

Research on the Dynamic Evolution of Sponge City Construction Risk Based on System Dynamics

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Research Article

Keywords: Sponge city, System dynamics, Grounded theory, Full life cycle, Risk dynamic evolution

Posted Date: October 6th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-902383/v1>

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Abstract

Following the research idea of "theoretical analysis – mechanism analysis – model simulation", the basic concept and basic theory of sponge city construction risk are firstly defined, and then the risk factors and internal mechanism of sponge city construction are analyzed by the grounded theory method. Finally, the system dynamics model is used for simulation. The dynamic development and key risk factors of each sub-risk system in the whole life cycle are analyzed, and the countermeasures to reduce the risk of sponge city construction are given.

Introduction

Climate observation data in the past 100 years show that the global climate is warming year by year, and the frequency of extreme rainfall is expected to continue to increase in the future (Shastri et al. 2019), leading to huge floods (Zolch et al. 2017). With the acceleration of urbanization, the increase of population density, building density and industrialization degree, urban water consumption and water frequency increase, water resources sharply reduced; The substitution of impervious pavement for natural ground such as vegetation and soil leads to the destruction of urban water ecosystem (Stovin et al. 2013; Visitacion et al. 2009). Climate change and urbanization bring dual challenges to storm water management systems and seriously threaten the safety of human life and property (Herslund and Mguni 2019; Burns et al. 2012; Mahaut and Andrieu 2019; Coffman 1999; Schueler 1987). The United States, Australia, New Zealand and other developed countries have put forward low Impact Development (Whelans et al. 1994), Best management Practices (Kostalova and Tetrevoa 2016) water Sensitive Urban Design (Martin et al. 2000), Low Impact Urban Design and Development (Danjie et al. 2016), Sustainable Drainage Systems (Kongjian et al. 2015; Hao 2013). The core idea is to treat flood and pollution from the source in the way of green infrastructure. Especially in China, China is simultaneously facing a series of serious water ecological problems such as water logging, water system pollution and habitat loss of aquatic organisms (Technical Guide for Sponge City Construction 2014). The Ministry of Construction surveyed 351 Chinese cities in 2010 and found that more than 60 percent had experienced water logging in the previous year, and nearly 40 percent had experienced more than three water logging disasters. An evaluation of more than 700 rivers by the Ministry of Water Resources found that 46 percent of them were polluted, and the country's seven major river basins are facing serious problems such as water shortage and water pollution. Water resources, water security and water ecology interwoven situation (Seyyed and Zahra 2012; Gerald 2003). With reference to the urban storm water management concept of developed countries, China has put forward a unique water treatment scheme – sponge city. Up to now, although the 30 pilot sponge cities in China have achieved obvious results, there is still a certain gap from the expected results. A series of problems, such as imperfect legal norms, imperfect management system and lack of technical experience, have been exposed in the construction process, resulting in the gradual decline of some sponge facilities, poor water logging control effect and the decline of the enthusiasm of the masses.

Based on this background, this research to sponge city construction in Jiangxi province as the research object, follow the "theoretical analysis, mechanism analysis, and model simulation research train of thought, first of all, introduce the basic concept of sponge urban construction risk and the basic theory, then through the method of grounded theory to explore risk factors for urban construction, sponge using system dynamics of relevant knowledge (Yizhuang 2007; Shuhua 2002; Kangyi et al. 1987; Vefie 1996), build dynamic evolution model of the urban construction risk, sponge using Vensim PLE software carries on the simulation experiments, through sensitivity analysis determine the main risk factors in each stage of whole life cycle and the influence mechanism between each system, and the risk, to simulate the results of different countermeasures and discusses the countermeasures should be taken to reduce the sponge urban construction risk, in order to put forward some suggestions for sponge city construction in the future. The overall research framework is shown in Fig. 1.

1 Literature Review

1.1 Research status of sponge city construction

In 1972, the Federal Water Pollution Control Act of the United States proposed best Management Practices for end control measures from the perspective of non-point source pollution control. Then, a theoretical system of Low Impact Development (LID) is developed and formed on the basis of best management measures (Vefie et al. 2012; Wu et al. 2014). In 1999, on the basis of low-impact development, the UK incorporated environmental and social factors into the drainage system construction and adopted comprehensive measures to improve urban environmental water cycle, which was named Sustainable Drainage Systems (Perales et al. 2016; Suripin et al. 2017). The Australian government reformed the domestic water industry and proposed water Sensitive Urban Design based on the traditional storm water management mode (Morison and Brown 2011; An et al. 2016).

After sponge city construction was put forward in China, a lot of scholars first discussed the connotation of sponge city. Scholars Qiu Baoxing (2015) Ying Jun and Zhang Qingping (2016) and Wu Danjie et al. (2016) pointed out that the difference between sponge city and traditional urban construction mode is that the latter brings destructive construction to the city, while the former emphasizes that the impact on the environment should be reduced during urban development.

However, some scholars point out that low-impact development is only a small part of sponge city construction (Danjie et al. 2016; Kongjian 2016), which is not equal to "big sponge" facilities such as simple drainage and water logging prevention, nor "small sponge" facilities such as rainwater reuse (Dhakal and Chevalier 2017; Matthews et al. 2015; Goulden et al. 2018; Tsihrintzis and Hamid 2015; Ghadim and Hin 2017). Che Wu et al. (2015) put forward that the difficulties to be solved in sponge city construction in the future are unclear cognition of connotation and index, difficulty of work and investment and financing mode in view of the current implementation status of sponge city. On this basis, Liu Jian et al. (2016) made an in-depth analysis of the construction process of the first batch of sponge city pilot cities, and added the existing problems in construction management. Li Tao (2015)

identifies and evaluates the risks applied in LID project construction with a variety of analytical methods, prioritises the relatively important risks with analytic hierarchy process, and finally puts forward suggestions on risk treatment. Xiang Pengcheng et al. (2018) conducted risk assessment on sponge city construction of Yuelai new city in Chongqing by combining intuitional fuzzy analytic hierarchy Process and grey theory, and believed that economic risk was the most influential factor, followed by management factors.

1.2 Research status of dynamic evolution of project risk

Western scholars are the first to realize that the traditional static risk management system is not suitable for risk prevention and control of long-span projects. Tummala (1994) pointed out that the risk management process is a dynamic cyclic process and advocated continuous risk management at different stages of the whole project cycle. Jaafari (2000; 2001) also proposed that risk management at different stages of a project should serve the goal of the whole project life cycle. Feng Yahong (2008), Zhai Yongjun and Lu Huimin (2007) believe that modern management industry urgently requires comprehensive identification and evaluation of project life-cycle risks in a more systematic and dynamic way. In terms of specific application, Ning Liang and Zhao Libo (2016) constructed an evaluation index system for risk factors of public service outsourcing, and made quantitative evaluation of the risks of the government's implementation of public service outsourcing by using fuzzy comprehensive evaluation method, and analyzed various risk factors affecting the success of outsourcing. Qiu Guangzhen and Xu Shulong (1998) took time as the variable and created six basic functions to describe different risk trends, and used analytic hierarchy process (AHP) to calculate the ranking weight of risk influencing factors of engineering projects. Sun Chengshuang and Wang Yaowu (2003) proposed the identification and monitoring method of dynamic risk factors of construction projects based on the time sensitivity of risk factors and the project income as the evaluation standard. Zhu Kun, Yang Jiaben and Chai Yueting (2004) put forward the concept of "risk bubble" and studied the dynamic transformation mechanism of risk factors theoretically by using the formalized language of risk bubble energy. Liu Wu, Du Zhida and Zhang Qiuyue (2008) took into account the influence of temporal and spatial changes of risks on construction, calculated network time parameters and Monte Carlo Simulation(MCS) on the basis of PERT network model, and obtained the influence index curve of each factor according to the principle of project impact. Thus, the dynamic risk analysis of project schedule is carried out.

