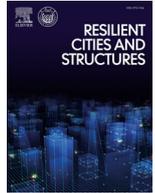




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Investing in resilience: A long-term analysis of china's flood protection strategies

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ABSTRACT

Investing in disaster risk reduction is crucial for minimizing the impacts of disasters. However, little is known about the factors that influence changes in investment levels over time. This study aims to identify the key socio-economic drivers behind increases and decreases in flood protection investment in People's Republic of China (PRC). Such information is crucial for policy makers to justify flood investments. By analyzing data on flood protection expenditures, economic losses from floods, and other relevant indicators from 1980 to 2020, the study evaluates the relationship between investment and disaster impacts through the lens of the flood investment cycle model. It was found that the country succeeded in reducing flood damage because of increasing investment in flood protection. The results indicate that changes in PRC's flood protection investment have been driven by three major factors: the occurrence of major disasters, the fiscal situation, and shifts in government policies. Investment tended to increase following large-scale events, such as the 1998 Yangtze River Basin flood and the 2008 Wenchuan earthquake, which prompted policy changes and renewed focus on DRR measures. Fiscal constraints limited investment in the 1990s, but reforms and stimulus measures improved the financial situation, enabling increased spending on flood protection. PRC's experience in steadily reducing flood damage through sustained investment and policy commitment offers valuable lessons for other developing countries facing similar challenges.

1. Introduction

Investment in disaster risk reduction (DRR) is critical to minimizing the damage caused by disasters [1,2]. The Sendai Framework for DRR, agreed by UN member states in 2015, emphasizes investment as one of the priority actions [3]. However, developing countries often face significant challenges in allocating sufficient resources for DRR due to competing priorities and limited fiscal capacity.

People Republic of China (PRC) has experienced frequent large-scale flood disasters in recent years, underscoring the importance of robust flood protection policies to mitigate damage. Flood events can have devastating consequences, resulting in loss of life, displacement of populations, destruction of infrastructure, and significant economic losses [4–6]. The integration of information and communication technologies can improve the resilience of infrastructure [7]. For example, in July 2021, heavy rains caused massive flooding in Henan Province, affecting 1478,000 people, killing 398 people, and causing direct economic losses of 120.6 RMB billion, or 16.7 billion USD [8].

The government has strengthened DRR capacities. For example, the recovery plan from the 2021 heavy flood cover not only restoring water, housing, infrastructure, education, and health services, but also improve structural and nonstructural measures against floods [9]. The government attaches great importance to DRR and has issued relevant policies. The National Comprehensive Disaster Prevention and Mitigation Plan announced in June 2022 presented a medium-term plan to 2025 and a long-term plan to 2035 on various policies, including flood protection policy [10]. The plan also aims at promoting the United Nations' 2030 Agenda for Sustainable Development (2030 Agenda) and the Sendai Framework for DRR.

While existing research has highlighted the effectiveness of flood protection investments in reducing damage in PRC [11,12], there is limited understanding of the factors that influence changes in investment levels over time. This study aims to address this gap by examining the drivers behind increases and decreases in flood protection investment from 1980 to 2020. By analyzing data on flood protection expenditures, economic losses from floods, and other relevant indicators, the

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Table 1
Disaster risk reduction and flood protection policies.

Law and Policy	Disasters and Events
1988 Water Law [Shui fa] (amendment 2002, 2009, 2016), 1988, Regulations on River Management [Hedao guanli tiaoli]	1987 United Nations designated 1990–2000 as International Decade for Natural Disaster Reduction
1991 Water and Soil Conservation Law [Shuitu baochi fa] (amendment 2010) 1991 Flood Control Regulation [Fangxun tiaoli] (amendment 2005, 2011)	1989 China National Committee for the International Decade for Natural Disaster Reduction (CCIDNDR) (rename at 2000, 2005)
1998 Disaster Reduction Plan of the PRC (1998–2010) [Zhonghua renmin gongheguo jianzai gui hua (1998—2010)] (1994 started preparation, 1996 drafting)	1992 “Agenda 21” adopted at United Nations Conference on Environment and Development, Earth Summit. 1994 China’s Agenda 21
1998 Flood Control law [Fanghong fa] (1997 promulgated, amendment 2009, 2015, 2016) 2000 Meteorology Law [Qixiang fa] (1999 promulgated, amendment 2009, 2014, 2016), 2007 The National 11th Five-year Plan on Comprehensive Disaster Reduction [Guojia zonghe jianzai “shiyiwu” gui hua] (2007–2010)	1998 Yangtze River flood
2009 China’s Actions for Disaster Prevention and Reduction, White paper [Zhongguo de jianzai xingdong, baipishu] 2010 Regulation on the Defense against Meteorological Disasters [Qixiang zaihai fangyu tiaoli] (amendment 2017) 2010 Decision on Accelerating Water Conservancy Reform and Development [Guanyu jiakuai shuili gaige fazhan de jue ding] (The No.1 central document of 2011 of the CPC Central and the State Council [2011 nian zhongyang 1hao wenjian]) 2011 The National Comprehensive Disaster Prevention and Mitigation Plan 12th Five-year Plan (2011–2015) [Guojia zonghe fangzai jianzai shierwu guihua (2011–2015)] 2016 The National Comprehensive Disaster Prevention and Mitigation Plan 13th Five-year Plan (2016–2020) [Guojia zonghe fangzai jianzai shisanwu guihua (2016–2020)]	2008 Major earthquake in Wenchuan, Sichuan Province
2022 National Comprehensive Disaster Prevention and Mitigation Plan 14th Five-year Plan (2021–2025) [Guojia zonghe fangzai jianzai shisiwu guihua (2021–2025)] 2023 In-depth study and implementation of Xi Jinping’s important exposition on water control [Shenru xuexi Guanche xijinping guanyu zhishui de zhongyao lunshu].	2021 extreme rainstorm and flood disaster in Zhengzhou, Henan Province

study evaluates the relationship between investment and disaster impacts through the lens of the flood protection investment cycle model proposed by Ishiwatari and Sasaki [13].

Analyzing PRC’s policies can provide valuable insights for other developing countries facing disasters. PRC is classified as an upper-middle income country by the World Bank. The findings can inform policy discussions and aid in the development of robust financing mechanisms and policy frameworks for enhancing resilience to flood disasters.

