

Article

A Comprehensive Method for Evaluating Marine Disaster Risk Reduction Capacity in China

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Abstract: A region's capacity for marine disaster risk reduction is characterized by the resources that can be mobilized. These resources include pre-disaster defense, disaster monitoring, warning, emergency response, post-disaster restoration, and reconstruction. It is a very important index to effectively evaluate the regional capacity to overcome marine disasters. At present, there is no unified model and method for comprehensively evaluating the regional marine disaster reduction capacity. This study proposes a novel evaluation index system for a county-level administrative region using expert opinions, questionnaires, and analytic hierarchy process methods. Based on the comprehensive evaluation in three pilot areas, the current situation of regional marine disaster reduction capacity is analyzed, which would contribute to the effective management of marine disaster risks in the future. The results and experiences are of great value to future disaster reduction capacity assessment promotion and practice in all coastal counties of China.

Keywords: marine disaster reduction risk capacity; evaluation index system; disaster risk management

1. Introduction

Different kinds of marine disasters are reported in China [1]. The frequency of disasters caused by super-typhoons, storm surges, and red tides increased significantly since 2000 [2]. With the rapid development of marine economy, maritime disasters often result in casualties and considerable economic losses. It is worth pointing out that the annual total economic loss of various marine disasters is still as much as 10 billion renminbi (RMB), for which the total economic loss reached its peak in 2005, about 33.2 billion RMB [3]. To reduce the risk of marine disasters, the marine disaster risk reduction (DRR) capacity needs to be improved. From Ten Years of International Disaster Reduction [4] to the Hyogo Framework for Action [5], and then to the Sendai Framework for Reducing Disaster Risk [6], the cognition of reducing disaster risk and DRR capacity is increasing continuously. It can be commenced from the initial proposition of developing and strengthening the disaster prevention and reduction capacity, followed by promoting the establishment of a disaster reduction system in the community, improving the disaster resistance and preparedness capacity, and eventually enhancing the disaster reconversion and reduction capacity.

At present, there is certain research on evaluating the regional DRR capacity, and several evaluation methods and processes were developed and applied. For example, the United Nations Development Program (UNDP) [7] evaluates the national DRR capacity in five technical areas (i.e., ownership,

institutional arrangements, roles, tools and resources, and relationships) through a semi-structured interview, a field visit, and analysis of many laws and regulations, policies, action plans, and project files. Based on the evaluation results, corresponding proposals are given according to five key actions mentioned in the Hyogo Framework for Action, which can serve as a basis for National Action Plan for Disaster Prevention and Reduction [8]. The World Meteorological Organization (WMO) evaluates the reduction capacity of meteorological and hydrological disasters for different countries worldwide on a national scale based on national survey data, as well as a gap analysis [9]. The United States, Japan, Australia, and other countries implement the evaluation of DRR capacity to fully understand the current situation of national DRR and promote disaster prevention and reduction studies [10–13].

The United States is the first and most successful country in the world in putting the DRR capacity assessment outcomes to practice. In 1997, the United States issued the State and Local Government Capability Assessment for Readiness (CAR) [11]. It constitutes a three-level evaluation index system consisting of 13 emergency management functions, 104 attributes, and 453 evaluation indicators. The assessment system includes disaster management, communication and early warning, training, public education information, financial management, etc. In 2000, all 56 states, territories, and insular areas in the United States applied the CAR in order to complete emergency response assessments [14]. The CAR is designed to focus on identifying the strengths and deficiencies in emergency management. In addition, each state has its own capacity assessment criteria based on this, and assessments are conducted at regular intervals [15]. Australia conducted an assessment of national natural disaster management in 2001 [16], which covered disaster-related policy development, disaster preparedness measures, emergency response measures, disaster reduction measures, and post-disaster assessment. Through evaluation and analysis, the advantages and disadvantages of the current natural disaster management measures were obtained, and 12 reform proposals were given. In 2002, Japan formulated the Evaluation System for Disaster Resilience of Local Public Organizations, which is evaluated by the local governments [17]. The assessment projects include risk mitigation strategies, emergency response and post-disaster reconstruction plans, education and training, etc. The China Seismological Bureau carried out a number of studies on urban earthquake risk assessment and established an evaluation index system relying on the 973 project (National Program on Key Basic Research Project) in 2000. Later, some Chinese research institutions performed several studies to evaluate earthquakes, floods, landslides, etc. [18–21]. On the eve of the International Day for Natural Disaster Reduction in 2006, China's State Council held a Symposium on Strengthening the Capacity Building of Integrated Disaster Risk Reduction [22], and declared the need to fully strengthen China's integrated DRR capacity. In November 2011, China's State Council issued A National Plan for Comprehensive Disaster Prevention and Reduction (2011–2015) [23], and proposed the idea of fully strengthening buildings for comprehensive disaster prevention and reduction capacity. In the 12th Five-Year Plan period, the National Disaster Reduction Center of the Ministry of Civil Affairs of China carried out a comprehensive DRR capacity evaluation framework supported by National Science and Technology Major Projects, and an initial priority work was conducted in Jiangxi province and other places [24]. Preliminary decision-making advice was provided to better understand the present situation of regional comprehensive DRR capacity, and to strengthen the regional comprehensive DRR capacity of building.

Based on the existing achievements, the main contents of marine DRR capacity focus on single disaster types, and disaster emergency response capacity evaluation. The standard of assessment indicators is not consistent. Therefore, it is not deep enough to understand the marine DRR capacity assessment mechanism. For sufficient and effective guidance for supporting regional marine DRR efforts, an assessment system for the marine DRR capacity and quantitative data are needed. In this sense, there is an urgent need for a system to evaluate the marine DRR capacity in order to provide an early warning for achieving disaster prevention and aid management decisions. Under the background of importance of marine disaster management, it is of great significance to systematically carry out theoretical research and operational application under the system organization of disaster management departments.

The objectives of this study are (1) to build an index system of regional marine DRR capacity for administration areas at the county level, and (2) to develop a quantitative method for assessing the marine DRR capacity and apply it to the pilot assessment. The results of this study should have important theoretical and practical implications for guiding government agencies to improve their DRR capacity building. They may also provide a good foundation for future assessments of marine disaster mitigation capacity across the whole country.

2. Materials and Methods

2.1. Study Area and Data Source

In a comprehensive evaluation for the regional marine DRR capacity (2015–2016) project [25], 11 coastal counties located in Weifang city of Shandong province, Taizhou city of Zhejiang province, and Huizhou city of Guangdong province were chosen to implement a pilot evaluation (Figure 1). In this study, an index system was established using multilateral methods. Experts with various professional backgrounds, coming from different central and local industrial sectors (related to marine DRR capacity), were invited by the Marine Disaster Reduction Center of State Oceanic Administration to participate in designing a reliable index system. The experts' professional backgrounds involved maritime, engineering, emergency, publicity and education, comprehensive disaster reduction, etc.

