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Lien-Kwei Chien
National Taiwan Ocean University

Yu-Chi Li
National Taiwan Ocean University

Chia-Feng Hsu
ChienKuo Technology University, sfhsu1013@ctu.edu.tw

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RESEARCH ARTICLE

Integrated Environmental Vulnerability Assessment and Adaptation Strategies for Coastal Areas Under Sustainable Development

Lien-Kwei Chien [a], Yu-Chi Li [a], Chia-Feng Hsu [b,*]

[a] National Taiwan Ocean University, Taiwan
[b] ChienKuo Technology University, Taiwan

Abstract

This research focuses on the holistic management and environmental vulnerability of coastal areas in Taiwan within the framework of sustainable development. With economic and social growth gravitating towards coastal regions, the strain on the natural environment is increasing. Therefore, discovering a balance between economic progress and environmental conservation is paramount. To decipher the vulnerability of Taiwan's coastal zones, this study first defines 'Integrated Environmental Vulnerability of Coastal Areas.' Key vulnerability factors were identified across environmental, social, and economic dimensions. Seven core determinants were determined using the Fuzzy Delphi method: biodiversity, coastal erosion, water pollution, population density, population aging, land utilization, and infrastructure. The weights for each determinant and dimension were determined through the Analytical Hierarchy Process, forming an assessment model for integrated environmental vulnerability. This model, integrated with Geographic Information System (GIS) technology, was used to create vulnerability maps. When applied to a pilot region, the model showed a significant overlap between high vulnerability zones and areas of environmental degradation and developmental stagnation, validating its efficacy and rationale. Based on these findings, appropriate adaptation strategies for varying vulnerability zones were proposed to offer insight into coastal management departments and achieve Taiwan's vision for sustainable coastal development.

Keywords: Integrated coastal management, Environmental vulnerability assessment, Sustainable development, Fuzzy Delphi method, Analytical Hierarchy Process

1. Introduction

1.1. Background

Considering Taiwan's societal restructuring and rapid economic growth, development has increasingly shifted from inland to coastal regions. This transition has led to diverse land uses in these areas, burdening the natural environment and, in turn, impacting social and economic development. Balancing environmental sustainability with socioeconomic growth is crucial, especially in light of global warming. Using the Shared Socioeconomic Pathways (SSP), the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) in 2021 warns of a potential 3.3—5.7 °C increase in global surface temperature by the end of the century under the extreme SSP5-8.5 scenario. This change could raise global mean sea levels by 0.63—1.02 m, leading to significant losses of coastal and arable lands. It could also impact many island nations including Taiwan.

1.1.1. Climate change

The Intergovernmental Panel on Climate Change [1] in its Sixth Assessment Report (AR6) indicates

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* Corresponding author.
E-mail addresses: lkchien@mail.ntou.edu.tw (L.-K. Chien), 11052027@mail.ntou.edu.tw (Y.-C. Li), sfhsu1013@ctu.edu.tw (C.-F. Hsu).

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that based on observational estimates and past climate archive data, improvements have been made in every component of the comprehensive climate system and its changes to date. New climate model simulations and new analytical methods combined with multiple lines of evidence help to better understand the impact of humans on a wide range of climate changes, including weather and extreme climate events. The National Climate Change Adaptation Action Plan for 107–111 years shows that under global climate change, Taiwan may face impacts including sea-level rise, drought, extreme rainfall, and high temperatures. To respond to climate change impacts, domestic planning involves cross-departmental and cross-domain cooperation, classifying adaptations under the impact into land use, capacity building, life support facilities, health, energy supply, water resources, oceans and coasts, industry, crop production, disasters, and biodiversity. These classifications enhance the nation's overall ability to respond to climate change, laying the foundation for climate change adaptation through cross-disciplinary methods such as regulatory strategies, scientific research, and educational advocacy.

1.1.2. Domestic and international coastal management

This section addresses domestic and international coastal management strategies, focusing on Integrated Coastal Zone Management (ICZM), a dynamic, interdisciplinary, and iterative process designed to foster sustainable coastal area management. ICZM aims for a long-term balance across environmental, economic, social, and cultural spheres.

The comprehensive coastal management plan discussed includes:

- Coastal Protection Areas: Governed through natural environmental planning, these areas are managed systematically based on regional sensitivity to preserve environmental and ecosystem balance, aiming for sustainable coastal resource utilization.
- Environmentally Degraded Areas: These are regions where ecological damage due to overdevelopment or natural disasters necessitates policy shifts, developmental mitigation, or environmental improvements for ecological restoration. (Article 35 of Taiwan's Spatial Planning Act).
- Developmentally Lagging Areas: Development in these areas follows principles that align with the overall coastal management strategy, industrial policy promotion, tourism strategies, and infrastructure development. Priority is given to environmental degradation management in areas overlapping with environmentally degraded regions.

The research will consider standards for coastal protection zoning and principles for designating environmentally degraded and developmentally lagging areas. This ensures the relevance of identified vulnerability factors to Taiwan's coastal challenges. Demonstration areas for the vulnerability assessment will be selected within the overlapping zones of environmental degradation and developmental lagging, as outlined in the overarching coastal management plan.

1.1.3. Overview of sustainable development initiatives both globally and in Taiwan

- Sustainable Development Goals (SDGs): In light of climate change, a variety of strategies, agreements, and goals have been developed internationally to achieve sustainable development amidst the challenges posed by climate change. Among these, the United Nations' [26] 17 Sustainable Development Goals (SDGs) stand out as a comprehensive framework addressing various dimensions, including environmental (climate change, marine resources, terrestrial ecosystems), economic (poverty, agricultural food security), and social aspects (lifelong learning, gender equality).

In addition, under each of these goals, numerous detailed sub-items are derived, thus further enhancing the realization of global sustainable development. In the subsequent vulnerability inventory section of this study, the detailed sub-items of each goal will be used as one of the major inventory bases, aligning the vulnerability factors assessed in this study with the SDGs, and achieving the goals of sustainable development along the coast of Taiwan.

- National Land Planning in Taiwan: The Ministry of the Interior [22] has formulated a spatial development plan focusing on conservation and utilization of land and marine resources within Taiwan's jurisdiction. This plan, national in scope, is designed to fulfill sustainable development objectives, setting targeted, policy-based, and holistic approaches to spatial development and land use. It acknowledges the triple challenges of environmental, economic, and social dimensions in Taiwan's path to sustainable development, extending beyond environmental conservation to encompass cross-sectoral development in societal and economic realms.

- Taiwan's Sustainable Development Goals: Commencing in 2016, the Executive Yuan's National Council for Sustainable Development has been developing Taiwan-specific sustainable development goals. These goals are tailored to Taiwan's unique developmental needs while aligning with the United Nations' SDGs. An outcome of this initiative is the formulation of 18 distinct 'Taiwan Sustainable Development Goals,' informed by the principles of the SDGs but customized to local contexts.

1.1.4. Vulnerability

This section delves into how vulnerability is conceptualized across various research disciplines, with applications spanning disaster, economic, and social assessments.

Conceptual definitions of vulnerability: Historical research endeavors have yielded diverse definitions of vulnerability in multiple contexts.

Since the 1980s, vulnerability has been widely studied and given various definitions. Gabor and Griffith [2] discussed the threats posed by chemicals in the United States and Canada to local areas, which caused significant problems during production, transportation, and storage processes, and posed dangers to communities within the region. However, local planners only formulated strategies based on the dangers faced. Therefore, it was proposed that vulnerability should also be assessed, which refers to the association and impact of chemical agents on the community, such as the distance between storage facilities and densely populated areas, locally available financial resources, and emergency preparedness plans. This is to establish more vulnerable areas, propose more precise protective actions, and allocate resources.

The National Science and Technology Center for Disaster Reduction [24] reviewed and analyzed existing risk-related studies on climate change hazards and disaster perspectives to obtain a deeper understanding of vulnerability. They considered both environmental and socio-economic vulnerabilities, with the former characterized by disaster potential and the latter by demographics, socio-economic progress, and output. Overall, vulnerability in the existing literature is fundamentally viewed as the extent or propensity of a system or domain to experience adverse effects.

Defining Integrative Coastal Environmental Vulnerability: Drawing from these insights, this study posits integrative coastal environmental vulnerability as "a metric indicating the extent to which the sustainability or integrity of various systems within a region diminishes or incurs damage in the event of a disturbance." The systems in question encompass the coastal region's natural environmental, social, and economic development systems. Hence, the indicators impacting the sustainability of these dimensions in coastal areas are regarded as constituents of integrative coastal environmental vulnerability.

Formulating vulnerability factors: This study preliminarily identifies relevant vulnerability factors aligned with its definition, based on an analysis of sustainable development goals from global and local literature, zoning principles in comprehensive coastal management plans, and vulnerability factors employed in prior research. These identified factors lay the groundwork for subsequent factor selection. A comprehensive environmental assessment model for coastal regions was also constructed by evaluating various vulnerability assessment models, including those with equal and differentiated weightings. Due to space limitations, relevant supplementary material on vulnerability factors is provided in Appendix Tables A1–A3.

1.2. Literature review

This section conducts a literature review and discussion based on relevant research in Taiwan over the past 15 years. The assessment of vulnerability encompasses a wide range of aspects, and depending on the specific research field, there are many considerations across various levels that remain consistent. Each research field may select a different combination of vulnerability factors to describe the overall vulnerability.

First, Chiu [3] adjusted the assessment scale and corresponding indicators of the UNEP index, focusing on disaster prevention principles, with an emphasis on considering the coast's ability to withstand external impacts. Based on the vulnerability defined by UNISDR [4] and tailored to the characteristics of Taiwan's coastal environment, the relevant indicators of physical, socio-economic, and natural environmental aspects were defined. This led to the derivation of indicators for assessing vulnerability in localized coastal areas.

Lin [5] referred to UNEP and measured the difficulty of obtaining domestic environmental and data status. They devised various indicator vulnerability factors susceptible to coastal inundation hazards: household numbers, comprehensive income, and land use categories, representing population structure, economic development, and urban-rural development, respectively. The Coastal Vulnerability Factors and Indicators established by Chien et al. [6] represent aspects such as population structure, economic development, and environmental development. The factors for each aspect include population (population density and population growth rate), total industrial output value, land use type, environmentally sensitive areas, and wave uprush height.

Liu [7], based on the definition of vulnerability proposed by UNISDR [8], utilized principal component analysis to analyze numerous vulnerability factors related to land subsidence impacts, eliminating inappropriate factors. Finally, the vulnerability factors were classified into first and second indicators according to their contribution rates. These vulnerability factors include population density, building structure and age, land elevation, building density, road density, land use, juvenile and elderly population, percentage of disabled population, dependency ratio, percentage of low-income households, and profit income. They are categorized into physical, social, economic, and environmental dimensions.

Yu [28], in addition to considering traditional resilience thinking, incorporated the concept of rapid recovery to a better state after system disruption. Factors were categorized into four major dimensions: organizational, social, infrastructure, and economic aspects. Using these dimensions, they developed flood resilience tailored for demonstration areas.

This study initiates by reviewing and synthesizing previous research to redefine ‘integrated environmental vulnerability of coastal areas’ as a metric indicating the decrease in sustainability or increase in damage when an event occurs. Vulnerability factors in environmental, social, and economic aspects are identified and selected using the fuzzy Delphi method. These factors are then weighted and integrated via the Analytic Hierarchy Process (AHP) to establish an assessment model for integrated environmental vulnerability. Unlike previous studies focusing solely on disaster aspects, this study emphasizes integrated coastal management and sustainable development, particularly analyzing coastal area vulnerability in Taiwan.

Considering Taiwan's sustainable development challenges—environmental, economic, and social—this study proposes assessing vulnerability across these three aspects and integrates it into the overall coastal management plan, prioritizing areas with overlapping environmental degradation and underdevelopment. Yunlin County is chosen as the research area, where an integrated environmental vulnerability assessment is conducted, resulting in a vulnerability map for coastal areas. Corresponding adaptation management strategies are then formulated based on the assessment results, including comprehensive evaluations and analyses of highly vulnerable villages. The study aims to provide valuable insights for coastal management authorities, contributing to sustainable coastal development in Taiwan by aligning with national policies and sustainable development principles. In essence, this research underscores the importance and practical application of integrating national policies with sustainable development, representing a significant contribution to the field.

1.3. Motivation and objectives

In recent years, sustainable development has become a global priority, underscored by the United Nations' Sustainable Development Goals (SDGs). However, past coastal risk assessments in Taiwan have primarily focused on disaster prevention, such as storm surges, land subsidence, flooding, and coastal erosion, with less attention toward social sustainability. This research pivots towards a combined focus on ‘vulnerability’ and ‘sustainable development’, integrating the ‘natural environment’ and ‘socio-economic’ aspects. It aims to assess and establish ‘Integrated Environmental Vulnerability’ factors for the coast, encompassing environmental, social, and economic dimensions.

