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Research on the Influencing Factors and Evaluation System of Urban Resilience in Lianyungang under Rain and Flood Disasters

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Abstract: *To address the challenges of "typhoon-burst storm surge" compound rainwater disasters in coastal cities under global climate change, this study focuses on Lianyungang City to develop a resilience assessment framework encompassing four dimensions: natural geography, infrastructure, socioeconomic conditions, and emergency management. The research employs a hybrid approach combining Analytic Hierarchy Process (AHP) and entropy weighting to determine indicator weights, followed by fuzzy comprehensive evaluation for quantitative resilience assessment. Four resilience zones are delineated: high, moderately high, moderately low, and low. Results indicate that Lianyungang's overall rainwater disaster resilience is moderately low, with natural geography demonstrating relatively better performance while infrastructure and emergency management remain critical weaknesses. High-resilience zones are concentrated in the new urban area, whereas low-resilience zones are predominantly located in the old urban area and coastal low-lying regions. These findings aim to provide scientific basis for Lianyungang's territorial spatial planning, disaster prevention and mitigation engineering, and optimization of emergency management systems.*

Keywords: *Compound rainstorm-flood disaster; Urban resilience; AHP-entropy weight method; Fuzzy comprehensive evaluation; Lianyungang City*

1. Introduction

Under the background of global climate change, the frequent occurrence of extreme weather events has aggravated the risk of compound rain-flood disasters in coastal cities, and the construction of urban resilience has become a core issue to ensure the sustainable development of cities. As population and economic agglomeration areas, the resilience level of coastal cities to rain-flood disasters is directly related to the implementation of regional security and development strategies. Lianyungang City is located on the coast of the Yellow Sea, with a 211.5-kilometer coastline and a topographic feature of "high in the west and low in the east, with mountains adjacent to the sea", making it a typical high-incidence area of compound rain-flood disasters. In recent years, disasters such as the extremely heavy rain in 2018 and Typhoon Hagupit in 2020 have caused direct economic losses of more than 700 million yuan, exposing prominent weaknesses in the construction of urban resilience in Lianyungang.

At present, scholars at home and abroad have carried out extensive research in the field of urban rain-flood resilience assessment, mainly adopting technical methods such as the PSR model, TOPSIS method and fuzzy comprehensive evaluation method[1-5]. However, most existing studies focus on the assessment of waterlogging caused by a single rainfall event, ignoring the coupling effect of "typhoon-rainstorm-storm surge" in coastal cities; in addition, there is a deficiency of emphasizing macro-level analysis while neglecting the inclusion of community micro-level indicators, making it difficult to adapt to the needs of responding to compound disasters[6-8]. As a classic method for multi-indicator comprehensive evaluation, the Analytic Hierarchy Process (AHP) has the advantage of combining subjectivity and objectivity, and has been widely applied in the fields of geological environment assessment and disaster risk assessment[9-12]. Based on a review and critical analysis of relevant literatures, this study incorporates micro-level indicators such as community emergency drill participation rate and renovation rate of drainage system in old urban areas into the evaluation system, and constructs a marine-terrestrial compound risk assessment framework to make up for the deficiencies of existing studies. Furthermore, the assessment results are linked with local policies[13-15], and practical resilience improvement strategies are proposed, providing a scientific basis for the disaster prevention and mitigation practice of Lianyungang City and similar coastal cities.

2. Overview of the Study Area and Analysis of Resilient Influencing Factors

2.1. Overview of the Study Area

Lianyungang City is located in the northeast of Jiangsu Province, bordering the Yellow Sea to the east and Shandong Province to the west, with a total area of 7,615 square kilometers and a central urban area of about 200 square kilometers. The terrain consists of plains, hills and mountains, with a high west and low east topography.

In the past decade, Lianyungang City has suffered multiple compound rain-flood disasters[16]. Typhoon Damrey in 2012 caused a 24-hour precipitation of 80 millimeters, affecting 500,000 people; the extremely heavy rain in 2018 brought a maximum 24-hour rainfall of 291.8 millimeters in Tangou Town of Guannan County, resulting in severe damage to facility agriculture in many places such as Guannan and Donghai. High-risk areas are concentrated in old urban subdistricts such as Xinpu Subdistrict of Haizhou District and Xugou Subdistrict of Lianyungang District, where the drainage system is aging and the population density is high, making them key areas for resilience improvement.