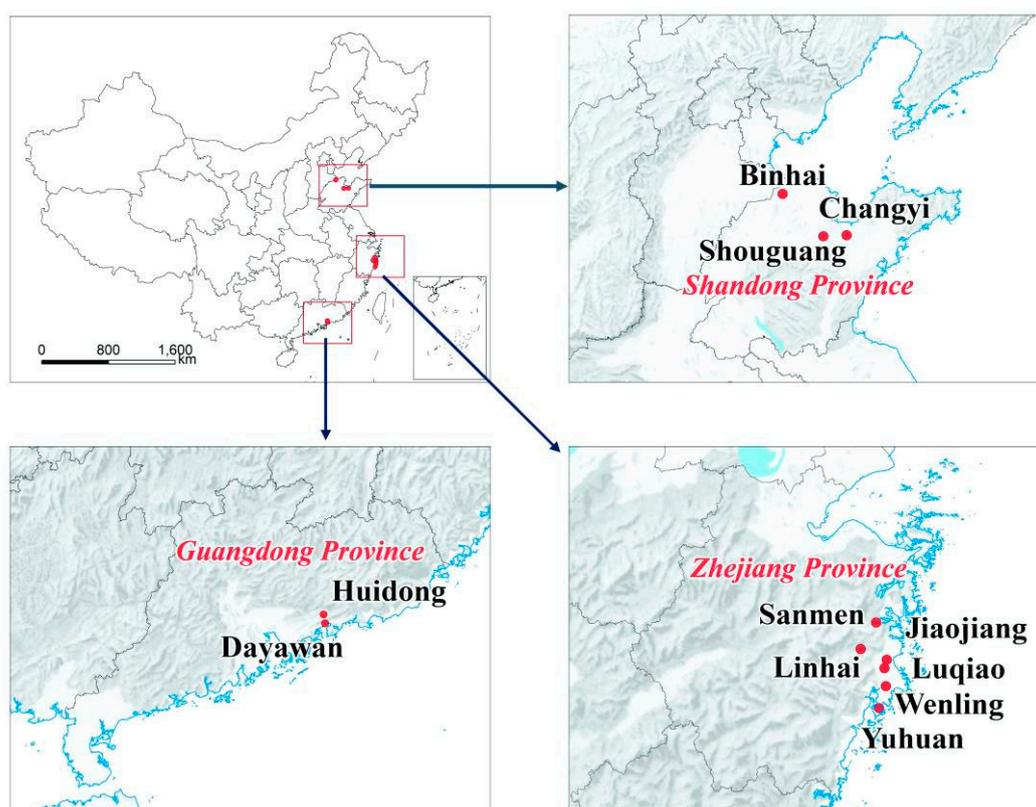


Figure 1. The location of study areas.

The working group and expert group were set up to develop the evaluation index system. The working group included 48 experts from 16 units: the Marine Disaster Reduction Center of State Oceanic Administration, Donghai Forecasting Center of State Oceanic Administration, South China Sea Planning and Environmental Research Institute of State Oceanic Administration, National Marine Information Center, the National Disaster Reduction Center of the Ministry of Civil Affairs, Marine Biology Institute of Shandong Province, Marine Monitoring Station of Shouguang City, Marine Development Planning Research Center of Guangdong Province, Guangdong Provincial Oceanic and

Fishery Administration, Zhejiang University, Zhejiang Provincial Marine Planning and Design Research Institute, Zhejiang Provincial Marine Monitoring and Forecasting Center, Zhejiang Provincial Oceanic and Fishery Administration, Zhejiang Provincial Key Laboratory of Hydraulic Disaster Prevention and Reduction, Zhejiang Institute of Hydraulics and Estuary, and Beijing Normal University. After extensive discussions, a three-grade index system (including six first-grade indices, 21 second-grade indices, and 136 third-grade indices) was finally adopted.

The raw data for calculating the weight values in the index system were derived from the experts' experience. Firstly, an expert questionnaire for county-level marine DRR capacity was designed, and each questionnaire included 30 marking tables (one for the first-grade indices, six for the second-grade indices, and 23 for the third-grade indices). Then, the questionnaires were distributed among 86 experts in 18 units, and eventually 69 valid questionnaires were collected with 2070 valid marking tables. To fully benefit from the experts' experience in all fields, the questionnaires were distributed among experts in hydrology, meteorology, emergency, and comprehensive DRR fields, in addition to the experts from 16 units in the working group. The affiliations of additional experts included China Institute of Water Resources and Hydropower Research, National Climate Center, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences, etc.

2.2. Development of an Evaluation Index System

Disaster risk assessment is an integral part of disaster management. When designing the DRR capacity assessment indicator system, the location of DRR capacity assessment in disaster management and the relationship with other disaster management measures need to be clarified before, during, and after the disasters, before fully considering their purpose, content, and application areas.

2.2.1. Management Phase and Capacity Assessment

Disaster mitigation capacity assessment and capacity building research should be based on a more complete disaster risk analysis. By analyzing the types, intensity/frequency, and spatial differentiation of natural disaster risks, combined with the capacity assessment results, the capacity building gap analysis can be conducted. After that, the needs analysis is set, the regional DRR targets are set at a certain stage, and finally specific capacity building projects can be implemented.

The management contents include disaster preparedness, forecasting, and early warning. Management in disaster mainly includes the emergency response, while that during the post-disaster stage mainly includes restoration and reconstruction. Disaster publicity and education run through all stages of disaster management. From the disaster prevention and mitigation perspective, disaster reduction measures are often divided into engineering measures and non-engineering measures. The former measures emphasize the construction of hardware facilities, while the latter measures include various soft measures outside the construction of hardware facilities. Therefore, when designing indicators, the current study fully considered the disaster management cycle and the means of disaster prevention and mitigation.

2.2.2. Capacity Needs and Priority Domains

The demand for disaster risk reduction capacity is often related to the magnitude of disaster risk. A greater risk suggests a greater need for DRR capacity building. However, human beings' pursuit of risk mitigation could be endless. Safety standards gradually rise with socioeconomic development. Hence, regional DRR capacity building targets should be rationally set in accordance with the regional risk levels and the region's safe standards. To reduce the risk of disasters and improve the level of safety, DRR capacity building requires the support of DRR resources and means.

2.2.3. Assessment Object and Construction Subject

The main bodies involved in the assessment of disaster mitigation capacity are diverse. From the administrative perspective, there are national, provincial, city, county, and township (town) levels.

From the social perspective, in addition to government departments, communities (villages), families, units, enterprises, and individuals are the main bodies of DRR. The capacity building of marine DRR should form an efficient multi-agent capacity building system. Moreover, the differences in capacity building objectives of different entities and departments should be considered. To effectively allocate resources, the relationship with DRR capacities of relevant departments (such as meteorology, water conservancy, earthquake, civil affairs, and agriculture) should be coordinated and handled.

2.2.4. Regional Commonality and Specificity of Indicators

To build a regional DRR capacity indicator system, we should consider the commonality and the regional individuality of indicators. For example, sea ice disasters generally occur in northern China. From a historical perspective, there is a need for sea ice disaster reduction. Sea ice-prone areas naturally form strong sea ice disaster mitigation capabilities, while southern coastal areas do not need the capacity to cope with sea ice disasters. Another example is the frequent tropical storm surges in southern China, which enabled the southern region to gain rich experience in dealing with tropical cyclones, while northern China has a relatively weak coping capacity.

The indicator system constructed here considered the different marine disaster risks when applying it in different pilot areas. The differences in regional indicators were considered. Through pilot research, the indicator system can be applied to the national assessment of marine disaster mitigation capacity; thus, the indicator system should be universal in China's coastal areas.

Each item in the established evaluation indices should be well documented and easily quantified, and each one can truly reflect the main characteristics and actual situation of regional marine DRR capacity in China. Meanwhile, the evaluation indices should be connected with the current statistical indices of Civil Affairs and Marine Management Departments in China, and they should be consistent to facilitate their work, measurement, and calculation. Maneuverability is also expressed so that decision-makers can further improve the regional marine DRR capacity using simple and reliable results. Since the study is still in its infancy, and statistical data for regional marine DRR capacities are scattered and incomplete, the available data were used to the utmost extent to extract the relevant information.

Based on scientific aspects, accessibility, typicality, and practicability principles for a comprehensive evaluation index of DRR capacity were established, as well as combining the literature's results with experts' and scholars' conclusions [26–28], thereby achieving a classified, hierarchical, and comprehensive evaluation index system for marine DRR capacity. It was developed through the selection and screening of various methods after the relevant units solicited opinions and suggestions from various experts and managers (who act on maritime disaster management at the primary level) (Table 1).

