Analysis on the suitability for port construction of shoreline resources of Zhoushan Archipelago

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Abstract. Port coastline resources are important marine resources. Coastal ports are not only important infrastructures for national economic and social development, but also important pillar industries and prominent growth points for the marine economy. Zhoushan Archipelago has rich coastline resources, but its unique island environment limits its transportation conditions, which make the methods of suitability evaluation different from the evaluation method of continents'. Taking Zhoushan as an example, this paper studied the evaluation method of port shoreline resources on the island shoreline, so as to provide scientific basis for port coastline resource utilization and sea-use planning.

1. Introduction

China has long shorelines with a length of over 32,000 kilometers, and has abundant resources of port shorelines [1]. Meanwhile, these resources are also extremely limited. The available shorelines are decreasing, accompanied by the abuse of the available shorelines, which consequently limits the overall shoreline-use efficiency of the shoreline. More and more port are built on the islands. In order to promote the proper use of port shorelines, the suitability assessment on shorelines should be further strengthened, which could improve the comprehensive shoreline-use efficiency [2].

In the late 1980s, researches on shoreline were started in China, mainly focus on the assessment of the shoreline development of rivers, especially on the Yangtze River. The selection of indicators mainly focuses on waterfront depth, shoreline stability, and waterfront breadth [3-6]. With further studies on coastal port shorelines, some scholars have integrated the actual conditions in the research area with appropriate assessment indicators. For example, Yang et al. [7] have implemented a comprehensive assessment on the coastal port resources in Liaoning Province in terms of water depth, shoreline length, sheltering conditions, land conditions, ice conditions, location conditions, the scale of city reliance, conditions of collection, distribution, and transport, as well as utilization conditions, etc. Huang [8] have established an indicator system for assessing the functional suitability of port, including types of coast, water depth conditions, port resources density, engineering geological conditions, sheltering conditions, traffic conditions, disaster preparation sand other indicators. Xu et al. [9] have assessed the resource suitability of the mainland shorelines in Zhejiang Province through the indicators of waterfront depth, channel width, shoreline stability, available depth and tide range.

However, there are few studies on the integrated methods of assessment indicators. Currently, there are four main methods. First, the Analytic Hierarchy Process (AHP) [10], which is a systematic and hierarchical decision-making analysis combining qualitative and quantitative method. Through the modeling and quantification of the decision-making process of complex systems, the problems can be simplified, where simple comparison and calculation between the factors can be performed. As a result,
the weights of different plans are accessible, which provides a basis for the best option. Second, the Maximum Value Method [11], that is, on a definite basis of various individual functional indicators, the highest appropriate grade of each function shall be the comprehensive grade of the unit in accordance with the principle of maximum value. Third, Method of Weighting [12], that is, from the perspective of port development and utilization value, various indicators are selected and given with a certain weight coefficient matching their importance, so that the natural endowments of shorelines are assessed. Lastly, Natural Breaks Method [13], that is, integrating scores and weights from each influence factor before the natural breaks method is introduced to divide the scores into 4 categories, which is the poor, fair, good and excellent.

In general, the current assessment research on island shorelines remains extremely limited. Meanwhile, the methods of assessment and integration mainly rely on expertise, which means the objective and comparable methods are still insufficient.

Zhoushan Archipelago, the largest archipelago in China, is a new development area themed around marine economy which is approved by the State Council. Zhoushan Archipelago enjoys exceptionally abundant port shorelines resources, but its unique island-like natural geographical environment can lead to the relative inadequacy of its port hinterland, limiting the conditions of collection, distribution, and transport. Thus, the method of suitability assessment on the port development is different from that of the mainland shoreline. Therefore, this paper takes Zhoushan Archipelago as an example to work out the assessment method of island port shorelines, aiming to achieve the objective assessment against the background of port shorelines, and to provide scientific basis for the rational use of the available resources.

