

Article

A Study on the Dynamic Evolution Paths of Social Risks in PPP Projects of Water Environmental Governance—From the Vulnerability Perspective

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Abstract: The Chinese economy is transitioning from high-speed development to high-quality development, and water environmental governance is a key factor promoting economic transformation. Due to low returns and high investment in China's water environmental governance, the PPP (public-private-partnership) model is often adopted. However, the PPP model has historically faced challenges adapting to local conditions in China, leading to social risks in the PPP projects of water environmental governance. To reduce these risks, this paper takes a vulnerability perspective, employing the system dynamics simulation method to explore the dynamic evolution process of social risks in the PPP projects of water environmental governance. The main results show the following: (1) the external manifestations of social risks during the construction and operation periods vary significantly, exhibiting notable fluctuations; (2) during the construction period, there is a surge in social risks followed by a returns to lower than normal levels, then a gradual upward trend; during the operation period, social risks initially decrease to a lower level before gradually increasing; and (3) city class, relevant legal systems, and resource reserves emerge as critical factors influencing vulnerability and social risks. The higher the city class, the lower the project vulnerability; the soundness of the legal system for PPP projects can effectively reduce vulnerability and social risks; sufficient resource reserves can reduce social risks. Based on the above findings, this paper proposes several suggestions aiming to reduce the vulnerability and social risks in PPP projects, optimize the process of water environmental governance, and further promote the sustainable development of water environmental governance and the high-quality economy of China.

Keywords: social risks; vulnerability; PPP projects; water environmental governance; dynamic evolution



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1. Introduction

The environmental issue is an essential part of China's ecological civilization construction, and water environmental governance is one of the most important parts of environmental governance. The "14th Five-Year Plan" has proposed "strengthening the ecological protection and governance of the Yangtze River, the Yellow River and other major rivers, and important lakes and wetlands". It illustrates that the ecological protection and systematic governance of major waters are closely related to the sustainable development of China. Due to the large scale and the difficulty of financial support, PPP projects are often adopted in water environmental governance. PPP refers to public-private partnership, which means a partnership between the government and private organizations in order to cooperate in the construction of urban infrastructure projects or to provide certain public goods and services, based on a concession agreement [1]. Meanwhile, a successful PPP project of water environmental governance depends on both financial support and public support during the operation period [2]. The stronger the financial support capacity is, the

more conducive it is to the landing of PPP projects; while the better the public support is, the more government and social capital to identify and fill gaps [3].

However, from the reality aspect, PPP projects have long been unsuitable for China's national conditions. According to the statistics of the World Bank, at the end of 2021, among the projects terminated early in China's PPP projects, the PPP projects of water environmental governance accounted for more than one-third. On the one hand, this is due to the residents' opposition to demolition and relocation; on the other hand, it is due to the continuous deterioration of the water environment caused by the early exit of the project company due to its inability to maintain profits during the operation period. Both of these issues result in the plummeting satisfaction of residents. In 2023, the PPP Center Project Library of the Ministry of Finance suspended storage, and PPP projects entered a state of suspension. To ensure the smooth implementation of future PPP projects of water environmental governance, it is essential to address social issues during the project period, especially those that may affect social stability or lead to group incidents. Therefore, assessments and analyses of social risks in PPP projects of water environmental governance are particularly important. It has become an increasingly important measure for long-term sustainable development and also provides a scientific and effective reference for social development planning [4].

In addition, from the academic aspect, research on social risks in PPP projects of water environmental governance basically concerns the governance process of risk identification, risk evaluation, risk response, risk control, and so on. However, there remain some gaps that need further exploration. Firstly, there is relatively less literature about social risks in PPP projects of water environmental governance. Secondly, existing research focuses on static evaluation, while studies on the dynamic evolution of social risks are fewer. Thirdly, most studies are direct risk analyses and lack project risk resistance analyses. Due to the characteristics of PPP projects of water environmental governance (multiple participants, difficult management, complex engineering construction process, fragmented information, etc.), traditional research ideas and methods are relatively insufficient, and to some extent, it is difficult to fundamentally solve related problems.

To address the above issues, this paper focused on the social risks in PPP projects of water environmental governance and analyzed the characteristics of PPP projects of water environmental governance. Firstly, when discussing social risk topics, vulnerability should be considered as an important condition [5]. Therefore, based on the vulnerability theory, this study analyzed the relationship between the social risks and vulnerability of PPP projects of water environmental governance and explored the diffusion-conduction mechanism of social risks and the theoretical governance path in PPP projects of water environmental governance under existing conditions. Secondly, by using the case study method, this paper found the current problems in the governance of social risks. Thirdly, the system dynamics model of the dynamic evolution of social risks in PPP projects of water environmental governance was constructed by combining the rooted theory with PPP project reality, and the dynamic simulations were conducted on social risks. Finally, through sensitivity analyses, the relevant governance measures of social risks are proposed. The sensitivity analysis is a method to observe the impacts of the changed variables on the model results [6]; the principle is that the values of some variables in the model are changed, while others remain unchanged.

The main contributions of this paper are as follows: (1) according to the correlation between vulnerability and risks, the dynamic evolution paths of social risks in PPP projects of water environmental governance are explored; (2) based on the system dynamics, the social risks in PPP projects of water environmental governance are simulated; to carry out dynamic risk assessments of PPP projects, and by adjusting the parameters, the key factors affecting the risks are found; and (3) this research can provide a theoretical basis and practical references for reducing social risks in PPP projects of water environmental governance, coping with negative public opinions, alleviating the problems of the incompatibility of PPP projects, and optimizing relevant policies.

2. Literature Review

2.1. Social Risks in PPP Projects

The scholars have studied social risks in PPP projects from different perspectives. Wang et al., by establishing a social risk decision-making model for social capital subjects in PPP projects, argued that the main sources of social risk in PPP projects were all related to governmental actions, and reasonable risk-sharing and good partnership could help reduce the social risks of PPP projects [7]. Solheim-Kile et al. believed that social and psychological mechanisms, such as trust, reciprocity, and intrinsic motivation, have benefits for reducing social risk in PPP projects, and full contractor participation, risk-sharing mechanisms, and good relationship building were important factors in achieving this goal [8]. Chen et al. concluded that the government side has the greatest influence on the occurrence of social risk in PPP projects by summarizing the formation mechanism of social risks in PPP projects and organizing the social risk accident tree of PPP projects from the perspectives of multiple stakeholders [9]. Yuan et al. proposed a social risk emergence model. Through calculations, they found that the revenue mechanism of PPP projects had a non-negligible impact on the level of social risks, and the risk level of the PPP project and the vulnerability of the project itself had an impact on the level of social risks in PPP projects [10]. El Kholi et al. analyzed the risks of PPP projects in Egyptian sewage treatment plants by investigating the risk factors that threaten the financial feasibility of social capital [11]. Jiang et al. presented a social risk tolerance (SRT) concept and proposed a model to quantify the tolerance of PPP projects to social risks [12].

2.2. The Relationship between Vulnerability and Risks

Most studies confuse the concepts of risk sources, risk events, and risk impacts [13]. Risk sources are the fundamental factors that lead to risk events, and risk events eventually lead to risk impacts [4]. For project managers, they want to know more about risk impacts; thus, the inherent attribute of water environment governance PPP projects, namely vulnerability, must be considered in the research [3]. Combining vulnerability with social risks can better help managers understand the influencing mechanism of social risks.

The term vulnerability was first used in China in the 1960s and was initially introduced in epidemiological, environmental, and ecological research [14]. According to Gabor et al., vulnerability refers to the possibility of human beings dealing with threats by harmful substances, including the ability to fight against hazardous chemicals, the ecological environment, and emergencies [15]. Dorland et al. consider that vulnerability is the ability to endure and resist natural disasters in a certain region [16]. Early scholars believed that vulnerability should include the size of unfavorable conditions, but recent scholars tend to think that the vulnerability of the system is the internal property of the system itself, which is the degree of the system's development to a negative situation after the occurrence of unfavorable conditions. It is undeniable that the vulnerability of the system will be manifested only when unfavorable conditions occur. Therefore, the main meaning of vulnerability should contain three parts: (1) sensitivity, the extent to which the system can withstand the impacts of unfavorable conditions; (2) exposure, the system's ability to resist interference, especially for long-term adverse changes; the smaller the impact is, the weaker the exposure; and (3) adaptability, the system's ability to return to the original state when unfavorable conditions disappear.