Disaster warning and forecasting capacity includes (1) monitoring capacity (i.e., the capacity of monitoring the occurrence, development process, and dynamic changes of various related factors in marine disasters), (2) warning and forecasting capacity (i.e., the capacity of forecasting and warning the time, location, intensity, and range of impacts of possible marine disasters), and (3) information publishing capacity (i.e., the capacity of government departments, sea-related enterprises and personnel, and the public receiving pre-alarm information through television, radio, internet, telephone, fax, newspapers, etc.).

Disaster preparedness capacity includes (1) disaster avoidance capacity (i.e., the capacity of an area to avoid the loss of people and assets from storms, waves, tsunamis, and other marine disasters, generally including disaster prevention awareness and disaster avoidance facilities), (2) material supporting capacity for disaster reduction and relief (i.e., covering the size of the disaster relief material reserve, the number of disaster relief materials, and the amount of relief material procurement funds), and (3) supporting capacity of social economic base (i.e., an important criterion for measuring the pre-disaster response capacity and post-disaster recovery capacity of a region).

2.3. Establishing the Evaluation Model

Herein, we made an attempt to consider that the regional marine DRR capacity is the comprehensive ability of the region in the whole process of disaster management including disaster prevention and reduction, emergency management, rescue and recovery, and post-disaster restoration and reconstruction. Therefore, when a comprehensive evaluation method was developed for regional marine DRR capacity, the importance of various capacities and the marine DRR performance of various regions were combined to eventually conduct a comprehensive evaluation.

When conducting a comprehensive evaluation, the corresponding score C_i' was determined according to certain criteria. Then, the results of comprehensive evaluation of regional marine DRR capacity for each region E was calculated by multiplying the assignment value of each index and the corresponding weights (W_i), and summing them up. A comprehensive evaluation model for regional marine DRR capacity is given by

$$E = \sum_{i=1}^{n_j} (C_i \times W_i) \quad (1)$$

where E denotes the comprehensive evaluation value for regional marine DRR capacity, C_i is a coefficient for quantitative scoring of each evaluation index, and W_i represents the weight of each evaluation index, where $i = 1, 2, \dots, n_j$. Here, j represents the third grade which is the lowest grade in the evaluation index system, and n_j denotes the number of third-grade indices.

The main characteristic of the analytic hierarchy process (AHP) decision-making method [29,30] is its simplicity of decision-making with respect to complex problems with multiple objective functions and multiple criteria. The AHP builds a hierarchy (ranking) of decision items using comparisons between each pair of items expressed as a matrix. The AHP method is particularly appropriate for situations where decision results cannot be directly and accurately measured [31,32].

The basic steps for conducting a comprehensive evaluation of regional marine DRR capacity based on the AHP method are described below.

2.3.1. Establishing a Hierarchical Structure Model

The efficient factors are decomposed into multiple grades from top to bottom according to their attributes. Thus, factors in the same grade may be affected by a factor at a higher grade, while factors in the same grade are dominant or may be affected by factors in the next grade. The top grade is taken as the target grade, typically involving only one factor. The bottom grade is usually the scheme or object grade. The middle grades may involve one or several grades, and they frequently represent the criteria or grades for index. When there are lots of criteria (e.g., more than nine criteria), the grades should be further decomposed into secondary grades.

Table 1. The integrated evaluation index system for marine disaster risk reduction (DRR) capacity.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
Engineering defense capacity A1	Public engineering defense capacity B1	The ratio of seawall meeting the protection requirement C1
		The ratio of standard seawall C2
		The proportion of protected people to seawall C3
		The reciprocal of the vulnerable point density of seawall C4
		The pump station density of seawall C5
		The drainage capacity of drainage facilities C6
		The management level of seawall C7
		The frequency of patrolling seawall during disasters C8
		The ratio of high standard seawall C9
		The length of 200-year return period of seawall C10
		The length of 100-year return period of seawall C11
		The length of 50-year return period of seawall C12
		The reciprocal of the density of pipes into the sea C13
	The defense capacity of important disaster-bearing bodies B2	The ratio of the area of culture zone protected by the standard seawall C14
		The ratio of the gross product of culture zone protected by the standard seawall C15
		The proportion of protected fishing boats C16
		The proportion of fishing ports above level 2 C17
		The number of fishing boats which can withstand wind above grade 7 C18
		The proportion of ports with ice-breaking capacity (only suitable for northern ports) C19
		Whether to carry out post-evaluation work regarding the protection capacity of ports C20
		The proportion of owned oil platforms with sea wave and sea ice warning guarantee information C21
		The proportion of platforms with emergency plan (considering the sea ice and sea waves in north and south divisions separately) C22

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
		The proportion of bulwarks with a designing return period of tidal level and waves above 50 years C23
		Whether the petrochemical zone formulated a marine disaster emergency plan C24
		The design of tidal level return period of nuclear power plants C25
		The design of wave height return period of nuclear power plants C26
		The design of maximum prevention tsunami waves of nuclear power plants C27
		The target achievement rate of wind resistance capacity C28
		The target achievement rate of the anti-ice capacity of bridge pier C29
		The ratio of boats which can withstand wind above grade 8 C30
		The ratio of large coastal projects carrying out a special evaluation of marine disaster risk C31
		The setting ratio of indicators (warning signs) C32
		The proportion of professional life-saving equipment C33
		The setting proportion of professional rescue teams C34
		The set number of emergency plans C35
		The number of emergency exercises C36
	Natural protection capacity B3	The area of protected forest (e.g., mangrove forest, Chinese tamarisk forest) per unit shoreline C37
		The area of salt marsh per unit shoreline C38
		The area of coral reef per unit shoreline C39
		The proportion of inhabited island C40

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
Disaster warning and forecasting capacity A2	Monitoring capacity B4	The sea wave observation point density C41
		The water level observation point density C42
		The water temperature observation point density C43
		The sea condition video monitoring capacity C44
		The usage capacity of satellite monitoring systems C45
		The mobile monitoring capacity C46
		The aerial monitoring capacity C47
	Warning and forecasting capacity B5	The tsunami monitoring capacity C48
		The team size of observers C49
		The number of marine forecasting organizations C50
		The team size of marine forecasters C51
		The marine disaster warning capacity C52
		The marine environmental forecasting capacity C53
		The computing power of high-performance computers C54
	The information publishing capacity B6	The operational numerical value forecasting capacity C55
		The receiving capacity of pre-warning products C56
		The publishing channels C57
		The maximum publishing frequency C58
		The publishing system of forecasting information C59
		The short message platform C60
		The number of outdoor display screens in the evaluation region C61
The number of fishing boats in the evaluation area equipped with safety environment guarantee service systems during fishery production C62		
The number of mobile phone applications on disaster warning and forecasting in the evaluation region C63		

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
Disaster emergency response capacity A3	Emergency command capacity B7	Whether a marine disaster emergency command organization is established C64
		The department of marine disaster emergency command organization C65
		The administrative position of the general command of the marine disaster emergency command organization C66
		The type of emergency command communication system C67
	Emergency response plan system B8	The type of emergency communication system under extreme disaster conditions C68
		The ratio of villages (communities) preparing the marine disaster emergency response plan in coastal towns (streets) C69
		The name and number of technical emergency response plans or operation manuals C70
		The number of emergency exercises for marine disasters last year C71
	The support capacity for assisting decision B9	Whether there is an expert technical supporting group for assisting decisions C72
		Whether to establish or use the supporting platform for assisting decisions C73
		Whether to establish or use a consultation system; if yes, please fill in the communication mode of the consultation system C74
		Whether there is a team of disaster information staff; if yes, please check the administrative division level of the established disaster information staff C75
		Whether to carry out risk evaluation work for marine disasters; if yes, please fill in the evaluated disaster type and scale C76
		Whether to establish a database of geographic information systems of the disaster-bearing system C77
		Whether to carry out verification work of warning tide level; if yes, please fill in the number of shorelines verified the warning tide level in the evaluation area C78

