Study on Risk Assessment of Typhoon Storm Surge Based on Public Safety Triangle Theory

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Abstract. Based on the “triangle theory” of public safety and combined with the formation mechanism and characteristics of storm surge disasters, this research comprehensively considered the danger of disaster events, disaster carriers in the affected area, and disaster prevention and mitigation capabilities such as emergency management and considered the possibility of secondary/derived disasters arising from disaster factors and whether they are in sensitive time periods with a view to studying the risk evaluation technology of storm surge disasters. According to this study, a risk assessment method is established to assess the risk of real-time dynamic events before emergency decision-making.

1. Introduction
As a severe marine disaster, storm surge greatly impacts the life and property of coastal people as well as the economic development of coastal zones. In recent years, with the rapid development of coastal zones, the economic value and population density have increased quickly in coastal zones and, as a result, the original barren lands and large deserted beaches have become or will soon become economic development zones worth of billions of yuan. [1] Despite storm surges as strong as the past, the coastal zones will suffer times of economic losses, so in order to maximize social benefits with less economic input, the risks and impacts of storm surge disasters must be fully considered in coastal economic development. [2,3]

Since the 1980s, foreign scholars have focused on the risk of storm surge disasters and formed scientific and effective evaluation theories and methods, which have been applied in many coastal cities. [4-8] In comparison, the research on storm surge risk assessment in China started late, mainly since the start of International Decade for Natural Disaster Reduction. [9,10] In the research process, scholars with different opinions on the components of the disaster system have different focuses, especially most early research that only focused on the disaster-causing mechanism but rarely paid attention to storm surge disaster carriers. In addition, the existing risk evaluations of storm surge disasters mainly focus on risk division and serve government planning and construction, insurance rate division, etc. The existing risk evaluations of storm surge disaster event mostly simulate and predict disaster-causing factors (e.g. surge and flood) or estimate possible direct economic losses and affected population in the entire event. It is the characteristic of this research that it comprehensively considered the type, location, number, importance, and vulnerability of sensitive carriers of storm
surge disaster and considered regional emergency capabilities, sensitive time periods of affected areas, and mesh scale of public concerns.

2. Risk assessment

Based on the "public security triangle theory", according to the historical case data of storm surges, actual business requirements for risk prevention and control, and the development process of the typhoon storm surge event chain, a comprehensive judgment is made from three aspects: the danger of the event, the hazard bearing body, and the emergency capacity. At the same time, considering the impact of sensitive time, a risk assessment model framework for typhoon and storm surge is established.[11]

![Figure 1. Risk assessment framework](image)

2.1. Public safety triangle theory

The three sides of the public security triangle framework represent emergencies, Hazard-affected carriers and emergency management, respectively. The nodes connecting the three sides are collectively referred to as disaster factors and include material, energy, and information. Disaster elements are essentially an objective existence. If these disaster factors exceed a critical quantity or encounter certain triggering conditions, they may lead to emergencies.
Emergencies usually manifest as the disastrous effects of disaster factors. Research on emergencies focuses on understanding the evolutionary laws of their gestation, occurrence, development, and mutation, and the types, intensity, and spatial-temporal distribution characteristics of emergencies. Hazard-affected carriers are the objects of emergency, and generally include people, things and systems. The hazard-affected carrier is a functional carrier for the harmonious development of human society and the natural environment, and is the object of emergency protection in the event of an emergency. The damage of the hazard-affected carriers under the action of emergencies is manifested in two forms: main body destruction and functional destruction. The destruction of the hazard-affected carrier may lead to the activation or accidental release of the disaster factors contained in it, leading to secondary derivative events and the formation of event chains.

Emergency management refers to various human intervention methods and processes that can prevent or reduce emergencies and their consequences. Emergency management includes: implementing human intervention for emergencies, reducing the probability of occurrence or reducing the intensity of emergencies; implementing prevention and protection against hazard-affected carriers, and strengthening the defense capabilities of hazard-affected carriers.

2.2. Hazard

The assessment of risk level of typhoon storm surge is the basis of disaster emergency, before which the corresponding emergency response should be started based on the risk level. Therefore, reasonable assessment of risk level is particularly important for disaster emergency response. In this study, the FM module of software MIKE21 of the Danish hydraulics institute was firstly adopted to conduct numerical simulation of the inundation range of the current typhoon storm surge to determine the range of risk assessment. The risk mainly takes into account factors such as the increase of water at sea, waves and the depth of submergence on land. Different disaster-causing factors have different disaster-causing mechanisms that may cause serious losses. The grading based on the risk index of multiple disaster factors is easy to estimate the disaster level comprehensively and give a targeted guidance to emergency response.