- The main objectives of this study are as follows:
- To collect domestic and international literature on coastal management and sustainable development, and to explore the relationship between the two.
- To redefine integrated coastal environmental vulnerability through past vulnerability research combined with the concept of sustainable development, and to discuss integrated coastal vulnerability factors in conjunction with SDGs and overall coastal management plans.
- To use expert questionnaire methods to screen and establish integrated environmental vulnerability factors and vulnerability assessment models applicable to coastal areas.
- To conduct vulnerability assessments and analyses for coastal demonstration areas, providing a reference for management units for the sustainable development of the coast, thereby promoting the sustainable development of Taiwan's coast.

2. Methodology

An overview of the methodology used in this study is presented in this section, focusing on the coastal demonstration areas selected for vulnerability assessment, related research data and statistics concerning vulnerability factors in these areas, and the integrative environmental vulnerability assessment model established for coastal regions. The section also delves into the analytical methods employed, including the Fuzzy Delphi Method, Analytic Hierarchy Process (AHP), and Geographic Information System (GIS) for mapping purposes.

2.1. Study area selection

In line with the research themes of coastal management and sustainable coastal development, this study identified priority areas based on the comprehensive coastal management plan, focusing on regions of environmental degradation and developmental delay. Fig. 1 illustrates selected coastal areas, characterized by overlapping zones of environmental degradation and developmental lag. Given the availability and completeness of vulnerability data and statistics, Yunlin County's coastal villages and neighborhoods were chosen as the

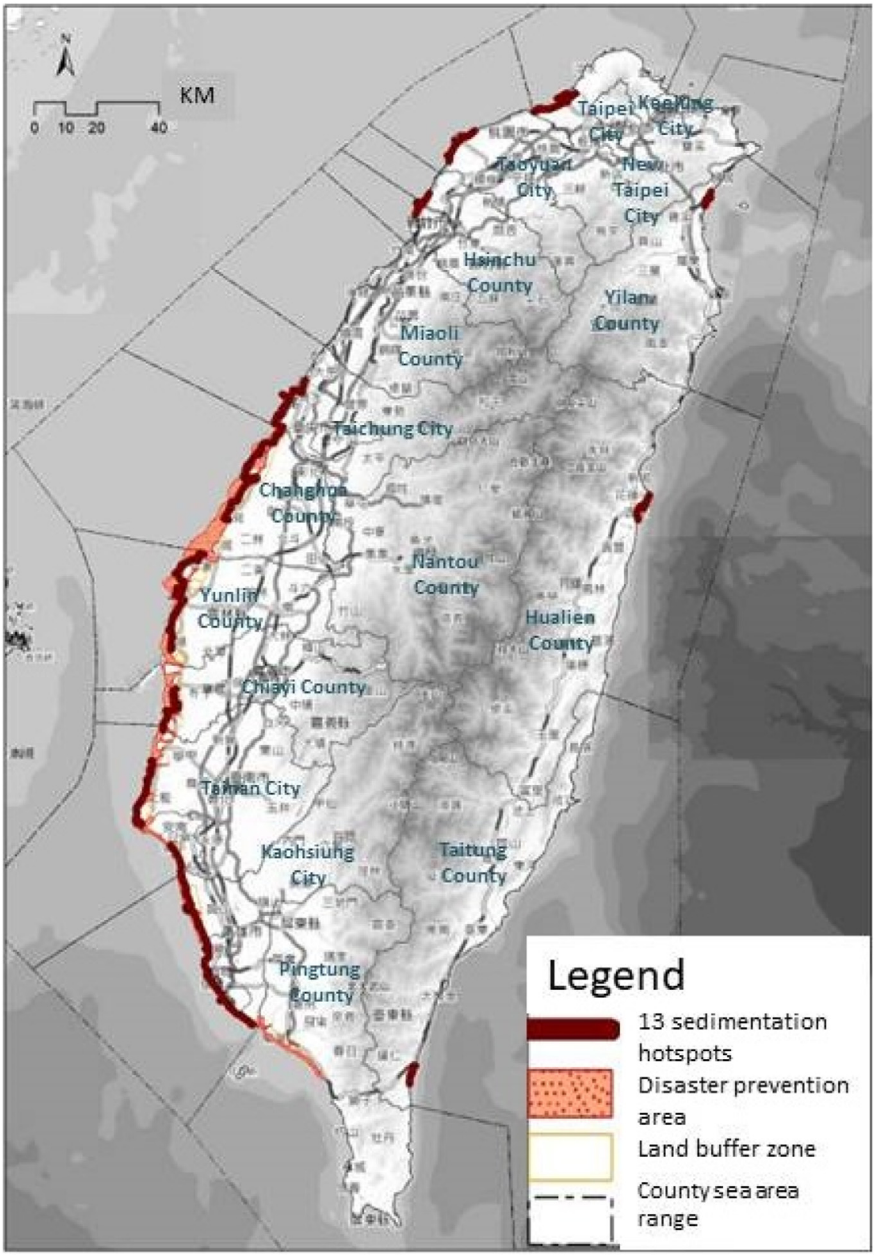

Fig. 1. Overlapping regions of environmentally degraded and developmentally lagging areas [23].

demonstration area for this vulnerability assessment. This encompasses Taisi, Mailiao, Kouhu, Sihhu, and Dongshi Townships. According to the coastal area delineations published by the Ministry of the Interior's Construction and Planning Agency, the demonstration area for this study includes 40 villages and neighborhoods, as depicted in Fig. 2.

2.2. Information on the study area

The data and sources for each factor used in this study are presented in Table 1.

2.3. Integrative vulnerability assessment model for coastal areas

The vulnerability assessment model primarily consists of weighted and equal-weighted analysis methods. This study opts for the weighted analysis method, because it better highlights differences in importance among various vulnerability factors. Simultaneously integrated with USGS, different vulnerability indexes are established and categorized into three dimensions: environmental, social, and economic vulnerability. The vulnerability levels

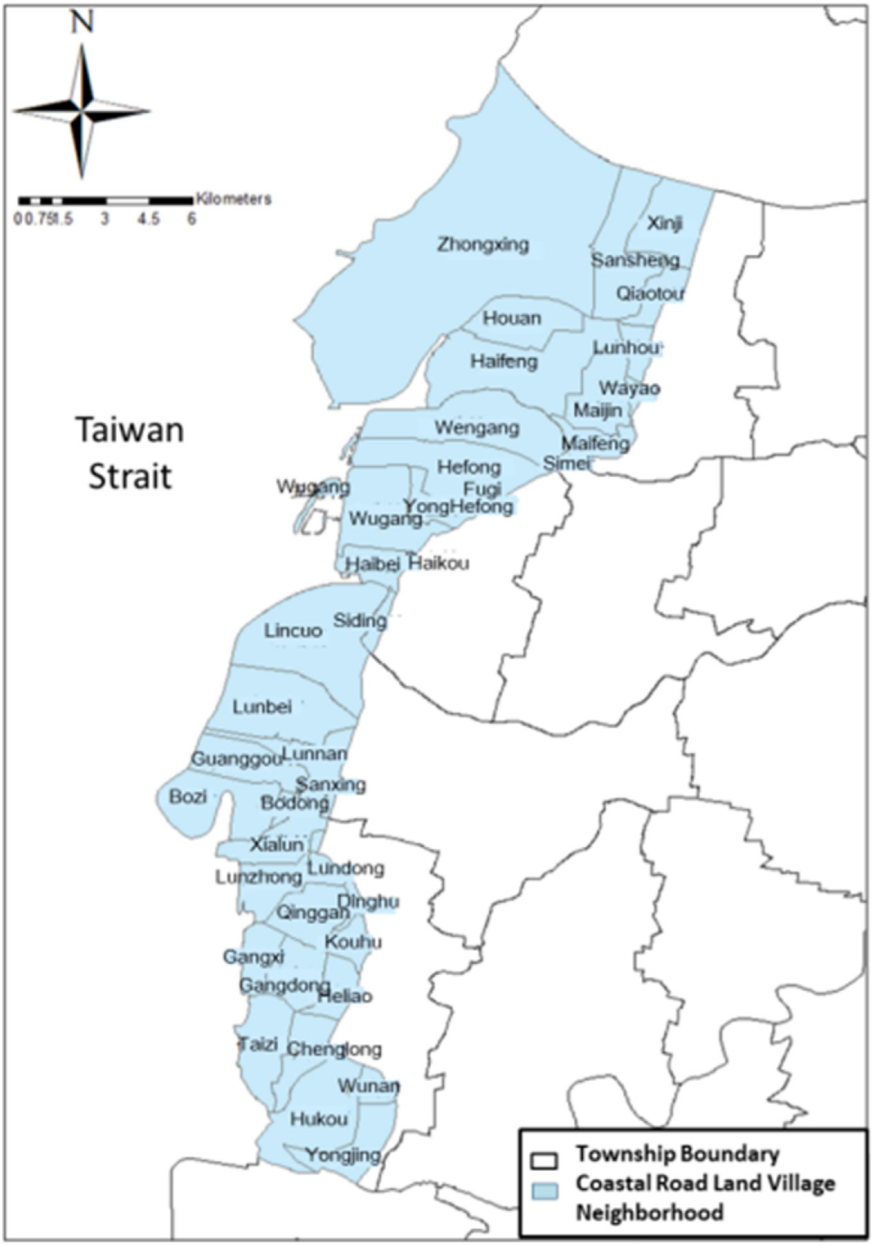

Fig. 2. Demonstration area of coastal villages in yunlin (Data source: Comprehensive Review of the Overall Coastal Management Plan by the Construction and Planning Agency, Ministry of the Interior) [21].

Table 1. Data and sources for each factor.

Aspect	Factor	Data information	Data source
C_1 Environmental	$C_{1\text{-}1}$ Biodiversity	2022–2023 Biodiversity Observation Records in Yunlin	County Council of Agriculture, Endemic Species Research and Conservation Center, Executive Yuan [17]
	$C_{1\text{-}2}$ Coastal Erosion Status	1997–2020 Yunlin Topographic DEM	Water Resources Agency, Ministry of Economic Affairs [27], Wu [9], Lu [10]
	$C_{1\text{-}3}$ Water Quality Pollution	2022–2023 River Water Quality Monitoring Data	National Water Quality Monitoring Information Network, Environmental Protection Administration, Executive Yuan
C_2 Social	$C_{2\text{-}1}$ Population Density	February 2023 Population Statistics by Village and Neighborhood	Mailiao Household Registration Office, Yunlin County [29]
	$C_{2\text{-}2}$ Elderly Population	February 2023 Single-Age Population Statistics by Village and Neighborhood	Department of Household Registration, Ministry of the Interior [20]
C_3 Economic	$C_{3\text{-}1}$ Land Development and Utilization	2020–2021 National Land Use Survey Results - Electronic Map Data	National Land Surveying and Mapping Center, Ministry of the Interior
	$C_{3\text{-}2}$ Infrastructure	2020–2021 National Land Use Survey Results - Electronic Map Data	National Land Surveying and Mapping Center, Ministry of the Interior

of each dimension can be obtained by normalizing and multiplying respective weights with vulnerability factors data. The integrated vulnerability assessment of coastal areas is completed by assigning weight relationships to the three dimensions, facilitating the combination of vulnerability levels. This process is achieved by applying GIS to draw vulnerability maps, presenting assessment results more intuitively within the evaluated scope, as shown in Fig. 3.

2.4. Analytical methods

This study compares the advantages and disadvantages of various research methods (Table 2), by adopting an improved version of the Fuzzy Delphi Method [19] and the Analytic Hierarchy Process [25] to address the shortcomings of the original methods. This approach also retains their advantages for filtering factors and assigning weights, thus ameliorating the difficulty of converging expert

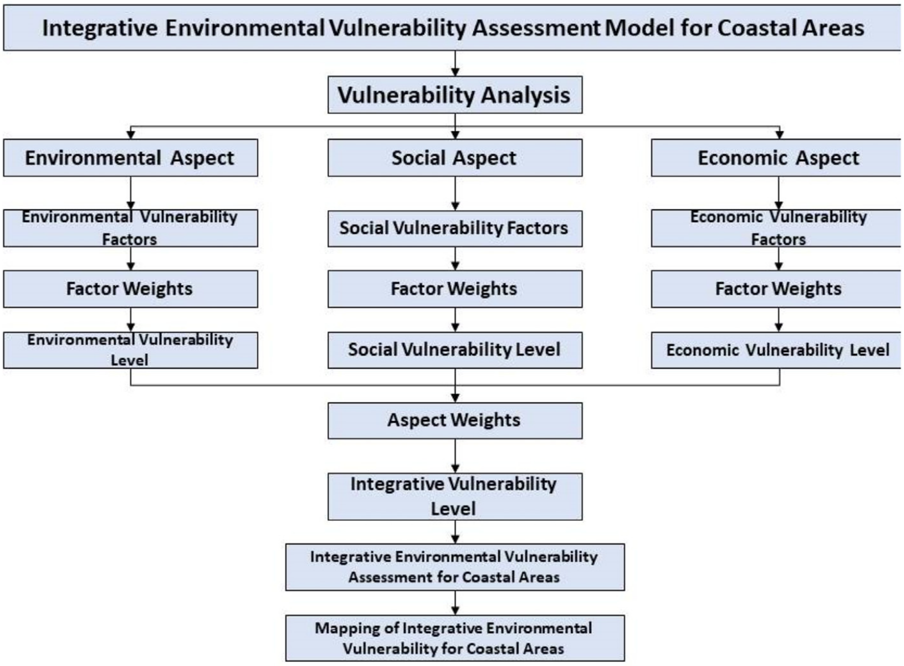

Fig. 3. Integrative vulnerability assessment model for coastal areas.

