Characteristics of Flood-Causing Water for Rail Transit under Extreme Weather Conditions

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Abstract. Due to the acceleration of global climate change and urbanization, many coastal cities are facing an increasing risk of flooding due to the interaction of multiple climatic factors. Urban flooding will not only threaten the safety of the people but also lead to flood invasion into rail space. Taking the Guangdong-Hong Kong-Macao Greater Bay area as an example, this paper studies the flooding risks caused by different flood-causing water. The results show that the rainfall tends to be enhanced and concentrated; storm surges are becoming more frequent and spatially focused; sea level is on a constant upward trend. The above factors will further exacerbate the risk of urban waterlogging in the future. On the other hand, the river runoff did not change significantly; the response time of groundwater is generally greater than 80 days. Therefore, river runoff and groundwater did not cause obvious urban waterlogging risks.

Keywords: Extreme weather conditions, extreme rainfall, storm surge, sea level change, river runoff, groundwater response time

1 Introduction

Global climate change and rapid urban development have led to flooding in urban areas caused by compound extreme weather, which has become a global hotspot issue [1]. In case of flood, part of the flood water invades the underground space, such as rail transit, and shopping malls [2]. However, there are relatively few studies on waterlogging events affecting the rail transit system, and there is a lack of analysis of the hazards caused by compound extreme weather events on the rail transit system. Most of the research on rail transit waterlogging is the analysis of waterlogging under general rainstorm conditions [3–5].

Against the background of the increasingly serious risk of flood disasters, many scholars have begun to analyze the triggering factors of urban flooding. However, traditional hazard analysis only tends to focus on the impact of heavy rainfall [6–7]. For coastal cities under compound weather environments, the flooding situation may become more severe. For example, during a strong typhoon, high tides, storm surges, and

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heavy rainfall occur simultaneously, which will increase the flood risk of coastal cities [8]. At the same time, factors such as the rise of the groundwater level [9] and the increase in river runoff [10] caused by sea level changes [11] may have an impact on the urban flood process. Based on the above research results, this paper mainly focuses on the composition of urban flood-causing water under extreme weather conditions, revealing the composition of flood-causing water that affects urban rail transit waterlogging and the flooding risk caused by each part.

2 Methodology and Data

This paper analyses the development trend of extreme weather factors in Guangdong Province through statistical data and trend fitting, taking the central and coastal cities of Guangdong Province as the study area. Among them, the rainfall data come from the weather process data and the "2007-2022 Guangzhou Climate Bulletin" of Guangzhou Meteorological; the storm surge data comes from the "2013-2015 Guangdong Marine Disaster Bulletin" of the Department of Natural Resources of Guangdong Province; The sea level data comes from China Oceanic Information Network's "2000-2022 China Sea Level Bulletin"; the 1979 to 2022 river runoff data comes from three monitoring points in the lower section of the Pearl River (113.45°, 23.5°; 113.65°, 22.75°; 113.75°, 22.75°); the groundwater data comes from the "Water Resources Bulletin" of the Water Resources Department of Guangdong Province.

3 Composition of Flood-Causing Water and Their Risk of Flooding

Compound weather conditions of coastal cities refer to the simultaneous occurrence of heavy rainfall, storm surges, and high tides during large-scale meteorological events, which can greatly increase the flood risk of coastal cities. For example, the "2020.5.22" rainstorm in Guangzhou caused severe flooding in the city, killing 4 people; typhoon "Mangkhut" in 2018 and typhoon "Hato" in 2017 successively affected the Pearl River Estuary, both of which caused record-breaking high tide levels [8]. Meanwhile, the formation of urban floods is also affected by the drainage network, river runoff, and groundwater levels (Figure. 1). Therefore, the trend and correlation of multiple flood triggers should be considered to comprehensively assess the hazard of compound floods.

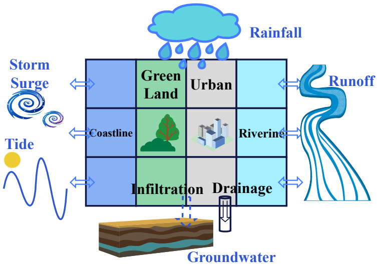

Fig. 1. Illustration of urban flood analysis in extreme compound weather events.

