

Article

## Flood Prevention Strategies in China: A Review of Policies, Technologies, and Practices

Hassan Raza\*

Department of Earth Sciences, Quaid-i-Azam University, Islamabad, Pakistan

\* Correspondence: [h.razadokota@gmail.com](mailto:h.razadokota@gmail.com)

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**Abstract:** Flooding remains a persistent challenge in China, attributed to its diverse geography, rapid development, and changing climatic conditions. This article offers a comprehensive account of China's flood prevention strategies, highlighting both infrastructural measures, such as dams and urban drainage systems, and non-structural strategies, including early warning systems, land use planning, wetland restoration, and community preparedness. The discussion extends to national policies, such as the Flood Control Act and the Sponge City Initiative, along with localised governance efforts that have enhanced China's ability to manage flood risks effectively. Despite these initiatives, challenges persist due to climate change, socio-economic disparities, and the increasing occurrence of extreme weather events. Rising sea levels, intensified rainfall, and accelerated urban growth exacerbate vulnerabilities, thereby necessitating sustainable and adaptive strategies. The paper underscores the importance of integrating green infrastructure, promoting inclusive governance, and fostering international collaboration to achieve long-term flood resilience. By analyzing China's successes, limitations, and future directions, this review provides valuable insights for flood-prone regions globally, emphasising the need for a holistic and adaptive approach to flood management.

**Keywords:** flood management; China; climate change adaptation; sponge city initiative; disaster risk reduction

## 1. Introduction

China experiences frequent flooding due to its varied geography, rapid urbanisation, and climatic conditions. Covering extensive land areas and diverse topographies, China encounters regular flooding events that impact lives and lead to economic and environmental consequences. As a nation prone to floods, China has developed and improved its flood management practices over time [1].

The Yangtze and Yellow Rivers are often termed as the lifelines of China. These rivers have been the centre point for the development of the country for centuries. But, these rivers are also causing substantial risks of floods. Alongside these water bodies, there have been big losses of life as well as economy due to floods, and it has caused the displacement of many communities. For example, in 1931, a flood in the Yangtze River was considered one of the most fatal natural calamities in history, claiming millions of lives [2]. Recently, such as in 1998 and 2020, floods have brought to light the ongoing vulnerability of China to such dangerous hydrological events. The relationship of natural factors, like monsoons and typhoons, with human-caused effects, including urbanisation and deforestation, has worsened flood risks in recent years [3].

In response to these problems, China has adopted a comprehensive and multi-faceted flood avoidance and management methodology. Traditionally, flood control attempts have concentrated on structural measures, like dams, reservoirs, embankments, and drainage systems. The Three Gorges Dam is an iconic project that exemplifies the large-scale engineering capabilities of China and its dependence on infrastructure to counter flood risks [4]. Although such measures have certainly slashed the intensity of many flood events, they have also initiated arguments over their social and environmental effects, including ecosystem disorder and population dislocation [5].

Acknowledging the restrictions of only structural measures, China has gradually implemented non-structural approaches to improve its flood management attempts. These involve the usage of advanced forecasting systems, planning for efficient land utilisation, ecosystem restoration, and community-driven disaster alertness programs. Technical innovations, such as the incorporation of Geographic Information Systems (GIS), artificial intelligence (AI), and big data analytics, have

fostered the capability of China to forecast, monitor, and manage floods more successfully [6]. These advancements permit real-time flood observation and more precise threat calculations, supporting more well-timed and effective responses.

Proper planning and control have also played essential roles in modelling the flood prevention framework of China. In this regard People's Republic of China has set up some regulations and National-level flood control plans, such as "the Flood Control Law of the (1997)", which provide a vigorous regulatory basis for flood management attempts [7]. Regional and local programs, international collaborations, and public-private partnerships have further reinforced China's capacity to tackle complicated challenges arising with flood management.

Regardless of these advancements, substantial challenges persist. Climate change, leading to rising sea levels and increased variability of rainfall, has increased overflow risks in recent times [8]. Fast expansion of urban centres, together with socio-economic differences, has established extra obstacles for applying efficient flood prevention measures. Complementary financial development with durable flood management has become a critical matter for officials and experts alike [9].