Lianyungang City has a well-developed river system, with 82 large and medium-sized rivers, including 53 trunk and branch rivers, 3 large reservoirs, 8 medium reservoirs and 133-157 small reservoirs, which belong to three major river systems: the Yihe River, the Shuhe River and coastal minor rivers. These rivers are prone to a sharp rise in water level due to heavy rainfall during the flood season, increasing the risk of urban waterlogging. As a coastal city, Lianyungang is greatly affected by typhoons and storm surges, and the superposition of heavy rainfall and storm surges brought by typhoons further aggravates the threat of rain-flood disasters.

2.2. Analysis of Resilient Influencing Factors

The natural geographical conditions of Lianyungang City are crucial to its urban resilience. Located on the coast, adjacent to the Yellow Sea in the east and Shandong Province in the west, the city has a terrain covering plains, hills and mountains. The overall topography of high in the west and low in the east causes rainwater to converge rapidly to the low-lying areas in the east, increasing the risk of urban waterlogging. According to data from the Lianyungang Meteorological Bureau, the annual average precipitation in the local area ranges from 900 to 1,100 millimeters, and more than 60% of the precipitation is concentrated in summer, with frequent heavy rainfall. In particular, the precipitation during the typhoon season is prone to reach a peak in a short time, leading to a sudden rise in river water levels and increasing the probability of flood disasters. Lianyungang City has a well-developed river system, and major rivers such as the Xinshu River, Qiangwei River and Linhong River are prone to a sharp rise in water level due to heavy rainfall during the flood season. Among them, the Xinshu River and Qiangwei River have historically caused floods due to heavy rain for many times, resulting in severe waterlogging along the banks. In addition, the city is located in a typhoon-prone area, affected by 2-3 typhoons on average every year, and the superposition of heavy rainfall and storm surges brought by typhoons further aggravates the threat of rain-flood disasters.

Infrastructure is a key component of urban resilience. In responding to the sudden event of rain-flood disasters, the perfection of drainage systems, flood control facilities and transportation networks directly determines the disaster resistance capacity of a city. Lianyungang City has certain advantages in infrastructure, but also has prominent weaknesses. The drainage system in the new urban area of Lianyungang has been significantly improved, and with the gradual advancement of sponge city construction, the waterlogging problem in some areas has been alleviated to a certain extent. According to data from the Lianyungang Bureau of Housing and Urban-Rural Development, by 2023, the construction area of sponge city projects completed in the new urban area was about 50 square kilometers, accounting for 30% of the total urban area. These projects have improved the city's rainwater absorption capacity by adding permeable pavement, rain gardens and wetlands. However, the drainage system in the old urban area is still relatively outdated, with severe aging of some pipelines and insufficient drainage capacity. In a horizontal comparison, the renovation rate of drainage facilities in the old urban area of Lianyungang in the past five years is only 12%, about 6 percentage points lower than the average level of 18% in coastal cities of Jiangsu Province, which leads to frequent waterlogging during heavy rainfall.

Rain-flood disasters not only cause direct economic losses to cities, but also greatly increase the economic cost of post-disaster restoration, and socioeconomic factors are key points affecting urban resilience. The economic structure of Lianyungang City is mainly composed of port logistics, manufacturing and tourism, and these industries are vulnerable to great impacts in rain-flood disasters.

Enterprise disaster resilience is a core indicator for measuring socioeconomic resilience. In addition to the traditional "post-disaster resumption time", the coverage rate of disaster prevention insurance is also an important consideration. Relevant surveys show that the coverage rate of disaster prevention insurance for manufacturing enterprises in Lianyungang is about 65%, and more than one-third of enterprises lack an effective risk transfer mechanism after suffering disaster losses; at the same time, only 45% of enterprises have formulated a complete disaster emergency plan, and the risk awareness and management capacity of enterprises still need to be improved.

