Study on territorial risk assessment in Beibu Gulf of Guangxi

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Abstract. This study is based on the theories of terrestrial exploration risk in the Beibu Gulf Economic Zone in the Guangxi Zhuang Autonomous Region. Using ArcGIS and modelling methods, the spatial distributions of resources and environmental carrying capacity, terrestrial exploration dynamics, and terrestrial exploration potential are studied and evaluated in an integrated way. The results of the study are as follows: Mashan county, Longan county, Luchuan county, et al. have some low-risk land that can be explored, and infrastructure investment should be increased in these locations. Whereas, low-risk terrestrial development is possible in Qinzhou city, Heng county, Longan county, et al. and should be carried out in a planned and gradual fashion. The medium risk regions are distributed all over the region, but are concentrated in the city area of Nanning. However, the middle and north parts of Yulin city, the south part of Chongzuo city, Qinnan district, et al. are also in the same category and priority can be given to improve the quality and efficiency of these regions. The high risk regions, mainly distribute in the Liangqin district, Yining district, Binyang county, et al. This region should focus on the development principles of priority protection, appropriate development, and point-like development. Whereas, the extremely-high-risk areas, of which more than 60% are in Tiandeng county, Daxin county, Shanglin county, et al., are unsuitable for further development. The three-dimensional risk matrix method can make up for the deficiencies of other methods and has broad prospects in regional terrestrial development risk assessment.

Keywords: The Beibu Gulf Economic Zone; resources and environmental carrying capacity; terrestrial development dynamics; terrestrial development potential; risk assessment
1. Introduction

The Beibu Gulf Economic Zone is the only gulf area in the South China. In 2008, the rapid industrialization and urbanization was included as the national general strategy for regional development. Therefore, Scientific evaluation of the spatial characteristics of territorial resources and identification of the risk factors related to the territorial development is important for the territorial planning of the Beibu Gulf Economic Zone.

Currently, the general trend of risk assessment is reflected by the transition from health risk assessment to eco-risk assessment as well as from the effects of individual pollutants to the inclusion of composite effects from more than one pollutant. Also from chemical pollutants to non-chemical pollution, local to regional studies even global studies and from qualitative to semi-quantitative and quantitative assessments.

There are several problems in recently conducted studies on the territorial development risks. (1) There is no uniformity in the concepts, such as environmental risk assessment, eco-risk assessment and urban development risk assessment. All are defined differently at present; none of these concepts provide an overall measurement technique for regional territorial development risks. (2) Limited efforts have been made to comprehensively study territorial development risks. While many authors have intensively studied various risks over the past few years [1-22], few of them have looked at these risks in a comprehensive fashion. (3) More intensive studies must be carried out on territorial development riskson a regional scale. However, due to limitations in methods and available data, the major risk assessment-related research units of China are limited to districts/counties, drainage basins or smaller administrative institutions, and few have attempted regional-scale research. (4) There are many methods for risk assessment, but methods for large-scale studies are not as operable. Facile methods that involve fewer indices are usually not sufficiently reliable. However, the results of some reliable models like the system kinematics model are frequently exposed to uncertainties in large regional studies as the model construction involves the establishment of complex feedback relations.

This study conducts a risk assessment on territorial development in the Beibu Gulf Economic Zone as a model for regional-scale research and explores the theory and practice of regional territorial development risks in order to provide new guidelines and referable research experiences on the territorial development risk assessment. In this study, territorial development risk assessment is defined to include three implications;

a) A comprehensive analysis of the resources and environmental carrying capacity, development, dynamics and development potential of different regions to establish the risk levels;

b) A division of different classes of risk regions according to spatial differentiation based on the natural environment, socioeconomic development level, eco-system characteristics and type of human activity;

c) The provision of risk-prevention measures after determining the risk type, risk distribution and risk level.

