IMPLEMENTING THE STRATEGIC ACTION PROGRAMME FOR THE YELLOW SEA LARGE MARINE ECOSYSTEM: RESTORING ECOSYSTEM GOODS AND SERVICES AND CONSOLIDATION OF A LONG-TERM REGIONAL ENVIRONMENTAL GOVERNANCE FRAMEWORK

(UNDP/GEF YSLME Phase II Project)

Dandong Vulnerability Assessment Report of Sea Level Rising

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Chapter I Introduction

1.1. Background

According to the sea level monitoring and analysis of Chinese Marine Disaster Bulletin 2018 issued by the Ministry of Natural Resources of People's Republic of China, the coastal sea level rise rate of China from 1980 to 2018 keeps at 3.3 mm/year. In 2018, China's coastal sea level is 48 mm higher than the average and 10 mm lower than 2017, ranking the sixth highest since 1980. China's coastal sea levels of recent seven years are all in the high level among the latest 40 years, with the orders of the highest sea level years as followed; 2016, 2012, 2014, 2017, 2013, 2018 and 2015 (Figure 1.1).

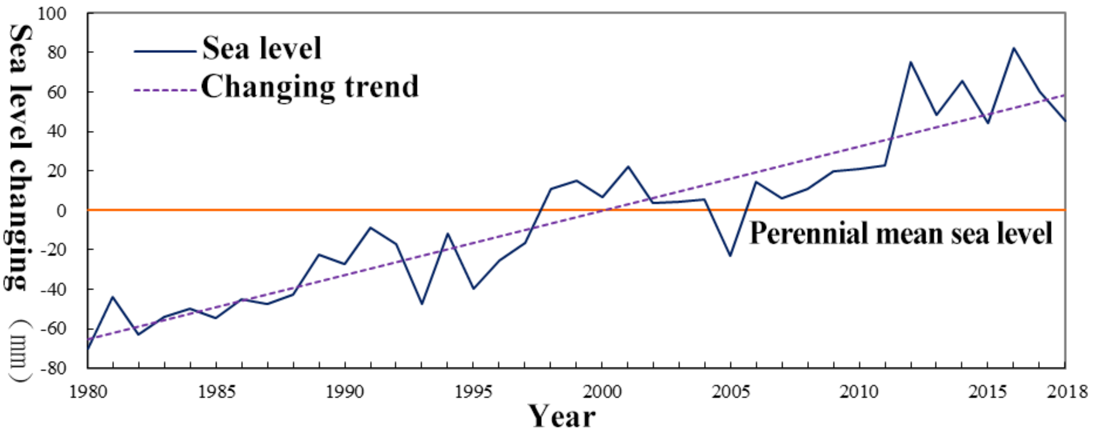


Figure 1.1 The sea level of China from 1980 to 2018

The coastal sea levels of the Bohai Sea, East China Sea and South China Sea in 2018 are 50-56 mm higher than the average, and the Yellow Sea just has a small rise. Compared with 2017, the coastal sea levels of Bohai Sea and Yellow Sea rise slightly in general while the East China Sea and South China Sea fall down for 16 mm and 44 mm respectively (Figure 1.2).

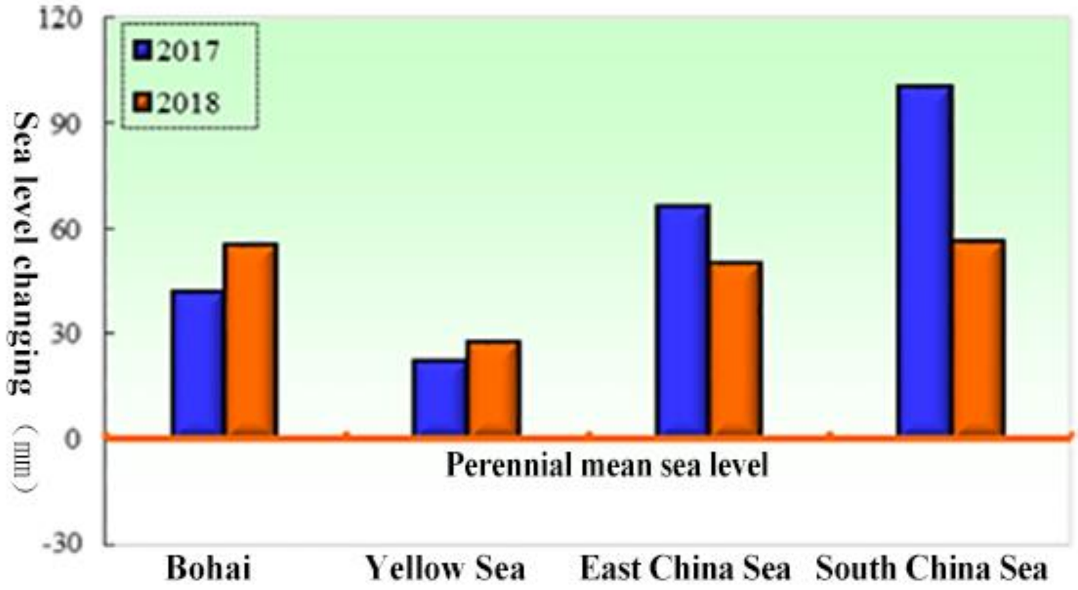


Figure 1.2 The sea level of different regions in China in 2018

For the Yellow Sea, in 2018, its coastal sea level is 28 mm higher than the average, slightly higher than that of 2017. August marks the second highest sea level at this period since 1980, with 105 mm higher than the average. February and October have the lowest sea level for the recent decade. Compared with the same month in 2017, sea level rises 170 mm in December and falls for 123 mm in October (Figure 1.3).

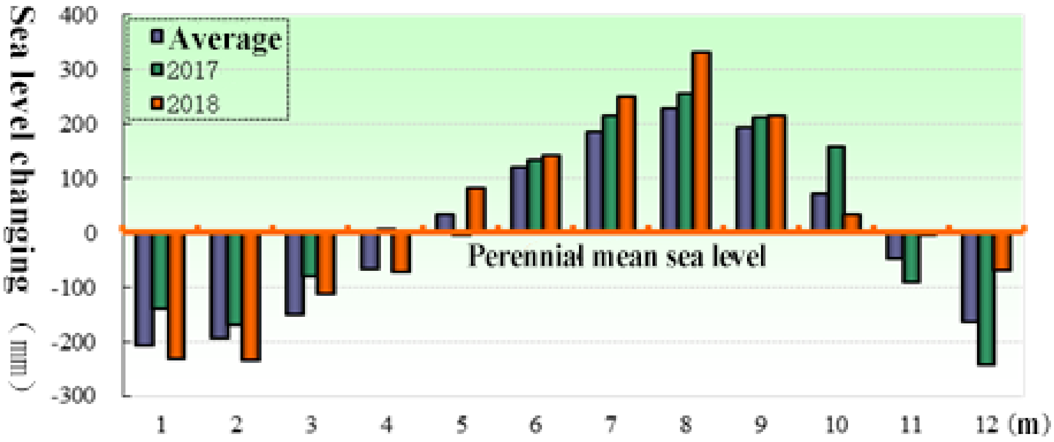


Figure 1.3 Average monthly sea level change in 2018

The coastal sea level of the Yellow Sea is anticipated to rise about 70-165mm in next 30 years.

In 2018, provincially, the coastal sea levels of Chinese provinces, including autonomous regions and municipalities, are higher than the average. Among them, Tianjin has an obvious rise in the coastal sea level of 82mm compared with the average. Next to Tianjin, the coastal sea level of Hebei, Zhejiang, Guangdong and Hainan rise 58 mm, 57 mm, 59 mm and 65 mm, respectively. Liaoning, Shandong and Guangxi rise 33 mm, 30 mm and 34 mm, respectively (Figure 1.4).

