Assessment of Urban Flood Resilience Based on an Innovative PSSR Concept Model

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Abstract. Urban flooding caused by extreme rainstorms is one of the most prominent and difficult problems to be solved in the expansion of the world's cities. This study draws on the Wuli-Shili-Renli (WSR) methodology, and on the basis of the Pressure-State-Response (PSR) index model, reconstructs the "Shili" factor, introduces the "Renli" factor, and constructs a new type of Pressure-State-Shili-Renli (PSSR) concept model of urban flood resilience (UFR). In addition, based on the cloud model of big data theory in computer technology, this study takes into account information randomness and fuzziness to construct a UFR assessment model. Taking Zhengzhou city as an example in 2017-2021, results of the proposed model show that UFR improves year by year, thus indicating that the model established in this study is reasonable and feasible.

Keywords: urban flood resilience; PSSR concept model; cloud model; assessment index system

1 Introduction

In the context of global climate change, flooding caused by extreme weather, particularly heavy rainfall, poses a constant and significant threat to major cities worldwide. The recently released the Sixth Assessment Report of the Inter-governmental Panel on Climate Change (IPCC AR6) report highlights the severe consequences of flooding in Asian cities, particularly in China. For instance, the "7.31" rainstorm in Beijing in 2023 caused 11 fatalities, 13 missing individuals, extensive property damage, ecological harm. The IPCC has introduced the concept of "climate resilience development," and China's "14th Five-Year Plan" emphasizes the strategic planning for building resilient cities. Consequently, enhancing urban flood resilience (UFR) has become crucial in the context of promoting the construction of resilient cities in China.

Currently, Pressure-State-Response (PSR) model is used to develop a resilience assessment index system as it focuses on the occurrence, causes, and management of events, forming a dynamic feedback system [1]. However, PSR model overly emphasizes objective factors at the physical system level, neglecting subjective factors such

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as social behavior, social psychology, social co-governance, and social action related to the human system level. The Wuli-Shili-Renli (WSR) methodology, proposed by Jifa Gu, examines the dynamic unity of three factors: the objective world, the organization, and the human being [2]. This provides a new idea for the deficiency of PSR model.

Cloud model in computer technology takes big data as the center, combines the development of granular computing, machine learning and statistics, and is continuously enriched and widely used [3]. The cloud model has characteristics of strong quantitative and qualitative analysis, so it can be applied in the evaluation of flood resilience.

Based on the above analysis, this study draws on WSR methodology and reconfigures the "Shili" factor based on PSR model, and the "Renli" factor is introduced, and constructs a new type of Pressure-State-Shili-Renli (PSSR) concept model of UFR. The performance of the PSSR concept model by cloud model of big data theory in computer technology is verified by taking Zhengzhou as an example.

2 Method

Based on PSSR concept model, UFR assessment index framework consists of four aspects: Pressure, State, Shili and Renli. The UFR assessment index system is shown in Table 1.

Table 1. UFR assessment index system

Target layer	Criterion layer	Indicators	Type
Urban Flood Resilience	Pressure	C1 Annual average rainfall (mm)	-
		C2 Unit energy consumption (%)	-
		C3 Urbanization rate (%)	-
	State	C4 Drainage pipe density (km/km^2)	+
		C5 Percentage of elderly and children (%)	-
		C6 population density (10^4 people/km^2)	-
		C7 Urban building exposure (%)	-
	Shili	C8 Monitoring and Early Warning (%)	+
		C9 Emergency Management (%)	+
		C10 Urban Maintenance and Construction (%)	+
		C11 Learning and Innovation (%)	+
	Renli	C12 communication and coordination (%)	+
		C13 Citizen Response (%)	+

Pressure (P) refers to the risk of urban flooding and the potential for suffering losses. Rainfall is a direct factor in the occurrence of urban flooding. Unit energy consumption affects climate change, which can lead to extreme weather events like heavy rainfall [4]. Urbanization contributes to an increase in impervious areas, which are prone to flooding. State (S) refers to a city's ability to resist flooding through its own resilience. A well-developed urban drainage system has water storage capacity and can timely discharge urban rainwater. The condition of vulnerable groups, populations, and buildings exposed to floods affects UFR [5].

