

## Research Article

# Study on the Impact of High-Quality Economic Development and Flood Resilience on Flood Damage in the Yangtze River basin: Evidence from Provincial Administrative Regions in the Yangtze River Basin

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Received 15 April 2022; Accepted 23 August 2022; Published 27 September 2022

Academic Editor: Atila Bueno

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China's economic development has shifted from a high-speed growth stage to a high-quality development stage, which promotes the sustainable economic development of the Yangtze River (YR) and also improves the response capacity of the YR basin's resilience system to floods. Flood resilience (FR) is not only just the achievement of high-quality economic development (HQED) but also the key to mitigating flood damage (FD). Therefore, based on panel data from 2000 to 2019 from provincial administrative regions (PARs) in the Yangtze River basin (YRb), the entropy weight method and the quantitative regression analysis method were used to empirically investigate the impact of HQED and FR on FD in the YRb. The empirical analysis results show the following. (i) HQED has an inverted U-shaped effect on FD in the YRb, meaning that HQED will reach a certain point and reduce flood losses. (ii) The HQED model, which has been pushed forward, will significantly improve the level of FR. Various mediating effect test methods revealed that FR has a significant negative mediating effect on the process of HQED to mitigate FD. Taken together, this reveals the importance of insisting on implementing an HQED model to mitigate FD in the YRb, gradually deriving an FR that is adapted to floods and has a high self-organizing and self-restoring capacity through high-quality development.

## 1. Introduction

The Yangtze River basin (YRb) crosses three large economic zones in southwest, central, and eastern China. The main-stream flows through 11 provincial administrative regions (PARs), including Qinghai, Tibet, Yunnan, Sichuan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Shanghai, which merges into the East Sea in Shanghai, and the tributaries flow through 8 PARs, including Gansu, Shaanxi, Henan, Guizhou, Guangxi, Guangdong, Fujian, and Zhejiang (see Figure 1). The YRb has superior natural conditions, concentrated urban areas, a dense population, a developed economy, and high industrial and agricultural output values [1]. As of the end of 2019, the catchment area of the YRb is about 1.8 million km<sup>2</sup>, involving 454 counties,

with a regional GDP of CNY 57.08 trillion, accounting for 57.93% of the national GDP, a grain output of 343.27 million tons, and a total water resource of 1054.26 billion m<sup>3</sup> [2]. Therefore, once a large-scale flood disaster occurs, it will have a huge impact on national economic and social development. In terms of topography and hydro-climatic characteristics, the YRb has various landform types such as plateaus, mountains, hills, basins, and plains. The geographical environment determines its distinctive East Asian subtropical climate, characterized by abundant rainfall [1]. According to statistics of the measured data for many years, the annual average precipitation of the YRb is 1100 mm, which concentrates 32% of the total precipitation in China and is prone to floods [1]. Especially in recent decades, high-intensity human development behavior has weakened the



FIGURE 1: Overview map of YRb.

flood storage and environmental purifying functions of the YRb and intensified the threat of floods [3]. It is recorded that the 1990s was a decade of frequent floods in the YRb following the 1950s [4], and the economic losses were multiplied for the same flooded area due to the growth of the economic aggregate. As can be seen from the flood damage (FD) statistics from 1978 to 2019 in Figure 2, in addition to the obvious decreasing trend in the number of flood deaths, floods in the YRb have also led to increased direct economic losses with large interannual differences, among which the direct economic losses in 1998, 2010, 2013, and 2016 were more than CNY 200 billion. During the time period of the FD statistics, although the annual change curves of the affected population and crop area were basically inverted U-shaped, they did not show a significant slowing trend until after 2010. As a result, while the YRb is booming, the flood has gradually become one of the serious natural disasters, threatening public safety in the YRb. In the future development period, further studies on the causes of floods and flood management in the YRb will become important tasks to ensure the sustainable development of the YRb.

To perform flood management, it is necessary to analyze the causes of floods. The causes of floods have been initially attributed to natural factors [5–7]. However, the basin-wide flood in the YRb in 1998 has stimulated scholars to pay attention to the formation mechanism behind natural disasters and clarified that economic and social factors also influence the frequency of natural disasters, as well as the scope and extent of disaster loss [8–10]. Liu [11] and Chen

and Yang [12] used causation analysis to analyze the impact of human activities on floods in the YRb and concluded that the threat of floods is exacerbated by human extensive production and living behaviors. Existing studies have tended to attribute the causes of floods in the YRb to a combination of natural and anthropogenic factors [13–15], while also revealing the driving effect of urbanization, one of the results of economic and social development, on urban flood risk [16, 17]. In general, existing studies have shown that there is a causal relationship between economic development and floods, and the research of disaster science has shifted from natural science research to multidisciplinary research that encompasses both natural and social sciences. Existing studies provide useful references for this study to identify the influencing factors of FD in the YRb, but the earlier studies seldom analyzed equally important FD influencing factors such as urban planning, administrative ability, and emergency disposal mechanisms, and the mitigation measures proposed basically focused on how to protect the ecological environment and increase flood control engineering facilities. After a long-term effort, China has entered a high-quality economic development (HQED) stage. HQED is an efficient, equitable, and green sustainable development that adheres to the new development concept of “innovation, coordination, openness, green, and sharing (ICOGS)” and aims to meet people’s ever-increasing needs for a better life [18]. Chen and Chen [19] argued that HQED is accompanied by the improvement of the environment and government governance capacity. Then, what impact will the