This study aims to establish the pattern, characteristics and mechanism of territorial development risks in coastal areas to provide both case support for regional-scale research on risk assessment in connection with territorial planning and a reference for the territorial planning of coastal economic zones.
2. Study area

Geographically the Beibu Gulf Economic Zone is located in the central south part of the Guangxi Zhuang Autonomous Region, it lies between 107° 22′ – 109° 05′ E, 21° 27′ – 24° 03′ N. Nanning, Beihai, Qinzhou, Fangchenggang, Yulin and Chongzuo are the important cities of this region. The economic zone has a population of approximately 22.12 million and covers about 7.34 million hectares of land. The region is densely occupied by platforms and large areas of hills and plains. The seafloor is host to rich oil and natural gas resources. There are many mineral resources typically include non-metallic minerals. Water resources are abundant in the region, mainly two major water systems; the Xijiang water system of the Pearl River basin and the river water systems along the coast of South Guangxi, which belong to the coastal basin. The mean annual water resource quantity is 34.96 billion cubic metres. The sea area of the economic zone is about 129,300km. Whereas, the coastline stretches from Gaoqiao Town on Baisha Peninsula at the Guangxi-Guangdong border in the east to Beilunhe estuary at the China-Vietnam border in the west. The total continental coastline is 1,628.59 km.

Territorial development in the Beibu Gulf Economic Zone is subject to the following risk groups:

1) The land resources development risk group composed of water and soil erosion risk, soil pollution risk, geologic disaster risk, arable land low productivity risk and land ‘three-ization’ (desertification, paludification and salinization) risk.

2) The water resources development risk group composed of flood disaster risk, drought risk, water pollution risk.

3) The marine resource development risk group composed of improper spatial arrangement of development and utilization, the need to adjust marine industry structures, low science and technology level, marine environmental pollution and marine eco-degradation.

4) And the mineral resources development risk group composed of low comprehensive utilization rate, insufficient deep processing capability, lack of a commercial mineral exploration mechanism, mine geologic disasters, land resource occupation and destruction, impact and destruction to groundwater systems and environmental impact from wastewater and waste residue.
3. Research data and methods

3.1. Research data

The data used in this study include land utilization survey data, statistical data of mineral resources, geologic disaster survey data, eco-conservation data, pollutant survey data and water resource survey data of 2009. Also, 30-m-resolution digital elevation model (DEM) and gradient data downloaded from the International Scientific Data Platform. The monthly weather observation data of 2000–2010 from 27 weather stations in and around the Beibu Gulf Economic Zone downloaded from the China Meteorological Data Sharing Service System (including air pressure, hours of sunshine (h), maximum/minimum temperature (°C), average temperature (°C), average relative humidity (%) and average wind velocity (m/s)). The soil map of China with a scale of 1:1000000 and transportation data downloaded from the Environmental and Ecological Science Data Center for West China (http://westdc.westgis.ac.cn) of the National Natural Science Foundation of China (including high-speed railways, general railways, expressways, national highways and provincial highways). Also, 1:2500000 geological map of China, 1:2000000 land utilization distribution map of the Beibu Gulf Economic Zone, and data of the planned urban development groups from ‘Territorial Plan of Beibu Gulf Economic Zone 2011–2030’[23] used in this study.

3.2. Research methods

3.2.1. Calculation of resources and environmental carrying capacity. The assessment index system for this study is designed using analytic hierarchical process (AHP) and includes ‘comprehensive
assessments of resources and environmental carrying capacity as the target layer and the indices measuring the resources and environmental carrying capacity as the index layer. A comprehensive assessment index system for resources and environmental carrying capacity is established, which covers four first-tier indices (land resources, water resources, geologic environment and eco-environment) and six second-tier indexes. The weights of these indices are established using the Saaty T. L1–9 scale.

Table 1. Index system of resources and environmental carrying capacity.

| Target Layer | Criterion Layer | Index Layer |
|--------------|-----------------|-------------|
| Territorial resource carrying capacity (0.25) | Available land resource abundance (0.5) | |
| Comprehensive assessment index system for resource and environmental carrying capacity | Land system susceptibility (0.5) | |
| Water resource carrying capacity (0.25) | Available water resource abundance (0.6) | |
| Geologic environmental carrying capacity (0.25) | Water environmental carrying capacity index (0.4) | |
| Eco-environmental carrying capacity (0.25) | Geologic disaster hazard (1) | |
| | Eco-function importance (1) | |

A mathematical assessment model is established using the index weighted average method:

\[ V = \sum_{i=1}^{n} W_i B_i \]

Here, \( V \) is the integrated weighted assessment score, \( W_i \) is the weight of each index, \( B_i \) is the assessment score of each index and \( n \) is the number of indices.