Shili (S) perspective analyzes the series of effective response measures taken by urban subjects to cope with flooding. Effective, authoritative, efficient and scientific measures can improve UFR and enable them to quickly return to normal and adapt to new conditions. Urban flood reasoning involves multiple links, fields, and elements, such as urban rain monitoring and early warning, emergency rescue and relief disposal, post-disaster urban maintenance and reconstruction, and learning innovation [6].

Renli (R), in the process of urban flooding, can be understood as individuals and groups, social behavior, social psychology, social co-governance, and social action and control. In the process of urban flooding, communication and coordination between multiple participating subjects, so as to achieve social consensus and joint action from the top and bottom with the same agreement is crucial to enhance UFR [7]. In addition, citizens' self-help ability and active measures during floods can reduce economic losses and casualties [8].

Cloud model of big data theory in computer technology is an algorithm based on probability theory and fuzzy set theory, which has characteristics of strong quantitative and qualitative analysis [9]. The cloud is represented by the parameter expectation *Ex*, entropy *En*, and hyper-entropy *He*, namely, *C* [*Ex*, *En*, *He*]. For quantitative indicators with bilateral constraints [c_{min}, c_{max}], the formula for its three parameters is:

$$Ex = \frac{c_{\min} + c_{\max}}{2}, \quad En = \frac{|c_{\max} - c_{\min}|}{2.355}, \quad He = d \tag{1}$$

where *d* is a constant and the uniform value of *d* is 0.01 in this study. Assessment process of UFR based on cloud model is shown in Fig. 1.

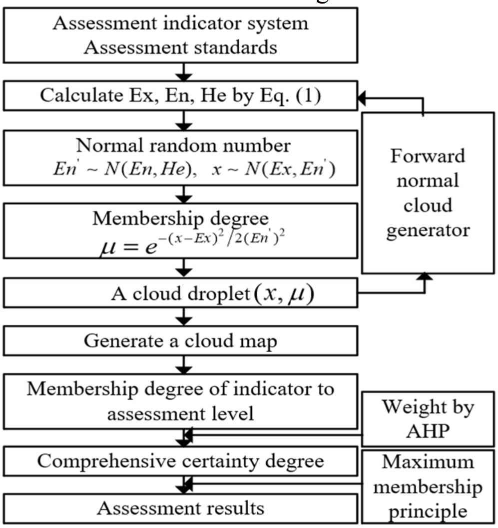

Fig. 1. Assessment process of UFR based on cloud model.

According to the relevant national norms and standards, UFR assessment standards are classified as five levels (very low resilience I, low resilience II, medium resilience III, high resilience IV, and very high resilience V). *Ex*, *En*, *He* are determined according to the assessment criteria and Eq. (1). To enhance credibility, the forward cloud generator is running 1500 times, and its average value is taken as the final membership degree *R*. The weights *W* determined by using analytic hierarchy process (AHP) [10] are combined with the membership degree to calculate the comprehensive certainty degree by

$$B = RW \tag{2}$$

Based on maximum membership principle, the assessment level corresponding to the maximum membership is selected as the final assessment result.

3 Example verification

Taking Zhengzhou City from 2017 to 2021 as an example, the quantitative indicators combined with the relevant data collected in the yearbook of Zhengzhou Municipal Bureau of Statistics are shown in Table 2. According to the UFR assessment process based on cloud model, it is used to calculate the results, shown in Table 3 and takes indicators C3, C8 and C13 as examples to draw cloud model map, as shown in Fig. 2.