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
	Aiding and rescuing capacity B10	Whether there is a professional marine rescue team C79
		The number of professional rescue teams C80
		The expenditure of professional rescue teams last year C81
		Whether there are rescue helicopters and ships C82
		The number of rescue helicopters per unit length of coastline C83
		The number of rescue ships per unit length of coastline C84
Post-disaster recovery and repair capacity A4	Post-disaster emergency repair guarantee capacity B11	Post-disaster electric power guarantee capacity C85
		Post-disaster water supply guarantee capacity C86
	Post-disaster resettlement capacity B12	Post-disaster resettlement organization capacity C87
		Post-disaster living guarantee capacity C88
	Mental recovery capacity B13	Psychological aid capacity C89
	Epidemic prevention capacity B14	Epidemic prevention capacity in disaster area C90
		Human epidemic prevention capacity C91
	Social mobilization capacity B15	The number of volunteers C92
	Economic recovery capacity B16	The government compensation capacity C93
		The mutual protection capacity of fishing boats C94
The mutual protection capacity of cultivation C95		
The insurance rate C96		
	The hardware construction of marine disaster reduction publicity and education B17	Whether bulletin boards for disaster prevention and reduction publicity are set up in the neighborhood committee, community, and shelter C97
		Whether bulletin boards for disaster prevention and reduction publicity are set up in other places (such as roads, squares, shopping malls, outdoor advertising columns) C98
		Whether a high-tone loudspeaker (alarm) is placed in the evaluated coastal community (village) C99

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
		Whether a warning tide level mark is set up in the evaluation area C100
		Whether a marine disaster warning sign is set up in the evaluation area C101
		The number of disaster prevention and reduction publicity and education bases for popularizing related knowledge of marine disaster prevention and reduction C102
		The capital amount the government used for the publicity and education of disaster prevention and reduction every year C103
		The capital amount the government used for the publicity and education of marine disaster prevention and reduction every year C104
Publicity and education capacity A5	Publicity and education capacity of marine disaster prevention and reduction B18	Whether there is a publicity and education plan on marine disaster prevention and reduction in the evaluation area C105
		Whether a uniform publicity plan on marine disaster prevention and reduction is set up in the evaluation area every year C106
		The number of specialized organizations working on the publicity and education of marine disaster prevention and reduction knowledge in the evaluation area C107
		The number of bulletin boards in the neighborhood committee, community, and shelter used for publicizing disaster prevention and reduction C108
		The number of publicity activities for marine disaster prevention and reduction held in the evaluation area every year C109
		The number of people attending marine disaster prevention and reduction training in the evaluation area every year C110
		The number of communities (villages) holding at least one publicity activity about marine disaster prevention and reduction every year C111
		The situation of compiling or using marine disaster prevention and mitigation publicity materials in the evaluation area C112
		The people working on the publicity and education of marine disaster prevention and reduction in the evaluation area C113
		Whether the marine disaster prevention and reduction knowledge is included in the middle school and primary school curriculum C114

Table 1. Cont.

First-Grade Indices	Second-Grade Indices	Third-Grade Indices
		Whether television and other media broadcast popular scientific knowledge of marine disaster prevention in the evaluation area C115
		The number of televisions and other media broadcasting popular scientific knowledge of marine disaster prevention in the evaluation area C116
		The number of emergency shelters per unit area C117
		The proportion of the emergency capacity C118
	The disaster avoidance capacity B19	The proportion of shelters suitable for marine disaster C119
		The number of havens per unit coastline C120
		The number of shelter anchor grounds per unit coastline C121
		The number of facilities that can bear level 12 wind waves C122
Disaster preparedness capacity A6		The number of sheltered boats C123
		The number of disaster relief material storage points C124
	The material supporting capacity for disaster reduction and relief B20	The area of disaster relief material storage points C125
		The types of reserve materials C126
		The quantity of reserve materials C127
		Whether there is a disaster preparedness agreement with local supermarkets C128
		The disaster relief material purchasing fund every year C129
		Fiscal revenue C130
		The traffic network density C131
	The supporting capacity of social economic base B21	The renminbi (RMB) deposit remaining C132
		Mobile phone ownership per head C133
		The proportion of fixed-line telephones C134
		The number of healthy technical workers per thousand people C135
		The number of medical beds owned per thousand people C136

2.3.2. Constructing Judgment Matrix

In the second grade of the hierarchical structure model, because of the existence of several factors at the same grade which are subjected to or may be affected by each factor in the upper grade, a judgment matrix is constructed by the paired comparison method extended to the bottom grade.

In this study, six first-grade indices were adopted to establish the judgment matrix, and each index was scaled and assigned according to its relative importance to the target grade using a 1–9 scaling method, and a 6×6 judgment matrix was constructed. For the second-grade indices, six judgment matrices were established using the same method and principle, and the dimensions of each matrix could be determined from the number of second-grade indices at the lower grade. In addition, for each second-grade index, 23 judgment matrices were established by comparing the relative importance of each third-grade index at the next grade. Since the second-grade indices for defense capacity of typical disaster-bearing bodies and the publicity and education management capacity of marine disaster prevention and reduction contained 24 and 14 matrices, respectively, the two judgment matrices were broken down into 11×11 and 12×12 judgment matrices and 6×6 and 8×8 judgment matrices in order to avoid the effect of superabundant matrix elements in the judgment of experts.

When comparing the importance of i elements and j elements relative to an element in the upper layer, a quantitative relative weight a_{ij} is used. When assuming that n elements participate in the comparison, then $A = (a_{ij}) n \times n$ is called a pairwise comparison matrix. For the criteria of the judgment matrix, the nature and importance of the elements being compared were assigned a value from 1–9 as follows:

$a_{ij} = 1$, i element and j element have the same importance as the upper level of factors;

$a_{ij} = 3$, i element is slightly more important than j element;

$a_{ij} = 5$, i element is more important than j element;

$a_{ij} = 7$, i element is much more important than j element;

$a_{ij} = 9$, i element is extremely more important than j element;

$a_{ij} = 2n$, $n = 1, 2, 3, 4$, the importance of i element and j element is between $a_{ij} = 2n - 1$ and $a_{ij} = 2n + 1$;

$a_{ij} = 1/a_{ji}$, $n = 1, 2, \dots, 9$, if and only if $a_{ji} = n$.

The characteristics of the pairwise comparison matrix were as follows: $a_{ij} > 0$, $a_{ij} = 1$, $a_{ij} = 1/a_{ji}$ (note that, when $i = j$, $a_{ij} = 1$).

The six first-level indicators were used to establish a judgment matrix. That is, the relative importance of each indicator relative to the target layer (integrated marine disaster reduction capacity), according to the 1–9 scale method, was used to create a 6×6 evaluation matrix $\text{PairMatrix}_{m,1,1}$, as shown in Table 2. The six first-grade indicators were expressed as follows:

A1: Engineering defense capacity;

A2: Disaster warning and forecasting capacity;

A3: Disaster emergency response capacity;

A4: Post-disaster recovery and repair capacity;

A5: Publicity and education capacity;

A6: Disaster preparedness capacity.

Table 2. First-grade index judgment matrix composition table.