The narrow definition of risk means risk events [17]; the same risk event on different systems will produce different effects [18]. Chang et al. believe that the path of risk should include four parts: risk source, risk event, risk generation, and risk outcome. Risk generation is generated by the coupling of threat and vulnerability. Under the influence of the same risk event, the greater the project vulnerability, the greater the risk loss (or risk outcome) [19]. Zhang et al. take project risk as an independent variable and verify that project risk can have a positive impact on project vulnerability by establishing the structural equation model of risk and vulnerability [20].

In summary, PPP project risk comes from the external environment, while PPP project vulnerability is an inherent property of the project itself. Therefore, it is important to explore the relationship between vulnerability and risk when analyzing PPP projects. According to the United Nations Committee on Disaster Reduction and Shao's research [21], the relationship between vulnerability and risk can be expressed through Formula (1).

$$R = \frac{H \cdot V}{C} \quad (1)$$

where R denotes project risk, H denotes a risk event, V denotes vulnerability, and C denotes coping capacity. According to this formula and related research, the mechanism diagram of the vulnerability–risk relationship of PPP projects is derived; see Figure 1.

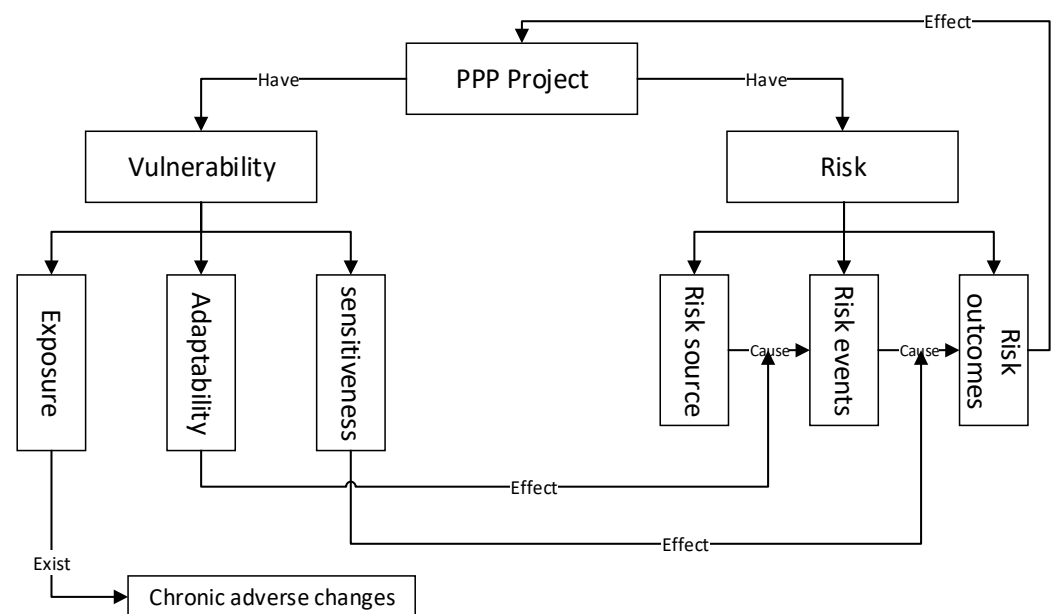


Figure 1. The mechanism diagram of the vulnerability–risk relationship of PPP projects.

2.3. The Generation of Social Risks in PPP Projects of Water Environmental Governance

PPP projects of water environmental governance involve two major issues, namely livelihood and environment. If not handled properly, it is likely that the final effect will be contrary to the project objectives and lead to social risks [22]. Based on previous research, the impact of water environmental governance projects on society is mainly reflected in aspects of environmental change, service provision, and corresponding price [23–25]; in addition, the safety issue of a project is also considered important [26]. Therefore, this paper summarizes environmental issues, safety issues, service issues, and price issues as four main reasons that trigger social risks, among which service issues and price issues are the problems faced during the operation period. In terms of projects of water environmental governance, the public is more concerned about whether the governance effect can be sustained and whether management is in place [27], while the operator and private capital are concerned about the government's subsidy mechanism [28]. Therefore, the main social risks in PPP projects of water environmental governance are environmental issues, safety issues, governance effect issues, and subsidy mechanism issues.

(1) Environmental issues. The term “environment” can refer to both the natural environment and an artificially created environment (social, economic, policy, etc.). Generally speaking, sudden changes in the natural environment can directly lead to huge losses or even the disintegration of the project. With the improvement in the cultural quality of people, they gradually understand the uncontrollability of natural disasters on the projects, and the government’s subsidy mechanism to pacify the affected people is more comprehensive and less prone to instability situations. On the contrary, the changes in an artificially created environment can produce greater social risks [29]. For example, in the first half of 2021, Japan’s discharge of nuclear wastewater into the Pacific Ocean resulted in the expansion of radioactive substances to the entire Pacific Ocean, causing high prices of most seafood, further creating public panic.

(2) Safety issues. These refer to accidents in which people are injured or even killed during the project period due to human errors, resulting in economic losses. These accidents will lead to public distrust in this type of project and also questions of the ability of the government and the project company [30]. For example, in 2015, a large-scale explosion occurred at the Tianjin Port dangerous goods warehouse, resulting in massive casualties; for a long time, the residents were unstable and had extreme distrust of dangerous goods warehouses.

(3) Governance effect issues. These contain two parts; one is whether the overall perception of the water environment (color, smell, etc.) can meet the requirements of the public and the qualified test just after the completion of a project. The other one is the deterioration speed of the water quality during the operation period of the projects. It is mainly related to whether the pollution source has been treated during the water environmental governance process and the level of management during the operation period [31].

(4) Subsidy mechanism issues. These refer to the question of whether a balance can be achieved among the inputs of the operating company, the management effect, and the government subsidy during the operation period. There are two common subsidy mechanisms; one is to assess and subsidize the construction and operation periods separately, and the other one is to assess the project as a whole without assessing the construction period separately [32].

2.4. The Diffusion of Social Risks in PPP Projects of Water Environmental Governance

When the risk arises, it may trigger risk events and cause social impacts. This requires information dissemination through the transmission, amplification, and even distortion of facts between individuals. In the age of internet connectivity, it is gradually transformed into the media’s information transmission. Considering the externality and non-exclusivity of PPP projects of water environmental governance, a very large number of people may become a link in the chain of information dissemination.

In the early stages of a risk event, the stakeholders of the event can be affected more directly. This part of people will generate bad feelings and also affect their neighborhood. The media, also through processing and exaggerating information about events, evokes sympathy among the target audience and stimulates social psychological identification [33]. When the target masses have empathy for the desperation, pain, and other psychological impacts felt, the bad mood will be spread. When the social risks accumulate to a certain extent, exceeding the threshold value that the region can carry, the social risks will continue to expand without taking measures, while the social risks will be suppressed when they are smaller than the threshold value. The specific diffusion transmission mechanism is shown in Figure 2.

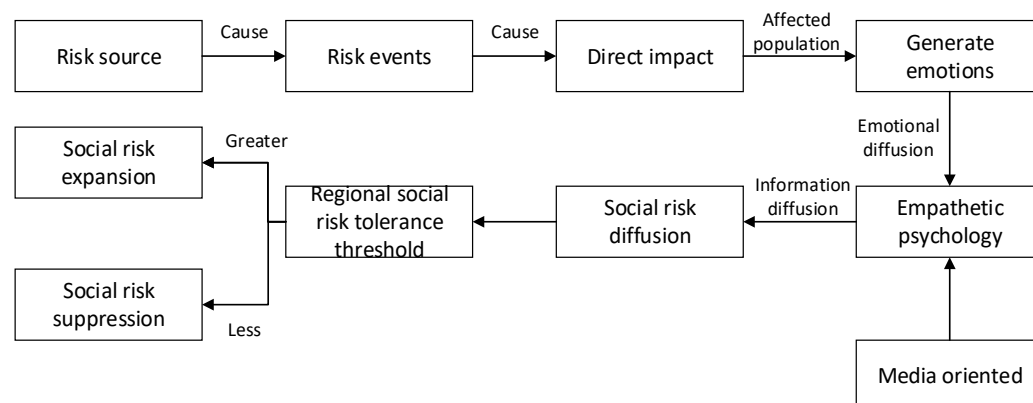


Figure 2. The diffusion and transmission mechanism of social risks.