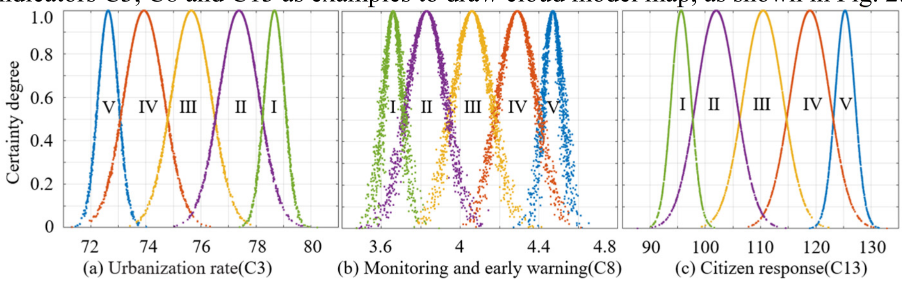

Fig. 2. Normal cloud model map

In Fig. 2, (b) Monitoring and Early Warning (C8) is a positive index, meaning that the more accurate the monitoring and early warning of urban floods and the more prepared the city is against floods, the more resilient the city is against floods. Conversely, (a) Urbanization rate (C3) and (c) Citizen Response (C13) are negative indexes. For example, (a) Urbanization rate (C3) indicates that a higher urbanization rate corresponds to lower flood resilience, with the resilience level inversely ordered in the cloud diagram. The broader the range of index values for each resilience level, the higher the probability of cloud drops falling within that level.

In Table 3, it is observed that UFR had a tendency of increasing gradually in Zhengzhou from 2017 to 2021, which had raised from III level in 2017 to IV level in 2021. This trend indicated that Zhengzhou has taken a series of measures in recent years to promote UFR. For example, Zhengzhou City has insisted on people-centered, accelerated the construction of public transportation, increased the area of public green space, vigorously developed the modern service industry, and strengthened scientific and technological innovation. These measures contribute to UFR.

In Table 3, it could be known that Zhengzhou's UFR pressure continues to rise, due to accelerate the construction of a national center city. Zhengzhou's UFR state is the opposite of pressure, which is related to the city's efforts to promote the construction of sponge-type ecological water systems. UFR shili toughness development is also on the rise in Zhengzhou from 2017 to 2021. This is related to the degree of improvement of the city's flood control and emergency system construction.

Unlike UFR pressure, state and shili factors, the city's renli factors have improved year after year, which had rised from I level (very low resilience) in 2017 to V level (very high resilience) in 2021. Throughout the study period, Zhengzhou City has prioritized a people-centered development ideology, recognizing the role of the public and other stakeholders as participants, experiencers, and perceivers of risks. This approach considers various subjects such as the government, enterprises, the public, the media, and social groups in disaster management and mobilizes their collective efforts through new media platforms. The establishment of effective communication, collaboration, and complementarity among multiple subjects has paved the way for a new approach to urban flood management in Zhengzhou.

Table 2. Raw indicators data

Criterion layer	Indicators	2017	2018	2019	2020	2021
Pressure	C1 (mm)	550.40	609.40	509.50	676.70	1570.50
	C2 (%)	17	16	14	13	13
	C3 (%)	72.20	73.40	74.58	78.40	79.10
State	C4 (km/km^2)	8.66	8.35	7.97	7.78	8.33
	C5 (%)	25	26	27	28	28
	C6 (10^4 $people/km^2$)	1.11	1.09	0.88	0.94	0.94
	C7 (%)	50	54	58	63	66
Shili	C8 (%)	3.61	3.90	4.21	4.29	4.52
	C9 (%)	26	27	25	25	25
	C10 (%)	6	10	12	13	14
	C11 (%)	14	14	16	18	20
Renli	C12 (%)	3.60	8.93	12.68	16.54	16.60
	C13 (%)	9.35	9.94	10.78	11.60	12.74

Table 3. Assessment results of UFR in Zhengzhou from 2017 to 2021

Year	Pressure	State	Shili	Renli	Result
2017	IV	III	II	I	III
2018	IV	III	II	III	III
2019	IV	III	III	III	III
2020	III	III	III	IV	IV
2021	II	IV	III	V	IV

4 Conclusion

This study proposes a new Pressure-State-Shili-Renli (PSSR) concept model to construct an urban flood resilience (UFR) assessment index system and evaluate UFR based on cloud model of big data theory in computer technology. The practicality and rationality of the model were verified taking Zhengzhou city as an example. The assessment results show that PSSR concept model aligns with the actual situation, confirming its reasonableness and feasibility. From 2017 to 2021, Zhengzhou's UFR improved each year, which had raised from III level (medium resilience) in 2017 to IV level (high resilience) in 2021. Key factors influencing the change in UFR during the study period include annual rainfall, drainage pipe density, emergency response system, and social consensus.

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