3.2.2. Calculation of the territorial development potential. The territorial development potential is defined as the theoretical territorial development potential minus the land available for development after the comprehensive limitations in territorial development. The higher the territorial development potential, the lower the territorial development risk. The theoretical territorial development potential is defined as the proportion of land available for development and utilization after deducting existing urban construction land, water conservancy land, special land and transportation land from the total land area of the administrative region from the total area of the region, as calculated by the following:

\[ Q_S = (1 - P_b - P_c - P_d - P_e - Z_D - Z_H - Z_Q - Z_S - Z_L) \times 100 \]

\[ Q_l = (1 - P_b - P_c - P_d - P_e) \times 100 \]

Here, \( Q_S \) is the territorial development potential, \( Q_l \) is the theoretical territorial development potential, \( P_b, P_c, P_d \) are the proportions of urban construction land, special land, transportation land and water conservancy land, respectively, in the total area, \( Z_D, Z_H, Z_Q, Z_S \) and \( Z_L \) are the landform, geologic disaster, climate, eco-safety and food safety limitations, respectively.
3.2.3. Calculation of the territorial development dynamics. (1) Accessibility. The distances of a region from the transport trunk lines such as high-speed railways, general railways, expressways, national highways and provincial highways are used to represent the accessibility of the region. First, a distribution map with a 30-m spatial resolution representing the distances from high-speed railways, general railways, expressways, national highways and provincial highways is produced by spatial analysis. Then, the calculation results are linearly normalized between 1 and 100. The accessibility is calculated according to the formula:

$$T = \sum T_i$$

Here, $T$ is the accessibility of a region, and $T_i$ is the linearly normalized distance from this region to the traffic trunk $i$. Finally, the natural breaks (Jenks) classification method is used to classify the accessibility.

(2) Urban construction land. The distances of a region from the existing urban and rural construction land are used to represent the influence of the land in this region. Specifically, a distribution map showing the shortest distances to the existing urban and rural construction lands calculated by spatial analysis is first drawn. The calculation results are then linearly normalized to between 0 and 100 to allow the calculation of territorial development dynamics. The larger the value of the influence of the existing urban and rural construction lands, the closer this region is to the existing urban and rural construction lands, and the greater the influence of the existing urban and rural construction lands of this region. Finally, the natural breaks (Jenks) classification method is used to categorize the influence of the existing urban and rural construction lands in the Beibu Gulf Economic Zone into five grades: low, sub-low, medium, sub-high and high.

(3) Influence of planned city groups. The distance of a region from the planned city group is used to represent the influence of this group in the region. Specifically, a distribution map showing the shortest distances from the planned city group calculated by spatial analysis is first drawn. The calculation results are then linearly normalized to between 0 and 100 to allow calculation of the land development potential. The larger the value of the influence of the city group, the closer this region is to the planned city group and the greater the influence of the city group in the region. Finally, the natural breaks (Jenks) classification method is used to classify the influence of the planned city group in the Beibu Gulf Economic Zone into five grades: low, sub-low, medium, sub-high and high.

(4) The territorial development dynamics. By integrating the accessibility, the influence of the existing urban and rural construction lands and the influence of the planned city group, the territorial development dynamics are calculated. Specifically, the averages of the accessibility, the influence of the existing urban and rural construction lands, and influence of the city group are first calculated. The calculation results are then linearly normalized to between 0 and 100. Finally, the territorial development dynamics are derived. And finally, the natural breaks (Jenks) method is used to classify the territorial development dynamics of the Beibu Gulf Economic Zone into five grades: low, sub-low, medium, sub-high and high.