	A1	A2	A3	A4	A5	A6
A1	$X_{1(1,1)}$	$X_{1(1,2)}$	$X_{1(1,3)}$	$X_{1(1,4)}$	$X_{1(1,5)}$	$X_{1(1,6)}$
A2		$X_{1(2,2)}$	$X_{1(2,3)}$	$X_{1(2,4)}$	$X_{1(2,5)}$	$X_{1(2,6)}$
A3			$X_{1(3,3)}$	$X_{1(3,4)}$	$X_{1(3,5)}$	$X_{1(3,6)}$
A4				$X_{1(4,4)}$	$X_{1(4,5)}$	$X_{1(4,6)}$
A5					$X_{1(5,5)}$	$X_{1(5,6)}$
A6						$X_{1(6,6)}$

For the second-grade indices, six judgment matrices were established using the same method and principle, and the dimensions of each matrix were determined by the number of second-grade indices at the lower grade. For example, for the first-grade indicator A1 (engineering defense capacity), the second-grade indicators of the next level (Table 3) were as follows:

- B1: Public engineering defense capacity;
- B2: The defense capacity of important disaster-bearing bodies;
- B3: Natural protection capacity.

Table 3. Second-grade index A1 judgment matrix composition table.

A1	B1	B2	B3
B1	$X_{2(1,1)}$	$X_{2(1,2)}$	$X_{2(1,3)}$
B2		$X_{2(2,2)}$	$X_{2(2,3)}$
B3			$X_{2(3,3)}$

The third-grade indicators under the second-grade indicator B1 (public engineering defense capacity) (Table 4) were as follows:

- C1: The ratio of seawall meeting the protection requirement;
- C2: The ratio of standard seawall;
- C3: The proportion of protected people to seawall;
- C4: The reciprocal of the vulnerable point density of seawall;
- C5: The pump station density of seawall;
- C6: The drainage capacity of drainage facilities;
- C7: The management level of seawall;
- C8: The frequency of patrolling seawall during disasters;
- C9: The ratio of high standard seawall;
- C10: The length of 200-year return period of seawall;
- C11: The length of 100-year return period of seawall;
- C12: The length of 50-year return period of seawall;
- C13: The reciprocal of the density of pipes into the sea.

Table 4. Third-grade index B1 judgment matrix composition table.

B1	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	$X_{3(1,1)}$	$X_{3(1,2)}$	$X_{3(1,3)}$	$X_{3(1,4)}$	$X_{3(1,5)}$	$X_{3(1,6)}$	$X_{3(1,7)}$	$X_{3(1,8)}$	$X_{3(1,9)}$	$X_{3(1,10)}$	$X_{3(1,11)}$	$X_{3(1,12)}$	$X_{3(1,13)}$
C2		$X_{3(2,2)}$	$X_{3(2,3)}$	$X_{3(2,4)}$	$X_{3(2,5)}$	$X_{3(2,6)}$	$X_{3(2,7)}$	$X_{3(2,8)}$	$X_{3(2,9)}$	$X_{3(2,10)}$	$X_{3(2,11)}$	$X_{3(2,12)}$	$X_{3(2,13)}$
C3			$X_{3(3,3)}$	$X_{3(3,4)}$	$X_{3(3,5)}$	$X_{3(3,6)}$	$X_{3(3,7)}$	$X_{3(3,8)}$	$X_{3(3,9)}$	$X_{3(3,10)}$	$X_{3(3,11)}$	$X_{3(3,12)}$	$X_{3(3,13)}$
C4				$X_{3(4,4)}$	$X_{3(4,5)}$	$X_{3(4,6)}$	$X_{3(4,7)}$	$X_{3(4,8)}$	$X_{3(4,9)}$	$X_{3(4,10)}$	$X_{3(4,11)}$	$X_{3(4,12)}$	$X_{3(4,13)}$
C5					$X_{3(5,5)}$	$X_{3(5,6)}$	$X_{3(5,7)}$	$X_{3(5,8)}$	$X_{3(5,9)}$	$X_{3(5,10)}$	$X_{3(5,11)}$	$X_{3(5,12)}$	$X_{3(5,13)}$
C6						$X_{3(6,6)}$	$X_{3(6,7)}$	$X_{3(6,8)}$	$X_{3(6,9)}$	$X_{3(6,10)}$	$X_{3(6,11)}$	$X_{3(6,12)}$	$X_{3(6,13)}$
C7							$X_{3(7,7)}$	$X_{3(7,8)}$	$X_{3(7,9)}$	$X_{3(7,10)}$	$X_{3(7,11)}$	$X_{3(7,12)}$	$X_{3(7,13)}$
C8								$X_{3(8,8)}$	$X_{3(8,9)}$	$X_{3(8,10)}$	$X_{3(8,11)}$	$X_{3(8,12)}$	$X_{3(8,13)}$
C9									$X_{3(9,9)}$	$X_{3(9,10)}$	$X_{3(9,11)}$	$X_{3(9,12)}$	$X_{3(9,13)}$
C10										$X_{3(10,10)}$	$X_{3(10,11)}$	$X_{3(10,12)}$	$X_{3(10,13)}$
C11											$X_{3(11,11)}$	$X_{3(11,12)}$	$X_{3(11,13)}$
C12												$X_{3(12,12)}$	$X_{3(12,13)}$
C13													$X_{3(13,13)}$

According to the framework of the above tables, a 3×3 paired evaluation matrix $PairMatrix_{m,2,1}$ and a 13×13 paired evaluation matrix $PairMatrix_{m,3,1}$ were formed. The pairwise comparison matrix

formed by the remaining secondary indicators and their corresponding tertiary indicators is not repeated here.

The pairwise comparison matrices generated under the different hierarchical relationships were all recorded as $PairMatrix_{m,i,j}$ (Equation (2)).

$$PairMatrix_{m,i,j} = \begin{bmatrix} x_{k,i,j}(1,1) & x_{k,i,j}(1,2) & x_{k,i,j}(1,n_j) \\ x_{k,i,j}(2,1) & x_{k,i,j}(2,1) & x_{k,i,j}(2,n_j) \\ x_{k,i,j}(n_j,1) & x_{k,i,j}(n_j,2) & x_{k,i,j}(n_j,n_j) \end{bmatrix}_{n_i \times n_i}, \tag{2}$$

where $m = 1, 2, \dots, k$, where k is the number of participating experts, and i is the number of hierarchical structures. In this study, $i = 1, 2, 3, 4, 5, 6$. The scheme layer was $j = 1, 7, \dots, n_i$, where n_i is the number of evaluation indices of the i layer. $x_{k,i,j}$ represents the relative importance values of the k expert for index a and index b of the $i + 1$ layer in the j sub-hierarchy of the i level with respect to its superior (i level) index. Assuming that the filled judgment matrix was $PairMatrix_{m,i,j} = x_{k,i,j}(a, b) n_i \times n_i$, the elements of each matrix were simplified to $x_{i,j}$. The judgment matrix had the following properties: $x_{i,j} > 0$; $x_{j,i} = 1/x_{i,j}$; $x_{i,i} = 1$.

2.3.3. Calculating Weight Vectors in Hierarchical Single Arrangement, as well as Conducting the Consistency Test

Compared with other methods for determining the index weight coefficient, the most significant advantage of the AHP method is performing a consistency test to ensure the experts' thoughts and logical coherence. For each comparative matrix pair, their maximum eigenvalue and corresponding eigenvector are calculated, and a consistency test is conducted using the consistency index, random consistency index, and consistency ratio. If the test is passed, the normalized eigenvector is the weight vector; otherwise, it is required to reconstruct the comparative matrix pairs.

2.3.4. Calculating the Weight Vector in Total Arrangement, in Addition to Conducting the Consistency Test

The combined weight vector for the bottom grade to the target grade is calculated, and consistency checking is conducted according to the mathematical relationships. If this test is passed, a decision can be made according to the results of the combined weight vector. Otherwise, the model should be regenerated or the comparative matrix pairs with a large consistency ratio should be reconstructed. Among the 2070 marking tables collected in this work, 1752 marking tables (about 84.6%) passed the consistency check. The box plots of the weights of the first- and second-grade indicators were completed, as shown in Figure 2.

