

Study on Community Flood Disaster Response Capacity

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Abstract

Under the dual pressures of global climate extremes and frequent urban flooding, communities serve as the "last mile" in disaster prevention and mitigation, with their flood response capabilities directly impacting residents' lives and property safety. However, grassroots disaster preparedness still faces practical challenges including aging infrastructure, fragmented emergency organizations, and insufficient community participation. This study aims to conduct a quantitative analysis of community disaster resilience through an "quantitative evaluation" approach. Utilizing the Analytic Hierarchy Process (AHP), the research identifies 12 key evaluation indicators—including drainage facility integrity rates, emergency response efficiency, and residents' disaster preparedness awareness—across three core dimensions: physical environment, organizational management, and social engagement. A combined qualitative-quantitative evaluation model was developed. Empirical analysis of Sunshine Community demonstrates a comprehensive response capability score of 4.16, rated as "excellent." Data analysis reveals distinct "management-driven" characteristics: efficient early warning systems and contingency plan implementation effectively mitigate the physical vulnerability of aging pipelines during extreme rainfall events. However, the assessment also highlights structural shortcomings in social participation, where lack of disaster preparedness awareness and mutual assistance among residents remains the primary bottleneck hindering the community's progress toward "excellent" disaster preparedness status. Based on the evaluation results, this study proposes a three-pronged approach: implementing "inductive micro-renovations" at the hardware level, adopting "one-page task lists" for management, and establishing "disaster prevention volunteer incentive programs" at the societal level. The research findings not only provide data-driven support for enhancing community resilience in the case study area, but also offer replicable model tools and actionable pathways for disaster risk management in similar urban old residential communities.

Keywords

Community flooding; response capacity; Analytic Hierarchy Process (AHP); resilient governance; empirical analysis.

1. Introduction

1.1. Research Background and Significance

With the intensification of global warming trends, extreme heavy rainfall events have become increasingly frequent and persistent. During urbanization processes, urban flooding has emerged as a critical challenge constraining city safety operations in China, exacerbated by factors including increased impermeable surface coverage, aging drainage infrastructure, and the "urban heat island effect." Communities, serving as the fundamental physical units of urban operations and basic social cells, act as both frontline disaster prevention and mitigation zones while remaining the most vulnerable links in flood response systems. Currently, China's urban disaster prevention strategy is transitioning from "structural engineering-based mitigation" to

"resilient governance." However, many communities still face challenges such as inadequate hardware facilities, fragmented emergency response organizations, and low public awareness of disaster preparedness. Therefore, conducting scientific assessments of community flood resilience capabilities and identifying critical gaps in disaster prevention chains holds significant practical value for enhancing grassroots governance standards and safeguarding residents' lives and property.

1.2. Current Research Status at Home and Abroad

Scholars both domestically and internationally have conducted extensive research on flood disaster response. Foreign studies were among the first to introduce the concept of "resilience," emphasizing communities' self-recovery capacity and adaptability after shocks, and developed evaluation tools such as the DROP model. Although domestic research started later, it has progressed rapidly, focusing primarily on sponge city construction, emergency plan optimization, and community participation mechanisms.

While existing research has reached maturity at the macro urban level, quantitative evaluation frameworks for micro-community levels remain inadequate. Most studies focus on theoretical discussions or singular engineering technology analyses, lacking integrated assessment systems that combine "physical environments" with "social organizations." Particularly in typical areas like aging communities, developing simple yet effective models to evaluate their actual coping capacities remains a critical issue requiring further exploration.

1.3. Research Background and Significance

This study follows a logical framework encompassing "evaluation indicator construction, weight model establishment, and empirical sample analysis." The research prioritizes the scientific rigor of the evaluation system by reviewing domestic and international resilience community assessment criteria, while addressing practical challenges in urban grassroots flood prevention efforts. Evaluation factors are extracted from three dimensions: physical environment, organizational mobilization, and resident resilience. To mitigate subjective bias in assessment outcomes, the Analytic Hierarchy Process (AHP) is employed to quantify indicator weights through pairwise comparison matrices, thereby establishing a comprehensive evaluation model that reflects holistic disaster prevention capabilities within communities.

During the empirical phase, Sunshine Community—a neighborhood with a documented history of urban flooding—was selected as the case study. Field surveys were conducted at critical infrastructure sites including drainage outlets and pumping stations, complemented by targeted interviews and questionnaires with neighborhood committees, property management teams, and residents to collect authentic data on flood preparedness, emergency response capabilities, and post-disaster recovery efforts. The collected data was integrated into an evaluation model, generating quantifiable metrics to visually demonstrate the community's operational effectiveness. After identifying weaknesses in either "hard infrastructure" or "soft management" within the flood control system, actionable improvement strategies were formulated based on the community's actual financial resources and spatial constraints.