2. Overview of the region
Located in the northeast of Zhejiang Province and with the vast economic hinterland of Yangtze River delta at the back, the city of Zhoushan holds the intersection of Chinese golden coast and the golden waterway of the Yangtze River (Figure 1). Zhoushan provides the world a window on China's eastern coast and the Yangtze River area. According to the 2018 Zhoushan Statistical Yearbook, Zhoushan covers a land area of 1,459 square kilometers. In addition, its coverage of sea area is up to 21,000 square kilometers with its length of coastlines exceeding 2444 kilometers[14] It is extremely suitable for the development of port infrastructures because of its long bedrock shorelines accounting for over 70% of overall coastline stretches.

![Figure 1. The location of Zhoushan Archipelago.](image-url)
3. Methods

3.1. Assessment indicator

Based on the objective indicators and accurate data, this study starts from the natural resources conditions of the port shorelines and selects six indicators from 3 aspects (shoreline, sea area and land area), including coastal bottom sediment, water depth, slope, the relief degree of land surface (RDLS), island area and turning basin, to assess the suitability of the resources of the island port shorelines.

1) Coastal bottom sediment

With the development of port construction technology, coastal sediment conditions are no longer a factor restricting port construction. There have been successful cases in China about port development under various coastal bottom sediment conditions such as bedrock, silt and sand. However, different types of sediments have different impacts on the ecological environment and changes in coastal natural resources. Port development has the biggest impact on the hydrodynamic conditions of sandy coasts and their adjacent sea area. The silty coasts can lead to more construction processes, higher periodic dredging costs, and larger changes in the properties of sea basins. The bedrock and artificial coasts have the least change in port development, and have little effect on the hydrodynamic conditions of the surrounding sea basins. Therefore, given the impacts of port development on natural conditions of the coast, bedrock and artificial coasts are more suitable for port development than silty coasts and sandy coasts.

2) Water depth

Water depth is the most important feature of port shoreline resources. According to the 'The Standard of Port Deepwater Shoreline' of the Ministry of Communications, coastal port deepwater shorelines refer to shorelines suitable for the development of various berth types with 10,000-ton and above. Since the full load draft of a 10,000-ton ship is 6m-10m, the 10m isobath is often used as the assessment standard. The water depth is calculated by using the distance from the shoreline to the 10m isobath. However, due to the small size of some islands or the rapid attenuation of the water depth in the surrounding seas, there will be errors in the drawing of isobath when calculating the coastline of islands with this method of calculation. Therefore, in this study, the buffer zone method has been adopted to assess the water depth of the island port shoreline through the measurement indicator, while the average water depth within a certain radius of the shorelines to the sea is used as the measurement index.

3) The slope of coastal zones and RDLS

Topographic conditions are usually required for ports to meet the needs of terminal productivity, logistics, business and port industries. Combined with the general requirements of urban development, this study is based on two indicators, slope and RDLS, to assess the topographic conditions of the coastal zones. The assessment method is similar to that of the water depth. A buffer zone with a certain radius extending from the shoreline (the center) is used as the assessment unit, and the average slope and RDLS in the unit are used as the topographic assessment results of the shore area.

4) Island area

Compared with the coastal land, the rear land space of the island is an important factor that determines the development of island ports. With stricter control of sea reclamation, the island's bearing space is critical to port development.

5) Turning basin

Ship turning basin refers to the waters that allow ships to enter and leave the port or the wharf. Islands, especially archipelago areas, have the disadvantages of short distances between each other as well as the inconvenience of turnaround traffic. Therefore, it is necessary to consider the molded dimensions of the passing ships and assess the conditions of turning basins. The assessment indicator is the distance to the nearest island.

3.2. Determination of classification threshold

When determining the classification threshold, the following two aspects are mainly taken into consideration. One is to calculate the molded dimension, the wharf land area indicator, and the ship turning basin scale for the 10,000-ton design ship, in accordance with the relevant industry specifications.
such as the General Design Specification for Seaports (JTS165-2013). The other one is the natural breaks method, combined with the actual data of Zhoushan Archipelago, such as water depth conditions.