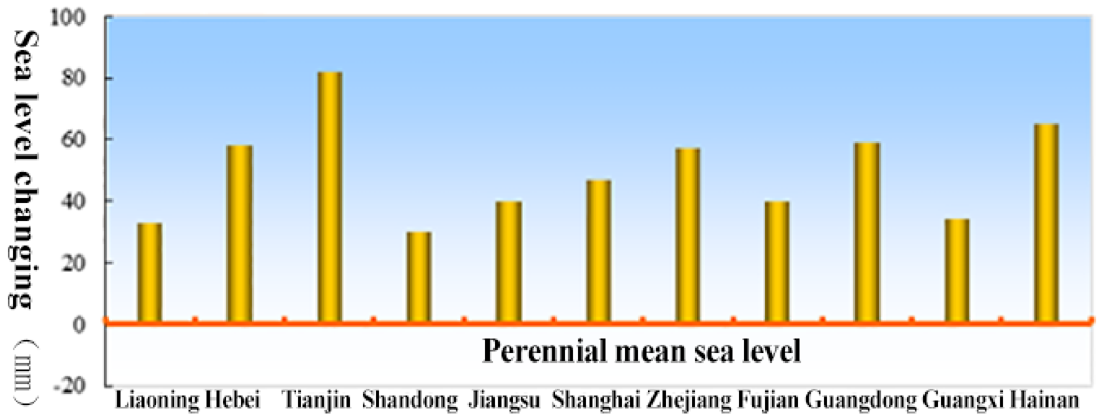


Figure 1.4 The sea level of China's provinces changes in 2018 relative to the perennial average

Compared with 2017, the coastal sea level from Liaoning to Jiangsu rises 3-24 mm in 2018 (Figure 1.5).

Figure 1.5 The sea level of China's provinces changes in 2018 compared to 2017

In 2018, Liaoning coastal sea level rises 33 mm compared to the perennial average, , but the sea level changes greatly among months.

For the east coast of Liaodong Peninsula in 2018, August marks its highest sea level for this period since 1980, rising around 100 mm than the average; In November and December, sea levels rise 106 mm and 125 mm, respectively, compared with the same months in 2017. In January, April and October, sea levels drop by 80 mm, 94 mm and 82 mm, respectively (Figure 1.6).

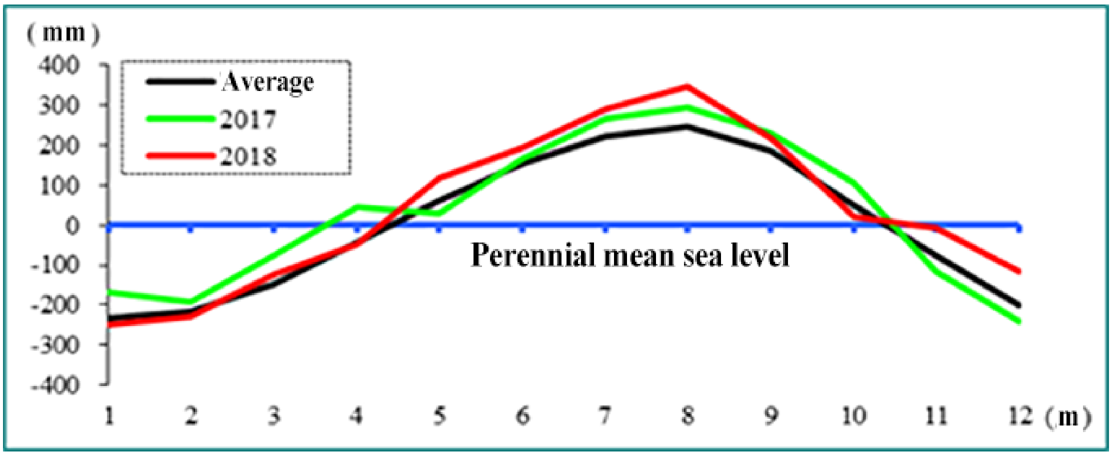


Figure 1.6 Monthly mean sea level changes along the eastern coast of Liaodong peninsula

For Liaodong Bay in 2018, the coastal sea level in July is the highest record at the same month since 1980, rising 95 mm than the average, while the sea level in October keeps the lowest record at the same time in the recent ten years. The sea level rises 105 mm in December and drops by 115 mm and 113 mm in January and April compared with the same months in 2017 (figure 1.7).

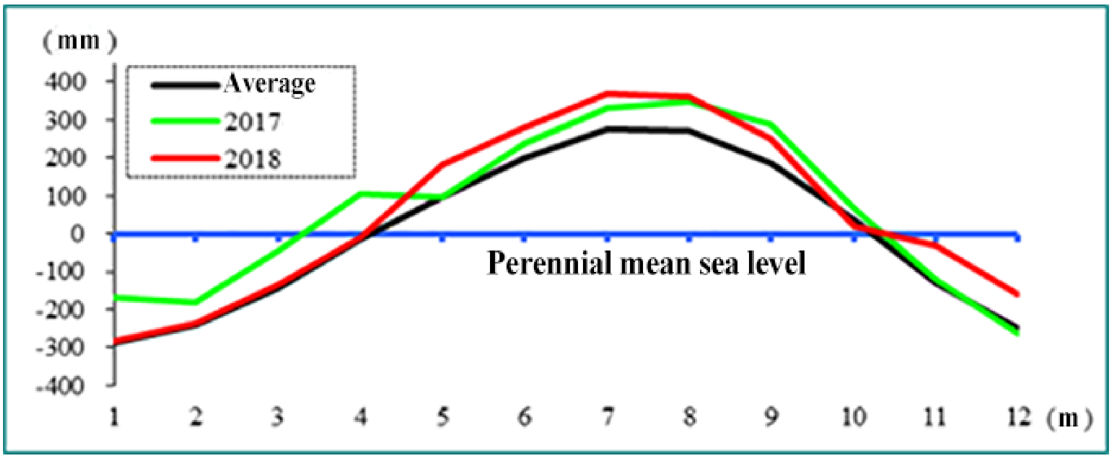


Figure 1.7 Average monthly sea level change in the coastal areas of Liaodong Bay

The period of coastal astronomical tide in Liaoning happens around May 8 and May 21 in 2019. Disasters including the extra-storm surge may occur.

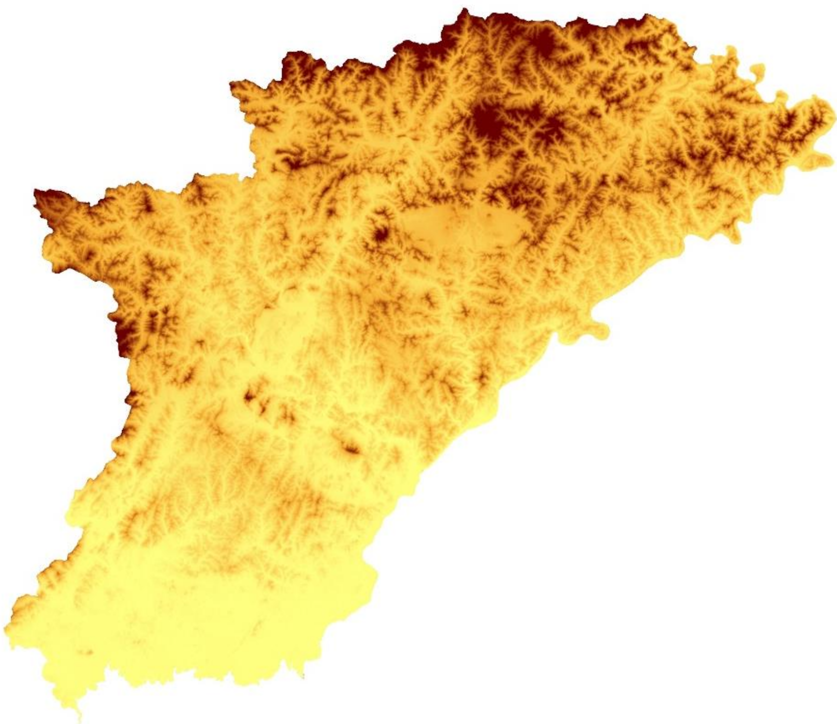


Figure 1.8 The situation of Dandong City 30 years after sea level rise

The coastal sea level of Liaoning coasts is anticipated to rise about 70-150 mm in next 30 years. The altitude of most areas in Dandong is over 2 m. Thus there will be very less submersion in the city (Figure 1.8).