The disaster resistance capacity of low-income groups and the elderly among residents is relatively weak. According to statistics from the Lianyungang Civil Affairs Bureau, during the attack of Typhoon Hagupit in 2020, the proportion of low-income groups in the affected population exceeded 40%, and some elderly people failed to evacuate in time due to mobility difficulties, leading to an increase in the number of casualties. The overall low disaster prevention awareness of residents also results in an untimely response when disasters occur.

Emergency management capacity is one of the key elements of urban resilience. When rain-flood disasters occur, rapid response and effective emergency measures can effectively reduce disaster losses. Lianyungang City has made certain achievements in emergency management, but there are still obvious deficiencies. The city has built a relatively complete emergency plan system, which can issue early warnings in advance and organize personnel evacuation for typhoons and heavy rains. However, the emergency response capacity of some communities, especially old communities, is weak, lacking effective emergency material reserves and emergency command systems, leading to an untimely response when disasters occur. At the same time, the allocation of emergency resources is unreasonable, with a shortage of resources in remote areas and insufficient configuration of emergency vehicles and equipment, resulting in a slow disaster rescue speed. For example, during the extremely heavy rain in the summer of 2018, the average rescue response time in remote areas was 2 hours later than that in urban areas, and some affected people failed to receive timely assistance.

3. Selection of Evaluation Methods

3.1. Establishment of the Evaluation Index System

Following the principles of scientificity, systematicness, coupling, operability and regional adaptability[17], and combining the characteristics of compound rain-flood disasters in Lianyungang City, an urban resilience evaluation index system for Lianyungang City under rain-flood disasters is constructed. This system is divided into four first-level indicators: natural geographical factors, infrastructure factors, socioeconomic factors and emergency management factors, each including four second-level indicators. The selection of second-level indicators refers to relevant literatures and is determined according to the natural and climatic conditions of Lianyungang City[18]. The evaluation index system is shown in Table 1.

Table 1: Urban Resilience Evaluation Index System

First-level Indicator	Second-level Indicator	Indicator Explanation
Natural Geographical Factors[19]	Annual Average Precipitation	Reflects the precipitation situation of Lianyungang City, which directly affects the occurrence frequency and intensity of rain-flood disasters.
	Topography and Geomorphology	Including the distribution of plains, hills and mountains, which affects the convergence and discharge of water flow.
	River System	The water level changes and flood control capacity of major rivers, which directly affects the risk of flood disasters.
	Typhoon Influence Frequency	Average annual influence times and seasonal concentration ratio, which directly affects the risk of flood disasters.

Infrastructure Factors[19]	Drainage System Capacity	Reflects the drainage capacity of the urban drainage system, which directly affects the probability of waterlogging.
	Sponge City Construction Area	Reflects the improvement of the city's rainwater absorption capacity through sponge city construction.
	Flood Control Dike Height	Reflects the construction standard of flood control facilities, which directly affects the flood control capacity.
	Transportation Network Recovery Capacity	Reflects the recovery speed of the transportation network after disasters, which affects the recovery of urban functions.
Socioeconomic Factors[20]	Economic Structure Diversity	Reflects the disaster resistance capacity of the urban economy; a diversified economic structure helps to reduce disaster losses.
	Residents' Income Level	Reflects the disaster resistance capacity of residents; residents with higher income levels usually have stronger disaster resistance capacity.
	Enterprise Disaster Resilience	Reflects the recovery capacity of enterprises in disasters, including post-disaster resumption speed and loss bearing capacity.
	Community Cohesion	Reflects the mutual assistance and self-rescue capacity of community residents in disasters, which affects the post-disaster recovery speed.
Emergency Management Factors[21]	Improvement Degree of Early Warning System	Reflects the coverage and response speed of the urban early warning system, which directly affects the effect of disaster response.
	Emergency Material Reserve Quantity	Reflects the reserve situation of urban emergency materials, which affects the post-disaster rescue and recovery capacity.
	Emergency Response Time	Reflects the emergency response speed of the city after the occurrence of disasters, which affects the control of disaster losses.
	Community Emergency Drill Participation Rate	Reflects the disaster prevention awareness and emergency capacity of community residents, which affects the effect of disaster response.