According to the degree of impact of port project development on the coast, the shoreline bottom sediment is divided into three grades: good, fair or poor, depending on the types of coast, namely artificial/ bedrock, silty, or sandy coast.

The water depth condition is calculated according to the average water depth within 2km of the shoreline to the sea. In the light of the actual circumstance of Zhoushan Archipelago, the water depth conditions are divided into three grades: good, fair or poor, depending on the average water depth, namely ≥20m, 10-20m and <10m.

The topography of the coastal zone is calculated according to the average slope and RDLS within 2km extending from the shoreline. Considering the development land standard, the slope is divided into three grades (good, fair or poor) with it range from ≤8°, 8-15° to >15°. In addition, the RDLS is divided into same grades ranging from ≤100m, 100-200m, to >200m.

The coverage of island area is based on preparing land area for the container and the bulk terminals in the land-use indicators of the wharf. It is divided into three grades according to the coverage of island area, namely >0.6 square kilometers, 0.2-0.6 square kilometers, or ≤0.2 square kilometers.

Based on the scale of a 10,000-ton ship’s turning basin, the standard of turning basin refers to 1.5-2.5 times of the ship’s design length measured by the diameter of the turning circle. The conditions of shoreline turning basins are divided into three grades, ‘good’ or ‘fair’ depending on the no-island-distribution range of 600m or 300m; or ‘poor’ as there is island distribution within 300m.

3.3. Integration of assessment indicators

Based on the interrelationship of indicators, the study is integrated through decision matrix. This method provides a quantitative scaling method of pairwise comparison, and the importance of different indicators can be determined based on a simple two-dimensional logical relationship.

First, two indicators are divided into three groups with pairwise integration according to their present elements. The coastal bottom sediment and the water depth conditions represent the conditions of the deepwater shoreline resources; the coastal zone slope and RDLS describe the coastal zone development conditions; and the island area and the turning basin characterize the landward and seaward conditions of depth (decision matrix shown in Table 1 - Table 3). Second, the deepwater shoreline resources conditions and the coastal zone topographic conditions are integrated into the coastal zone resources conditions (decision matrix shown in Table 4). Finally, the spatial depth conditions are included into the integration, producing a suitability assessment result (decision matrix shown in Table 5).

| Water depth | Coastal bottom sediments |
|-------------|--------------------------|
| Good        | Good                     |
| Fair        | Good                     |
| Poor        | Poor                     |

| Slope | RDLS   |
|-------|--------|
| Good  | Good   |
| Fair  | Fair   |
| Poor  | Poor   |

| Island area | Turning Basin |
|-------------|---------------|
| Good        | Good          |
| Fair        | Fair          |
| Poor        | Poor          |

Table 1. Decision matrix of the deepwater shoreline resource conditions.

Table 2. Decision matrix of coastal zone topographic conditions.

Table 3. Decision matrix of spatial depth conditions.
Table 4. Decision matrix of coastal zone resources conditions.

| Coastal zone topographic conditions | Deepwater shoreline resource conditions |
|------------------------------------|----------------------------------------|
| Good                               | Good | Fair | Poor |
| Fair                               | Good | Fair | Poor |
| Poor                               | Poor | Poor | Poor |

Table 5. Decision matrix of port shoreline resources suitability.

| Coastal resources conditions | Spatial depth conditions |
|------------------------------|--------------------------|
| Good                         | Suitable     | Generally suitable | Unsuitable |
| Fair                         | Generally suitable | Generally suitable | Unsuitable |
| Poor                         | Unsuitable   | Unsuitable         | Unsuitable |