Although some scientists believe that the ice on the earth will need at least 5000 years to melt, we could generate a world without ice again after 30 million years if we continue to increase carbon emissions. When the earth's average surface temperature goes up for 12 degrees, the sea level will rise 66 m, thus leading to the changing of continents coastline and submersion of big cities around the world.

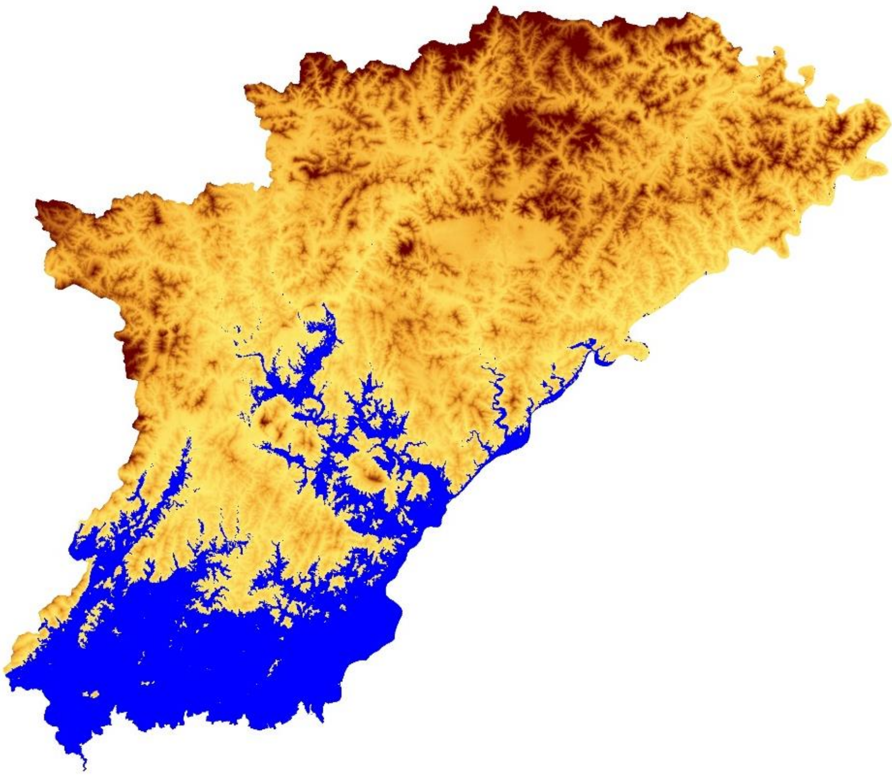


Figure 1.9 The situation of Dandong City after 66 meters of sea level rise (blue part is sea water)

Assuming that the ice on the earth melts away and the sea level rises 66 m, nearly one fifth of Dandong city will be submerged be sea water. The remaining part will be the northern mountains only.

1.2. Related Concepts

Sea Level

Sea level is the average height of the sea surface after eliminating various disturbances. It is usually obtained by calculating the average value of the observed tide level over a period of time. According to the time range, there are daily mean sea level, monthly mean sea level, annual mean sea level and multi-year average sea level.

Fluctuation of Sea Level

The fluctuation of sea level is the change in mean sea level height caused by changes in total sea mass, seawater density and ocean basin shape. In the context of global warming, glaciers melting and seawater expanding, the sea levels worldwide are on the rise.

Vulnerability

This term in Chinese stems from the word “vulnerability” in English, which refers to the ability of the system to withstand changes in external conditions, and is often used in the study of ecological systems and socio-economic systems. In the field of geosciences, Timmerman P. (1981) first proposed the concept of vulnerability. Today, due to different research objects and disciplinary perspectives between diverse application fields, the definition of "vulnerability" is very different, and the connotation is different when the same concept is used by different scholars (Figure 1.1). Natural sciences such as the study of natural disasters and climate change consider vulnerability to be the extent or possibility of damage to the system due to adverse effects such as disasters, focusing on the multiple effects of single disturbances. Social sciences such as the study of poverty and sustainable livelihoods, believe that vulnerability is the ability of the system to withstand adverse effects, focusing on the analysis of the causes of vulnerability. Li He et al. (2008) believe that vulnerability refers to an attribute that makes the structure and function of the system easy to change due to the sensitivity of the system (subsystem and system components). It is an intrinsic property that originates within the system, but only when the system is disturbed.

Table 1.1 The concept of vulnerability in different areas

Concept	Description	Emphasis
Vulnerability is exposed to the possibility of adverse effects or damage	(1) vulnerability refers to individuals or groups are exposed to the possibility of disasters and its adverse effect; (2) the vulnerability refers to the external disturbance due to strong events and expose components of vulnerability, leading to the damage possibility of life, property and environmental	Similar to the concept of "risk" in natural disaster research, it focuses on the analysis of the potential impact of disasters.
Vulnerability is the degree of damage or threat from adverse effects	(1) The vulnerability is the process of response of the system or part of the system when the adverse events occurred in disaster, (2) vulnerability refers to the system, subsystem, system components due to exposure to the disaster (disturbance or stress) and possible damage degree.	Common in natural disasters and climate change studies, the emphasis is on the results of systems facing adverse disturbances (disaster events).
Vulnerability is the ability to withstand adverse effect	(1) The vulnerability is the individual or social group's ability to respond to disasters, this ability is based the situation of the natural environment and social environment, (2) The vulnerability refers to the individual or social group	This description highlights the impact of social, economic, institutional, power and other human

	prediction, processing, resistance to adverse effects (climate change), and the ability to recover from the adverse effects.	factors on vulnerability, and focuses on the analysis of human factors driving vulnerability.
Vulnerability is a collection of concepts	(1) The vulnerability should include three meanings: (a). it shows that the system, group or individual exists inherent instability, (b) the system, group or individual is more sensitive to outside interference and change (natural or manmade), (c) under the stress of outside interference and the external environment change, the system, groups or individuals are vulnerable to a "kind of loss of or damage to the extent, and difficult to recover. (2) The vulnerability refers to ability of the exposure unit susceptible to damage due to exposure to disturbance and pressure and the degree of exposure unit processing, deal with and adapt to these disturbances and stress. (3) The vulnerability is a state in which the system is vulnerable due to the stress and disturbance brought by environmental and social changes and the lack of adaptability.	It includes a series of related concepts such as "risk", "sensitivity", "adaptability" and "resilience". It not only considers the impact of internal conditions on system vulnerability, but also includes the interaction characteristics between the system and the external environment

Vulnerability has also undergone a process of conceptual connotation expansion: from the inherent (natural) vulnerability of purely natural systems to a broader concept of meaning to nature and social systems. The focus on vulnerability transformed from the environment-centered concept, which focuses on the assessment of vulnerability caused by the natural environment, to a human-centered concept, which stresses the role of human beings in the formation of vulnerabilities and the reduction of vulnerability. It is changed from merely negatively or passively confronting or evaluating the damage suffered by nature or society to taking human initiative adaptability as the core issue of vulnerability assessment.

Coastal vulnerability in the context of global change refers to the instability and trends of natural and social environmental systems in the region when they are influenced by the global change in their internal structure and function, the existence of the substrate environment, as well as human being and wealth. In the background of global change, the ability to counterbalance is limited and to recover and regenerate is poor. It is easy to develop towards a vicious direction, and ultimately will no longer sustain human survival and sustainable development.

Based on the actual situation of Dandong and in line with the people-oriented basic principle, this paper explores the rising sea level vulnerability by focusing on human tolerance.

