# Sustainable Urban Resilience Assessment under Public Health Emergencies Based on Symbiosis Theory

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**Abstract.** Frequent public health emergencies (PHEs) impact urban resilience and threaten sustainable development. In view of the differing focuses on resilience and sustainability, the paper considered long-term sustainable development while assessing short-term urban resilience. Due to close cooperation among social structures, this paper viewed social structures as symbiotic units and evaluated sustainable urban resilience under PHEs based on symbiotic theory. To address evaluation uncertainty, a data-driven weighting approach was proposed. Additionally, empirical research was conducted on five major cities in Sichuan, a heavily affected province during COVID-19. Finally, Overall recommendations and city-specific suggestions were put forward to enhance resilience.

**Keywords:** Urban resilience; public, health emergencies, symbiosis theory, hesitant, fuzzy evaluation

## 1      Introduction

The accelerated urbanization process hinders the sustainable development of cities, promoting nations to endorsed the 17 Sustainable Development Goals (SDGs). Among them, the 11th SDG "Sustainable cities and communities" aims to make cities and human settlements resilient and sustainable. In support of this goal, policies to cultivate resilient cities and articles on sustainable cities emerged.

Resilience and sustainability are distinct concepts. Resilience is primarily concerned with how systems perform under short-term extreme impacts 1, while sustainability focuses on long-term development that meets current needs without harming future generations' ability to do so 2. The two concepts can compete or complement with each other 1. Urban resilience involves the rapid absorption, adaptation, and transformation of sudden disaster risks. However, SDGs demand not only resilience but also development that avoids harming economic, ecological, and social environments. Therefore, integrating urban resilience with sustainability is crucial in managing uncertainty.

In recent years, urban resilience assessments have emerged for natural disasters 3 and infrastructure system 4, but few have focused on public health emergencies (PHEs). With the global PHE experience, especially COVID-19, there's a growing consensus on enhancing pandemic resilience, leading to the expansion of the concept of pandemic-resilient cities. Previous research has developed resilience evaluation systems based on disaster and resilience theories, with some focusing on urban subsystems. However, no studies have assessed resilience from the perspective of urban social structures, despite the need for tight coordination among them during PHEs 5. To evaluate sustainable urban resilience, a holistic understanding of interacting components is essential.

In light of this, this paper introduces symbiosis theory to construct an indicator system. Introduced by Anton de Bary 6, "symbiosis" describes organisms living harmoniously for mutual benefit, a concept extended to social sciences. Cities, as complex systems of interconnected social structures, can be seen as symbiotic systems. Similar to the organisms and their ecological environments, social structures and environments within urban systems need to maintain stability through cooperation.

## 2      Key Problem Statement

### 2.1      Symbiosis Theory Consideration under PHEs

Generally, a symbiotic system comprises symbiotic units, relationships, and environments 7. In 1998, these three elements were proposed and widely used. Symbiotic units are basic for energy production and exchange. Symbiotic relationships refer to the interactions or combination of units. Symbiotic environments facilitate the sustenance and evolution of symbiotic relationships. A justified framework for assessment was offered as followed (Figure 1):

(1) Correspondence between elements of symbiosis and evaluative dimensions. While assessing urban resilience, resistance 8, coordination 9, and adaptability 10 are considered. Resistance means symbiotic units (governments, enterprises, social organizations, community residents) persist under disasters 11. Coordination among units (symbiotic relationship) is essential for resilience implementation 11. Adaptability of symbiotic environments reflect the city's capacity to respond to external changes and is always tied to urban economic, social, and ecological environment 11.

(2) Similar principle. The principle of symbiosis emphasizes mutual benefits among symbiotic units 12, reflecting multi-sector collaboration and cross-domain integration in urban governance.

(3) Same goal nature. The symbiosis theory clarifies rules for collaborative development among units for efficient evolution 13. Likewise, cooperation among social structures and long-term symbiotic environment help cities effectively address complex challenges such as PHEs.
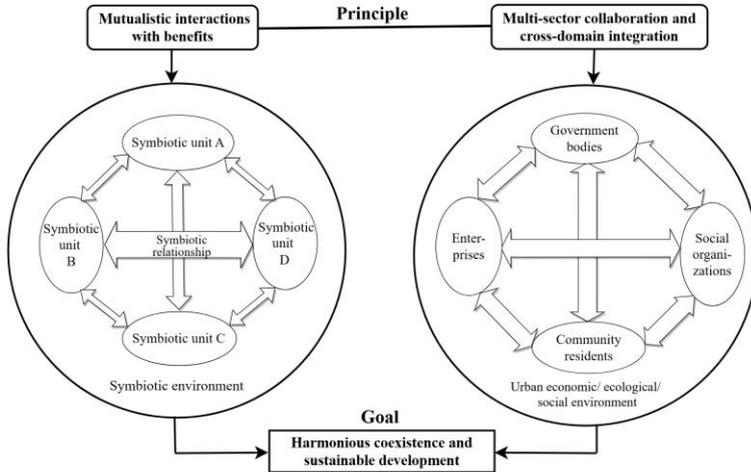
Figure 1. The combination of symbiosis theory and sustainable urban resilience