1.3 Review of research status

Sponge city construction projects are time-consuming and involve many stakeholders. According to the current research situation, it is urgent to conduct in-depth research. Citespace software was used to analyze the knowledge graph of literatures related to sponge city construction risk, and collate the publication trend of literatures related to sponge city construction risk in the past decade. The results are shown in Figure 2. Through combing relevant literatures and theories on influencing factors of sponge city construction and dynamic evolution of engineering project risks, it is found that :(1) sponge city risk research needs to be strengthened in the application of risk identification theory and system dynamics

theory and other related basic theories. There are many researches on risk decision-making and management of single urban construction project in China, and they focus on the single dimension of economy and society. However, few studies have been done on the identification of the complex background and risks peculiar to such group construction projects as sponge city. (2) When studying the risks related to sponge cities and construction, domestic and foreign scholars are mostly problem-oriented, studying the causes and manifestations of problems in the construction process and proposing solutions. However, they do not pay enough attention to the multi-stage development characteristics of storm water management risks. (3) The risk of sponge city construction is a dynamic system with variability, and the existing studies have not formulated corresponding countermeasures according to the different characteristics of each stage. In addition, in the traditional security system, they are all suggestions, without empirical consideration of the implementation effect of the scheme.

2 Related Concepts And Theoretical Basis

2.1 Sponge City

Sponge city is in response to climate change and rapid urbanization on the city caused by the negative influence of major urban construction strategy, as well as to realize the sustainable development of urban environmental construction of key concept, is refers to the use of the natural process to manage storm water runoff, which make the city to adapt to the environment change and respond to natural disasters, etc, like a sponge, it has good "elasticity" (Vogel et al. 2015). The action mechanism of sponge city is shown in Fig. 3.

2.2 Risk of sponge city construction

Sponge city construction risk refers to the factors that fail to achieve the expected goals due to adverse results caused by various elements and their combination and interaction within the whole life cycle of sponge city project initiation, planning and design, construction, completion acceptance and later operation and maintenance. The probability of risk occurrence and the severity of risk loss are regarded as the risk evaluation criteria.

2.3 system theory

The basic idea of system theory was first proposed by the biologist Bertalanfy in the early 1920s. In the later development process, it was supplemented by the mutation theory of The French mathematician Thom and the synergy theory of the German physicist Haken, and gradually formed a set of theoretical methods with its own characteristics. And it has been applied to the research of various disciplines (Qianhu et al. 2018). Bertalanfy (2007) believes that a system is a collection of interconnected and interacting elements, rather than a simple addition of various elements. Qian Xuesen (2002), a Chinese scholar, further supplemented and deepened the definition of system, believing that it is an organic whole with specific functions synthesized by several components that interact and depend on each other, and a

System theory emphasizes the role of elements, levels, structures, functions and other factors in the system as well as the mutual relationship between various parts (Mees et al. 2013), and calls such relationship "coupling" (Yongwei et al. 2018).

2.4 Full life cycle

Every engineering project has specific development stages, and the specific definition and division of each stage changes with different projects, and these stages constitute the whole life cycle of engineering projects (Kostalova and Tetrevova 2016). According to the process that a project goes through from start to finish, the whole life cycle theory divides a project into five stages: "identifying requirements, proposing solutions, implementing the project, accepting the project and closing the project". Based on the reading of relevant literature, this study divides the whole life cycle of sponge city construction into five stages according to the principles of consistency in time, similarity in content and integrity of project results, as follows: Project start-up stage (pss), planning and design stage (pds), construction and construction stage (ccs), completion and acceptance stage (cas) and operation and maintenance stage (oms).

3 Risk Identification Of Sponge City Construction Based On Grounded Theory

The American Project Management Institute divides the process of risk management into the following parts: risk identification, qualitative and quantitative analysis, strategy development and risk monitoring. Among them, risk identification is the basis of risk dynamic evolution mechanism research and refers to the process of risk judgment, classification and identification.

3.1 Selection of risk identification methods

At present, the risk identification methods commonly used in the academic circle can be roughly divided into two categories: analysis method and expert investigation method. Analysis methods include fault tree analysis, WBS work decomposition method, check list method and case analysis method, etc. Expert investigation methods include Delphi method, brainstorming method and scene analysis method. Different risk identification methods have different advantages and disadvantages (see Appendix 1) and are also suitable for different scenarios. Considering the characteristics of sponge city construction risks, this paper chooses grounded theory as the risk identification method, and the specific application steps are shown in Fig. 4.

3.2 Risk identification of sponge city construction

3.2.1 Collection of original data

By December 31, 2020, a total of 67 Chinese literatures related to sponge city subject were retrieved from CSSCI database. After deleting literatures irrelevant to the subject, 21 literatures remained. A total of 579

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js 27 representative articles were selected

according to the topic, citation volume, download volume and time. Related literatures were retrieved from the core library Of Web Of Science, and 15 English literatures were selected. Interviews were conducted with relevant personnel in sponge city pilot cities to further supplement risk factors in sponge city construction.

3.2.2 Risk identification

(1) Initial coding

Coding is the basic step of grounded theory to analyze qualitative data (Xiaoe 2011). To adopt the way of every code in Chinese and English literature and interview the statement in conceptual analysis, some of the more obscure and inconsistent after interview records deleted, try to use the original literature and the participant's words as code name to minimize the effects of the researchers' subjective bias, the resulting initial code 142. See Appendix 2 for the initial coding and editing process of literature and interview data.

(2) Focus coding

At this stage, according to the frequency of the initial coding in the original data mentioned above, after continuous comparison and correction with the original data, the codes with similar meanings are summarized and integrated, and a total of 23 focused codes are obtained. After a preliminary conceptualization of the initial coding, five main categories including regulations, management, capital, technology and society are summarized and generated. See Appendix 3 for the coding integration process.

3.2.3 Identification results

After the above coding process, use the reserved literature theoretical saturation test and interview, showed the study theory of generic has been rich enough, the sponge effect of five main categories of the construction of the city did not form a new important category, and internal also did not form a new form factor, combined with expert for determine risk factors of life cycle,

The final risk identification results are shown in Table 1.

Table 1
Risk identification results

| Classify | Risk factor | Phases |
|---------------------|---|-------------------------|
| Regulation R_1 | Imperfect regulations at the national level, a_1 | pss, pds, ccs, cas, oms |
| | Planning system and planning permission system are not perfect, a_2 | pds |
| | Construction technical standard is not perfect, a_3 | ccs, cas |
| | Operation and maintenance rules are not perfect, a_4 | oms |
| | Investment and financing laws and regulations are not perfect, a_5 | pss, pds, ccs, cas, oms |
| Management R_2 | Local governments are not paying enough attention, b_1 | pss, pds, ccs, cas, oms |
| | No overall management organization has been established, b_2 | pss, pds, ccs, cas, oms |
| | The cross-departmental coordination mechanism is not perfect, b_3 | pss, pds, ccs, cas, oms |
| | The performance appraisal mechanism is not perfect, b_4 | pss, pds, ccs, cas, oms |
| | The public participation mechanism is not perfect, b_5 | pss, pds, ccs, cas, oms |
| | Investment and financing mechanisms are not perfect, b_6 | pss, pds, ccs, cas, oms |
| | The supervision mechanism is not perfect, b_7 | pds, ccs, cas, oms |
| Funds R_3 | The economic benefit is not obvious, c_1 | pss |
| | Insufficient funding for planning and design, c_2 | pds |
| | Construction funds are not in place, c_3 | ccs, cas |
| | Insufficient funds for operations and maintenance, c_4 | oms |
| Technical R_4 | Poor planning and design skills, d_1 | pds, ccs, oms |
| | Construction technology is not good, d_2 | ccs, cas, oms |
| | Poor operation and maintenance techniques, d_3 | oms |
| Society | The level of urban infrastructure construction is backward, e_1 | pss, pds, ccs, oms |

| Classify | Risk factor | Phases |
|----------|---|--------------------|
| | The level of regional economic development is backward, e_2 | pss, pds, ccs, oms |
| | The public doesn't know about sponge cities, e_3 | pss, ccs, oms |
| | The public cultural quality is not high, e_4 | pss, ccs, oms |

4 Construction Of Sponge City Construction Risk Model Based On System Dynamics

4.1 Introduction to system dynamics

System dynamics is a method of studying the dynamic behavior of systems developed by MIT Professor Forrester in 1956. It is based on the theory of systems thinking and incorporated into computer simulation models. Referring to the basic steps of system dynamics modeling (Wang 2017), the construction of sponge city construction risk model and simulation procedures are shown in Fig. 5.