1.3. Evaluation Process

a. Collect satellite remote sensing images, basic geographic information, DEM (Digital Elevation Model), population, GDP (Gross Domestic Product) and other statistical data of Dandong. By using GIS (Geographic Information System) and remote sensing technologies to process data, establish a Dandong coastal zone vulnerability assessment database, and extract information such as topographic information, population and GDP distribution of Dandong.

b. Based on the collected data, the evaluation area is confirmed, and the evaluation indicators are selected from the aspects of disaster causation and disaster suffering aspects in line with the index selection principle.

c. Establish an evaluation index system, standardize the index data, eliminate the influence of different dimensions, and analyze and calculate comprehensively the importance of each index. By using the method of analytic hierarchy process (AHP), the weight of each index can be determined and calculated in the mathematical model to evaluate the vulnerability of Dandong sea level rise.

d. Based on the evaluation results, the features of sea level rise vulnerability in Dandong can be analyzed.

Chapter II Areas Overview Assessment

2.1. Natural Geography

The geographical location of Dandong City is N39°44′-41°09′ and E 123°23′-125°42′. Dandong is along the Yalu River in the east and opposite to the Xinyizhou City of the Democratic People's Republic of Korea. It is adjacent to the Yellow Sea in the south, adjacent to Zhuanghe City of Dalian in the southwest, Xiuyan County of Anshan City in the west, Liaoyang County of Liaoyang City in the northwest, and Changbai Mountain in the north. Dandong is bordered by Benxi County of Benxi City, and the northeast is separated from the Qianjiang River in Ji'an City of Jilin Province and connected with Huanren County of Benxi City.

Topographical features

Dandong is in the Liaodong mountainous hilly area consisting of Qianshan branch and veins extending to the southwest of the Changbai Mountains. It is bounded by the Cao River near the Shendan Railway. The eastern part belongs to the Changbai Mountains and the west belongs to the Qianshan Mountains of the Changbai Mountain Branch. The overall trend of the mountain range is north-east, and there are many groups of directions from north to south and east-west. The terrain of the whole region gradually decreased from northeast to southwest. According to the height and topographical features, it can be divided into three types of large-scale geomorphic units: the middle-low mountain area in the north, the low mountain-hill area in the middle and south, and the coastal plain area in the southern margin. Among them, low mountain-hill area is the main area, accounting for 82% of the whole area; medium-low mountain area is about 2,000 square kilometers, accounting for 13% of the whole area; coastal plain area is about 800 square kilometers, accounting for 5% the area of the whole area. There are also small geomorphic units such as mountain basins and river terraces. The main mountain ranges (mountain peaks) include Huabo Mountain, Maokui Mountain, Bamianwei Mountain, Xiangshuigou Mountain, Sifangding Mountain, Guozi Ridge, Motian Ridge, Baishilazi Mountain and Baiyun Mountain. The highest peak in the territory is in the northern part of Kuandian Manchu Autonomous County, 70 kilometers away from Kuandian County. It is 1336.1 meters above sea level and is the highest peak in Liaoning Province. It is called “Liaoning Roof”. The area along the Yalu River and the Dayang River is below 2 meters from sea level, forming a large swamp.

Climate

Dandong is a continental monsoon climate in the warm temperate sub-humid zone. It is characterized by no cold in winter, no heat in summer, four distinct seasons, rich precipitation, moist and foggy and fresh air. The regional climate is unique, with cloudy mountains, smog along the river, and snowy landscapes in winter, which is a rare summer resort in eastern China. The average annual temperature is 9.2 ℃, the average temperature in January is -7.3 ℃, and the extreme minimum temperature is -28 ℃. The average temperature in July is 23.1℃, and the extreme maximum temperature is 35.5 ℃. The minimum monthly average temperature is -16.7℃, and the highest monthly average temperature is 30.2 ℃. The annual temperature range is 31.6℃, and the maximum diurnal range is 16.4 ℃. The growth period averages 160 days per year. The frost-free period averages 173 days, with a maximum of 180 days and a minimum of 165 days. The average annual sunshine hour is 2459 hours, and the duration above 0 ℃ is 229 days. The annual average precipitation is 961.2 mm, and the annual average rainfall days are 90 days, up to 119 days, and at least 68 days. Rainfall is concentrated in July to August each year and most in July.

Rivers

The Dandong area is densely populated by rivers, including the Yalu River system, the Dayang River system and the coastal water system. There are 944 rivers over 2 kilometers in the region, including 4 rivers and rivers with a river basin area of over 4,983 square kilometers, namely Yalu River, Minjiang River, Aihe River and Dayang River. The per capita water volume is 1.5 times that of the national per capita water.

Marine resources

The coastline of Dandong is 125 kilometers long, the coastline of the sea island is 32.5 kilometers long, and there are 30 coastal reefs. It is mainly concentrated on the coasts on both sides of the Dayang estuary. Among them, there are 28 shallow-water near-shore islands with an area of more than 500 square meters, with a total area of 5.9 square kilometers. The larger island reefs include Xiaodao, Ludao, and Zhangdao.

The water depth of the Dandong Sea is 8-40 meters, the seabed topography is gentle, and the average slope is less than 1‰, which is inclined from the northwest to the southeast. There are 363,000 mu of tidal flats in the intertidal zone, and 923,000 mu of shallow sea between 0-10 m isobath. The sea floor is extremely flat and the slope is 1.06 ‰. The sediment of the sea area is composed of clay silt, silt, sandy silt and powder. It is composed of sandy sand and fine sand, and its particle size gradually becomes thicker from the shore to the sea and from west to east.

2.2. Socioeconomic Profile

According to preliminary calculations, Dandong City achieved a GDP of 81.67 billion RMB, ranking 11th in Liaoning Province. It was calculated at comparable prices, an increase of 0.4% over the previous year, and the growth rate ranked 14th in the province. Among them, the added value of the primary industry was 13.64 billion RMB, up 3.4%; the added value of the secondary industry was 24.96 billion RMB, down 0.5%; the added value of the tertiary industry was 43.08 billion RMB, down 0.5%. The added value of the three industries accounted for 16.7:30.6:52.7 of the regional GDP. The annual per capita GDP is 34,193 RMB, calculated at comparable prices, an increase of 1.2% over the previous year, and converted at an annual average exchange rate of 5167.1 US dollars.

The annual CPI (Consumer Price Index) rose by 2.5% over the previous year. Among them, the price of health care rose the most, up 12.9% over the previous year; food, tobacco and alcohol rose second, up 2.8%. The ex-factory price index (PPI) of industrial producers in the city increased by 1.6% over the previous year. The number of new jobs in the town was 17,577. In the whole year, there were 23,251 registered unemployed persons in urban real estate, and the urban registered unemployment rate was 4.66%, an increase of 0.98 percentage points over the previous year.

Chapter Ⅲ Data and Methodology

3.1. Data Source and Processing

The remote sensing images here are from the Landsat-8 OLI remote sensing data of the United States Landsat, which were imaged on March 20, 2018. The spatial resolution is 15 m for the full-color band and 30 m for the multi-spectral band. The basic geographic information of Dandong City comes from the 30 m resolution DEM data of the International Scientific Data Service Platform. Dandong economic and social data (population, GDP, etc.) are derived from the work reports of the county and district governments and other literature documents. The base year for all data is 2018.

a. Remote sensing data

For image preprocessing, the procedure is shown in Figure 3.1, including geometric correction, image mosaic, image cropping, and atmospheric correction. The obtained Landsat-8 OLI remote sensing image which covers the whole Dandong city is already a pre-processed L1T product. We believe that its spatial accuracy and radiation error meet the project requirements, so there is no need to conduct pre-processing again.