## 2.2    Resolution of Subjectivity and Uncertainty of Evaluation

In multi-criteria decision making (MCDM), subjective expert evaluation faces challenges due to accuracy decreasing with more indicators. Objective methods, like entropy method and MDM (maximizing deviation method) 14, focus on variations in alternatives' data to assign weights. However, in many cases, evaluation data cannot be obtained for fuzzy indicators. Hence, this study adopted relatively objective methods for scoring and weighting indicators, reflected in: (1) Urban residents' evaluation during PHEs, despite individual subjectivity, reveal overall trends and consensus through statistics analysis. (2) The hesitancy fuzzy evaluation method is adopted for scoring. (3) An objective weighting model based on MDM is established for weighting.

# 3    Selection of Indicators

## 3.1    Resistance Indicators

(1) Government resistance (R1). Commonly, the emergency response capacity (R11) and infrastructure resilience (R12) gauge governments' disaster response 15. Early warning efficiency (R111) is often adopted in response evaluation. The timeliness (R112) and reliability (R113) of official information is vital for accurate communication. During PHEs, transport connectivity aids rescue and evacuation, measured by urban road area per capita (R121).  (2) Enterprise resistance (R2). During PHEs, medical, pharmaceutical, and manufacturing enterprises are crucial. Thus, R2 includes: medical equipment supply(R21), medicine supply(R22), and material supply(R23). Medical enterprises provide equipment assessed by the number of hospitals, beds, and

doctors per 10,000 perple (R211, R212, R213) 16. R22 evaluates adequacy and availability of medicines (R221) and reasonable medicine prices (R222). R23 was measured by adequacy and quality of medical and daily materials (R231, R233, R232, R234). (3) Resident resistance (R3). Sustainable resistance needs good physical fitness and economic resources. The percentage of population aged between 15 and 59 (R31) reflects overall physical health 19. Besides, disposable income and balance of savings deposits (R32, R33) assess economic capability 20.

## 3.2    Coordination Indicators

Four aspects were proposed from the perspective of multi-unit collaboration. (1) Management of public health resource (C1). Under PHEs, C1 includes financial support and material supplies 5. The proportion of local financial expenditure on health (C11) shows government's financial support for relevant social structures. The efficiency and fairness of material distribution (C12) also evaluates coordination 21, impacting social trust over time. (2) Propaganda of prevention and control knowledge (C2). Residents' emergency concept is the basis of PHE management. The coverage of emergency publicity and education (C21) measures the breadth of the activity, while public health knowledge level of residents (C22) assesses the depth of educational activities. (3) Telecommuting and community service (C3). C3 is related to the policy coordination and resource allocation among four symbiotic units. Contribution of home office/learning (C31) measures the effect of isolation policy and community satisfaction (C32) of residents reflects whether service provision are sufficient. (4) Mental health maintenance (C4). C4 involves coordination among government, residents, and social organizations. To evaluate C4, accessibility of psychological counseling services (C41) measures the degree of participation and effects of psychological counseling (C42) measures the depth.

## 3.3    Adaptability Indicators

(1) Economic environment (A1). Three aspects were included in A1, namely, gross domestic product (GDP, A11), tertiary industry as a percentage of GDP (A12), and employment rate (A13) 3. (2) Social environment (A2). The urbanization rate (A21) measures the development of society and is correlated with disaster resilience 16. (3) Ecological environment (A3). Ecological environment indexes under PHEs included the greening rate (A31) and sewage treatment rate (A32) 15.

# 4    Methodology

## 4.1    Improved Weighting Model Based on MDM

Let $A_i$ ($i=1,2,…,m$) be alternatives, $C_j$ ($j=1,2,…,n$) be criteria. Each crisp indicator has $t$ values over $t$ periods. $C_j$ belongs to crisp set $J_c$ or hesitant fuzzy set $J_h$. $S_{ij}$ ($i=1,…,m$, $j=1,…,n$) is the number of respondents evaluating the $j$-th indicator of the $i$-th alterna-

tive. **Step 1.** Suppose that $Q_{ij}^{(y)}$ $(y=1,2,...,t)$ denotes $t$-th values of crisp indicator $C_j$. Each

crisp indicator values is normalized by $\bar{Q}_{ij}^{(y)} = \dfrac{Q_{ij}^{(y)}}{\sum\limits_{i=1}^{m}\sum\limits_{y=1}^{t}Q_{ij}^{(y)}}, j \in J_c$ , preserving the maximum