This review objects to specify a thorough overview of flood prevention policies in China, concentrating on both structural and non-structural attempts, scientific improvements, and policy regulations. By examining case studies and lessons learned, this paper seeks to highlight the successes, limitations, and future directions of China's flood management efforts. Understanding China's strategies and experiences can offer valuable insights for other flood-prone regions around the world, emphasizing the importance of a holistic and adaptive approach to flood prevention.

## 2. Background

### 2.1 History and Impacts of Floods in China

The history of China is deeply connected with its rivers, which have been both a source of life as well as a challenge to the nation due to their flooding and overflow at times. The Yangtze and the Yellow Rivers have been fundamental for agricultural prosperity and civilisation for thousands of years. Yet, these rivers

have also been the cause of some of the most destructive and disastrous floods in human history [10].

In China, one of the first recorded floods dates back to 2,000 BCE, a period linked with the fictitious "Great Flood" tale, when widespread flooding supposedly led to the advancement of flood control systems by the renowned figure "Yu the Great". While this account remains partially mythological, it reflects China's long-standing battle with flood-related disasters [11].

Historically, floods in China have caused widespread devastation. The infamous 1931 Yangtze River flood resulted in an estimated 3.7 million deaths, making it one of the deadliest natural disasters ever recorded. The flood submerged vast areas, disrupted transportation networks, and caused famine and disease. More recently, the 1998 Yangtze River flood, triggered by excessive rainfall, displaced millions, damaged infrastructure, and caused significant economic losses amounting to \$20 billion [12].

Flooding in China is influenced by both natural and human factors. The annual summer monsoon season brings heavy rainfall, particularly in southern and central regions, while typhoons exacerbate coastal flooding. Human-induced factors, such as deforestation, urbanization, and agricultural expansion, have worsened the problem by reducing the natural capacity of ecosystems to absorb excess water. Recurring flooding incidents have severely impacted the economy, infrastructure, and communities in China, highlighting the urgent need for viable flood management systems [13].

## 2.2 Overview of China's Flood Management Framework

China has formulated a massive flood control and management framework, combining historical examples with modern developments. This framework joins structural measures with non-structural methodologies to decrease flood risks and minimise damage [6].

### Structural Measures:

Historically, China has focused on large-scale infrastructure projects to manage floods. The Three Gorges Dam on the Yangtze River, the world's largest

hydroelectric dam, exemplifies China's reliance on engineering solutions to regulate water flow, generate hydroelectric power, and mitigate floods [14]. Similarly, levees, embankments, and flood diversion channels protect urban and agricultural areas, while reservoirs, such as the Danjiangkou Reservoir, store excess water and reduce downstream flooding. Despite their effectiveness, these measures have sparked debates over ecological disruptions, sedimentation issues, and the displacement of local communities [15].

**Non-Structural Measures:** Recognizing the limitations of structural solutions,

China has increasingly adopted non-structural measures, including:

**Early Warning Systems:** Advanced meteorological and hydrological monitoring systems provide timely flood forecasts and warnings, enhancing disaster preparedness [9].

**Land Use Planning:** Flood-prone areas are designated as no-build zones or repurposed for agriculture to mitigate risks. Urban planning initiatives, such as "sponge cities," integrate green infrastructure to absorb and store rainwater.

**Community Preparedness:** Public education campaigns and disaster response drills have empowered communities to respond effectively to flood events [11].

China's flood management policies are centralised, with the central government playing a leading role in decision-making and resource allocation. The Ministry of Water Resources oversees water-related issues, including flood prevention, while provincial and local governments implement region-specific measures. "The Flood Control Law of 1997" created a legal framework for flood risk control and management, while recurring Five-Year Plans set targets for infrastructure improvement and catastrophe risk decline [12].

Contemporary flood control in China heavily depends on advanced techniques and engineering innovations. Geographic Information Systems (GIS), Remote sensing, and Big Data analytics are extensively used to monitor river basins, predict flooding, and plan mitigation strategies [13]. Artificial intelligence also improves flood prediction

systems, assisting in faster and more precise responses. For example, AI models can investigate extensive datasets to forecast rainfall patterns and flood possibilities, helping in resource distribution and emergency planning [14].