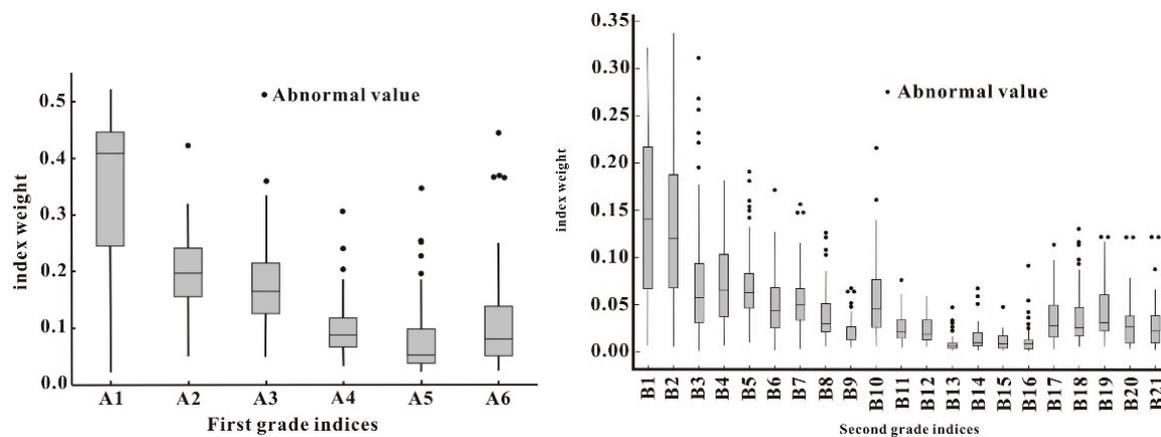


Figure 2. Boxplots of weights for indicators of the first- and second-grade indices.

2.4. Determining the Basis for Grade Rating

Different methods were used in different studies for determining the basis of each index. In this paper, the relative importance of each index was considered, which required ranking the index grade in different regions. Meanwhile, the collected data were easily translated into evaluation scores to assess the DRR capacity for each region. The grade was divided into poor, medium, and excellent grades using the interval method, taking the grade rating threshold offered by pilot units as a reference. Then, the value of importance of ranking was assigned to each index in order to determine the score. The value of importance of ranking was assigned according to the score of the corresponding grade. After that, the actual data were converted into comparable score values. A standardized index was used to normalize all values of the third-grade index in the range 0–1. Based on histogram analysis, the evaluation indices for the first-grade index for regional marine DRR capacity were divided into poor, medium, and excellent grades with scores of 0.45, 0.45–0.60, and 0.60, respectively.

3. Evaluation Results for Pilot Regions

According to the proposed comprehensive evaluation index for regional marine DRR capacity, the degree of importance of each index was analyzed, the index weight was determined, and then the regional marine DRR capacity was calculated. The calculated index was comparatively analyzed with the actual situation, and the reliability, rationality, and feasibility of the index system were verified, in addition to the established model and the proposed methodology for evaluating regional marine DRR capacity.

3.1. Evaluation Results for Pilot Regions in Guangdong Province

Two pilot regions, Dayawan and Huidong, were selected for evaluation and analysis in Guangdong province (Figure 3). In general, in terms of the evaluation results for the regional marine DRR capacity, Dayawan (0.6139) obtained an excellent grade and was slightly superior to Huidong (0.5651), which obtained a medium grade. Furthermore, in the Dayawan region, the disaster emergency response capacity and disaster preparedness capacity obtained an excellent grade, while the engineering defense capacity, disaster warning capacity, post-disaster recovery and repair capacity, and publicity and education capacity obtained a medium grade. On the other hand, in the Huidong region, the engineering defense capacity, disaster emergency response capacity, and disaster preparedness capacity were all ranked as excellent, whereas the publicity and education capacity was ranked as medium, and the disaster warning capacity and post-disaster recovery and repair capacity were ranked as poor.

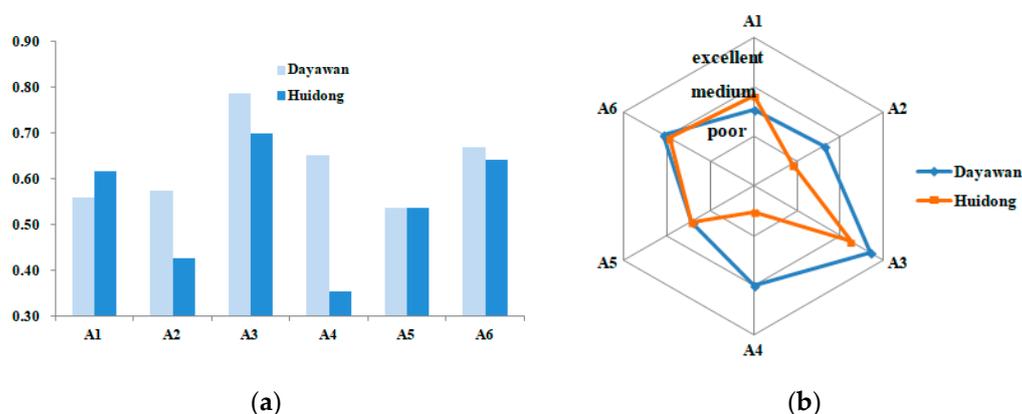


Figure 3. Evaluation results for pilot regions in Guangdong province: (a) the result value; (b) the result level. In the figure, A1 stands for engineering defense capacity, A2 stands for disaster warning and forecasting capacity, A3 stands for disaster emergency response capacity, A4 stands for post-disaster recovery and repair capacity, A5 stands for publicity and education capacity, and A6 stands for disaster preparedness capacity. The meanings of A1–A5 are the same in Figures 2 and 3.

3.2. Evaluation Results for Pilot Regions in Shandong Province

Three pilot regions in Shandong province, including Binhai district, Changyi district, and Shouguang city, were selected for evaluating the achieved results (Figure 4).

In general, in terms of a comprehensive evaluation index for regional marine DRR capacity index, the index values for the three pilot regions were all near 0.6, and their difference was negligible. Shouguang city (0.6356) and Binhai district (0.6172) were ranked as excellent, while Changyi district was ranked as medium. In Binhai district, the engineering defense capacity, disaster emergency response capacity, and disaster preparedness capacity were ranked as excellent, whereas the disaster warning capacity and publicity and education capacity were ranked as medium grade, and the post-disaster recovery and repair capacity was ranked as poor. Similarly, in Changyi district, the engineering defense capacity, disaster emergency response capacity, and disaster preparedness capacity were all ranked as excellent, whereas the disaster warning capacity and publicity and education capacity were ranked as medium grade, and the post-disaster recovery and repair capacity was ranked as poor. However, in Shouguang city, all capacities obtained an excellent grade, except for post-disaster recovery and repair capacity, which was poor.