3.2.4. Calculation of the Territorial Development Risk. Three-dimensional risk matrix refers to the 3D magic cube that incorporates resources and environmental carrying capacity, territorial development potential and existing development potential into one single framework and forms a $3 \times$
3 × 3 matrix in a three-dimensional space (Figure 2). There are 27 types of combinations, each representing a region with a different development risk. Specifically, the scores of individual cells representing resources and environmental carrying capacity, whereas, the existing development dynamics and regional development potential are prioritized by value and classified according to some prominent mutation points in the data sequence. The overall scores of resources and environmental carrying capacity, existing development dynamics and regional development potential are clustered into three grades: low, medium and high. The highest score of the cluster is recorded as class 1 and coordinated at 3. The medium score is recorded as class 2 and coordinated at 2. The lowest is recorded as class 3 and coordinated at 1. Thus, the coordinates of the cells are expressed by the combinations of 1, 2 and 3, and each of these combinations represents one magic cube unit in the 3D magic cube. According to the risk level represented by each magic cube unit, the risk level of each cell (low, sub-low, medium and high risk grades), is obtained (Table 2). In this study, a region with no potential is defined as a very high-risk region and excluded from the three-dimensional risk matrix calculation.

![Figure 2. Three-dimensional risk matrix model representing terrestrial development risk.](image)

### Table 2. The units of the magic cube and orientation of major development function.

| Cube Unit                                                                 | Risk Rating Region |
|--------------------------------------------------------------------------|--------------------|
| (3,1,3); (3,2,3); (3,1,2); (2,1,3)                                         | Low                |
| (3,2,2); (3,2,1); (3,1,1); (2,2,3); (2,1,2); (2,1,1)                        | Sub-low            |
| (1,3,3); (1,3,2); (2,3,3); (2,3,2); (3,3,3); (3,3,2); (3,3,1); (1,1,2)    | Medium             |
| (1,2,1); (1,1,1); (1,2,2); (1,2,3); (1,1,3); (1,3,1); (2,3,1); (2,2,1); (2,2,2) | High               |
| Regions with no development potential                                     | Very high          |

Note: The 3D magic cube units are resources and environmental carrying capacity, existing development dynamics and regional development potential.

Low-risk regions are characterized by high resources and environmental carrying capacity, low development dynamics and great development potential. They are suitable for mass development, which can involve modest risk.
Sub-low-risk regions are characterized by high resources and environmental carrying capacity and average development dynamics and development potential; they can be taken as a key backup development region. The development of these regions must address the potential impact on the eco-environment and be implemented in a scheduled, progressive manner.

Medium-risk regions are characterized by high development potential, low resources and environmental carrying capacity and great development potential.

High-risk regions are characterized by low resources and environmental carrying capacity along with high or average development potential. The development of these regions must be implemented in a cautious manner so that the resources and the environment are conserved.

Very high-risk regions are defined as regions with no development potential. No development is recommended for these regions.

4. Analysis and results

4.1. Resources and Environmental Carrying Capacity
The single-factor analysis of resources and environmental carrying capacity indicates that more than half of the land system in the Beibu Gulf Economic Zone has higher susceptibility. Regions with susceptible land systems are typically found in the north-central and eastern areas of the Beibu Gulf Economic Zone. Nanning, Yulin, Beihai and Qinzhou cities have relatively susceptible land systems, whereas Fangchenggang and Chongzuo have more ideal land system conditions. The surface water environment capacity of the Beibu Gulf Economic Zone appears to be overload-free. The offshore water environment of Guangxi has quite good quality. Most waters are clean or relatively clean, and the water environmental carrying capacity is excellent. The geological disaster hazard in the Beibu Gulf Economic Zone is comparatively low, although many unstable slopes exist that could cause geologic disasters. The major part of the Beibu Gulf Economic Zone is ecologically important, only the downtown areas of Chongzuo and Yulin, Tianteng, Long’an and Binyang counties, and some of the coastal counties/cities have relatively low ecological importance.