The flood management framework of China reveals an active approach to minimising the effects of floods. By merging conventional engineering solutions with advanced technology and sustainable practices, the country has substantially decreased its liability to floods. Nevertheless, challenges like climate change, rapid urbanisation, and resource restraints still endure, highlighting the necessity for adaptive and progressive policies. Attempts to balance environmental sustainability with economic growth will be central in shaping the future of flood control in China.

### 3. Structural Flood Prevention Strategies

Structural flood prevention approaches are significant components of China's attempts to control and reduce the risks of floods. These approaches include the building of infrastructure planned to control, redirect, and store surplus water, in this manner reducing the effects of heavy flooding on populations and the environment.

#### 3.1 Dams and Reservoirs

##### The Three Gorges Dam

The Three Gorges Dam, constructed on the Yangtze River, is one of the most magnificent and meaningful flood prevention projects in the world. It was completed in 2012 and was designed to control the gigantic water streams of the Yangtze, which historically have caused serious flooding downstream. The dam helps to control water levels by storing excess water during the rainy season and gradually releasing it, thereby reducing flood peaks and protecting downstream regions, including the industrial hub of Wuhan.

##### Benefits:

Significantly reduces the frequency and severity of flooding downstream.

Generates hydroelectric power, contributing to China's energy needs.

Improves navigation on the Yangtze River, boosting trade and connectivity [16].

##### Controversies:

Displacement of over 1.3 million people.

Loss of biodiversity and ecosystem disruption in the surrounding areas.

Increased seismic risks due to changes in land pressure and hydrology [17].

##### Other Dams and Reservoirs

Other large-scale projects, such as the Xiaolangdi Dam on the Yellow River, play crucial roles in flood control and water regulation. Numerous smaller reservoirs and multipurpose dams across China support regional water management needs, providing a vital buffer against extreme weather events [18].

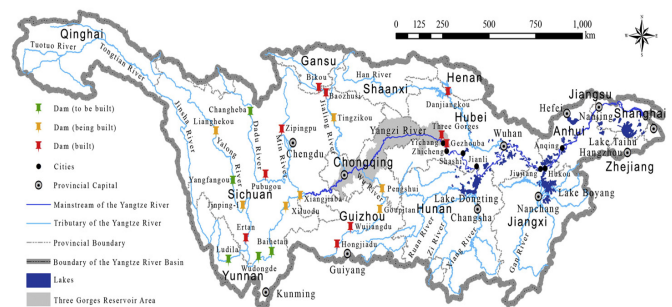


Figure 1. Map of Yangtze River and its tributaries

#### 3.2 Urban Drainage Systems and Levees

##### Urban Drainage Systems

Rapid urbanization in China has made effective urban flood management systems increasingly critical. Cities are particularly vulnerable to flooding due to the high concentration of impervious surfaces, which prevent water absorption and increase runoff.

##### Sponge Cities:

Cities like Shenzhen and Wuhan have implemented "sponge city" initiatives that integrate green infrastructure, such as permeable pavements, green roofs, and rain gardens, to absorb and store rainwater.

These systems reduce reliance on conventional drainage networks, mitigate flooding, and improve water quality .

### **Levees and Embankments**

Levees and embankments provide critical protection along major rivers like the Yangtze and Yellow Rivers. These physical barriers prevent overflow and protect urban and agricultural areas during high water levels.

#### **Challenges:**

Aging infrastructure and sediment buildup have led to occasional levee failures.

Maintenance and reinforcement projects are necessary to ensure long-term reliability [19].

### **3.3 Diversion Channels and Flood Storage Areas**

#### **Diversion Channels**

Flood diversion channels redirect floodwaters away from vulnerable areas, such as urban centers or critical infrastructure. For example, the Jingjiang Flood Diversion Project channels water from the Yangtze River into designated lower-risk regions, effectively reducing downstream flood risks [20].

#### **Flood Storage Areas**

Flood storage areas, also known as detention basins, are low-lying lands or wetlands designated to temporarily hold excess water during flood events. Dongting Lake and Poyang Lake act as natural flood basins, absorbing excess water from the Yangtze River during heavy rainfall. Restored wetlands and protected floodplains in these areas enhance ecological functionality, improve biodiversity, and maintain water quality [21].

