Does the Flood resilience Index actually work?

An in-depth study on urban flood resilience in the Yangtze River Delta region of China

Yuxuan Zhang

April,2023

Master's Thesis for the Spatial Planning programme

Specialisation in Cities, Water and Climate Change

Nijmegen School of Management
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Supervisor Radboud University: Prof. Dr. S.V. Meijerink

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Radboud Universiteit

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Preface

As the thesis was about to be completed, I had a lot of feelings. This thesis is about the urban flood resilience index in the Yangtze River Delta of China and conducts in-depth research on the flood resilience index based on actual flood disaster situations. By completing this research, I hope to complete my Master's programme in Spatial Planning specializing in city, water, and climate change at Radboud University. The writing process of the thesis is a new challenge for me because my undergraduate major is in landscape architecture, which is a design-oriented major. Although stepping out of my comfort zone was very difficult, I still don't regret the decision that I choose to challenge myself. Because I have grown in the process of overcoming difficulties. In the process of writing this thesis, I received a lot of help and support from different people. Firstly, I am truly grateful to my supervisor, Dr. Sander Meijerink, for providing me with very useful feedback and suggestions on my thesis. In addition, he gave me full patience, even though I am not as familiar with academic writing as Dutch students and the always pleasant and relaxed meetings have increased my confidence on finishing my thesis. Secondly, I would also like to thank Dr. Huub Ploegmakers for his advice on the statistical issues of the thesis. And all the people I met in the Netherlands, including classmates, roommates, landlords, and staff from the Radboud University. Thank them for their help in my life and studies. Thirdly, I would like to thank my boyfriend, my family, and my friends for their company and unconditional support and care when I have to finish my master's thesis and fight against depression at the same time. Finally, this thesis is dedicated to my grandfather. It is a pity that he cannot share this final joy with me, but I know he is proud of me and I wish that he has started a new journey.

Thank you for taking your precious time to read my thesis. I hope you will enjoy reading it!

Yuxuan Zhang

Pingnan, China,4-27-2023

Summary

In recent years, with the frequent occurrence of flood disasters, especially some extreme floods, many losses have been caused. And due to the impact of climate change and population growth, the impact of floods will continue to increase in the future. In this context, the urban flood resilience has become the focus of many studies. Many scholars have evaluated and predicted the flood resilience of different cities through the calculation of the flood resilience index. However, some theoretically high flood resilience cities still suffer heavy losses after a flood.

The research area of this thesis, cities in the Yangtze River Delta, is one of the most economically developed regions in China. These cities are considered to have high flood resistance, but there are still serious losses caused by floods every year, especially the floods in the summer of 2020, which caused huge economic losses and even personnel deaths. Therefore, it is questionable whether the theoretical urban resilience truly reflect the actual flood resilience. To address this issue, the goal of this thesis is to investigate which flood resilience index reflects the actual flood resilience, and to formulate recommendations for Flood risk management of Yangtze River Delta cities.

The thesis is the combination of qualitative research and quantitative research. The quantitative research section includes:1) Reliability analysis and revision of the flood resilience index. 2) The flood resilience of cities in the Yangtze River Delta was recalculated based on the new resilience index and the results were correlated with the actual flood losses. 3) Correlation analysis will be conducted between different indicators and real flood disasters loss to obtain indicators that effectively reflect actual flood resilience. The qualitative research part is zoomed to Anhui Province, the worst hit province in the 2020 flood event, to obtain more detail information through this specific case to help verify the results obtained from the quantitative research.

From this research, it can be concluded that four indicators: Mobility, Employment, People vulnerability, and Social insurance that can reflect the true flood resilience, and propose six suggestions for flood risk management in the Yangtze River Delta.

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1. Introduction

In recent years, the earth on which we live has repeatedly sent out crisis signals.At this late hour, the outbreak of COVID-19 in 2020 still affects the daily life of people in most parts of the world (Debata et al., 2020; Heriyati, 2020; Li et al., 2022); In 2021, the record-breaking heavy rain in Europe triggered floods. Belgium, Germany, Italy, Luxembourg, the Netherlands and some other European countries suffered serious floods, some of which were catastrophic, causing many deaths and extensive damage (Cornwall, 2021; Szymczak et al., 2022). In addition to COVID-19 and flood disasters, the crisis signals sent by the earth also include frequent anomalies around the world. In September 2021, Cameroon unexpectedly ushered in a rare snowfall and hail weather. This is a small probability event for this African country near the equator, which has almost never happened (Western Cameroon Faces Snow, 2021). What's more, there are high temperatures and severe cold weather in many places that are not seen in a thousand years. Many cities in Central and North America, including the United States and Canada, have experienced record-breaking high temperature weather (Mo et al., 2022), while South Africa has experienced a rare low temperature (Mokhoali, 2021). These abnormal events remind us again and again that the climate change of the earth may have reached a critical point. In the face of the frequent occurrence of such disasters and accidents, and the whole earth is suffering, it may become a new normal to prepare for disaster emergency. When considering how to deal with these shocking global disasters, we should also realize that this may be a kind of rescue for the earth, or a warning for the earth, which is an advance warning of the impending crisis for the arrogant and ignorant human being. What is the future and fate of all mankind? What should we do?

This thesis will focus on one of these disturbing disasters which is flood disaster. This is not only because flood is one of the most pervasive disasters in the world (Schanze, 2006). Over the past fifty years, a series of catastrophic floods have caused greater damage, and the impact is expected to increase in the future due to climate change and population growth (Schanze, 2006). It is also because that it is the one of the most threatening natural disasters for human society, resulting in the interruption of people's lives and livelihood sources around the world (Schanze, 2006). Flood not only poses a direct threat to human health, but also has a long-term impact on the displacement of some people and the deterioration of living conditions. Floods can cause irreparable damage and suffering, and the poor suffer enormously. Especially in low-income countries, infrastructure systems such as drainage and flood control are underdeveloped (Rentschler et al., 2022). Although countries with different levels of development have flood risks, almost the entire population (89%) with flood risks in the world lives in low income and medium income countries (Rentschler et al., 2022). If the flood problem can be solved, or even partly solved, it will greatly help to improve the lives of those poor population. Therefore, in this context, this thesis selects the issue of flood disaster for in-depth research.

1.1. Problem statement

As mentioned above, in recent years, the scale and frequency of flood events in the world have shown an upward trend, which has attracted people's attention（Kotzee & Reyers，2016). Floods can have many direct and indirect consequences and cause serious social, environmental and economic losses for the most vulnerable and unintended cities in the world. As the world's population is becoming more and more urbanized and more extreme rainfall is caused by climate change, the problem of urban flood begins to show an upward trend (Hammond et al., 2013). Urbanization has led to a significant decline in vegetation coverage and green space area, and increased impermeability in different urban areas, making many cities face serious flood risks（Majidi et al., 2019. This situation is no exception in China. With the development of urbanization in China, the urban surface infrastructure (roads, buildings, etc.) is covered, and the impervious area is expanding, resulting in the reduction of rainwater infiltration in urban areas（Leng et al., 2020). In the context of global climate change, the uncertainty of rainfall intensity and duration has contributed to the occurrence of flood events in China. Under the influence of the above multiple factors, China has experienced many catastrophic flood events in the past decade（Rehman et al. 2019). Since 2006, 157 cities in China have been seriously affected by urban floods, which can be expected to increase（Imran et al. 2019. This also means that China's traditional urban flood risk management measures face challenges（M. Wang et al., 2018）. In the face of such a severe situation, with the introduction of rainwater and flood management concepts in European and American countries, such as low-impact development, the concept of sponge city proposed by Chinese scholars has been recognized and strongly supported by the government. With the popularization and application of the concept, urban flood risk management in China has gradually shifted from traditional defensive measures to adaptive measures (Jia et al., 2017). This is a commendable change. At the same time, the concept of urban flood resilience has also aroused widespread concern. Many scholars and experts use resilience to measure the ability of cities to cope with floods. Some studies try to calculate the flood resilience index of cities or communities, hoping to obtain the level of flood resilience in different cities or communities (P. Wang, Li, & Zhang, 2021; Zhu et al., 2021). However, it is doubtful whether the measured results of urban flood resilience truly reflect the capacity of the cities to cope with the flood. Some cities are considered to have high flood resilience, but there are still severe losses caused by a large number of floods every year, especially the flood in the summer of 2020, which caused huge economic losses and a large number of deaths (Jia et al., 2022). Based on this, this study will deeply explore the relationship between the measured or calculated urban flood resilience and the real urban flood resilience.

1.2 Research aim and research question

Research aims

The research aims are to investigate which flood resilience index reflects the actual flood resilience, and to formulate recommendations for Flood risk management of Yangtze River Delta cities.

Research question

Which flood resilience index reflects the actual flood resilience of Yangtze River Delta cities?

There are 5 sub-questions to help answer the main research question.

1.How to measure the flood resilience of different cities?

2. What is the flood resilience index of Yangtze River Delta cities?

3. To what extent is the flood resilience assessment framework internally sound and robust?

4. Does the resilience index reflect the actual flood resilience of Yangtze River Delta cities?

5. What are the suggestions for improving the resilience index and Flood Risk Management in in Yangtze River Delta?

1.3 Social relevance

Firstly, this study will summarize the different dimensions related to urban flood resilience, which shows a wide range of urban flood risk management objectives. This will help planners and policymakers raise their awareness of urban flood resilience and promote the improvement of urban flood management in a more resilient direction.

Secondly, this study will validate different measurement indicators and provide a series of effective indicators through screening. This will provide a common language for decision makers to promote effective communication. At the same time, it will be convenient for the company staffs or civil servants to evaluate the flood resilience of a city by providing a unified reference index for data collection.

Finally, this study will validate the calculated flood resilience index. If a proven effective flood resilience index is obtained, it will better provide information for planners and policymakers to make more effective policies.

1.4 Scientific relevance

Firstly, to some extent, this thesis helps to avoid the subjectivity of selecting flood resilience indicators. In many studies on flood resilience index, the selection of indicators is usually based on the experience of experts, so there are subjective factors that affect the effectiveness of indicators (Burton, 2014; Zhu et al., 2021). This thesis provides objective criteria for selecting indicators through statistical analysis of specific flood disaster situations and theoretical resilience. Secondly, the thesis fills the gap in previous scientific research where the flood resilience index deviates from the actual situation. Many studies try to explain the concept of resilience in depth and try to turn it into an operable concept. Some of these studies have calculated flood resilience index for different cities and regions based on different evaluation frameworks (Bulti et al., 2019; Wang et al., 2021; Zhu et al., 2021). However, few studies have empirically verified the flood resilience index by use of disaster impact (Bakkensen et al., 2016). This study will try to validate the flood resilience index by comparing the calculated flood resilience index with the actual disaster situation, and test the indicators for calculating the flood resilience index. It is expected to fill in the gaps of this part of the research.

2. Literature review

2.1 Flood Risk and flood risk management

Flood risk is determined by three components: hazard (the occurrence probability of a flood event); exposure (the number of people and the value of assets affected by flooding); and vulnerability (the ability of society to respond to an event) (Koks et al., 2015; Kron, 2005). In the practice of flood control in many countries, even in some developing countries, the first two items are also the focus of work when preventing losses caused by flood events (Kundzewicz et al., 2019; Whitworth & Baily, 2020). However, reducing hazard and exposure often requires investing a lot of money to strengthen flood control infrastructure and relocation vulnerable populations. At the same time, with the increase of extreme flood events caused by global climate change, the uncertainty of flood disasters increases, and only focus on these two aspects cannot fully cope with flood disasters (Morrison et al., 2017). The ability of society to respond to flood disasters (vulnerability) should also play an important role. Therefore, when it comes to how to solve the increasing flood problem in the world, we should inevitably consider all three parts. The increasing attention to flood risk comes as people increasingly realize that absolute flood prevention or protection cannot be achieved, and shift their attention to managing flood risk from a more comprehensive perspective (Birkholz et al., 2014).Risk management has been established as a clear procedure for dealing with risks caused by natural, environmental or man-made hazards, and flood is the representative of it(Plate, 2002).In a narrow sense, flood risk management is the process of dealing and managing current flood risk situations(Plate, 2002), broadly speaking, flood risk management is the sum of actions to take reasonable measures to mitigate flood disasters, and is the synthesis of a series of strategies. Its purpose is to reduce the threat of some flood disasters, prevent the loss of life during flood events, and reduce the loss after flood (Morrison et al.,2017; Plate, 2002). To sum up, flood risk management refers to the sum of a series of measures and strategies to control flood disaster losses to the minimum.