3. Methodology

3.1. System Dynamics Method

According to the above analyses, the social risks in PPP projects of water environmental governance are dynamic and complex, and the evolution laws cannot be described by a simple or static mathematical model. It is necessary to study this topic from a dynamic perspective; therefore, referring to Liu et al.'s research [34], the SD (system dynamics) method is applied in this paper. It is a common research method in system dynamics and was proposed by Professor Forrester. It was originally called industrial dynamics [35] and is a discipline that analyzes and studies information feedback systems, as well as a cross-integrated discipline that recognizes system problems and solves system problems. Compared with traditional research methods, such as social network analysis [36] and the Markov chain [37], the system dynamics method can better obtain the risk changes in projects in the whole life cycle, and its model boundary is wider.

Based on the previous analyses, the level of social risks in PPP projects of water environmental governance is dynamically changing, and the social risks in the construction period and the operation period present different specific performances. Thus, traditional research methods cannot carry out targeted research. Scholars have also searched for certain approaches. For example, Ren et al. proposed a complex network model that combines risk and vulnerability; the idea of the risk evolution trend has a meaningful breakthrough and reference value [38]. Based on the dynamic spatial Durbin model, Zhang et al. analyzed the characteristics of real estate financial risk evolution and its influencing factors [39]. No matter what kind of model is used, it is necessary to reflect the dynamic change in risks; therefore, this paper selects the system dynamics model as the research tool.

SD is a science that closely integrates system science theory and computer simulation to study the feedback structure and behavior of a system [40]. It is an important branch of system science and management science, which was initially known as “industrial dynamics” and was renamed “system dynamics” with the expansion of the concept [41]. The construction of the system dynamics model should follow the following: firstly, finding out the vulnerability driving factors of PPP projects of water environmental governance based on the three major attributes of vulnerability; secondly, constructing the causal loop diagram related to vulnerability and social risks and also constructing the stock–flow model; thirdly, using a case study to carry out a certain dynamic simulation on the social risks of PPP projects of water environmental governance and obtaining the trends of social risks; fourthly, changing the values of relevant parameters, carrying out a certain sensitivity analysis of social risks and finding out the sensitivity factors; and finally, putting forward governance suggestions. In this study, the VenPLE32 software is adopted to carry out the system dynamics simulation and sensitivity analyses.

3.2. Identification of Vulnerability Driving Factors in PPP Projects of Water Environmental Governance

Considering that there is relatively less literature on directly identifying the vulnerability of PPP projects of water environmental governance, this paper combines general PPP projects with the characteristics of water environmental governance projects to carry out the research. Since the vulnerability of PPP projects is based on their internal attributes, and most literature uses sensitivity, adaptation, and exposure to measure vulnerability, this paper also divides the vulnerability of PPP projects of water environmental governance into these three dimensions for identification. The results are shown in Table 1.

Table 1. Vulnerability driving factors of PPP projects of water environmental governance.

Primary Influencing Factors	Secondary Influencing Factors	Third Influencing Factors
Exposure (anti-interference ability)	Relevant Legal Systems	PPP project policies
		Risk response experience and mechanism
		Project supervision mechanism
		Project evaluation system
		Project approval system
	System Stability	Project integrity
		Responsible for government stability
		Stability of project company personnel
	Partnership	Participant partnership
		Personnel communication efficiency
	Competence Indicators	Quality of materials and equipment
		Qualification of participants
		Relevant experience of participants
		Participant related talents
		Familiarity with construction technology
Sensitivity (degree of impact)	Project Goal Setting	Setting water environment goals
		Setting social goals
	Fund Recovery Capability	Subsidy during operation period
		Project operation capability
		Business environment
		Social support
	Project Properties	Project scale
		Project investment amount
		Financing structure
	Adaptability (resilience)	Resource Reserve
Participant talent reserve		
Participant fund reserve		
Restore Elasticity		Education and training efforts
		Design capacity
		Project management capability

3.3. Construction of Causal Loop Diagram

The causal loop diagram is the logical framework of the system dynamics model, and its role is to connect various elements of a system. It is a primary task of building a system dynamics model and also the basis for analyzing the subsequent quantitative model [42].

Based on the previous analyses, the social risks in PPP projects of water environmental governance should include two subsystems: vulnerability subsystem and risk evolution subsystem.

(1) Vulnerability Subsystem

The vulnerability subsystem contains three aspects, the exposure subsystem, sensitivity subsystem, and adaptability subsystem.

① Exposure Subsystem

The exposure subsystem reflects changes in the exposure intensity of PPP projects of water environmental governance. Exposure intensity mainly reflects the anti-interference ability during the construction period and the operation period, including relevant laws and regulations, system stability, cooperative relationships, and capacity indicators. The causal loop diagram of the exposure subsystem is shown in Figure 3.

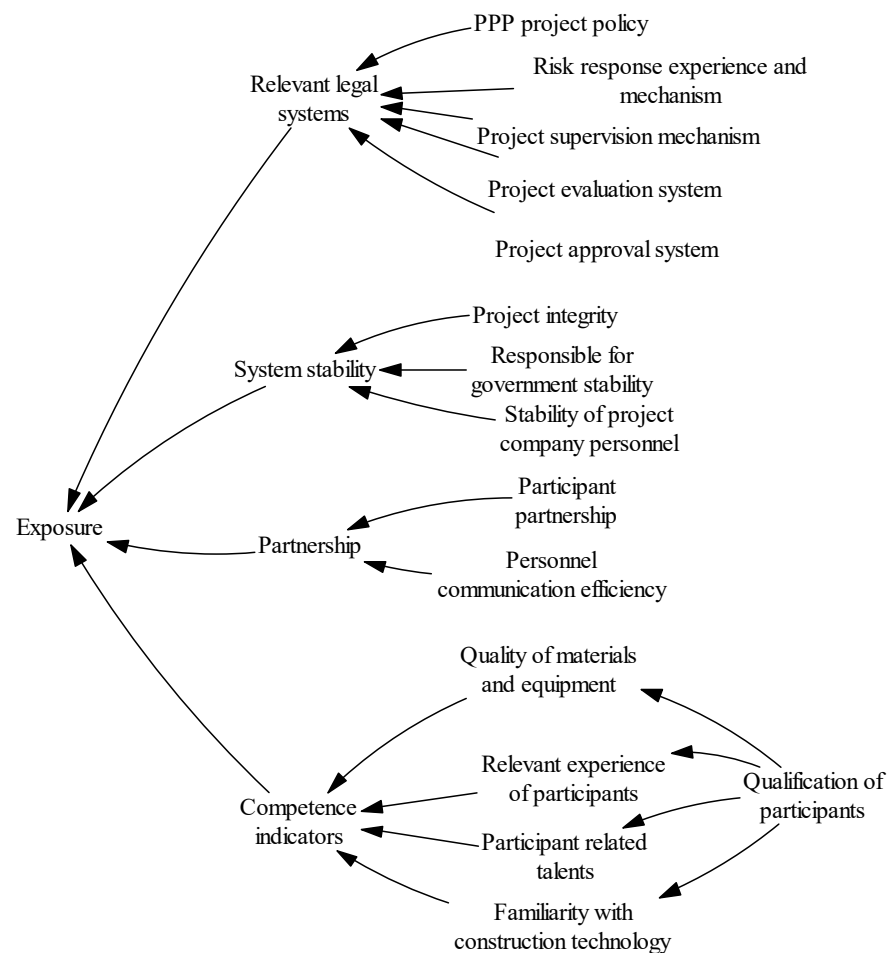


Figure 3. Causal loop diagram of exposure subsystem.

② Sensitivity Subsystem

The sensitivity subsystem reflects the changes in the sensitivity intensity of PPP projects of water environmental governance. The sensitivity intensity mainly reflects the state and inherent attributes of a project during the decision-making period. The lower the sensitivity intensity is, the lower the impact of a risk event is. It includes three factors, project target setting, capital recovery ability, and project characteristics. The causal loop diagram of the sensitivity subsystem is shown in Figure 4.