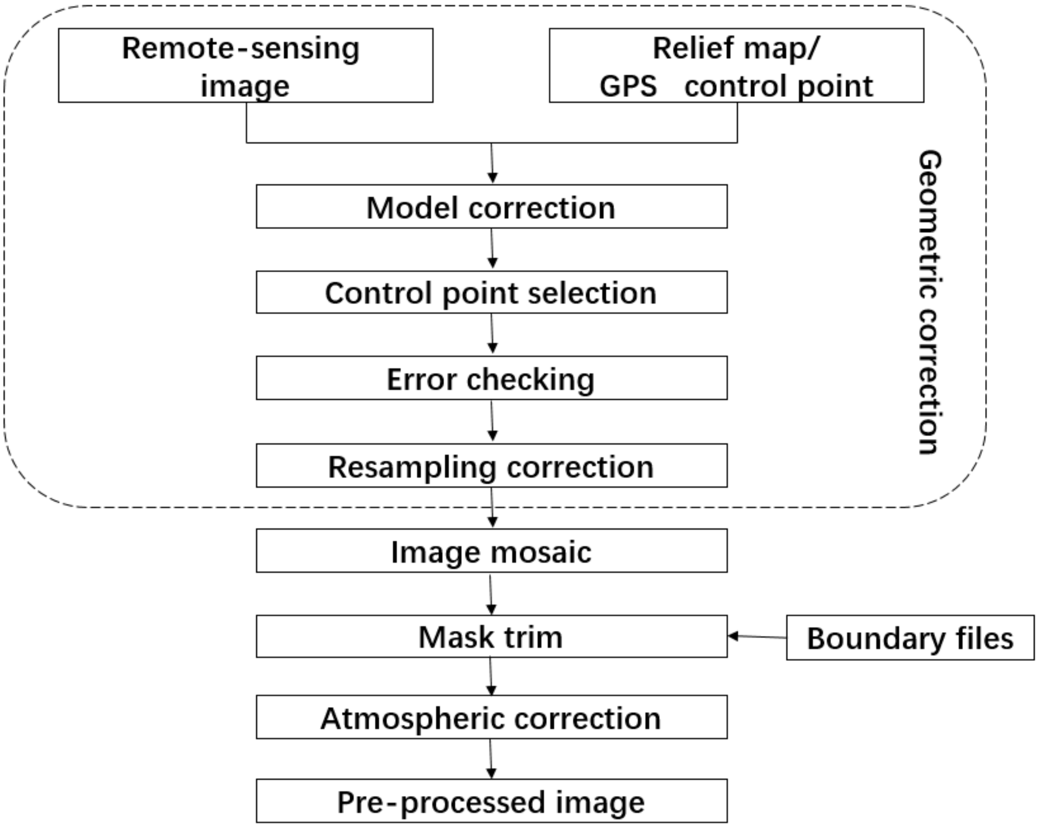


Figure 3.1 Remote sensing image pre-processing process

Follow-up work includes multi-spectral band combination, resolution blending, image cropping etc. The final remote sensing image is shown in Figure 3.2.

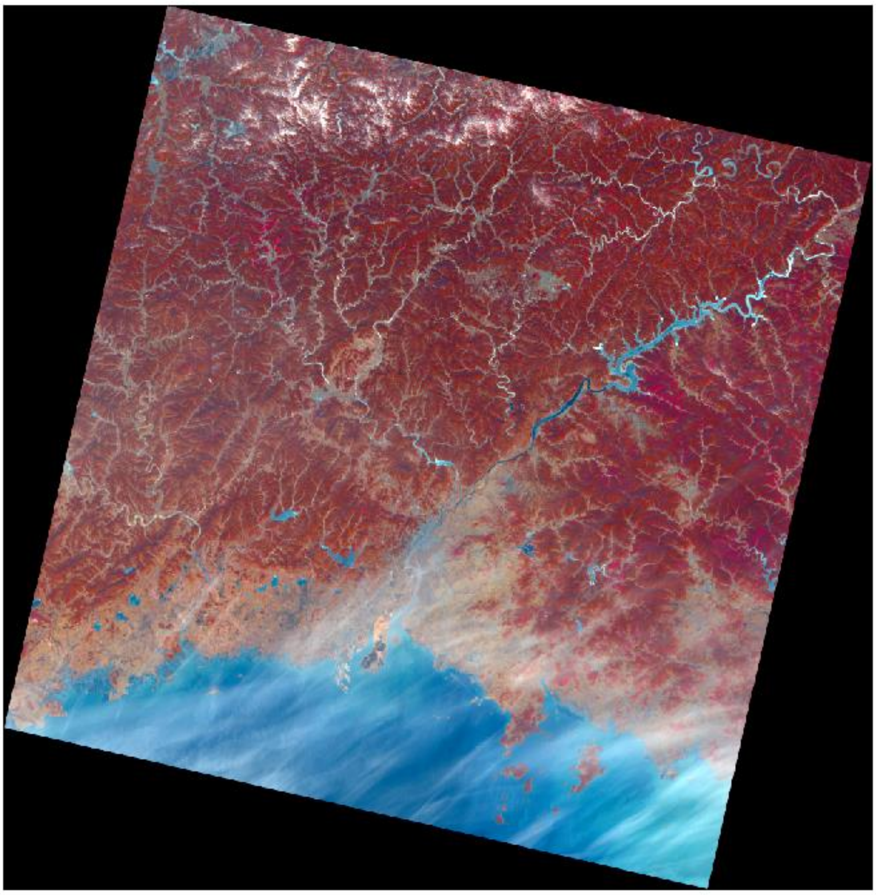


Figure 3.2 Post-processing remote sensing images

b. DEM Data

Coordinate correction

The acquired DEM data may be different from the coordinate system we used, and this is why the coordinate correction is required.

Eliminate data exception

Due to various reasons, there may be data exception in the DEM data, which will affect the normal use of DEM data. Therefore, the elimination of noise is required.

Depressions fill

Due to the interpolation during the production process or the existence of some special topography, there are some unnatural recessed areas on the surface of the DEM. These areas can affect the results of elevation analysis. Therefore, before analyzing and calculating, the original DEM data should be firstly filled to get the innocent DEM.

Data clipping

To avoid calculation redundancy and improve calculation efficiency, data will be selected only with Dandong City. The elevation range is from 0 m to 1320 m, as shown in Figure 3.3.