2. Flood protection in PRC

2.1. Disasters and changes in flood protection policy

PRC is prone to various natural disasters and has repeatedly suffered from large-scale floods, such as the Banqiao Dam failure in 1975 and the Yangtze River basin floods in 1998. More recently, a major flood in Henan Province in July 2021 has received considerable attention.

PRC’s flood protection policy has undergone various changes since its establishment in 1949 (Table 1). The Ministry of Water Resources and various departments and agencies related to water resources were established in the central government in 1949. Since then, the country has experienced the Great Leap Forward and the Cultural Revolution. Since the reform and opening-up policy in December 1978, water resources policy has entered a new phase. In 1987, the United Nations General Assembly proclaimed 1990–2000 as the International Decade for Natural Disaster Reduction [14]. In response, PRC established the China National Committee for the International Decade for Natural Disaster Reduction (CCIDNDR) in 1989 and began to implement DRR activities [15]. When Agenda 21 was adopted at the United Nations Conference on Environment and Development, also known as the Earth Summit, in 1992, the government announced China’s Agenda 21 in 1994. This international advocacy prompted the country to improve its laws and sys-

tems related to DRR. Specifically, the following laws and policies were enacted: The Water Law in 1988; the Water and Soil Conservation Law in 1991; the Flood Control Law; and the "Law on Protection Against and Mitigation of Earthquake Disasters" in 1998. In 1998, the "Disaster Reduction Plan of the PRC (1998–2010)", a medium- to long-term disaster reduction plan, was formulated under the leadership of the CCIDNDR [16]. In addition, the National Disaster Reduction Commission and the Ministry of Civil Affairs designated May 12 as Disaster Prevention and Reduction Day to commemorate the Wenchuan earthquake in Sichuan in 2008. On this day, disaster management training and commemoration ceremonies for the Sichuan earthquake are held to raise DRR awareness throughout the country.

2.2. Relationship between flood disaster and flood protection investment

Existing research and government reports suggest that investment in flood protection can reduce flood damage in PRC. The country has formulated flood protection policies after flood disasters. However, there is a limited number of studies that have examined the factors that lead to increased or decreased investment in flood protection.

As a result of the government’s series of structural and non-structural policies, the number of deaths, economic losses, and flood damage areas have been significantly reduced in the past 20 to 30 years [17,18]. Recognizing the importance of DRR, PRC has invested in flood-prone areas and built capacity in structural measures, recovery, early warning, and emergency response [19]. Guo et al. [11] analyzed the relationship between water resources investment and damage reduction using data from 1990 to 2011 and found that investment is effective in reducing drought and flood damage across the country. In addition, the northeastern region of China is more resilient to flooding than the southeastern region. Flood protection investment in the northeast region is higher while economic growth is lower in the northeast region [12]. There is

also a tendency for flood protection measures to be particularly effective in the eastern part of the country [11,12]. At the city level, policies, systems, and resource allocation can have an impact on urban resilience [20].

The objectives of flood protection policy are changing over time due to the country’s economic and social development. According to Wang [21], significant turning points in water conservation were in 1998 and 2011. In 1998, the country experienced large-scale floods, especially the Yangtze River flood, which caused significant damage. PRC shifted from traditional flood protection policies to modern ones. In 2011, the No. 1 Central Document emphasized the need to accelerate the modernization of water conservation.

The amount of flood protection investment is changed by the policy and financial system. The investment expenditure can be divided into three periods [22]. The first period, from 1949 to 1979, saw significant investment in flood protection, with investment accounting for more than 5 % of national expenditure. The second period, from 1980 to 1991, saw a decline in investment to 2.8 % due to a change in fiscal policy towards decentralization. The third period, after 1992, saw an increase in investment to 4.2 % due to the promotion of infrastructure construction by the central government.

3. Research methods and data

3.1. Investment cycle model of flood protection

Ishiwatari and Sasaki [13] developed an investment cycle model for flood protection, that elucidates the cyclical patterns in flood management investments and their outcomes. Drawing parallels with business cycle theory—which describes periodic fluctuations in corporate facility durability and capital investment timing—they conceptualized a dynamic framework to analyze the relationship between flood protection budgets and flood damage patterns.(Fig. 1).

Their model identifies a cyclical four-phase progression:

- i. Initial Phase: Characterized by escalating flood damage, often due to aging infrastructure or changing environmental conditions
- ii. Response Phase: Marked by increased investment in flood protection infrastructure, directly catalyzed by significant flood events
- iii. Mitigation Phase: Distinguished by a reduction in flood damage, attributable to the implementation of enhanced protection measures
- iv. Deceleration Phase: Exhibits declining investment levels, typically due to reduced perceived risk and competing budget priorities

This cyclic pattern continuously repeats, creating a feedback loop between damage events and protective investments. The model provides a theoretical framework for understanding the temporal dynamics of flood protection investment decisions and their consequences.

Their study examined the relationship between flood damage and flood protection investment in major Asian economies. It was found that government budgets for flood protection increased in response to major

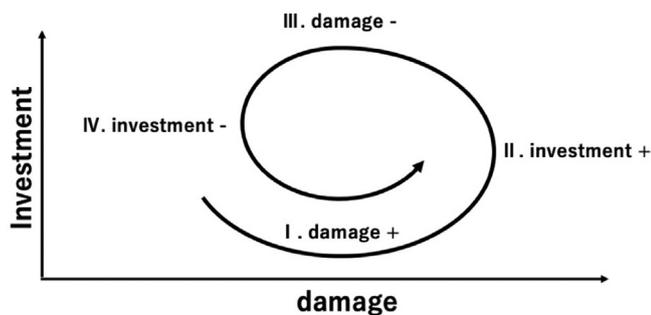


Fig. 1. The cycle of flood damage and investment. Source: Ishiwatari and Sasaki [9].

Table 2 Data sources.

China Water Statistical Yearbook [24]	Flood protection investment: 1980–2020 Amount of damage (Direct economic loss): 1990–2020 Number of deaths: 1980–2020 Damaged-Area: 1980–2018 (no data from 2019 to 2020) Disaster-affected Area: 1980–2020
China Water Yearbook [25]	Central government expenditure: 1980–2020, Local government expenditure: 1980–2020, Gross Domestic Products: 1980–2020

flood disasters, but then decreased due to their unsustainable nature. Ishiwatari and Sasaki [23] evaluated the flood protection investment cycle in Japan over a period of about 150 years and identified five cycles. Japan established funding mechanisms in response to the major flood disasters. In addition, the research shows that external shocks such as war, economic recession, disasters, and tight government finances have significantly affected flood protection investments.