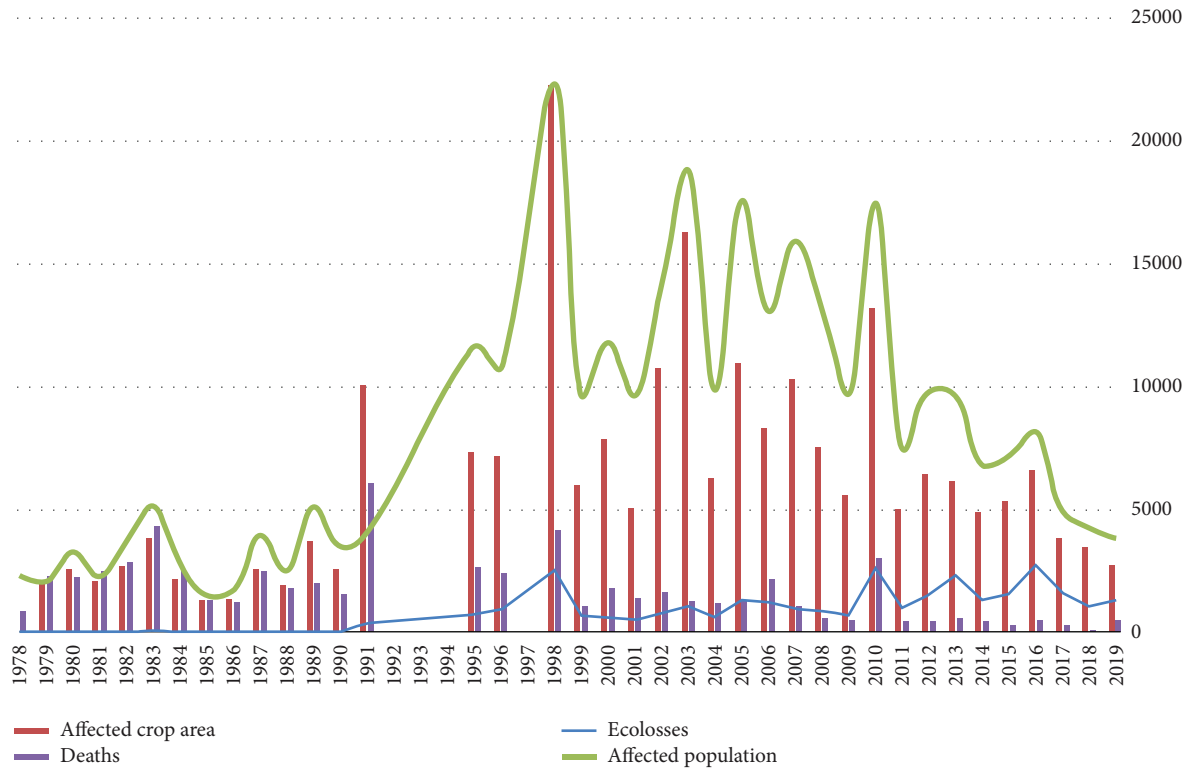


FIGURE 2: FD in the YRb from 1978 to 2019 (lack of data for 1992–1994, and 1997). Data source: Flood and Drought Disaster in the Yangtze River basin compiled by Yangtze Water Resources Commission of the Ministry of Water Resources; China Water Conservancy Yearbook; China Flood and Drought Disaster Bulletin.

HQED model have on FD? Could it be a new dynamic to mitigate FD in the YRb? If the answer is affirmative, what is the mechanism of action? These questions have not been clearly answered by existing studies. However, the answers can provide theoretical support and reference for mitigating FD, discerning the driving factors of floods, and guiding the sustainable development of the YRb. In the past, to cope with floods, academia and government departments tended to increase flood control projects. However, in recent years, the severe localized floods and the frequent waterlogging events in cities have revealed that static flood control infrastructure is not a reliable mitigation approach in the face of climate change uncertainties and that it also increases long-term flood risk by harming riverine ecosystems [20, 21]. The grey infrastructure, with the single idea of “rapid discharge,” barely copes with the stormwater dilemmas that arise during rapid urbanization [22]. Therefore, a new disaster countermeasure and theoretical system are needed to solve the contradiction between floods and the need for stable economic and social development. The new academic concept of “resilience” was introduced into the field of flood management because it characterizes the ability of a system to cope with risks and its ability to recover after the risks have passed. Eventually, the theoretical system of flood resilience (FR) was formed [23]. It refers to the ability of a complex system to resist, absorb, and adapt to flood risks by taking a series of measures to keep its main structures and functions intact in the face of flooding [24]. Unlike the single function of flood control projects, FR involves the organizational

forces of natural, physical, social, and economic systems and institutions [25], while the HQED model coincides with the coordinated development of economic, political, cultural, social, and ecological civilization construction [26]. Therefore, we hold that compared to the extensive economic growth model that drives floods, the HQED model can improve the resilience of exposed systems to cope with floods through multiple channels, and, thus, mitigate FD in the YRb.

In order to verify our points presented in this study by quantitatively analyzing the impact of HQED and FR on FD in the YRb. We collected panel data from 2000 to 2019 from PARs in the YRb, and based on measuring the levels of HQED and FR, we first empirically tested the impact path of HQED on FD in the YRb using a fixed effect model and then introduced FR as a mediating variable and tested the mechanism of action of HQED on FD in the YRb using the mediating effect model (MEM).

The main contributions of this study are as follows:

- (i) Compared with existing studies that emphasize the driving effect of economic development on FD, this study provided evidence for the proposition that “HQED mitigates FD in the YRb” by constructing an evaluation index system (EIS) to measure the level of HQED and using a fixed effect model to test, which filled a gap in recent quantitative analysis. In addition, unlike most studies that focused on the linear effect of economic development on FD, this

study focused on identifying and discussing the nonlinear effect of HQED on FD.

- (ii) Few studies have analyzed the impact mechanism between economic factors and FD. This study combined the FR theory to establish a theoretical system, adopted various mediating effect test methods to explore the fundamental problem of the mechanism of action of HQED on FD, and supported the idea that FR plays a mediating role in the process of mitigating FD through HQED. Therefore, the results of this study have stronger policy references.
- (iii) The EIS of HQED and the EIS of FR were established, respectively, based on the new development concept and disaster response process, which strengthened the theoretical basis for the construction of these two EIS and combined the entropy weight method and various mediating effect test methods to enrich the quantitative research on the theme of FD influencing factors.

The rest of this study is organized as follows. Section 2 reviews the literature related to this paper. Section 3 discusses the theoretical analysis and hypothesis construction, including the impact mechanism of HQED on FD and the mediating effect of FR. Section 4 presents the multiple regression analysis, the mediating effect test process, and robustness checks, and Section 5 presents the main conclusions and discussion.

## 2. Literature Review

The research of flood disasters in the YRb has gone through three stages. The first stage focused on the study of the natural attributes of floods within the YRb. In terms of its hydro-meteorological characteristics, the YRb is located in a subtropical region in the eastern part of the Eurasian continent and is bordered by the vast Pacific Ocean in the east, belonging to a typical monsoon climate zone [1]. Once the atmospheric circulation is abnormal, the upper, middle, and lower reaches of the rainy season overlap and the stem and tributary floods interact, making it easy for floods to form. Zhou et al. [27] analyzed the characteristics of climate factors in the YRb and pointed out that YR floods are mainly formed by heavy rainfall. Therefore, as a river prone to pluvial floods, flood disaster is natural and inevitable in the YRb. However, at the end of the 20th century, the YRb, which was not in a period of abundant precipitation, experienced frequent floods, especially after the 1998 floods, which pushed scholars to shift from focusing on the natural attributes of floods to the second stage of focusing on the social attributes of floods. Chen et al. [28] showed that the increase in floods after the 1980s did not correspond to a period of abundant precipitation, but was more the result of human activities. As shown by Li and Wang [29] and Xu et al. [30], a number of production and living behaviors, such as deforestation and lake reclamation, have negative impacts, which lead to an increase in the frequency of floods. Zhou [3] found that the growth of FD also coincided with

the trend of economic development and population increase. Xu et al. [31] argued that the urbanization process accompanied by economic development will increase the frequency of floods by changing the urban climatic conditions and the underlying surface conditions of urban areas. At this stage, research on the social attributes of floods focused on the socioeconomic determinants of floods and the impact of floods on economic and social systems. Compared to China, foreign research on the social attributes of natural disasters started earlier, beginning in the 1950s [32]. For example, Dacy and Kunreuther [33] explored the economic determinants of natural disasters earlier. Toya and Skidmore [9] found that countries with a higher income, higher educational attainment, greater openness, more complete financial systems, and smaller governments experienced fewer losses in a comparative analysis of all countries, OECD countries, and developing countries. Pais and Elliott [34] proposed that overinvestment in economic development and underinvestment in environmental protection will lead to more people and property being threatened by natural disasters. Both domestic and international research analyses have shown that socioeconomic and natural environmental factors in the formation mechanism of disaster risks and damage need at least equal attention. Most of the relevant research findings have given policy recommendations around ecological restoration and flood control engineering facilities to mitigate FD.