4.2 Draw causal loop diagram and stock flow diagram of system dynamics

4.2.1 Causal loop diagram

After the logical relationship between major risks and boundary factors is fully grasped in the theoretical coding stage, all risk factors are integrated into a system, and the causal loop diagram is drawn as shown in Fig. 6. The arrow in Fig. 6 indicates that there is a causal relationship between the two variables, while "+" and "-" respectively indicate that there is a positive causal relationship and a negative causal relationship between the two factors.

4.2.2 Stock flow chart

The difference between the stock flow diagram and the causal loop diagram is that the causal loop diagram is a static diagram describing the logical relationship of risks, while the numerical and mathematical formulas added to the stock flow diagram can express the dynamic changes of risks in the construction process. To summarize the interaction relationship between risk factors, and according to the above drawing of the causal loop diagram, will "sponge urban construction risk" as the state variables of the total system, construct a state variable, rate and auxiliary variables of three variables in the form of urban construction risk system dynamics sponge stock flow diagram, as shown in Fig. 7.

4.3 Entropy weight and G1 integrated weighting method

Chen Bin et al. (2017) first proposed entropy method and applied it in the field of thermodynamics. The entropy method calculates the influence of the change degree of each index on other indexes, and

line the objective weight index. It calculates the

measured value of an index completely according to actual data without any subjective component. However, G1 method can fully reflect the subjective consciousness of the evaluator, take the subjective will of the decision maker into consideration, and find out the internal connection of the importance of risk factors on the basis of the sequential relationship between risk factors without testing consistency (Xuejun and Yajun 2006). The risks of Sponge city PPP projects are complex and difficult to be quantified. The pure subjective or objective weighting will have an impact on the subsequent risk evaluation, while the integrated weighting method integrates the advantages of both subjective and objective weighting methods, which can not only reflect the subjective will of the chooser, but also apply objective theories and methods. The steps to determine the weight of the integrated weighting method are as follows:

W_j represents the weight of the risk factor j after the comprehensive integration of the two weighting methods, where W_j^1 represents the weight calculated by entropy method and W_j^2 represents the weight calculated by G1 method, namely:

$$w_j = \alpha w_j^1 + (1 - \alpha) w_j^2$$

1

Where, α is the proportion of objective weight to combination weight. Taking the objective of minimizing the sum of squares of weight deviations by subjective and objective methods, the objective function is established as follows:

$$\min z = \sum_{j=1}^n \left[(W_j - w_j^1)^2 + (W_j - w_j^2)^2 \right]$$

2

Substitute Eq. (1) into Eq. (2) to obtain:

$$\min z = \sum_{j=1}^n \left\{ \left[\alpha w_j^1 - (1 - \alpha) w_j^2 - w_j^1 \right]^2 + \left[\alpha w_j^1 - (1 - \alpha) w_j^2 - w_j^2 \right]^2 \right\}$$

3

Take the derivative of Eq. (3) with respect to α , and let the first derivative be zero, and obtain $\alpha = 0.5$. Substitute $\alpha = 0.5$ into Eq. (1) to obtain:

$$W_j = 0.5 * w_j^1 + 0.5 * w_j^2$$

4

It can be seen that the integrated weight result is optimal when the subjective weight and the objective weight account for half respectively.

4.4 Simulation analysis and radar diagram

By inputting the numerical and dynamic equations of risk factors obtained in the above calculation process into Vensim PLE software, the system simulation diagram of 23 risk factors and 5 risk subsystems changing over time in the whole life cycle can be obtained, and the influence of each key risk factor on the risk subsystem can be identified through sensitivity analysis. However, in order to intuitively identify the risk subsystems that each stage has a great impact on the risk of sponge city construction, the risk level of each stage is summarized by using radar chart.

Radar chart, also known as spider web chart, is often used in the analysis of financial statements, with intuitive and clear advantages. This method is used for reference in the risk analysis of sponge city construction. Appropriate coordinate axes are established to represent the simulation results of each key risk factor in five stages of the whole life cycle, and the main risk factors in a certain stage are obtained.

5 Empirical Study – Taking Sponge City Construction In Jiangxi Province As An Example

5.1 Overview of the study area

Pingxiang, Jiangxi Province, China, is located in the Hunan-Jiangxi watershed, which is a typical hilly region in the South of the Yangtze River. Most of the basin is mountainous and hilly, and only 11% is plain valley. During the rainstorm, the mountain flood comes rapidly, the river level rises sharply, and the phenomenon of river embankment overflow occurs in the plain valley. After the rain, the mountain flood subsided, the river lack of water supply, river flow is small, dry season almost dry. There are 4 historical water logging areas in the old city, and 84 low-lying potential water logging points are at high risk of water logging. Take wanlongwan water logging area with the most severe water logging as an example. On July 8, 2016, it rained 79.8 mm. Wanlongwan waterlogged an area of 1.2 square kilometers, with the maximum water depth exceeding 1 meter. The contradiction between city and nature, human and water is prominent. In view of the reality of frequent flood disasters and water shortage coexisting due to the hydro logical characteristics of the typical jiangnan hilly region, Pingxiang creatively proposed the systematic construction idea of "whole-domain control – system construction – zoning management".

Since the pilot project, sponge city construction in Jiangxi province has made some achievements, but the effect is far from ideal. Case based on this, through field visits and consulting for practitioners, found in the process of the sponge construction of city in jiangxi province, the imperfection of the laws, regulations and policies concerning the mechanism of management to organize the implementation of efficient enough, related technology is not mature, inadequate social participation degree, are the construction and maintenance of sponge carries risks.

5.2 Scoring boundary risk factors

After fitting the risk flow diagram of sponge city construction project, the boundary risk factors were identified, and the assignment values of 23 key risk factors and 5 risk subsystems were obtained through

relevant practitioners and university researchers

in the pilot cities of sponge cities. A total of 128 questionnaires were distributed, and 93 effective questionnaires were recovered, with an effective recovery rate of 73%. The reliability of the questionnaire was analyzed by SPSS software. The Cronbach coefficient (Cronbach) was 0.873, which had a high reliability. KMO = 0.79 > 0.7, significance level P = 0.000 < 0.01, indicating that the data is relatively valid and can be processed in the next step.

According to the above discussion on the theoretical basis, the possibility of risk occurrence and the severity of consequences are mainly considered, and the probability of risk occurrence and severity of consequences are divided into five grades, with 1–5 points respectively, with 1 point indicating the lowest degree and 5 points indicating the highest degree. The risk factor function is $R = f(p, r)$. According to the multi-factor multiplication comprehensive analysis model commonly used in academia, its calculation formula is as follows:

$$R_{ij} = P_{ij} \times C_{ij}$$

5

Where, R_{ij} represents the size score of the subject j on the risk factor i ; P_{ij} represents the score result of the respondent j on the occurrence possibility of the risk factor i ; C_{ij} represents the score of the respondent j on the risk degree of the risk factor consequence i . The initial value of this risk factor was obtained by averaging the scores of all survey experts, and the calculation formula was as follows:

$$R = \frac{1}{n} \sum_{j=1}^n R_{ij}$$

6

Where, n represents the number of respondents; R_{ij} represents the scoring result of the respondent j on the risk of the risk factor i ; R represents the initial value of the state variable.