This study evaluates the relationship between flood damage and flood protection investment in PRC by applying the flood protection investment cycle and examines the factors that influence the increase or decrease in investment.

3.2. Data source

This study analyzes the ratio of flood protection investment and economic losses to GDP. The Sendai Framework for DRR also uses the ratio of economic losses to GDP as an indicator. The data sources are statistics published by the Ministry of Water Resources and the National Bureau of Statistics of China (Table 2).

Since data on economic is available only since 1990, this study mainly analyzes the period 1990–2020 with reference to other data for the period 1980–1990. The affected and affected areas may contain some bias due to the difficulty of interpreting the data.

4. Results

4.1. Relationship between disaster and investment

This subsection examines the overall trends in disaster damage and investment in flood protection in PRC. Investment in flood protection remained low until 1997 but started to increase in 1998 (Figs. 2(a)-(f)). It peaked once in 2002, followed a downward trend until 2008, and increased again since 2008. Similar trends can be observed in the ratio of flood protection investments to government expenditure (Figure 2(b)) and in the ratio of investments to GDP (Fig. 2(c)).

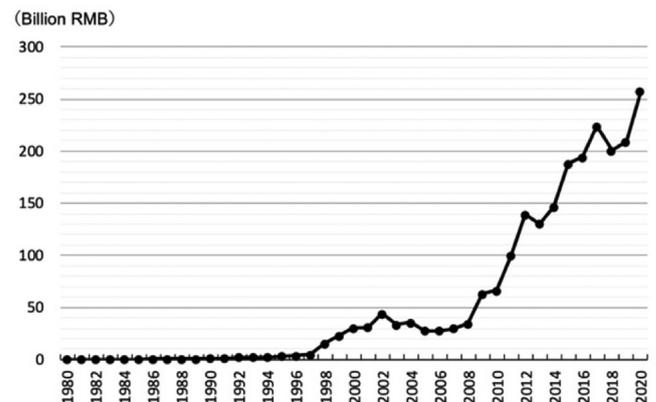


Fig. 2(a). Investment in flood protection.

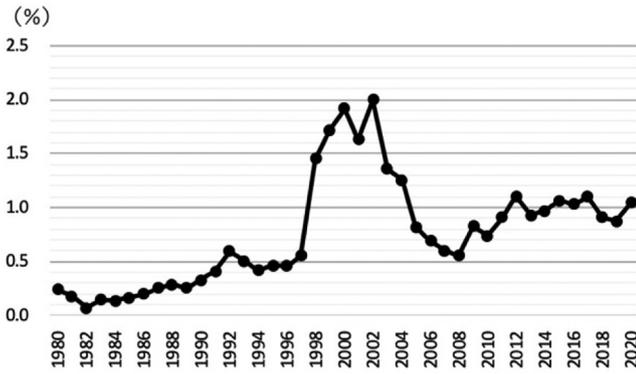


Fig. 2(b). Investment in flood protection to government expenditure ratio.

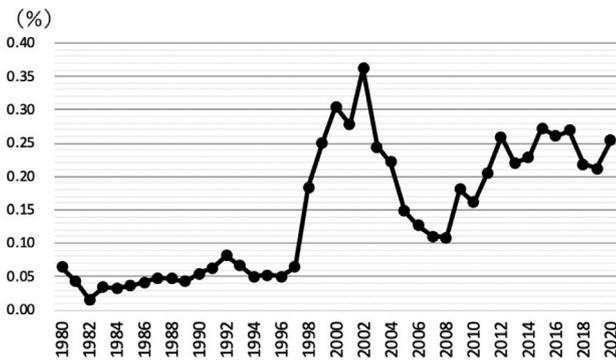


Fig. 2(c). Investment in flood protection to GDP ratio.

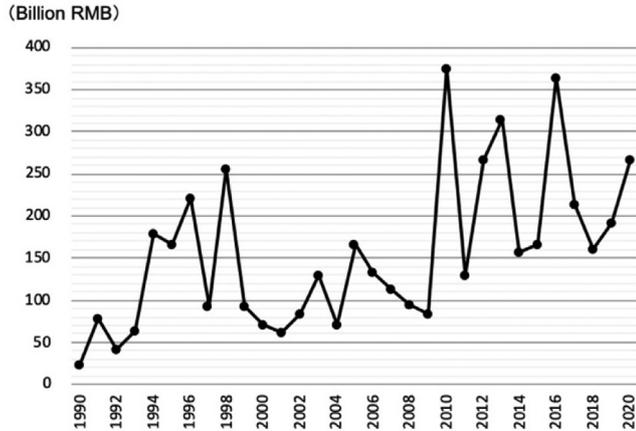


Fig. 2(d). Direct economic losses.

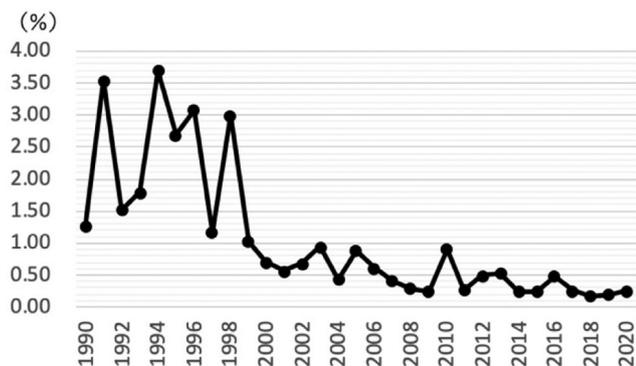


Fig. 2(e). Direct economic losses to GDP ratio.

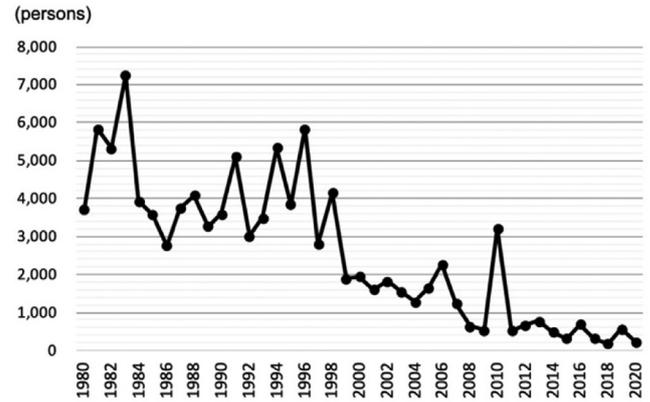


Fig. 2(f). Fatalities.