However, in the 21st century, a large number of floods at home and abroad have shown that, in most cases, flood control projects cannot cope with extreme disasters due to climate change. Therefore, scholars formally entered the third stage of flood research by introducing the concept of "resilience." "Resilience," as a system's ability to absorb, recovers, and improves in response to the disturbance of disaster events, was first introduced into the field of disaster science by Timmerman [35]. With increasing awareness about the response to extreme disasters, the concept of resilience was later introduced into the study of climate change adaptation strategies for urban systems [36]. The concept of FR, which is used to cope with floods, came into being and became one of the important branches of resilience systems. Similarly, studies of FR have been pioneered in foreign countries. The research content mainly includes the planning of flood-resilient cities and FR assessment systems. First, as for the planning of flood-resilient cities, Godschalk [37] first formally applied the concept of resilience to urban planning. After that, frequent extreme disasters pushed the research of resilient cities in the direction of improving the adaptability of cities to disasters [38]. Novotny et al. [39] proposed planning principles and an optimization direction for flood-resilient communities by considering the interaction between communities and stormwater. Gralepois et al. [40] proposed a communicable and symbiotic boundary between stormwater and cities in stormwater urban design. Secondly, concerning FR assessment systems, many scholars have designed evaluation indicators to quantify FR. For example, Zhong et al. [41] proposed building indicators from the fields of society, economy, infrastructure, and environment to assess urban

FR. Restemeyer et al. [42] explored building a heuristic framework for evaluating urban FR from three aspects: robustness, adaptability, and transferability. The research on FR in China has been deeply influenced by foreign countries. Liao [43] first introduced the FR theory in China, advocated the use of natural floodplain functions to enhance the stormwater capacity of the system, and proposed the index of “percent floodable area” to measure the urban FR capacity. Xu et al. [44] constructed an urban waterlogging elasticity evaluation system including three dimensions of resistance, recovery, and adaptability. Huang and Liu [45] emphasized that we need to cultivate the wisdom of cities to coexist with floods based on the attributes of resilience, including self-organization, self-regulation, and an achievable transformation system. By summing up the suggestions put forward in the relevant research conclusions, the planning content of FR tends to take social, economic, and political factors into account in flood risk management.

By summarizing the relevant literature, we find that FR is significantly different from the traditional flood management concept. It puts more emphasis on improving the ability to respond to occasional floods. FR is a more comprehensive theory that pays attention to the endogenous self-organization and self-adaptive ability of the system. However, it has been found that domestic research on the combination of floods and resilience is not abundant. Few scholars have directly analyzed the relationship between HQED, FR, and FD, which leaves room for this study. By understanding the connotation of the HQED model and FR, we reexamined the impact mechanism of HQED on FD in order to enrich the theoretical and practical research on FR.

### 3. Theoretical Analysis and Research Hypotheses

*3.1. Impact Mechanism of High-Quality Economic Development on Flood Damage.* It has been proven that there is an economic regularity in the variation in FD, and the underlying reason is that disaster losses are closely related to economic development [10, 46]. The development model focusing on economic magnitude growth has caused ecological degradation and neglected safety issues, leading to frequent floods and increasing FD within the YRb. The HQED model implements the new development concept and reflects the quality content of development effectiveness, the ecological environment, and social services. It can not only relieve the constraints of land space, population bearing capacity, the ecological environment, and other factors but also solve the outstanding problems of accumulation of risk factors, destruction of natural ecology, serious environmental pollution, etc., derived from the extensive growth model, and thus, mitigate the irreversible FD. From an analysis perspective, firstly, more secure development has been undertaken, ensuring that government departments can control natural disaster risks within certain limits, avoiding the outbreak of crises due to uncontrolled risks. Secondly, under the strategic positioning of ecological priority and green development that needs to be adhered to for

the development of the YR economy, we have always placed the protection and restoration of the ecological environment as a top priority and thus have the opportunity to cultivate ecological wisdom to deal with floods. In addition, high-quality urbanization will also be a companion to HQED and can mitigate FD by improving urban systems’ resistance and resilience to floods. Overall, an HQED model that focuses on green, stable, and sustainable development will positively mitigate FD in the YRb.

In the above interpretation of the connotation of HQED in the context of stormwater, the dynamic trend of HQED is also implied, which is expressed as a stage-by-stage evolutionary path [26]. The dynamic trend of HQED is reflected in “quality improvement, pursuing better livelihood, inclusiveness, and green development” [47]. The trend of quality improvement indicates that it is necessary to pass the critical stage of the transformation of the economic growth mode to realize the resilience of economic and social structures; the trend of pursuing a better livelihood indicates that the people’s sense of gain, happiness and security must be increased through the provision of effective products and services and the resilience of urban systems; the trend of inclusiveness shows that, for the fruits of economic development to be shared, it is necessary to strengthen the governance capacity of government departments and alleviate outstanding problems such as incompatibility between economic development and ecology and nonequalization of basic public services; the trend of green development emphasizes that, to form a spatial pattern and industrial structures that protect the environment, it is necessary to provide more high-quality ecological products and restore the ecological environment. At the microlevel, this means that HQED will first go through a crucial stage of transformation and expansion of the number of public goods, so the benefits of HQED will tend to be stable, mature in fluctuations, and eventually lead to the gradual release of the mitigation effect of the HQED model on FD in the YRb.

Furthermore, detailed analysis shows that, in the context of the crucial stage of transformation of HQED, government departments often need to pay higher public costs to solve the outstanding contradictions, such as the low efficiency of government services, the deterioration of the ecological environment, and the high vulnerability of cities. Therefore, the improvement of the quality of economic growth at this stage is slow and unstable, which cannot guarantee the mitigation of FD. On the contrary, it can increase the cost value exposed to flood risk because of the pursuit of a scale effect in the material dimension and the transformation of the human lifestyle. After the crucial stage of transformation, the level of “quality” of economic development will maintain stable growth, and the speed of “quantity” of economic development will continue to converge. HQED will then enter a mature stage, and the goal of the coordinated development of politics, economy, society, and ecology can be achieved. In the context of stormwater, this is mainly reflected in the optimization of territorial space, the improvement of the disaster prevention planning system, the highly coordinated development of the ecological

environment and economic quality, the sharing of high-quality public goods and services, and the improvement of various natural disaster insurance mechanisms. As a result, the driving factors of floods will be reduced, and HQED and FD will form a virtuous cycle. Therefore, the first hypothesis is proposed.

H1: the impact of HQED on FD in the YRb has an inverted U-shaped Kuznets curve.

**3.2. The Mediating Effect of Flood Resilience.** The concept of FR originates from system ecology, which is a type of ability to avoid, resist, or respond to floods promptly, to not be affected by floods, or to recover from floods and minimize their impact on life safety, the environment, and the economy. FR meets the basic requirement of building a modern flood adaptation system. In the field of flood disaster governance, FR is proposed for the vulnerability of traditional flood control patterns, which challenges the traditional thinking of “the city must control floods” and advocates adopting the coping modes of “adaptation” [43]. Additionally, FR relies on the ecological elasticity of natural drainage systems, the engineering elasticity of artificial drainage systems, and the social elasticity of systems for disasters [48]. Therefore, FR can better adapt to climate change. As a complex of ecology, engineering, and social economy, the practical content of FR includes three aspects: the construction of ecological water safety and water environments; the perfection of flood control and drainage engineering measures; the management of flood disaster losses through socioeconomic departments [49]. While HQED implements the new development concept and focuses on sustainable development, it can promote the level of FR after going through the transformation stage. For instance, a stable and efficient economic operation can promote the perfection of flood control engineering facilities; a scientific and balanced territorial spatial planning can match the degree of the territorial spatial development with the carrying capacity of its resources and environment; more equitable sharing of results can provide more high-quality public products and services and improve the resilience of urban systems to floods; green and sustainable economic development can form a more harmonious relationship between humans and nature to improve the ability for ecological self-rehabilitation and realize the cyclic utilization of rain-flood resources. Faced with the negative impact of floods, regions with a higher level of FR possess relatively strong resistance to floods and a shorter recovery time post-disaster, and they can quickly adjust the structure and function of the regional system in case of disasters, to realize the improvement of FR due to disasters [50, 51]. Obviously, the constantly advancing HQED can significantly mitigate FD by improving the level of FR (see Figure 3). Therefore, the second hypothesis is proposed:

H2: the HQED model, which has been pushed forward, will exert a positive impact on FR and promote FR to play a negative mediating role in the process of mitigating FD through HQED.