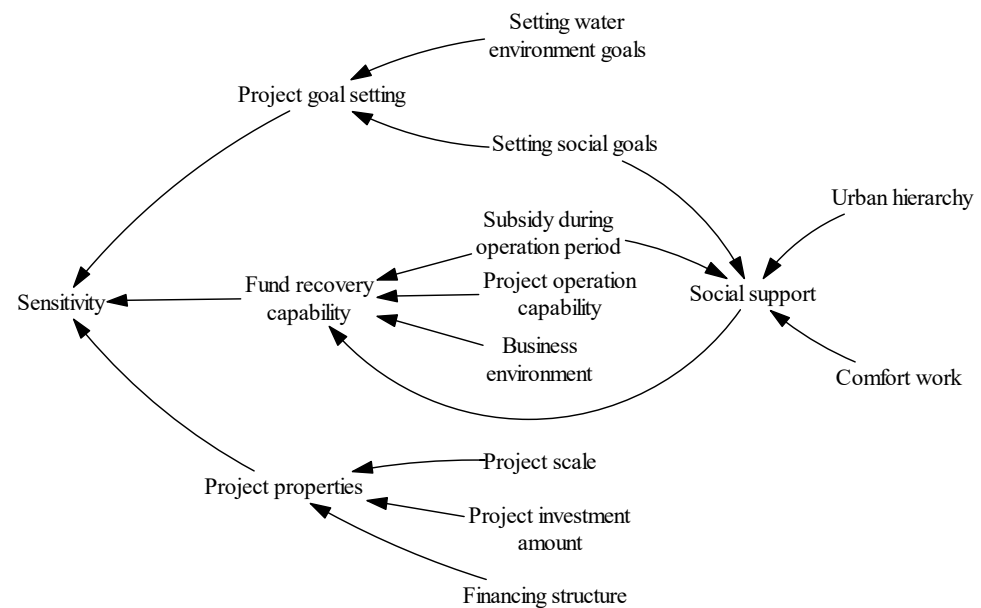


Figure 4. Causal loop diagram of sensitivity subsystem.

③ Adaptability Subsystem

The adaptability subsystem reflects the changes in the adaptive strength of PPP projects of water environmental governance. Adaptive strength mainly reflects the amount of resource reserve and the flexible resilience of the project constructor, including resource reserve and restore elasticity. The causal loop diagram of the adaptability subsystem is shown in Figure 5.

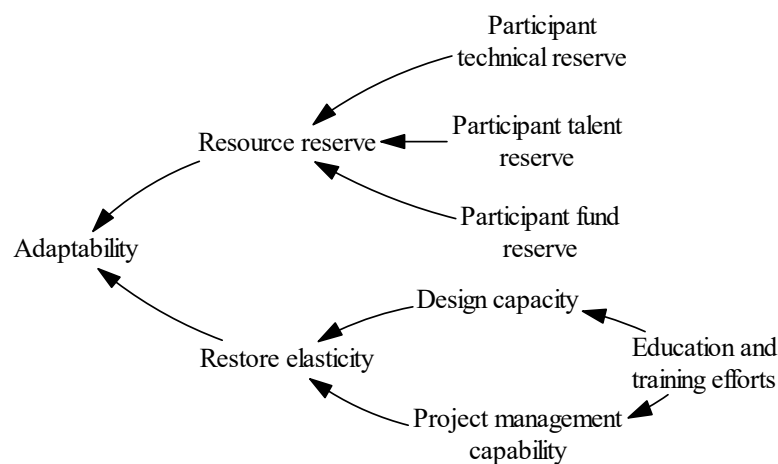


Figure 5. Causal loop diagram of adaptability subsystem.

(2) Risk Evolution Subsystem

In the formation process of the public opinion dissemination behavior of social networks, a self-digesting mechanism will exist in the social system, which means there is a possibility of the self-dissolution of the network public opinion [43]. Therefore, the threshold for the occurrence of social risks should exist, which is named the “social risk threshold”. When the sentiment of the society exceeds this threshold, it will lead to the occurrence of social risks [44]. Therefore, the causal loop diagram of the social risk evolution subsystem is established (without vulnerability-related influencing factors), which is shown in Figure 6.

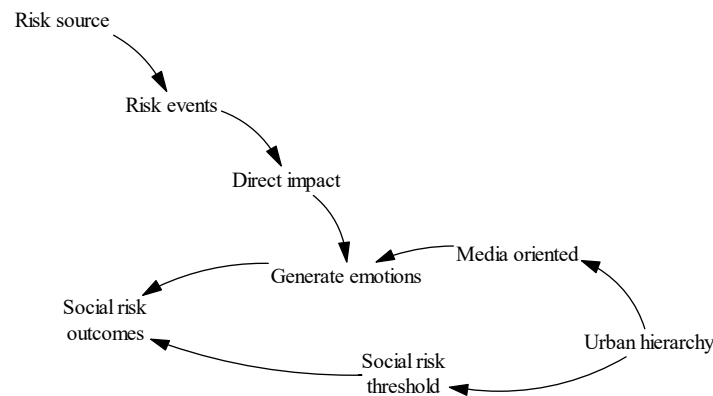


Figure 6. Causal loop diagram of social risk evolution subsystem.

By combining the above analyses, a complete causal loop diagram of the social risk evolution in PPP projects of water environmental governance is formed and shown in Figure 7.

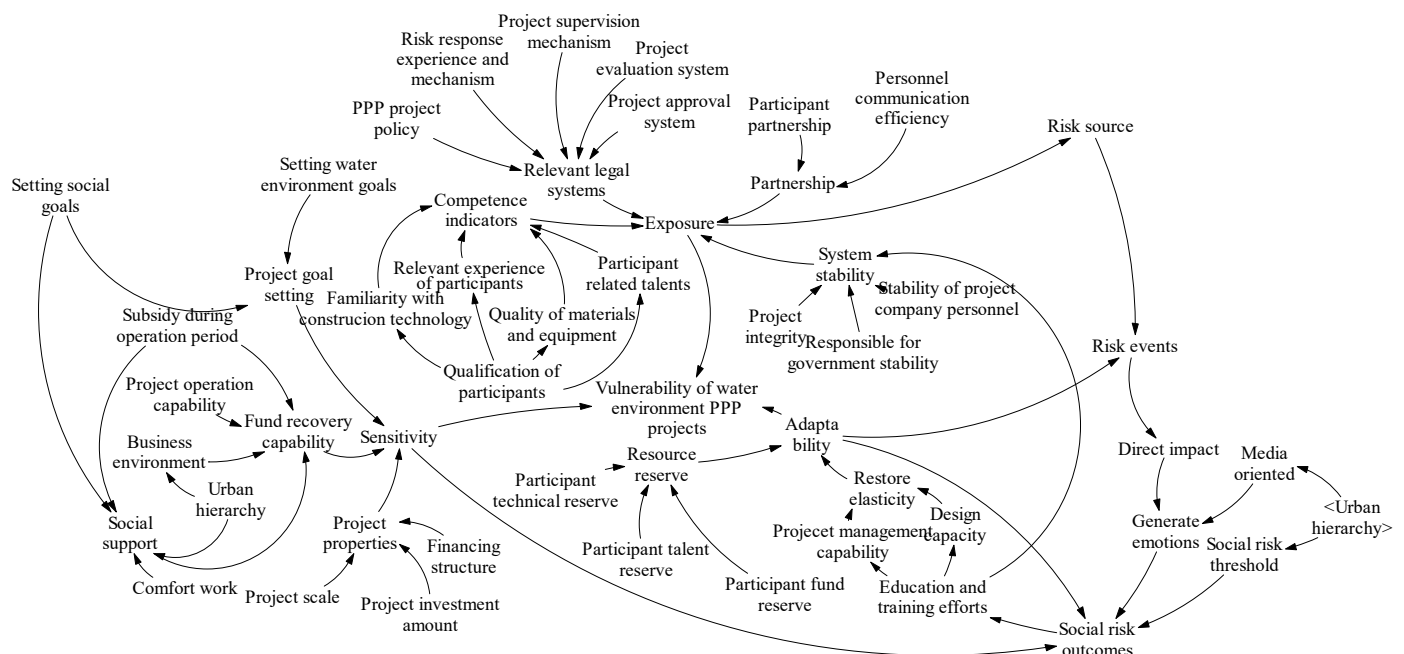


Figure 7. Causal loop diagram of social risk evolution in PPP projects of water environmental governance.

3.4. Construction of Stock–Flow Model

The causal loop diagram of the social risk evolution of PPP projects of water environmental governance is mainly used to describe the internal structure and function of the system and qualitatively depicts the relationship between social risks in PPP projects of water environmental governance and related factors [45]. Based on the above causal loop diagrams, the nature of each driving factor in Figure 7 is clarified. To further probe the mechanism of each driving factor, the stock–flow model of the social risk evolution of PPP projects of water environmental governance is established and shown in Figure 8.