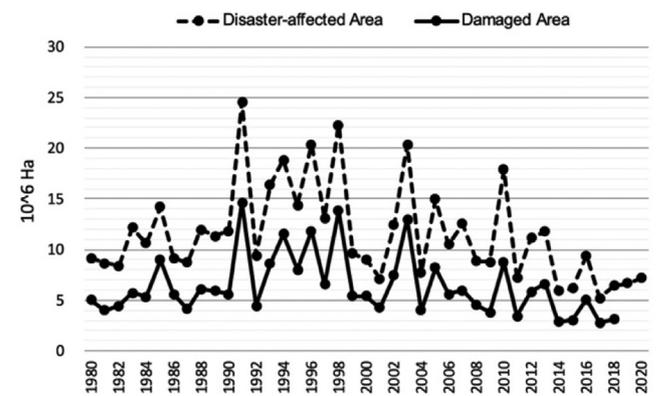


Fig. 2(g). Flood disaster-affected area and damaged area.

Economic losses due to floods (Fig. 2(d)) were high in two periods: from the mid to late 1990s and after 2010. However, the ratio to GDP has been low for about 20 years since 1999, with a downward trend (Fig. 2(e)). The number of deaths caused by floods has been decreasing overall, except for fluctuations in the mid-1990s and in 2010 (Fig. 2(f)). The damaged area and the disaster-affected area did not change significantly between 1980 and 1990 but increased between 1991 and 1998 (Fig. 2(g)). Since 2003, the overall trend has been downward.

Comparing flood protection investment and central and local government expenditure, the turning points of increase and decrease can be identified in the same period. Central and provincial government expenditure increases from 1997 to 2002, then levels off and starts to increase again in 2008. It then levels off again around 2012 (Fig. 2(h)).

In order to compare these figures, the data are shown with adjusted figures in Fig. 3. Economic losses, disaster-affected area, and damaged area show similar trends. The scale of damage was relatively small in the 1980s, increased in the 1990s, and decreased thereafter. The number of fatalities shows an overall decreasing trend from 1980 to 2020, with a similar fluctuation to the economic losses and the disaster-affected area. Flood protection expenditure as a percentage of GDP increased rapidly from 1997, reaching a peak of 0.36% in 2002. After a decline, it increased rapidly again from 2008 and has been stable at a level of over 0.2% since 2012.

Although there is a time lag of several years, the model of the flood protection investment cycle can be applied as investment increases after damage increases. However, further analysis is needed to examine the increase and decrease of investment.

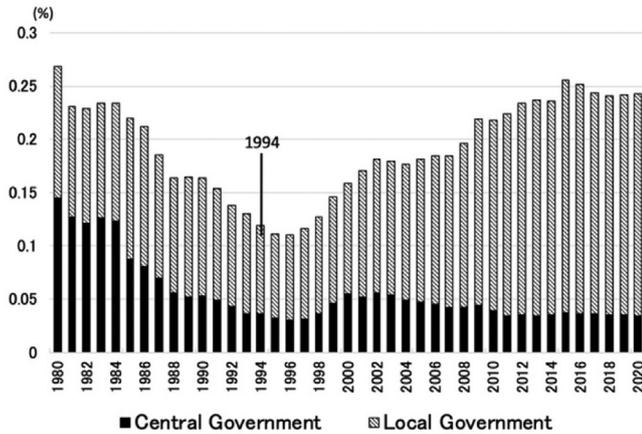


Fig. 2(h). Government expenditure.

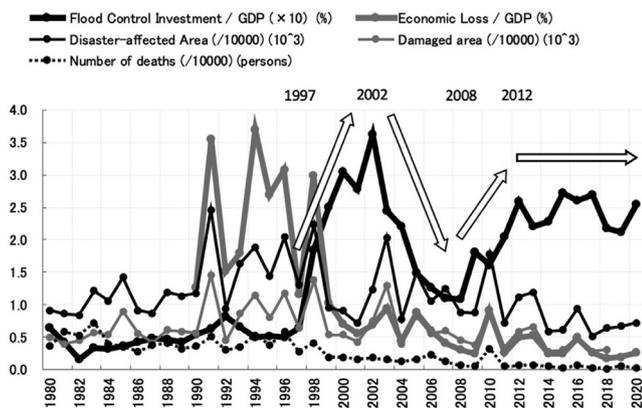


Fig. 3. Investment and flood damages.

4.2. Analysis based on flood protection and investment cycle

This subsection examines the relationship between economic losses and flood protection investments. Fig. 4 shows the relationship between the ratio of flood protection investment to GDP and the ratio of economic losses to GDP. The data for 1990–2020 are divided into the following five periods based on the point of increase and decrease of flood protection investment: (i) 1990–1997, (ii) 1997–2002, (iii) 2002–2008, (iv) 2008–2012, and (v) 2012–2020.

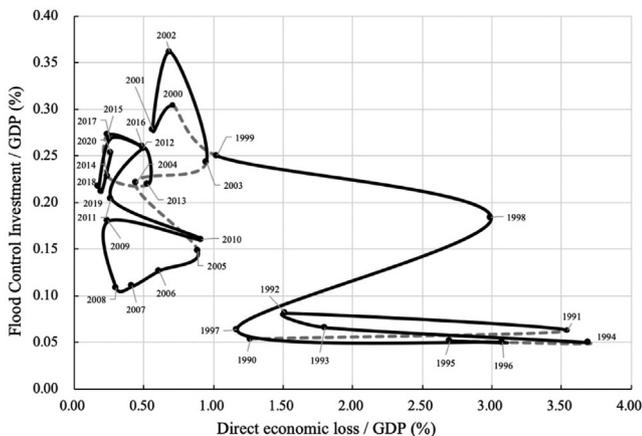


Fig. 4. The relationship between flood protection investment and economic losses: 1990–2020.