The initial values of the risk factors obtained after averaging the values assigned to each risk factor by each expert (see Appendix 4 for details) are shown in Table 2.

Table 2
Initial values of risk factors

| Risk factors | Regulatory risk | Management risk | Capital risk | Technical risk | social risk |
|----------------|-----------------|-----------------|--------------|----------------|-------------|
| Initial values | 9.36 | 11.03 | 5.36 | 13.09 | 4.09 |

5.3 Sponge city construction risk factor assignment based on integrated weighting method

As there are few research theories on sponge city construction at present, the authoritative weight of subjective and objective preference coefficient has not been obtained, and the weight coefficient will

According to derivation of 4.3, when the objective

preference coefficient is 0.5, the sum of squares of the deviation between the final weight and the subjective and objective weight is the smallest. Therefore, the average value of the objective weight and subjective weight is taken as the final weight result, and the specific result is shown in Table 3.

Table 3
Objective weight of risk factors

| Risk subsystem | Border risk | Objective weight | Subjective weight | Comprehensive weight |
|---------------------|--------------------|------------------|-------------------|----------------------|
| Regulation R_1 | a_1 | 0.254 | 0.207 | 0.230 |
| | a_2 | 0.152 | 0.144 | 0.148 |
| | a_3 | 0.146 | 0.207 | 0.177 |
| | a_4 | 0.219 | 0.172 | 0.196 |
| | a_5 | 0.239 | 0.144 | 0.192 |
| Management R_2 | b_1 | 0.170 | 0.164 | 0.167 |
| | b_2 | 0.142 | 0.151 | 0.147 |
| | b_3 | 0.115 | 0.126 | 0.120 |
| | b_4 | 0.165 | 0.138 | 0.151 |
| | b_5 | 0.140 | 0.083 | 0.112 |
| | b_6 | 0.088 | 0.090 | 0.089 |
| | b_7 | 0.097 | 0.146 | 0.121 |
| | b_8 [Regulation] | 0.092 | 0.124 | 0.108 |
| Funds R_3 | c_1 | 0.074 | 0.159 | 0.116 |
| | c_2 | 0.162 | 0.230 | 0.196 |
| | c_3 | 0.158 | 0.133 | 0.145 |
| | c_4 | 0.134 | 0.191 | 0.163 |
| | c_5 [Regulation] | 0.164 | 0.102 | 0.133 |
| | c_6 [Management] | 0.182 | 0.102 | 0.142 |
| | c_7 [Society] | 0.136 | 0.102 | 0.118 |
| Technical R_4 | d_1 | 0.220 | 0.279 | 0.249 |
| | d_2 | 0.203 | 0.199 | 0.201 |

| Risk subsystem | Border risk | Objective weight | Subjective weight | Comprehensive weight |
|----------------|--------------------|------------------|-------------------|----------------------|
| | d_3 | 0.184 | 0.166 | 0.175 |
| | d_4 [Regulation] | 0.133 | 0.114 | 0.124 |
| | d_5 [Management] | 0.117 | 0.139 | 0.128 |
| | d_6 [Funds] | 0.175 | 0.126 | 0.150 |
| Society | e_1 | 0.197 | 0.181 | 0.189 |
| R_5 | e_2 | 0.168 | 0.190 | 0.179 |
| | e_3 | 0.156 | 0.201 | 0.178 |
| | e_4 | 0.082 | 0.144 | 0.113 |
| | e_5 [Regulation] | 0.192 | 0.159 | 0.176 |
| | e_6 [Management] | 0.219 | 0.159 | 0.189 |
| Total risk | f_1 [Regulation] | 0.251 | 0.181 | 0.216 |
| R_0 | f_2 [Management] | 0.207 | 0.260 | 0.234 |
| | f_3 [Funds] | 0.157 | 0.181 | 0.169 |
| | f_4 [Technical] | 0.227 | 0.216 | 0.222 |
| | f_5 [Society] | 0.173 | 0.181 | 0.177 |

5.4 Establish the equations of each subsystem

The weight assignment obtained from Table 3 above is substituted into the prepared subsystem equation as follows:

1. Change in regulatory risk = $0.230 \times a_1 + 0.148 \times a_2 + 0.177 \times a_3 + 0.196 \times a_4 + 0.192 \times a_5$

2. Manage risk variability = $0.167 \times b_1 + 0.147 \times b_2 + 0.120 \times b_3 + 0.151 \times b_4 + 0.112 \times b_5 + 0.089 \times b_6 + 0.121 \times b_7 + 0.108 \times b_8$

3. Variation of capital risk = $0.116 \times c_1 + 0.196 \times c_2 + 0.145 \times c_3 + 0.163 \times c_4 + 0.133 \times c_5 + 0.142 \times c_6 + 0.119 \times c_7$

4. Change in technical risk = $0.249 \times d_1 + 0.201 \times d_2 + 0.175 \times d_3 + 0.124 \times d_4 + 0.128 \times d_5 + 0.150 \times d_6$

5. Changes in social risks = $0.189 \times e_1 + 0.179 \times e_2 + 0.178 \times e_3 + 0.113 \times e_4 + 0.176 \times e_5 + 0.189 \times e_6$

6. Risk change of sponge city construction = $0.216 \times f_1 + 0.234 \times f_2 + 0.169 \times f_3 + 0.222 \times f_4 + 0.177 \times f_5$

7. Regulatory risk = INTEG (Change in regulatory risk, 9.36)

8. Management risk = INTEG (Management risk change, 11.03)

9. Capital risk = INTEG (Capital risk change, 5.36)

10. Technical risk = INTEG (Change in technical risk, 13.09)

11. Social risk = INTEG (Change in social risk, 4.09)

12. Sponge city construction risk = INTEG (Change in sponge city construction risk, 0)

5.5 Analysis of empirical results

After consulting relevant practitioners of sponge city construction in Jiangxi Province, it is found that the start-up phase is 1 month, the planning and design phase is 2 months, the construction phase is 6 months, and the operation and maintenance warranty period is 2 years. In order to have a better simulation effect, the simulation duration of the model is set as 15 months to simulate the risk changes from project approval to six months of operation. The above system equations were brought into the Vensim PLE software (Qifan 2009; Yongguang et al. 2013; Dickson et al. 2011), and the function changing with time was set for each auxiliary variable according to the existence time of each risk, and the operation results of each risk were observed.

5.5.1 Full life cycle simulation analysis of regulatory risks

In regulatory risk in this subsystem, incomplete "construction technology standard" and "operation maintenance rules are not perfect" both of these factors will exist in the construction and operational stage, so the time function as constraints, namely in the planning and design phase of the risk factors of risk value is set to 0, do so with the rest of the time the functions below. In order to further explore the dynamic impact of each risk factor on the regulatory risk subsystem, the initial value of each factor was reduced by 30% and other factors remained unchanged for sensitivity analysis. The adjustment scheme is shown in Table 4, and the final analysis result is shown in Fig. 9 (a).

Table 4
Description of regulatory risk sensitivity analysis scheme

| Scenario name | Project instruction |
|---------------|--|
| A1 | Keep the initial values of each factor unchanged |
| A2 | Initial var of a_5 is reduced by 30% |
| A3 | Initial var of a_1 is reduced by 30% |
| A4 | Initial var of a_2 is reduced by 30% |
| A5 | Initial var of a_4 is reduced by 30% |
| A6 | Initial var of a_3 is reduced by 30% |

Through sensitivity analysis, it can be found that regulatory risk is most sensitive to a_1 factor, followed by a_5 , and least sensitive to a_4 , indicating that promoting the construction of national regulations and the improvement of investment and financing laws in the start-up stage has a significant impact on the reduction of regulatory risk level.

The low sensitivity of factor a_4 is mainly due to the fact that this factor begins to affect sponge city construction in the last stage of the whole life cycle. However, it can be seen from the change trend of each scheme after 9 months that a_4 factor has a extreme influence on the decrease of regulatory risk level. In order to better analyze this factor, the model of the simulated time extended to 30 months, found that the factors effect on the risk regulations is not lower than the other factors except a_1 , this shows that in the future urban construction run longer sponge maintenance phase, a_4 will risk occupy larger influence on construction of city sponge weights, as shown in Fig. 9 (b).