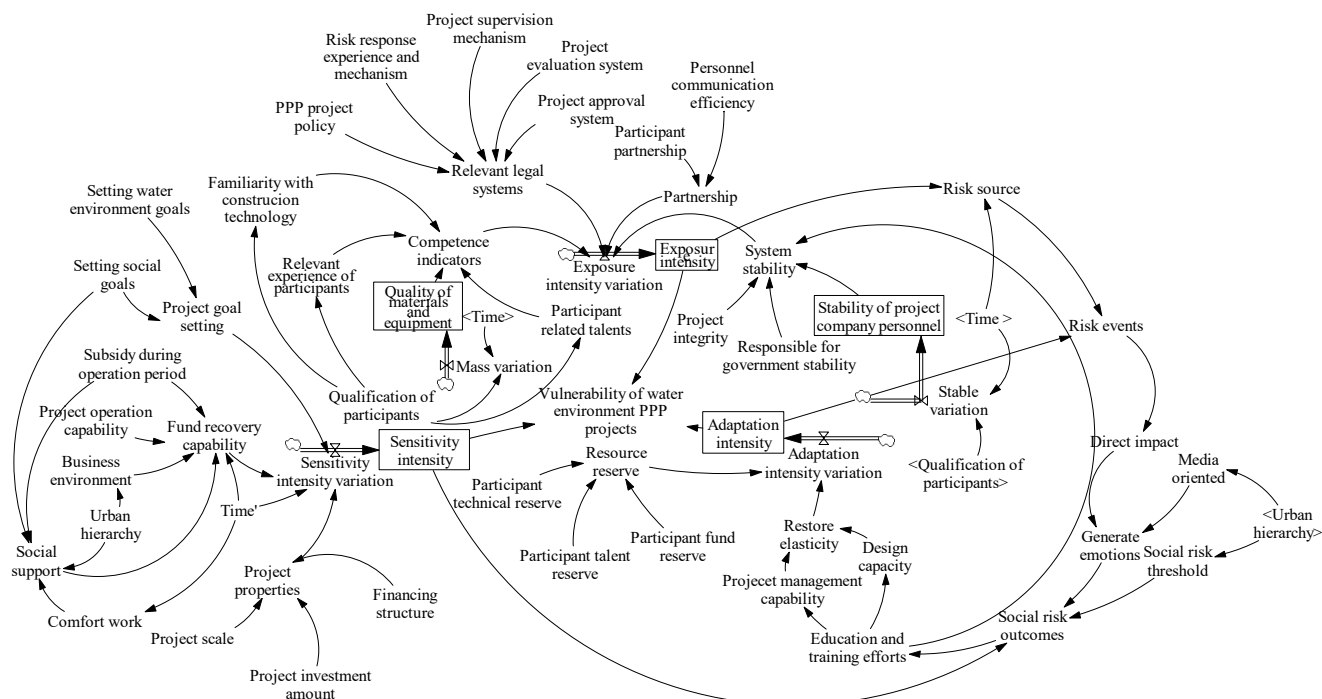


Figure 8. Stock model of social risk evolution of PPP projects of water environmental governance.

3.5. Case Study

The PPP project of the water environmental governance of Siyang County, Jiangsu Province, China, is chosen to be the case subject. This project is relatively standardized in the PPP mode operation process, the construction content involves a wide range, and the investment is large, which is a very good study case. Through the study of the project, we can sum up the relevant laws of social risks in China's water environmental governance PPP projects.

Siyang County has a well-developed water system, surrounded by four major watersheds, namely, Yi, Huai, Shu, and Si. Bounded by the ancient Yellow River, the Huai River system is in the south, and the Yishu and Surabaya systems are in the north. There are 45 major county rivers and 189 major township and street rivers. It is also known as a flood corridor. Hongze Lake, one of the four largest freshwater lakes in China, is neighboring Siyang County to the south, with a water area of 300 square kilometers. The lake is rich in fish, shrimp, turtles, and crabs, making a great contribution to the local aquaculture industry.

Siyang County has undergone a series of changes in the original water system through the governance, straightening, and dredging of the rivers in the county. Now there are more than fifty rivers in the county, which belong to four major water systems separately, the Hongze Lake, the General Liutang River, the Dajian River, and the Central Canal. Siyang County, after years of development, has been economically and technically equipped with the prerequisites for water modernization. However, there are still some problems, for example, the gap between the national and regional overall strategic goals of comprehensive water environmental governance, poor culture environment, and dirty water bodies. These make Siyang County the research subject. The PPP project was adopted by Siyang County for water environmental governance and applied a revenue-payment return mechanism.

A PPP project company should be responsible for the daily operation, management, and maintenance of the river, pipeline network, roads, and ancillary facilities. It undertakes flood fighting tasks during flood seasons to ensure the safe operation of the project and gives full play to the project benefits as well. As the management institution, the main obligations are the following: (1) promoting and organizing the implementation of laws and regulations on the management of rivers, pipe networks, and roads; (2) establishing

an inspection system to ensure the normal operation of the management works; (3) formulating practical management protocols and systems by the content of the management; (4) dealing with accidents and damages to rivers, pipe networks, and roads on time; and (5) equipping with corresponding observation facilities, transportation and flood prevention rescuing equipment, and management facilities by relevant laws and regulations and norms combined with the actual project.

The construction period of this project is three years, and the investment is made year by year according to 30%, 40%, and 30%. According to the “Notice of the State Council on Adjusting and Improving the Capital Funding System for Fixed Asset Investment Projects”, the capital fund of the project is about CNY 540 million. The initial registered capital of the equity-funded project company was calculated at CNY 540 million. The basic capital contribution is as follows: the proportion of the selected social capital party and Siyang County Water Investment Co., Ltd., is 9:1, the selected social capital party contributed CNY 486 million, and Siyang County Water Investment Co., Ltd., contributed CNY 54 million.

The capital contribution form is monetary funds. The return mechanism of this project is a feasibility gap subsidy. The calculated formula is annual feasibility gap subsidy = construction cost and investment return payable in the current year + operation and maintenance fee in the current year $\pm$ performance appraisal awards and penalties in the current year—user fee income collected by the government in the current year.

3.6. Weight Determination

To construct the statistic dynamics equation, it is necessary to find the functional relationship between the driving factors and determine each factor’s weight [46]. To avoid the disadvantages of average value calculation, this paper uses the OWA (Ordered Weighted Averaging Operator) assignment method to weigh the vulnerability of the PPP project of water environmental governance in Siyang County. In this paper, five experts were invited to rate factors’ importance, and the questionnaire was in the form of a five-point Likert scale. Taking the “relevant legal systems” as a calculation example, its subordinate influencing factors are the PPP project policy, risk response experience and mechanism, project supervision mechanism, project evaluation system, and project approval system. The evaluation scores are shown in Table 2.

Table 2. Influencing intensity score of subordinate influencing factors of relevant legal systems.

Factors	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
PPP project policy	3	4	4	5	4
Risk response experience and mechanism	5	5	5	5	5
Project supervision mechanism	3	3	4	5	4
Project evaluation system	2	2	3	2	1
Project approval system	3	2	3	4	3

The OWA operator is used to unify the scores of the five experts; then, the absolute impacts of the PPP project policy, risk response experience and mechanism, project supervision mechanism, project evaluation system, and project approval system on relevant legal systems are as follows:

$$\frac{C_{5-1}^0 \times 5}{2^{5-1}} + \frac{C_{5-1}^1 \times 5}{2^{5-1}} + \frac{C_{5-1}^2 \times 4}{2^{5-1}} + \frac{C_{5-1}^3 \times 4}{2^{5-1}} + \frac{C_{5-1}^4 \times 4}{2^{5-1}} = 4.31 \quad (2)$$

$$\frac{C_{5-1}^0 \times 5}{2^{5-1}} + \frac{C_{5-1}^1 \times 5}{2^{5-1}} + \frac{C_{5-1}^2 \times 5}{2^{5-1}} + \frac{C_{5-1}^3 \times 5}{2^{5-1}} + \frac{C_{5-1}^4 \times 4}{2^{5-1}} = 4.94 \quad (3)$$

$$\frac{C_{5-1}^0 \times 5}{2^{5-1}} + \frac{C_{5-1}^1 \times 4}{2^{5-1}} + \frac{C_{5-1}^2 \times 4}{2^{5-1}} + \frac{C_{5-1}^3 \times 3}{2^{5-1}} + \frac{C_{5-1}^4 \times 3}{2^{5-1}} = 3.75 \quad (4)$$

$$\frac{C_{5-1}^0 \times 2}{2^{5-1}} + \frac{C_{5-1}^1 \times 2}{2^{5-1}} + \frac{C_{5-1}^2 \times 2}{2^{5-1}} + \frac{C_{5-1}^3 \times 2}{2^{5-1}} + \frac{C_{5-1}^4 \times 1}{2^{5-1}} = 1.94 \quad (5)$$

$$\frac{C_{5-1}^0 \times 4}{2^{5-1}} + \frac{C_{5-1}^1 \times 3}{2^{5-1}} + \frac{C_{5-1}^2 \times 3}{2^{5-1}} + \frac{C_{5-1}^3 \times 3}{2^{5-1}} + \frac{C_{5-1}^4 \times 2}{2^{5-1}} = 3.00 \quad (6)$$

The relative weights of all the influencing factors were calculated by adding and recalculating, and the values were 0.2404, 0.2753, 0.2091, 0.1080, and 0.1672, respectively.