Strategies and measures of flood risk management

Oosterberg et al. (2005) summarized the strategies of flood risk management according to the three components of the flood risk, which is helpful to further deepen the understanding of flood risk management concept mentioned above. First, hazard reduction means "keep floods away from urban areas". This strategy is the backbone of flood risk management. Through engineering-based means such as dikes, spillways, and dredging; also includes well-established drainage systems and pumps in cities (Oosterberg et al. al., 2005). In addition, spatial measures to reduce the probability of flooding have become common. Examples include the retention area along water rivers, or green infrastructure in cities and ecological river restoration (Oosterberg et al., 2005; Reaney, 2022, Glaus et al., 2020). These nature-based solutions slow water flow through storage and filtration to prevent flooding (Reaney, 2022). Second, vulnerability reduction is "prepare urban areas for floods". This part of the strategy mainly refers to people taking precautions and make adjustments to the physical environment to make cities and people's homes more flood-proof. While modifying the environment to be adequate for flooding is the focus of this part of the strategy, early warning and emergency response still play an important role when flooding occurs (Oosterberg et al., 2005). People can react to impending disasters in advance, reducing damage and loss of life. Finally, exposure reduction means "keep urban areas away from floods". The strategy addresses issues of land use and urbanization, and requires robust spatial planning systems to develop human habitats holistically and to minimize the number of people on flood-prone lands (Oosterberg et al., 2005). Relocation will be performed when necessary.

In addition to the classification of flood risk management measures according to the three components of flood risk, the STARFLOOD framework adopted in flood risk management in the European Union is to arrange flood risk management measures according to the process of flood occurrence. STARFLOOD, which represents strengthening and redesigning European flood risk practices - establishing appropriate and resilient flood risk management arrangements (Starflood, n.d.), is a European Union Framework project focused on flood risk governance (Wiering, 2019). This framework also summarized the diversity of flood risk strategies. These core strategies include (as seen on Figure 1): Risk Prevention (1), Flood Defence (2), Flood Mitigation (3), Flood Preparation (4), and Flood Recovery (5). Among them, risk prevention mainly involves advocating spatial planning; Flood prevention includes taking physical defense measures such as dikes and dams; Flood mitigation refers to the use of urban greening infrastructure, flood retention and urban management; Flood preparation is related to warning system, disaster planning and evacuation plan; Flood recovery includes regional reconstruction and insurance system (STARFLOOD, n.d.)

Although these five core strategies are summarized in the content of European countries, due to the universality and universality of flood risk, these strategies and classifications are also applicable to other countries and cities in the world. However, the specific strategies vary according to the different political, economic and geographical contexts of flood risk management in different countries and regions.

Figure 1. STARFLOOD Approach (Starflood, n.d.)

Trends in flood risk management

From the flood risk management strategy mentioned above, it is not difficult to see that the overall trend of flood risk management is from physical defense strategy to spatial defense strategy, from a single strategy to a comprehensive and comprehensive strategy. Flood risk management stems largely from resistance strategies. In the past, flood risk management in most countries usually adopted resistance-based strategies - trying to control flood threats by improving infrastructure, such as dams and dykes (Morrison et al., 2017). This is also the reduction of the probability of occurrence of flood events to reduce the flood losses as described above. Although the flood risk management strategy based on resistance can prevent the flood threat as much as possible and minimize the possibility of adverse impact of flood on society, it can provide some protection for the city when flood occurred. However, with the increase in extreme flood events caused by global climate change, the occurrence and scale of flood events become unpredictable. This flood risk management strategy shows its disadvantage, that is, it cannot deal with flood uncertainty well. There is a realization that by focusing solely on fighting floods we may not be able to deal with future flood disasters. Society's ability to respond to events (vulnerability) and reduce flood exposure should also play an important role in the content of flood risk management. Flood risk management is gradually shifting from defensive measures of resistance to measures that combine resistance and adaptation (Morrison et al., 2017). Although over the years, countries around the world have greatly improved their understanding of flood risk management, and gradually started to pay more attention to vulnerability and exposure to floods, the application of vulnerability reduction and exposure reduction strategies in flood risk management is still very complex (Koks et al., 2015).

The multi-layered safety approach in the Netherlands is a good example to show the trend described above. The essential idea of this framework is to distinguish three layers of flood risk management. The first part is the layer which is invested in technical infrastructure to keep water out of the city (Bosoni et al., 2021). These could be dikes or dams to keep the water out. The second layer is about spatial design (Bosoni et al., 2021). This is about the spatial planning within the areas of the first layer. It can be seen as a safety net for when dikes or dams do not seem to work. The last layer is about the evacuation strategies. This layer is about if something ultimately goes wrong, residents can get out of this area rather quickly and efficiently (Bosoni et al., 2021). The Multi-layered safety Framework suggests that people should not only think about the first layer, where keeping the water out of the city is important, but also should address more attention to the second and third layers, which is in line with the general trend of flood risk management in the world.

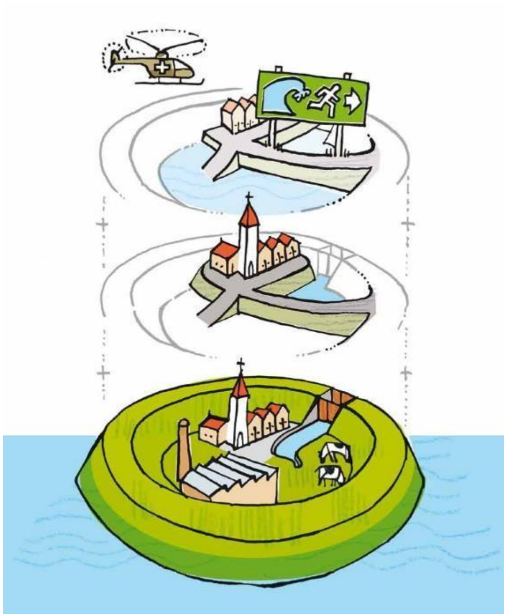

Figure 2. Multi-layered safety approach (Bosoni et al., 2021)

Flood Risk Management in China

China has been plagued by flood disasters since ancient times. From ancient times to modern times, many flood control works of different scales have been carried out (Kundzewicz et al., 2019). In recent decades, China's flood control expenditure has been increasing and the scale of flood control has been expanding. However, it is impossible to completely control the flood. Catastrophic floods continue to plague the country frequently (Z. Kundzewicz et al., 2019; Z. W. Kundzewicz & Jun, 2004). Therefore, effective flood risk management to reduce flood risk is very important in China. For many years, in order to cope with flood risks, Chinese government has always favored the use of control measures to build hard flood control engineering facilities (Chan et al., 2018). The main measures to control river/river floods in China have always been to build dams. Since 1950, more than 97000 dams have been built (Chan et al., 2018). Especially after the flood in 1998, China accelerated large-scale infrastructure construction. The dikes along the river and its tributaries and lakes have been comprehensively strengthened, forming a strong line of defense against floods (Jia et al., 2022). Such engineering measures are effective in controlling rivers or river floods in the upstream catchment area, but due to China's rapid urbanization, it is increasingly difficult to ensure the protection of downstream areas (Chan et al., 2018). Therefore, in the past few decades, urban flood control has begun to receive attention, and in addition to basic engineering solutions (gray infrastructure), environmental protection solutions (green infrastructure) are also receiving attention and increasingly being implemented (Jia et al., 2022). One of these important measures is to return farmland to the lake on a large scale. Taking Dongting Lake as an example, returning farmland to forests has increased the lake area by about 800 square kilometers (Jia et al., 2022).

In addition, since 2015, the Guiding Opinions on Promoting the Construction of Sponge Cities issued by the State Council has made it a national policy to build "sponge cities". The concept of sponge city is based on the advanced water management methods of other countries and the actual situation of China, including the low impact development (LID) method of the United States; UK's sustainable urban drainage systems (SuDs) and blue-green cities (BGCs) approach; It also draws on Australia's Water Sensitive Urban Design (WSUD) or New Zealand's Low Impact Development Urban Design (LIDUD), (Chan et al., 2018; Griffiths, Chan, Shao, Zhu, & Higgitt, 2020). The core of sponge cities is to increase the water storage capacity of lakes, parks, wetlands and rivers in various ways: (1) To use green infrastructure to change the way of rainwater collection, and (2) to use the characteristics of green infrastructure to filter and absorb rainwater, reduce surface runoff and help reduce flood (Wang, Mei, Liu,& Shao, 2018).The goal of the sponge city is to reduce the impact of urban development on natural ecosystems and address urban water use issues.(Griffiths, Chan, Shao, Zhu,&Higgitt, 2020). In this way, the city can absorb, store and treat rainwater, and provide stored water to the public through green infrastructure applications, including green roofs, rainwater gardens or biological retention (Nguyen et al., 2019). The implementation of the Sponge City Project not only helps to balance the urban water circulation system, but also creates a high-quality living environment for humans and wildlife (Chan et al., 2018). There are still great challenges in the implementation of sponge cities, ranging from technical issues to public acceptance, financial issues and the overall legal framework (Griffiths, Chan, Shao, Zhu, & Higgitt, 2020). However, compared with China's traditional defensive flood risk management measures since ancient times, this policy is a breakthrough.

In addition to the measures mentioned above, there are also some measures that aim at reducing flood risk exposure and vulnerability. In the past 20 years, some villages in low-lying areas have been relocated, especially those vulnerable to floods (Jia et al., 2022). Prediction and early warning capabilities have been improved. The accurate prediction of flood peak can ensure that appropriate disaster prevention measures are taken before the flood occurs. Prediction and early warning make it possible to evacuate people in time. After the flood alarm is issued, villagers can take action on the spot, which greatly reduces the casualties and property losses during the flood (Jia et al., 2022). However, the accuracy and quality of forecast and early warning need to be further improved (Jia et al., 2022).

In general, China's flood risk management can be said to have achieved some "exposure" and "vulnerability" reduction. However, these two parts have not become an integral part of flood risk management, and a flood risk management system considering the three components of flood risk management, has not yet been formed yet. China's flood risk management faces some governance issues as well. For example, administrative fragmentation and lack of cooperation between relevant functions or agencies in the government administrative system (Griffiths, Chan, Shao, Zhu,&Higgitt, 2020); The cooperation between the government, local authorities, industry, academic partners and local citizens is not close (Rubinato et al., 2019); The public's awareness of flood risk needs to be improved, whether it is public awareness of flood risk or self-management of flood risk (Griffiths, Chan, Shao, Zhu,&Higgitt, 2020; Jia et al., 2022).

2.2 Resilience

2.2.1Resilience

The term “resilience” was first used in the field of ecology, and has since been widely used in other fields such as social sciences, psychology, and disaster management (Holling, 1973； McClymont et al., 2019). In general, resilience refers to the ability of the system to recover its function after interference (McClymont et al., 2019). In order to make the concept of resilience more specific, Martin-Breen and Anderies (2011) reviewed the research about resilience and obtained a relatively complete concept: resilience includes engineering resilience, systems resilience and complex adaptive systems resilience. Engineering resilience means maintaining the status quo, emphasizing the ability of the system to return to its previous state after interference. Systems resilience is related to maintaining system functions in case of interference. The difference from engineering resilience is that in case of interference, different states can be adopted to maintain the function instead of always restoring the original state. Complex adaptive systems resilience focuses on the ability of the system to adapt and transform. It refers to the ability of the system to fundamentally change to a new state after interference. This study will use this concept as the basis for understanding the concept of flood resilience.

2.2.2Flood resilience

When describing the concept of flood resilience, it is inevitable to accurately describe the concept of resistance first. In flood risk management, resistance usually refers to reducing the possibility of flood disaster by building dams and dykes. In most flood risk management literature, flood risk management strategies are usually divided into resistance and resilience strategies, which explains why resistance and resilience are often regarded as two opposite aspects (Douven et al., 2012; Hooijer et al., 2004; Restemeyer et al., 2015; Vis et al., 2003). Some scholars, however, have questioned this view. Restemeyer et al. (2015) believe that resistance is an important aspect of resilience. De Bruijn et al. (2015) also believe that resilience should be regarded as a dual concept, with two complementary aspects rather than opposites. Restemeyer et al. (2015) argue that resilience requires three aspects: robustness, adaptability, and transferability. Nguyen and James (2013) mention three common adaptive capacities: speed of recovery, degree of disturbance relative to threshold, and ability to learn/adapt/transform. Hegger et al. (2016) defines resilience using three capabilities: the ability to resist; the ability to absorb/recover; and the ability to transform. The concept of flood resilience defined in this thesis uses the three aspects mentioned by Hegger et al. (2016): Flood resilience refers to the ability of a site, city or region to prevent flooding, absorb/recover and transform after flooding occurs.

2.2.3Flood resilience index

In order to measure urban flood resilience, a flood resilience index may be used. A flood resilience index is a way to quantify flood resilience. Many scholars have built a framework for measuring resilience and calculated the resilience index. A city is a complex system composed of many interacting subsystems (Wang et al., 2021), and the dynamic interaction between urban subsystems enables the city to effectively respond to the impacts disturbances, such as floods (Dhar&Khirfan, 2017; Rus et al., 2018; Wang et al., 2021).). Therefore, the resilience assessment framework can be set up from a system perspective. At the same time, urban resilience is also multidimensional and corresponds to different subsystems of the city. Different researchers have different views on the division of different dimensions of resilience. Ribeiro and Pena Jardim Gonçalves (2019) divided urban resilience into five dimensions: physical, economic, social, material and institutional. Bulti et al. (2019) added more dimensions of resilience, including physical, economic, human, social, cultural, community capabilities, institutions and organizations, and technology, and also made a more nuanced division of each dimension. Wang et al., (2021), according to the multi-dimensional characteristics of resilience, used seven dimensions of resilience: social, economic, natural, physical, institutional, human and political. Kotzee and Reyers (2016) proposed a method to measure the resilience of systems to floods, including resilience indicators related to floods and the associated social, ecological, infrastructural and economic aspects. In summary, according to the literature resilience involves six key dimensions.