5.5.2 Life-cycle simulation analysis of management risk

In the management risk subsystem, the b_7 factor appears after the planning stage, so it is constrained by a time function.

In order to further explore the dynamic impact of each factor on the management risk subsystem, the initial value of each factor was reduced by 30% and other factors remained unchanged for sensitivity analysis. The adjustment scheme is shown in Table 5, and the final analysis result is shown in Fig. 9 (c).

Table 5
Sensitivity analysis description of management risk

| Scenario name | Project instruction |
|---------------|--|
| C1 | Keep the initial values of each factor unchanged |
| C2 | Initial var of R_7 is reduced by 30% |
| C3 | Initial var of b_7 is reduced by 30% |
| C4 | Initial var of b_2 is reduced by 30% |
| C5 | Initial var of b_7 is reduced by 30% |
| C6 | Initial var of b_6 is reduced by 30% |
| C7 | Initial var of b_5 is reduced by 30% |
| C8 | Initial var of b_4 is reduced by 30% |
| C9 | Initial var of b_3 is reduced by 30% |

Sensitivity analysis shows that regulatory risk can be effectively reduced by controlling regulatory risk at the initial stage of start-up. In the category of management risk subsystem, management risk is most sensitive to b_7 factor, followed by b_4 and b_2 , indicating that perfecting laws and regulations and performance appraisal mechanism, strengthening government attention and establishing overall management organization have obvious effect on reducing management risk in the start-up stage.

5.5.3 Life-cycle simulation analysis of capital risk

In the subsystem of capital risk, only the c_7 factor exists in all stages of the whole life cycle, while the c_4 factor only affects the planning and design stage, the c_3 factor only affects the construction stage, and the c_4 factor only appears in the operation and maintenance stage. Therefore, the time function is used as the constraint for these three factors. In order to further explore the dynamic impact of each factor on the capital risk system, the initial value of each factor was reduced by 30% and other factors remained unchanged for sensitivity analysis. The adjustment scheme is shown in Table 6, and the final analysis result is shown in Fig. 9 (d).

Table 6
Description of capital risk sensitivity analysis scheme

| Scenario name | Project instruction |
|---------------|--|
| D1 | Keep the initial values of each factor unchanged |
| D2 | Initial var of R_1 is reduced by 30% |
| D3 | Initial var of R_2 is reduced by 30% |
| D4 | Initial var of R_5 is reduced by 30% |
| D5 | Initial var of c_1 is reduced by 30% |
| D6 | Initial var of c_2 is reduced by 30% |
| D7 | Initial var of c_3 is reduced by 30% |

Through sensitivity analysis, it can be found that the influence of regulation, management and social risk control is far greater than that of the internal factors of the fund subsystem. Among them, management risk has a particularly significant impact on capital risk, indicating that a perfect management mechanism plays an important role in capital investment and allocation. All risk factors under the capital subsystem have little influence on the system, among which operation and maintenance capital has a relatively high influence on the capital subsystem.

5.5.4 Full life cycle simulation analysis of technical risk

In the subsystem of technical risk, three sub-factors, d_1 , d_2 and d_3 , respectively exist in the stages of planning, construction and operation and maintenance, all of which are constrained by time function. In order to further explore the influence of each sub-factor on the technical risk system, the initial value of each factor was reduced by 30% and other factors remained unchanged for sensitivity analysis. The adjustment scheme is shown in Table 7, and the final analysis result is shown in Fig. 9 (e).

Table 7
Sensitivity analysis description of technology risk

| Scenario name | Project instruction |
|---------------|--|
| E1 | Keep the initial values of each factor unchanged |
| E2 | Initial var of R_1 is reduced by 30% |
| E3 | Initial var of R_2 is reduced by 30% |
| E4 | Initial var of R_5 is reduced by 30% |
| E5 | Initial var of d_1 is reduced by 30% |
| E6 | Initial var of d_2 is reduced by 30% |
| E7 | Initial var of d_3 is reduced by 30% |

Through sensitivity analysis can be found in the early stage of project startup management risk and regulatory risk control, can effectively reduce the sponge urban construction technical risk, but far less than the effects of poor planning and design technology, to reduce the risk of technical subsystem, should be in the prophase planning technology in the research and training.

5.5.5 Life-cycle simulation analysis of social risks

In the subsystem of social risk, e_1 , e_2 , e_3 and e_4 factors exist in all stages of the whole life cycle, so there is no need to use time function to constrain them. In order to further explore the impact of each factor on the social risk system, the initial value of each factor was reduced by 30% and other factors remained unchanged for sensitivity analysis. The adjustment scheme is shown in Table 8, and the final analysis result is shown in Fig. 9 (f).

Table 8
Sensitivity analysis description of society risk

| Scenario name | Project instruction |
|---------------|--|
| F1 | Keep the initial values of each factor unchanged |
| F2 | Initial var of R_1 is reduced by 30% |
| F3 | Initial var of R_2 is reduced by 30% |
| F4 | Initial var of e_3 is reduced by 30% |
| F5 | Initial var of e_1 is reduced by 30% |
| F6 | Initial var of e_2 is reduced by 30% |
| F7 | Initial var of e_4 is reduced by 30% |

Through sensitivity analysis, it can be found that the control of management risks will have a significant impact on social risks, which may be due to the government's emphasis on publicity and education, and the improvement of public participation mechanism, so as to reduce social risks. In the category of social risk subsystem, social risk is sensitive to e_1 and e_3 . With the control of such risks in the early stage of the project, social risks can be effectively reduced.

5.5.6 Life-cycle simulation analysis of sponge city construction risk

In order to analyze the influence of the sub-systems of legal risk, management risk, capital risk, technical risk and social risk on the total risk of sponge city construction, the initial risk value of each sub-system was reduced by 30%, and other factors remained unchanged, and the dynamic change of the total risk level was observed. The adjustment scheme is shown in Table 9, and the final analysis result is shown in Fig. 9 (g).

Table 9
Sensitivity analysis description of Sponge City Construction risk

| Scenario name | Project instruction |
|---------------|--|
| G1 | Keep the initial values of each factor unchanged |
| G2 | Initial var of R_1 is reduced by 30% |
| G3 | Initial var of R_2 is reduced by 30% |
| G4 | Initial var of R_3 is reduced by 30% |
| G5 | Initial var of R_4 is reduced by 30% |
| G6 | Initial var of R_5 is reduced by 30% |

As can be seen from Fig. 9 (g), the risk level of management risk in all stages of the whole life cycle is high, and the management system needs to be further improved in the future. The risk level of legal risk in the start-up stage is high, but with the change of time, the proportion of the total risk of sponge city construction is getting lower and lower. In contrast, technological and social risks have become more and more important over time. The risk level of capital risk in all stages of the whole life cycle is obviously lower than that of other systems, which may be because jiangxi province has a high level of economic development, and the support of national and provincial pilot cities makes local governments have low economic worries in sponge city construction. Therefore, management risk and technical risk should be focused on in the whole life cycle stage, regulatory risk control should be strengthened in the start-up stage, and social risk control should be strengthened in the operation and maintenance stage.

5.5.7 Life-cycle key risk factors radar map

Will be entirely into the startup phase of mentioned above, planning and design stage, construction stage, Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js, each risk subsystem simulation results in 1

month, 3 months, in September and 15 months in the key points of the summary to the radar map, can be more intuitive to see changes in the different stages of the risk, as shown in Fig. 9 (h).

The data of system dynamics constructed in this study are mostly subjective and qualitative, and the simulation accuracy is low, so the precise value of risk level cannot be obtained. However, the dynamic change trend of risk level of each subsystem in the whole life cycle of sponge city can be discussed from the general change trend.