Other influencing factors follow the same calculating process, and each influencing factor's weight is calculated and normalized. The results are shown in Table 3. In Table 3, the numbers represent the weights of the subordinate influencing factors that account for the superior influencing factors. A larger number suggests a high weight of a subordinate influencing factor over a superior influencing factor, while a smaller number suggests the opposite.

Table 3. Weights of influencing factors of PPP projects of water environmental governance.

Primary Influencing Factors	Secondary Influencing Factors	Third Influencing Factors	Weight
Exposure (0.4020)	Relevant Legal Systems (0.2016)	PPP project policy	0.2404
		Risk response experience and mechanism	0.2753
		Project supervision mechanism	0.2091
		Project evaluation system	0.1080
		Project approval system	0.1672
	System Stability (0.3087)	Project integrity	0.2356
		Stability of project company personnel	0.3029
		Education and training efforts	0.0817
		Stability of project company personnel	0.3798
	Partnership (0.2428)	Participant partnership	0.5664
		Personnel communication efficiency	0.4336
	Competence Indicators (0.2469)	Quality of materials and equipment	0.2244
		Relevant experience of participants	0.2475
		Participant related talents	0.2640
		Familiarity with construction technology	0.2640
Sensitivity (0.2965)	Project Goal Setting (0.1951)	Setting water environment goals	0.5208
		Setting social goals	0.4792
	Fund Recovery Capability (0.3232)	Subsidy during operation period	0.3265
		Project operation capability	0.2163
		Business environment	0.2571
		Social support	0.2000
	Project Properties (0.4817)	Project scale	0.4048
		Project investment amount	0.4702
		Financing structure	0.1250
Adaptability (0.3015)	Resource Reserve (0.3828)	Participant technical reserve	0.2727
		Participant talent reserve	0.3011
		Participant fund reserve	0.4261
	Restore Elasticity (0.6172)	Design capacity	0.3952
		Project management capability	0.6048

4. Research Results

4.1. Simulation Analyses

The Vensim software is used to test whether all variables in the model have been weighed as well as the system dynamics equations established between all variables. The feedback is “Model is OK”, which means the model has no problem. Then, the whole system is simulated, and the trend graph of the project vulnerability index and the trend graph of the project’s social risk evolution are obtained, which are shown in Figures 9 and 10.

In Figure 9, the overall vulnerability index of the project shows an upward trend, following a trend of fast–slow–fast. In Figure 10, the social risks of the project do not show a linear evolution trend. It fluctuates both during the construction periods and the operation periods. Specifically, during the construction period, it shows a trend of first high and then low. During the beginning of the operation period, it shows a downward trend, while in the middle and late stages of the operation period, it shows an upward trend.

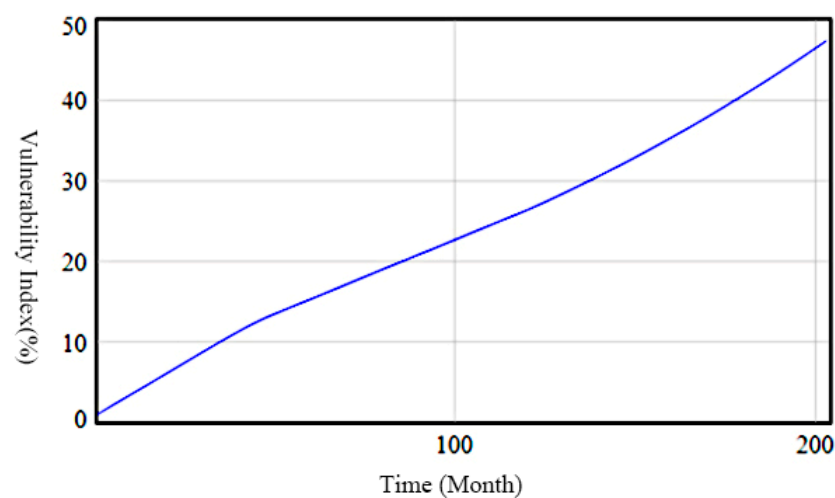


Figure 9. Project vulnerability index change trend.

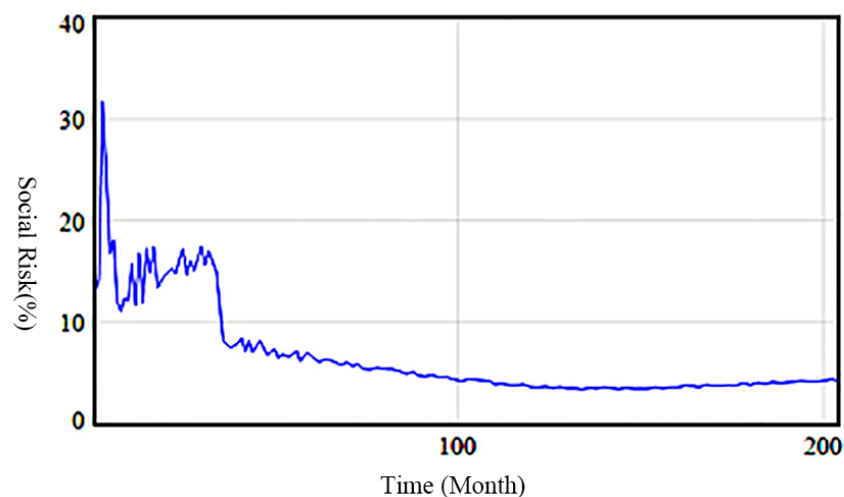


Figure 10. Project social risk evolution trend.

4.2. Sensitivity Analyses

To extend the research results to more water environmental management projects, it is necessary to change some variables in the system, while others remain unchanged [47]; the evolutionary trend of social risks and the vulnerability of PPP projects of water environmental governance are observed and the driving effect on social risks. Considering that there may exist many factors that affect the vulnerability and social risks of a project,

based on previous studies [48–51], this paper selects city class, relevant legal systems, and resource reserves as the changed variables.

(1) City Class

This variable is varied in the model to simulate the impact of external socio-economic conditions on social risks in PPP projects of water environmental governance. The vulnerability trend is shown in Figure 11, and the social risk evolution trend is shown in Figure 12. From Figure 11, the impact of city class on the vulnerability exists but is not strong, and the vulnerability of the first-tier cities is at the bottom. From Figure 12, the city class and vulnerability show a U-shaped relationship, that is, the social risks of the first-tier cities are the highest, while the second-tier cities are the lowest.

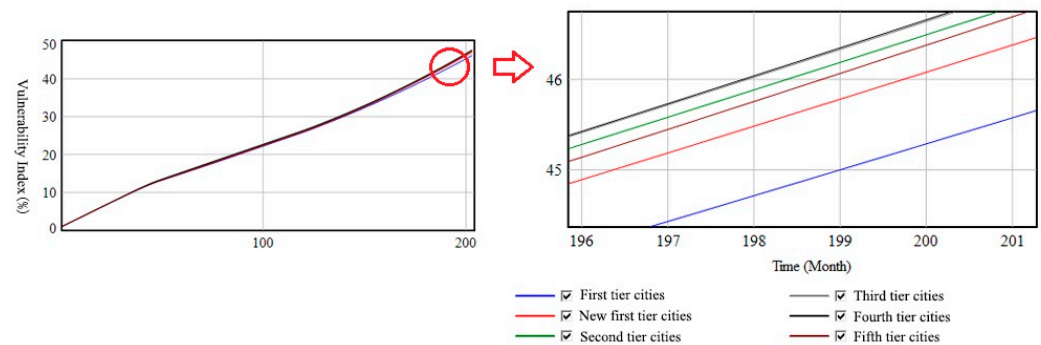


Figure 11. Sensitivity result of vulnerability trend (city class).