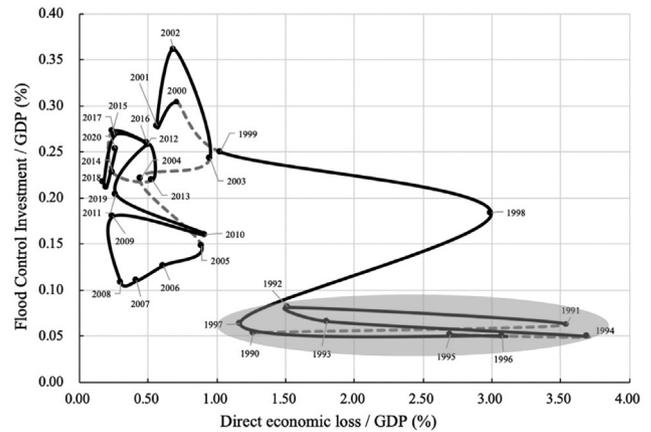


Fig. 5. Flood protection investment and economic losses: 1990–1997.

4.2.1. 1990–1997: low level of investment despite economic losses

During the period 1990–1997, economic losses was high, ranging from 1.3 to 3.7% of GDP, with more than 3% in 1991, 1994 and 1996. On the other hand, investment in flood protection remained below 0.1% of GDP regardless of changes in economic losses. The overall fiscal balance and the ratio of central government expenditure to GDP continued to decline from the 1980s to 1996 (Fig. 5). In 1994, the Chinese government launched a major reform of central-local fiscal relations, replacing the previous revenue-sharing system with a tax-sharing system ("fen-shui-zhi"), ultimately aimed at curbing fiscal decline. The fiscal decline including budgets of flood protection had resulted from the revenue sharing system in place until 1993 [26].

4.2.2. 1997–2002: increased investment, reduced economic loss

Investment in flood protection remained less than 0.1% of GDP until 1997, but increased rapidly from 1998, reaching 0.36% of GDP in 2002. One of the reasons for this is the 1998 Yangtze River Basin Flood, which caused historic damage with an economic loss of about 3% of GDP and a very large area of damage in that year. A series of floods, including the Yangtze flood, caused historic damage. By the end of August 1998, 223 million people were affected, 3004 people died (including 1320 in the Yangtze River basin), 4.97 million houses were destroyed, and economic losses was 166.6 billion RMB, or 23.1 USD [27]. After the flood, investment in flood protection started increasing in the same year to improve DRR capacity. The central government invested 241.1 billion RMB, or 33.3 billion USD in flood protection and soil conservation from 1998 to 2004, of which 160.7 billion RMB, or 22.2 billion USD was invested in flood protection, accounting for 67% of the total investment [28].

The country strengthened its flood protection policy by developing laws and policies, including the "Disaster Mitigation Regulations of PRC (1998–2010)" in 1998 and the "Flood Control Law" in 1998. The government strengthened the prevention of excessive deforestation, which increased flood damage [29]. Another important factor is the improved fiscal situation of the government. The ratio of government revenues to GDP was on a declining trend until the mid-1990s but began to increase after 1997 due to the 1994 fiscal reform. This made it financially possible to increase investment in flood protection (Fig. 6).

4.2.3. 2002–2008: declining investment, low economic loss

Investment in flood protection peaked at 0.36 % of GDP in 2002 and declined to about 0.11% in 2008. Economic losses remained below 1 % since 2000 and decreased further to about 0.3 % in 2008 (Fig. 7). Investment did not increase due to the low level of economic loss. During this period, total central and local government spending as a percentage of GDP was flat, and there was a slight downward trend in central government spending as flood protection investment declined.

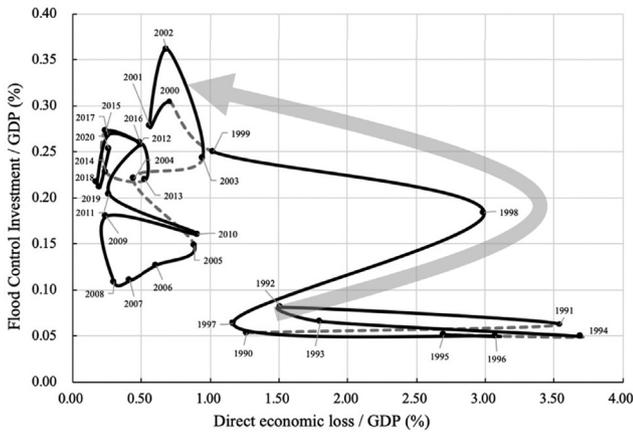


Fig. 6. Flood protection investment and economic losses: 1997–2002.

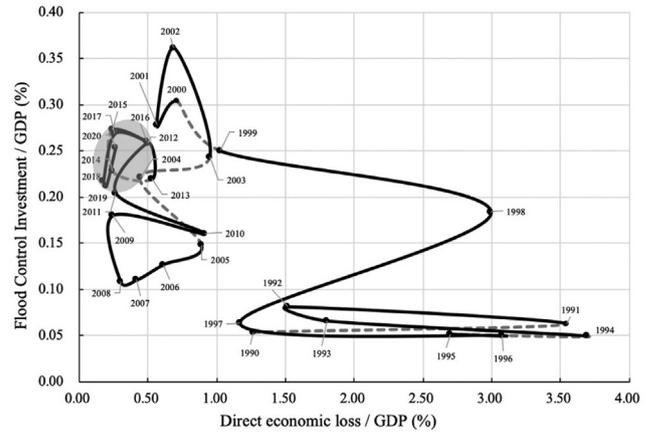


Fig. 9. Flood protection investment and economic loss: 2012–2020.

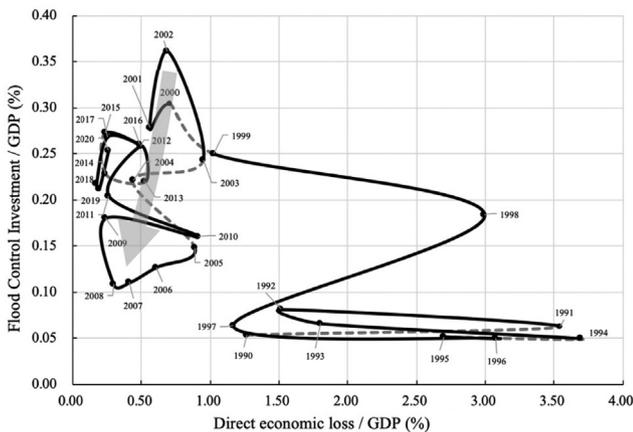


Fig. 7. Flood protection investment and economic loss: 2002–2008.

