URBAN WATER SECURITY ANALYSIS BASED ON FUZZY COMPREHENSIVE EVALUCATION MODEL

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Abstract - In this paper, we are trying to propose the concept of urban resiliency to solve the problem of urban water security. We develop a comprehensive framework to examine and measure the integrated urban resiliency which is shaped by four interacting domains. They are water volume resiliency, stability-resiliency, service function resiliency, and organizational structure resiliency. The approach Fuzzy Comprehensive Evaluation Model (FCE) was adopted for the evaluation of its role to assess urban resiliency.The result indicates that the integrated urban resiliency is mainly affected by the organizational structure resiliency in the four domains.Recommendations for improving the urban resiliency of different sub-levels are made to help guide the decision-makers to adjust urban water management governance approaches to local conditions.

Keywords - Fuzzy Comprehensive Evaluation Model, urban resiliency, urban water security, cluster analysis, sponge city.

INTRODUCTION

In recent years, freshwater use and management is growing more important overall the world (Strayer and Dudgeon, 2010; Christ and Burritt, 2017; Chapagain and Tickner, 2012). As a sort of scarce resource, many scholars have worked to develop different concepts and approaches to focus on the issue of limited freshwater availability (Pervez and Henebry, 2015; Godskesen et al., 2013). Since 1990s, water science programs and conferences have been held around the world by international organizations (Xue and Mary, 2015; Kourosh and Zoran, 2015). The purpose of theses conferences was to ensure that everybody could access safe water and live a healthy life. So the water security issue is becoming more and more important (Fu, et al., 2016; Dickson, et al., 2016). Nowadays, China's cities are facing different kinds of water scarcity, water pollution (Cordell et al., 2011), water environmental damage. The great shrinking of Lake areas, wetlands and other natural water bodies because of the speeding up urbanization affects the function of lakes in adjusting water volume and destroys ecological condition of the area, leads to frequent disasters (Metson et al., 2015). The number of flood disaster has been increasing significantly in recent years, and the lives and properties of citizens in these cities are heavy threaten. Meanwhile, pollution from storm water runoff is increasing with development of urbanization because of the expansion of impermeable surface area. It has become a pollution source which cannot be neglected. The phenomenon of clean water turning to black and smelly occurred frequently. At the same time, the utilization of rainwater is very low. In the last few years, Beijing, Shanghai, Guangzhou and other international big cities have suffered heavy downpours.Actually, urban flood disaster has become an important research topic. Through this exploration, this paper contributes to the planning, design and flood prevention departments with tools to minimize urban flood disaster. In contrast to the extensive literature describing countries, regions and large-scale watersheds (Bogardi et al., 2012), (Grey and Sadoff, 2007), little attention has been paid to urban water security (Noiva et al., 2016; Mollinga and Gondhalekar, 2014; Wescoat, 2014). The definition and scope of water security has differed with specific purpose and issues by some researchers (Cook and Bakker, 2012; Falkenmark, 2013; Hendrix and Salehyan, 2012; Paton et al., 2014). In water security system, although water resources carrying capacity is an important part of natural resources carrying capacity especially with the shortage of water resources in a country or a region. It has a crucial effect on the integrated development and sustainable development of the region. As the research of sustainable development and a basic subject in the study of water resources security strategy, the academia has paid close attention to the ecological carrying capacity. Water resources carrying capacity has become a hot and focus scientific research problem now. While, Chinese academics and professionals more focus on the research of application and quantitative methods about water resources carrying capacity, less study on the concept of water security system. According to the concept of water security, urban water security system is divided into three aspects. Water resource, water environment, and water disaster compose the UWSS. For the urban governors, they need to take into consideration economic, society, technology and environment. An integrated and accepted methodology is desired to maintain the sustainability of urban water security. The object of this paper is to account for these impact domains in urban water security through urban resiliency indicators. In this paper, we adopt the concept defined by Patricia (Romero-Lankao and Gnatz, 2016); urban water security includes two components, sustainable