The grade of storm surge elevation refers to the assessment of storm surge disaster risk and the classification in the guidelines of zoning technology. The surge elevation ≥251 cm is class I; the surge elevation 201 ~ 250 cm is class II; the surge elevation 151 ~ 200 cm is class III; the surge elevation 0 ~ 150 cm is class IV.

| Hazard rank | Class I | Class II | Class III | Class IV |
|-------------|---------|----------|-----------|-----------|
| rising water value(cm) | ≥251 | 201 ~ 250 | 151 ~ 200 | 0 ~ 150 |

For disaster-affected bodies on land, the impact of submerged water depth on them is mainly considered. Coastal cities may be flooded if a levee overflow occurs. The immersed water depth is divided into four grades according to different risks.
Table 2. Submerged water depth rating

| Hazard rank | Class I | Class II | Class III | Class IV |
|-------------|---------|----------|-----------|----------|
| Submerged water depth value (cm) | ≥300 | 120～300 | 50～120 | 15～50 |

A sea wave usually refers to a wave generated by the wind in the ocean, mainly including stormy waves, surge and near-sea waves. In this research method, according to the literature investigation, the waves were divided into four levels, except the situation of no waves. Class I is Great Surge, Class II Large Surge, Class III Medium Surge and Class IV Small Surge.

Table 3. Significant wave height rating

| Hazard rank | Class I | Class II | Class III | Class IV |
|-------------|---------|----------|-----------|----------|
| Significant wave height (m) | H_{1/3}≥6 | 2.5≤H_{1/3}＜6 | 0.5≤H_{1/3}＜2.5 | 0＜H_{1/3}＜0.5 |

2.3. Disaster-affected body

The exposure and vulnerability of disaster-affected body are mainly taken into account in the analysis of typhoon storm surge disaster-affected body. The exposure degree of the disaster-affected body mainly considers the type, quantity, importance degree of the disaster-affected body in the affected area and factors such as the possible secondary derivative events caused by it. The vulnerability of disaster-affected body takes physical vulnerability into consideration, which mainly refers to the degree of possible damage of disaster-affected body under different levels of disasters.

The disaster-affected body refers to the main body of human society directly affected and damaged by the disaster. It mainly includes various aspects of the human and social development, such as industry, agriculture, energy, construction industry, transportation, communication, education, culture, entertainment, various engineering facilities for disaster reduction, facilities of production and living services, and various kinds of wealth accumulated by people. The sensitivity of disaster-affected body is different with different disaster-causing factors. In this research method, the storm surge disaster-affected were divided into the marine key protection target and the coastal key protection target. Further consideration should be given to the importance of each type of disaster-affected body and the secondary derivative events that may result from its impact. Based on the above factors, the exposure of the disaster-affected body was comprehensively estimated.

Physical vulnerability refers to the possibility of loss of disaster-affected body under different disaster-causing degrees. It is a quantitative estimation of disaster resistance of disaster-affected body on a micro scale. The failure states are generally divided into basic intact, minor, moderate and severe damage. In this study, the vulnerability of disaster-affected body is divided into four grades based on the degree of damage of disaster-affected body under different disaster-causing factors: no damage assignment, minor damage assignment, moderate damage, and severe damage.

Table 4. Disaster bearing body classification(a)

| Type | Hazard-affected body | Secondary derived event |
|------|----------------------|------------------------|
| Key protection targets along the coast | Coastal Airport | Flight Delayed, Stranded Passengers, Traffic Accident |
| | Main Highway | Traffic Accident |
| | Railway | Train Delay, Stranded Passengers, Traffic Accident |
| | Nuclear Power Plant | Fire, Explosion, nuclear leak |
| | Thermal Power Plant | Fire, Explosion |
| | Steelworks | Safe Accident |
| Type | Hazard-affected body | Secondary derived event |
|------|---------------------|-------------------------|
|      | Chemical Industrial Park | Fire, Explosion, Chemical Leakage |
|      | Oil Storage Depot | Fire, Explosion |
|      | Gas Station | Fire, Explosion |
|      | Tourist Area | Financial Loss |
|      | Shipyard | Safe Accidents |
|      | Reservoir Dam | Dam Break |
|      | Cropland | Financial Loss |
|      | Hospital | Casualties |
|      | School | Casualties |
|      | Population Area (villages and towns) | Casualties |

Table 5. Disaster bearing body classification(b)

| Type | Hazard-affected Body | Secondary Derived Event |
|------|---------------------|-------------------------|
|      | Oceanic Ranch | Social Group Event |
|      | Haven | Traffic Accident |
|      | Port and Pier | Traffic Accident |
|      | Cross-sea Bridge | Traffic Accident |
|      | Sea Lane | Traffic Accident |
|      | Offshore Oil Platforms | Fire, Explosion, oil spilling |
|      | Offshore Wind Farm | Safe Accident |
|      | Offshore Solar Power Plant | Safe Accident |
|      | Tidal Power Station | Safe Accident |
|      | Key protection targets at sea | |

2.4. Emergency capacity
Compared with the increasing storm surge risk, the current emergency capacity to storm surge in China is still relatively weak. It is mainly in the following aspects: the insufficient equipment for storm surge emergency, the dispersal storage, the uneven quality and business level of emergency team personnel, etc. The emergency capacity of storm surge directly affects the response effect of storm surge disaster. The emergency ability mainly refers to the reaction and coping capacity to emergencies. In this method, two indicators are established to indirectly confirm the coping capacity to the storm surge in a region. Two indicators mainly refer to the frequency of storm surge and local economic level.