5.6 Suggestions on risk prevention and control of sponge city construction

The five dimensions of risk run through each life cycle stage of sponge city construction, but have different development trends. Therefore, risk management should also dynamically consider the impact of various risks on the overall project and put forward suggestions. Combined with simulation and sensitivity analysis, the following suggestions are proposed for the key factors of the five subsystems. (1) Sponge city pilot cities should actively carry out the compilation of operation and maintenance specifications in the future, and further revise them according to the actual project operation situation. (2) in the construction of the sponge, etc in the process of the organization as a whole, we should widely transferring backbone, each related department in order to establish a direct and strong, solid work, coordinate clear in different stages of the urban construction, the main responsibility of the sponge and setting up a long-term mechanism to sponge a gradual shift in urban construction are normalized to the construction of content. (3) Use technical means to build an intelligent scheduling platform for sponge facilities, assist scheduling management with comprehensive information, and realize the whole process comprehensive management of sponge city planning, construction, operation management and environmental performance. (4) Strengthen the publicity of sponge city concept, guide social participation, solicit public opinions, understand public preferences, and incorporate reasonable opinions into sponge city planning. (5) While strengthening sponge city publicity, effectively guide market participation and sustainable investment of capital, fully guide the enthusiasm of social capital to participate in sponge city construction, cultivate and guide the incubation of sponge city-related industries, and form new industrial momentum.

6 Conclusion

In recent years, China has paid more and more attention to the problems of urban water security, water resources and water ecology. This study finally identified 23 risk factors affecting the construction effect of sponge city under the five sub-systems of regulation, management, capital, technology and society, judged the life cycle stages of the main risks, analyzed the risk causes, and preliminarily concluded the mechanism of action among the five sub-systems. It is found that management risk and regulatory risk have a significant impact on other risk subsystems. Through sensitivity analysis, it is found that a_1 , b_1 , c_4 , d_1 , e_3 and other factors significantly affect the effectiveness of sponge city construction. By summarizing and analyzing the risk changes of the whole life cycle through the radar chart, it is found that the

management risk has a great impact on each stage of the whole life cycle, the technical and regulatory risks continue to climb along with the life cycle, while the regulations decline, and the level of capital risk is always low.

There are also some shortcomings in this study. In the selection of indicators, the indicators are mostly subjective factors such as "poor technology" and "imperfect system and mechanism", which are directly determined by assigning values through expert interviews, lacking rigorous theoretical verification. Although it does not have a significant influence on the running state of the system in the simulation of system dynamics model. However, more scientific methods should be used to determine the values of constants and phase relation in the model in the future.

Declarations

Ethical Approval

There are no ethical issues with this study.

Consent to Participate

All authors agree to participate.

Consent to Publish

All authors agree to participate in the publication.

Authors Contributions

Conceptualization, Zhijie LI and Hui Zhao; methodology, Hui Zhao.; software, Zhijie LI; validation, Zhijie LI, Hui Zhao and Jingqi Zhang.; formal analysis, Zhijie LI and Hui Zhao; investigation, Zhijie LI; resources, Zhijie LI and Hui Zhao; data curation, Zhijie LI; writing—original draft preparation, Zhijie LI and Hui Zhao; writing—review and editing, Zhijie LI; visualization, Zhijie LI and Hui Zhao; supervision, Zhijie LI and Jingqi Zhang.; project administration, Hui Zhao and Jingqi Zhang.; funding acquisition, Hui Zhao All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by National Natural Science Foundation of China, grant number 71471094,71874123,71704162.

Acknowledgments

Thanks for the contribution of sponge city construction experts and construction personnel in Pingxiang City, Jiangxi Province.

Competing Interests

Availability of data and materials

Not applicable.

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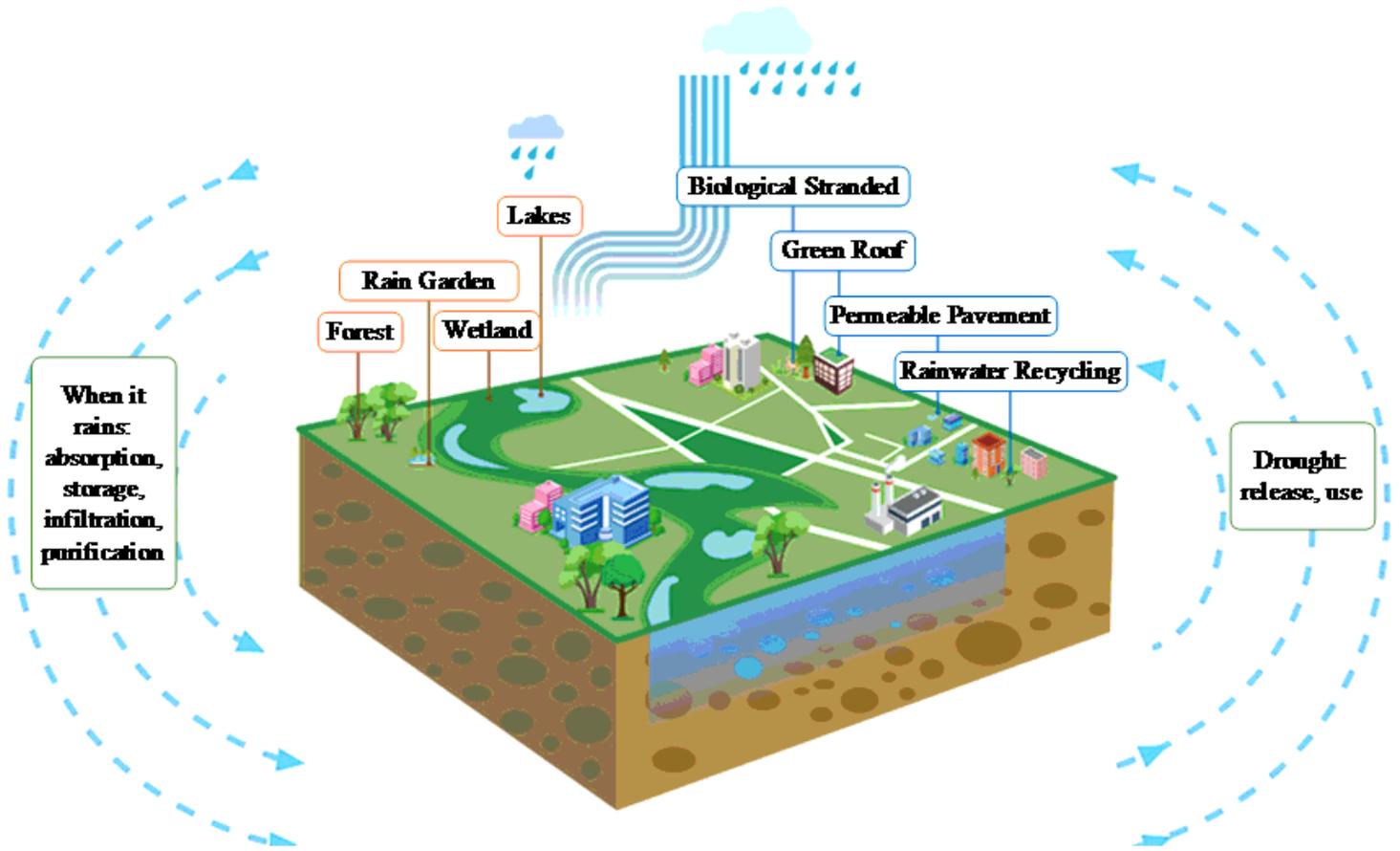


Figure 3

Schematic diagram of sponge city action mechanism (The picture shows the construction composition and water resource utilization principle of sponge city)