China's structural flood prevention strategies, encompassing dams, urban drainage systems, levees, diversion channels, and flood storage areas, have significantly reduced the frequency and severity of flood events. These measures have effectively protected lives and property, particularly in flood-prone regions. However, they are not without limitations, such as ecological degradation,

community displacement, and the need for ongoing maintenance.

To enhance flood resilience in the face of climate change and rapid urbanisation, China must integrate structural solutions with sustainable, non-structural approaches. Modifying infrastructure, including green solutions like sponge cities, and focusing on environmental effects, will be critical in formulating the next phase of China's flood prevention efforts.

### **4. Non-Structural Flood Prevention Strategies**

Non-structural flood prevention strategies include minimising flood possibilities via active planning, accurate prediction, and community involvement. These approaches put emphasis on preparedness, prevention, and sustainability, accompanying structural measures to build a comprehensive flood management strategies.

#### **4.1 Early Warning Systems and Risk Forecasting**

Well-timed and precise flood prediction is critical for decreasing the impacts of floods. China has developed innovative early warning systems and risk evaluation frameworks to look after and forecast flood events efficiently.

#### **Technological Integration**

The early warning systems of China use a combination of weather-related data, hydrological models, and advanced techniques to identify possible flood events. The National Meteorological Center and the Ministry of Water Resources work together to issue real-time warnings, letting local governments and communities get ready for forthcoming floods [22].

#### **Advanced Monitoring Tools:**

Satellite-based remote sensing, Geographic Information Systems (GIS), and radar technologies are extensively used to monitor weather patterns and river levels. Artificial Intelligence (AI) and Big Data analytics have further enhanced the accuracy and efficiency of these systems [23]. Predictive models, particularly for the Yangtze and Yellow Rivers, incorporate historical data, rainfall patterns, and topographical information to assess vulnerabilities.



### **Challenges:**

Despite advancements, gaps remain in forecasting extreme weather events caused by climate change. Further integration of localized data, such as community-level rainfall measurements, is necessary to improve forecasting precision .

### **4.2 Land Use Planning and Wetland Restoration**

Proper land use planning and ecological restoration play a crucial role in reducing flood risks while promoting environmental sustainability.

#### **Zoning and Urban Planning:**

Flood-prone areas are often zoned for specific uses, such as agriculture or conservation, to minimize risks to human settlements and infrastructure. Urban planning in China increasingly integrates flood risk assessments, ensuring that critical facilities and dense populations are not located in high-risk zones [24].

#### **Sponge City Initiative:**

Cities like Wuhan and Shenzhen have pioneered the "sponge city" initiative. This approach incorporates permeable surfaces, green spaces, and rainwater harvesting systems to mitigate urban flooding. By absorbing and storing rainwater, sponge cities reduce surface runoff and enhance resilience to heavy rainfall .

#### **Wetland Restoration:**

Wetlands act as natural sponges, absorbing excess water and reducing downstream flood risks. China has recognized their importance in flood prevention, with efforts to restore and protect wetlands playing a key role in national strategies.

**Dongting Lake and Poyang Lake:** Natural floodplains along the Yangtze River serve as critical flood storage basins. Restoration efforts, such as reducing agricultural encroachment and halting industrial pollution, have enhanced their flood absorption capacity [25].

#### **Additional Benefits:**

Wetlands not only mitigate flooding but also improve water quality, support biodiversity, and provide livelihoods for local communities.

### **4.3 Community Disaster Preparedness**

Community-based approaches are essential to reducing the social and economic impacts of floods. Empowering local populations with knowledge and resources enhances resilience and recovery.

#### **Public Awareness and Education:**

Public awareness campaigns inform communities about flood risks and safety measures. Schools and community centres serve as hubs for disaster preparedness training, including evacuation drills and first aid [26].

#### **Flood Response Planning:**

Local governments and community organisations collaborate to develop tailored flood response plans. These plans outline evacuation routes, shelter locations, and emergency communication systems. Participating attempts confirm that community representatives are actively engaged in decision-making, improving the effectiveness of these plans [27].

#### **Real-Time Communication:**

Social media platforms and mobile applications have become significant tools for circulating real-time flood warnings and safety information. Government-established apps give specified information, guiding people on evacuation methods and safe areas [28].