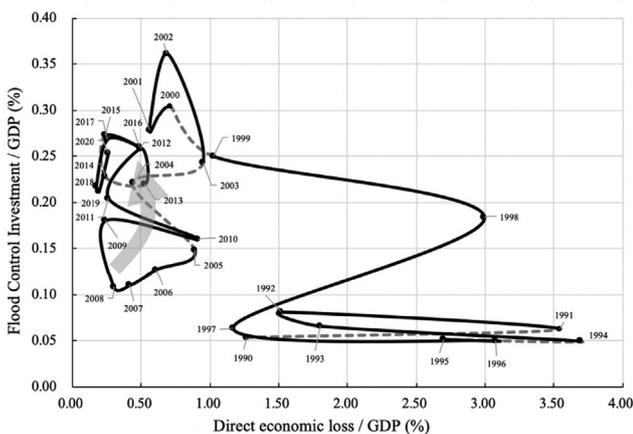


Fig. 8. Flood protection investment and economic losses: 2008–2012.

4.2.4. 2008–2012: increased investment again

Investment in flood protection increased again from 2008, while economic losses remained below 0.9%, lower than in the 1990s (Fig. 8). Several factors drove the increase in investment. The 2008 Wenchuan earthquake, which measured 8.0 on the Richter scale, killed 69,226 people, injured 374,643, and left 17,923 missing [30]. The country designated May 12, the date of the great earthquake, as "Disaster Prevention and Mitigation Day" to raise awareness of disaster risk reduction. The budget increase was supported by financial policies. The government

implemented a fiscal stimulus package of RMB 4 trillion, or 0.55 billion USD in the aftermath of the 2008 global financial crisis.

The year 2011 marked a milestone in flood protection. As the No.1 central document, the Central and State Councils of the Communist Party of China jointly issued the "Decision on Accelerating the Reform and Development of Water Conservancy"[31]. The No.1 Central Document, which is issued annually from December 31 to early January, is the most important policy document of the year. The document set the goal of building flood and drought protection and relief systems by 2020 and improving the flood and drought protection capacity of major cities and regions. The document also set the goal of doubling water resources investment from 2 trillion RMB, 0.23 billion USD, in 2010 to RMB 4 trillion, 0.55 billion USD in the next 10 years (2011–2020).

4.2.5. 2012–2020: maintaining high levels of investment despite low economic loss

During this period, economic losses remain low at 0.18–0.53 % of GDP, while investment remains relatively high at 0.21–0.27 % of GDP (Fig. 9). This is because the No. 1 Central Document of 2011 is effective until 2020. Second, the Xi Jinping administration has prioritized water resources and flood protection. As summarized in the State President's discussion, PRC is currently paying great attention to flood protection [32].

5. Discussion

The analysis of flood protection investment and flood damage in PRC from 1980 to 2020 reveals several key insights into the dynamics of DRR policies and their implementation. PRC has made significant progress in reducing flood damage over the past few decades, with economic losses declining from over 1 % of GDP until 1999 to less than 0.6 % from 2012 onward. This can be attributed to increased investment in flood protection, which rose from less than 0.1 % of GDP until 1997 to over 0.2 % of GDP from 2012 onward. The changes in flood protection investment in PRC have been driven by three main factors: the occurrence of major disasters, the country's fiscal situation, and shifts in government policies and priorities related to DRR (Fig. 10, Table 3).

The study's findings largely support the flood protection investment cycle model proposed by Ishiwatari and Sasaki [13]. The data demonstrates a cyclical pattern in flood protection investments, with periods of increased investment following major flood events, followed by periods of decreased investment as the perceived risk diminishes. The 1998 Yangtze River Basin Flood and the 2008 Wenchuan earthquake both triggered significant policy responses and increases in flood protection investment. These events served as catalysts for the development of new laws, regulations, and investment strategies, demonstrating the reactive nature of DRR policymaking. The country formulated Flood Control Law

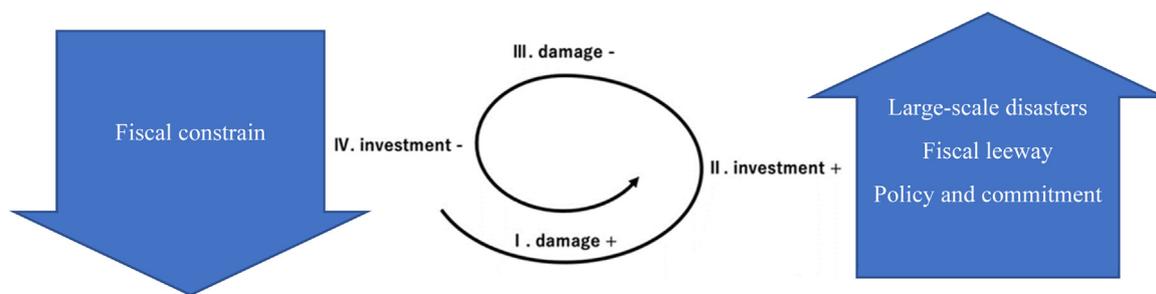


Fig. 10. Factors affecting flood protection investment.

Table 3
Factors affecting investment for each period.

Budget Increase		Budget Decrease
1990–1997		Fiscal income declines before 1994 Low economic losses in the 1980s
1997–2002	Great Yangtze River Basin Flood Economic losses increased in the 1990s Fiscal reform of 1994 Relevant legal and policies	
2002–2008		Flat fiscal situation (a little decrease in the central government) Low economic losses in the 2000s
2008–2012	Frequent floods in 2010 Fiscal policy and increased government expenditure to respond to the 2008 global financial crisis Measures against disasters after the 2008 Wenchuan Earthquake No.1 Central document of 2011	
2012–2020	Leader’s attention for water resources management	

in 1998, and the Central and State Councils of the Communist Party of China issued the influential policy of "Decision on Accelerating the Reform and Development of Water Conservancy" in 2011 [31].

The cycle appears to have some unique characteristics. The research reveals a strong correlation between PRC’s overall economic and fiscal situation and its capacity to invest in flood protection. Investment was limited to less than 0.1 % of GDP until 1997 due to a tight fiscal situation. The fiscal reforms of 1994 and the improved economic conditions in the late 1990s and 2000s enabled increased investment in flood protection to over 0.1 % of GDP from 1998. This underscores the importance of economic stability and fiscal capacity in supporting sustained DRR efforts.

The applied cyclical model can explain factors of not only increasing budgets but also decreasing budgets even under economic growth. This is different from previous studies. The model developed by Zhang et al. [12] can explain only a direction that economic and financial improvement can strengthen flood resilience.