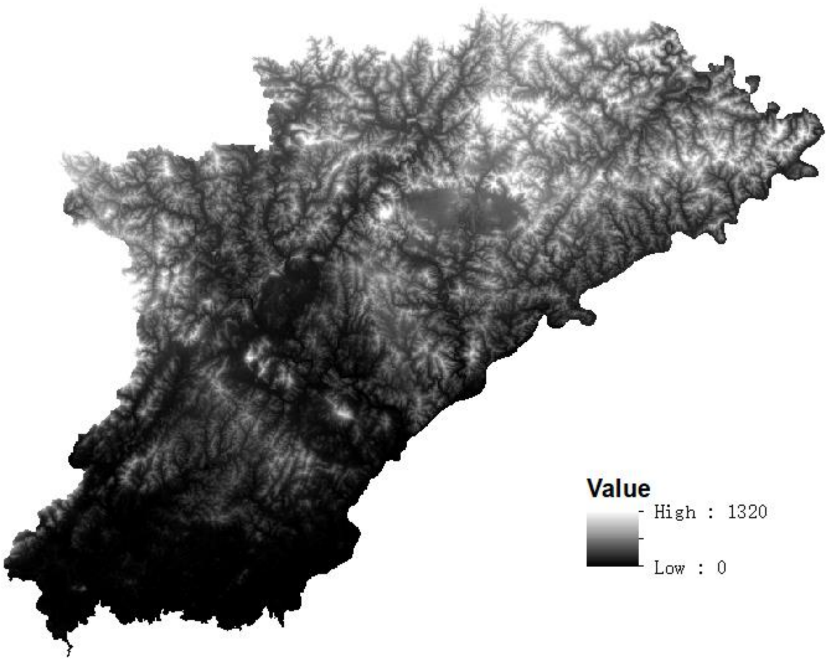


Figure 3.3 Dandong DEM Data

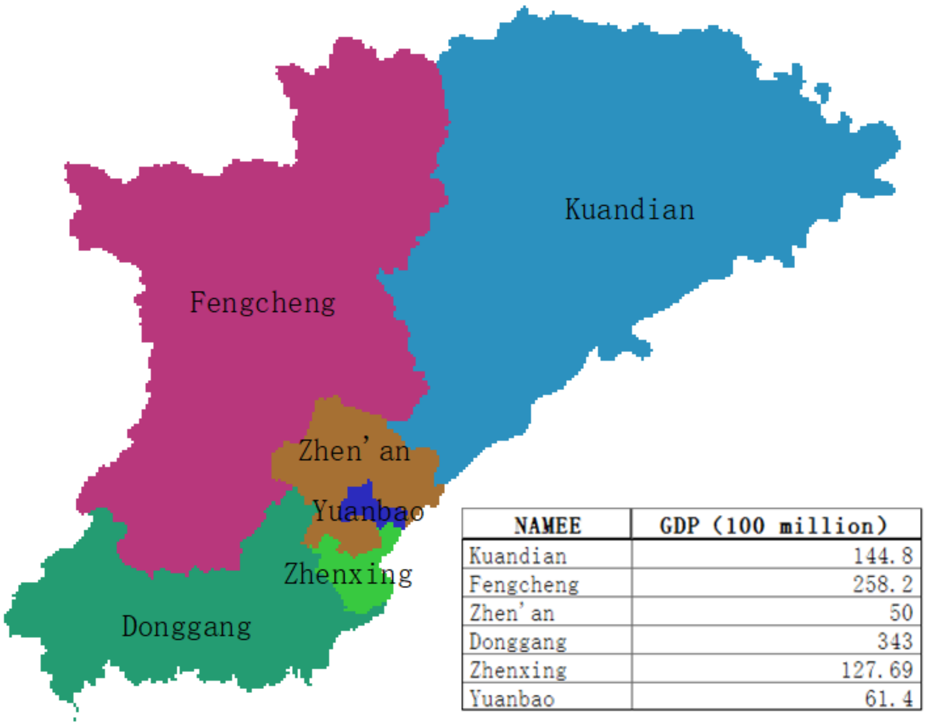
c. Population and GDP

According to the government work reports of Dandong districts and counties, by 2018, the GDP of Dandong was 98.509 billion RMB, with the population of 2.511 million (Table 3.1).

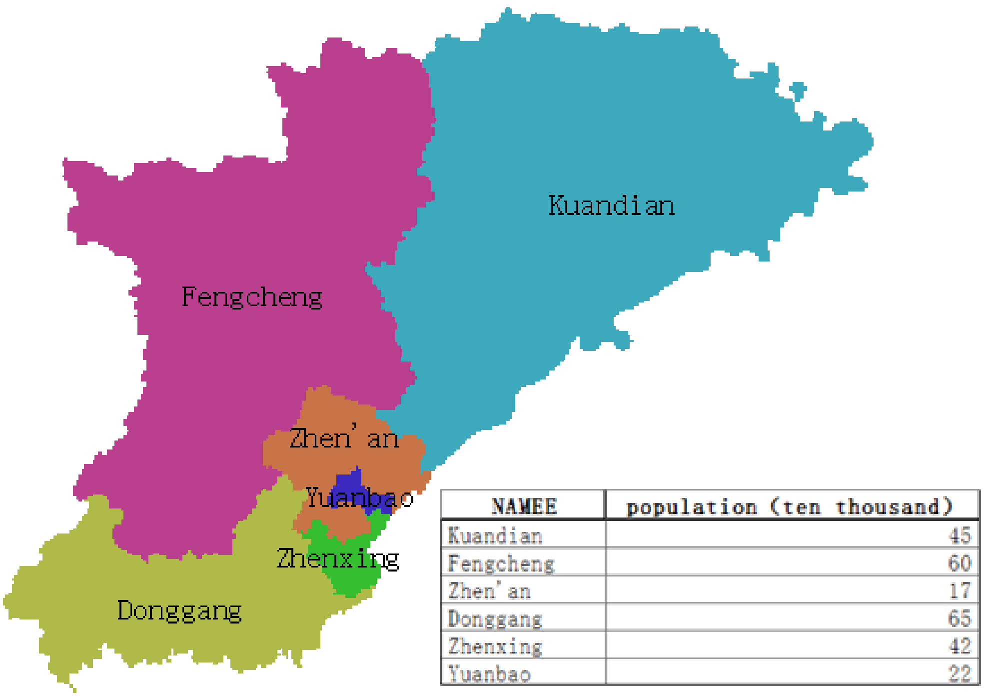
Table 3.1 Population and GDP of all districts and counties in Dandong City

Area / Indicator	Fengcheng	Kuandian	Donggang	Zhenxing	Zhenan	Yuanbao
Population (10^4)	60	45	65	42	17.1	22
GDP (10^8) RMB	258.2	144.8	343	127.69	50	61.4

Here obtained the surface vector distribution image of Dandong population and GDP (Figure 3.4).



NAMEE	GDP (100 million)
Kuandian	144.8
Fengcheng	258.2
Zhen' an	50
Donggang	343
Zhenxing	127.69
Yuanbao	61.4



NAMEE	population (ten thousand)
Kuandian	45
Fengcheng	60
Zhen' an	17
Donggang	65
Zhenxing	42
Yuanbao	22

Figure 3.4 Digital population and GDP data

3.2. Evaluation Methods

Common ways to evaluate vulnerability include synthetic index method, graph stacking method, vulnerability function model evaluation method, fuzzy matter element evaluation method and risk analysis method.

a. Synthetic index method

It establishes an evaluation index system from the aspects of vulnerability performance characteristics and causations, and uses statistical methods or other mathematical methods to form a vulnerability index to indicate the relative size of the vulnerability of the evaluation unit. It is the commonly used vulnerability assessment at present. The commonly used mathematical statistical methods in this method include weighted summation (average) method, principal component analysis (PCA), analytic hierarchy process (AHP), and fuzzy comprehensive evaluation method.

The synthetic index method is widely used in vulnerability assessment for its simplicity and easy operation. However, this method lacks a systematic view on the evaluation of vulnerability, neglects the interaction mechanism between various components of vulnerability. At the same time, there is no effective way to select indicators and determine weights. The causations and performance characteristics of vulnerabilities have strong regional differences in space and dynamic variability in time, so it is hard to establish a cross-region evaluation system. In addition, the effectiveness of the evaluation results obtained by this method is rarely verified.

b. Graph stacking method

It is developed based on GIS technology. According to its evaluation ideas, it can be divided into two stacking methods: (1) graph stacking layers of vulnerability components; (2) different vulnerability components layers. This method provides a research idea for vulnerability assessment in the context of multiple perturbations (natural, economic) but does not consider the differences between risks of various disturbances and their impacts on the overall vulnerability of the system. So the evaluation results are very difficult to reflect the main factors affecting regional vulnerability, and there is little inspiration for how to reduce system vulnerability.

c. Vulnerability function model evaluation method

Based on the understanding of vulnerability, this method first quantitatively evaluates the components of vulnerability, and then establishes a vulnerability assessment model based on the interaction between the components of vulnerability. The functional model evaluation method has a strong correspondence between the vulnerability assessment and the vulnerability content, and can reflect the interaction between the components of the vulnerability, which is helpful to explain the causations and characteristics of the vulnerability. The evaluation results can reflect the overall vulnerability of the system. However, there is no commonly accepted concept, components and interactions of vulnerability, and it is hard to quantitatively express vulnerability components, which makes the evaluation method progress slowly, but this method has been studied and draws attention of more and more scholars.

d. Fuzzy matter element evaluation method

In this method, the relative vulnerability of each study area is determined by calculating the degree of similarity between each study area and a selected reference state (highest or lowest vulnerability). Based on the basic theory and method of matter-element analysis, combined with fuzzy set theory and European closeness concept, the fuzzy matter element evaluation method based on European closeness is established. The regional water security is evaluated by the closeness of each region and the optimal reference state. This method does not synthesize many indicators into a comprehensive index. Therefore, it is not necessary to consider the correlation between variables, and the information of the original variables can be fully utilized. The disadvantage is that the definition of the reference unit lacks a scientific and reasonable method, and the evaluation result selects the standard for the reference unit. The change is very sensitive, and the evaluation results reflect less information. It can only reflect the relative size of the vulnerability of each research area, and it is difficult to reflect the determinants of the spatial difference of vulnerability and the characteristics of vulnerability.

e. Risk analysis method

The method meatures the Euclidean distance between the vector value of each variable of the research unit and the vector value of each variable in the natural state. It is considered that the larger the distance, the more fragile the system is, and the easier it is to completely change the structure and function of the system. This method is mostly used for ecological environment vulnerability assessment, which can reflect the extent to which the system deviates from the natural state, and thus reflects the ecological risk degree of the research unit to some extent. On the other hand, the human activity is set to be none, while the range of other ecological variables is relatively stable in the natural state, so the selection of the reference state does not change much, which makes the selection of the reference point more stable. The shortcoming of this method is that it assumes that the region in the natural state is the region with the least vulnerability. This assumption ignores the promotion of the improvement of the ecological environment by human activities. At the same time, there are many uncertainties in the setting of the natural state. The treatment of these uncertainties usually adopts some fuzzy values, but it is easy to produce the evaluation results that most of the research units are close to the natural state, and a few research units are highly vulnerable. Although this method can reflect the ecological risk degree of the research unit, the extent to which the system vulnerability is not reflected, and there is no established vulnerability threshold.