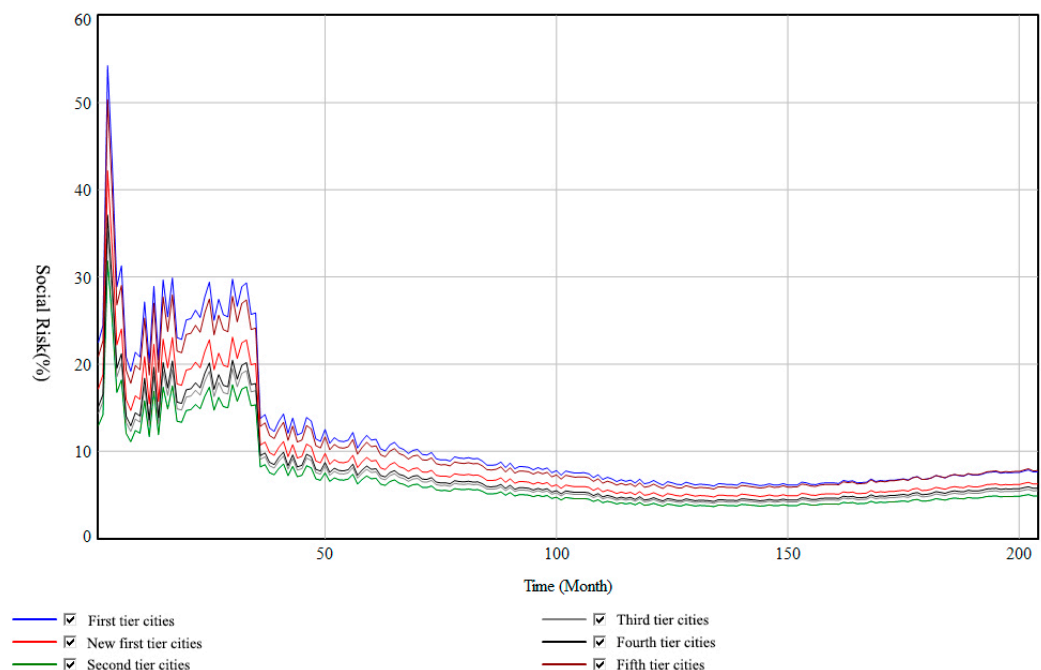


Figure 12. Sensitivity result of social risk evolution trend (city class).

(2) Relevant Legal Systems

Considering the fact that PPP projects are not well suited in China [52], the evaluation mechanism and approval mechanism of PPP projects are therefore set at a low value of 0.55 and 0.6, respectively. In the sensitivity analysis, it is assumed that a 20% rise in the relevant legal system is entered into the model as a condition for a sound legal system. The vulnerability trend and the social risk evolution trend are shown in Figures 13 and 14. From Figure 13, the soundness of the legal systems of PPP projects can effectively reduce the vulnerability of PPP projects to water environmental governance. From Figure 14,

the soundness of the legal systems of PPP projects can reduce the social risks during the construction period, especially for the early stage of construction involving the demolition, relocation, and compensation parts. During the construction period, the maximum social risks can be reduced by about 30%.

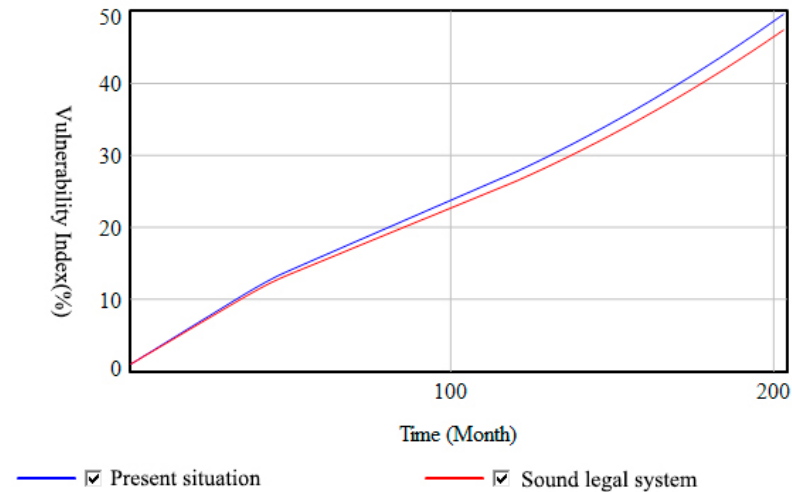


Figure 13. Sensitivity result of vulnerability trend (relevant legal systems).

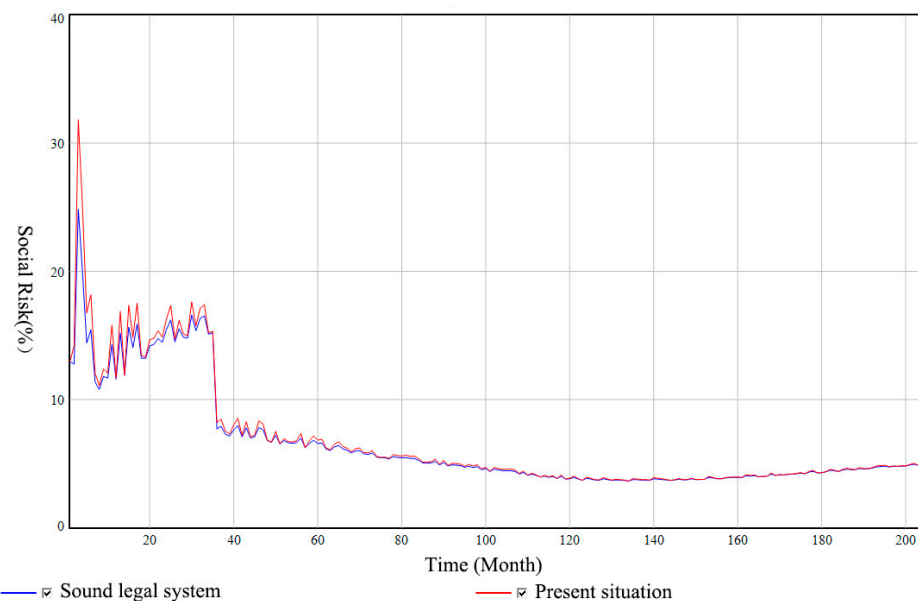


Figure 14. Sensitivity result of social risk evolution trend (relevant legal systems).

(3) Resource Reserves

Increasing resource reserves by 20% as a condition for sufficient resource reserves, the vulnerability trend and the social risk evolution trend are shown in Figures 15 and 16. From Figure 15, resource reserves have a significant effect on reducing the vulnerability of the projects by more than 10%. From Figure 16, the change in the social risks in PPP projects of the water environmental governance during the construction period is not obvious, but in the operation period of the project, it has a certain effect on the reduction in social risk.

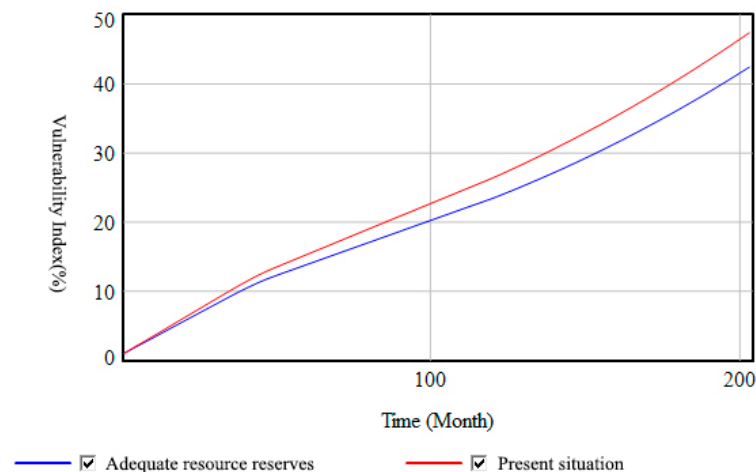


Figure 15. Sensitivity result of vulnerability trend (resource reserves).

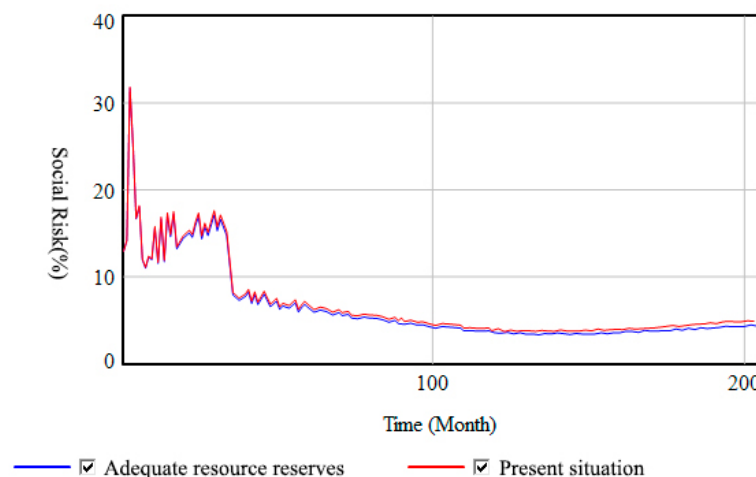


Figure 16. Sensitivity result of social risk evolution trend (resource reserves).