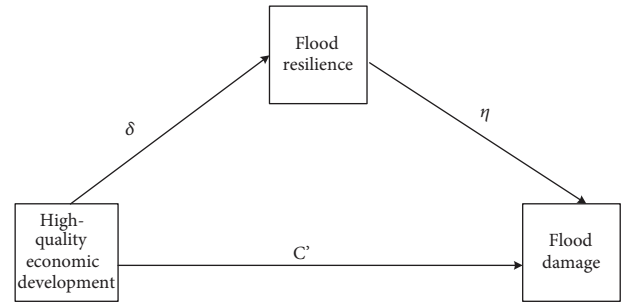


FIGURE 3: The mediating effect of FR ( $C'$  represents the direct effect of HQED on FD; the product of  $\delta$  and  $\eta$  represents the indirect effect of HQED transmitted to FD through FR).

## 4. Research Method and Empirical Test

**4.1. Research Method.** The empirical analysis mainly used the entropy weight and quantitative regression analysis methods. First, since HQED is guided by the new development concept and the new development concept runs through the whole process of HQED, we referred to the existing literature [52, 53] and used the entropy weight to construct a systematic and scientific index system of HQED based on the five development concepts of ICOGS. Since FR is also a comprehensive planning concept, we broke through the traditional thinking of resilience assessment focusing on “static” and “horizontal” and used the entropy weight method to establish the EIS of FR according to the four stages of the disaster response process, including resistance, warning, response, and recovery [54, 55]. The purpose is to measure the levels of HQED and FR. Then, through the establishment of a fixed effect model and MEM, we empirically tested the impact direction and mechanism of HQED on FD.

**4.1.1. Entropy Weight Method.** Entropy is a term related to physical quantities [56]. In 1948, Shannon first introduced the concept of entropy into information theory and gave the mathematical expression for calculating information entropy [57]. After that, the entropy weight method has been widely used in engineering technology and social economic fields. We used the information entropy method to calculate the entropy weight of each indicator. The weight of the index system is corrected by the entropy weight in order to obtain the relatively objective index weight, and then, the comprehensive level of the index is also obtained. Refer to relevant literature [55]. The steps are as follows.

First, we conduct dimensionless processing for each indicator. In the primitive indicators listed in Tables 1 and 2, the energy consumption per unit GDP, the emission rate of industrial waste gas per unit GDP, the difference coefficient of per capita disposable income of urban and rural residents, Engle’s coefficient of urban households, and the registered urban unemployment rate are all inverse indicators, which need to take reciprocal numbers for positive treatment. Then, we use the extreme method to process all positive indicators to eliminate the impact of the difference in the



TABLE 1: EIS of HQED.

Dimension	Indicator/unit	Calculation method	Data source	Indicator direction
Innovation	R&D expenditure input intensity/ %	The expenditure on R&D/GDP	The China Statistical Yearbook on Science and Technology (CSYST)	Positive
	Patent applications per 10000 population/piece	The patent applications/per 10000 population	CSYST	Positive
Coordination	Proportion of tertiary industry/%	The added value of tertiary industry/GDP	The China Statistical Yearbook (CSY)	Positive
	Rate of urbanization/%	The nonagricultural population/total population	CSY	Positive
Openness	Interdependent level to foreign trade/%	The total value of imports and exports/GDP	CSY	Positive
	Foreign direct investment intensity/%	The total amount of foreign direct investment/GDP	The China City Statistical Yearbook	Positive
Green	Energy consumption per unit GDP/tee/CNY 10000	The total energy consumption/GDP	The China Energy Statistical Yearbook	Negative
	Proportion of investment completed for pollution treatment/%	The investment completed for pollution treatment/GDP	CSY	Positive
	Emission rate of industrial waste gas per unit GDP/%	The volume of industrial SO <sub>2</sub> discharged/GDP	CSY	Negative
Sharing	Proportion of welfare expenditure/%	The total amount of science, education, culture, and health care expenditure/general public budget expenditure	The Finance Yearbook of China (FYC)	Positive
	Difference coefficient of per capita disposable income of urban and rural residents/%	The per capita disposable income of urban residents/per capita disposable income of rural residents	CSY	Negative
	Engle's coefficient of urban households/%	The total amount of food expenditure/consumption expenditure in cash	The Statistical Yearbook of PARs	Negative

indicator dimension on the evaluation results. The calculation formula for positive indicators is

$$h_{ij} = \frac{x_{ij} - \min_j}{\max_j - \min_j} + \lambda, \quad (1)$$

where  $h_{ij}$  is a dimensionless value processed by the extreme method,  $\max_j$  and  $\min_j$  represent the maximum and minimum values of item  $j$ , respectively, and  $\lambda$  is 0.0001.

Second, we calculate the information entropy  $e_j$  by

$$e_j = -k \sum_{i=1}^n \frac{h_{ij}}{\sum_{i=1}^n h_{ij}} \ln \left( \frac{h_{ij}}{\sum_{i=1}^n h_{ij}} \right), \quad i = 1, 2, 3 \dots n. \quad (2)$$

Third, we calculate the indicator weight  $w_j$  by

$$w_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)}, \quad j = 1, 2, 3 \dots m. \quad (3)$$

Fourth, the total score  $u$  is calculated by

$$u = \sum_{j=1}^m w_j h_{ij}. \quad (4)$$

**4.1.2. Quantitative Regression Analysis.** To empirically investigate the impact of HQED and FR on FD, we constructed Equations (5)–(7) according to the MEM [58], and the nonlinear relationship between natural disaster losses and economic

growth has been confirmed by the existing literature [46, 59]. Among them, (5) aims to test whether the first hypothesis proposed in this paper is valid; Equations (5)–(7) aim to test whether the second hypothesis proposed in this paper is valid:

$$\frac{\text{Inecolosses}_{it}}{\text{Inaffectedpopu}_{it}} = \beta_1 + C_1 \text{HQED}_{it} + C_2 \text{HQED}_{it}^2 + \theta_1 X_{it} + \alpha_i + \gamma_t + \xi_{1it}, \quad (5)$$

$$\text{FR}_{it} = \beta_2 + \delta_1 \text{HQED}_{it} + \delta_2 \text{HQED}_{it}^2 + \theta_2 X_{it} + \alpha_i + \gamma_t + \xi_{2it}, \quad (6)$$

$$\frac{\text{Inecolosses}_{it}}{\text{Inaffectedpopu}_{it}} = \beta_3 + C'_1 \text{HQED}_{it} + C'_2 \text{HQED}_{it}^2 + \eta \text{FR}_{it} + \theta_3 X_{it} + \alpha_i + \gamma_t + \xi_{3it}, \quad (7)$$

where  $i$  represents the province,  $t$  represents the year,  $\alpha_i$  represents the individual fixed effect,  $\gamma_t$  represents the time fixed effect, and  $\varepsilon_{it}$  is a random perturbed variable. Moreover,  $\text{Inecolosses}_{it}$  focuses on direct economic losses due to floods, and  $\text{Inaffectedpopu}_{it}$  focuses on the affected population due to floods. In order to test if the relationship between HQED and FD is nonlinear,  $\text{HQED}_{it}$  and  $\text{HQED}_{it}^2$  are introduced simultaneously. To investigate the mechanism of action of HQED on FD through the mediating effect test,  $\text{FR}_{it}$  is taken.  $X_{it}$  represents a series of control variables.