Table 2. Comparative advantages and disadvantages of research methods (Data source: compiled by this project).

Research method	Advantages	Disadvantages
Principal Component Analysis	1. Rapid and objective 2. Can eliminate inter-factor influences	1. Dimension reduction affects original variables 2. Social context is difficult to interpret
Analytic Hierarchy Process	1. Systematizes complex problems 2. High accuracy in areas of expertise	1. Requires consistency between levels 2. Influenced by questionnaire design
Delphi Method	1. Brainstorming benefits 2. High accuracy in areas of expertise 3. Anonymous survey maintains impartiality	1. Time-consuming with repetitive steps, difficult to converge 2. Influenced by questionnaire design
Fuzzy Delphi Method	1. Retains the advantages of the Delphi Method 2. Less time-consuming 3. Easier to converge and reach consensus	Influenced by questionnaire design

opinions, which is a known limitation of the original Delphi Method.

After evaluating the advantages and disadvantages of various methods, the Fuzzy Delphi Method and the Analytic Hierarchy Process (AHP) were selected to analyze factors. The Fuzzy Delphi Method improved upon the main shortcomings of the original Delphi Method while retaining its advantages. Therefore, in the first phase of the questionnaire process, the Fuzzy Delphi Method was utilized to filter out suitable factors for the integrative environmental vulnerability of coastal areas in Taiwan. The AHP overcomes the limitation of the Principal Component Analysis, which struggles to account for social impacts, a significant concern in this research. Consequently, in the second phase, the AHP is employed to assign weight relationships to various factors. The questionnaire distribution process illustrated in Fig. 4.

The Fuzzy Delphi Method relies on analyzing the consensus among experts and scholars to decide whether to retain or eliminate factors.

This study used a quantitative to assess disaster risk, including an overall hazards and vulnerabilities. This study adopts the operational definition of risk suggested by the United Nations Office for Disaster Risk Reduction (UNISDR) based on disaster risk assessments that have received significant attention in recent years and compiled research on risk assessment by domestic and international scholars: Risk (Risk) = Hazard (Hazard) × Vulnerability (Vulnerability).

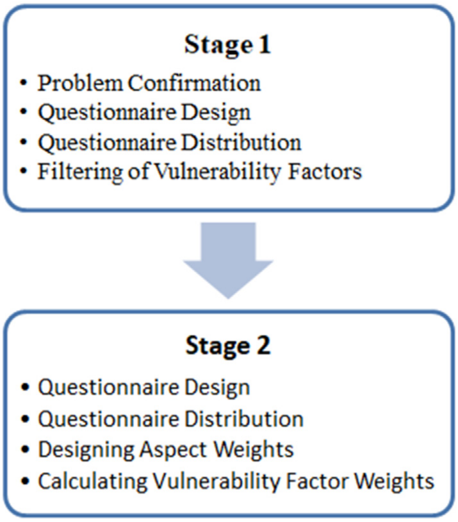

Fig. 4. Expert questionnaire distribution process diagram.

This formula, which encompasses the concept of a risk matrix, combines the degree of hazard and vulnerability in a matrix format, representing a comprehensive consideration of the severity of the hazard and the degree of susceptibility to disaster. The numerical values post-matrix quantification are then categorized into several levels.

2.5. Geographic information systems

A review of recent studies on the potential for soil liquefaction shows that the majority of presentations and analyses are conducted using Geographic Information Systems (GIS). GIS has become one of the important tools for researching the potential for soil liquefaction and assessing other natural disaster risks. GIS can integrate a variety of data sources, such as topography, geology, land use, climate, and soil liquefaction-related parameters like pore water pressure, shear wave velocity, and shear strength. By analyzing, processing, and visually presenting these data, researchers can better understand the potential and risks of soil liquefaction to develop effective disaster prevention measures and management strategies.

3. Expert questionnaire planning and vulnerability factor analysis results

This section explains the planning, design, process, and results of the two-stage expert questionnaire, including the selection of respondents. It also describes the first and second stage results of vulnerability factor filtering and vulnerability factor weight analysis, respectively. Finally, the questionnaire analysis results were used to perform the integrated environmental vulnerability assessment analysis for coastal areas in this study.

3.1. Expert questionnaire planning and design

This research employs the Fuzzy Delphi Method and the Analytic Hierarchy Process (AHP) for questionnaire analysis, thus involving a two-stage questionnaire distribution. In the first stage, the expert questionnaire details the environmental, social, and economic vulnerability factors identified earlier, providing a complete expression of the meaning represented by each factor. By referencing the quantification method proposed by Zheng [11] for the degree of importance, the questionnaire allowed experts to fill in the maximum, optimum, and minimum values of each vulnerability factor (Appendix Tables A4–1 to A4–3). This information facilitated consensus calculations using the Fuzzy Delphi Method after questionnaire collection by filtering and establishing integrated vulnerability factors for coastal areas.

In the second stage of the expert questionnaire, we referred to the suggestions from the first stage of experts and added an explanation of the research background and objectives, allowing respondents to better understand the research topic and thereby express their opinions more accurately. Based on the vulnerability factors filtered out in the first stage, a hierarchical structure was established for the questionnaire, including integrated aspects and individual factors. In the questionnaire design, we used the common format of AHP, quantifying the importance level between factors on a scale from 1 to 9 (Detailed in Appendix Tables A4). This helps to establish the required pairwise comparison matrix after the questionnaire collection, which is then used to calculate the weights for the integrated vulnerability assessment of coastal areas.

The questionnaire was distributed to experts with backgrounds in civil engineering, hydraulic engineering, marine engineering, biological sciences, climate change, disaster prevention, and related fields, including members of relevant government advisory committees. A total of 30 questionnaires were distributed, and 16 were returned, resulting in a response rate of 53.3%. The returned questionnaires covered four major sectors: industry, public sector, academia, and research.

3.2. Vulnerability factor selection

In Section 3.2, the first phase of the questionnaire aimed to filter vulnerability factors by employing the Fuzzy Delphi Method for analysis and questionnaire design. This method quantifies experts' subjective judgments by asking participants to provide minimum, optimum, and maximum values for the importance of each assessment item.

3.2.1. Calculation of environmental vulnerability factors

3.2.1.1. Biodiversity. Coastal biodiversity reflects the state of natural ecology and conservation efforts in the area, making it one of the crucial factors affecting environmental sustainability. Content related to SDGs 14 and 15 aims for the sustainable development of the overall ecosystem. In this study, biodiversity is represented by species density in various villages within the demonstration area and calculated as per Formula 1.

$$\text{Biodiversity} = \left(\begin{matrix}\text{Number of Species}\\ \text{Observations}\end{matrix}\right) \Big/ (\text{Village Area})\,(km^2) \tag{1}$$

3.2.1.2. Coastal erosion status. Coastal erosion can lead to negative impacts such as land loss and damage to coastal facilities, making it one of the regulated coastal disasters under the Coastal Management Act. Additionally, coastal erosion affects the sustainable development of various systems in coastal areas, including the natural environment, coastal industries, and human habitation.

In this study, the erosion and accretion status of coastal sections was used as a representative factor for coastal erosion. Formula 2 is used to calculate the result.

$$\begin{aligned}\text{Coastal Erosion} \big/ \text{Accretion} = {} & (\text{Change in the 0} \\ & -\text{Meter Shoreline of the Coast in meters}) \\ & \big/ (\text{Time Period in years})\end{aligned} \tag{2}$$

3.2.1.3. Water quality pollution. Water resources are one of the essential resources for various developmental needs, impacting not only the environmental and ecological aspects but also agricultural production, domestic water supply, and more. Good water quality contributes to the possibility of achieving sustainable development in these areas. SDG 6 specifically targets water resources, aiming to protect and manage them.

In this study, the River Pollution Index (RPI), announced by the Environmental Protection

Administration, was used as a representative data for water quality pollution. RPI consists of four parameters: dissolved oxygen, biochemical oxygen demand, suspended solids, and ammonia nitrogen. Each parameter has specified content standards and corresponding points. The calculation involves adding these points and obtaining the average, as demonstrated in Formula 3.

$$\mathrm{RPI} = \frac{1}{4}\sum_{i=1}^{4} Si \tag{3}$$

where:

RPI: River Pollution Index
Si: Pollution Points
i: Water Quality Parameter
Calculation of social vulnerability factors

3.2.1.4. Population density. This study adopted a sustainable development perspective when examining the population density factor. High population density not only reflects an increase in affected individuals when an event occurs. It also indicates population overcrowding in urban settlements within the area, affecting various aspects of residents' lives. In this research, the population density for each village was calculated using population statistics data from the Mailiao Township Household Registration Office in Yunlin County for February 2023. The calculation was performed by dividing the population by the area of each village, as shown in Formula 4.

$$\text{Population Density} = (\text{Total Population of Each Village}) / (\text{Village Area}) \tag{4}$$

3.2.1.5. Elderly population. Population aging is reflected in rising dependency ratios, increased healthcare demand, and a decline in the working-age population, among other factors. It also has implications for socio-economic development, leading to a reduction in overall system sustainability. The National Development Council further estimates that the country will enter a super-aged society by 2025. In this research, data from the Ministry of the Interior's Department of Household Registration for February 2023, specifically single-age population statistics, were used to calculate the proportion of the elderly population for each village using Formula 5.

$$\text{Population Aging} = (\text{Number of People Aged 65 and Above in Each Village}) / (\text{Total Population of Each Village}) \tag{5}$$

Calculation of social vulnerability factors

3.2.1.6. Land development and utilization. This study primarily refers to the method of land use analysis by Liu [7], which considers the safety of people's lives and property. The study merges and classifies first-level land use categories announced by the Ministry of the Interior's National Land Surveying and Mapping Center. Subsequently, referring to Hsu [12], the study focuses on land used for construction and public use, which have the highest levels of vulnerability, as the basis for land development and utilization analysis. The ratio of the aforementioned types of land use to the total area of each village is calculated according to Equation (6).

$$\text{Land Development and Utilization} = \text{Public Land Use Area} / \text{Village Area} \tag{6}$$

3.2.1.7. Infrastructure. In past studies of coastal disaster risk assessment, infrastructure has been categorized under "disaster resilience." However, this study approaches from the perspective of "sustainable development," examining the correlation between transportation and economic development within the demonstration area. The factor analysis was conducted using the 2020 National Land Use Survey status map data from the Ministry of the Interior's National Land Surveying and Mapping Center. First-level land use classifications announced by the Surveying and Mapping Center were used in this study, focusing on areas designated for transportation and water resource utilization. The land area used for transportation and water resources divided by the total area of each village, as shown in Equation (7), yields the proportion of land allocated to transportation and water resources.

$$\text{Land Development and Utilization} = \text{Public Land Use Area} / \text{Village Area} \tag{7}$$

The collected data were used to analyze whether there is a consensus among experts on the importance of a particular factor and the degree of this consensus (G_i). This consensus value is compared to a set threshold value (S) to complete the selection of vulnerability factors. Tables 3–5 show specific analysis results.

This study, referencing the works of Chen [13] and Qian [14], eliminated factors where M_i - Z_i was negative, meaning there was no consensus among the experts, and some experts' extreme opinions differed significantly from those of others, leading to

Table 3. Fuzzy delphi method analysis results (Environmental).

Aspect	Vulnerability factor	Z_i	M_i	M_i-Z_i	G_i	S (6.607)
Environmental	Biodiversity	1	4.0599	3.0599	7.3852	Passed
	Coastal Erosion	3	3.9433	0.9433	6.0829	Failed
	Water Quality Pollution	1	3.8975	2.8975	5.5105	Failed
	Soil Pollution	1	3.9173	2.9173	7.4201	Passed
	Air Pollution	2	3.7220	1.7220	6.8561	Passed
	Noise Pollution	5	3.9001	−1.099	FALSE	Failed

Z_i is the geometric mean rating; M_i is the geometric mean of maximum value; M_i-Z_i is the difference; G_i is the consensus degree; S is the threshold value.

Table 4. Fuzzy delphi method analysis results (Social).