If typhoons and storm surges disaster occurs frequently in a region, the region always strengthens its protection against such disasters and is fully prepared, so the emergency capacity is relatively strong; If a place has few storm surge disasters, the region may not be as well prepared for the disasters as that suffers from storm surge disasters frequently, therefore it has a weak capacity to respond to such disasters.

If typhoons and storm surges occur frequently in a region which has a backward economy, it is not conducive to the improvement of the emergency response capacity in this region. If typhoons and storm surges occur frequently in a region which has a developed economy, and the region has some ability to improve the emergency capacity.

2.5. Sensitization time
Sensitization time mainly refers to some important meetings and activities held during the storm surge disaster. When it happened to be a sensitization time during a storm surge, the risk level can rise by one level.
Table 6. Sensitive time classification

| Item                                      | Type                                      |
|-------------------------------------------|-------------------------------------------|
| Important Meeting                         |                                           |
| Military Exercise                         |                                           |
| Sports Event                              |                                           |
| Marine Fishery Activity                   |                                           |
| Maritime Scientific Research              |                                           |
| Exploration of Marine Resources           |                                           |
| Maritime Rights Protection Activities      |                                           |

2.6. Comprehensive risk assessment
The results of comprehensive risk assessment take into account the number of disaster-bearing bodies, the importance of disaster-bearing bodies, the vulnerability of disaster-bearing bodies under different hazard, the emergency response capacity and the sensitive time. Firstly, the risk value of each disaster-bearing body in the study area was calculated, and then the risk value of all sensitive disaster-bearing bodies in the assessment area was superimposed to obtain the risk assessment result.

3. conclusion
This article starts with a comprehensive perspective and conducts research and analysis on the comprehensive risk assessment of typhoon storm surge. The basic framework and process of comprehensive risk assessment for storm surge disaster are established. In the process of comprehensive risk assessment of typhoon storm surge, the key factors of comprehensive risk assessment are hazard, vulnerability of disaster-bearing body, secondary derivative events, emergency response capacity and sensitive time.

Prior to the vulnerability analysis of hazard source carrier, it is necessary to make clear the corresponding relationship between storm surge disaster risk and disaster causing factors according to historical disaster statistics. The vulnerability rules of disaster-bearing bodies were established for risk assessment under different disaster-causing factors.

The result of risk assessment should contain three elements: "time, space and horizontal value".[9] Traditional probabilistic risk represents the potential loss of a disaster in the study area. On the basis of considering the risk and the disaster-bearing body, the method in this paper increases the judgment of emergency capacity and sensitive time, and makes the risk assessment result more instructive.

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References
[1] China's State Oceanic Administration (2013). China Marine Disaster Bulletin. http://www.coi.gov.cn/gongbao/.
[2] Ming X, Wei X, Ying L. (2015) Quantitative multi-hazard risk assessment with vulnerability surface and hazard joint return period. Stochastic Environmental Research & Risk Assessment, 29(1): 35-44.
[3] Carl B, Ioannis G, Georgios P. Balomenosc, Jamie E. Padgetta. (2019) Assessing the accessibility of petrochemical facilities during storm surge events. Reliability Engineering and System Safety 163: 51–59.
[4] Jiachun L, Bingchuan N. (2017) Storm surge prediction: present status and future challenges. Procedia IUTAM25:3-9
[5] Kleinosky L R, Yarnal B, Fisher A. (2007) Vulnerability of Hampton Roads, Virginia to Storm-Surge Flooding and Sea-Level Rise. Natural Hazards, 40(1): 43-70.
[6] Muhammad A. H, Biswajeet P, Naser A, Sanjoy R. (2019). Tropical cyclone risk assessment using geospatial techniques for the eastern coastal region of Bangladesh. Science of the Total Environment 692: 10–22.

[7] Sabarethinam K, Jamie E. P. (2018) Storm surge fragility assessment of above ground storage tanks. Structural Safety 70: 48–58.

[8] Mehebub S, Haroon S. (2019) Vulnerability to storm surge flood using remote sensing and GIS techniques. A study on Sundarban Biosphere Reserve, India. Remote Sensing Applications: Society and Environment 13: 106–120.

[9] Xueping Sun. (2018) Study on Comprehensive Risk Assessment of Marine Environment Safety Based on Public Safety Triangle Theory. In: E3S Web of Conferences. Guilin. pp. 1-5.

[10] Xiaobing Yu, Xianrui Yu, Zhonghui Ji. (2019) Risk assessment of typhoon disaster in China's South-East coastal areas -based on information diffusion theory. Journal of Catastrophology. 34(1) : 73 -77.

[11] Fan W C. (2007). Bull Natl Nat Sci Found Chin 2.7177