4.3. Result Discussions

Based on the above analyses, social risks show significant fluctuations throughout the entire project period, which is in line with the studies of Chen et al. and Jiang et al. [9,12]. Additionally, by dividing the project period into the construction period and the operation period, this paper finds that social risk shows an inverted U-shaped trend during the construction period, while it shows a U-shaped trend during the operation period. The main reasons may be the following: (1) at the beginning of the construction period, due to slow compensation for resettlement fees, seedling fees, and other expenses, some affected residents and villagers may engage in small-scale resistance behavior, causing the social risk value to soar to a higher level in a very short period; (2) with the appeasement work of the government and the project company, some residents and villagers gradually understand, and the social risk value is restored to a more normal level; (3) as the project proceeds, the social risk value rises slowly with fluctuations due to the long duration of the project, which more or less disturbs the travel and rest of the neighboring residents, and some complaints may also occur; (4) after the completion of the project, with the improved environment, the social risk value dropped rapidly, even lower than the level before construction, and continued to decline slowly over a long period with reduced volatility; and (5) at the late stages of the project's operation, the social risk value shows a tendency to rise because of environmental deterioration, weakening continuous operation ability, equipment aging, etc.

The city class does have an impact on the social risks of projects, which is consistent with the research of Liu and Kang et al. [48,53]. In addition, this paper finds that the relationship between city class and social risks is U-shaped; the first-tier and fifth-tier cities have the highest social risks. The main reasons may be the following: (1) in the first-tier cities, due to a strong awareness of rights protection, legal awareness, and a high level of education, they focus more on their own interests and are prone to discontent encouraged by the media; (2) while in the fifth-tier cities, because of lacking enough education, residents have more radical means of defending their rights, which can lead to social risk events; and (3) in the other tier cities, due to a certain level of cultural and legal education, as well as relatively mild ways of expressing dissatisfaction, social risk levels are minimized.

The more perfect the relevant legal system is, the lower the social risks in PPP projects of water environmental governance, and the trend of their vulnerability changes will also slow down. These findings are similar to Walker and Wang et al. [49,50]. Furthermore, this paper also finds that improving relevant legal systems mainly reduces social risks during the construction period but has little impact on social risks during the operation period. The main reasons may be the following: during the construction period, through institutional regulations and guidance, all parties involved in the project will invest more in the management of social risk systems, making the compensation process more standardized, and taking into account the feelings of surrounding residents. As a result, social risks are reduced.

Enhancing resource reserves can reduce the social risks in PPP projects of water environmental management, which is in line with Ohlsson et al. [51]. Furthermore, this paper finds that enhancing resource reserves mainly reduces social risks during the operation period but has little impact on social risks during the construction period. The main reasons may be the following: (1) During the construction period, the construction company has accumulated rich resources and experience, and the usage of resources is appropriate. However, during the operational period, the operation management of a project is an unfamiliar field for most construction companies, and existing resources and experience are also not applicable; (2) the resource reserves of PPP projects include the technical reserves, talent reserves, and financial reserves of participants, which ensure the long-term effectiveness of PPP projects. However, due to the lack of attention to the operational cycle, the resource reserves of PPP projects are generally low (resources), which can lead to the breakage of the project's funding chain during the operation period, especially in the later stage, and thus cause social risks.

Since Siyang County is a relatively standardized project in the PPP mode operation process, the results and conclusions can help solve the common problems of water environmental governance projects in China to some extent. The research method, the social risk assessment model, the overall trend of social risk changes, and influencing factor analyses can be extended to other water environmental governance PPP projects in China and help them to solve their own problems.

5. Conclusions and Suggestions

5.1. Conclusions

This paper explores the characteristics and the system dynamic evolution paths of social risks in PPP projects of water environmental governance. By using SD, the OWA operator, simulation analysis, etc., the system dynamics equations and the stock-flow model have been established. In addition, taking the representative case of the Siyang County PPP project helps sum up relevant laws of social risks in China's PPP projects of water environmental governance. The main conclusions are as follows: (1) the level of social risks in a PPP project during the construction period is higher than that in the operation period, especially in the early stage of the construction period; (2) during the completion period, the level of social risks is reduced to a low level; (3) during the middle and late operation period, the level of social risks shows an increasing tendency due to the

deterioration of the environment; and (4) from sensitivity analyses, city class, relevant legal systems, and resource reserves are the greatest influencing factors.

5.2. Theoretical Implications

Existing research has explored social risks in PPP projects of water environmental governance [22–25], but there still needs to be further discussions of sources and influencing factors of social risks. This paper establishes the theoretical framework of social risks by combining vulnerability, which deepens the understanding of the influencing mechanism of social risks. In addition, most research is from a static perspective to study social risks in PPP projects of water environmental governance [7,11,27,29]. However, due to the complex management system, the long operation cycle, and the different social risks of different phases of a project, it is necessary to probe this top from a dynamic perspective. By introducing the system dynamics theory, the social risks throughout the entire phases of a PPP project can be predicted, and the prevention measures and emergency plans can be proposed theoretically, which expands research perspectives and enriches the related theoretical basis.

5.3. Suggestions

Based on previous analyses and conclusions, some suggestions are put forward to reduce the vulnerability and social risks in PPP projects of water environmental governance.

(1) Enhancing the local residents' literacy and legal awareness based on the characteristics of different city classes.

From the sensitivity analyses, the social risks in PPP projects of water environmental governance are related to the city class. Public dissatisfaction varies among different classes of cities. When the infringement occurs, extreme behaviors are often generated according to the residents' own benefits, such as violent resistance, illegal demonstrations, etc., which will interfere with the normal conduct of a project. Therefore, it is necessary to carry out legal education activities for local residents, especially low-class cities, and to inform them of reasonable and legitimate complaints as a way to avoid the disruption of the project process and the local security environment.

(2) Improving the legal system and establishing the assessment mechanism for PPP projects of water environmental governance.

Relevant legal systems are also an important influencing factor of social risks in PPP projects of water environmental governance. Therefore, establishing the assessment mechanism for PPP projects of water environmental governance can help match the water environment quality with the government subsidies given to the project company during the operation period. It can also help project companies increase investments in the protection of the water environment so that the water environment is maintained at a high level for a long time.

(3) Increasing resource reserves and strengthening the auditing of bidding companies' resources.

Resource reserves can affect the social risks of PPP projects of water environmental governance. Increasing resource reserves can increase the possibilities of the continuous maintenance and operation of PPP projects so that the water environment is maintained at a better and stable level, which can significantly reduce social risks during the operation period. In addition, urging bidding companies to increase their resource reserves can also help them enhance their own strength, reduce their capital debt ratio, and especially for large companies, prevent their wild expansion. Furthermore, it can effectively avoid heavy damages from both outside and other projects and enhance the successful probability of the sustainable operation of PPP projects of water environmental governance.

(4) Implementing differentiated governance approaches and focusing on monitoring the risk sources.

According to the research results, the social risks show a different fluctuating trend during the construction period and the operation period, respectively. It is necessary to monitor the most important sources of social risks in line with the different phases and importance. At the beginning period, it is important to know whether residents are satisfied with the relevant compensation policy for demolition and relocation by conducting a detailed investigation and visit. Additionally, during the whole construction period, it is necessary to control the dust and noise of the construction and provide convenience for residents, such as reasonably planning travel routes and appropriately fencing in different areas and at different times. During the operation period, the government, society, and project companies should work together to prevent pollution and to carry out environmental protection reviews of the upstream enterprises that may cause pollution, such as urging them to use the wastewater treatment equipment and discharging the wastewater that meets the standard.

6. Research Limitations

Due to the complexity and randomness of the social risk mechanism of PPP projects of water environment governance, and the different influencing factors during the construction and operation periods, there is a lack of unified measurement standards and measurement methods. Although this article partially addresses the shortcomings of this problem by introducing the system dynamics, there are still issues such as small system boundaries, the subjective selection of factor relationships, and so on. Therefore, subsequent research can explore by expanding system boundaries and incorporating external economic, environmental, and other factors into the model.

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