and minimum to form a HFE $r_{i,j}$ $(j \in J_C)$ of length 2. **Step 2.** Suppose that $r_{i,j}^{(p)}$ $(j \in J_H, p=1,2,...,S_{ij})$ is the p-th HFE of hesitant fuzzy indicators. Extend original HFEs to length L. $r_{i,j}^{(p,k)}(k=1,2,...,L, p=1,2,...,S_{ij})$ signifies the k-th degree of membership. Then, the weight average operator method is utilized to determine the new HFE $a_{i,j}=(u_j,v_j,\pi_j)$ $(j \in J_H)$ . **Step 3.** Let $w=(w_1,w_2,...,w_n) \in I$ be the weight vector, where $w_j \geq 0, j=1,2,...,n$, $\sum_{j=1}^{n} w_j =1,$ $E$ is a set of the weight interval. Weights can be determined by the proportion of deviation 23 and also influenced by proportion of hesitance degree, as its larger value indicates less accuracy of evaluation. To ensure result accuracy, we guaranteed that sums of crisp and hesitant fuzzy indicator weights obtained from two calculation methods are equal. Then, the weight interval set was calculated. **Step 4.** The model considered maximizing score deviation and minimizing

overall hesitancy. For two HFEs $r_{i,j}$ and $r_{k,j}$ of length $l$ , distance was proposed as: $d(r_{i,j},r_{k,j})=\dfrac{1}{l}\sum\limits_{p=1}^{l}\left|r_{i,j}^{(p)}-r_{k,j}^{(p)}\right|$ , where $r_{k,j}^{(p)}$ is the p-th values in $r_{k,j}$ . Then, one function to maximize deviation based on MDM 23 and another to minimize overall hesitancy was created to calculate weights as:

$$\begin{cases} \max D(w) = \sum\limits_{j \in J_c}\sum\limits_{i=1}^{m}\sum\limits_{k=1}^{m} d(r_{i,j},r_{k,j})w_j + \sum\limits_{j \in J_h}\sum\limits_{i=1}^{m}\sum\limits_{k=1}^{m} d(a_{i,j},a_{k,j})w_j \\[2mm] \min H(w) = \sum\limits_{j \in j_c}\sum\limits_{i=1}^{m}\left|r_{i,j}^{(1)}-r_{i,j}^{(2)}\right|w_j + \sum\limits_{j \in j_h}\sum\limits_{i=1}^{m}\dfrac{1}{s_{ij}}\sum\limits_{p=1}^{s_{ij}}\left|r_{i,j}^{(p,1)}-r_{i,j}^{(p,2)}\right|w_j \\[2mm] \text{Subject to } \omega \in E, \sum\limits_{j=1}^{n} w_j =1, w_j \geq 0, \text{ j=1,2,...,n} \end{cases}$$

(1)

The linear weighting method solved the multi-objective model by multiplying each objective by weight coefficient $\lambda_i$ $(i=1,2,...,r)$ (based on importance) and summing them into a single programming problem, namely $\max f = \sum\limits_{i=1}^{r}\lambda_i f_i(x)$ , where $\sum\limits_{i=1}^{r}|\lambda_i|=1$ .

## 4.2    Hybrid Information Aggregation Based on TOPSIS

When a certain target point is closest to the positive ideal solution while being farthest from the negative ideal solution, it is considered as the optimal solution. **Step 1.** The weighted standardization HFE $S_{ij}$ was explained as: $S_{ij}=\left(\dfrac{w_j \cdot u_{i,j}^{(1)}}{\max\limits_{i}\left\{u_{i,j}^{(1)}\right\}}, \dfrac{w_j \cdot u_{i,j}^{(2)}}{\max\limits_{i}\left\{u_{i,j}^{(2)}\right\}}\right)$ . **Step 2.** For

all indicators, define $s_j^+$ and $s_j^-$ as the positive and negative ideal solution by: $s_j^+ = (\max_i s_{ij}^{(1)}, \max_i s_{ij}^{(2)})$, $s_j^- = (\min_i s_{ij}^{(1)}, \min_i s_{ij}^{(2)})$. Then, the distance between alternatives and two ideal solutions are as: $d_i^+ = \sum_{j=1}^{n} D(s_{ij}, s_j^+)$, $d_i^- = \sum_{j=1}^{n} D(s_{ij}, s_j^-)$.

**Step 3.** The equation $C_i^* = \dfrac{d_i^-}{d_i^+ + d_i^-}$ calculates relative closeness of each alternative to the ideal solution, where the value of $C_i^*$ ranges between 0 and 1, and higher values indicate more optimal solutions.