Using the administrative map of the Beibu Gulf Economic Zone and the GIS spatial graphic expressions, each district/county is assigned a spatial cluster type and identified on the map to derive an integrated distribution map of the resources and environmental carrying capacity of the Beibu Gulf Economic Zone (Figure 3).
The high carrying capacity regions are characterized by great overall resources and environmental carrying capacity, including 11 districts/counties (Mashan county, Fangcheng district, Qinnan district, Hepe county, Haicheng district and most of the districts/counties in Yulin city), which all together make up 30% of the total area of the economic zone. These regions have relatively abundant land and water resources, excellent geological and water environment, low eco-susceptibility, modest eco-importance and relatively high eco-environment support capability.

Medium carrying capacity regions are characterized by medium resources and environmental carrying capacity, including 11 districts/counties (Long’an and Shanglin counties of Nanning city, Dongxing city, Yinhai and Tieshangang districts of Beihai city, Chongzuo city, and most of the counties/districts of Qinzhou city), which collectively contribute 45% of the total area of the economic zone. Most of these districts/counties have limited available land resources, whereas some of them have insufficient water resources, medium or better geological safety, good water and atmospheric environments and average eco-susceptibility and eco-importance.

Low carrying capacity regions are characterized by relatively poor resources and environmental carrying capacity, they include 12 districts/counties (Jiangzhou district, Pingxiang city and Tiandeng county of Chongzuo, Gangkou district of Fangchenggang and most parts of Nanning city), which mutually contribute 25% of the total area of the economic zone. These areas have limited available land resources, relatively abundant available water resources, relatively safe geological environment, good water and atmospheric environments, slightly susceptible ecosystems, and quite high
eco-importance. In general, the eco-environmental carrying capacity is superior to the resource carrying capacity in these areas.

4.2. Territorial development potential
Figure 4 shows the cluster analysis result of the territorial development potential of the Beibu Gulf Economic Zone.

![Figure 4. Cluster analysis of terrestrial exploration potential in the Beibu Gulf Economic Zone.](image)

The above map shows the territorial development potential of the Beibu Gulf Economic Zone is generally great, with significant spatial differences between the east and west. Regions with greater theoretical potential are typically found in the plateaus and mountains in the west, while the coastal plain areas in the south have smaller potentials. By and large, Qinzhou city possesses a high overall territorial development potential, whereas, the south-central part of Chongzuo and the northern part of Nanning have relatively high territorial development potentials. Yulin and Beihai cities have lower territorial development potentials. The low development potential of Tiandeng County in northern Chongzuo is attributable to the heavy soil rocky causing the major part of the area unsuitable for development potential.

4.3. Territorial development dynamics
Figure 5 shows the territorial development dynamics of the Beibu Gulf Economic Zone.
Figure 5. Cluster analysis of terrestrial development dynamics in the Beibu Gulf Economic Zone.

The above map shows that the territorial development dynamics of the coastal and border areas of the Beibu Gulf Economic Zone is noticeably higher than that of the inland areas. The development dynamics of the central south of Beibu Gulf Economic Zone are higher than that of the north. Beihai and Fangchenggang cities have high territorial development dynamics grades across the cities. The downtown area of Nanning and the downtown and neighboring areas of Yulin also have high development dynamics.

4.4. The territorial development risk

On the basis of the 3D Magic Cube units, the main types of the resulting Magic Cube units of the districts/counties are analyzed in three types. A territorial development risk division plan of the Beibu Gulf Economic Zone is worked out (Figure 6).
Figure 6. Planning map of the terrestrial development risk in the Beibu Gulf Economic Zone.

**Low-risk regions:** These regions share the characteristics of high resources and environmental carrying capacity, relatively high eco-safety, relatively low existing development density and sufficient future development potential. Future more, these low-risk regions should fully utilize their resource advantages and speed up industrialization and urbanization. In addition, they should also receive industrial transfers from optimized development regions and population transfers from restricted and prohibited development regions and boost industrial clustering. They should also address the protection of the local eco-environment.