availability and resilient urban areas and ecosystems. Integrated urban resiliency includes water volume resiliency, stability-resiliency, service function resiliency, and organizational structure resiliency. In order to quantize and measure integrated urban resiliency, the choice of fuzzy comprehensive evaluation model was used. We established standard value of evaluation indicator in accordance with some methods, these standards stand for a resilient city. The most widely used and cited definition of resiliency was proposed by (Hashimoto et al., 1982). According to this definition the higher the probability of recovery, the higher the resiliency of the component/domain is. In other words, it represents the higher the resiliency of the component/domain is, the safer the urban water security system. Next, based on the evaluation results, we classified the evaluated cities in 3 sub-levels with cluster analysis. It will be more appropriate to present different countermeasures for different resilient levels of city.

II. METHODOLOGY

2.1. Index system

As shown in Table 1, based on scientific, typical, combination of qualitative and quantitative, available, comparable principles (Pinter, et al., 2012), considering the connotation of urban water security in the study area, the index system has been given. The categories of urban resiliency contained water volume resiliency (A), Stability resiliency (B), Service function resiliency (C), and Organizational structure resiliency (D). Water volume resiliency (A) contained two indicators, corresponding to water supply and demand. Different cities have different water supply and water use mode, because of different backgrounds of water resources endowments, food production subsystem and ecological subsystem. Stability resiliency (B) and Service function resiliency (C) also had two indices respectively, corresponding to ecological function and susceptibility to hazards. Organizational structure resiliency (D) aggregated economic structure, socio structure, and natural structure. An explanation and quantification method, as well as the data sources of these indicators and criteria was given in the following tables (1-3). In order to achieve the sustainability of urban water security, it will be necessary to combine and aggregate methods to illuminate different levels of influence among the four interconnected and multidimensional domains.

Category	Description	Indicators①
water volume resiliency (A)	Water supply and demand	Exploitationratio of water resources(A1) Water supply per capita (A2)/cu.m
Stability resiliency (B)	Anti-interference measures	Investment in water infrastructure including water supply and sewerage(B1)/% Treatment rate of sewage(B2)/%
Service functionresiliency (C)	City Public Utilities	Per Capita Area of Parks and Green Land(C1)/sq.m Per capita urbanroad area(C2)/sq.m
Organizational structure resiliency (D)	Economic structure	The proportion of the tertiary industry in GDP(D1)/% Per capita Gross Domestic Product(D2)/10 thousandyuan
	Socio structure	Holding high educational qualifications per ten thousand of people(Persons) (D3) Population density(persons/sq.km)(D4)
	Natural structure	Green covered area as % of completed area(D5)/% Ratio of ecological water to total water demand(D6)/%

Table1:Assessment index system and assessment standard of urban resiliency

Indexes	Low-low(L1)	Low-high(L2)	Moderate(L3)	High-low(L4)	High-high(L5)	method
A1	110	102.5	95	87.5	80	②
A2	300	262.5	225	187.5	150	②
B1	1.5	2.375	3.25	4.125	5	②
B2	50	61.25	72.5	83.75	95	②
C1	7	10.25	13.5	16.75	20	②
C2	10	14.5	19	23.5	28	②
D1	30	42.5	55	67.5	80	②
D2	0.70	2.53	4.35	6.18	8.00	②
D3	100	325	550	775	1000	②
D4	1500	900	400	200	50	②
D5	20	27.5	35	42.5	50	②
D6	2	2.75	3.5	4.25	5	②

Table 2: Criteria of assessment indicator

Index	A1	A2	B1	B2	C1	C2
Weight	0.03	0.10	0.15	0.03	0.04	0.06
Index	D1	D2	D3	D4	D5	D6
Weight	0.07	0.14	0.05	0.04	0.08	0.22

Table 3: Weights of assessment indicators

2.2. FCE Modeling Methodology

The FCE model is set up by introducing vague set theory to the process of comprehensive evaluation. Suppose there is two limited universe of discourse, one is evaluated set, another is a standard set. According to calculating membership degrees of every indicator to every grade, we get the membership degrees matrix. Then in the principles of weighted average and biggest value, we calculate the membership degrees of every category's resilience and integrated resiliency to every grade.