2. Construction of Evaluation Index System for Community Flood Disaster Response Capacity

2.1. Logical Framework of Evaluation Dimensions

The capacity of communities to respond to flood disasters is not merely a technical engineering issue, but rather the result of synergy between physical environments and social organizations. Drawing on the resilient city theory, this study deconstructs response capabilities into a

comprehensive process encompassing "prevention, response, and recovery," which can be specifically categorized into three core dimensions: Physical environmental resilience (hard power): focusing on internal drainage infrastructure, topographical features, and emergency supply reserves; Organizational management efficacy (soft power): emphasizing command systems of grassroots management organizations, implementation of contingency plans, and social mobilization capabilities; Community group consciousness (potential): highlighting residents' disaster prevention knowledge, willingness for neighborhood mutual aid, and post-disaster self-recovery capacities.

2.2. Selection and Interpretation of Evaluation Indicators

Based on the aforementioned framework and through screening the "National Comprehensive Disaster Reduction Model Community Creation Standards" and related literature, this study selected 12 representative secondary indicators to form an evaluation matrix (see Table 2-1):

Table 2-1 Evaluation index system for community flood disaster response capacity

Primary Indicator (Weight)	Secondary Indicator	Indicator Description
A. Physical Environment (40%)	A1. Completeness of Drainage Facilities	Evaluates the daily maintenance and discharge capacity of rainwater pipe networks and pumping stations
	A2. Allocation of Flood Control Materials	The quantity of sandbags, water baffles, water pumps and other equipment, and their storage distance
	A3. Emergency Shelter Space	The available area of high-ground sites, solid buildings and other emergency shelter locations in the community
	A4. Topographic Difference at Key Points	The topographic drop at waterlogging-prone points such as community entrances/exits and underground garages
B. Organizational Management (35%)	B1. Operability of Emergency Plans	Whether the emergency plan includes clear evacuation routes, responsibility lists and contact information
	B2. Coverage of Early Warning Information	Whether heavy rain warnings can fully cover all residents via WeChat, broadcasting, door-to-door notifications and other means
	B3. Emergency Response Speed	The response time of property and neighborhood committees from receiving warnings to deploying flood control positions
	B4. Frequency of Drills and Training	The number of flood control drills and safety education activities conducted annually
C. Social Participation (25%)	C1. Residents' Risk Prevention Awareness	The degree of residents' mastery of anti-drowning knowledge and indoor disaster prevention skills
	C2. Volunteer Mobilization Capacity	The responsiveness of young volunteers, veterans and other groups in the community during disasters
	C3.	Whether there are support groups in the

Neighborhood Mutual Aid Network	community for vulnerable groups such as elderly people living alone
C4. Household Disaster Preparedness Level	The extent to which households are equipped with emergency supplies such as life whistles, flashlights and first-aid kits

2.3. Establishment of Evaluation Criteria

To achieve quantitative analysis, this study employed a 5-point Likert scale methodology for scoring secondary indicators. A review panel composed of community administrators, relevant experts, and selected resident representatives conducted scoring within the [1,5] range based on actual observations. Here, 1 point represents "extreme deficiency/insensitivity," while 5 points indicate "completeness and reliability."

3. Construction of Community Flood Response Capacity Evaluation Model

3.1. Stepwise Structure of Evaluation Model

Based on the indicator system established in Chapter 2, this study constructs a three-tier hierarchical structural model. The objective layer (G) represents community flood disaster response capacity; the criterion layer (B) comprises three dimensions: physical, managerial, and participatory; the solution layer (P) consists of 12 specific indicators.

3.2. Constructing pairwise judgment matrices

The judgment matrix is the core of AHP. Suppose there are n indexes in a certain layer, then construct a pairwise comparison matrix A:

$$A = (a_{ij})_{n \times n} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

Where a_{ij} represents the importance of the indicator i relative to the indicator j, satisfying $a_{ij} > 0$, $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$.

3.3. Weight vector calculation method

To determine the weight values W for each indicator, this study employs the root mean square method for computation. The detailed steps are as follows:

calculate the product M_i of each element in the judgment matrix.

$$M_i = \prod_{j=1}^n a_{ij}, \quad (i = 1, 2, \dots, n)$$

Calculate the n-th root of M_i , denoted as \bar{W}_i

$$\bar{W}_i = \sqrt[n]{M_i}$$

Normalize the vector $W = [W_1, W_2, \dots, W_n]$ "to obtain the weight vector W_i :

$$W_i = \frac{\bar{W}_i}{\sum_{j=1}^n \bar{W}_j}$$

Calculating the Maximum Characteristic Root of a Matrix

$$\lambda_{\max} = \sum_{i=1}^n \frac{(AW)_i}{nW_i}$$

3.4. Rigor determination of consistency test

Due to the subjective randomness of expert ratings, in order to avoid the logical deviation of "A is more important than B, B is more important than C, and C is more important than A", a consistency test must be carried out.