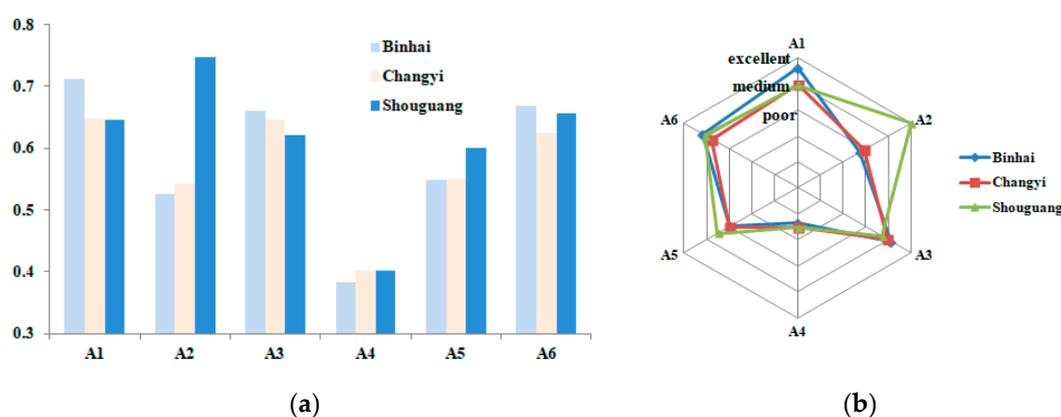


Figure 4. Evaluation results for pilot regions in Shandong province: (a) the result value; (b) the result level.

3.3. Evaluation Results for Pilot Regions in Zhejiang Province

Six pilot regions in Zhejiang province were selected and analyzed (Jiaojiang district, Linhai city, Luqiao district, Sanmen county, Wenling city, and Yuhuan county).

Generally, in terms of the comprehensive evaluation index for the regional marine DRR capacity index, Yuhuan County (0.6508), Jiaojiang district (0.6488), and Wenling city (0.6157) were ranked as excellent. However, Linhai city (0.6030), Luqiao district (0.5687), and Sanmen County (0.5678) were all ranked as medium (Figure 5).

In Jiaojiang district, the engineering defense capacity, disaster warning capacity, disaster emergency response capacity, and disaster preparedness capacity were all ranked as excellent, whereas the post-disaster recovery and repair capacity was ranked as poor. In Linhai city, the engineering defense capacity and disaster preparedness capacity were ranked as excellent, whereas the disaster warning capacity, disaster emergency response capacity, and publicity and education capacity were ranked as medium, and the post-disaster recovery and repair capacity was ranked as poor. In Luqiao district, the engineering defense capacity and disaster preparedness capacity were ranked as excellent, whereas the disaster emergency response capacity and publicity and education capacity were ranked as medium, and the disaster warning capacity and post-disaster recovery and repair capacity were ranked as poor. In Sanmen County, the engineering defense capacity and disaster preparedness capacity were ranked as excellent, whereas the disaster emergency response capacity and publicity and education capacity were ranked as medium, and the disaster warning capacity and post-disaster recovery and repair

capacity were ranked as poor. In Wenling city, the engineering defense capacity, disaster emergency response capacity, and disaster preparedness capacity were all ranked as excellent, whereas the disaster warning capacity and publicity and education capacity were ranked as medium, and the post-disaster recovery and repair capacity was ranked as poor. In Yuhuan County, the engineering defense capacity, disaster warning capacity, and disaster emergency response capacity were all ranked as excellent, whereas the publicity and education capacity was ranked as medium, and the post-disaster recovery and repair capacity was ranked as poor.

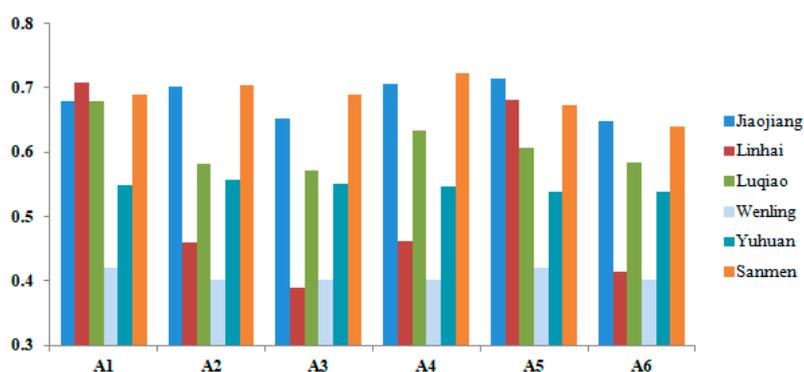


Figure 5. Evaluation results for pilot regions in Zhejiang province.

3.4. Comparing the Evaluation Results

After comparatively analyzing the regional marine DRR capacity for 11 pilot regions, it was revealed that the values of comprehensive evaluation indices for regional marine DRR capacity were relatively close together (Figure 6). Both the maximum and the minimum values belonged to Zhejiang province, where the Jiaojiang district achieved the maximum value, and Sanmen County had the minimum value. Furthermore, the evaluation results of regional marine DRR capacity for Guangdong Dayawan, Shandong Binhai, Shandong Shouguang, Zhejiang Jiaojiang, Zhejiang Wenling, and Zhejiang Yuhuan all obtained an excellent grade. The evaluation results of regional marine DRR capacity for Guangdong Huidong, Shandong Changyi, Zhejiang Linhai, Zhejiang Luqiao, and Zhejiang Sanmen all obtained a medium grade.

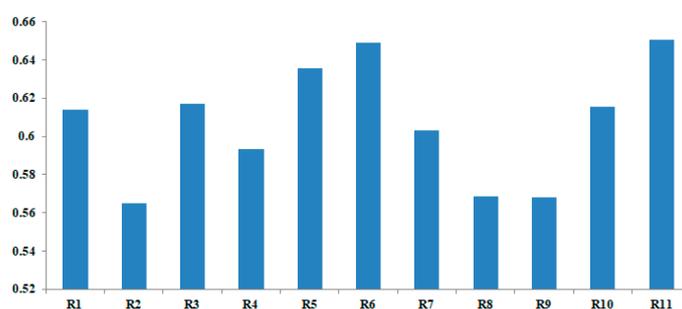


Figure 6. Regional comparison of assessment results of comprehensive regional marine disaster risk reduction (DRR) capacity in pilot area. In the figure, R1 stands for Guangdong Dayawan, R2 stands for Guangdong Huidong, R3 stands for Shandong Binhai, R4 stands for Shandong Changyi, R5 stands for Shandong Shouguang, R6 stands for Zhejiang Jiaojiang, R7 stands for Zhejiang Linhai, R8 stands for Zhejiang Luqiao, R9 stands for Zhejiang Sanmen, R10 stands for Zhejiang Wenling, and R11 stands for Zhejiang Yuhuan. The meanings of R1–R11 are the same in Figure 7.

The regional comparison of assessment results of various marine DRR capacities is shown in Figure 7. It is disclosed that the evaluation values of engineering defense capacities for the 11 pilot regions were basically the same. The evaluation values of engineering defense capacity for the other

10 pilot regions were all higher than 0.6, except for Guangdong Dayawan (0.5589), which was below 0.6. Additionally, the evaluation value of engineering defense capacity for Shandong Binhai (0.7115) was higher than 0.7, and evaluation values were equal to 0.6928, 0.6850, 0.6791, 0.6496, 0.6483, 0.6458, 0.6293, 0.6285, and 0.6163 for Zhejiang Yuhuan, Zhejiang Wenling, Zhejiang Linhai, Zhejiang Jiaojiang, Shandong Changyi, Shandong Shouguang, Zhejiang Luqiao, Zhejiang Sanmen, and Guangdong Huidong, respectively.