The natural dimension represents the availability and accessibility of natural resources such as plants, water and land (Bulti et al., 2019). Natural resources play an important role in enhancing the city's ability to resist flooding. For example, wetlands can absorb the effects of flooding and improve the recovery process. Natural resources in cities mainly refer to parks, green spaces and some green infrastructure. According to Zimmermann et al. (2016), by enhancing the green infrastructure (GI) in urban areas, such as green roofs, parks and green spaces, the risk of urban flooding can be mitigated. This is because increasing vegetation coverage increases retention capacity and increases storage capacity and soil infiltration, thereby reducing rainwater runoff.

The physical dimension mainly includes the urban built environment and the flood resistance level of the existing grey infrastructure. The architectural layout of a city, such as the distance between buildings, average building size, building coverage, etc., and the state of urban gray infrastructure can all affect the urban flood resilience ((Bruwier et al., 2020; Yang et al., 2021).

The economic dimension mainly involves the current level of economic development. This mainly affects the funds invested in flood control in the early stage, such as infrastructure maintenance and upkeep. On the other hand, a strong economic system helps generate the contingency funds needed for emergencies and disaster (Bruneau et al., 2003; Bulti et al., 2019).

The human dimension mainly refers to the part that affects the ability of the city to prepare and recover from the adverse effects of flood events. For example, populations with higher education levels are better able to prevent flood damage (Grothmann & Reusswig, 2006). In addition, personal physical and economic conditions can also affect urban flood resilience (bulti et al., 2019).

The social dimension refers to the social resources used to prevent and respond to floods (Bulti et al., 2019). For example, simulated practice in response to a crisis or education and training on flood hazards. In addition, solidarity among city citizens is also important, including mutual aid, trust, and inclusive urban ethos.

Finally, the institutional/organizational dimension refers to the organizations and institutions responsible for urban flood risk management and realizing urban disaster resilience. Specifically, it includes the measures formulated and the leadership in implementing management, the ability to respond to floods, and the improvement and renewal of their own capabilities. In addition, communication and contact among various institutions is also one aspect of improving flood resilience.

The flood resilience index adopted by Zhu et al. (2021) was used in this thesis which will be introduced in detail in Chapter 2.6, this flood resilience index combines natural and physical dimensions into a physical environment dimension, incorporating institutional and organizational dimensions into social dimensions, and ultimately obtaining a flood resilience index that includes three dimensions: physical environment dimension, social dimension, and economic dimension.

2.3 Exploring the relation between flood risk management and flood resilience

As mentioned above, resilience has become increasingly popular in the academic literature of natural disasters in general, especially flood disasters (Fuchs&Thaler, 2018; Kelman, Gaillard, Lewis,&Mercer, 2016; MacAskill&Guthrie, 2014). And with the rethinking of floodreisk management strategies, resilience has become a new trend in flood risk management (Fekete, Hartmann,&J ü pner, 2019). However, is resilience a new concept, different from flood risk management, or is it just a renaming of flood risk management (Fekete, Hartmann,&J ü pner, 2019; Fuchs&Thaler, 2018)? What is the relationship between resilience and flood risk? Because this research always runs through these two concepts, it is necessary to clarify the relationship and difference between these two concepts.

The most direct difference between flood resilience and flood risk management is based on quantitative and qualitative concepts. Flood risk management mainly focuses on asset losses. This is a method that focuses on flood management and considers aspects that can be directly quantified (for example, the monetary value of assets such as houses and infrastructure) (Dise, Johnson, Leandro,&Hartmann, 2020). Flood resilience focuses on more qualitative aspects, which are also important (including social response and population vulnerability) (Batica&Gourbesville, 2016,).

In terms of flood response strategy, flood risk management strategy is very direct and the period of investment income is short. The initial cost of the recovery strategy is very high, and the benefits, namely the reduction of flood risk, can only be felt in the long term. On the other hand, compared with flood risk management strategy, resilience strategy is more flexible and provides more opportunities for natural and landscape development (Vis, Klijn, De Bruijn,&Van Buuren, 2003). Resilience provides a more comprehensive approach to flood management by measuring and strengthening the less obvious aspects of flood risk management. By combining flood resilience and flood risk, it can effectively deal with a wider range of hazards than considering any method alone (Dise, Johnson, Leandro,&Hartmann, 2020).

As for the relationship between the two, flood resilience is generally seen as a supplement to flood risk management (Hartmann&J ü pner, 2020; Morrison, Westbrook,&Noble, 2017). Because flood risk management is usually based on resistance, it is a way to reduce the adverse impact of flood on society by eliminating the threat of extreme change (Morrison, Westbrook,&Noble, 2017). However, as global climate change is accompanied by increasingly serious flood disasters, and flood events are usually unpredictable, society is more vulnerable to the impact of flood disasters. Flood risk management based on resistance is not always effective. Although it can provide some substantive protection, it is difficult to deal with uncertainty (Morrison, Westbrook,&Noble, 2017). Resilience can make up for this defect: Resilience focuses on the ability of systems affected by disasters to absorb shocks, and can cope with the uncertainty of flood disasters (Dise, Johnson, Leandro,&Hartmann, 2020). In addition to helping flood risk management to cope with the uncertainty of floods, flood resilience also plays a role in reducing community vulnerability. According to Vis, Klijn, De Bruijn,&Van Buuren (2003), vulnerability refers to the degree to which a system is vulnerable to flood due to exposure, disturbance and its ability (or inability) to respond, recover or adapt. The concept of resilience plays a major role in this process, because this method defines the disturbance level of the system as a whole to maintain stability during and after the flood (Vis, Klijn, De Bruijn,&Van Buuren, 2003). Although resilience is considered to have the potential to supplement flood risk management, the actual application of resilience is not widespread. In practical cases, resilience is often not indispensable in flood risk management (Dise, Johnson, Leandro,&Hartmann, 2020).

In addition to complementing flood risk management in strategy, resilience can also bring new progress to traditional flood risk management. The concept of flood resilience has brought a new concept to the urban system: "coexistence with flood" (Batica&Gourbesville, 2016). This means that more and different stakeholders and actors will be involved in flood risk management than ever before, such as landowners or spatial planners, and more actions are also needed by homeowners and citizens (Hartmann&J ü pner, 2020). With the resilience of flood, flood risk management has turned more strongly to social and political science than ever before. This means that the importance of social, institutional and economic factors must be recognized when managing flood risk (Batica&Gourbesville, 2016; Hartmann&J ü pner, 2020). In the past decade, with the in-depth study of flood resilience, the academic community has paid more attention to all aspects of flood risk governance, especially the participation of stakeholders, the effectiveness of policies, the operation mode of flood risk institutional structure, the tools that help flood forecasting and planning, and the framework that helps organizations and supports flood risk implementation to a lesser extent (Morrison, Westbrook,&Noble, 2017).

2.4 Flood loss

Quantitative assessment of flood losses is very important for describing flood losses (Li, Wu, Dai,&Xu, 2012). Generally speaking, flood losses can be roughly divided into two types: direct losses and indirect losses. The direct loss of flood is caused by direct contact with flood events, while the indirect loss is not directly caused by flood (Li, Wu, Dai,&Xu, 2012). According to the disaster report issued by China, the number of casualties, economic losses, ecological environment losses and disaster relief losses are often used for the assessment of flood losses. Economic losses include direct losses and indirect losses. The former refers to direct material loss caused by flood; The latter refers to the damage or interruption caused by flood to economic production and service development.

2.5 Conceptual framework

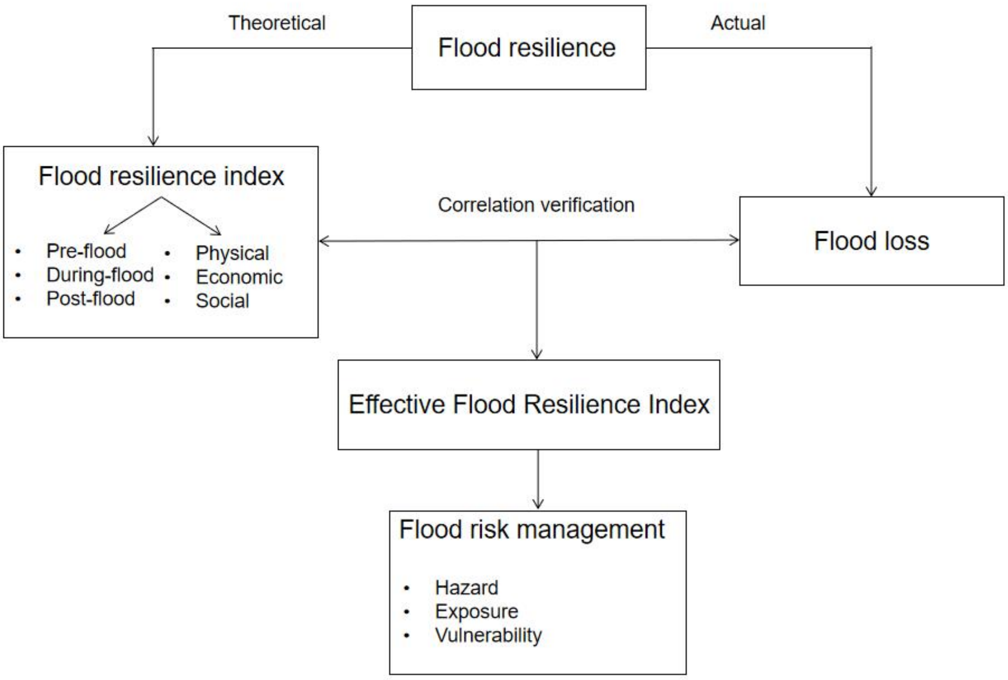

Figure 3. Conceptual framework

This framework shows the process of validating the theoretical value of resilience index and the actual situation of flood resilience to improve flood risk management. The whole framework is mainly aimed at connecting the three core concepts of this study: first, flood resilience index, understanding the different dimensions of resilience index, including natural dimension, physical dimension, economic dimension, human dimension, social dimension, and institutional and organizational dimension, forming a comprehensive index to measure urban flood resilience capacity. At the same time, the measurement standard of resilience index cannot refer to the flood in isolation, but also covers the flood disaster cycle, including the pre-flood (the indictor that works before the flood event), during-flood (the indictor that works during the flood event) and post-flood (the indictor that works after the flood event) these 3 periods of the flood. Secondly, the loss of flood disaster, including the number of casualties, economic loss, ecological environment loss and disaster rescue loss. The last core concept is flood risk management, including hazard, exposure and vulnerability reduction. The correlation verification of the first two core concepts is to obtain indicators that can truly reflect the flood disaster situation. This is one of the purposes of this study. At the same time, it is also for another purpose of this study: to provide suggestions for improving flood risk management in China.

2.6 Operationalisation of the conceptual framework

In order to operationalize this framework, the most important concepts are the flood resilience index and flood losses.

Flood resilience index

The resilience index selected in this study is from Zhu et al. (2021), as shown in Figure 4, Figure 5 and Figure 6. The flood resilience index has a total of 16 indicators, including:

R1: Building exposure (built-up area/urban area*100%)

R2: Infrastructure exposure (road area/urban area*100%)

R3: Green coverage (green covered area/urban area*100%)

R4: Flood exposure (area with standard level of flood depth/urban area *100%),

R5: People exposure (registered population at year-end/urban area)

C1: Health access (number of hospitals/urban area)

C2: Medical capacity (number of hospital beds/registered population at year-end)

C3: Storm water absorption capacity (drainage length/urban area)

C4: People vulnerability (number of vulnerable people/registered population at year-end*100%)

C5: Economic tolerance (total income − expenditure)/total income *100%),

RA1: Public transport service (number of public transport vehicles/registered population at year-end)

RA2: Mobility (number of subscribers of mobile telephones at year-end/registered population at year-end*100%)

RA3: Social insurance (persons covered of insurances/registered population at year-end)

RA4: Learning mechanism (number of government policies and regulations)

RA5: Local economical level (per capita gross regional product)

RA6: Employment (average number of employed staff and workers/registered population at year-end*100%)

These indicators are divided into three stages according to the time period of disaster occurrence: pre-flood stage indicator (R1, R2, R3, R4, R5) which are indicators that play a preventive role in the occurrence of floods. during-flood stage indicator (C1, C2, C3, C4, C5) which are indicators that play a major role in the occurrence of floods. and post-flood stage (RA1, RA2, RA3, RA4, RA5, RA6) which are indicators that play a major role in flood recovery after the occurrence of floods. At the same time, these indicators are also divided into three dimensions according to different dimensions: physical dimension (R1, R2, R3, R4, C1, C2, C3, RA1, RA2), social dimension (R5, C4, RA3, RA4) and economic dimension (C5, RA5, RA6). The reason for choosing this resilience index is that its application scope is the same as that of this study, that is, the Yangtze River Delta region, and the flood resilience index of these cities have been calculated.