# 5 Case Study

## 5.1 Study Area and Data Collection

The sustainable urban resilience evaluation system under PHEs was applied to 5 cities in Sichuan Province. During COVID-19 from 2020 to 2022, Sichuan Province was one of the worst-hit provinces in China. Five surveyed cities are Chengdu (U1), Mianyang (U2), Yibin (U3), Deyang (U4) and Zigong (U5), which together account for 43.82% of the population and 67.53% of the total number of confirmed cases of Sichuan province. The indicator system includes 30 basic indicators: 14 hesitant fuzzy and 16 crisp indicators. Crisp indicators data were derived from Sichuan Statistical Yearbook and hesitant fuzzy indicators were from questionnaire surveys among residents in five cities. According to the Cochran formula, 1067 respondents were needed. Then, a total of 1900 responses were recruited and 1540 valid questionnaires were obtained (validity rate of 81.05%). The sample size for each city was based on relative population proportion, with a balanced sex ratio and age distribution reflecting local demographics. The questionnaires passed reliability and validity test.

## 5.2 Results

Weight coefficients of three objectives were set as: λ1=0.6, λ2=0.2, λ3=0.2. By calculation, the weights of resistance, coordination and adaptability are 0.51845, 0.2175, and 0.26405. Then, applying the TOPSIS method, the sustainable urban resilience under PHEs is U3<U5<U4<U2<U1. Despite relatively high resilience, results indicate that Chengdu has limited public health education, low psychological counseling prevalence, unsatisfactory community health services. On top of that, for all 5 cities, the adequacy and affordability of pharmaceutical supplies remains a common concern.

Relative closeness to the ideal solution of each city in three dimensions was shown in Figure 2. Overall, all cities demonstrate similar resistance performance. Chengdu, while lower in coordination capacity, excels in adaptability. Besides, figure 3 highlights the strengths and weaknesses of five cities. The ranking of the cities in terms of resistance aligns with the overall ranking. Chengdu ranks lower in coordination due to poor performance in C11, C22, and C41. Then, C31 of Mianyang is the reason for its poor coordination. By contrast, Deyang's and Zigong's slow economic development

affects A11 and adaptability. Meanwhile, Yibin ranks lower in resistance due to smaller R121, fewer R213, and lower R33.

In the proposed model, the weight coefficient of the first objective, $\lambda 1$, is from 0.5 to 1. The sensitivity analysis considers different combination of weight coefficients. The results of the variation in multi-objective weighting coefficients demonstrate that the rankings of the five cities are unaffected by the weighting coefficients, indicating the robustness of the ranking results.
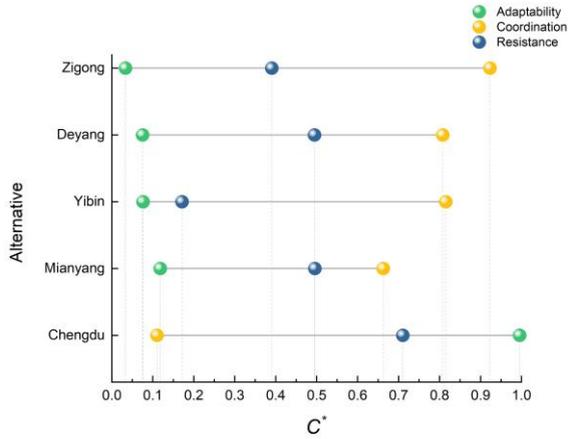


Figure 2. Relative closeness to the ideal solution



Figure 3. Dimensional ranking versus overall ranking

## 6        Suggestions

To promote sustainable resilient cities in the face of PHEs, the following overall recommendations were put forward. (1) Establish a "medicine bank" system funded by corporate/individual donations, social crowdfunding, and government subsidies. Meanwhile, it should set up emergency repositories and form mutual assistance networks among cities/regions. (2) Develop a dynamic pricing mechanism that adjusted medicine prices in real-time based on supply/demand, emergency severity, stock, and logistics costs. The local Development and Reform Commission should draft emergency price adjustment policies. (3) Psychological counseling sinking community and digital transformation. Encourage mental health institutions to create "community psychological support groups" and assign counselors. Meanwhile, collaborate with relative companies to establish remote counseling network.

Then, specific recommendations were provided. (1) Strengthen chengdu's cooperation among organizational structures by boosting healthcare expenditure in budgets and funding hospital construction to boost bed capacity. (2) Mianyang and Deyang show similar urban resilience with robust infrastructure but lack sufficient hospitals for long-term PHE response. (3) Yibin and Zigong have average conditions with low urbanization and income. In particular, yibin's low tertiary industry GDP proportion hinders development and urban resilience.

## 7        Conclusions

For the first time, we constructed an sustainable urban resilience evaluation system from perspectives of social strctures based on symbiosis theory. Then, the proposed weighting method considered both the effects of deviation and hesitation on weights, alleviating subjective issue of expert evaluation. Finally, we offered practical management suggestions to enhance sustainable urban resilience for the five major cities of Sichuan Province under PHEs.

## 8        Acknowledgements

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