Aspect	Vulnerability factor	Z_i	M_i	M_i-Z_i	G_i	S (6.318)
Social	Population Density	2	3.9929	1.9929	6.8031	Passed
	Educational Level	3	3.8028	0.8028	5.8413	Failed
	Vulnerable Groups	5	2.9536	−2.046	FALSE	Failed
	Cultural Assets	2	3.2777	1.2777	5.8396	Failed
	Medical Health	4	3.5749	−0.425	FALSE	Failed
	Elderly Population	2	3.4186	1.4186	6.8679	Passed

Z_i is the geometric mean rating; M_i is the geometric mean of maximum value; M_i-Z_i is the difference; G_i is the consensus degree; S is the threshold value.

Table 5. Fuzzy delphi method analysis results (Economic).

Aspect	Vulnerability factor	Z_i	M_i	M_i-Z_i	G_i	S (5.733)
Economic	Vulnerability Factors	4	2.8485	−1.1514	FALSE	Failed
	Industrial Structure	2	3.3114	1.3114	7.0505	Passed
	Land Development and Utilization	7	4.9789	−2.0210	FALSE	Failed
	Composite Income	6	5.1666	−0.8333	FALSE	Failed
	Fiscal Allocation	3	3.5436	0.5436	6.4815	Passed
	Infrastructure	4	4.5233	0.5233	4.1242	Failed

Z_i is the geometric mean rating; M_i is the geometric mean of maximum value; M_i-Z_i is the difference; G_i is the consensus degree; S is the threshold value.

a divergence in the final consensus. Therefore, the item's importance was not effectively represented and such items were deleted. This study adopted the method proposed by Wang [15] and Zhuang [16], setting the threshold value as the geometric mean of the consensus importance level. After calculation, the threshold values for environmental, social, and economic aspects were 6.607, 6.318, and 5.733, respectively.

Following the threshold value filtering, the vulnerability factors for the environmental aspect with a threshold greater than 6.607 were biodiversity, coastal erosion status, and water quality pollution. Social aspects with a threshold greater than 6.318 were population density and the elderly population. Economic aspects with a threshold greater than 5.733 were land development and utilization, and infrastructure, as shown in Table 6. The aforementioned seven factors represent the integrated environmental vulnerability factors for coastal areas in this study and were numbered accordingly.

Table 6. Integrated environmental vulnerability factors for coastal areas.

Aspect	Factor	Data information
C_1 Environmental	$C_{1\text{-}1}$ Biodiversity	7.3852
	$C_{1\text{-}2}$ Coastal Erosion Status	7.4201
	$C_{1\text{-}3}$ Water Quality Pollution	6.8561
C_2 Social	$C_{2\text{-}1}$ Population Density	6.8031
	$C_{2\text{-}2}$ Elderly Population	6.8679
C_3 Economic	$C_{3\text{-}1}$ Land Development and Utilization	7.0505
	$C_{3\text{-}2}$ Infrastructure	6.4815

3.3. Vulnerability factor weights

The purpose of the second-stage expert questionnaire was weight analysis. This research used the Analytic Hierarchy Process (AHP) to design the questionnaire and analyze data. Appendix Table A4 includes the questionnaire format. The AHP primarily systematizes, stratifies, and simplifies complex problems to achieve the final objective. By combining the results of vulnerability factor selection in Section 3.2 with the AHP, the establishment of hierarchies is completed, as shown in Fig. 5. The first hierarchy integrates the three aspects, and the second hierarchy includes the vulnerability factors of each aspect. This structure was used to design the questionnaire and analyze weight relationships.

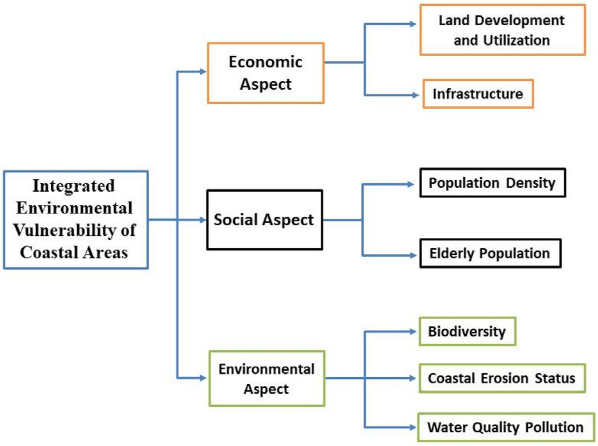

Fig. 5. Schematic diagram of integrated environmental vulnerability levels for coastal areas (Data source: created by this study).

Based on the questionnaires retrieved, we obtained comparative importance values for assessment items from various experts and scholars. The data were then arithmetically averaged to establish pairwise comparison matrices for each aspect and vulnerability factor. Subsequently, using the steps mentioned in Section 2.4, we can calculate the weights between the items. Tables 7 and 8 present weight calculation results. The consistency ratios (C.R.) for each item are less than 0.1, which falls within an acceptable range and passes the consistency check.

4. Results of the integrated environmental vulnerability assessment for coastal areas

This section focuses on the assessment and analysis of various factors identified in Subsection 3.2. By applying the weight relationships obtained in Subsection 3.3, the factors were combined to determine vulnerability levels and scores for environmental, social, and economic aspects. Ultimately, the weights between these aspects were used to integrate the three aspects' vulnerability levels and calculate the integrated environmental vulnerability level. This integrated level was then visualized using GIS to create a vulnerability map, completing the integrated environmental vulnerability assessment for coastal areas. The GIS maps represent various vulnerabilities or degree levels with colors ranging from dark green, light green, yellow, and orange to red, indicating low to high vulnerability. This manuscript was supplemented with analysis explanations. Fig. 6 shows the assessment process. Finally, based on the assessment results, corresponding adaptation strategies are proposed.

Table 7. Integrated aspect weight calculation results.

Aspect	Weights
C_1 Environmental	0.51
C_2 Social	0.16
C_3 Economic	0.33
Total	1

Table 8. Vulnerability factor weight calculation results (Data source: compiled by this study).

Aspect	Vulnerability factor	Weights
C_1 Environmental	$C_{1\text{-}1}$ Biodiversity	0.39
	$C_{1\text{-}2}$ Coastal Erosion Status	0.25
	$C_{1\text{-}3}$ Water Quality Pollution	0.36
Total		1
C_2 Social	$C_{2\text{-}1}$ Population Density	0.62
	$C_{2\text{-}2}$ Elderly Population	0.38
Total		1
C_3 Economic	$C_{3\text{-}1}$ Land Development and Utilization	0.70
	$C_{3\text{-}2}$ Infrastructure	0.30
Total		1

4.1. Environmental vulnerability

In this section, various factors identified and selected for assessment in Section 3.2 are evaluated and analyzed. This study combines these factors using the weight relationships obtained in Section 3.3 to determine environmental, social, and economic vulnerability levels and scores. By integrating these three dimensions of vulnerability with the assigned weights, integrated environmental vulnerability levels were calculated. This information is then used in conjunction with GIS to create vulnerability maps for coastal areas, completing the assessment of integrated environmental vulnerability. Finally, adaptation strategies are proposed based on the assessment results.

4.1.1. Factor analysis

4.1.1.1. Biodiversity. This study relies on the biodiversity network established by the Council of Agriculture's Endemic Species Research Institute as a data reference. Data from species observations in Yunlin County for the years 2022 and 2023 were used for calculations. In total, there were 1486 observation records within the demonstration area. Species density for each village was calculated using Formula 1, representing the biodiversity factor. The calculation results are shown in Fig. 6.

4.1.1.2. Coastal erosion status. In this study, the erosion and accretion status of coastal sections is used as a representative factor for coastal erosion. The calculation is done following Formula 2. Data primarily referenced Wu [9] and Lu [10]. Control sections were established every 500 m, and the calculation was based on the position of the 0-meter shoreline in the Yunlin County coastal topographic DEM (Digital Elevation Model), as shown in Fig. 7. This calculation determined the erosion and accretion status for each section. Fig. 8 presents the results using GIS.

4.1.1.3. Water quality pollution. This study primarily relies on water quality monitoring data from the Environmental Protection Administration's Water

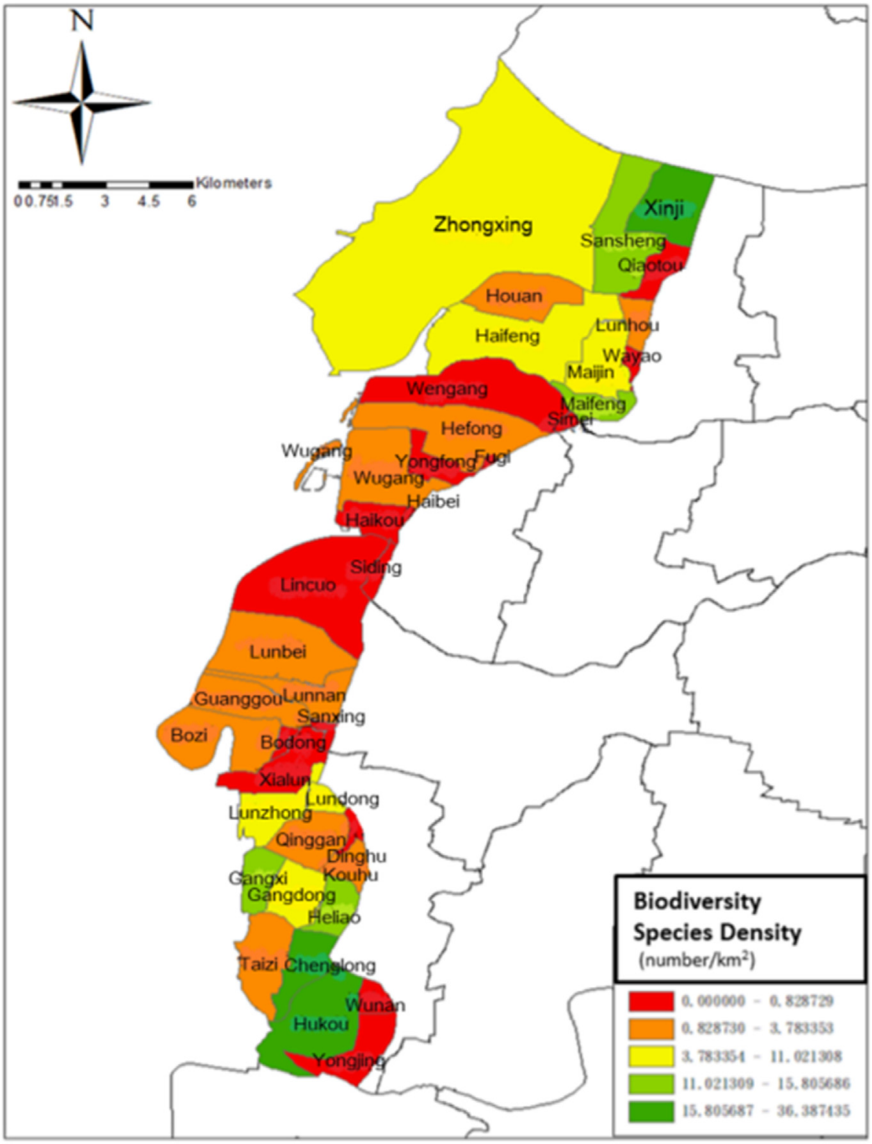

Fig. 6. Research demonstration area species density distribution.

Quality Monitoring Information Network for the years 2022 and 2023 [18]. The original data consists of monitoring station location information. Therefore, in this study, spatial interpolation techniques were employed to convert this data into spatial data. Subsequently, the study area was delineated within the research demonstration area, as depicted in Fig. 9. The average RPI within the boundaries of each village was then calculated as a representative value. Fig. 10 visualizes these results using GIS.

4.1.2. Weight analysis

According to the weight analysis results of vulnerability factors in Section 3.3, weights were obtained for the environmental dimensions of biodiversity, coastal erosion status, and water quality pollution at 0.39, 0.25, and 0.36, respectively. Since the units and meanings of these factors' data are not directly comparable, data normalization is required to prepare the data for integration, as shown in Formula 8. After normalization, the data were then multiplied by their respective weights to obtain vulnerability scores. These scores were classified using the Jenks Natural Breaks method into categories ranging from 1 to 5, with category intervals as shown in Table 9.