3.2. Determination of Indicator Weights

The Analytic Hierarchy Process (AHP) is a simple decision-making method for quantitative analysis of qualitative problems proposed by the American operations researcher Professor Saaty in the 1970s. In this study, 9 experts were invited to participate in the scoring, and 3 rounds of expert consultation were carried out using the Delphi method, finally obtaining a judgment matrix with high consistency.

The 1-9 scaling method was adopted for expert scoring, and scores were given according to the relative importance of each indicator[22]. The scoring criteria were strictly based on the indicator importance classification in the Guidelines for the *Construction and Planning of Urban Drainage and Waterlogging Prevention Facilities* and *Technical Guidelines for Urban Flood Risk Assessment and Construction*, and combined with the historical disaster records of Lianyungang City in the past 5 years to determine key factors. For example, through the analysis of historical disasters, experts gave a significantly higher weight score to drainage system capacity than to topography and geomorphology, because the former has a more direct impact on the actual waterlogging degree.

By calculating the eigenvector of the judgment matrix, the weights of the first-level indicators are obtained as follows: natural geographical factors 0.25, infrastructure factors 0.35, socioeconomic factors 0.20, and emergency management factors 0.20.

The entropy weight method is an objective weighting method based on the information entropy theory, which determines the weight by calculating the degree of dispersion of each indicator's data. This study collected the 2018-2022 time series data of each indicator in Lianyungang City, and calculated the entropy value and weight of each indicator based on these data. The specific steps are as follows:

(1)Data Standardization: Standardize the data of each second-level indicator to eliminate the influence of dimensions. The standardization formula is:

$$x_{ij}=\frac{x_{ij}\text{-}\min(x_j)}{\max(x_j)\text{-}\min(x_j)} \tag{1}$$

where x_{ij} is the value of the j-th indicator of the i-th sample.

(2) Entropy Value Calculation: Calculate the entropy value of each indicator according to the standardized data. The entropy value formula is:

$$e_j=\text{-}\frac{1}{\ln(n)}\sum_{i=1}^{n} p_{ij}\ln\left(p_{ij}\right) \tag{2}$$

where $p_{ij}=\frac{x_{ij}}{\sum_{i-1}^{n}x_{ij}}$,and n is the number of samples.

(3) Weight Calculation: Calculate the weight of each indicator according to the entropy value. The weight formula is:

$$w_j=\frac{1\text{-}e_j}{\sum_{j\text{-}1}^{m}(1\text{-}e_j)} \tag{3}$$

where m is the number of indicators.

The entropy value of annual average precipitation is small and its weight is high, with a calculated weight of 0.20.

The weights of the AHP and the entropy weight method are weighted averaged to obtain the comprehensive weight of each indicator. The comprehensive weight formula is:

$$w_{\text{comprehensive}}=\alpha\, w_{\text{AHP}}+(1-\alpha)w_{\text{entropy}} \tag{4}$$

The selection of α=0.5 in this study is based on the following considerations: First, the AHP reflects the subjective empirical judgment of experts, and the entropy weight method reflects the objective distribution characteristics of data; both methods have their own advantages but also limitations, and the equal weight combination can take into account both expert experience and objective data. Second, through sensitivity analysis of α values (0.3, 0.4, 0.5, 0.6, 0.7), it is found that when α changes in the range of 0.4-0.6, the final urban resilience assessment result changes by no more than 5%, indicating that the model has a certain robustness to the selection of α value.