Indicators	**Formula**	**Dimension**	**Effect**
Pre-flood resilience: resistance capacity FRR			
R1: Building exposure	R1 = built-up area/urban area * 100%	physical	negative
R2: Infrastructure ex posure	R2 = road area/urban area * 100%	physical	positive
R3: Green coverage	R3 = green covered area/urban area *10 0%	physical	positive
R4: Flood exposure	R4 = area with standard level of flood de pth/urban area *100%	physical	negative
R5: People exposure	R5 = registered population at year-end/u rban area	social	negative

Figure 4. Pre-flood resilience index (Zhu et al., 2021)

Indicators	Formula	Dimension	Effect
During-flood resilience: Coping capacity FRC			
C1: Health access	C1 = number of hospitals/urban area	physical	positive
C2: Medical capacit y	C2 = number of hospital beds/registered population at year-end	physical	positive
C3: Storm water abs orption capacity	C3 = drainage length/urban area	physical	positive
C4: People vulnerab ility	C4 = number of vulnerable people/regist ered population at year-end * 100%	social	negative
C5: Economic tolera nce	C5 = (total income – expenditure)/total in come *100%	economic	positive
RA6: Employment	RA6 = (average number of employed sta ff and workers/registered population at year-end) *100%	economic	positive

Figure 5. During-flood resilience index (Zhu et al., 2021)

Indicators	Formula	Dimension	Effect
Post-flood resilience: Recovery and adaptation capacity FRRA			
RA1: Public transpor tation service	RA1 = number of public transport vehicl es/registered population at year-end	physical	positive
RA2: Mobility	RA2 = number of subscribers of mobile t elephones at year-end/registered popul ation at year-end * 100%	physical	positive
RA3: Social insuranc e	RA3 = persons covered of insurances/re gistered population at year-end	social	positive
RA4: Learning mech anism	RA4 = number of government policies a nd regulations	social	positive
RA5: Local economic level	RA5 = per capita gross regional product	economic	positive

Figure 6. Post-flood resilience index (Zhu et al., 2021)

Flood resilience index of 27 Yangzte river cities

This part shows the theoretical value of flood resilience. The following histogram shows the theoretical resilience of 27 cities in the Yangtze River Delta. The following urban flood resilience data are from the study of Zhu et al., (2021), because its research area is the same as that of this thesis, both are cities in the Yangtze River Delta, so these data can be directly used.

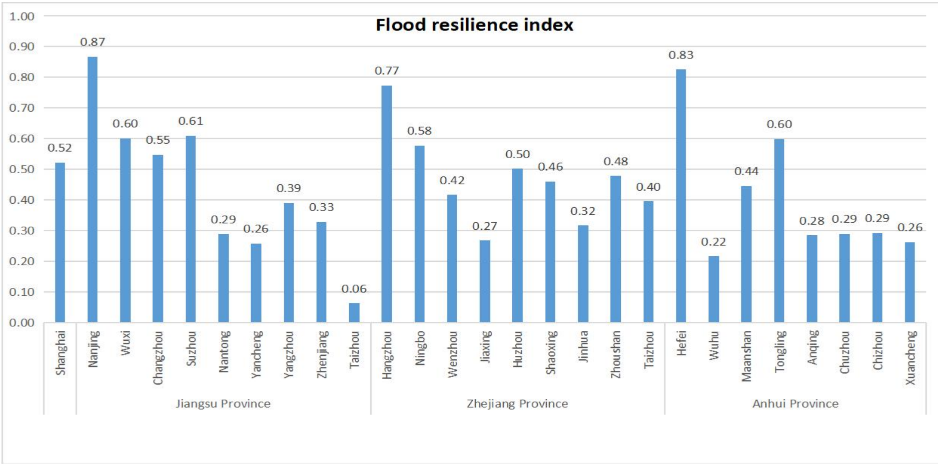

Figure 7: Flood resilience of 27 Yangzte river cities (Zhu et al., 2021)

According to the histogram, Nanjing has the highest value of 0.87 and Taizhou the lowest (0.06). Among the 27 cities in the Yangtze River Delta region, the provincial capitals of three provinces have high levels of flood resilience. The flood resilience of the two provincial capital cities of Nanjing (0.87) in Jiangsu Province and Hefei (0.83) in Anhui Province is the first and second of the 27 cities, while the other provincial capital city of Hangzhou (Zhejiang Province) also shows a high flood resilience, with a value of 0.77. However, Shanghai, the municipality directly under the Central Government, is only moderately resilient. According to Zhu et al. (2021), the reason may be the different physical, economic and social characteristics of these cities. Further explanation is that although the infrastructure and economic development level in Shanghai are relatively high, the situation of population vulnerability is more severe. The proportion of vulnerable population (Under 15 and over 60) in Shanghai exceeds 33%, ranking first in the country (Zhu et al., 2021). From the perspective of geographical location, cities in the southeast coastal areas have better resilience than those cities that are far from the sea, mainly due to economic conditions and flood risk awareness (Zhu et al., 2021). There are far fewer policies or regulations related to floods in inland cities. From the provincial level, the flood resilience of Zhejiang (0.4647) is better than that of Jiangsu (0.4388) and Anhui (0.4013) (Zhu et al., 2021). The whole Yangtze River Delta region (0.4394) is at a relatively medium level of urban flood resilience (Zhu et al., 2021).

Flood loss

Among the above flood loss assessment indicators, population and economic losses are the important consequence types among the factors affected by flood disasters (Li, Wu, Dai,&Xu, 2012), so casualties and economic losses are usually the main objects of flood loss assessment. At the same time, it is difficult to quantify the qualitative factors involved in the destruction of ecological environment and disaster relief losses. Therefore, in this study, flood loss is defined as the direct impact on the population and economy of the region after the flood disaster, that is, the direct economic loss and the number of the affected population.

3.Methodology

3.1 Research philosophy

The term research philosophy refers to the belief and hypothesis system about the development of knowledge. Ontology, epistemology and methodology together constitute a basic belief system or worldview to guide researchers to conduct social research (Guba&Lincoln, 1994). For academic research, the perspective of researchers is very important. It is necessary to select a suitable research philosophy to solve the research problem.

Ontology is the science of existence. The ontological problem involves "what exists, or what we think exists", and "what assumptions" we have made to how the world works ". Epistemology is the theory of knowledge and cognition. Epistemological issues involve "our understanding of the world and how we understand the world", and "what statements we will accept to prove the existence we believe in" (Dieronitou, 2014). Methodology refers to the general concept that supports how people explore the social environment and prove the effectiveness of the acquired knowledge. The problem of methodology is related to "how to find the real answer?" They are the basis of research methods.

Guba and Lincoln (1994) developed four research paradigms. Research paradigms include positivism, post-positivism, critical theory and constructivism. Positivism believes that only one reality can be understood and recognized. Therefore, quantitative methods are used to measure this only reality (Guba&Lincoln, 1994). Positivism in research is a philosophy related to the concept of real investigation. The research philosophy based on positivism adopts strict methods to conduct systematic research on data sources. The interpretive method is used in most qualitative research in the field of social science; Its premise is that there are many realities rather than a single reality. According to the view of the interpretionist, human behavior is complex and cannot be predicted with predetermined probability. Human behavior is not as easily controlled as scientific variables. The term interpretionism refers to the methods of acquiring knowledge of the universe, which depend on the interpretation or understanding of the meaning of human behavior. Constructivism is a theory that emphasizes learners' initiative in knowledge and learning. Constructivists believe that learning is a process completed through social and cultural interaction, and this process is based on the meaning generation and understanding construction of learners' existing knowledge and experience (Guba&Lincoln, 1994). Post-positivism assumes that reality is objective, but is subject to imperfect knowledge and probability. The post-positivist researcher is an objectivist, but he is critical of the nature of knowledge. Generally speaking, the research of resilience is often based on positivism, but this research will adopt the post-positivism research paradigm. Since the purpose of this survey is to better understand the relationship between theoretical resilience and actual conditions, which occurs in the real-world involving cities and their economic and natural environment, this study is suitable for post-positivism. It includes the subjectivity of the selection of the resilience index and the objectivity of the verification of the real world and theoretical results, which is in line with the ontological position of critical realism.

3.2 Research design and strategy

The validation of the flood resilience index consists of two parts. For the first part, it is necessary to validate the components and structure of the flood resilience index by checking the reliability of the flood resilience index and its different dimensions (sub-question3). For the second part of the validation, the correlation of the flood resilience index and the indicators for flood loss needs to be investigated (sub-question4). Finally, based on the results obtained, suggestions for how to improve the index, and recommendations for flood risk management in China will put forward (sub question5).

This study adopts a combination of qualitative and quantitative methods. Qualitative research, mainly through the literature review to determine the flood resilience index, including different dimensions and indicators. When getting the flood resilience index of the 27 cities and the data of flood loss in 27 cities are collected through in different methods, a quantitative analysis will be done. After that, a case study will be carried out to zoom in on a certain flood event and explore the research question in this context.

In order to answer the research questions, the research is divided into seven stages:

1. Literature review, the purpose of this stage is to obtain relevant dimensions and indicators that can be used in calculating the flood resilience index (see Chapter 2).

2. Collect data for flood resilience index through official government websites and official government publications of the 27 Yangzte river delta cities.

3. Collect data the flood loss through official government websites and official government publications of the 27 Yangzte river delta cities.

4. Revise the flood resilience index through reliability analysis and calculate the revised flood resilience index of each city.

5. Analyze the flood resilience index of each city and the actual disaster situation to validate the correlation between them.

6. Zooming in on a certain flood event and specific areas, as a specific case study, to further validate the results obtained in the former steps. This specific case study will choose the 2020 floods in southern China as the research background of the specific case study, rather than using the average data of recent years for statistics as in the previous steps. At the same time, select the most severely affected province as the research area of the specific case study, rather than selecting all cities in the Yangtze River Delta as in the previous steps. The purpose of conducting this specific case study is to obtain more information beyond statistics to help better answer research questions.

7. Draw conclusions and put forward suggestions for flood risk management in China

3.3 Data collation

The data collection is divided into 2 parts, the quantitative and qualitative data collection.

Quantitative data

Because the data involved in this part, such as the direct economic loss in flood loss or the urban greening coverage and building density in flood resilience index, require a large number of professional statistics to ensure the effectiveness of the data. These data cannot be obtained through questionnaires or interviews. Therefore, the data of this study are applied for from national government departments or obtained from the official website and public publications of government departments.

Qualitative data

This part of the data comes from literature and government documents. The government report documents related to the flood event will be searched and analyzed. The documents were collected through the websites of national disaster prevention and mitigation departments, municipal authorities, provincial and national governments.

3.4 Data analysis

In general, the data of qualitative research is used for sub-questions 1 and 2 and the case study. The data of the quantitative study is used to answer sub-questions 3 and 4. This part of data is analyzed by SPSS. It includes reliability analysis and correlation analysis.

The data analysis will be explained in the order of the sub- research questions

1.How to measure the flood resilience of different cities?

This part of the data comes from the literature. Through the literature, we learned about the concept of resilience and the various dimensions of resilience.

2.What is the flood resilience of Yangtze River Delta cities?

The data in this section comes from literature. Data on flood resilience of 27 cities that have been calculated have been obtained through literature. But in the next step, the flood resilience obtained through literature is revised and recalculated the value of flood resilience for 27 cities.

3.To what extent is this framework internally sound and robust?

This part of data comes from the statistical yearbook issued by the government department. In order to make the results more accurate and reliable, the data analysis is carried out using the statistical software SPSS. In order to answer this sub-question, reliability analysis is needed to do the flood resilience index validation. Cronbach's alpha, which measures the internal consistency of indicators according to a certain formula, is a commonly used reliability evaluation tool. Cronbach's α is mainly used to evaluate the consistency of continuous variables and ordered classification variables, and this part of data is continuous variables, so it is applicable to the research data of this study. Therefore, this study uses Cronbach's alpha to test the reliability of the selected flood resilience index. The purpose of this step is to check the internal consistency of the flood resilience index. This step provides empirical evidence for measuring the internal robustness of the flood resilience index. At the same time, the flood resilience index can be revised by deleting the indicators that are not relevant or consistent with other indicators according to the results of reliability analysis.