TABLE 2: EIS of FR as a mediating variable.

Dimension	Indicator/unit	Calculation method	Data source	Indicator direction
Resistance	Completed reservoirs/unit	The total amount of storage area that is formed by constructing a dam to detain and store water and regulate runoff	The China Water Conservancy Statistical Yearbook (CWCSY)	Positive
	Length of urban sewage pipes/1000 km	The total length of general drainage, trunks, branch and inspection wells, connection wells, inlets and outlets, etc.	CSY	Positive
	Embankment length/km	The total length of the embankment is the sum of completed levees or dikes along a river or lake, sea dikes, and flood control walls	CWCSY	Positive
	Total area of afforestation/1000 hectare	The total area of land suitable for afforestation, including barren hills, idle land, sand dunes, nontimber forest land, woodland, and “grain for green” land	CSY	Positive
	Flood control investment/CNY 100 million	The total government investment for river regulation, reservoir reinforcement, urban levees, and flood control projects	CWCSY	Positive
Warning	Meteorological observatories and stations/unit	The total number of institutions that conduct meteorological observations and accumulate and compile meteorological data	CSY	Positive
	Hydrological station/unit	The number of hydrological observation stations that are located in rivers, canals, lakes, and reservoirs or river basins for gathering hydrological data	CWCSY	Positive
	Radio coverage of population/%	The total population that can receive one central, provincial, city, prefecture, or country radio program by wireless, cable, satellite, or other technical means/total population	CSY	Positive
Response	Graduates of higher education/10000 persons	The total number of graduates from full-time universities, colleges, institutions of higher professional education, institutions of higher vocational education, and others	The Educational Statistics Yearbook of China	Positive
	Health care and medical institutions/1000 unit	The total number of hospitals, community health institutions, specialized public health institutions, and other healthcare institutions	CSY	Positive
	Area of paved roads/10 <sup>8</sup> sq.m	The total area of paved roads except soil land, including high-grade, sub-high-grade, and ordinary roads	CSY	Positive
Recovery	Registered urban unemployment rate/%	The number of registered unemployed persons in urban areas/(the number of persons employed in various units + laid-off staff and workers in urban units + owners of private enterprises in urban areas + owners of self-employed individuals in urban areas + employees of private enterprises in urban areas + employees of self-employed individuals in urban areas + the registered unemployed persons in urban areas)	The China Population and Employment Statistical Yearbook; CSY	Negative
	Per capita saving deposits of residents/CNY	The saving deposits of residents/total population	CSY;the Statistical Bulletin on National Economic and Social Development of PARs	Positive
	Per capita fiscal revenue/CNY	(The general public budget revenue + net income from transfer)/total population	FYC	Positive

In addition, this study deflated all value variables with the provincial consumer price index of 1997 = 100 as the deflator, and the natural log of horizontal variables in control variables was introduced.

*4.2. Sample Selection and Data Source.* Based on the data of PARs in the YRb, this study measured the levels of HQED

and FR and then built the panel data for quantitative regression analysis. The FD data come from the China Water Conservancy Yearbook (2001–2006) and the China Flood and Drought Disaster Bulletin (2006–2019). The variable data for the evaluation of HQED and FR and the control variable data are from the China Statistical Yearbook (2001–2020), the China Water Conservancy Statistical



Yearbook (2001–2020), the Finance Yearbook of China (2001–2020), the China Population and Employment Statistical Yearbook (2001–2020), the China Statistical Yearbook on Science and Technology (2001–2020), the Educational Statistics Yearbook of China (2001–2020), the China City Statistical Yearbook (2001–2020), the China Energy Statistical Yearbook (2001–2020), and the Statistical Yearbook of PARs (2001–2020), as well as the Water Resources Bulletin of PARs (2000–2019) and the Statistical Bulletin on National Economic and Social Development of PARs (2000–2019). In addition, considering that there are too many missing values in Tibet, the sample regions in the quantitative regression analysis exclude Tibet.

### 4.3. Measuring Tool

**4.3.1. Dependent Variables.** This study used direct economic losses and the affected population caused by floods as dependent variables in the baseline regression test: (i) direct economic losses ( $\ln\text{ecolosses}_{it}$ ) were measured by the loss of or reduction in the value of affected bodies after the impact of floods, including agricultural losses, industrial and mining enterprise losses, infrastructure losses, and public service facility losses; (ii) the affected population ( $\ln\text{affectedpopu}_{it}$ ) was measured by the number of people (including the nonresident population) who suffered losses due to floods in the administrative region. In addition, the dead population and the intensity of economic losses in each region were used as dependent variables in the robustness test: (i) the dead population ( $\ln\text{deaths}_{it}$ ) was measured by the total number of deaths caused by floods in a limited region within a certain period (usually one year); (ii) the intensity of economic losses ( $\ln\text{EL}_{it}$ ) was measured by the proportion of direct economic losses to GDP.

**4.3.2. Independent Variables.** (i)  $\text{HQED}_{it}$ : based on the five dimensions of ICOGS of the new development concept, 12 indicators were selected to constitute the EIS of HQED (see Table 1). (ii)  $\text{FR}_{it}$ : based on the four stages of resistance, warning, response, and recovery of the disaster response process, 14 relevant indicators were selected to establish the EIS of FR (see Table 2).

**4.3.3. Control Variables.** Moreover, other factors also affect the FD in the YRb [3, 28, 30]. We classify them as control variables: (i) the annual average precipitation ( $\ln\text{MAP}_{it}$ ) was measured by the average annual precipitation of many years in the target area; (ii) the completed investment of soil conservation and ecological restoration ( $\ln\text{SCAER}_{it}$ ) was measured by the total government investment in soil conservation and ecological environment engineering; (iii) the total population ( $\ln\text{popu}_{it}$ ) was measured by the sum of living individuals at a specific time point (usually one year) and within a particular region; (iv) the land area ( $\ln\text{landarea}_{it}$ ) was measured by the sum of areas within the limits of land tenure; (v) the urban built-up area ( $\ln\text{builtarea}_{it}$ ) was measured by the area which has been developed and

contains municipal public facilities within the urban administrative region; (vi) urban parks and green areas ( $\ln\text{UPGA}_{it}$ ) were measured by the total area occupied for green projects, including green parkland, green production land, green protection land, and other green areas; (vii) the forest coverage rate ( $\text{FCR}_{it}$ ) was measured by the percentage of the area of afforested land in the administrative region to the area of total land; (viii) the wetland area ( $\ln\text{wetarea}_{it}$ ) was measured by the total area of marshland, peat bog, and water-covered areas, whether natural or artificial, permanent, or temporary.

### 4.4. Hypothesis Testing and Result Analysis

**4.4.1. Descriptive Statistical Analysis.** The descriptive statistics of the variables are shown in Table 3. First, there are significant differences in FD in various regions in the YRb. The maximum value of all types of damage degree variables is about 2–3 times the minimum value. At the same time, there are more prominent gaps in the levels of HQED and FR in various regions. Among them, the minimum value of HQED is 0.0629, which corresponds to the data of Guizhou Province in 2000, and the maximum value of 0.8679 corresponds to the HQED of Shanghai in 2017. The minimum value of FR is 0.0819, which corresponds to the data of Qinghai Province in 2006, and the maximum value of 0.6281 corresponds to the data of Jiangsu Province in 2011.