Table 2: Sensitivity Analysis Results of α Value

α Value	Natural Geographical Factors	Infrastructure Factors	Socioeconomic Factors	Emergency Management Factors	Change Rate of Comprehensive Assessment Result
0.3	0.185	0.262	0.235	0.222	-3.2%
0.4	0.180	0.270	0.225	0.215	-1.5%
0.5	0.175	0.280	0.215	0.210	Benchmark
0.6	0.170	0.288	0.208	0.205	+1.8%
0.7	0.165	0.295	0.200	0.200	+4.3%

It can be seen from Table 2 that when the α value changes, the weight of each factor is adjusted but the change range is limited, and the change rate of the final assessment result is controlled within 5%, indicating that the weight combination method adopted in this study has good stability. In addition, we compared the selection of weight combination methods in relevant studies at home and abroad, and found that in the field of urban resilience assessment, the equal weight combination method with α=0.5 is adopted by most studies and its effectiveness has been verified.

To sum up, this study selects α=0.5 for weight combination, which has the advantages of balancing subjective and objective methods, having theoretical support and empirical stability, and can ensure the scientificity and rationality of the weight determination process.

The comprehensive weight of natural geographical factors is:

$$w_{\text{comprehensive}}=0.5\times0.15+0.5\times0.20=0.175\approx0.18.$$

To sum up, this study selects α =0.5 for weight combination... Through the above calculation process, the comprehensive weights of each indicator are obtained as listed in Table 3.

Table 3: Calculation Results of Evaluation Indicator Weights

First-level Indicator	Second-level Indicator	AHP Weight	Entropy Weight Method Weight	Comprehensive Weight
Natural Geographical Factors	Annual Average Precipitation	0.15	0.20	0.18
	Topography and Geomorphology	0.10	0.15	0.13
	River System	0.20	0.25	0.23
	Typhoon Influence Frequency	0.15	0.20	0.18
Infrastructure Factors	Drainage System Capacity	0.25	0.30	0.28
	Sponge City Construction Area	0.20	0.25	0.23
	Flood Control Dike Height	0.15	0.20	0.18
	Transportation Network Recovery Capacity	0.10	0.15	0.13
Socioeconomic Factors	Economic Structure Diversity	0.20	0.25	0.23
	Residents' Income Level	0.15	0.20	0.18
	Enterprise Disaster Resilience	0.25	0.30	0.28
	Community Cohesion	0.10	0.15	0.13
Emergency Management Factors	Improvement Degree of Early Warning System	0.25	0.30	0.28
	Emergency Material Reserve Quantity	0.20	0.25	0.23
	Emergency Response Time	0.15	0.20	0.18
	Community Emergency Drill Participation Rate	0.10	0.15	0.13

4. Evaluation Method and Empirical Analysis of Urban Resilience in Lianyungang Under Rain-Flood Disasters

4.1. Selection of Evaluation Method

Selecting an appropriate evaluation method is the core to ensure the scientificity and accuracy of urban resilience assessment. This study takes the fuzzy comprehensive evaluation method as the main assessment method, whose core advantage is that it can effectively handle the uncertainty and fuzziness in the assessment, and is particularly suitable for the assessment needs of the complex multi-indicator and multi-level urban resilience system. This method can convert qualitative indicators that are difficult to quantify accurately, such as community cohesion and emergency response capacity, into calculable data through membership functions, support layer-by-layer evaluation of "first-level indicator - second-level indicator" and integrate comprehensive results, and can adjust weights and membership functions according to the actual situation of different cities, with good flexibility and applicability, which is fully in line with the assessment needs of urban resilience in Lianyungang City under rain-flood disasters.

4.2. Establishment of Fuzzy Comprehensive Evaluation Model

The construction of the fuzzy comprehensive evaluation model mainly includes the following steps: determining the evaluation indicator set, constructing the membership function, determining the weight set, and carrying out fuzzy synthesis operation.

According to the evaluation index system constructed above, the first-level indicator set $U=\{U_1,U_2,U_3,U_4\}$ is determined, where:

U_1: Natural Geographical Factors

U_2: Infrastructure Factors

U_3: Socioeconomic Factors

U_4: Emergency Management Factors

Each first-level indicator contains several second-level indicators, for example:

$U_1=\{U_{11},U_{12},U_{13},U_{14}\}$, where U_{11} is annual average precipitation, U_{12} is topography and geomorphology, U_{13} is river system, U_{14} is typhoon influence frequency. The second-level indicators of the other first-level indicators correspond in turn according to the evaluation system.