4. Whether the flood resilience index actually shows the capacity of flood risk management?

In order to answer sub-question 3, different analyses are carried out to test the impact of flood resilience index, different dimensions of flood resilience and different indicators of flood resilience on the results of real flood event. Firstly, correlation analysis is used to test the relationship between flood resilience and actual flood event results, and to learn whether the flood resilience index reflects the real situation. In addition, regression analysis was conducted to test the ability of the flood resilience index, and its different dimensions, indicators and periods to predict flood results. This analysis consists of the following three parts:

a. Influence of flood resilience index and different indicators on flood performance

Verify the relationship between flood resilience index and different indicators and representative variables of flood performance- correlation analysis

Through the contribution of flood resilience index and different indicators to flood performance, find the indicators that directly affects flood performance - regression analysis

b. Influence of different dimensions of flood resilience index on flood performance - regression analysis

c. Which and to what extent do pre-disaster conditions and post-disaster conditions contribute to flood performance? -regression analysis

5. What are the suggestions for improving the resilience index and the performance of Flood Risk Management in China? -Based on the results according to sub question 1-4

3.5 Validity and reliability

The data used in this study come from government official websites and government publications, and other researchers can use the data used in this study to validate, replicate and improve the final results. This improves the Validity of the research to a certain extent.

The data obtained from government reports and statistical yearbooks can increase the reliability of the research to a certain extent.

3.6 Study areas

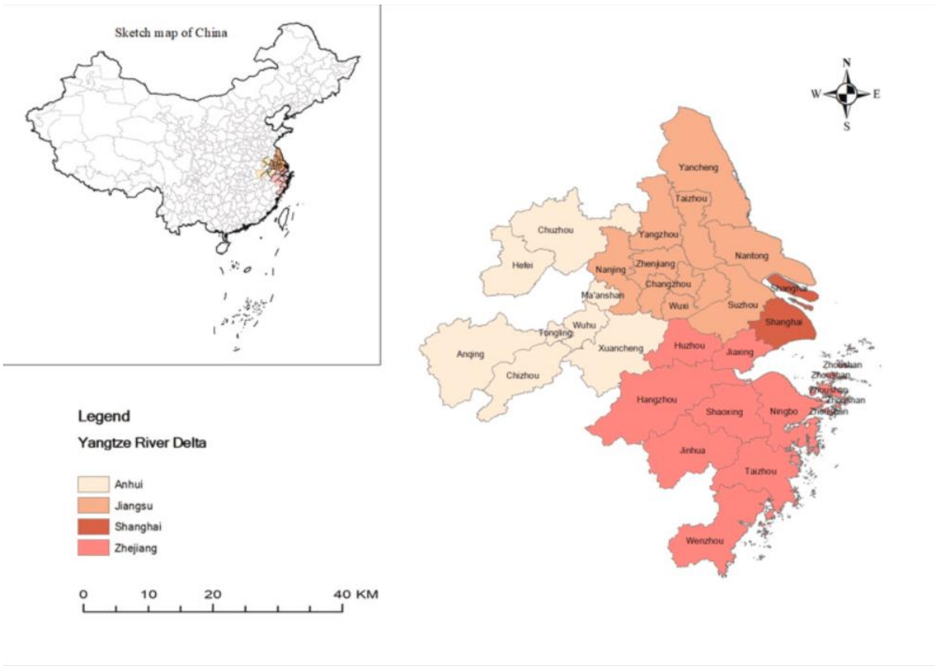

Figure 8: Location map of cities in the Yangtze River Delta (Zhu et al., 2021)

The study area of this study is the cities in the Yangtze River Delta region of China. With a total area of 358000 square kilometers, there are 3 provinces, 26 cities and 1 municipality directly under the Central Government (Zhu et al., 2021). Next, we will introduce the study area based on four aspects: geographical location, population, economy and climate.

Geographic location: The Yangtze River Delta is located at the lower reaches of the Yangtze River, bordering the Yellow Sea and the East China Sea, with numerous coastal ports (Zhu et al., 2021).

Population: The Yangtze River Delta has a large and densely populated population. The total population is more than 150 million, accounting for 11% of the national population. With an average population of more than 500 to 600 people per square kilometer, it is one of the densely populated areas in China (Zhu et al., 2021).

Economy: The Yangtze River Delta urban agglomeration is a highly developed region in the eastern coastal region of China (Zhu et al., 2021). It is the largest economic circle and economic center in China, with high degree and speed of urbanization.

Climate: The Yangtze River Delta is located at the boundary between subtropical and temperate climates, with an annual average temperature of 14~18 ℃. The Yangtze River Delta is rich in water, with annual precipitation of 1000~1400 mm. At the same time, due to its location in the low-lying plain and abundant rainfall, flood disasters often hit the Yangtze River Delta. In addition, about 70% of rainfall is concentrated in spring and summer, which makes these two seasons more prone to floods (Zhu et al., 2021). Over the years, the Yangtze River Delta region has adopted various methods to deal with flood problems, including direct engineering control technologies such as flood control walls and flood gates, and non-engineering measures such as sponge city policies (Zhu et al., 2021). However, the flood problem cannot be fundamentally solved. Flood disasters still occur from time to time. At the same time, due to the large population in the region, each flood disaster caused a lot of loss of people and property.

3.7 Case selection

Flood event

The case study of this thesis is the flood disaster in the south of China in 2020. The flood disaster in southern China in 2020 refers to the severe flood disaster in many places caused by multiple rounds of heavy rainfall in southern China since the flood season in 2020. The flood lasted about two months in the Yangtze and Huaihe River basins. The main flood season began on June 1, 2020. In July, the middle and lower reaches of the Yangtze River, Poyang Lake, Dongting Lake and the Taihu Lake continued to have high water levels, causing large-scale floods in the middle and lower reaches of the Yangtze River (Jia et al., 2022). On August 2, 2020, when the rainy season ended, the emergency response level of flood control in many places decreased (Jia et al., 2022). In this flood disaster, the average precipitation of the Yangtze River basin (259.6 mm) is the highest since 1961 (Qin et al., 2022). The average precipitation of the Huaihe River basin (256.5 mm) is 33% higher than that of the same period last year, and part of the Huaihe River flows into the Yangtze River (Qin et al., 2022).

Affected by the heavy rainfall, the water flowing into the Huaihe River increased by 1.5 to 2 times over the same period of the previous year, which also led to an increase of 4% to 6% in the water flow to the middle and lower reaches of the Yangtze River compared with the previous year, resulting in serious floods (Qin et al., 2022). According to the statistics of the Ministry of Emergency Management of China, a total of 38.173 million people were affected by the flood disaster, 56 people were dead or missing, and 2.996 million people were urgently transferred; 27000 houses collapsed and 240000 houses were damaged to varying degrees; 38687 square kilometers of crops were affected; In 2020, the direct economic loss of the flood was 109.74 billion yuan. The flood was a record rainfall and flood disaster.

In this flood event, Anhui Province was the most severely affected province, so Anhui Province was chosen as the study area for a specific research case.

4.Results

This chapter will show the results of this thesis. Firstly, the correlation analysis of flood resilience and flood loss of 27 cities in the study area is carried out (4.1). The theoretical flood resilience is obtained according to the literature. Since the result of correlation analysis shows that the correlation between flood resilience and flood loss is not strong, it is considered whether the flood resilience index itself is reliable. Therefore, the internal verification of the flood resilience index is carried out next. Through the reliability analysis of the flood resilience index and its three dimensions (4.2), the results show that the flood resilience and its physical, social and economic dimensions are inconsistent internally. Then the flood resilience index was revised, and a new internally consistent flood resilience index was obtained after the revision, and the flood resilience of 27 cities was recalculated according to the new flood resilience index (4.3). Next, the correlation analysis between flood losses and the new flood resilience index was carried out. It includes the correlation between flood loss and flood resilience (including different dimensions and different flood disaster stages) (4.4). As the result failed to pass the external test, it was concluded that also the revised flood resilience index could not truly reflect the actual disaster resilience. Therefore, it was further explored whether there are independent indicators that can reflect the actual flood resilience better (4.5). Finally, take the situation of flood disaster in Anhui Province during a flood in the summer of 2020 as a case study for further in-depth study to assist in validating the results obtained (4.6).

4.1 Correlation analysis between theoretical flood resilience index and flood loss

This part will explore whether there is a correlation between the flood resilience index and flood loss. The number of casualties, economic losses, ecological environment losses and disaster relief losses of the affected people are often used for flood loss assessment. Since only the data of direct economic loss and affected population of 19 cities in Shanghai, Zhejiang and Jiangsu are available, this thesis uses direct economic loss and affected population as the two indicators of flood loss. Direct economic losses refer to direct economic losses caused by flood disasters, including house losses, infrastructure losses, etc. The affected population refers to the population affected by the flood disaster, including the casualties and the population relocated due to the flood. Whereas the urban flood resilience index is calculated based on the data in 2018, the data of flood losses collected is up to 2018, including the data from 2011-2018. Since the annual flood disaster does not occur in every city, the flood loss of only one year cannot fully reflect the real situation of the local flood disaster. Therefore, this thesis uses the average flood disaster loss to obtain more accurate results: the correlation analysis between the average disaster loss of 3 years, 5 years and 8 years and the urban flood resilience index is carried out. This part of the data is retrieved from the statistical yearbooks of Shanghai, Zhejiang and Jiangsu provinces from 2011 to 2018. In the following, the results of the correlation analysis between the flood resilience index and the affected population (4.1.1) and the correlation analysis between the flood resilience index and the direct economic loss (4.1.2) is presented in turn.

4.1.1 Correlation analysis between the flood resilience index and the affected population

	Pearson Correlation	Sig(2-tailed)	R square
Affected population (3year)	-0.475**	0.04	0.226
Affected population (5year)	-0.567**	0.011	0.322
Affected population (8year)	-0.442*	0.058	0.195

Asterisks indicate signature level: Significant at *10%, **5%, ***1% level

Table 1: The result of the correlation analysis of the flood resilience index and the average affected population of recent 3, 5 and 8 years

Firstly, Parson correlation analysis of flood resilience and affected population was carried out. The results are shown in the Table 1. The Parson correlation coefficients between the flood resilience and the average affected population in 3 years, 5 years and 8 years are -0.475, -0.567 and -0.442, respectively. Among them, the correlation coefficient of average 3 years and average 5 years is significant when $p<0.05$, and the correlation coefficient of average 8 years is not significant, which means that there is a linear correlation between the flood resilience index and average 3 years and average 5 years of affected population. At the same time, because the correlation coefficient is negative, there is a significant negative correlation between the flood resilience and the affected population, that is, the higher the flood resilience index, the less the affected population. However, since the correlation coefficient is less than 0.7, the relationship between flood resilience and the affected population is not close. The results of linear regression analysis show that the R square of the 3-year and 5-year flood resilience and the affected population are 0.226 and 0.322, respectively, with an average value of 0.274, indicating that the flood resilience can explain 27.4% of the affected population.

4.1.2 Correlation analysis between the flood resilience index and direct economic loss

	Pearson Correlation	Sig(2-tailed)	R square
Directed economic loss (3year)	0.096	0.695	0.009
Directed economic loss (5year)	0.101	0.681	0.010
Directed economic loss (8year)	-0.038	0.876	0.001

Asterisks indicate signature level: . Significant at *10%, **5%, ***1% level

Table 2: The result of correlation analysis between the flood resilience index and the average direct economic loss of recent 3, 5 and 8 years

Firstly, Parson correlation analysis of flood resilience and direct economic loss is carried out. The results are shown in the Table 2. The Parson correlation coefficients between the flood resilience and the average affected population in 3 years, 5 years and 8 years are 0.096, 0.101 and -0.038, respectively, which are not significant. This means that there is no obvious linear correlation between the flood resilience index and direct economic loss in average 3 years, average 5 years and average 8 years. At the same time, the linear regression analysis results of the flood resilience index and direct economic losses show that the R square of the average affected population and flood resilience in 3, 5 and 8 years are 0.009 and 0.010, 0.001 respectively, which also shows that the linear correlation between the two is not obvious.

In summary, the result of correlation and regression analysis of the flood resilience index and the flood affected population shows that there is a negative correlation between the flood resilience index and the flood affected population which means that the city with higher flood resilience index has less affected population. But the relation is not very strong. The regression analysis result show that, on the average, flood resilience index can only explain 27.4% of the difference of affected populations in different cities. The result of correlation analysis of the flood resilience index and the direct economic loss shows that there was no significant correlation between the flood resilience index and the direct economic loss.

4.2 Reliability analysis of the flood resilience index

Since the correlation analysis of flood resilience index and flood loss in the previous part concluded that they are not highly correlated, it is reasonable to question whether the resilience index would need to be revised. Therefore, the next step is to conduct an internal reliability test of the resilience index. Reliability was first introduced by Spearman into psychological measurement in 1904, referring to the consistency or reliability of test results. The internal reliability of the flood resilience index refers to whether the indicators measure the same concept, that is, the internal consistency between these indicators. The internal reliability test of the flood resilience index can find indicators with very low correlation or inconsistent with other indicators, which is helpful to revise the selected index. Generally speaking, Cronbach's α is the most commonly used reliability measurement method. Cronbach coefficient is a statistic, which refers to the average value of the half-reliability coefficient obtained by all possible item division methods of the scale (Adamson & Prion, 2013). It was first named by American educator Lee Cronbach in 1951. Cronbach's α is mainly used to evaluate the consistency of continuous variables and ordered classification variables(Adamson & Prion, 2013). As the data of this thesis are based on continuous variables, the internal reliability measurement used in this thesis is the Cronbach coefficient. This study first completes the reliability analysis of all indicators. The data were collected from the 2018 statistical yearbook of Shanghai municipality, Zhejiang province and Jiangsu province. Generally speaking, the larger Cronbach's α, the stronger the internal consistency. According to the literature, as long as Cronbach's α is greater than 0.7, it is considered that the consistency between indicators is good.