The flood risk of coastal cities has been increasing over time. The frequency of extreme weather events triggered by climate change is the main driver of this trend. As a result, extreme flooding events that have not been seen in the past are expected to occur in the future. This paper will take the Guangdong-Hong Kong-Macao Greater Bay area as an example to analyze the trends of various flood triggers and assess the main water composition of future urban flooding.

3.1 Rainfall

After analyzing the trend of 212 extreme rainfall events in Guangzhou from 2007 to 2022, it is found that the amount of rainfall, average rainfall intensity, and maximum rainfall intensity in Guangzhou show a fluctuating increase trend, with a slow decrease in the rainfall duration. The extreme rainfall events in Guangzhou are increasing and tend to be concentrated.

3.2 Storm surge

According to the data of nearly 29 typhoon storm surges along the coast of Guangdong from 2013 to 2022, the storm surge in Guangdong is closely related to the change of typhoon intensity, and there is a certain slow downward trend in all of them. However, statistics show that the frequency of typhoon storm surges in Guangdong is increasing. In the future, there may be multiple storm surge disasters that land on the coast of Guangdong in succession, which will lead to an overlay of hazards. At the same time, the central region is distributed with all the completed rail transit systems, so rail transit is significantly affected by the spatial distribution of storm surges.

3.3 Sea level change

With the intensification of global warming, it has become an indisputable fact that the global average sea level is rising. At the same time, the number of seasonal sea level anomalies has increased significantly, which will raise the base level of storm surge, backwater the sea drainage channel, and aggravate the flood disasters caused by heavy rainfall.

The analysis of sea level rise along the coasts of China, the South China Sea, and Guangdong Province from 2007 to 2022 shows that the overall sea level shows a fluctuating upward trend, as shown in Figure. 2a, and the increasing rate is higher than the global level (2.8 mm/a) for the same period. The linear fitting of the sea level data from July to November in the Pearl River Estuary from 2011 to 2022 is shown in Figure. 2b, which indicates that the sea level in the Pearl River Estuary shows a fluctuating upward trend. The sea level in the Pearl River Estuary is high in October, and the increasing rate in October is the largest (12.6 mm/a), which is much higher than the rate along the coast of China and Guangdong Province.

As a result, when the coast of Guangdong Province encounters storm surge disasters in the future, the rising trend of sea level will further aggravate the threat of extreme rainfall and storm surge disasters to cities and people.

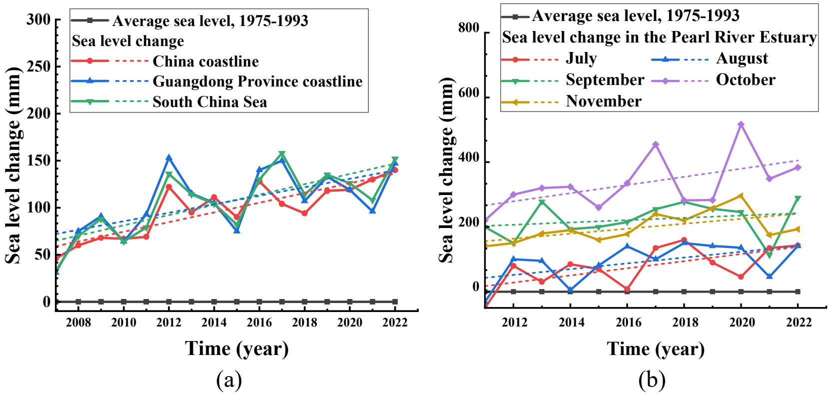

Fig. 2. Variation of sea level: (a) Trends of sea level rise along the coast of China, South China Sea, and Guangdong Province, 2007-2022; (b) Trend of November Sea level change in the Pearl River Estuary, 2011-2022. (In this paper, the 1975-1993 average sea level is defined as the perennial average sea level)

3.4 River runoff

Against the backdrop of global warming, a series of natural disasters such as backwater and saltwater intrusion caused by changes in river levels and runoff have made riverine areas vulnerable and sensitive to climate change.