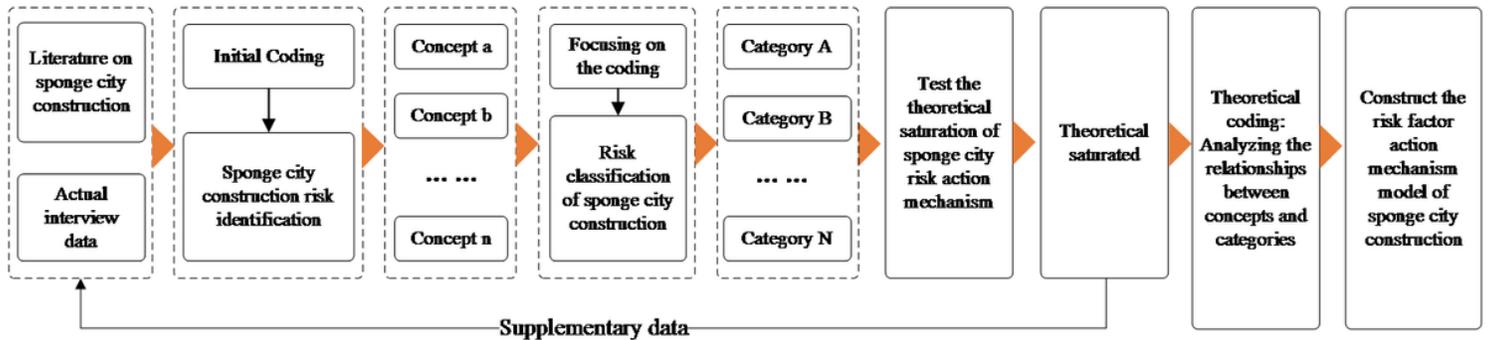


Figure 4

Research procedure of grounded theory

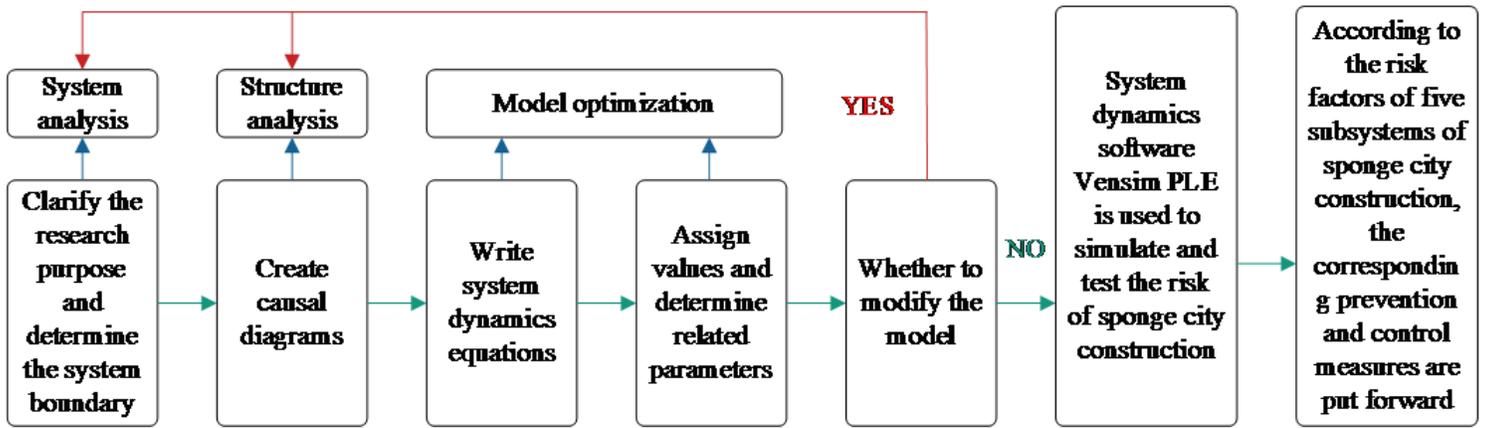


Figure 5

Application steps of system dynamics

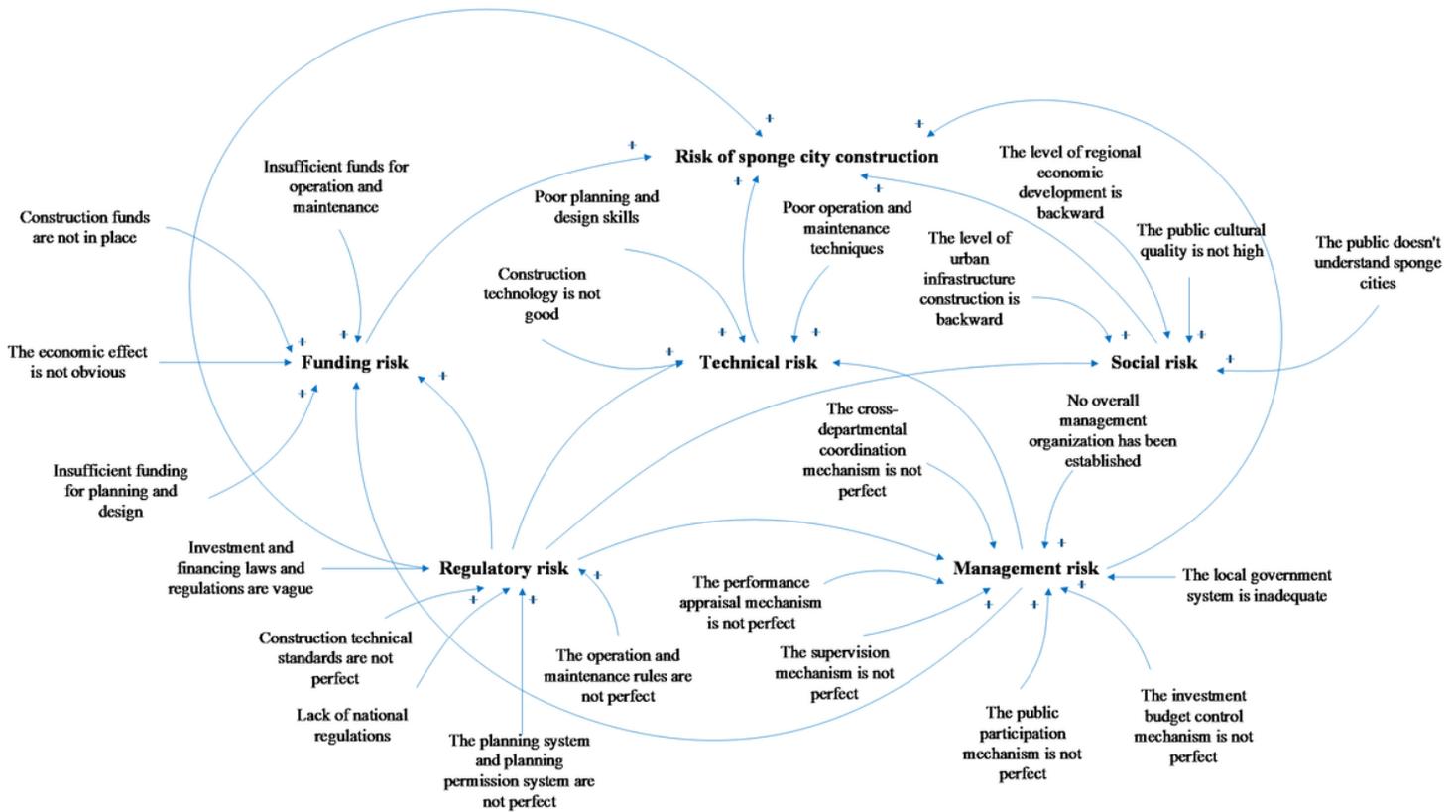


Figure 6

Causality relationship graph of the risk of Sponge City Construction

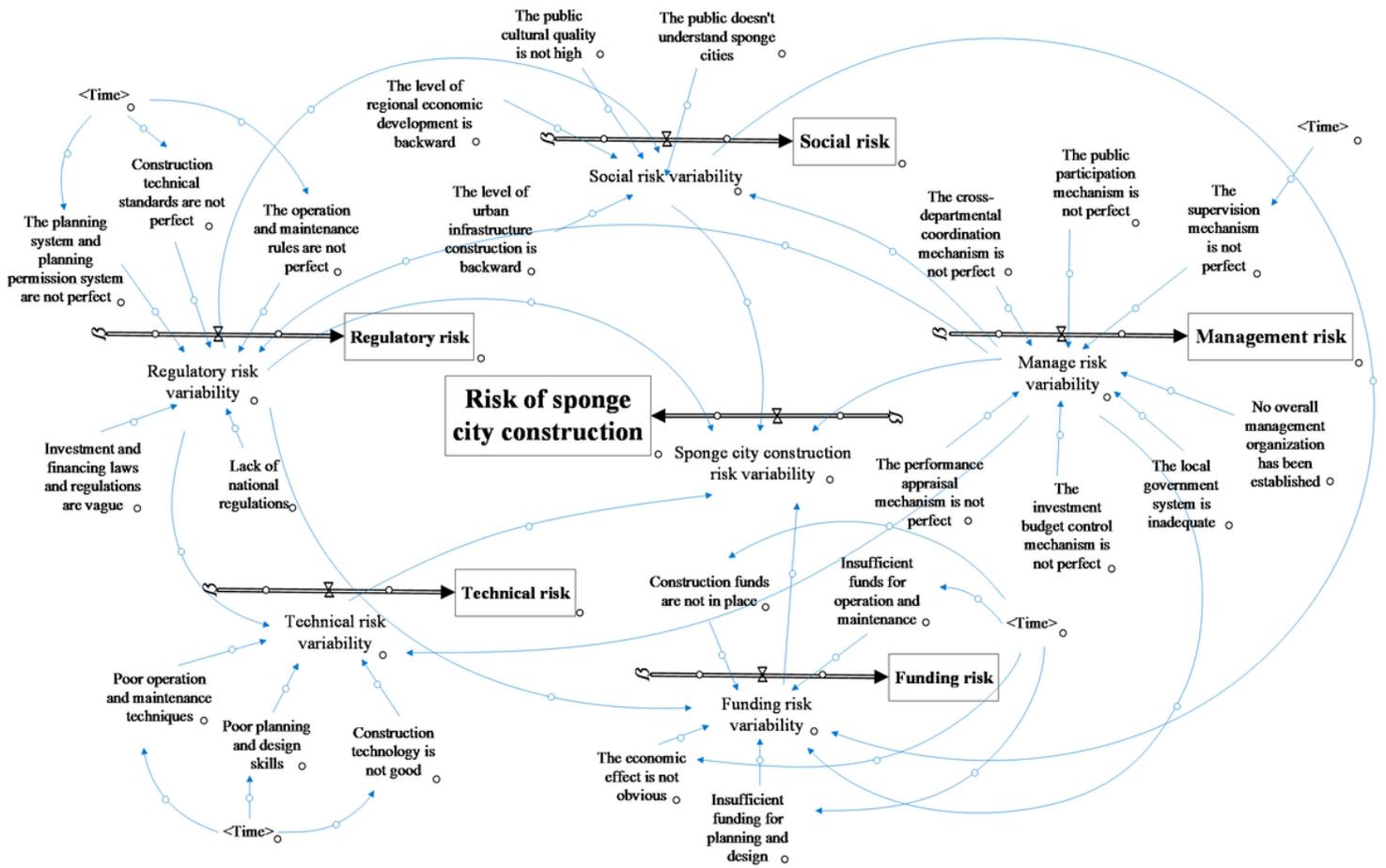
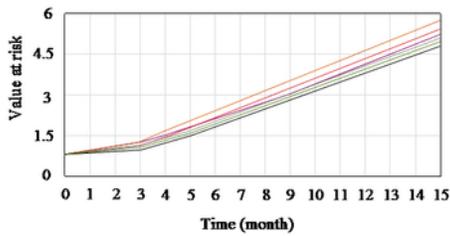


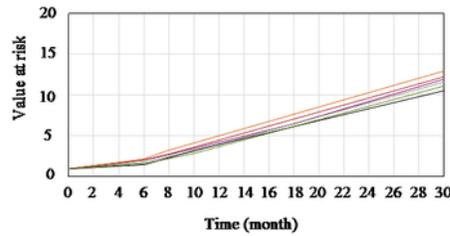
Figure 7

Stock flow chart of society risk of Sponge City Construction



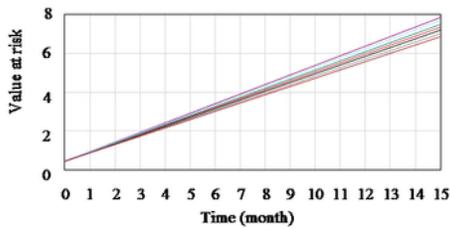
regulatory risk: A1
regulatory risk: A2
regulatory risk: A3
regulatory risk: A4
regulatory risk: A5
regulatory risk: A6

(a)



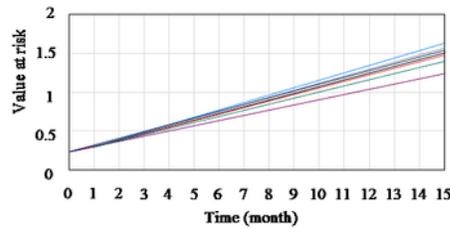
regulatory risk: B1
regulatory risk: B2
regulatory risk: B3
regulatory risk: B4
regulatory risk: B5
regulatory risk: B6

(b)



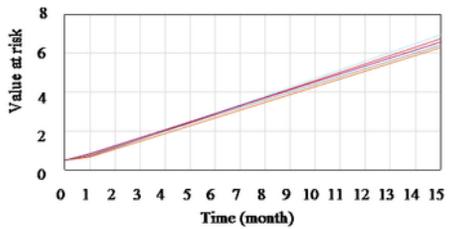
management risk: C1
management risk: C2