Given biodiversity's positive impact on the system's overall sustainability, the normalization process should be modified using Formula 9 to

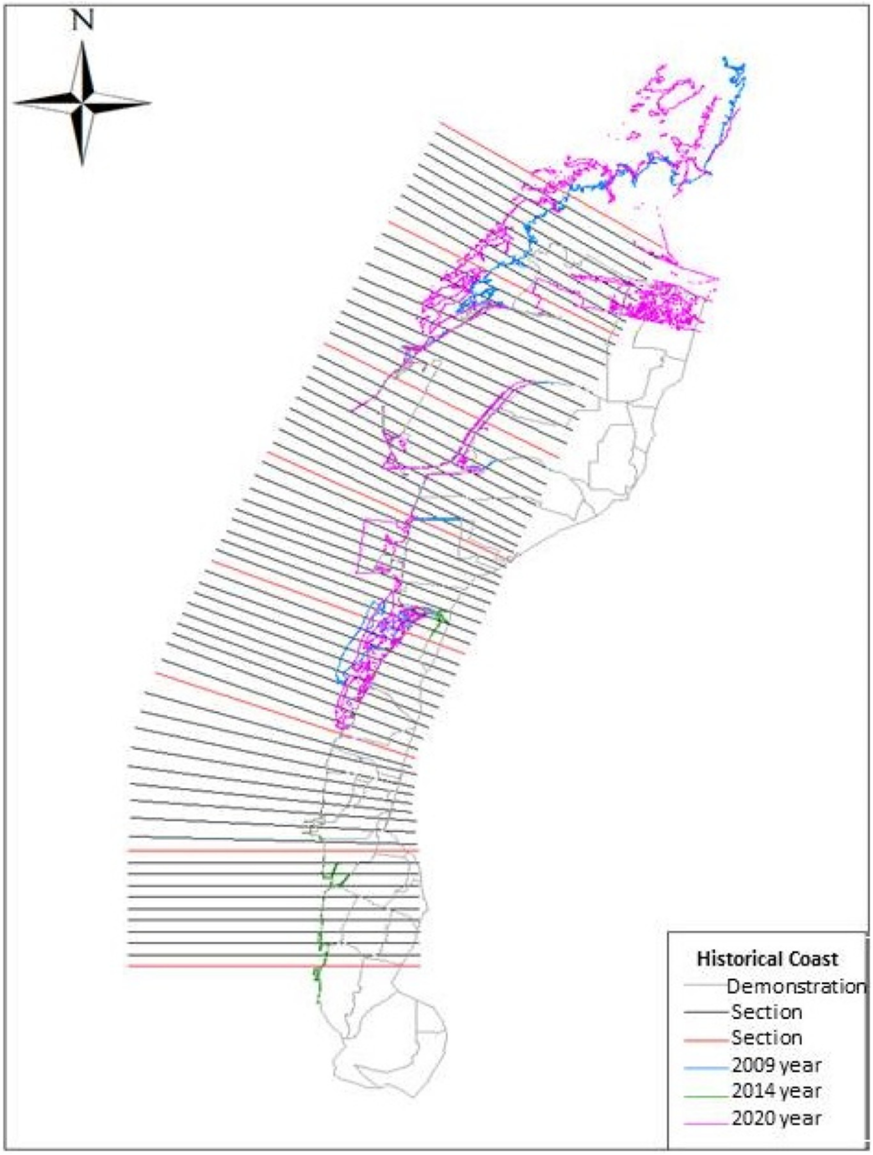

Fig. 7. Coastal 0-meter shoreline and control section. (Source: drawn for this study).

accurately represent the meaning of vulnerability in this study.

$$x_{norm} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \in [0,1] \tag{8}$$

$$x_{norm} = \frac{x_{max} - x_i}{x_{max} - x_{min}} \in [0,1] \tag{9}$$

where

x_{norm} = Normalized Data

x_i = Original Data

x_{min} = Minimum Value of the Original Data

x_{max} = Maximum Value of the Original Data

Using the classification standards from Table 9, a research demonstration area environmental vulnerability map was created in conjunction with GIS, as shown in Fig. 11. From this vulnerability map, it is evident that the lower vulnerability levels, Level 1 and Level 2, are mostly located in the southern regions of Lunzhong Village and Lundong Village. Levels 3 to 5 are distributed mainly in the northern area, from Hou'an Village to Xiding Village. Notably, the region between Hou'an Village and Xiding Village exhibits Level 5 as the highest vulnerability level. The primary reasons for this include lower biodiversity in this area, higher coastal erosion rates in Lincuo Village, and elevated River Pollution Index (RPI) values recorded at the Mosquito Port Bridge, Haifeng Bridge, and Feng Bridge monitoring stations in the northern

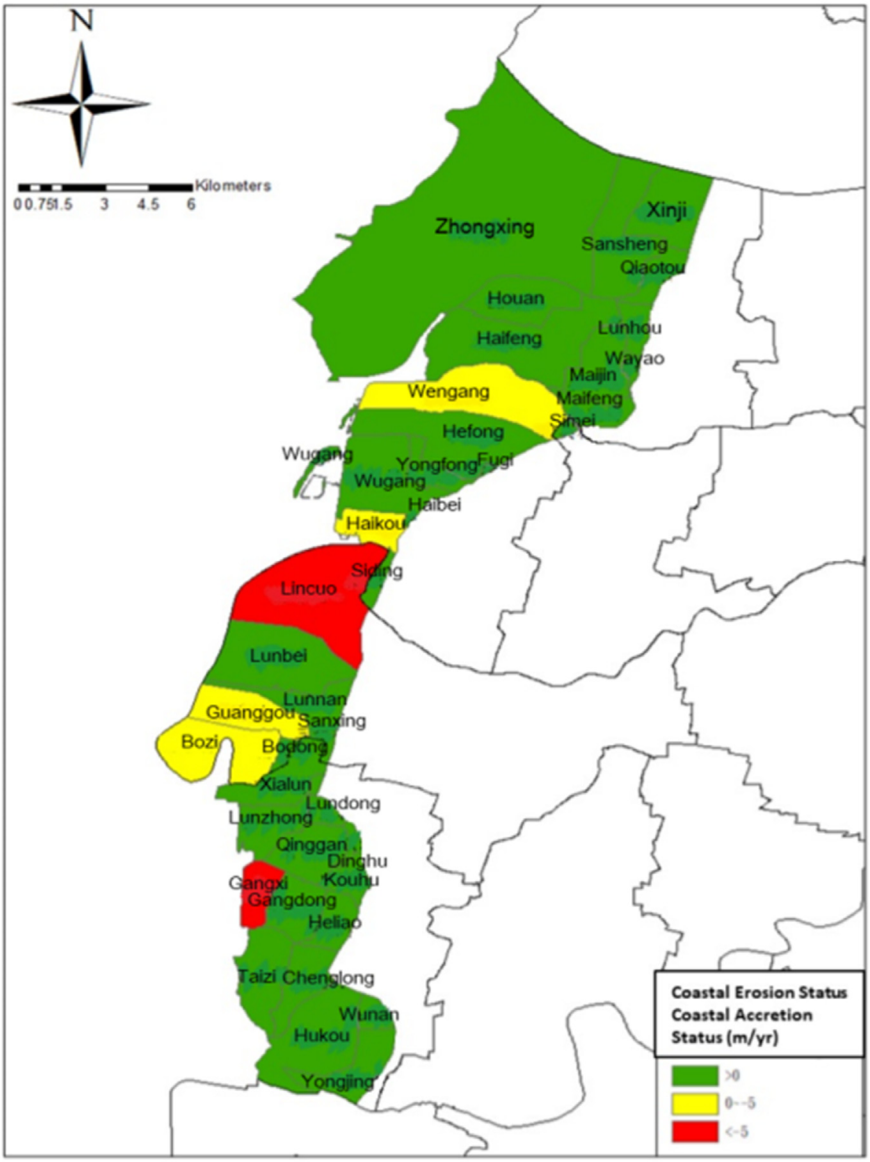

Fig. 8. Coastal erosion status distribution map in the research demonstration area (Source: drawn for this study).

Xinhuwei River basin. These factors contribute to the increase in environmental vulnerability levels in this region.

4.2. Social vulnerability

4.2.1. Factor analysis

4.2.1.1. Population density. In this research, the population density for each village was calculated using population statistics data from the Mailiao Township Household Registration Office in Yunlin County for February 2023. This calculation was performed by dividing the population by the area of each village, as shown in Formula 4. These calculation are presented using GIS in Fig. 12.

4.2.1.2. Elderly population. In this research, single-age population statistics from the Ministry of the Interior's Department of Household Registration for February 2023 were used to calculate the proportion of elderly people in each village according to Formula 5. Fig. 13 presents the distribution of the calculation results using GIS.

4.2.2. Weight analysis

Based on the vulnerability factor weight analysis results in Section 3.3, the weights for population

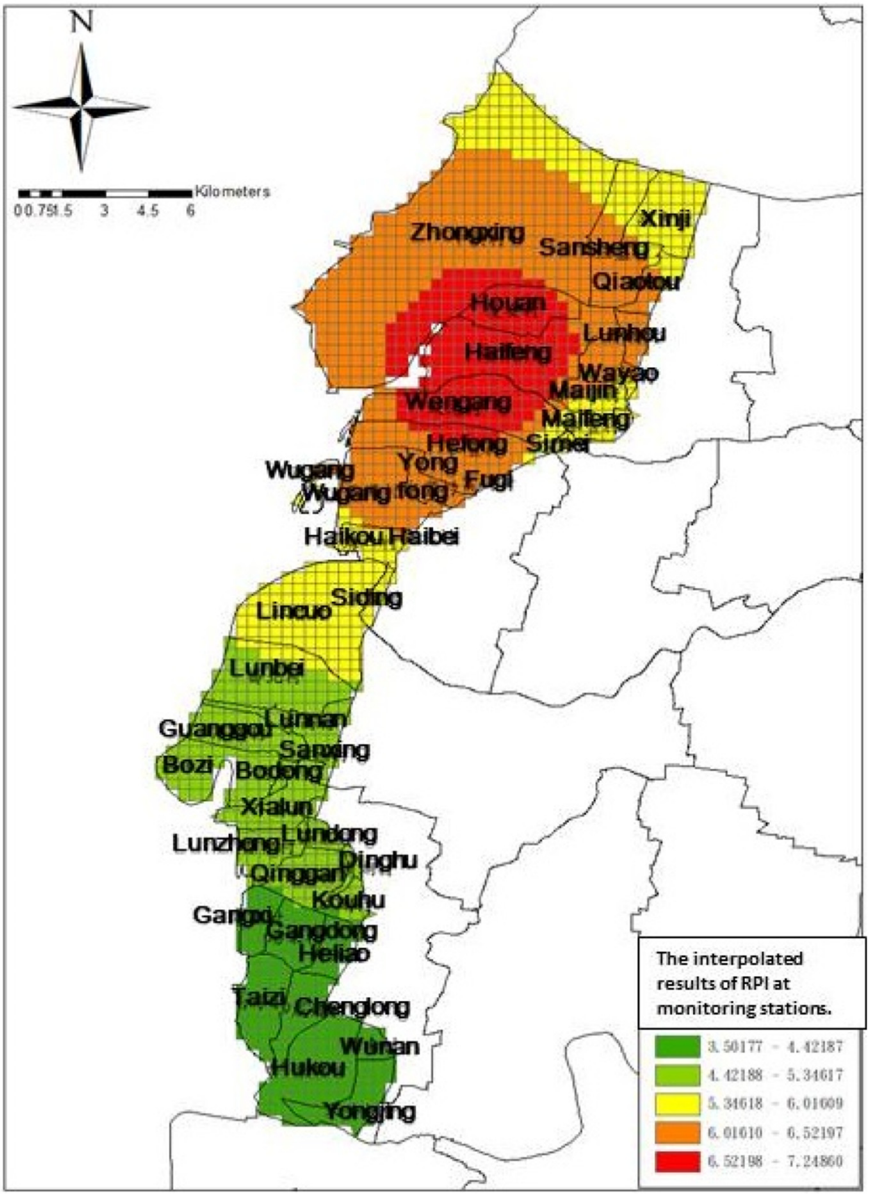

Fig. 9. Distribution of RPI in the research demonstration area (Data source: compiled for this study).

density and elderly population in the social dimension are 0.62 and 0.38, respectively. Since the units and interpretations of these factors' data were not directly comparable after calculation, they could not be integrated directly. Therefore, organizing the data through normalization is necessary. After normalization, the data were multiplied by their respective weights to obtain the vulnerability score. The calculation results were then classified using the Jenks Natural Breaks method, ranging from low to high as levels one to five with classification intervals, as shown in Table 10.