**4.4.2. Endogenous Test and Model Setting Test.** According to the theoretical analysis of this study, the constantly advancing HQED can significantly mitigate FD by improving the level of FR. However, the disaster resilience of a system, in turn, also ensures the stable development of the local economy, so there may be a circular causal relationship between the HQED variable and the FR variable. Similarly, FR may also be promoted by FD. This is a key aspect in which the concept of FR is superior to traditional flood prevention. However, considering the time inconsistency, we hold that there is no circular causal relationship between FD and FR.

To be cautious, based on Equations (5)–(7), we used the Hausman test and the heteroskedasticity-robust DWH test to test the endogeneity of the HQED variable, the  $\text{HQED}^2$  variable, and the FR variable in columns (1)–(6) of Table 4. The test results show that the  $P$  value of the Hausman test in column (1) was 0.7628, which did not reject the null hypothesis significantly; the  $P$  value of the Hausman test in column (2) was 0.0000 which did not accept the null hypothesis at the 1% level; the  $P$  value of the Hausman test in column (3) was 0.8550, which also did not reject the null hypothesis significantly; the  $P$  value of the Hausman test in column (4) was 0.5987, which did not reject the null hypothesis significantly; the Hausman test result of column (5) was consistent with that of column (2); the  $P$  value of the Hausman test in column (6) was 0.7631, and the null hypothesis was not significantly rejected. Therefore, the independent variables in Equations (5) and (7) were exogenous variables, while the HQED variable and the  $\text{HQED}^2$  variable in Equation (6) were endogenous variables. In addition, we also

TABLE 3: Descriptive statistics.

Variables	Obs	Mean	Std. dev.	Min	Max
Lnecolosses	357	3.2224	1.5297	-3.5066	6.2541
Lnaffectedpopu	357	5.6441	1.6636	-2.3026	7.9609
IEL	357	0.6813	0.8675	0.0000	7.1760
Lndeaths	323	3.2431	1.4108	0.0000	7.3633
HQED	360	0.2858	0.1824	0 .0629	0.8679
FR	360	0.3079	0.1252	0.0819	0.6281
LnMAP	360	6.9366	0.5306	5.4604	7.8254
LnSCAER	347	0.7396	1.5513	-4.6052	4.3031
Lnpopu	360	8.3792	0.6571	6.2500	9.3519
Lnlandarea	360	2.8125	0.9746	-0.4620	4.2783
Lnbuiltarea	360	6.9672	0.8160	4.5196	8.7637
LnUPGA	360	3.8002	1.0787	0.3293	6.2193
FCR	360	33.4225	18.8394	0.4300	66.8000
Lnwetarea	360	6.5479	1.0241	3.7658	9.0050

TABLE 4: Regression results of causal steps' approach.

	Lnecolosses (1) FE/SCC	FR (2) GMM	Lnecolosses (3) FE/SCC	Lnaffectedpopu (4) FE/SCC	FR (5) GMM	Lnaffectedpopu (6) FE/SCC
FR			-1.874 (1.419)			-4.022* (2.136)
HQED	6.946*** (2.270)	-0.273 (0.193)	6.858*** (2.325)	5.076* (2.566)	-0.273 (0.193)	4.880* (2.625)
HQED <sup>2</sup>	-9.464** (3.611)	0.541** (0.265)	-9.201** (3.647)	-4.901 (4.039)	0.541** (0.265)	-4.327 (3.933)
LnMAP	3.647*** (0.756)	0.005 (0.015)	3.652*** (0.762)	2.903*** (0.369)	0.005 (0.015)	2.913*** (0.381)
LnSCAER	0.029 (0.097)	0.000 (0.002)	0.031 (0.098)	-0.050 (0.085)	0.000 (0.002)	-0.046 (0.089)
Lnpopu	0.412 (1.246)	0.017 (0.076)	0.236 (1.242)	0.981 (1.834)	0.017 (0.076)	0.592 (1.743)
Lnlandarea	-16.869** (7.841)	0.032 (0.183)	-16.768** (7.700)	-13.421** (4.650)	0.032 (0.183)	-13.184*** (4.307)
Lnbuiltarea	1.828* (1.002)	0.113*** (0.020)	1.988* (0.970)	0.201 (0.886)	0.113*** (0.020)	0.527 (0.940)
LnUPGA	-0.308 (0.605)	-0.038*** (0.015)	-0.371 (0.621)	-0.698** (0.253)	-0.038*** (0.015)	-0.829*** (0.266)
FCR	-0.016 (0.012)	0.002*** (0.001)	-0.017 (0.013)	-0.010 (0.008)	0.002*** (0.001)	-0.011 (0.010)
Lnwetarea	-0.033 (0.306)	-0.008 (0.007)	-0.014 (0.314)	0.225 (0.208)	-0.008 (0.007)	0.268 (0.198)
Constant	11.266 (14.863)	-0.698 (0.690)	12.030 (14.143)	14.919 (16.859)	-0.698 (0.690)	16.706 (16.550)
Year FE	YES	NO	YES	YES	NO	YES
Province FE	YES	YES	YES	YES	YES	YES
Hansen <i>J</i> statistic		0.322			0.322	
Observations	314	287	314	314	287	314
R-squared	0.339	0.416	0.341	0.391	0.416	0.402

Note. \*\*\*, \*\*, and \* mean statistically significant at 1%, 5%, and 10%. The values in brackets are robust standard errors. The Hansen *J* statistic reports the *P* value. Constant terms in columns (2) and (5) are reported by the `xtivreg` command, with standard errors in brackets.

used the heteroskedasticity-robust DWH method to conduct a robust endogeneity test and obtained estimation results consistent with the Hausman test results. Therefore, in the following benchmark regression analysis, we adopted the instrumental variable (IV) method to solve the endogenous variables in Equation (6). The traditional IV method is implemented through “two-stage least square” (2SLS). However, considering heteroskedasticity and serial correlation problems that often exist in panel data, we used the “generalized method of moments” (GMM), which is more effective than 2SLS, to eliminate the endogeneity problem. To avoid the bias of IV selection, we used lagged first- and second-order endogenous variables as instrumental variables. Since the number of instrumental variables was larger than the number of endogenous independent variables, the orthogonality of the instrumental variables needed to be tested by overidentifying at the same time. The results show that the Sargan–Hansen statistic was 2.266, and the *P* value was 0.322, so all the instrumental variables selected in this paper were exogenous.

Finally, the model setting test was continued based on Equations (5)–(7). First, the calculation of the *F*-statistic was used to test whether the fixed effect model or random effect model was suited to the panel data in columns (1)–(6) of Table 4, and then, the Hausman test was conducted. The results show that the *P* values from columns (1)–(6) in Table 4 were 0.0035, 0.0008, 0.0130, 0.0412, 0.0008, and 0.0524, respectively, and no null hypothesis was accepted, so Equations (5)–(7) needed to adopt the fixed effect model. We took the estimation results of the improved fixed effect model (SCC model) as the criterion because the SCC model can better control heteroskedasticity and serial correlation [60].