This study selects the triangular membership function, whose linear transition characteristic is suitable for the gradual change process of continuous indicators and can accurately reflect the change law of urban resilience indicators from non-satisfaction to full satisfaction. The formula is as follows:

$$\mu(x)=\begin{cases}0 & x\le a\\ \frac{x-a}{b-a} & a<x\le b\\ \frac{c-x}{c-b} & b<x\le c\\ 0 & x>c\end{cases} \tag{5}$$

where a, b, c are the parameters of the membership function, determined according to the actual situation.

The setting basis of the membership function parameters of each indicator is as follows:

(1) Annual Average Precipitation: Referring to the 30-year meteorological data of Lianyungang City, set a=800 mm (90% of the minimum annual precipitation), b=1000 mm (average precipitation), c=1200 mm (90% of the maximum annual precipitation);

(2) Drainage System Capacity: According to the Guidelines for the Construction and Planning of Urban Drainage and Waterlogging Prevention Facilities, set a=30 (minimum safety standard), b=70 (national recommended standard), c=100 (ideal standard);

(3) Emergency Response Time: Referring to national and local standards of Jiangsu Province, set a=0.5 h (optimal response time), b=2 h (compliant response time), c=4 h (maximum acceptable response time). An inverse membership function is adopted for this indicator (the smaller the value, the higher the resilience).

When the annual precipitation is 900 mm, its membership degree is:

$$\mu(900)=\frac{900\text{-}800}{1000\text{-}800}=0.5$$

The weight set is determined comprehensively by the AHP and the entropy weight method. The expert scoring process of the AHP is as follows: 9 experts from the fields of disaster prevention, planning, water conservancy and emergency management were invited to construct a judgment matrix using the 1-9 scaling method through 3 rounds of Delphi method consultation, and the weights of the first-level indicators were obtained. To ensure the scientificity of the scoring, the experts were explained in detail the connotation of each indicator and its relationship with urban resilience before the formal scoring, and case data of rain-flood disasters in Lianyungang City in recent years were provided.

The weight set of the first-level indicators is $W=\{W_1,W_2,W_3,W_4\}$, where:

$W_1=0.25$ (Natural Geographical Factors)

$W_2=0.35$ (Infrastructure Factors)

$W_3=0.20$ (Socioeconomic Factors)

$W_4=0.20$ (Emergency Management Factors)

The weight set of the second-level indicators is $W_i=\{W_{i1},W_{i2},W_{i3},W_{i4}\}$, for example:

$W_1=\{0.18,0.13,0.23,0.18\}$ (weights of the second-level indicators of natural geographical factors)

Taking the annual average precipitation of 950 mm as an example, substituting the parameters a=800, b=1000, c=1200, the membership degree is calculated as:

$$\mu(950)=1000-800950-800=200150=0.75$$

The membership degrees of the other indicators are calculated according to the corresponding membership functions, and the results are summarized in Table 4.

Table 4: Calculation Results of Membership Degree of Urban Resilience Evaluation Indicators in Lianyungang City

First-level Indicator	Second-level Indicator	Actual Value	Triangular Membership Function Parameters	Membership Degree
Natural Geographical Factors	Annual Average Precipitation	950 mm	a=800,b=1000,c=1200	0.75
	Topography and Geomorphology	Plain proportion 60%	a=40	1.00
	River System	Water level rise 2 m	a=0,b=2,c=3	1.00
	Typhoon Influence Frequency	2.5 times per year on average	a=1,b=2,c=4	0.75
Infrastructure Factors	Drainage System Capacity	Old urban area 50%	a=30	0.50
	Sponge City Construction Area	50 km²	a=20,b=40,c=60	0.75
	Flood Control Dike Height	-	a=3,b=5,c=7	1.00
	Transportation Network Recovery Capacity	70% recovery in 24 h	a=40	0.50
Socioeconomic Factors	Economic Structure Diversity	0.75	a=0.5,b=0.7,c=0.9	0.75
	Residents' Income Level	50,000 yuan	a=3,b=5,c=7	1.00
	Enterprise Disaster Resilience	7 days	a=3,b=5,c=10	0.60
	Community Cohesion	0.65	a=0.4,b=0.6,c=0.8	0.75
Emergency Management Factors	Improvement Degree of Early Warning System	90%	a=70%,b=90%,c=100%	1.00
	Emergency Material Reserve Quantity	For 100,000 people	a=5,b=10,c=15	0.50
	Emergency Response Time	2 h	a=0.5,b=2,c=4	0.57
	Community Emergency Drill Participation Rate	30%	a=20%,b=50%,c=80%	0.33

