radar data, and increased numerical power have made two-dimensional models more popular. The main advantages of 2D flood modelling are the integrated representation of flow dynamics and the small-scale topographic features that are the main factors in the formation of urban floods. In addition, the uncertainties in the model are mainly due to the lack of high-resolution topographic data and advanced computing facilities.

A typical example of a three-dimensional flood model is the Navier-Stoke equation, which treats the flow of a flood as three-dimensional. Similar to 2D models, the implementation and application of 3D models are greatly influenced by high resolution data sets and high-end computing facilities[13].

In addition, the transferability of external locations of flood models is often limited by the lack of parametric data and sensitivity analysis, resulting in poor model calibration.

6. Discussion

The hydrological model is to be used as a user-friendly instrument to visualize the main stages in a flood scenario and to generate outcomes from the flood risk cartography, such as flood elevation, flood extent, fluxes, flow rates, volumes and durations of floods. The main advantages and weakness of current modelling software on flood risk assessment is shown on table 1.

The results can be obtained by putting real data into the model, and the data post-processing of these software shows its powerful post-processing capabilities by obtaining flow field vector maps, contour lines, physical quantities of water depth. Finally, to validate the accuracy of several of the models mentioned above, the comparison of the data input to the model with the measured hydrological data shows that the errors are relatively small, and the accuracy is relatively high.

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Table 1. Main strengths and weakness of current modelling software.

	Scenario		Data acquisition		Key flood hazard parameters	
Software	Strength	Weakness	Strength	Weakness	Strength	Weakness
Mike21	Consideration of local conditions; User-friendly interface Separate wet and dry units	The rectangular network calculation module is not refined	Local data Facilitates simulation of beach currents	Not applicable	Define multiple types of water boundary conditions 2D application	Not applied in 3D carried out under hydraulic assumptions
Delft 3D	Flexible framework Mainly for free surface water environment	Suitable for shallow lakes	Local data	Less adjustable parameters for shallow water	2D\3D application	Difficulties with targeted simulation
GIS	Spatial Dynamic	User-interface not friendly	Local data Latest data	Lack of direct integration with DEM and RS	Not applicable	Difficult to manipulate individual targets and gridded data Poor precision
SOBEK	Based on GIS	Not applicable	Local data Open MI	Not applicable	2D application Reveal water mixing Water transport and transformation	Not applied in 3D

7. Conclusion

Coastal flooding is often accompanied by the combined effects of typhoons, heavy rainfall, high tide levels and sea level rise combined with ground subsidence, while the compound flood risk due to such extreme complex events has not been effectively investigated. In the context of the combination of climate change and urbanization, scholars have begun to focus on the modelling of compound events, but these studies usually consider the correlation between two variables only.

As science and technology continue to advance, the study of the properties and movement of fluids will continue to advance. At the same time, due to the extreme complexity of fluid motion, there are still significant limitations in terms of the understanding of the fluid. Although physical model tests are a common method for studying fluid motion, data simulations can only give specific information about the relevant flow field due to the complexity and difficulty of measuring the flow within the complex shape of a large number of boundaries that exist in actual engineering. Experiments can often only give parameters of the total flow, while the flow within the zone and specific information can be derived by relying on numerical simulations [13]. Flood risk assessment is a complicated task and it is difficult to use a single model for the completion of flood risk assessment. Rapid and effective modelling of floods at high spatial and temporal resolution remains a major challenge. Accuracy is related to underlying data collection constraints, the complexity and chaotic nature of floods and the uncertainties associated with the inherent nature of hydrological modelling. Therefore, it is necessary to combine models such as flood frequency models, flood infiltration models and flood loss models with actual data, coupling

DOI: 10.54254/2755-2721/3/20230379

different models to integrate them in a flood risk assessment system which is built on a particular software platform, and combining several of them through data conversion to increase the flexibility and accuracy of the models.

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