### **5. Technological and Policy Innovations**

Technological progress and modernisation of policies have drastically reinforced China's capacity to manage and control floods. The combination of modern inventions such as Artificial Intelligence (AI), Geographic Information Systems (GIS), and Big Data, together with strong national policies and governance, has boosted the effectiveness and usefulness of flood control tactics.

#### **5.1 Role of GIS, AI, and Big Data in Flood Management**

High-tech innovations have revolutionised dealing with natural disasters like flood by permitting better prediction, risk estimation, and real-time reaction. GIS technology performs a key role in mapping and analysing areas which are affected or may be affected by floods. By incorporating hydrological data with geographical and infrastructural information, GIS is employed to detect high-risk regions and vulnerable communities. It may help in planning evacuation routes and allocating emergency resources efficiently. It may also help in monitoring floodplain shifts over time to evaluate the effect of urbanisation and climate change. Moreover, it supports land usage planning and zoning to minimise flood exposure risks [23].

AI has transformed flood prediction and decision-making by investigating massive datasets swiftly and precisely. AI helps in processing historical data and real-time weather shifts to forecast the location, time, and severity of rains and resulting floods. Machine learning models estimate flood liability by factorisation of population density, environmental conditions, and infrastructure. AI-powered systems preset flood alerts and trigger pre-planned relief measures, like shutting floodgates or initiating pumps [22].

Big Data facilitates thorough analysis of information from miscellaneous sources, including satellites, weather stations, and social media. It helps in real-time monitoring of water levels, rainfall, and river flows. It also facilitates analysis of historical flood patterns to advance risk predictions. Furthermore, it uses population data from local communities to enhance situational awareness and supports post-calamity rescue by measuring damage and prioritising resources. GIS, coupled with AI and Big Data, permits policymakers and disaster management authorities to respond to floods efficiently, minimising casualties and financial losses.

## 5.2 National Policies and Local Governance

The flood control and management system of China is governed by a combination of proper and centralised planning, national policies, and localised implementation. These attempts make certain harmonised action across all levels of government and address the exceptional challenges due to natural calamities.

Important national policies for flood mitigation and management include Flood Control Act of 1997,

five-year plans, climate adaptation strategies, and sponge city initiatives.

The Flood Control Act of 1997 establishes guidelines for flood risk management, covering river basin management, infrastructure development, and emergency response practices. China's Five-Year Plans regularly highlight water resource management and flood prevention, promoting durable and unified strategies [29]. Contemporary policies address the effects of climate change, comprising rising sea levels and rainfall variability, by advocating green infrastructure and improving ecosystem resilience [25].

Sponge City Initiative, launched in 2015, incorporates flood control with urban planning by promoting absorbing surfaces, green roofs, and natural water retaining systems in urban areas.

Local governments perform a basic role in executing area-specific measures designed to their geographical and socio-economic circumstances. Responsibilities of the local government include developing and maintaining local flood infrastructure, such as levees and drainage systems, conducting risk assessments and zoning flood-prone areas. They are also responsible for organising community preparedness programs and training local emergency response teams. Moreover, managing water resources to balance flood control, irrigation, and ecological needs is also their duty [26].

Cooperation between public and private units has become a necessary element of China's flood management tactics. Private firms contribute to hi-tech innovation, infrastructure development, and financing, while government agencies ensure regulatory fulfilment and equitable implementation [30].

## 5.3 Challenges in Policy and Governance

Despite significant progress in formulating governmental policies, there are still several challenges that need to be addressed. Rapidly growing urban areas and infrastructure expansion often compete with flood control measures, particularly in compactly populated areas. Efficient flood management needs seamless harmonisation between national, provincial, and local authorities,

which can be difficult given China's vast and diverse geography. Making sure that exposed populations and under-resourced areas receive satisfactory protection and support remains a pressing concern [29].

## 6. Challenges and Future Directions

Substantial efforts in flood control and management in China have resulted in positive outcomes, but still challenges are remaining due to the variability and vulnerability of environmental, social, and economic factors. Growing effects of climate change, socio-economic differences, and the call for sustainable and adaptive plans require sustained innovation and policy progression.