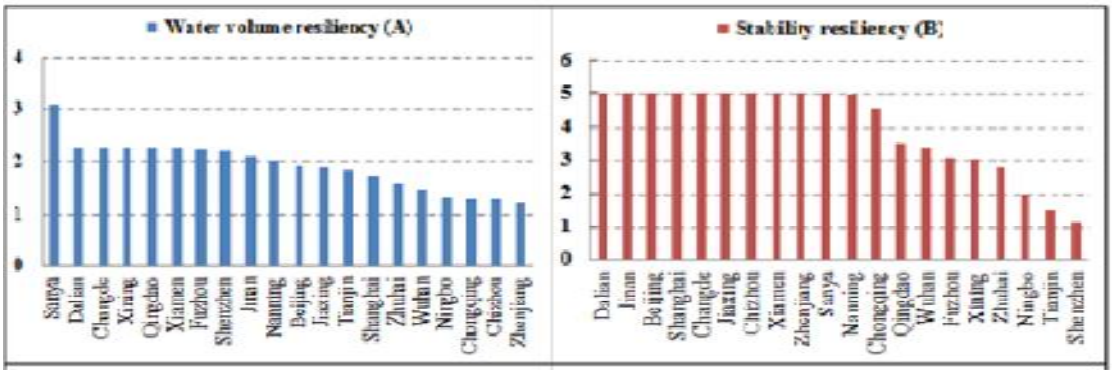
III. RESULTS AND DISCUSSION

3.1. Impact analysis of every domain in urban water security

First of all, we analyzed the water volume resiliency in different cities. Just as the results Fig.1(A) showed that Low-high resilience contained Beijing, Jiaxing, Tianjin, Shanghai, Zhuhai, Wuhan, Chongqing, Ningbo, Chizhou, Zhenjiang, the member degree values was 1<= <2. It meant exploitation of water resources in these cities were over water resources capability and water supply per capita was relatively lower than national average level.It has exceeded sustainable level; water utilization almost approached the carrying capacity. While Dalian, Qingdao, Jinan, Shenzhen, Changde, Xining, Nanning, Xiamen, Fuzhou belonged to the moderate state, the value scale was 2<= <3, where water supply can basically meet the water demand. Only Sanya city was located in High-low state, where there was a surplus in the water supply. There was no city situated in Low-low and High-high. From the spatial distribution regular, ranked top 10 cities were located on the eastern coast of China except for Xining and Changde. But Changde was surrounded by Dongting Lake. In other words, these cities have abundant water resources in natural endowment except Xining, which led to higher per capita water resource. Although Xining didn't have access much fresh water, its exploitation of water resources was very low. It had the great development potential and its water volume resiliency is higher relatively than other cities.From Fig.1 (B), we concluded that the stability-resiliency of Shenzhen, Tianjin, and Ningbo was Low-high.Cities in the top third were Zhuhai, Qingdao, and Zhenjiang in Fig.1(C). Most important was the index of per capita area of parks and the green land was high in the three cities.In this organizational structure domain, we aggregated economic structure, socio structure and natural structure in Fig.1 (D). It reflected the structure resiliency of the city.

3.2. The results of integrated urban resiliency using weighted average principle

For governors, it is important to realize which part is the key factor and influences the integrated urban resiliency markedly.Comparing the integrated resiliency of the each city revealed that cities with higher organizational structure resiliency had larger integrated resiliency, while cities with lower organizational structure resiliency had smaller integrated resiliency (Fig.2). The cities with the largest integrated resiliency were Beijing, Qingdao, and Jiaxing, the U value which was all beyond 4.0, representing the biggest resilient level. So if the manager wants to improve or strengthen the integrated urban resiliency, the fastest and effective way is to focus on organizational structure. In order to provide brief information results for policy-maker, cities were divided into three groups, according to these comprehensive evaluated and compared factors. The clustering results with the ward linkage method were shown in Fig.3.