management risk: C3
management risk: C4
management risk: C5
management risk: C6
management risk: C7
management risk: C8
management risk: C9

(c)



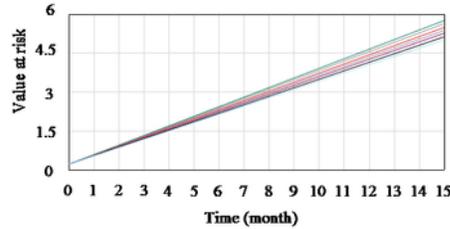
funding risk: D1
funding risk: D2
funding risk: D3
funding risk: D4
funding risk: D5
funding risk: D6
funding risk: D7
funding risk: D8

(d)



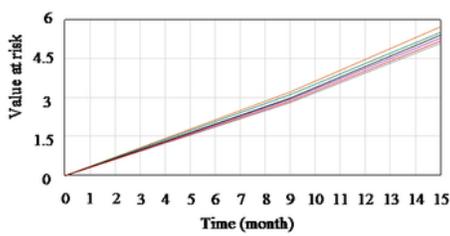
technical risk: E1
technical risk: E2
technical risk: E3
technical risk: E4
technical risk: E5
technical risk: E6
technical risk: E7

(e)



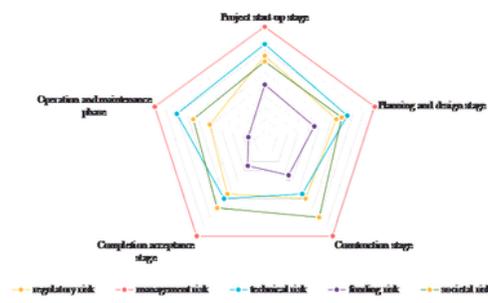
societal risk: F1
societal risk: F2
societal risk: F3
societal risk: F4
societal risk: F5
societal risk: F6
societal risk: F7

(f)



construction risk: G1
construction risk: G2
construction risk: G3
construction risk: G4
construction risk: G5
construction risk: G6

(g)



(h)

Figure 8

Sensitivity analysis results and radar diagram of sponge city construction risk factors