**4.4.3. Baseline Regression Results.** Based on the data from 2002 to 2019, this study estimated the impact of HQED on FD. Table 5 shows the direction and magnitude of HQED on FD. From column (3) and column (6), the impact of HQED on FD has an inverted U-shaped Kuznets curve. Other

methods were used to estimate Equation (5), where the nonlinear effect of HQED on FD still exists. More specifically, the direct economic losses and the affected population due to disasters show a trend of increasing first but then decreasing with the increase in the level of HQED, which supports hypothesis 1 proposed in this paper. However, when  $\ln\text{affectedpopu}_{it}$  is taken as the dependent variable,  $\text{HQED}^2_{it}$  does not have a significant positive impact on the affected population, which is because the size of the affected population is often not primarily determined by socioeconomic factors [10]. Moreover, the absolute values of coefficients concerning HQED in column (3) are higher than those in column (6), indicating that  $\text{HQED}_{it}$  and  $\text{HQED}^2_{it}$  have a higher power of interpretation in the model taking  $\ln\text{incolosses}_{it}$  as the dependent variable. Therefore, the estimation results in Table 5 are generally consistent with the theoretical expectation.

Other regression results of independent variables are as follows. (i) The coefficient value of  $\ln\text{MAP}_{it}$  is positive and significant, indicating that the increased rainfall intensity or extraordinary rainfall amount has a promoting impact on FD. (ii) The estimated coefficient value of  $\ln\text{landarea}_{it}$  is negative and significant. The reason may be that the larger the land area in a region, the greater the land development and utilization opportunities without affecting the flood-carrying capacity. Another reason may be that the larger the land area, the greater the space to move the population and industries along the river. (iii) The relationship between  $\ln\text{incolosses}_{it}$  and  $\ln\text{builtarea}_{it}$  is significantly positive, consistent with the existing research conclusions [61]. The reason is that the built-up area positively correlates with the urban impervious surface, which makes the original rainwater retention capacity in the basin decrease sharply and the runoff coefficient increase significantly. The flood wave is more vulnerable to short-term, high-intensity rainfall. (iv) The relationship between  $\ln\text{affectedarea}_{it}$  and  $\ln\text{UPGA}_{it}$  is negative and significant, since parks and green areas have the function of absorbing rainwater and storing precipitation. When faced with high-intensity rainfall, they can store surface runoff, weaken the intensity of flood peaks, and delay the arrival time of flood peaks to save time for disaster resistance. The estimated coefficients of the remaining independent variables are not significant, so they will not be described here.

In order to further investigate the transmission mechanism of HQED to mitigate FD and whether hypothesis 2 proposed is supported, we used Equations (5)–(7) to test the mediating effect of FR on the relationship between HQED and FD by the causal steps' approach [62]. Among them, (5) reflects the total effect of HQED on FD, (6) reflects the effect of HQED on FR, and (7) simultaneously reflects the effects of HQED and FR on FD. The regression results are shown in Table 4. When  $\ln\text{incolosses}_{it}$  is taken as the dependent variable, the coefficient values  $C_1$  and  $C_2$  in (5) are significant at the 1% and 5% levels, respectively, indicating that the total effect is significant. The coefficient value  $\delta_2$  in (6) is positive and significant at the 5% level, indicating that a high level of HQED can improve the level of FR. However, the coefficient value  $\eta$  in (7) is negative and nonsignificant, failing to pass the test of joint significance, indicating that a mediating

effect of FR does not exist. In comparison, taking  $\ln\text{affectedpopu}_{it}$  as the dependent variable, the coefficient values  $\delta_2$  and  $\eta$  are significant, and  $\text{FR}_{it}$  shows a significant negative mediating effect.

However, according to the research point of Fritz and MacKinnon [63], the test power of the causal steps approach is low, and it can easily misjudge the conclusion that the product term is nonsignificant. Certainly, in the case of taking  $\ln\text{affectedpopu}_{it}$  as the dependent variable, we obtain a significant product result, and the problem of low test power does not exist. Therefore, in the case of taking  $\ln\text{incolosses}_{it}$  as the dependent variable, we chose to continue to directly test the significance of the product term  $\delta_2\eta$  using the bootstrap method, which is considered to be more effective [63]. The estimation results (see Table 6) show that, after 1000 bootstrap repetitions, the 95% confidence interval of the mediating effect of FR was  $[-2.191, -0.170]$ , which did not include 0, confirming the product term  $\delta_2\eta$  was significant. It is worth discussing that, according to the test results in Table 6, a direct effect of HQED on FD did not exist and  $\text{FR}_{it}$  had a full mediating effect. Although Baron and Kenny [62] argued that a full mediating effect is the strongest proof of the existence of a mediating effect, researchers easily misjudge the result of the full mediating effect, so given the limited sample size of this study, we upheld the point of Preacher and Hayes [64] to abandon the concept of the full mediating effect and regarded various mediating effects as the partial mediating effect. In general, the causal steps approach and the bootstrap method strongly confirmed that  $\text{FR}_{it}$  has a negative mediating effect on HQED to mitigate FD. Hypothesis 2, proposed in this study, is verified.

**4.4.4. Robustness Checks.** In order to ensure the robustness of the above empirical analysis results, we expanded the time data to 2000–2019, increased the number of dependent variables, and adjusted the EIS of HQED (added the indicator of fiscal expenditure intensity for science and technology in the innovation dimension, added the GDP growth rate in the coordination dimension, added the number of inbound tourists in the openness dimension, and replaced Engle's coefficient of urban households in the sharing dimension with the registered urban unemployment rate) to perform the robustness test of hypothesis 1. The relevant estimation results are shown in Table 7, indicating that neither expanding the time data nor adjusting the dependent and independent variables changes the baseline regression results of hypothesis 1, i.e., that the effect of HQED on FD has an inverted U-shaped Kuznets curve.

Regarding the robustness test of hypothesis 2, the bootstrap method and Sobel–Goodman method, which can directly test whether the coefficient product  $\delta_2\eta$  is significantly not equal to zero, were used on the basis of enlarging the data time window and increasing the number of dependent variables. The test results of the bootstrap method are shown in Table 8. It can be seen that, in the case of the different statistical indicators of FD as dependent variables,

TABLE 5: Baseline estimation result.

	Lnecolosses			Lnaffectedpopu		
	(1) OLS	(2) FE	(3) FE/SCC	(4) OLS	(5) FE	(6) FE/SCC
HQED	6.946** (3.239)	6.946** (3.243)	6.946*** (2.270)	5.076 (3.200)	5.076* (2.877)	5.076* (2.566)
HQED <sup>2</sup>	-9.464** (4.266)	-9.464** (3.714)	-9.464** (3.611)	-4.901 (4.458)	-4.901 (3.679)	-4.901 (4.039)
LnMAP	3.647*** (0.490)	3.647*** (0.540)	3.647*** (0.756)	2.903*** (0.414)	2.903*** (0.535)	2.903*** (0.369)
LnSCAER	0.029 (0.064)	0.029 (0.067)	0.029 (0.097)	-0.050 (0.064)	-0.050 (0.097)	-0.050 (0.085)
Lnpopu	0.412 (1.711)	0.412 (1.206)	0.412 (1.246)	0.981 (1.679)	0.981 (1.148)	0.981 (1.834)
Lnlandarea	-16.869*** (6.013)	-16.869*** (3.336)	-16.869** (7.841)	-13.421*** (4.391)	-13.421** (5.665)	-13.421** (4.650)
Lnbuiltarea	1.828* (0.953)	1.828** (0.669)	1.828* (1.002)	0.201 (0.867)	0.201 (0.658)	0.201 (0.886)
LnUPGA	-0.308 (0.430)	-0.308 (0.350)	-0.308 (0.605)	-0.698** (0.316)	-0.698** (0.241)	-0.698** (0.253)
FCR	-0.016 (0.015)	-0.016 (0.014)	-0.016 (0.012)	-0.010 (0.013)	-0.010 (0.013)	-0.010 (0.008)
Lnwetarea	-0.033 (0.296)	-0.033 (0.347)	-0.033 (0.306)	0.225 (0.250)	0.225 (0.156)	0.225 (0.208)
Constant	6.675 (20.425)	11.266 (11.571)	11.266 (14.863)	12.196 (17.973)	14.919 (20.793)	14.919 (16.859)
Year FE	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES
Observations	314	314	314	314	314	314
R-squared	0.703	0.339	0.339	0.790	0.391	0.391

Note. \*\*\*, \*\*, and \* mean statistically significant at 1%, 5%, and 10%, respectively. The values in brackets are robust standard errors.