According to Table 10, a social vulnerability map of the study demonstration area can be drawn using GIS, as shown in Fig. 14. From the map, it is evident that the lower levels, levels one and two, are primarily distributed south of Lunzhong Village and north of Zhongxing Village in the study area. Levels three to five are mostly located between Xialun Village and Hou'an Village, with Maizhen Village and Maifeng Village being the highest at level five. The main reason for this distribution is the population density. Although the elderly population scores are higher in the areas south of Wengang

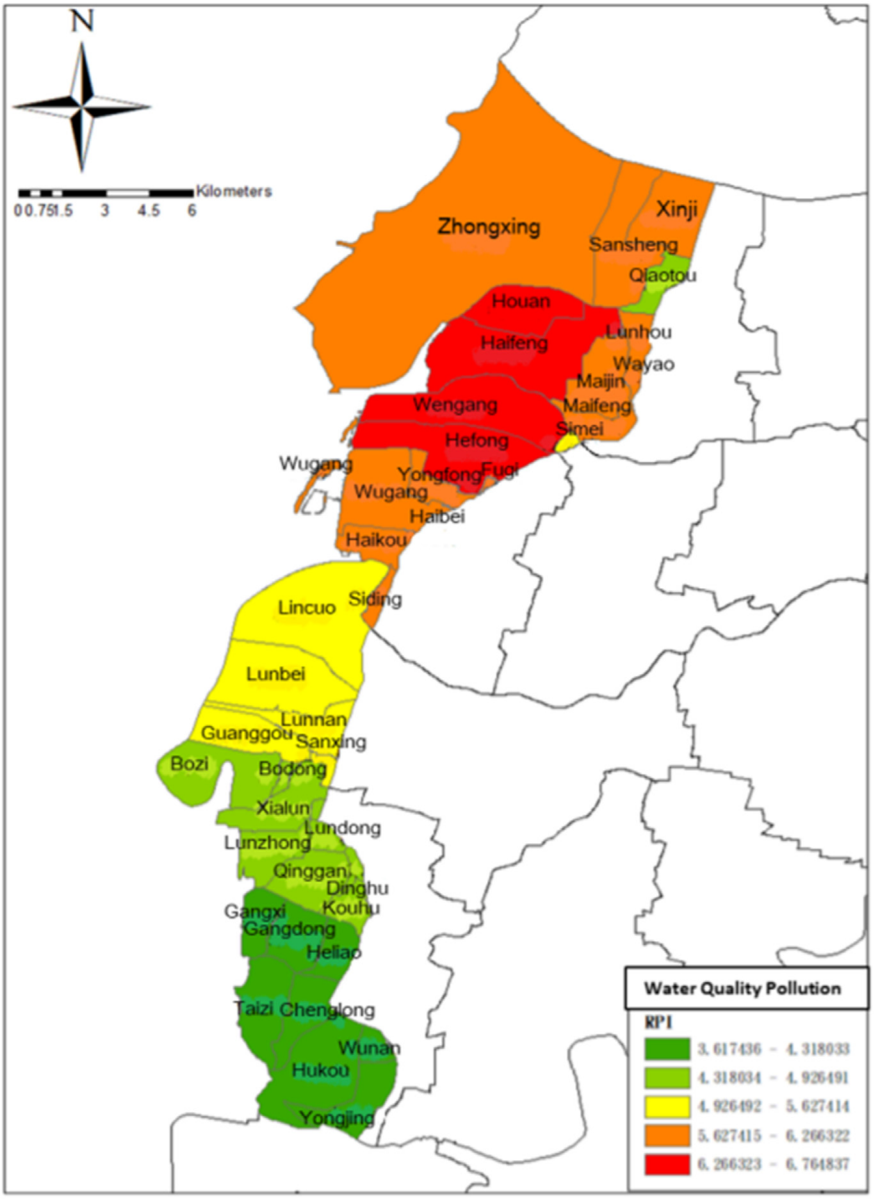

Fig. 10. Distribution map of water quality pollution in the research demonstration area (Data source: compiled for this study).

Village, their lower weight means that the overall social vulnerability level distribution is more closely aligned with the population density distribution.

4.3. Economic vulnerability

For the economic aspect, a threshold value of 5.733 was set based on the first-stage expert questionnaire results. According to these results, the vulnerability factors that exceeded the threshold set by the fuzzy Delphi method were 'Land Development and Utilization' and 'Infrastructure.'

4.3.1. Factor analysis

4.3.1.1. Land development and utilization. A factor analysis was conducted using status map data from the 2020 National Land Use Survey conducted by

Table 9. Environmental vulnerability score classification.

Environmental	Classification method	Level 1	Level 2	Level 3	Level 4	Level 5
Vulnerability Score	Natural Breaks (Jenks)	0.035 | 0.063	0.063 | 0.409	0.409 | 0.524	0.524 | 0.617	0.617 | 0.735

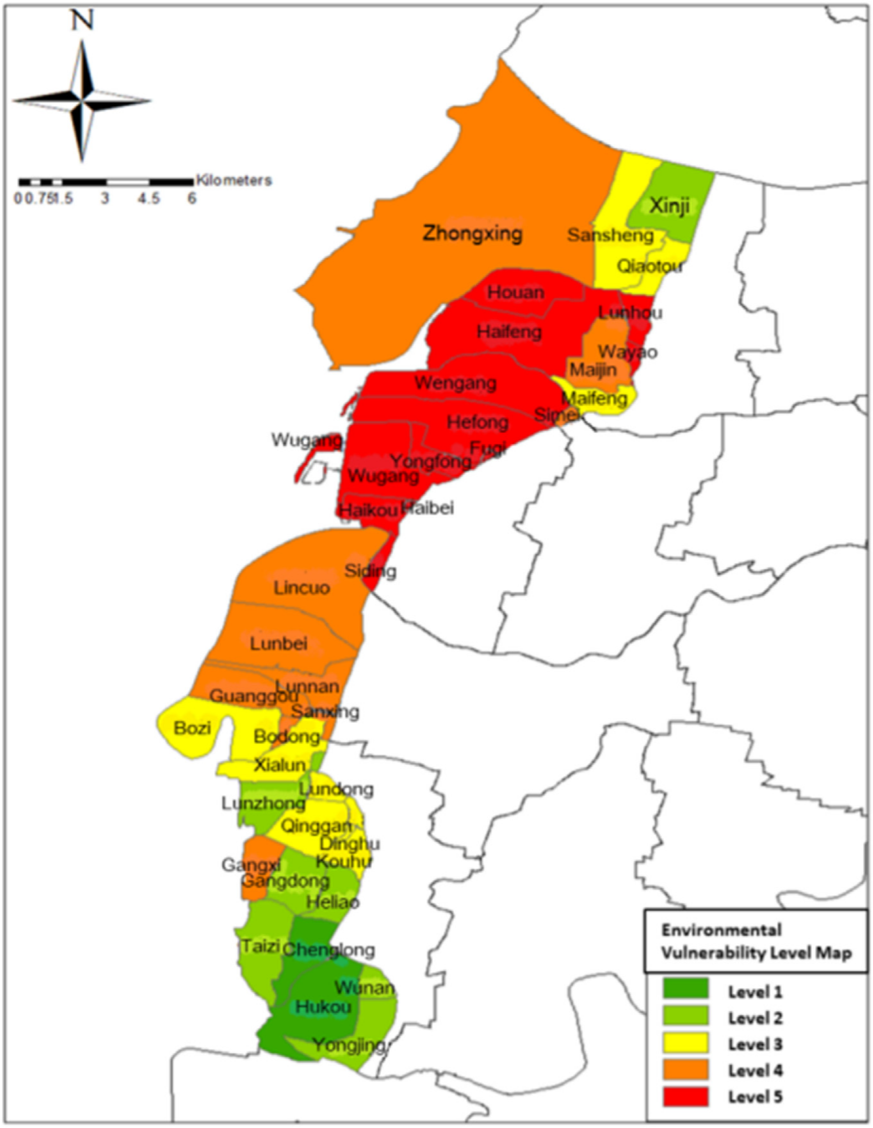

Fig. 11. Environmental vulnerability level map of the research demonstration area (Data source: compiled for this study).

the National Land Surveying and Mapping Center. The proportions of land used for construction and public use in each village were calculated and presented with GIS, as shown in Fig. 15.

4.3.1.2. Infrastructure. This proportion represents the region's infrastructure factor. Fig. 16 shows the calculation results using GIS.

4.3.2. Weight analysis

According to the vulnerability factor weight analysis results in Section 3.3, the weights for land development and utilization and infrastructure in the social aspect are 0.62 and 0.38, respectively. To organize the data, normalization is necessary since data units and interpretations differ for each factor and cannot be directly integrated. After normalization, the data are multiplied by their respective weights to obtain the vulnerability score. Regarding infrastructure, this factor has a positive impact on the overall system's sustainability. Therefore, the normalization process should be calculated using Equation (9) to accurately express the meaning of vulnerability in this study. The grading intervals are shown in Table 11.

Using the vulnerability scores and classification standards from Table 11 in conjunction with GIS, an economic vulnerability map of the study area was

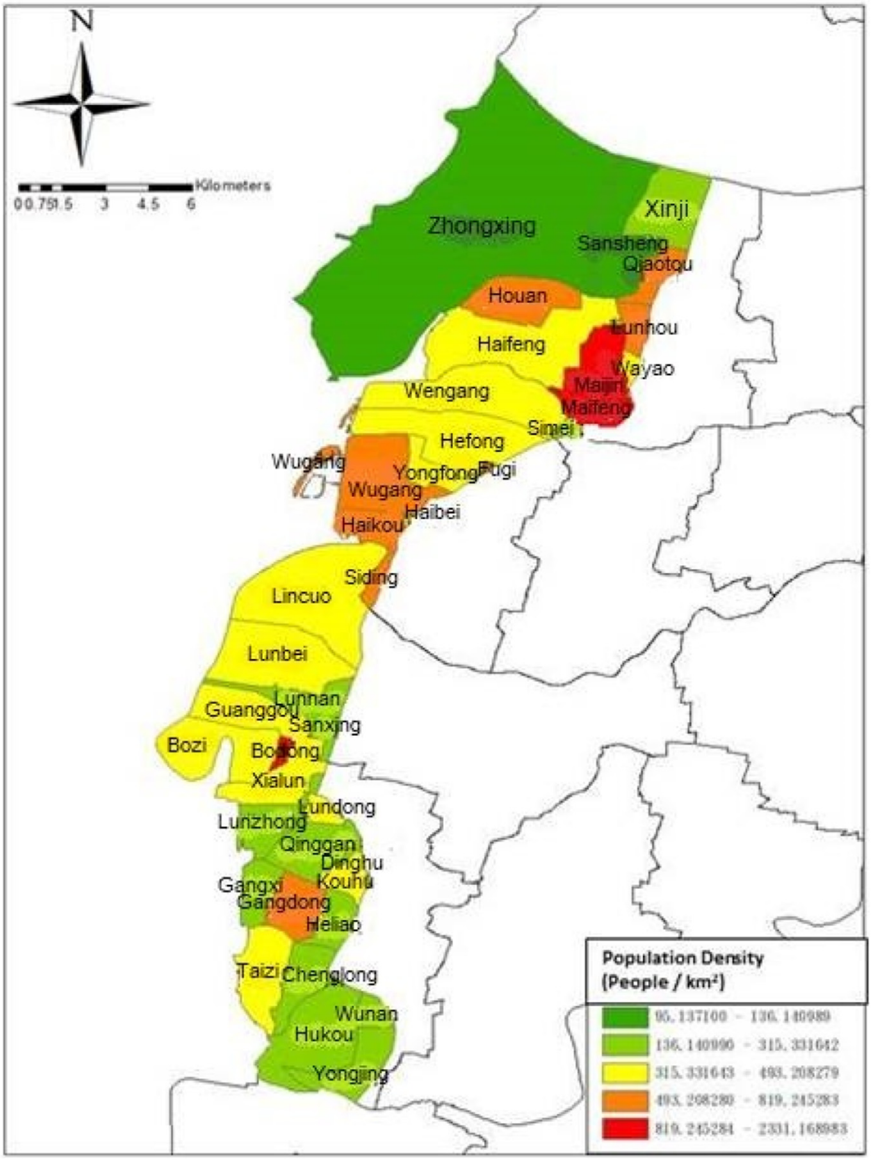

Fig. 12. Population density map of the research demonstration area. (Data source: compiled for this study).

drawn, as shown in Fig. 17. From the map, it is observed that the areas with higher vulnerability levels are predominantly distributed in the study demonstration area from Feng Village to Hou'an Village and from Lunbei Village to Kouhu Village. Specifically, Qiaotou Village, Maizhen Village, Maifeng Village, and Fudong Village are classified as level five. Their distribution is mainly related to land development and utilization. In the aspect of land development and utilization, this can be linked with the previously mentioned population density factor, where higher population density leads to a higher proportion of land used for construction and public purposes in these villages.