The above vulnerability assessment methods all have their own advantages and disadvantages in dealing with complex systems. It is necessary for evaluators to integrate methods in a complementary manner according to the purpose of evaluation, and to strengthen the application of integrated methods in vulnerability assessment.

With the deepening of vulnerability research, the vulnerability assessment method is increasingly diversified and complicated, but the vulnerability assessment should start with a simple evaluation method, and be based on the overall understanding of the vulnerability of the evaluation area. Complex evaluation methods are used for in-depth and detailed evaluation. If the evaluation objectives or evaluation results obtained by several evaluation methods are similar, a simple vulnerability assessment method should be preferred.

The evaluation of sea level rise vulnerability in Dandong mainly combines the weighted summation method and the analytic hierarchy process in the comprehensive index method. By integrating that into GIS, the graph stacking method is used to complete the data processing and the final vulnerability assessment calculation.

Firstly, the data acquisition and preprocessing is mainly used for basic preprocessing of remote sensing images, basic geographic information and other source data, including correction of remote sensing images, and slope and aspect extraction based on DEM data.

Secondly, in the research and analysis phase, the model theory and basic mathematical statistics methods are mainly used. Through modeling, the specific research content is refined and systematized. In this paper, not only in the weight analysis part of the indicator data, it is applied to the statistical analysis, the analytic hierarchy process is also used in the work of superposition analysis of geospatial elements by using mathematical statistics tools and methods to clearly extract and express the required research results.

Finally, the most widely used spatial analysis tools are software of ArcGIS and ERDAS. They can help to realize mask processing, raster computing, surface layer analysis, partition statistics, overlay analysis, classification expression, etc.

Chapter IV Dandong Sea Level Rise Vulnerability Assessment

4.1. Selection Principle of Assessment Indicator

To assess the vulnerability of regional sea level rise, it is necessary to establish the scientific evaluation index system and evaluation model, which involves diverse aspects such as nature, society and economy. This requires that the evaluation of regional economic, social, and natural aspects and other aspects should be involved in the indicator selection process, and it should fully reflect the essential characteristics of sea level rising vulnerability. Therefore, the following basic principles should be followed when constructing a sea level rising vulnerability indicator system.

a. Scientific principle

The sea level rise vulnerability assessment index should be consistent with the local actual situation, and the structure must be scientific and reasonable, which can correctly reflect the threat degree of sea level rise disaster. The logical structure should be strict.

b. System principle

The indicator that reflects the vulnerability of sea level rise should be a relatively complete system. Although there are primary and secondary factors, they all reflect different aspects of sea level rise vulnerability. At the same time, the types, structures, and meanings of indicator factors must conform to the relevant national norms and be coordinated with each other.

c. Operability principle

The selection of the indicators will eventually need to be quantified, and the acquisition and update of the corresponding quantitative data should be operational. In the process of selection, we should choose indicators that fit the objective conditions. Though some indicators have better performance in indicating sea level rise vulnerability, with data shortage, we cannot do quantitative analysis. Therefore, it is necessary to follow the operability principle and put quality before quantity.

d. Independence principle

The selected indicators are not only a relatively complete system, but also independent to each other. To avoid overlapping representation, each indicator should be the most representative one of its field.

4.2. Construction of Indicator System

The vulnerability of sea level rise is mainly restricted by two factors, namely the disaster causations and the disaster suffering aspects. The disaster causations selected in this paper are the ground elevation, surface slope and gully density.

Ground elevation: This indicator is the decisive factor for the vulnerability of sea level rise areas. It represents the elevation value of a location. The larger the value, the less likely it is to be submerged or become disaster-prone when sea level rises.

Surface slope: The slope represents the steepness degree of the surface. Under the same conditions, the coastal surface in the same sea level rises, the larger the slope, the smaller the area that may be submerged or disaster-prone.

Gully density: It refers to the total length of the erosion ditch (or hydrological network) per square kilometer (shown in km/km^2), or cutting crack. It is an indicator to measure the degree of surface fragmentation. The density of gully is related to the precipitation and runoff characteristics, topographic slope, lithology, soil erosion resistance, vegetation status, land use pattern, etc. It is also a way of soil erosion, which can be used as a reference indicator for soil erosion. In this paper, it is used as one of the indicators to measure the vulnerability of sea level rise. The sea level rises through the energy transmitted by the gully and further erodes the newly formed sea (ditch) bank in the area that hasn't be submerged. The greater the density of the gully, the greater the vulnerability of the disaster (Figure 4.1).

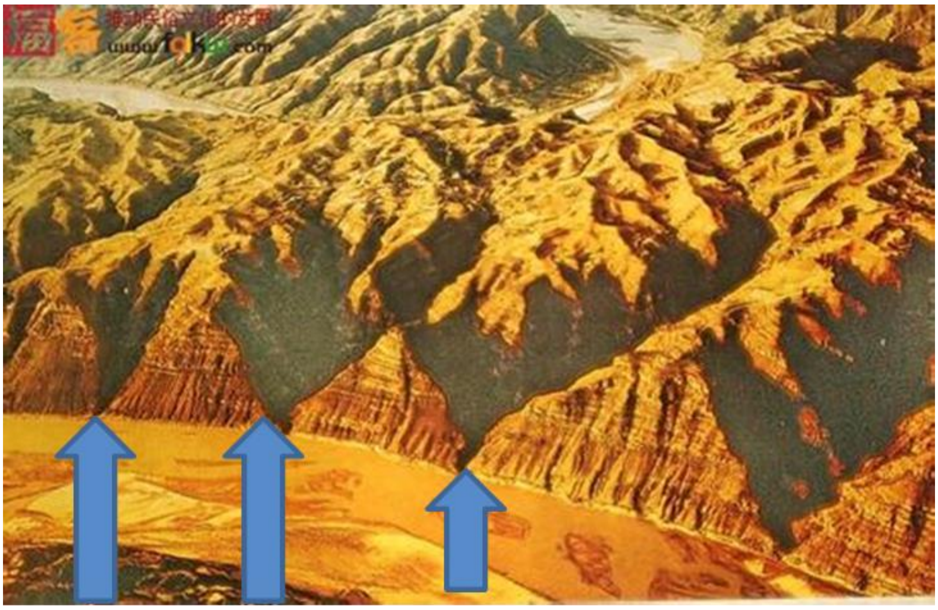


Figure 4.1 The energy signal of sea water through the ravine

The disaster suffering aspects include the population density and GDP per capita.

Population density: The number of people living on a unit of land. It is based on the data from the county-level government work report in 2018, which is the total population of the county/the total land area of the county.

GDP per capita: It refers to GDP per square kilometer of land, reflecting the efficiency of land use (which can partially reflect the industrial and commercial intensity of the area). GDP per capita is an excellent indicator to show the density of output and level of economic development. It can also reflect the development level of the region and the degree of its economic concentration.

Based on the actual situation of natural and social environment of Dandong, a sea level rise vulnerability assessment system is constructed, aiming at sea level rising vulnerability, starting from the disaster causations and disaster suffering aspects, and taking the ground elevation, surface slope and population density as the assessment factors.