TABLE 6: Bootstrap test results of mediating effect.

Path	Effect size	Boot Std. Err.	95%CI lower limit	95%CI upper limit
Direct effect: HQED <sup>2</sup> →Lnecolosses	-1.030	1.178	-3.171	1.373
Indirect effect: HQED <sup>2</sup> →FR→Lnecolosses	-1.093	0.502	-2.191	-0.170

TABLE 7: Robustness test analysis results.

	Expanding the time data FE/SCC							
	Increasing the number of dependent variables				Adjusting the EIS of HQED			
	Lnecolosses (1)	Lnaffectedpopu (2)	Lndeaths (3)	IEL (4)	Lnecolosses (5)	Lnaffectedpopu (6)	Lndeaths (7)	IEL (8)
HQED	7.587*** (2.175)	5.549** (2.459)	21.983*** (6.588)	4.915*** (1.423)				
HQED <sup>2</sup>	-10.469*** (3.447)	-5.762 (3.774)	-18.410** (6.564)	-3.525** (1.557)				
HQED <sub>1</sub>					22.818*** (6.171)	18.495*** (5.630)	21.983*** (6.588)	16.680*** (5.208)
HQED <sub>1</sub> <sup>2</sup>					-20.847*** (5.754)	-15.277** (5.747)	-18.410** (6.564)	-14.414*** (4.261)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	345	345	313	345	345	345	313	345
R-squared	0.360	0.402	0.433	0.354	0.353	0.404	0.433	0.351

Note. \*\*\*, \*\*, and \* mean statistically significant at 1%, 5%, and 10%, respectively. The values in brackets are robust standard errors. The results of other control variables are not displayed in the table.

the 95% confidence interval of the mediating effect of FR did not include 0, which means there is a negative mediating effect of FR in the process of mitigating FD through a high level of HQED. Sequentially, the test results of the Sobel–Goodman method are shown in Table 9. It can be seen

that the Sobel Z statistic values were negatively significant at different levels, which also supports the existence of a negative mediating effect of FR. In summary, the above test results are consistent with the baseline regression results of hypothesis 2.

TABLE 8: Bootstrap test results of mediating effect.

Path	Effect size	Boot Std. Err.	95% CI lower limit	95% CI upper limit
Direct effect: HQED <sup>2</sup> →Lnecolosses	-0.678	1.071	-2.747	1.375
Indirect effect: HQED <sup>2</sup> →FR→Lnecolosses	-1.054	0.464	-2.033	-0.239
Direct effect: HQED <sup>2</sup> →Lnaffectedpopu	-3.625	0.917	-5.377	-1.795
Indirect effect: HQED <sup>2</sup> →FR→Lnaffectedpopu	-0.804	0.432	-1.736	-0.016
Direct effect: HQED <sup>2</sup> →Lnedeaths	5.094	1.175	2.712	7.368
Indirect effect:HQED <sup>2</sup> →FR→Lnedeaths	-2.446	0.688	-3.962	-1.190
Direct effect: HQED <sup>2</sup> →IEL	0.492	0.733	-0.970	1.940
Indirect effect: HQED <sup>2</sup> →FR→IEL	-1.143	0.447	-2.122	-0.347

TABLE 9: Sobel–Goodman test results of mediating effect.

	Lnecolosses	Lnaffectedpopu	Lnedeaths	IEL
Mediating effect ( $\delta_2\eta$ )	-1.054	-0.804	-2.446	-1.143
Std. err.	0.463	0.416	0.657	0.359
Z statistic	-2.277**	-1.935*	-3.722***	-3.182***
Direction of mediating effect	—	—	—	—
Hypothesis 2 is verified	Yes	Yes	Yes	Yes

Note. \*\*\*, \*\* and \*mean statistically significant at 1%, 5%, and 10%.

## 5. Conclusion and Discussion

**5.1. Conclusion.** By elaborating the logical relationship between HQED and FD in the YRb, we have constructed a theoretical framework for the impact of HQED and FD. Then, based on panel data from 2000 to 2019 from PARs in the YRb, we used the entropy weight method and quantitative regression method to test the impact of HQED and FR on FD in the YRb and draw the following conclusions. First, both from the theoretical logic and empirical tests, this study showed that the effect of HQED on FD has an inverted U-shaped Kuznets curve. When HQED reaches a certain level, it can significantly mitigate FD in the YRb. Second, the results of the mediating effect test showed that the HQED model, which has been pushed forward, can significantly improve the level of FR. As a comprehensive index of flood response, FR had a significant negative mediating effect in the process of mitigating FD through a high level of HQED.

**5.2. Discussion.** Compared existing studies have revealed the driving effect of extensive economic development on flood risk and FD. This study introduced HQED and FR into the analytical framework of FD and focused on identifying and discussing the nonlinear effect of HQED on FD in the YRb and found that, as the level of HQED increases, its effect on FD shows a variation law, thus, providing a new perspective for dynamic analysis in this field. In addition, this study combined FR theory to explore the fundamental problem of how socioeconomic factors affect FD under a unified framework, supporting the idea that FR plays a mediating role in the process of mitigating FD through HQED, thus providing possible channels for increasing disaster mitigation.

Based on the above conclusions, we consider that there will be an increasing demand to improve stormwater safety and build flood-resilient cities within the YRb. Therefore, we

need to deepen our cognition of the sociality of FD and investigate the social collective response action under the background of floods. It is necessary to complete a paradigm shift from flood control to flood adaptation and construct an FR management system with high self-organization and self-adaptability, which integrates the three dimensions of ecology, engineering, and socioeconomic systems. On the one hand, we persist in raising the level of HQED, by paying attention to ecological security, increasing the accessibility of public services, and improving the balanced development of the territorial spatial planning to improve the level of FR; on the other hand, we integrate the HQED process, the construction of FR, and FD management into a unified planning and social governance system, not only to select FR planning as an organic part of the development of the YRb and a vital tool for FD mitigation but also to bring ecosystem patterns, economic and social activities, and sustainable flood management measures into spatial planning. The purpose is to cultivate the concept of symbiosis between urban spaces and floods and improve the adaptability of the flood-carrying capacity in the YRb.

In summary, this study has systematically analyzed the impact of HQED and FR on FD in the YRb. However, there are still some research limitations in this study. First, restricted by the availability of FD data, the research sample in this study stays at the provincial level. Future research can use the case study method to better prove the correctness of the theoretical mechanism in this study. Second, HQED and FR are new topics in recent years, and the literature and data information available are limited. This study proposed its own EIS by referring to the relevant literature, and the selected indicators were difficult to portray the full picture of the relevant concepts. In the future, we should consider integrating more disciplines and adopting more research methods to build a systematic and standardized evaluation method system.

## Data Availability

The original data used to support the findings of this study can be obtained from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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