4. Result and discussion
The suitability assessment on island port shoreline has taken Zhoushan Archipelago as an example. Based on GIS, a grid unit with a length of 20m was developed to determine the grades of port shorelines, namely suitable, general suitable and unsuitable, as shown in Figure 2. Suitable shorelines account for about 20% of the total length, and unsuitable shores account for about 75%. The shorelines that are suitable for port are mainly distributed in the east of Jintang Island, Cezi Island, northwest and north parts of Zhoushan Island, northwest part of Liuheng Island, Taohua Island and surrounding islands, west part of Xiushan Island, southeast part of Daishan Island, Zhongjieshan Islands, Yushan Island, south part of Qushan Island, Yangshan Island, south part of Sijiaoshan Island, Huaniaoshan Island, Luhua Island, etc. Those islands are quite consistent with the distribution of existing port areas. (Figure 3).

Figure 2. Grading Diagrams of suitability assessment on the development of shoreline resource port in Zhoushan Archipelago.
The resource conditions of the deepwater shorelines of Zhoushan Archipelago are superior in terms of constraints. About 45% of the shorelines rank good in the light of bottom sediment or water depth conditions. However, since Zhoushan Archipelago is in the landform of mountains and hills, slopes with over 15° account for 56% of the total land area. Moreover, many uninhabited islands are small in size and close in distance. After the integration of the coastal zone topography and depth indicators, the number of suitable shorelines is further cut by half. Therefore, the land conditions are a significant factor restricting the development of Zhoushan Port.

![Figure 3. Diagram of the Layout of Sea Port Area in Zhoushan Archipelago.](image)

As one of the non-renewable natural resources with huge potential to exploit, the shorelines possess tremendous driving forces for the development of port economy. According to the 'Overall Planning (2014-2030) of Ningbo-Zhoushan Port', a total of 362.1 kilometers of port shorelines have been planned. Up to now, 141.5 kilometers have been developed, accounting for only 5% of the total, with much potential for future development. However, as a result of geographical constraints, the economic development and material shipment in Zhoushan Archipelago hinge on port, displaying "wide scope but in small size" characteristics. There are 11 port areas in Zhoushan, distributed in over 20,000 square kilometers of waters. Although this model has made indispensable contributions to the economic development of the archipelago cities, its limitations have meanwhile restrained the effective port economy and hindered the upgrading of modern port facilities.

However, it is worth noting that the selection of port location should be considered in an integrated manner, because it involves not only natural resources and environmental conditions but socioeconomic factors. The suitability assessment on port shoreline resources cannot replace the complex and comprehensive special planning on port. The assessment on environmental carrying capacity and national spatial development suitability remains the significant scientific premises and basis for national spatial planning. Meanwhile, the positioning of suitability assessment on port shoreline resources should also be connected with national spatial planning, especially the basic support for the marine development and spatial layout. Therefore, the suitability assessment on port shoreline resources is rooted in natural resources. By focusing on regional spatial resources, hydrodynamics and environmental conditions, it...
is expected to achieve the goal of strengthening environmental and resource conservation. Moreover, it
is the references for the optimal adjustment of port shipping functional areas, rather than the precise
selection of port locations by building huge and various indicator systems.

5. Conclusion
Taking Zhoushan Archipelago as an example, this paper studied the suitability evaluation method of the
shoreline resource suitability of island ports. The main conclusions are as follows:

1. Studied an evaluation method for the suitability of island port shoreline. Taking the overall
planning of land and sea into consideration, this paper established an index system from three aspects
of coastline, land area and sea area. At the same time, use the discriminant matrix method to objectively
determine the classification threshold to evaluate the suitability of the port shoreline.

2. The suitable shoreline of the port coastline in the Zhoushan Islands waters accounts for about 20%
of the total coastline length. They are mainly distributed on Jintang Island, Zhoushan Island, Liuheng
Island, Daishan Island, Yushan Island, Qushan Island, Yangshan Island, etc. The results were highly
consistent with the distribution areas of the existing port area. At present, the developed coast section
only accounts for 5% of the total coastline length, and there is still a large development space and
potential.

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