### 6.1 Climate Change and Increasing Risks

Climate change is a big and growing concern for flood management. It can amplify the frequency and severity of extreme weather events leading to devastating floods. Rising global temperatures have exaggerated rainfall patterns, leading to longer monsoon seasons and an upsurge in typhoon activity, predominantly in coastal regions. This worsens the problem of urban flooding as cities fight to control the unprecedented stormwater volumes [21].

Melting glaciers in western regions of China contribute to increasing water levels in major rivers, and intensifying flood risks. Coastal areas, such as the Pearl River Delta and Shanghai, face dual threats from storm surges and sea-level rise, risking densely populated and economically significant areas [22].

Addressing climate-induced risks requires the integration of adaptive measures into flood management frameworks. Enhanced forecasting capabilities, incorporating localized data and advanced technologies, are critical for anticipating and mitigating extreme events [23].

### 6.2 Socio-Economic Barriers to Implementation

Several socio-economic barriers hinder the effective implementation of flood prevention strategies. Urban expansion has outpaced infrastructure development, leaving many cities vulnerable to flash floods. Informal settlements often lack adequate drainage systems, disproportionately exposing marginalized communities to flood risks [24].

Urban areas benefit from large-scale projects and technological advancements, while rural regions rely on outdated infrastructure and receive limited funding. This imbalance increases vulnerability in under-resourced areas [25]. Maintaining and modernizing flood prevention systems is expensive. Balancing these investments with other developmental priorities, such as industrial or agricultural expansion, creates significant tensions. Expanding infrastructure often conflicts with ecological preservation, particularly in regions where wetland restoration or natural floodplain management is essential [26].

### 6.3 Recommendations for Sustainable Flood Prevention

Addressing these challenges requires sustainable and integrated flood prevention strategies. Expanding green infrastructure, such as the Sponge City Initiative, which promotes permeable surfaces, natural water retention, and ecosystem restoration is a good initiative. Likewise, restoring wetlands and protecting natural floodplains to mitigate risks while improving biodiversity and water quality is also necessary [27]. Enhancing forecasting technologies using AI, GIS, and Big Data for accurate and localized predictions, empowering communities to respond effectively is the need of the hour [28]. It also needs prioritizing vulnerable populations in flood prevention policies to ensure equitable protection and funding and engaging local communities in disaster planning and preparedness efforts to build resilience at the grassroots level. Another important step is encouraging public-private partnerships to mobilize resources and drive innovation for economically viable and socially inclusive solutions [29].

Flood control and management should be coupled with comprehensive urban planning, water resource management, and climate change control policies with executing adaptive strategies that develop in response to emergent risks and technological advancements. It also needs getting international collaboration and knowledge-sharing to adopt global best practices in flood management [30].

## 7. Conclusions

China has made some serious and commendable efforts to prevent and control floods by giving valuable insights into the complications of addressing an insistent and evolving challenge. Over the past



decades, the country has implemented a multifaceted strategy, coupling structural measures like dams, reservoirs, levees, and drainage systems with non-structural approaches like early warning systems, land usage planning, and wetland restoration. Technical and Scientific innovations, including GIS, AI, and Big Data, have fine-tuned the country's capability to monitor, forecast, and control flood risks. National policies and efficient local governments make sure that a coordinated action is taken such natural calamities across regions.

Along with these significant advancements, there are also some challenges that should be addressed. Rapid urbanisation, and climate change are challenges that continue to pose significant risks. Elevating sea levels, varying rainfall patterns, and the increasing intensity of extreme weather condition demand flexible and durable strategies. Improving economic situation of public, especially the differences between urban and rural areas, is crucial to making sure equitable safety and resource allocation. Additionally, balancing economic development with environmental protection remains a matter of grave concern.

Looking forward, combining green infrastructure, comprehensive and efficient governance, and international cooperation will be major factor to improve China's flood management. Consolidating involvement of local communities and encouraging public-private partnerships can better organise resources and improve innovation to address emergent flood risks. By implementing an all-inclusive and adaptive strategy for flood control and management, China can not only protect its population and economy but also sets an example of efficient and sustainable practices for other countries. In this era climate vulnerability, every country needs to follow these foot steps.

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