4.2.1 Reliability test of the flood resilience index

Indicator of physical environment dimension	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
R1	0.554	0.625
R2	0.536	
R3	0.673	
R4	0.734	
R5	0.555	
C1	0.620	
C2	0.664	
C3	0.560	
C4	0.570	
C5	0.682	
RA1	0.577	
RA2	0.590	
RA3	0.566	
RA4	0.650	
RA5	0.558	
RA6	0.561	

Table 3: Reliability test result of Flood resilience index

The Table 3 shows that the reliability test result of flood resilience index is Cronbach's α 0.625 <0.7, indicating that the internal consistency of the flood resilience index is low.

The multi-dimensional nature of the flood resilience index leads to internal inconsistencies. This is because the components that measure the specific dimensions of the resilience index may have low correlation with the measurement indicators of other components. For example, the economy includes variables selected for regional economic development, while the social dimension only focuses on population vulnerability and flood related policies. There are significant differences between the concepts of these two different dimensions. They do not share common variables. Therefore, it is more useful to investigate the reliability of the indicators for each dimension.

4.2.2 Physical environment dimension

Indicator of physical environment dimension	Cronbach's Alpha if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha
R1	0.436	0.831	0.588
R2	0.449	0.699	
R3	0.672	-0.321	
R4	0.696	-0.1	
R5	0.475	0.632	
C1	0.524	0.457	
C2	0.587	0.181	
C3	0.483	0.633	
RA1	0.510	0.467	
RA2	0.661	-0.157	

Table 4: Reliability test result of physical environment dimension

It can be seen from Table 4 that the reliability test result of physical environment dimension of flood resilience is Cronbach's α It is 0.588<0.7, indicating that the internal consistency of the physical environment dimension of flood resilience is low. From the Cronbach's Alpha if Item Deleted column in Table 4, it can be seen that when the R4 item is deleted, Cronbach's α increased from 0.588 to 0.696, close to 0.7. At the same time, the correlation coefficients of C2 and RA2 with other indicators are 0.181 and -0.157 respectively, both less than 0.3. Generally speaking, if the correlation coefficient is less than 0.3, the correlation between this indicator and other indicators is not strong, so C2 and RA2 can also be eliminated.

4.2.3 Social dimension

Indicator of social dimension	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
C4	0.222	0.484
RA3	-0.090	
RA4	0.727	

Table 5: Reliability test result of physical social dimension

Table 5 shows the reliability test result for the social dimension of flood resilience, which is Cronbach's α 0.484<0.7. From the Cronbach's Alpha if Item Deleted column in Table 5, when RA4 is deleted, Cronbach's α increased from 0.484 to 0.727, greater than 0.7. At the same time, because the correlation coefficient between RA4 and other indicators is 0.047, which is less than 0.3, the correlation between this indicator and other indicators is not strong, which means that this indicator can be eliminated.

4.2.4 Economic dimension

Indicator of social dimension	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
C5	0.734	0.401
RA5	-0.276	
RA6	0.198	

Table 6: Reliability test result of economic dimension

The Table 6 above shows that the reliability test result of the economic dimension of flood resilience is Cronbach's α 0.401<0.7., indicating that the internal consistency of the economic dimension of flood resilience is low. From the Cronbach's Alpha if Item Deleted column in Table 6, when C5 is deleted, Cronbach's α increased from 0.401 to 0.734, greater than 0.7. As the correlation coefficient between C5 and other indicators is 0.067, less than 0.3, the correlation between this indicator and other indicators is not strong, so it can be deleted as well.

In summary, we conclude that the internal consistency of the three dimensions of flood resilience is low.

4.3 A revised and recalculated resilience index

This part will revise and recalculate the flood resilience index. To that end we first revise the index based on the results of the reliability analysis, and then calculate the new index.

4.3.1 Revised flood resilience index

According to the results of reliability analysis, the physical environment dimension excludes the indicators R4, C2 and RA2, the economic dimension excludes the indicators C5, and the social dimension excludes the indicators RA4, and the following revised flood resilience index is obtained:

Indicators	**Formula**	**Dimension**	**Effect**
Pre-flood resilience: resistance capacity FRR			
R1: Building exposure	R1 = built-up area/urban area * 100%	physical	negative
R2: Infrastructure exposure	R2 = road area/urban area * 100%	physical	positive
R3: Green coverage	R3 = green covered area/urban area *10 0%	physical	positive
R5: People exposure	R5 = registered population at year-end/ urban area	social	negative

Figure 9: Revised Pre-flood resilience index

Indicators	**Formula**	**Dimension**	**Effect**
During-flood resilience: Coping capacity FRC			
C1: Health access	C1 = number of hospitals/urban area	physical	positive
C3: Storm water absorption capacity	C3 = drainage length/urban area	physical	positive
C4: People vulnerability	C4 = number of vulnerable people /registered population at year-end * 100%	social	negative

Figure10: Revised During-flood resilience index

Indicators	**Formula**	**Dimension**	**Effect**
Post-flood resilience: Recovery and adaptation capacity FRRA			
RA1: Public transport ation service	RA1 = number of public transport vehicles/registered population at year-end	physical	positive
RA3: Social insurance	RA3 = persons covered of insurances/ registered population at year-end	social	positive
RA5: Local economic level	RA5 = per capita gross regional product	economic	positive
RA6: Employment	RA6 = (average number of employed staff and workers/registered population at year-end) *100%	economic	positive

Figure 11: Revised Post-flood resilience index

	Cronbach's Alpha
Flood resilience index	0.818
Physical environment dimension	0.786
Economic dimension	0.734
Social dimension	0.727

Table7: Reliability test result of revised flood resilience index

A re-test the reliability of the revised flood resilience index shows that Cronbach's α of the flood resilience index is 0.818 ,which is pretty high, and Cronbach's α of the physical environment dimension, economic dimension and social dimension of the revised flood resilience index are 0.786, 0.734 and 0.727 respectively, which are greater than 0.7, indicating that the revised flood resilience index has high internal consistency.

4.3.2 Recalculated resilience index

This part recalculates the resilience index according to the revised flood resilience index obtained above. First of all, the scores for each dimension are calculated. The indicators of the physical environment dimension are calculated using the principal component analysis method. Principal component analysis is a multivariate statistical method that transforms multiple indicators into a few comprehensive indicators through dimensionality reduction. Since there are only two indicators left for the social dimension and the economic dimension, the mean method is used to calculate the flood resilience score for these dimensions. Finally, using the scores for the three dimensions, the mean method is used to calculate the overall score of flood resilience.

City	**Physical**	**Economic**	**Social**	**Total**
Shanghai	0.858	0.830	0.944	0.877
Nanjing	0.442	0.652	0.295	0.463
Wuxi	0.993	0.866	0.348	0.736
Changzhou	0.389	0.737	0.316	0.481
Suzhou	0.486	1.000	0.331	0.606
Nantong	0.444	0.478	0.482	0.468
Yancheng	0.083	0.290	0.493	0.289

Yangzhou	0.288	0.469	0.389	0.382
Zhenjiang	0.482	0.597	0.296	0.458
Taizhou	0.331	0.431	0.515	0.426
Hangzhou	0.280	0.829	0.642	0.584
Ningbo	0.358	0.774	0.148	0.427
Wenzhou	0.737	0.348	0.067	0.384
Jiaxing	0.387	0.691	0.658	0.579
Huzhou	0.311	0.453	0.515	0.426
Shaoxing	0.248	0.588	0.160	0.332
Jinhua	0.179	0.408	0.434	0.340
Zhoushan	0.241	0.594	0.518	0.451
Taizhou	0.373	0.376	0.303	0.351
Hefei	1.205	0.488	0.528	0.740
Wuhu	0.462	0.323	0.433	0.406
Maanshan	0.475	0.339	0.611	0.475
Tongling	0.212	0.132	0.522	0.288
Anqing	0.437	0.200	0.396	0.345
Chuzhou	0.322	0.221	0.408	0.317
Chizhou	0.032	0.291	0.477	0.267
Xuancheng	0.089	0.155	0.521	0.255

Table 8: Results of recalculated flood resilience index of 27 cities in Yangtze River delta

4.4 Correlation analysis between revised flood resilience index and flood loss

This part will analyze the correlation between the revised resilience index and flood loss, so as to explore whether the revised flood resilience index does a better in predicting actual flood loss. The results are shown below:

Indicators	Correlation with direct economic loss			Correlation with affected population		
	3year	5year	8year	3year	5year	8year
Index (original)	0.009	0.010	0.001	0.226**	0.322**	0.195*
Index (recalculated)	0.004	0.003	0.026	0.000	0.053	0.052
Physical	0.013	0.005	0.039	0.006	0.059	0.096
Economic	0.039	0.201*	0.172*	0.004	0.005	0.010

Social	0.005	0.012	0.001	0.082	0.042	0.065
During-disaster	0.020	0.030	0.012	0.047	0.072	0.042
Pre-disaster	0.012	0.005	0.040	0.001	0.043	0.070
Post-disaster	0.000	0.000	0.004	0.028	0.148*	0.107*

Asterisks indicate signature level: Significant at *10%, **5%, ***1% level

Table 9: The results of correlation analysis between revised flood resilience index and flood loss

It can be seen from the above Table 9 that the correlations between the revised flood resilience index and the flood loss are not significant, which means the flood resilience index has not passed the external test of flood loss. The internal consistency of the revised flood resilience index is enhanced, but the ability to predict the results of flood disasters is worse. Although the internal consistency of the index was enhanced by eliminating some indicators, this came at the cost of the index' ability to predict flood loss.

4.5 Correlation analysis between different indicators of flood resilience and flood losses

As a result of the correlation analysis between the revised flood resilience index and the real flood disaster, it is concluded that the revised resilience index cannot truly reflect the flood disaster situation. The next part of the analysis is to explore whether there are independent indicators that can reflect the true situation of the flood, so the 16 indicators were re-verified for the correlation of flood disasters to learn more about indicators which do well in predicting actual flood loss.

R1: Building exposure

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.185	0.448
Affected population (5year)	-0.317	0.186
Affected population (8year)	-0.347	0.145
Directed economic loss (3year)	-0.162	0.507
Directed economic loss (5year)	-0.125	0.611
Directed economic loss (8year)	-0.263	0.278

Table 10: The result of correlation analysis of Building exposure (R1) with affected population

and direct economic loss

The results show that the correlation between R1 Building exposure and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) values are greater than 0.05, that is, building exposure is not related to affected population and direct economic loss.

R2: Infrastructure exposure

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.094	0.702
Affected population (5year)	-0.096	0.697
Affected population (8year)	-0.177	0.469
Directed economic loss (3year)	-0.041	0.868
Directed economic loss (5year)	-0.012	0.960
Directed economic loss (8year)	-0.112	0.647

Table 11: The result of correlation analysis of Infrastructure exposure (R2) with affected population and direct economic loss

The results show that the correlation between R2 Infrastructure exposure and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, infrastructure exposure is not related to affected population and direct economic loss.

R3: Green coverage

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.054	0.825
Affected population (5year)	0.237	0.329
Affected population (8year)	0.103	0.675
Directed economic loss (3year)	0.257	0.288
Directed economic loss (5year)	0.262	0.278
Directed economic loss (8year)	0.066	0.790

Table 12: The result of correlation analysis of Green coverage (R3) with affected population and direct economic loss

The results show that the correlation between R3 Green coverage and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) values are greater than 0.05, that is, green coverage is not related to affected population and direct economic loss.

R4: Flood exposure

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.266	0.270
Affected population (5year)	-0.287	0.233
Affected population (8year)	-0.353	0.138
Directed economic loss (3year)	0.104	0.672
Directed economic loss (5year)	0.173	0.480
Directed economic loss (8year)	0.043	0.863

Table 13: The result of correlation analysis of Flood exposure (R4) with affected population and direct economic loss

The results show that the correlation between R4 Flood exposure and the average affected population of recent 3 years, 5 years and 8 years, and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) values are all greater than 0.05, that is, flood exposure is not related to the average affected population and direct economic loss.

R5: People exposure

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.071	0.774
Affected population (5year)	-0.165	0.499
Affected population (8year)	-0.222	0.362
Directed economic loss (3year)	-0.082	0.739
Directed economic loss (5year)	-0.056	0.821
Directed economic loss (8year)	-0.191	0.434

Table 14: The result of correlation analysis of People exposure (R5) with affected population and direct economic loss

The results show that the correlation between R5 People exposure and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) values are greater than 0.05, that is, people exposure is not related to affected population and direct economic loss.