**Sub-low-risk regions:** These regions share the characteristics of relatively high resources and environmental carrying capacity along with average existing development density and regional development potential. As backup key development regions, it is important that development takes account of potential impacts of the eco-environment, utilize more labor and funds for resource regeneration, try to improve the resource and environmental carrying capacity to the extent that exceeds the total resources and environmental consumption needed for the economic–social development, and proceed in a scheduled, progressive manner. To develop livable, pioneering, regional, modern, and central cities poised to have manufacturing and modern services. It is important for these areas to build themselves into livable modern central cities, important bases to receive industrial transfers, famous minor business cities and demonstration areas for unified urban–rural development. Further, to increase agricultural resource conservation and industrial upgrading, conserve and efficiently utilize resources, and strike a balance between the protection of agricultural production lands and urbanization and industrialization.
Medium-risk regions: These regions share the characteristics of large population density, highland development ratio, relatively high energy or water consumption per unit industrial output value and high existing development density. Also, supported by their physical locations, technological potential and the economic dynamics. Because of the financial strength accumulated from previous economic development, the regional development potentials are still quite high. In addition, medium-risk regions should prioritize quality and efficiency and strive to develop land and energy efficient industries.

High-risk regions: These regions share the characteristics of weak resources and environmental carrying capacity, low existing development dynamics, low population density, bad economic concentration conditions, average regional development potential, and large areas of natural conservation zones within the territory. In future development, high-risk regions should first follow the principle of conservation, moderate development and point development, control the development intensity, gradually shrink the land spaces of towns and rural resident settlements, further implement incentive development within the existing layout, and reserve more spaces for safeguarding the virtuous cycle of the ecosystem.

Very high-risk regions: These regions are not recommended for further development. Instead, mandatory protection should be implemented according to the law and relevant plans. Any human interference with the natural ecology should be controlled, and tourist and eco industries should be moderately developed. In Tiandeng, Mashang and Shanglin counties, where the land is heavily rocky desertified, and the eco-environment is relatively susceptible, it is important that more effort be made to protect ecologically important spaces like woodlands and eco-functions such as water-soil conservation and water source conservation, strengthen the protection of important water source conserving functions like Liuwanshan of Yulin city, develop green landscape resources on three-dimensional bases, and strongly explore traditional Chinese medicine and tourism businesses characterized by local cultures, sightseeing, and eco-resorts.

5. Conclusions

Based on GIS technology, a risk assessment index system and a 3D magic cube risk assessment model for territorial development are established to assess the risks involved in the territorial development of the Beibu Gulf Economic Zone. Some recommendations for territorial development in this study area are provided. Following are the main conclusions:

(1) It is important to define the right direction for future territorial development of different types of risk regions. Low-risk regions should put more investment on infrastructure to prepare themselves to receive industrial and population transfers from other regions, speed up industrialization and urbanization, make more effort to protect local eco-environments, and avoid predatory development. Sub-low-risk regions should take account of potential eco-environmental impacts to avoid the mass exhaustion of regional resources and environmental carrying capacity and implement scheduled, progressive development. Medium-risk regions should prioritize quality and efficiency, optimize their economic structures, transform their growth modes, and strive to develop land- and energy-efficient industries. High-risk regions should first follow the principle of conservation, moderate development and point development, strictly control the development intensity, explore green, pollution-free industries by adjusting measures to the local particularities, and become important eco functions of the Beibu Gulf Economic Zone. Very high-risk regions are not recommended for further development.
They should control any human interference to the natural ecology and moderately develop tourism and eco industries.

(2) In view of the existing risks involved in the development and utilization of territorial, water and mineral resources in the Beibu Gulf Economic Zone, measures must be taken to prevent or control these risks by continuing to stabilize the arable land size, moderately increase the construction land size, improve the intensive utilization level of construction land, refine the seismic disaster control mechanism, improve the water supply capability, establish strict water-conservation standards, strengthen water quality supervision, intensify geologic exploration to boost ore-prospecting breakthroughs, adjust the energy structure to extend industrial chains and safeguard the demand–supply balance of mineral resources.

(3) The assessment results indicate that the three-dimensional risk matrix assessment method offers a comprehensive assessment approach based on a number of territorial development system indices. It can overcome the shortcomings of other assessment methods and has vast potential when used for the comprehensive assessment of risks involved in regional territorial development. Further in-depth research on performing comparative result analysis by using three-dimensional risk matrix assessment method, principal component analysis method and k-means clustering method shall be conducted.

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