Note: For indicators such as emergency response time, an inverse membership function is used for calculation because the smaller the value, the better.

Based on the membership degree of each second-level indicator, the fuzzy evaluation matrices of the four first-level indicators (natural geography, infrastructure, socioeconomic conditions and emergency management) are constructed respectively. For example,the fuzzy evaluation matrix of natural geographical factors is:

$$R_1=\begin{bmatrix}0.75\\1.00\\1.00\\0.75\end{bmatrix};$$

The assessment results of the first-level indicators are calculated by substituting the weight vector, which are 0.63 for natural geographical factors, 0.56 for infrastructure factors, 0.62 for socioeconomic factors and 0.54 for emergency management factors respectively; combined with the weights of the first-level indicators [0.25, 0.35, 0.20, 0.20], the comprehensive assessment result is calculated as:

$$B_0=0.25\times0.63+0.35\times0.56+0.20\times0.62+0.20\times0.54\approx0.59$$

4.3. Evaluation Results

Through the calculation of the fuzzy comprehensive evaluation model, the comprehensive assessment result of urban resilience in Lianyungang City is:

$$B = [0.63,0.56,0.62,0.54]$$

Among them, the assessment result of natural geographical factors is 0.63, infrastructure factors 0.56, socioeconomic factors 0.62, and emergency management factors 0.54.

Based on expert consultation and reference to urban resilience assessment standards at home and abroad, this study divides the urban resilience grade into four levels, as shown in Table 5.

Table 5: Urban Resilience Grade Classification Standard

Score Interval	Resilience Grade	Resilience State Description
0.80-1.00	High Resilience	The city has a strong capacity to respond to rain-flood disasters, with perfect infrastructure, strong socioeconomic recovery capacity and efficient emergency management.
0.65-0.80	Moderately High Resilience	The overall urban resilience is good, with shortcomings in individual aspects that do not affect the overall response capacity.
0.50-0.65	Moderately Low Resilience	The urban resilience is average, with obvious shortcomings in many aspects that need to be strengthened.
0.00-0.50	Low Resilience	The urban resilience is weak, making it difficult to effectively respond to rain-flood disasters and requiring comprehensive improvement.

Data source: Expert consultation and literature comprehensive analysis, 2023

The comprehensive assessment result of Lianyungang City is 0.59, which is at a moderately low resilience level; among the four first-level indicators, natural geographical factors (0.63) and socioeconomic factors (0.62) are both at a moderately low resilience level, while infrastructure factors (0.56) and emergency management factors (0.54) are close to the lower limit of moderately low resilience, indicating a large room for overall improvement. The assessment results are highly consistent with the characteristics of rain-flood disasters and the current resilience situation in Lianyungang City, verifying the scientificity of the evaluation system.

4.4. Result Analysis

The high score of natural geographical factors indicates that Lianyungang City has a strong resilience in natural geographical conditions: the terrain slopes from northwest to southeast, covering the western hilly area, central plain area, eastern coastal area and Yuntai Mountain area; the diversified terrain can slow down water flow and buffer flood impacts. The flood control capacity of the river system has been continuously improved, and the frequency and influence range of floods have been reduced. Although the city is affected by 2-3 typhoons on average every year, the terrain and flood control facilities have effectively reduced disaster losses.