The study highlights the significance of political will and long-term planning in sustaining DRR investments. The inclusion of water resources and flood protection in China’s No. 1 Central Document in 2011, setting a 10-year investment target, demonstrates a commitment to long-term DRR strategies. This approach has allowed for sustained high levels of investment, even in the absence of major flood events. The maintenance of high investment levels since 2012, despite low economic losses from floods, indicates a shift towards more proactive DRR strategies. This approach aligns with global trends in DRR, as outlined in the Sendai Framework, which emphasizes the importance of investing in disaster prevention and mitigation rather than solely focusing on post-disaster response.

While the study primarily focuses on the drivers of investment rather than its outcomes, the decreasing trend in economic losses relative to GDP and the reduction in flood-related fatalities suggest that the increased investments have been effective in reducing flood impacts. The northeast region is stronger resilience to flooding than the southwest region because of higher investment in flood protection as a proportion

of fiscal expenditure [12]. Further research is needed to quantify the direct relationship between investment and damage reduction.

Maintaining adequate investment in flood protection will remain a challenge, as the risks posed by climate change and ongoing economic development activities, such as deforestation, urbanization, and the degradation of wetlands and lakes, are likely to increase the frequency and severity of flood events [33,34]. The government’s plan to improve DRR capabilities following the 2021 flooding in Henan Province underscores the importance of continued efforts in this area [9]. China has broken the cycle of disaster reduction, with low damage and stable investment. However, as climate and social conditions worsen, the damage could increase, requiring more investment and repeating the cycle of investment in flood protection and damage.

PRC’s experience offers valuable lessons for other developing countries facing similar challenges in DRR. The importance of establishing robust funding mechanisms, the need for long-term planning and political commitment, and the benefits of shifting from reactive to proactive DRR strategies are all key takeaways that could inform policymaking in other contexts. However, in applying these lessons to other countries, it is important to keep in mind that China has had high continuous economic growth and fiscal capacity to invest.

This study primarily focused on economic indicators and broad policy changes. Future research could benefit from a more granular analysis of specific flood protection measures implemented, their costs, and their effectiveness. Additionally, investigating the spatial distribution of investments and their impacts across different regions of PRC could provide further insights into the equity and efficiency of flood protection strategies.

6. Conclusion

PRC has successfully reduced the damage caused by floods over the past few decades through increasing investment in flood protection measures. This study demonstrates that while the flood protection investment cycle model provides a useful framework for understanding PRC’s

DRR efforts, the country's unique economic, political, and policy contexts have shaped a distinctive approach to flood protection investment.

In recent years, PRC has maintained a high level of investment in flood protection despite relatively low economic losses as a percentage of GDP. This suggests that the country has established a sustainable financing mechanism for flood protection, supported by strong leadership and legislative frameworks. The commitment to prioritizing flood protection, as exemplified by initiatives such as the 2011 No. 1 Central Document and the continued emphasis by leaders on water resources management, has played a crucial role in sustaining investment. The country was able to move away from a cyclical model in which financial constraints and fluctuating disaster losses led to reduced budgets for flood protection. This is an important lesson for policymakers seeking to establish sustainable budgeting mechanisms for protecting against floods.

PRC's experience demonstrates that reducing flood damage is an achievable goal for developing countries, provided there is a long-term commitment to investment, policy formulation, and the implementation of a comprehensive DRR approach. The shift towards sustained, proactive investment strategies represent a promising development in DRR policy that merits further study and potential emulation in other developing countries. By drawing lessons from PRC's successes and challenges, other nations can better position themselves to mitigate the risks posed by floods and other disasters, safeguarding lives, livelihoods, and economic development.

Relevance to resilience

Investing in infrastructure is crucial for strengthening resilience to natural disasters. This study identifies the key drivers behind flood protection investment changes in the People's Republic of China (PRC) from 1980 to 2020. The analysis shows that the PRC successfully reduced flood damage through increased investment driven by three factors: major disasters, fiscal conditions, and government policy shifts. Investment rose after events like the 1998 Yangtze River flood, while fiscal reforms enabled sustained spending despite initial constraints. The PRC's experience in reducing flood damage through sustained investment and policy commitment provides valuable lessons for other developing countries working to enhance their disaster resilience.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to edit English. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRedit authorship contribution statement

Koji Watanabe: Writing – original draft, Investigation, Formal analysis, Data curation. **Mikio Ishiwatari:** Writing – review & editing, Methodology, Conceptualization. **Daisuke Sasaki:** Supervision, Methodology. **Akiko Sakamoto:** Resources, Funding acquisition. **Mikiyasu Nakayama:** Supervision.