This paper takes the lower section of the Pearl River as the research object, which is not only affected by sea level change but also significantly influenced by urbanization in the riverine area. Using the river flow data from three monitoring sites in the lower Pearl River from 1975 to 2022, the long-term interannual variation trend of river runoff is analyzed. The result in Figure. 3 shows that the change rates of river flow at these sites are close to zero, that is, the river flow in the lower section of the Pearl River has fluctuated interannually in the last 48 years but is essentially unchanged. It has not been affected by sea level rise and urbanization around the river and shows no significant trend.

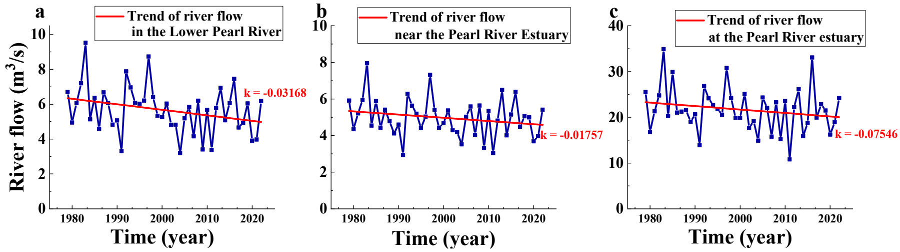

Fig. 3. Trends of river runoff in the lower Pearl River from 1975 to 2022 at three different monitoring places.

3.5 Groundwater response time

Under stable natural conditions, the recharge and discharge of an aquifer remain in balance over many years. However, as the frequency of extreme weather events has shown an increasing trend, there have been variations in the response of groundwater levels to climate change. The change in groundwater level is of great significance to the infiltration of river floods, which is an important factor affecting the severity of flood disasters. Therefore, it is of great importance to study the response characteristics of groundwater to flood infiltration and prevent the groundwater level from rising into disaster.

This paper analyzes the groundwater level data of the Bayin River monitored by Yang [9], as shown in Figure. 4. The results showed that the response time of groundwater level rise increased with the distance from the river, and the response time was over 80 days. Therefore, under short-duration floods, changes in groundwater level will not affect flood infiltration. Taking the Guangdong-Hong Kong-Macao Greater Bay area as an example, the trends of various flood components under compound extreme weather conditions in the future are analyzed and listed in Table. 1.

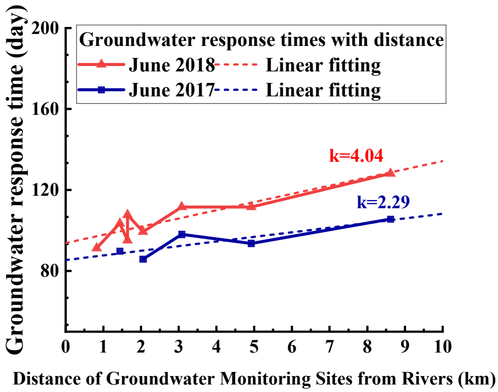

Fig. 4. Trends in groundwater response time with distance from the river channel.

Table 1. Composition of flood-causing waters and the related risk of flooding

Water composition	Characteristic parameter	Trends	Risk of flooding
Rainfall	Rainfall Intensity	Increasing	Sharpen
Storm Surge	Max Storm Surge	Slowing Decline	Sharpen
Sea Level	Sea Level Height	Increasing	Sharpen
River	River Runoff	Unchanged	Unaffected
Groundwater	Groundwater Response Time	Unchanged	Unaffected

4 Conclusions

This paper analyzes the flooding risks caused by the composition of various flood-causing water and their trends under compound weather. The result shows that under the compound extreme weather conditions in the future, the intensity of rainfall presents an enhanced and concentrated trend; the frequency of storm surges will increase and be spatially concentrated; the sea level will continue to rise fast. The rate of sea level rise is the greatest in October, and the height of the sea level is the highest. Rainfall, storm surge, and sea level rise will continue to aggravate the city's flooding risk. On the other hand, the river runoff remains stable, and the response time of groundwater changes is generally longer than 80 days, which means that short-term urban flooding will not affect the infiltration. Therefore, the river flow and groundwater are unaffected by global climate change and do not significantly contribute to urban flooding risk.

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