4.4. Integrated vulnerability of coastal areas

After completing the analysis of seven vulnerability factors in the environmental, social, and economic aspects, an integrated assessment of coastal environmental vulnerability was conducted based on the integrated weights analyzed in Section 3.3. The process mainly involved using the environmental, social, and economic vulnerability levels analyzed in the pre-vious subsection, multiplying them by the respective aspect weights, and then adding them for integration. The summated levels were rounded to the nearest integer for classification purposes, serving as the integrated

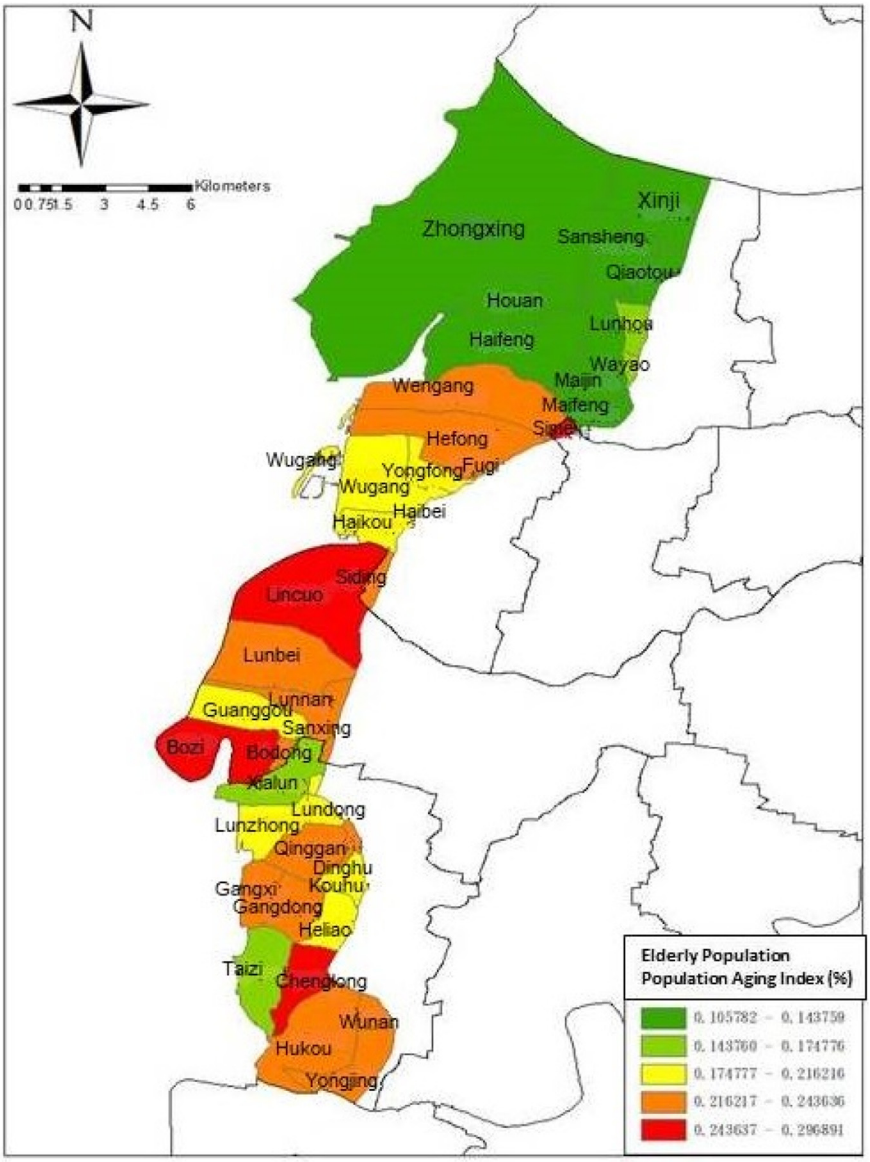

Fig. 13. Distribution map of the elderly population in the research demonstration area (Data source: compiled for this study).

vulnerability levels of the coastal environment. The calculation results were presented using GIS to display the Integrated Environmental Vulnerability Level Map of the coastal area, as shown in Fig. 18.

The key points of the text are summarized as follows:

(1) Comprehensive Vulnerability Assessment Method: An analysis of seven vulnerability factors across environmental, social, and economic dimensions was completed for the coastal area in this study. By integrating the vulnerability levels of these factors with their respective weights, a

Table 10. Social vulnerability score classification.

Social	Classification method	Level 1	Level 2	Level 3	Level 4	Level 5
Vulnerability Score	Natural Breaks (Jenks)	0.029 | 0.156	0.156 | 0.274	0.274 | 0.343	0.343 | 0.436	0.436 | 0.620

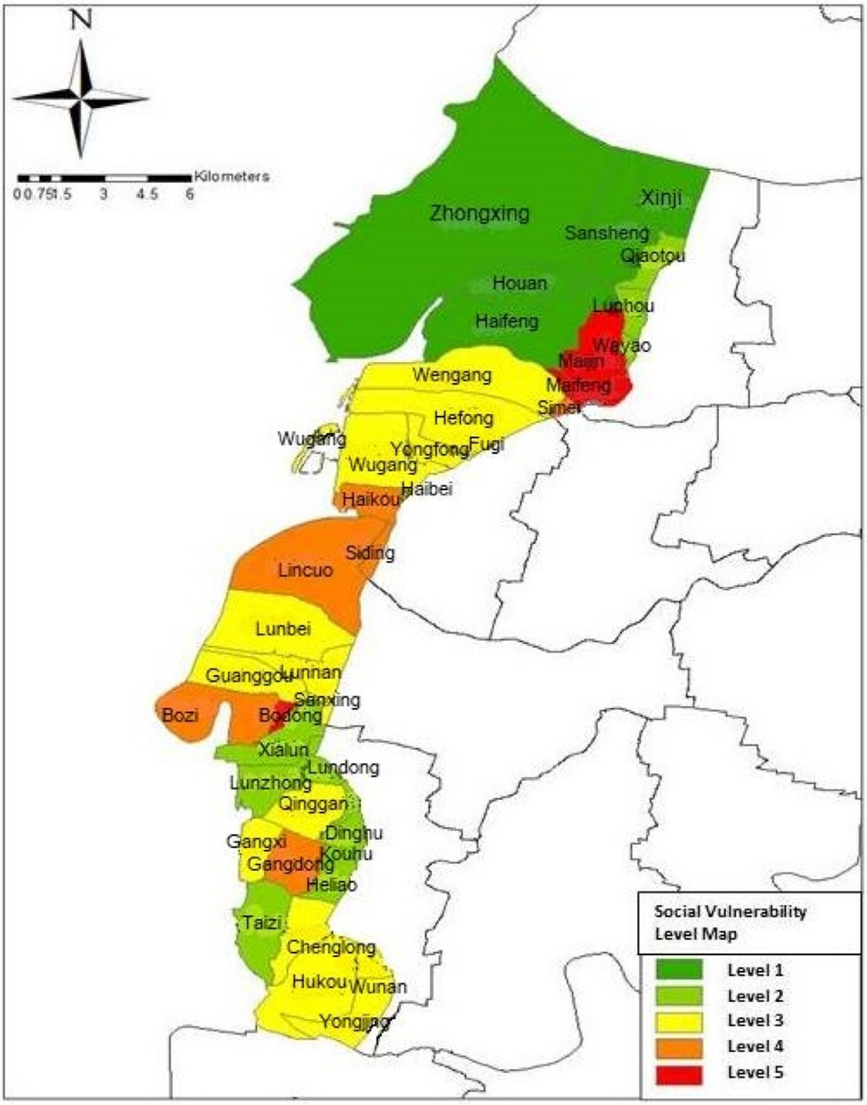

Fig. 14. Social vulnerability level map of the research demonstration area (Data source: compiled for this study).

comprehensive assessment of the coastal area's overall vulnerability was conducted;

(2) Vulnerability Levels and Distribution: Within the study's demonstration area, the distribution of vulnerability levels among the villages ranged from level two to level four, with no occurrence of levels one or five. This variation results from the different weights assigned to each dimension, leading to changes in the integrated vulnerability level;

(3) Application of GIS Maps: Geographic Information System (GIS) technology was employed to present an Integrated Environmental Vulnerability Level Map of the coastal area;

(4) Comparison with Previous Studies: This study differs from past research, including studies by Zhuang Boyun, Cai Mingyan, Xu Haoran, etc., in its vulnerability assessment approach because it encompasses a broader range of aspects, including environmental, social, and economic factors. Furthermore, this study used the Fuzzy Delphi Method and Analytic Hierarchy Process for a more comprehensive and substantiated selection and weighing of factors;

(5) Importance of Vulnerability Factors: This study emphasizes the need for an integrated consideration of environmental, social, and economic dimensions in assessing coastal areas' integrated

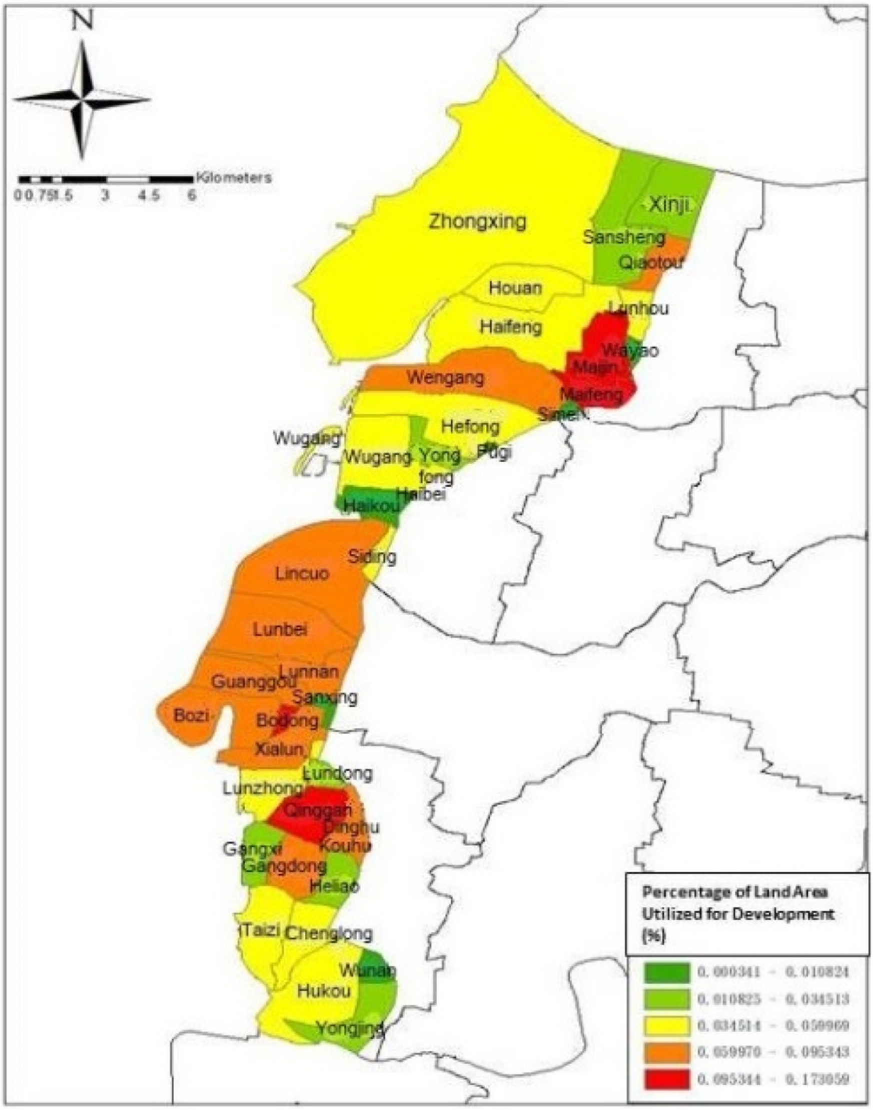

Fig. 15. Land development and utilization distribution map of the study demonstration area (Data source: created by this study).

environmental vulnerability. It advocates for adjustments and management based on different dimension weights to achieve overall sustainable development.

4.5. Adaptation strategies for integrated environmental vulnerability in coastal areas and discussion

This study investigates the intricacies of coastal management, primarily focusing on the principles of protection and sustainable utilization within comprehensive management plans. These plans are vital frameworks that designate specific areas and establish management guidelines tailored to each region's needs. Notably, the study highlights the significance of addressing coastal erosion, advocating for restrictions on development within prohibited zones, and implementing protective measures such as natural solutions and infrastructure.