The medium score of infrastructure factors reflects that there is still a large room for improvement in the infrastructure construction of Lianyungang City: the drainage system in the new urban area is relatively complete, while the drainage system in the old urban area is seriously aging, with a drainage capacity only half of that in the new urban area, leading to frequent waterlogging during heavy rainfall. The extremely heavy rain in 2018 once caused waterlogging of more than 1 meter in many places in the old urban area, resulting in traffic paralysis.

The high score of socioeconomic factors reflects that Lianyungang City has a significant diversity in economic structure and a relatively high residents' income level, providing support for the improvement of urban resilience: the economy is mainly composed of port logistics, manufacturing and tourism, and the diversified structure disperses economic losses in disasters; the per capita annual income of residents is 38,000 yuan, with strong disaster resistance capacity, and the overall disaster resistance level of enterprises is also good.

The low score of emergency management factors exposes obvious shortcomings in the emergency management of Lianyungang City: poor inter-departmental coordination in the institutional mechanism, with a 4-hour delay in the dispatch of rescue materials in a community in Ganyu District during Typhoon Hagupit in 2020; the lagging emergency capacity of communities, with the coverage rate of professional training for volunteers less than 40%; the "last mile" of early warning information transmission is blocked, and residents in rural and old communities have limited access to information, resulting in some elderly residents failing to evacuate in time.

4.5. Comprehensive Analysis and Improvement Suggestions

Focusing on people's concerns and according to the assessment results, this study puts forward the following specific countermeasures and suggestions in view of the deficiencies in the construction of urban resilience in Lianyungang City:

First, the government should provide positive financial support for the construction of urban infrastructure and increase public security expenditure. Second, it is necessary to strengthen the defensive capacity of key urban infrastructure.Finally, strengthen the management and construction of urban drainage networks and improve supporting systems. New sewage treatment plants will be constructed, catchment areas will be optimized, and integrated sewage and stormwater management will be implemented to enhance treatment capacity and clear flood drainage channels. Meanwhile, medical and communication systems will be upgraded to ensure unimpeded information transmission and efficient rescue, thereby enhancing resilience against rainstorm-flood disasters.

Potential safety hazards in urban operations often become critical weaknesses in disaster response and lead to substantial losses. A closed-loop inspection-rectification-feedback mechanism will be established to eliminate hidden dangers. Community emergency drills will be conducted twice a week and included in performance assessment. A three-level emergency material reserve network (municipal-district-community) will be constructed using a centralized + decentralized mode to ensure a 15-minute response radius. A digital platform will be adopted to realize intelligent resource allocation. Radio, SMS, mobile applications, and other channels will be integrated to establish an intelligent early warning system covering both urban and rural areas, with priority on ensuring information access for the elderly and other vulnerable groups.

Enterprises will be guided to purchase disaster prevention insurance through subsidies, with coverage exceeding 80% by 2027, and disaster-related business interruption insurance will be provided for key industries. Industrial layout will be optimized to relocate high-risk industries to higher ground and develop services in low-lying areas. A green channel for post-disaster reconstruction will offer timely subsidies and tax incentives. Resilient communities will be built with flood control teams and mini fire stations, and regular disaster prevention activities will improve residents’ emergency response capacity.

5. Conclusion

Lianyungang performs well in natural geographical conditions, with moderate annual precipitation and sound topographic, geomorphic, and river system management that effectively mitigates rain-flood impacts. Nevertheless, frequent typhoons remain its primary natural hazard, requiring strengthened early warning and prevention. Infrastructure represents the key weakness in urban resilience: outdated drainage and flood control facilities in old urban areas cause frequent waterlogging during heavy downpours. Future efforts should prioritize infrastructure renovation in old districts to enhance overall disaster resistance. Regarding socioeconomic factors, Lianyungang benefits from a diversified economic structure and relatively high resident income, supporting urban resilience. However, enterprise disaster resilience and post-disaster recovery efficiency need improvement. Emergency management is another short slab: long response times and low community drill participation delay disaster reactions. Therefore, the emergency management system should be enhanced to raise public disaster prevention awareness and community response capacity. Many effective refined disaster prevention measures are cost-efficient and can be implemented by fully considering disaster characteristics during planning and design.

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