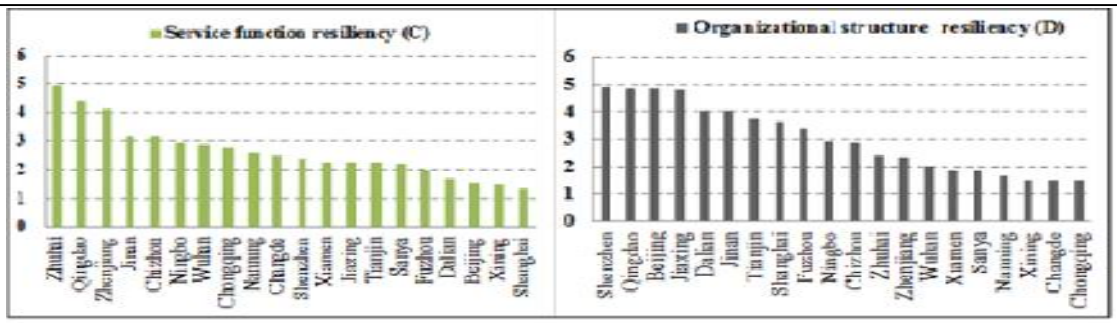


Fig.1. Membership degree values of water volume resiliency (A), stability-resiliency (B), service function resiliency(C), organizational structure resiliency (D), respectively.

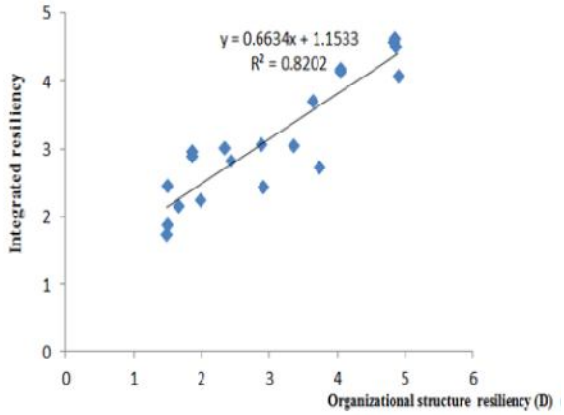


Fig.2. Relationship between integrated and organizational structure resiliency for each city

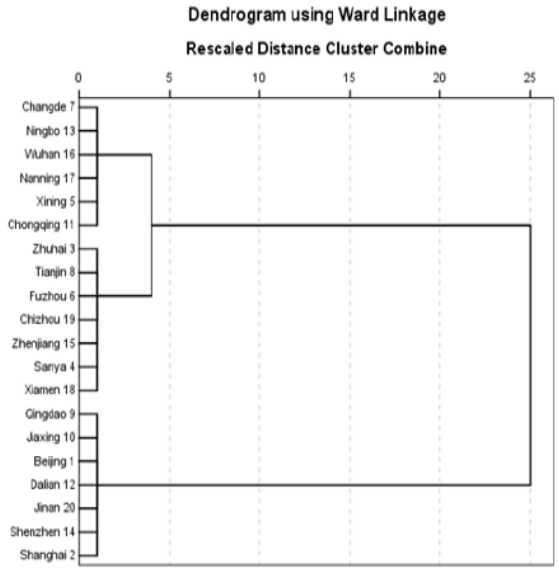


Fig.3. the 3 sub-levels cluster tree results of 20 cities.

CONCLUSIONS

Cluster analysis of the urban integrated resiliency for each sub-level provides information on which to base some policy recommendations for improving the resilient performance of the different sub-levels:

1. For High resilience cities, the urban water security is better. The character of these cities is that the organizational structure is developed. But water volume, service function, stability need to improve according to different cities condition.
2. For Moderate resilience cities, the urban water security state is general. The governance focus can be placed on every domain of the urban resiliency. Use of traditional technology and engineering should be reduced, and faced with the problems, it need introduce new concepts and technological means to change and solve;
3. For Low resilience cities, the urban water security is bad. Such as Xining, if the city wants to improve urban water security effectively, we suggested the planner to pay more attention to the organizational structure. It is a direct and efficient approach.

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