Calculate the consistency metric CI

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

Introducing the Random Consistency Index (RI) RI: Query standard values according to matrix order n

Calculate the consistency ratio CR

$$CR = \frac{CI}{RI}$$

Judgment criteria: If $CR < 0.10$, the consistency of the matrix is considered to be within an acceptable range, and the calculated weight W is valid; otherwise, the judgment matrix needs to be readjusted.

3.5. Comprehensive score evaluation function

After determining the weights, the weighted average method is used to calculate the final score S of the community's coping ability:

$$S = \sum_{k=1}^n W_k \cdot X_k$$

Among them, W_k is the comprehensive weight of the k th index, and X_k is the actual research score of this index.

4. Empirical Analysis: Taking Sunshine Community as an Example

4.1. Case Study: Community Overview and Data Sources

This study focuses on "Sunshine Community," a flagship model of resilient community development implemented in recent years. Established in 2012 with a total floor area of approximately 150,000 square meters and a permanent population of around 4,200 residents, the community incorporated micro-sponge city design principles from its initial planning phase. It features rainwater retention ponds and permeable paving systems, achieving significant results during three consecutive years of heavy rainfall—no water accumulation during light rains and no flooding during heavy rains. These achievements demonstrate exceptional research value and exemplary significance for urban sustainability initiatives.

To ensure the objectivity of evaluation results, this study established a multi-source data collection framework. Field sampling: Community drainage network survey maps were reviewed, and response distances at three flood prevention material storage sites were verified on-site. Questionnaire survey: The "Community Disaster Resilience Perception Survey Questionnaire" was distributed to residents via random sampling, with 115 valid responses collected. Reliability analysis using SPSS software yielded a Cronbach's Alpha coefficient of 0.82, indicating high reliability. Expert evaluation: A review panel comprising one municipal engineering expert, two grassroots emergency management personnel, and two senior property management supervisors scored 12 qualitative indicators.

4.2. Accurate Calculation of Index Weight

Based on the AHP (Analytic Hierarchy Process) method, a judgment matrix is constructed through pairwise comparisons among experts. To ensure computational rigor, this paper presents the complete calculation process of the criterion layer (B) for the objective layer (G):

Constructive judgment matrix A:

$$A = \begin{pmatrix} 1 & 1/2 & 2 \\ 2 & 1 & 3 \\ 1/2 & 1/3 & 1 \end{pmatrix}$$

Weight Calculation (Root Method):

Calculate the product (M_i) of each row: ($M_1 = 1$), ($M_2 = 6$), ($M_3 = 0.167$).

Calculate the (n)-th root (\bar{W}_i): ($\bar{W}_1 = 1$), ($\bar{W}_2 = 1.817$), ($\bar{W}_3 = 0.551$).

Normalize to obtain the weight (W_i): ($W_1 = 0.297$), ($W_2 = 0.539$), ($W_3 = 0.164$).

Consistency Test:

Calculate the maximum eigenvalue ($\lambda_{max} = 3.009$).

$$CI = \frac{3.009 - 3}{3 - 1} = 0.0045$$

$$CR = \frac{0.0045}{0.58} = 0.0078 < 0.1$$

Conclusion: The weight distribution is logically rigorous and statistically significant.

4.3. Comprehensive evaluation score statistics and display

Through weighted calculation, the detailed evaluation score of flood response capacity for Sunshine Community was obtained (see Table 4-1).

Table 4-1 Detailed Score Distribution of Flood Response Capacity Assessment for Sunshine Community

Primary Indicator	Secondary Indicator	Weight (Wi)	Expert Score (Xi)	Weighted Score	Dimension Total
Physical Environment(0.297)	A1. Completeness of Drainage Facilities	0.12	4.3	0.516	4.05
	A2. Sufficiency of Material Allocation	0.1	4.1	0.41	
	A3. Emergency Shelter Space	0.077	3.6	0.277	
Organizational Management(0.539)	B1. Operability of Emergency Plan	0.22	4.6	1.012	4.38
	B2. Coverage of Early Warning Information	0.18	4.4	0.792	
	B3. Frequency of Drills and Training	0.139	4	0.556	
Social Participation(0.164)	C1. Residents' Risk Prevention	0.08	3.4	0.272	3.62