C1: Health access

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.194	0.426
Affected population (5year)	-0.230	0.343
Affected population (8year)	-0.155	0.525
Directed economic loss (3year)	-0.161	0.511
Directed economic loss (5year)	-0.198	0.416
Directed economic loss (8year)	0.007	0.979

Table 15: The result of correlation analysis of Health access (C1) with affected population and direct economic loss

The results show that the correlation between C1 Health access and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, health access is not related to affected population and direct economic loss.

C2: Medical capacity

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.209	0.390
Affected population (5year)	-0.217	0.371
Affected population (8year)	-0.102	0.679
Directed economic loss (3year)	-0.089	0.716
Directed economic loss (5year)	-0.158	0.518
Directed economic loss (8year)	0.250	0.303

Table 16: The result of correlation analysis of Medical capacity (C2) with affected population and direct economic loss

The results show that the correlation between C2 Medical capacity and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, medical capacity is not related to affected population and direct economic loss.

C3: Storm water absorption capacity

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.043	0.860
Affected population (5year)	-0.124	0.613
Affected population (8year)	-0.196	0.420
Directed economic loss (3year)	-0.048	0.845
Directed economic loss (5year)	0	1
Directed economic loss (8year)	-0.066	0.790

Table 17: The result of correlation analysis of Storm water absorption capacity (C3) with affected population and direct economic loss

The results show that the correlation between C3 Storm water absorption capacity and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, storm water absorption capacity is not related to affected population and direct economic loss.

C4: People vulnerability

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.484**	0.036
Affected population (5year)	0.667***	0.002
Affected population (8year)	0.635***	0.003
Directed economic loss (3year)	-0.185	0.449
Directed economic loss (5year)	-0.163	0.504
Directed economic loss (8year)	-0.094	0.702

Asterisks indicate signature level: . Significant at *10%, **5%, ***1% level

Table 18: The result of correlation analysis of People vulnerability (C4) with affected population and direct economic loss

The results show that the Sig (2-tailed) values of C4 People vulnerability and the average affected population of recent 3 years are less than 0.05, and the Sig (2-tailed) values of C4 People vulnerability and the average affected population of recent 5 years and 8 years are both less than 0.01. Therefore, the correlation between C4 People vulnerability and affected population is significant and close. The Sig (2-tailed) values of C4 People vulnerability and the average direct economic loss of recent 3 years, 5 years and 8 years are both greater than 0.05, so the correlation between C4 People vulnerability and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant, that is, people vulnerability is not related to direct economic loss.

C5: Economic tolerance

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.128	0.600
Affected population (5year)	0.337	0.159
Affected population (8year)	0.205	0.400
Directed economic loss (3year)	0.282	0.243
Directed economic loss (5year)	0.356	0.134
Directed economic loss (8year)	0.027	0.912

Table 19: The result of correlation analysis of Economic tolerance (C5) with affected population and direct economic loss

The results show that the correlation between C5 Economic tolerance and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, economic tolerance is not related to affected population and direct economic loss.

RA1: Public transportation service

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.304	0.205
Affected population (5year)	-0.451*	0.053
Affected population (8year)	-0.454*	0.051
Directed economic loss (3year)	-0.183	0.452
Directed economic loss (5year)	-0.165	0.500
Directed economic loss (8year)	-0.273	0.258

Asterisks indicate signature level: . Significant at *10%, **5%, ***1% level

Table 20: The result of correlation analysis of Public transportation service (RA1) with affected population and direct economic loss

The results show that the correlation between RA1 Public transportation service and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, public transportation service is not related to affected population and direct economic loss.

RA2: Mobility

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.312	0.194
Affected population (5year)	-0.507**	0.027
Affected population (8year)	-0.303	0.207
Directed economic loss (3year)	-0.067	0.786
Directed economic loss (5year)	-0.179	0.464
Directed economic loss (8year)	0.111	0.650

Asterisks indicate signature level: Significant at *10%, **5%, ***1% level

Table 21: The result of correlation analysis of Mobility (RA2) with affected population and direct economic loss

The results show that the Sig (2-tailed) values of RA2 Mobility and the average affected population of recent 5 years are less than 0.05 which means the correlation between them is significant, while the Sig (2-tailed) values of other correlation relationships are greater than 0.05, that is, the correlation is not significant. It can be considered that there is a significant correlation between mobility and affected population, while there is no correlation between mobility and direct economic loss.

RA3: Social insurance

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.272	0.309
Affected population (5year)	-0.641***	0.007
Affected population (8year)	-0.446*	0.083
Directed economic loss (3year)	-0.121	0.655
Directed economic loss (5year)	-0.211	0.433
Directed economic loss (8year)	-0.131	0.629

Asterisks indicate signature level: Significant at *10%, **5%, ***1% level

Table 22: The result of correlation analysis of Mobility (RA2) with affected population and direct economic loss

The results show that the Sig (2-tailed) values of RA3 Social insurance and the average affected population of recent 5 years are less than 0.05 which means the correlation between them is significant, while the Sig (2-tailed) values of other correlation relationships are greater than 0.05, that is, the correlation is not significant. It can be considered that there is a significant correlation between social insurance and affected population, while there is no correlation between social insurance and direct economic loss.

RA4: Learning mechanism

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	0.102	0.677
Affected population (5year)	0.184	0.451
Affected population (8year)	0.197	0.419
Directed economic loss (3year)	-0.042	0.865
Directed economic loss (5year)	0.057	0.817
Directed economic loss (8year)	0.106	0.665

Table 23: The result of correlation analysis of Learning mechanism (RA4) with affected population and direct economic loss

The results show that the correlation between RA4 Learning mechanism and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, learning mechanism is not related to affected population and direct economic loss.

RA5: Local economic level

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.053	0.831
Affected population (5year)	-0.233	0.338
Affected population (8year)	-0.298	0.215
Directed economic loss (3year)	0.201	0.409
Directed economic loss (5year)	0.241	0.321
Directed economic loss (8year)	-0.059	0.809

Table 24: The result of correlation analysis of Local economic level (RA5) with affected population and direct economic loss

The results show that the correlation between RA5 Local economic level and the average affected population of recent 3 years, 5 years and 8 years and the average direct economic loss of recent 3 years, 5 years and 8 years is not significant because the Sig (2-tailed) value is greater than 0.05, that is, local economic level is not related to affected population and direct economic loss.

RA6: Employment

	Pearson Correlation	Sig(2-tailed)
Affected population (3year)	-0.298	0.215
Affected population (5year)	-0.563**	0.012
Affected population (8year)	-0.431*	0.065
Directed economic loss (3year)	-0.117	0.633
Directed economic loss (5year)	-0.136	0.579
Directed economic loss (8year)	-0.121	0.623

Asterisks indicate signature level: Significant at *10%, **5%, ***1% level

Table 25: The result of correlation analysis of Employment (RA6) with affected population and direct economic loss

The results show that the Sig (2-tailed) values of RA6 Employment and the average affected population of recent 5 years are less than 0.05 which means the correlation between them is significant, while the Sig (2-tailed) values of other correlation relationships are greater than 0.05, that is, the correlation is not significant. It can be considered that there is a significant correlation between employment and affected population, while there is no correlation between Employment and direct economic loss.

Summary of the above findings on the influence of different flood resilience indicators on flood loss: Only 4 indicators show a significant correlation with the flood loss, which are RA2: Mobility, RA6: Employment, C4: People vulnerability and RA3: Social insurance.

4.6 The results of a specific case study

The case study zooms in on a specific area, the Yangtze River Delta in Anhui Province. There are 16 cities in Anhui Province, of which 8 are located in the Yangtze River Delta, which is the area of this case study. The case study is based on the actual situation of these cities in the Yangtze River Delta in Anhui Province during the catastrophic flood in the summer of 2020. The reason why Anhui Province was chosen as the case study is that Anhui Province was the most seriously affected by the floods in the summer of 2020. This part of data comes from the disaster report released by the Anhui Provincial Government after the flood. The purpose of the case study is to further validate the results obtained above. The case study mainly explores three questions: 1. Does the resilience index reflect the actual flood resilience of the city? 2. Which stage of the flood event has the most losses? 3. Do cities with high mobility, high employment rates, fewer vulnerable populations, or higher insurance coverage have lower flood losses during flood event?

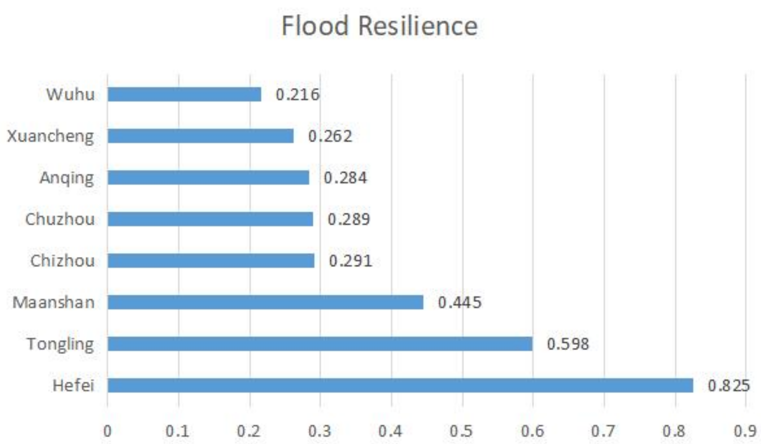

Figure 12: Flood resilience of 8 cities of Anhui Province(Zhu et al., 2021)

City	Affected population/10000person （person）	Death due to disasters (person)	Direct economy Loss/10000person (10000 yuan)
Hefei	1280	3	2012
Wuhu	2530	0	1440
Maanshan	1961	0	2184
Tongling	2515	0	1746
Anqing	1657	2	2752
Chuzhou	753	0	241

Chizhou	2839	0	737
Xuancheng	2365	1	1070

Table 26: Disaster losses of Anhui Province in 2020 flood (Anhui Provincial Government Flood Disaster Investigation and Evaluation Team,2021)

In the index ranking of flood resilience, Hefei has the highest resilience but the largest number of deaths, while Wuhu City is considered to have the lowest resilience but no deaths. Tongling City ranks the second in flood resilience. It is expected that its flood disaster response capacity is strong and the flood loss is small. However, in the 2020 flood, Tongling City is in the forefront of both the affected population and direct economic losses. In addition, Anqing City and Chuzhou City were considered as cities with reduced flood resilience, but these cities performed unexpectedly well during and after flood disaster. It can be seen that cities with a higher flood resilience index do not who higher actual flood resilience, and the flood resilience index does not really reflect the ability of cities to cope with floods. The reason why the flood resilience index did not accurately predict the actual situation of the flood event may be that the resilience index fails to take the speed and capacity of disaster response into account or does not select indicators that accurately reflect these two elements. After in-depth investigation, one of the causes of death of three people in Hefei was a man who was struck by lightning and fell to the ground during the patrol inspection of a section of the dam at Zuiwei in Luohe Community, Luochang River (Anhui Provincial Government Flood Disaster Investigation and Evaluation Team,2021). The other two men were on the way to rescue the trapped villagers in Lianhe Village, Tongda Town, by rubber boat, and died because the rubber boat was involved in the torrent vortex and overturned and fell into the water (Anhui Provincial Government Flood Disaster Investigation and Evaluation Team,2021). These were all actions taken in response to the flood disaster, resulting in accidental death. It is commendable and necessary to be able to respond to flood disasters quickly and positively, but there is a misunderstanding about the contribution of urban flood resilience. The rapid response of cities to flood events after a flood does not necessarily mean that the cities have high resilience. More importantly, it is important to avoid losing manpower and material resources during the response process.

In this flood disaster, in addition to the three deaths in Hefei mentioned above, 2 people died in Anqing and one person died in Xuancheng. The cause of the death in Anqing was that one woman was killed by lightning while sheltering from the rain under the tree, and another woman was killed by lightning while working in her farm (Anhui Provincial Government Flood Disaster Investigation and Evaluation Team,2021). The cause of death in Xuancheng was a man who collapsed in the process of clearing the slope behind the house and was buried (Anhui Provincial Government Flood Disaster Investigation and Evaluation Team,2021). Including the three deaths described above, all occurred at the time and after the flood. This means that if we want to improve the level of flood resilience, we cannot ignore the prevention during and after the flood. If we want to truly reflect the flood resilience of the city, we should pay more attention to the indicators of these two periods.

From the study of quantitative analysis, 4 indicators which is RA2: Mobility, RA6: Employment, C4: People vulnerability and RA3: Social insurance have a significant impact on flood results. Therefore, in this specific case study, we explored whether cities with high mobility, high employment rate, fewer vulnerable populations, or high insurance coverage in Anhui Province had lower flood losses after the 2020 flood event. In the four indicators obtained above, what is worth noting is the employment rate. The flood resilience of Chuzhou and Anqing is low, but their performance in terms of the number of people affected and direct economic losses in the flood disaster in 2020 is good, and the disaster losses are low. However, the employment rate of these two cities is in the forefront. The resilience of Tongling City ranks the second among the eight cities, but the loss in this flood was large. It is interesting that his performance in mobility and employment indicators is also very poor, both at the end. Although Hefei was at the forefront of direct economic losses in the flood, the proportion of affected people in 10000 people performed well, while the proportion of vulnerable people in Hefei was the lowest and the social insurance coverage was the largest. In general, the flood resilience in areas with high mobility, high employment rate, less vulnerable population or high insurance coverage is higher.