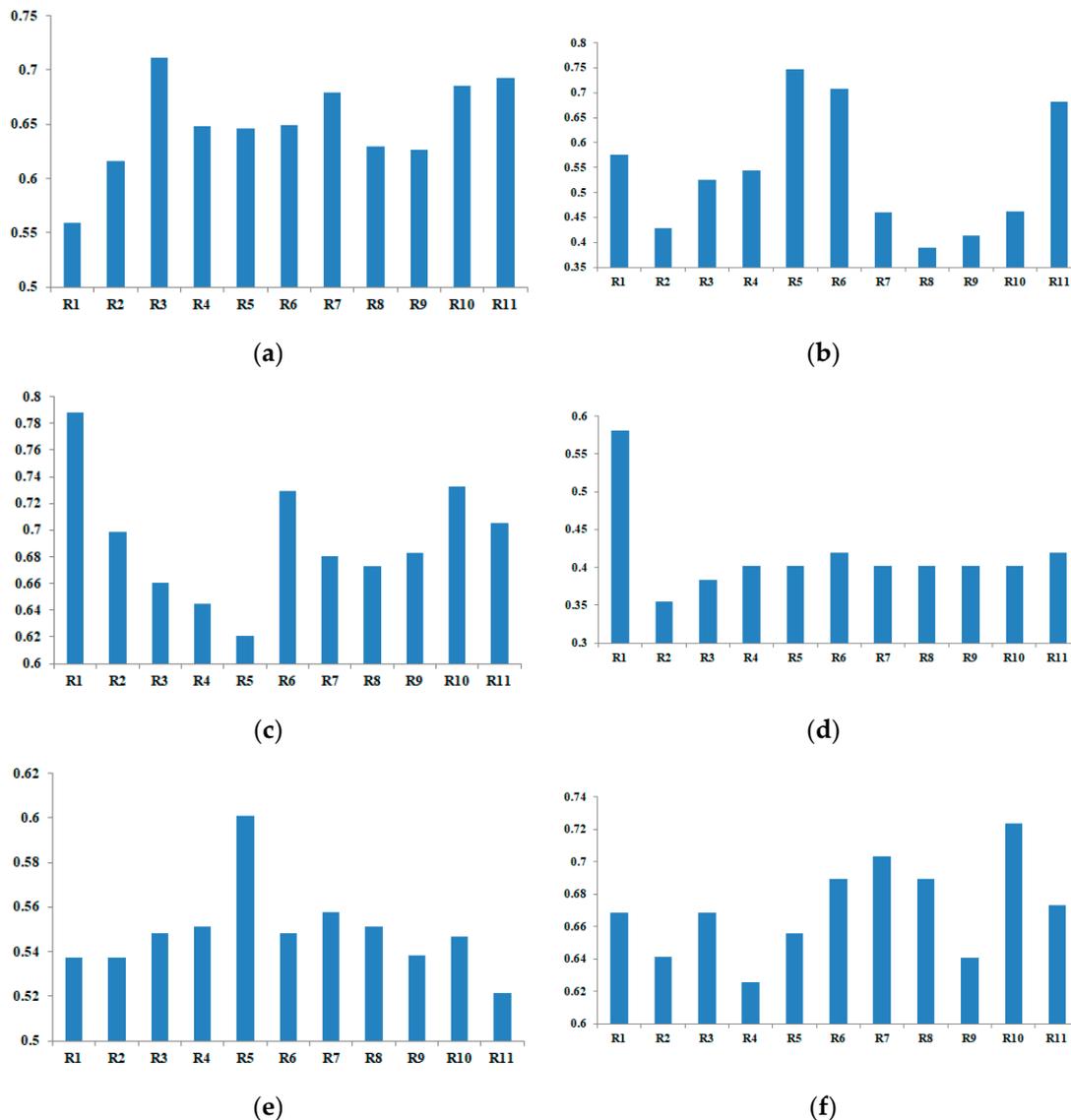


Figure 7. Regional comparison of assessment results of various marine DRR capacities in pilot areas. (a) Engineering defense capacity; (b) disaster warning and forecasting capacity; (c) disaster emergency response capacity; (d) post-disaster recovery and repair capacity; (e) publicity and education capacity; (f) disaster preparedness capacity.

4. Discussions

The key point in the assessment process was whether the set of index weights was reasonable or not. Therefore, communication and on-site training were fully conducted with the help of experts for decision-making, and to ensure that the index weights given by experts passed the significance test. In the future, appropriate sampling methods should be used to select working group members

consisting of experts. When a quantitative weight is synthesized for expert opinions, the contribution of experts should be determined according to the experts' research field for each index.

In the future, a relationship between DRR capacity assessment and disaster management should be created, and a normal evaluation mechanism should also be established. Technical guidance for evaluating marine DRR capacity should be issued in a timely manner by the Marine Disaster Reduction Center of State Oceanic Administration, and the evaluation database for DRR capacity and the development of reliable and efficient software should be carried out to promote the broad application of the evaluation results.

The benefits of comparing marine DRR capacities among the three Chinese provinces (i.e., Guangdong province, Shandong province, Zhejiang province) still need further study. The current situation of marine disaster mitigation capacity in the study areas will be further analyzed, and the evaluation results will be compared and analyzed. The specific measures and recommendations will be proposed for the water conservancy department, marine department, civil affairs department, and hygiene department.

Under the macro guidance of the national DRR plan [33], a regional DRR plan should be formulated in accordance with the background of disaster zoning. It is also necessary to conduct land-use planning for future developments in coastal areas in order to avoid new investments where the hazard level is high. There is an urgent need to establish coordination mechanisms between departments, to closely coordinate and integrate resources, and share information. According to the needs of prevention and management of marine natural disasters, we must pay close attention to the formulation and revision of regulations and national standards. It is necessary to establish prevention-oriented work ideas based on the characteristics of marine disasters, and to accelerate the construction of working mechanisms such as marine disaster prediction and warning, information reporting, emergency response, reconstruction, and investigation. There is an urgent need to strengthen the publicity and education of marine emergency management in order to maximize the ability of society to respond to marine disasters. It is also necessary to carry out extensive marine disaster emergency training in all walks of life.

5. Conclusions

Based on the current situation of marine DRR capacity building in China, a three-level index system was proposed. An expert questionnaire and the AHP method were applied to quantify the weights of the three-level indicators. The key conclusions are as follows:

- (1) The relationships between regional marine DRR capacity and various aspects of disaster management before, during, and after disasters were developed systematically. Disaster cycle, risk response, object and subject of capacity assessment, regional commonality, and specificity of indicators were considered comprehensively. By integrating the DRR experience of experts in various fields (such as ocean, hydrology, meteorology, civil affairs, emergency, education, and comprehensive DRR), we established a three-level indicator system for regional marine DRR capacity assessment. It includes six first-level indicators, 21 second-level indicators, and 136 third-level indicators.
- (2) The Evaluation Index Weights Expert Questionnaire was designed. The questionnaires were handed out to various departments and university experts involved in marine DRR capacities. After calculating the average of the weights provided by these experts, the final weights were found to be reasonable. Reasonable integration of the weights of experts in relevant fields enriched the knowledge and accumulated valuable experience for supporting the regional marine DRR capacity assessment and capacity building.
- (3) The evaluation of the three-level indicator system and the index weight results was performed in 11 pilot counties in Shandong, Zhejiang, and Guangdong Province. Through capacity assessment, gap analysis and demand analysis were further refined. It was possible to finally set regional DRR targets within a certain period. The results have important theoretical and practical implications

for guiding regional DRR capacity building. They contribute a good foundation for future regional assessment of regional marine DRR capacity.

- (4) When implementing the constructed indicator system in different pilot areas, one should account for the different marine disaster risks that need to be dealt with in different regions. The differences in regional indicators should be considered. Through pilot research, the indicator system could eventually be applied to the national assessment of marine disaster mitigation capacity; thus, the indicator system should be versatile in China's coastal areas. The evaluation indicated that there were very few indicators with regional characteristics. This had almost no impact on the evaluation results; thus, a unified indicator system could be adopted throughout the country.
- (5) In pilot assessments, the analysis should cover the hazards, hazard-affected environments, hazard-affected bodies, and response capacity of the marine disaster system. The availability of data on the grassroots management departments should be considered. Representative evaluation indicators need to be further screened and condensed. It is necessary to get a good balance among the integrity of the indicator system and data availability, the representation of indicators and number of indicators, and the key indicators and alternative indicators.

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