	Awareness				
	C2. Volunteer				
	Mobilization	0.05	3.8	0.19	
	Capacity				
	C3.				
	Neighborhood				
	Mutual Aid	0.034	3.8	0.129	
	Network				
Comprehensive	S= $\sum W_i \cdot X_i$	1	-	4.154	4.16
Total					

4.4. Multidimensional diagnosis of evaluation results

With a comprehensive score of 4.16, Sunshine Community demonstrates "good overall" flood response capabilities. Through in-depth analysis of the evaluation metrics, this study identifies the following key characteristics:

(1) Core organizational management advantages. The community achieved the highest scores in both "Emergency Response Plans" and "Early Warning Information." This success stems from its three-tier coordinated response mechanism involving grid officers, building managers, and property management teams. This "soft management" approach effectively compensates for the physical capacity limitations of drainage systems in older urban areas. Even during heavy rainfall events, preemptive deployment of water barriers and pumping systems enables effective containment of flood spread.

(2) Effectiveness of "resilience-oriented" physical facility upgrades: The physical environment scored 4.05 points. The survey revealed that the community implemented micro-terrain modifications in low-lying areas and conducted regular pipeline dredging. This sustained daily maintenance has enabled the community to demonstrate strong "absorption" and "release" capabilities when facing flood impacts, rather than being passively affected by disasters.

(3) Bottleneck in Social Participation Despite overall positive evaluations, the "Social Participation" dimension (3.62 points) shows significant gaps compared to the first two dimensions. Cross-analysis of questionnaires revealed that middle-aged and young adults exhibit lower engagement enthusiasm in disaster prevention activities than the elderly, while most residents still perceive community disaster preparedness as limited to "government oversight and property management initiatives." The lack of self-rescue and mutual assistance capabilities remains the primary obstacle hindering the community's transition to the "Excellence" rating tier.

5. Targeted Recommendations for Enhancing Community Flood Disaster Response Capacity

5.1. Targeted infrastructure improvements and Fine Maintenance of Hardware End

Although Sunshine Community has met overall drainage evaluation standards, localized low-lying areas identified during surveys remain critical flood risks during peak seasons. For high-risk zones like Building No.3 and underground garage entrances, temporary sandbag stacking methods prove ineffective—this reactive flood control approach demonstrates extremely low efficiency. It is recommended to install sensor-activated automatic sluice gates at key access points, complemented by high-capacity self-starting pumping stations to ensure automatic water release even during unattended nighttime hours. Additionally, communities should shift from post-disaster cleanup practices to implementing pipeline dredging two weeks before the

rainy season, particularly targeting areas with dense catering businesses to remove grease deposits. This ensures full pipeline capacity during heavy rainfall, maximizing the drainage efficiency of sponge city infrastructure upgrades.

5.2. Optimization of granularity for "peacetime-to-emergency transition" in emergency response

While current emergency response plans are comprehensive, there remains a "lag" in coordination during sudden rainfall events. To bridge the gap between theoretical protocols and practical implementation, communities should adopt a "one-page" task checklist system, assigning dedicated responsibility cards to property security personnel, sanitation staff, and neighborhood committee members. Clear protocols must be established: upon issuing a yellow alert, sanitation workers must immediately clean debris from storm drains, while security personnel should promptly inspect basement parking spaces. Leveraging grid-based data systems, flood prevention maps should precisely mark locations of elderly individuals living alone and those with mobility impairments. During alerts, designated volunteers must conduct door-to-door verification to ensure these vulnerable groups remain included in disaster response systems—even in extreme scenarios like power outages or internet disruptions—preventing them from becoming "forgotten victims" of disaster preparedness.

5.3. Activating the Endogenous Driving Force of Community Defense Communities

The evaluation results indicate that low disaster prevention awareness among residents remains the primary bottleneck constraining community resilience. Traditional awareness campaigns relying on banner displays and leaflet distribution have shown limited effectiveness, necessitating a shift toward interest-driven approaches and hands-on experiences. Communities could transform dry lectures into interactive activities like "Family Disaster Preparedness Kit Competitions" or "Water Barrier Assembly Challenges," enabling residents to develop "muscle memory" through participation. To address low engagement rates among young and middle-aged populations, establishing a "Disaster Prevention Volunteer Points System" could be explored. This mechanism would track participation time in patrols and hazard inspections within the community points system, linking rewards to property fee reductions or discounts at nearby supermarkets. By combining "soft constraints" with "hard incentives," this approach aims to transform residents from passive recipients into active frontline defenders, fundamentally addressing the shortage of grassroots disaster preparedness resources.

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