Furthermore, this research emphasizes the importance of sustainable utilization principles, which encompass both general management guidelines and specific measures for environmental protection. By promoting ecosystem conservation and sustainable resource use, these principles aim

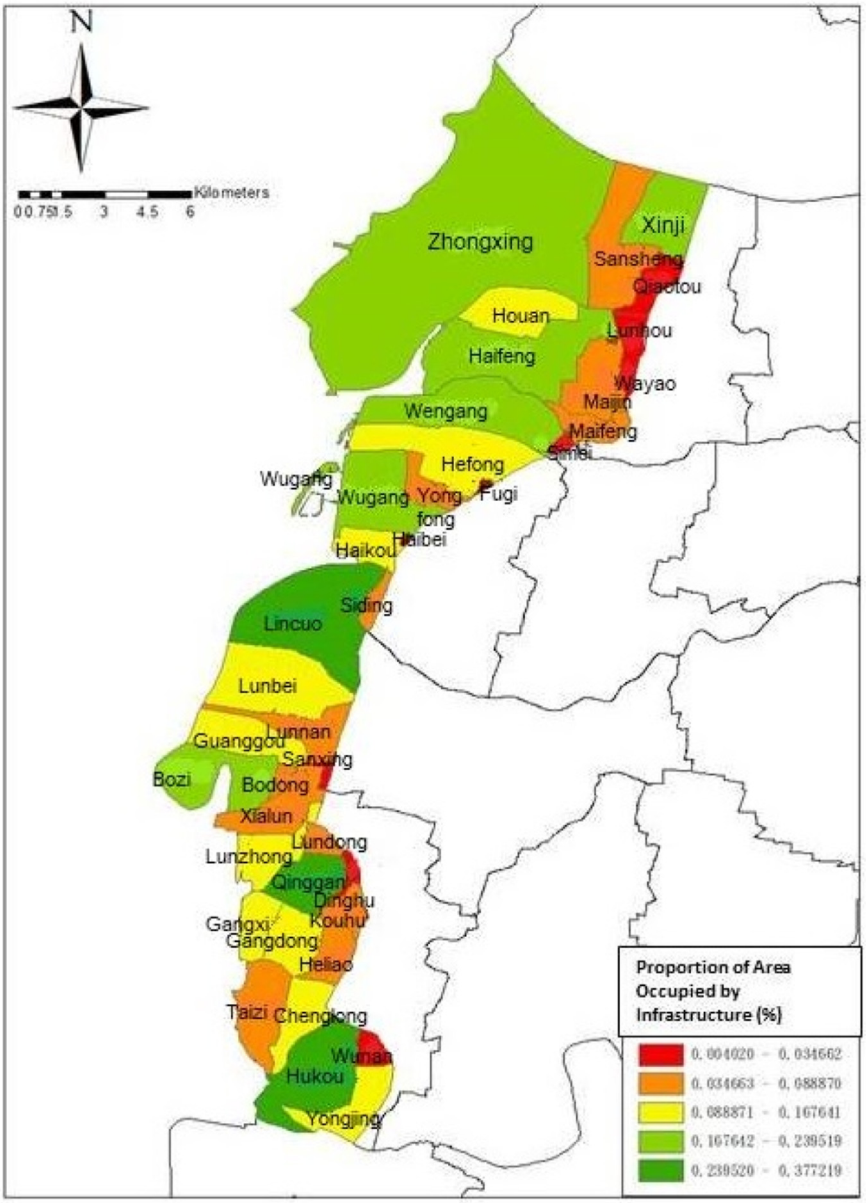

Fig. 16. Infrastructure distribution map of the study demonstration area (Data source: created by this study).

to strike a balance between development and conservation efforts along the coast.

Nature-based Solutions (NbSs) are an essential aspect explored in this study. These solutions, rooted in natural processes, offer promising avenues for addressing coastal challenges effectively. With principles centered on biodiversity enhancement, economic viability, and evidence-based management, NbSs are increasingly recognized as integral components of coastal management strategies.

This research methodology employed a comprehensive approach, synthesizing existing

Table 11. Economic vulnerability score classification.

Economic	Classification method	Level 1	Level 2	Level 3	Level 4	Level 5
Vulnerability Score	Natural Breaks (Jenks)	0.241 | 0.300	0.300 | 0.366	0.366 | 0.445	0.445 | 0.563	0.563 | 0.963

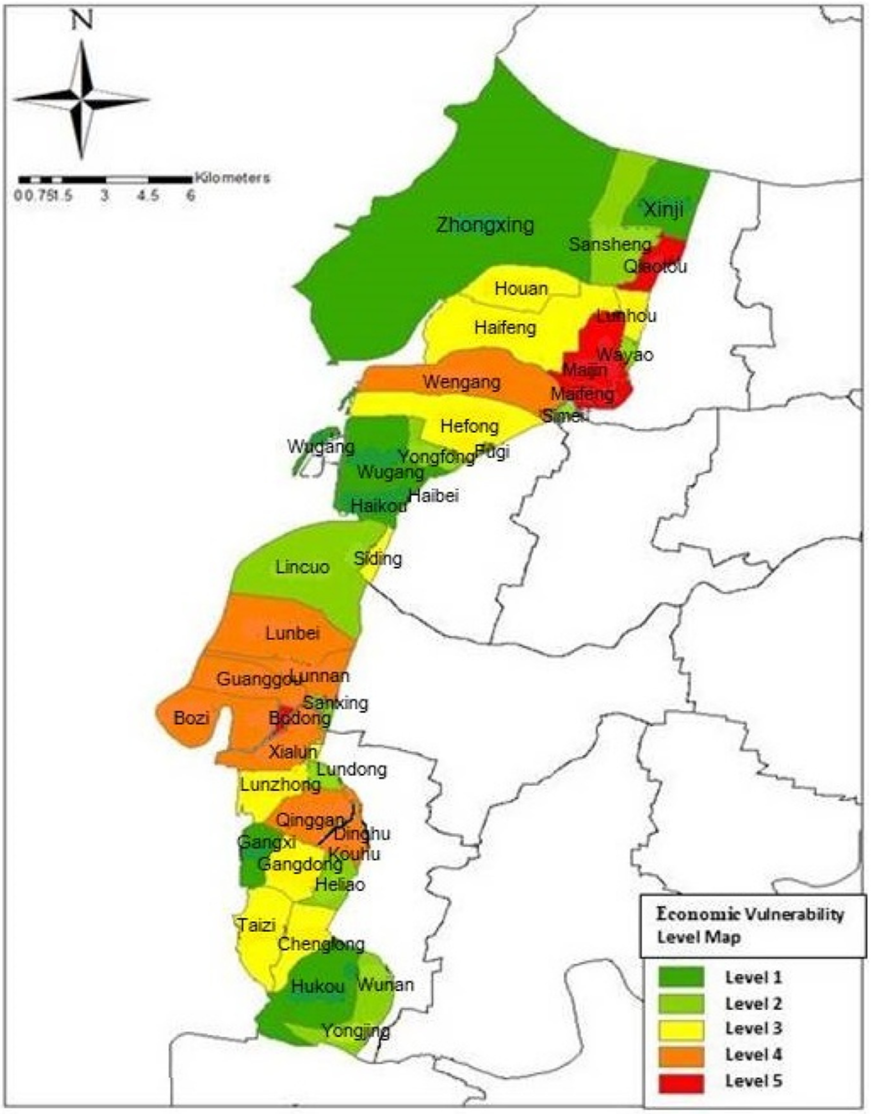

Fig. 17. Economic vulnerability level map of the study demonstration area (Data source: created by this study).

literature to develop adaptation strategies from both macro and micro perspectives. Environmental, social, and economic factors were all considered, reflecting the multidimensional nature of coastal management.

Proposed adaptation strategies vary based on different villages' vulnerability levels. For highly vulnerable areas, such as those rated at level four, targeted measures are recommended to address specific challenges such as water quality pollution, biodiversity conservation, and infrastructure improvement. By tailoring strategies to local contexts, the aim is to reduce vulnerability and enhance resilience in coastal communities.

In conclusion, this study offers valuable insights into the formulation and implementation of coastal management policies in Taiwan. By integrating comprehensive management principles, leveraging nature-based solutions, and adopting targeted adaptation strategies, coastal areas can mitigate risks, protect valuable resources, and foster sustainable development along the coast.

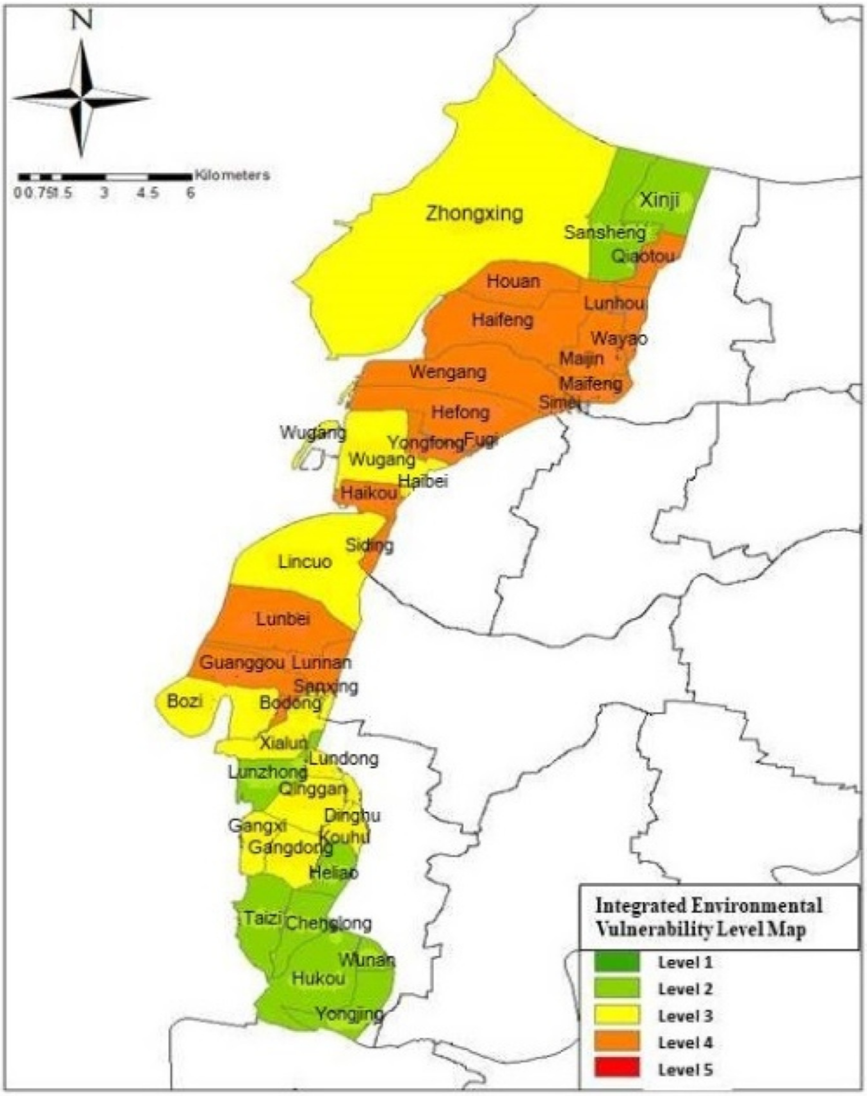

Fig. 18. Integrated environmental vulnerability level map of the coastal area (Data source: created by this study).

5. Conclusion

5.1. Summary

This research focused on managing and promoting sustainable development in coastal areas by conducting an inventory of coastal vulnerability factors and selecting key factors through the Fuzzy Delphi Method. This study established an integrated set of environmental vulnerability factors that consider environmental, social, and economic dimensions.

Utilizing the Analytic Hierarchy Process (AHP), this research analyzed the relationship between factors and their integrated weights, leading to the creation of a coastal area integrated environmental vulnerability assessment model. This model evaluated coastal areas designated for environmental degradation and delayed development of the overall coastal management plan.

Key findings include the redefinition of integrated environmental vulnerability in coastal areas as an indicator measuring the decrease in overall system sustainability or increased damage during events. Seven vulnerability factors were identified: biodiversity, coastal erosion, water pollution, population density, elderly population, land development and utilization, and infrastructure. The assessment model calculated and integrated these factors, categorizing them into five levels using weighted analysis.

This study offers analysis and adaptation strategies tailored to different vulnerability levels in various villages. For example, villages with high environmental vulnerability due to factors such as low biodiversity or high coastal erosion rates require specific adaptation measures.

Emphasizing an integrated approach, this research provides comprehensive management strategies to reduce vulnerability levels and enhance sustainable coastal development. The established factors, assessment model, and adaptation strategies can serve as a reference for future research in coastal sustainable development and vulnerability assessment, as well as for relevant coastal management authorities.

Overall, this research significantly contributes to coastal management by offering a nuanced and integrated approach to addressing and mitigating environmental vulnerabilities in coastal regions.

5.2. Recommendations

Risk-Oriented Research Expansion: Future research can enhance the contributions of this study, which primarily assessed the integrated environmental vulnerability of coastal areas, to sustainable development along Taiwan's coast by integrating natural or anthropogenic hazards into the analysis, thereby focusing on the risk aspect.

Consideration of Temporal Dynamics: The current study does not consider the temporal variability of vulnerability factors, which limits its ability to project future scenarios. Future studies should incorporate factors with temporal characteristics and integrate them with climate change scenarios for forecasting. Clarity in factor selection to avoid overlaps is essential, and using the most recent data across the same time scale for all vulnerability factors is recommended.

Methodological Improvement in Expert Surveys: This study relied on expert questionnaires for analysis. Future research using similar methods should carefully review the selection of respondents or consider conducting interviews. These measures will ensure that participants have sufficient understanding of the research area, thereby enhancing the accuracy and representativeness of the results.

Geographical Scope and Site-Specific Analysis: The current study focuses on village-level assessment within Yunlin County, potentially limiting diverse outcomes. Expanding the demonstration area to cover Taiwan's entire western coast may reveal more pronounced differences. Additionally, while the factors and assessment models in this study have a national perspective, a deeper look at specific target regions and conducting field visits to better understand actual conditions or regional characteristics would enrich the contribution of the research findings.

Ethics statement

This study has no violations of academic ethics.

Conflict of interest

There is no conflict of interest.

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