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References

- [1] Chatterjee R, Shiwaku K, Gupta RD, Nakano G, Shaw R. Bangkok to Sendai and beyond: implications for disaster risk reduction in Asia. *Int J Dis Risk Sci* 2015;6(2):177–88.
- [2] Ishiwatari M, Surjan A. Good enough today is not enough tomorrow: challenges of increasing investments in disaster risk reduction and climate change adaptation. *Progr Dis Sci* 2019;1:100007.
- [3] UNISDR Sendai framework for disaster risk reduction 2015–2030. Geneva, Switzerland: UNISDR; 2015 https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.
- [4] Capshaw Kendall M, Padgett Jamie E. A global analysis of coastal flood risk to the petrochemical distribution network in a changing climate. *Resil Cit Struct* 2022;1(3):52–60.
- [5] Fioklou Ameh, Alipour Alice. Probability of failure estimation for highway bridges under combined effects of uncorrelated multiple hazards. *Resil Cit Struct* 2022;1(3):79–93.
- [6] Zhao Bingyu, Tang Yili, Wang Chaofeng, Zhang Shuyang, Soga Kenichi. Evaluating the flooding level impacts on urban metro networks and travel demand: behavioral analyses, agent-based simulation, and large-scale case study. *Resil Cities Struct* 2022;1(3):12–23.
- [7] Huang Guanying, Li Dezhi, Zhou Shenghua, Ng SThomas, Wang Wentao, Wang Lingxiao. Public opinion on smart infrastructure, 93. China: Evidence from social media, Utilities Policy; 2025.
- [8] Disaster investigation team of the state council [Guowuyuan zaihai diaocha zu], the probe result on “7·20” Torrential rain-caused extraordinarily serious natural disaster in Zhengzhou. ministry of emergency management, Henan [Henan zhengzhou “7·20” teda boyu zaihai diaocha baogao], January 2022. <http://www.wujiang.gov.cn/zgwj/c111970/202203/5556e4add95542c29141dbc98b949e4a/files/f042aad0df564f0c991ea574ad515d2a.pdf>
- [9] Henan provincial people's government, national development and reform commission [Henan xing renmin zhengfu, Henan xing renmin zhengfu], master plan for post extremely serious rainstorm and flood disaster recovery and reconstruction of Zhengzhou, Henan [Henan zhengzhou dengdi teda baoyu honglao zaihai zaihou huifu chongjian zongti guihua]. 2022. http://www.gov.cn/xinwen/2022-03/14/content_5678960.htm.
- [10] The national commission for disaster reduction [Guojia jianzai weiyuan hui], the national comprehensive disaster prevention and mitigation Plan 14th Five-year Plan, 2022. https://www.gov.cn/zhengce/zhengcekuo/2022-07/22/content_5702154.htm.
- [11] Guo Zhen, Zeng Fusheng. An assessment of the effectiveness of water conservancy investment in disaster mitigation: an empirical study based on inter-provincial panel data in China [Shuilitouti jianzaxiaoguo pinggu: jiyu zhongguo shengji mianban-shuju de zhizhengyanjiu]. *J Hohai Univ (Philos Soc Sci)* 2014;16(3).
- [12] Huiming Zhang, Jiayun Yang, Lianshui Li, Danyun Shen, Guo Wei, Haroonur Rashid Khan, Sujiang Dong. Measuring the resilience to floods: a comparative analysis of key flood control cities in China. *Int J Dis Risk Red* 2021;59(1):10224.
- [13] Ishiwatari Mikio, Sasaki Daisuke. Investments in flood protection: trends in flood damage and protection in growing asian economies. Japan: JICA Institute: Tokyo; 2021.
- [14] United Nations international decade for natural disaster reduction, united nations general assembly, A/RES/42/169, December 11, 1987.
- [15] The State Council [Guowuyuan], Approval of the establishment of the China national committee for the international decade for natural disaster reduction [Guanyu chengli zhongguo guoji jianzai shinian weiyuanhui de pifu], 1989. https://www.gov.cn/zhengce/content/2011/03/24/content_8025.htm
- [16] CCIDNDR, The China disaster reduction plan (1998-2010) [Zhonghua renmin gongheguo jianzai gui hua (1998-2010)], 1998.
- [17] Wei Ding, et al. A review of flood risk in china during 1950–2019: urbanization, socioeconomic impact trends and flood risk management. *Water* 2022;14(20).
- [18] Zhou Y, Li N, Wu W, et al. Socioeconomic development and the impact of natural disasters: some empirical evidences from China. *Nat Hazards* 2014;74:541–54. doi:10.1007/s11069-014-1198-0.
- [19] Jia Huicong, et al. Flood risk management in the Yangtze River basin —comparison of 1998 and 2020 events. *Int J Dis Risk Red* 2022;68:102724.
- [20] Huang Guanying, Li Dezhi, Zhu Xiongwei, Zhu Jin. Influencing factors and their influencing mechanisms on urban resilience in China. *Sustain Cities Soc* 2021;74:103210.
- [21] Wang, Yahua., Strategic implication of the new stage of China's water conservancy development [Zhongguo Shuili Fazhan Jinzhan Jinru Xin Jieduan Ji Qi Zhanlv Hanyi], water resources development research [Shuili Fazhan Yanjiu]. Vol. 22, No. 2, pp. 40–44. 2022.
- [22] Du, Rongjiang., Analysis of relationship between water conservancy investment situation and national economy [Woguo Shuili Touzi Zhuangkuang Yu Guomin Jingji Guanxi Fenxi], advances in science and technology of water resources [Shuili Shuidian Keji Jinzhan]. Vol. 28, No. 6, 2008.
- [23] Ishiwatari, Mikio., Sasaki, Daisuke., Disaster risk reduction funding: investment cycle for flood protection in Japan. *Int J Environ Res Public Health*. Vol. 19, No. 6, 3346, 11. <https://doi.org/10.3390/ijerph19063346>.
- [24] Ministry of Water Resources., China water statistical yearbook. China Water Power Press, Annually
- [25] National Bureau of Statistics of China, China statistical yearbook, annually, China Statistics Press. <https://www.stats.gov.cn/english/Statisticaldata/yearbook/>
- [26] Zhang Le-Yin. Chinese central-provincial fiscal relationships, budgetary decline and the impact of the 1994 fiscal reform: an evaluation. *China Q* 1999;157:115–41.
- [27] Report on the current national flood fighting and rescue situation [Guanyu dangqian

- quanguo kanghong qiangxian qingkuang de baogao], the People's Daily [Renmin ribao], 1998.
- [28] Wang Yahua. Research on the development stage of water resources in china [Zhongguo shuili fazhan jieduan yanjiu]. Tsinghua University Press; 2013. p. 57.
- [29] Sen Wang, Cornelis G, van Kooten Bill, Wilson. Mosaic of reform: forest policy in post-1978 China. *For Policy Econ* 2004;6(1):71–83.
- [30] The central people's government of the People's Republic of China, Sichuan Wenchuan earthquake, 69,226 Dead, 17,923 Missing, China News Service (CNS), 2008. <https://www.chinanews.com.cn/gn/news/2008/08-21/1356471.shtml>.
- [31] The CPC central and the state council, decision on accelerating water conservancy reform and development [Zhonggong Zhongyang Guowuyuan Guanyu Jiakuai Shuili Gaige Fazhan De Jueding], 2010. http://www.lswz.gov.cn/html/zmhd/wmfw/2018-06/14/content_234975.shtml.
- [32] Ministry of Water Resources editor (Shuili-bu zuzhi ed), in-depth study and implementation of Xi Jinping's important exposition on water control [Shenru xuexi Guanche xijinping guanyu zhishui de zhongyao lunshu]. People's Publishing House [Renmin chuban she]; 2023.
- [33] ZW, Kundzewicz., Su, Buda., Wang, Yanjun., Xia, Jun., Huang, Jinlong., Jiang, Tong., Flood risk and its reduction in China. *Adv Water Resour*, Vol. 130, pp. 37–45.
- [34] Jiang R, Lu H, Yang K, et al. Substantial increase in future fluvial flood risk projected in China's major urban agglomerations. *Commun Earth Environ* 2023;4(389).