5. Conclusion and discussion

5.1 Answers to the research questions

This research aimed to investigate the flood resilience index through the actual disaster situation, and give suggestions on how to improve the index and flood risk management of Yangtze River Delta cities.

The main research question is Which flood resilience index reflects the actual flood resilience of Yangtze River Delta cities??

This question is divided into five sub questions to answer:

1.How to measure the flood resilience of different cities?

The flood resilience index is a way to quantify flood resilience. In general, resilience indicators are selected from natural, physical, social, economic, and institutional and organizational dimensions. The flood resilience index adopted by Zhu et al. (2021) combines natural and physical dimensions into a physical environment dimension, incorporating institutional and organizational dimensions into social dimensions, and ultimately obtaining a flood resilience index that includes three dimensions: physical environment dimension, social dimension, and economic dimension. Among them, physical dimension includes R1: Building exposure, R2: Infrastructure exposure, R3: Green coverage, R4: Flood exposure, C1: Health access, C2: Medical capacity, C3: Storm water absorption capacity, RA1: Public transport service, RA2: Mobility, social dimension includes R5: People exposure, C4: People vulnerability, RA3: Social insurance, RA4: Learning mechanism and economic dimension including C5: Economic tolerance, RA5: Local economic level, RA6: Employment. In addition, Zhu et al. (2021) also classifies these indicators according to the time period of disaster occurrence: before flood including R1: Building exposure, R2: Infrastructure exposure, R3: Green coverage, R4: Flood exposure, R5: People exposure ure, during flood including C1: Health access, C2: Medical capacity, C3: Storm water absorption capacity, C4: People vulnerability , C5: Economic tolerance and after flood RA1: Public transport service, RA2: Mobility , RA3: Social insurance , RA4: Learning mechanism, RA5: Local economical level , RA6: Employment. Based on the results of internal consistency testing, this thesis revises the flood resilience index proposed by Zhu et al. (2021), deleting R4: Flood exposure, C3: Storm water absorption capacity, and RA2: Mobility from the physical environment dimension, RA4: Learning mechanism from the social dimension, and C5: Economic tolerance from the economic dimension

The results are as follows:

Indicators	Formula	Dimension	Effect
Pre-flood resilience: resistance capacity FRR			
R1: Building exposure	R1 = built-up area/urban area * 100%	physical	negative
R2: Infrastructure exposure	R2 = road area/urban area * 100%	physical	positive
R3: Green coverage	R3 = green covered area/urban area *10 0%	physical	positive
R5: People exposure	R5 = registered population at year-end/ urban area	social	negative

Figure 9: Revised Pre-flood resilience index

Indicators	Formula	Dimension	Effect
During-flood resilience: Coping capacity FRC			
C1: Health access	C1 = number of hospitals/urban area	physical	positive
C3: Storm water absorption capacity	C3 = drainage length/urban area	physical	positive
C4: People vulnerability	C4 = number of vulnerable people /registered population at year-end * 100%	social	negative

Figure10: Revised During-flood resilience index

Indicators	Formula	Dimension	Effect
Post-flood resilience: Recovery and adaptation capacity FRRA			
RA1: Public transport ation service	RA1 = number of public transport vehicles/registered population at year-end	physical	positive
RA3: Social insurance	RA3 = persons covered of insurances/ registered population at year-end	social	positive
RA5: Local economic level	RA5 = per capita gross regional product	economic	positive
RA6: Employment	RA6 = (average number of employed staff and workers/registered population at year-end) *100%	economic	positive

Figure 11: Revised Post-flood resilience index

2.What is the flood resilience of Yangtze River Delta cities?

According to the flood resilience index data before the revision, the highest value in Nanjing is 0.87, and the lowest value in Taizhou is 0.06. After the revision, the flood resilience index in Shanghai is the highest value of 0.88, while that in Xuancheng is the lowest value of 0.26 In the flood resilience index before revision, among the 27 cities in the Yangtze River Delta region, the provincial capitals of three provinces have high flood resistance capabilities. In the revised flood resilience index, Hefei City in Anhui Province and Hangzhou City in Zhejiang Province still have high flood resilience. However, the results in Nanjing of Jiangsu Province were different, moving from first to middle level. Through calculation, it is found that the flood resilience of the social dimension in Nanjing after revision decreases by only 0.29%. The reason for this may be that during revision process, the indicator RA4 Learning mechanism affected the internal consistency of social dimensions, so it was removed. Nanjing has more policies and regulations related to rainwater and flood management, and has a higher institutional level compared to other cities. However, the revised flood resilience index was not included in this indicator, resulting in a decrease in the social dimension score of flood resilience in Nanjing, and also affecting the final score. Both pre and post revision flood resilience indices show that the average flood resilience index of cities in the Yangtze River Delta is at a medium level. Among them, cities in the southeast coastal areas have better resilience than inland cities. This is mainly due to economic reasons. Coastal cities are more economically developed than inland cities, which also results in better flood control infrastructure in coastal cities than inland cities, leading to an increase in the overall score due to an increase in the physical environment dimension of coastal cities.

3. To what extent is the flood resilience index internally sound and robust?

The selection of flood resilience indicators is based on expert experience to determine whether they are included in the flood resilience index, and is subjective. At the same time, it is difficult to directly see the internal consistency and accuracy of the flood resilience index. Therefore, it is necessary to verify this flood resilience index through city specific data. In summary, the internal consistency of the flood resilience is low. On the whole, the consistency of all indicators of the flood resilience index is low, which may be due to the fact that the flood resilience index has three different dimensions, and indicators of different dimensions reflect different content, with significant differences. It is this multidimensional nature that leads to internal inconsistencies in the flood resilience index. From the perspective of different dimensions, the internal consistency of the three different dimensions is poor, with the internal consistency of the physical environment dimension slightly higher than the other two dimensions. After excluding R4: Flood exposure, C3: Storm water absorption capacity, and RA2: Mobility from the physical environment dimension, RA4: Learning mechanism from the social dimension, and C5: Economic tolerance from the economic dimension, the internal consistency of each dimension has been significantly improved, and the overall internal consistency has also reached consistency.

4.Does the flood resilience index actually show the capacity of flood risk management of Yangtze River Delta cities?

In general, neither the flood resilience index before nor after revision is able to predict flood disaster losses. Therefore, the conclusion is that the comprehensive flood resilience index cannot truly reflect the situation of flood disasters. When testing individual indicators, only 4 indicators show a significant correlation with the flood results, which are RA2: Mobility, RA6: Employment, C4: People vulnerability and RA3: Social insurance. This also partially explains the reason for the failure of the flood resilience index: incorrect understanding or quantification of the flood resilience index and indicators. It is not that the selected flood resilience index has no impact on urban flood resilience, but rather that it is an operational error in quantifying this index. Quantification is indeed a very difficult step. For example, the correlation analysis results of RA4: Learning mechanism and flood disaster losses show that there is no significant correlation between the two. However, this does not mean that cities do not need sufficient flood control related policies, but perhaps the number of policies and regulations does not reflect the level of urban flood resilience. The implementation of policies and regulations and the results obtained are more useful. When selecting indicators, it is assumed that the number of policies and regulations is equivalent to the flood resilience of the city. Although the number of policies and regulations is undoubtedly the most direct and simple method for quantifying RA4: Learning mechanism, this result only proves that this method is not effective. In addition, there is C1 Health access, which is quantified by the number of hospitals/urban area. This may seem quite reasonable, but in real flood disasters, many emergency calls come from the suburbs rather than the urban areas. However, this quantitative approach generalizes the health accessibility of suburbs and urban areas, and the uneven health accessibility of suburbs and urban areas is ignored. It will occur that a city has higher health accessibility, but still has higher flood losses, as this loss occurs in the suburbs.

4. What are the suggestions for improving the Flood Risk Management in in Yangtze River Delta?

Based on the results of this study, six suggestions can be made.

1.Attention needs to be paid to forecasting and early warning systems

The research results show that there is a correlation between mobility (number of subscribers of mobile phones at year end/registered population at year end * 100%) and flood losses. This is because through mobile phones, people can be warned earlier. Due to the popularity of social media, mobile phones can also make news of flood disasters spread faster, and also enable people to initiate rescue calls anytime and anywhere, effectively reducing the affected population and reducing the impact of floods. This also means that early warning of flood disasters is effective. At the same time, unlike earthquakes or other natural disasters, floods have a strong early warning ability. By observing the upstream water regime, they can provide early warning of downstream flood risks, making it possible to transfer property and reduce losses. Therefore, improving the early warning system can reduce the impact of floods.

2.Improve insurance coverage

The research results show that there is a correlation between social insurance (persons covered of insurances/registered population at year end) and flood losses. The insurance data in the study includes all types of insurance, while flood insurance is not emphasized. The government should strengthen the flood insurance system and provide financial subsidies for flood insurance for residents in areas prone to flooding. Improving insurance coverage can not only provide financial compensation after floods, but also help before floods occur. In order to reduce possible compensation, some insurance companies actively assist the insured enterprises in property transfer before the flood, which not only reduces insurance compensation, but also reduces the loss of social wealth.

3. Focus on vulnerable populations

The research results show that there is a correlation between people's vulnerability (number of vulnerable people/registered population at year end * 100%) and flood losses. The vulnerable population in the study mainly refers to the underage and the population aged over 65. In addition, attention should also be paid to populations with mobility difficulties and disabilities. Pay attention to the accessibility of information and rescue conditions for these populations during flood disasters. Community-based flood prevention systems for vulnerable populations can be promoted. This is because community-based statistics can ensure the accuracy and targeted assistance of vulnerable populations.

4. Increase employment rate

The results show that there is a correlation between employment (average number of employed staff and workers/registered population at year end) * 100% and flood losses. A higher level of employment means that cities have a higher economic level. The economic level of a city affects the financial investment in its flood control infrastructure. At the same time, people who participate in work have more social insurance, which will also provide them with an additional protection against flood risks. The government should provide as many jobs as possible, and at the same time, it can add some free skills training to increase skilled personnel, in order to promote the employment of unemployed people in cities.

5.Avoiding flood losses when actively and quickly responding to floods

In case studies, it has been observed that many flood losses are secondary injuries that occur when actively and quickly responding to floods. It is necessary for civil society and the government to respond quickly and actively to flood disasters after the occurrence of floods, and it is also an aspect of urban flood resilience. However, misunderstandings about the ability to respond quickly and positively should be avoided. Not being a positive and rapid response means that it will play a role in high flood resistance while avoiding the loss of human and material resources in the response process.

6.Suggestions for future research on flood resilience in cities in the Yangtze River Delta

The indicators of flood resilience index selected in this study are far more in the physical environment dimension than in the economic and social dimensions, which leads to a relatively large proportion of physical environment dimension indicators. Therefore, more economic and social dimension indicators can be appropriately selected in future research. In addition, the quantification methods of some indicators in the flood resilience index of this study need to be discussed. In future studies, different quantification methods can be selected to verify them to obtain more accurate results.

Due to the lack of mathematical knowledge, the flood resilience calculation after improving the flood resilience index in this article does not use the same calculation method as (Zhu et al. (2021), but uses the mean method and principal component analysis to calculate. Future research can use the same calculation method to obtain more accurate results.

5.2 Discussion

Previous research on flood resilience index often remained at the theoretical level, rarely linking the theoretical flood resilience with the actual flood disaster situation. However, this study compares the two. The research results show that flood resilience index does not fully reflect the flood resilience level of the cities. This reminds us of the flaws in the theoretical flood resilience index, which may be due to incorrect selection or inaccurate quantification of flood resilience indicators. We can know from the results that the four indicators of Mobility, Employment, People vulnerability, and Social insurance are significantly correlated with the flood disaster situation in cities, while the other indicators show no correlation. This means that these four indicators can be directly included in the flood resilience index in future research, while the remaining indicators need to be re-quantified and validated. This also suggests that relying solely on expert experience and subjective opinions in the selection of flood resilience indicators may lead to some errors, and empirical research needs to be conducted based on actual flood disaster situations. In addition, previous studies have often focused too much on the selection of indicators for flood resilience index at the physical environment level. The results of this study show that indicators of the physical environment dimension show no significant correlation with flood losses. This is very surprising, apart from the reasons for the incorrect quantification of these indicators. It is also possible to consider whether the protection brought about by the physical environment begins to fail when the flood scale is too large. At a time when the extent and frequency of flood disasters are increasingly extreme, the role of economic and social dimensions should be taken seriously. Therefore, in the current era of frequent occurrence of extreme floods, future research should increase the emphasis on economic and social dimensions, with an average focus on each dimension.

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