4.3. Weight Calculation

The weights of indicators are calculated by Analytic Hierarchy Process (AHP) combined with quantitative and qualitative methods. Firstly, according to the actual situation of Dandong, indicators are rated by experts by using the nine-scale method (1-9). Then the judgment matrix is constructed separately to calculate the relative importance of each indicator.

Firstly, establish a hierarchical structure that clearly shows the relationship between levels. There are two levels in this paper: the baseline layer and the indicator layer.

Secondly, by using the nine-scale method to compare factors between layers and the same layer, establish a comparison matrix $A_n=(a_{ij})_{n\times n}$, where a_{ij} uses 1, 2, 3, 4, 5, 6, 7, 8 , 9 and their reciprocal representations. Their meanings are: l (A_i is as important as A_j), 3 (A_i is a little bit more important than A_i), 5 (A_i is important than A_i), 7 (A_i is more important than A_i) and 9 (A_i is much more important than A_i); 2, 4, 6, 8 mean that the value is between the above two neighbors. The reciprocal of each scale has the opposite meaning. Any judgment matrix satisfies $a_{ii} = 1$，$a_{ij}=1/ a_{ji}$, see Table 4.1.

Table 4.1a Disaster Factor Judgment Matrix

	Gully density	**Ground elevation**	**Surface slope**
Gully density	1	(1/3)	3
Ground elevation	3	1	5
Surface slope	(1/3)	(1/5)	1

Table 4.1b Affected factor judgment matrix

	Population density	GDP
Population density	1	5
GDP	(1/5)	1

Finally, the matrix weights are calculated. The weights of the index layer are multiplied by the weights of the reference layer to get the final weight values of each indicator. The result is shown in Table 4.2.

Table 4.2 Results of the calculation of each indicator's weight

Factors	**Gully density**	**Ground elevation**	**Surface slope**	**Population density**	**GDP per capita**
weighted value	0.215264	0.530842	0.08729	0.138847	0.027757

4.4. Data Processing and Standardization

Based on the pre-processing of the source data, the indicator data can be extracted and post-processed. Because data of different indicators have different dimensions, it is necessary to standardize the multiple indicator data to achieve dimensionless data. The method adopted is the Min-max standardized method, and the formula is:

New data = (original data - minimum value) / (maximum value - minimum value)

The data is mapped in the interval [0, 1]. In order to make the new data close to the numerical range of the source data, the formula is slightly modified to:

New data = (original data - minimum value) *1000 / (maximum value - minimum value)

The processed data range is (0, 1000), which facilitates the direct participation of different indicators in sea level rise vulnerability calculation.

Ground elevation: The pre-processed DEM data is used, and the value range is between [0, 1320], which is standardized by GIS. Because the elevation is negatively correlated with the sea level rise vulnerability, the data must be multiplied by -1 before standardization before calculation. The final data result is shown in Figure 4.2.

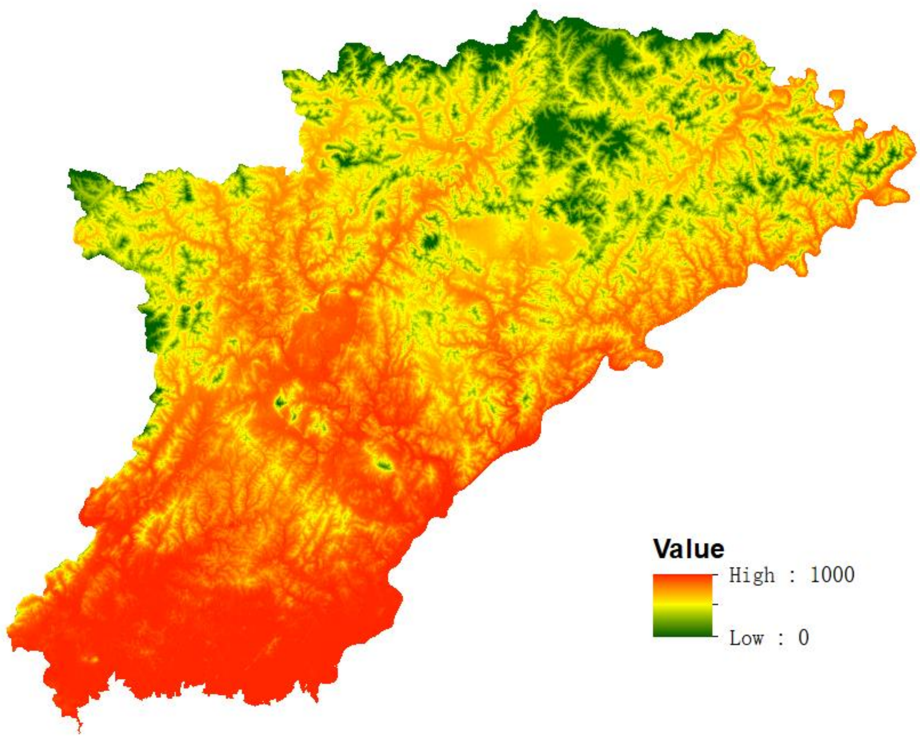


Figure 4.2 Standardized elevation data

Surface slope: The slope data is extracted based on DEM data. The value range is [0, 68.02]. Similar to the elevation data, the slope of the ground surface is negatively correlated with the sea level rise vulnerability. The standardization method keeps the same. The result is shown in Figure 4.3.

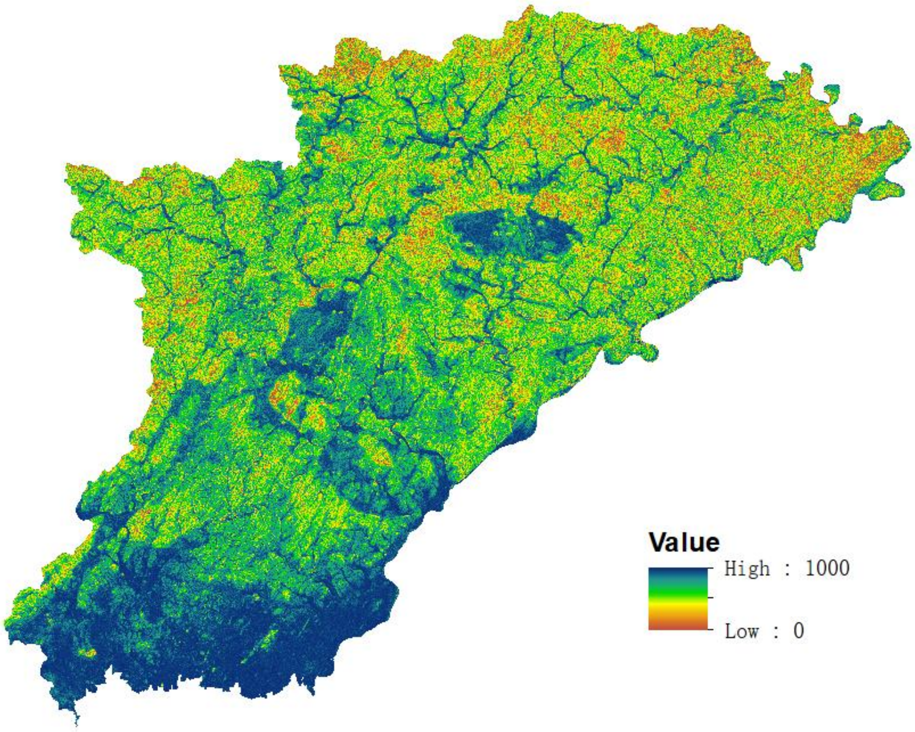


Figure 4.3 Standardized slope data

Gully density: The pre-processed DEM data is used to conduct hydrological topographic analysis in GIS, producing the gully distribution data of Dandong. Use the grid with a side length of 1 km to cover the gully data and calculate the gully density, and assign the value of each grid. The geometric center point is further calculated by interpolation to obtain the final gully density distribution map with the value range of [0, 4.78] (Figure 4.4).

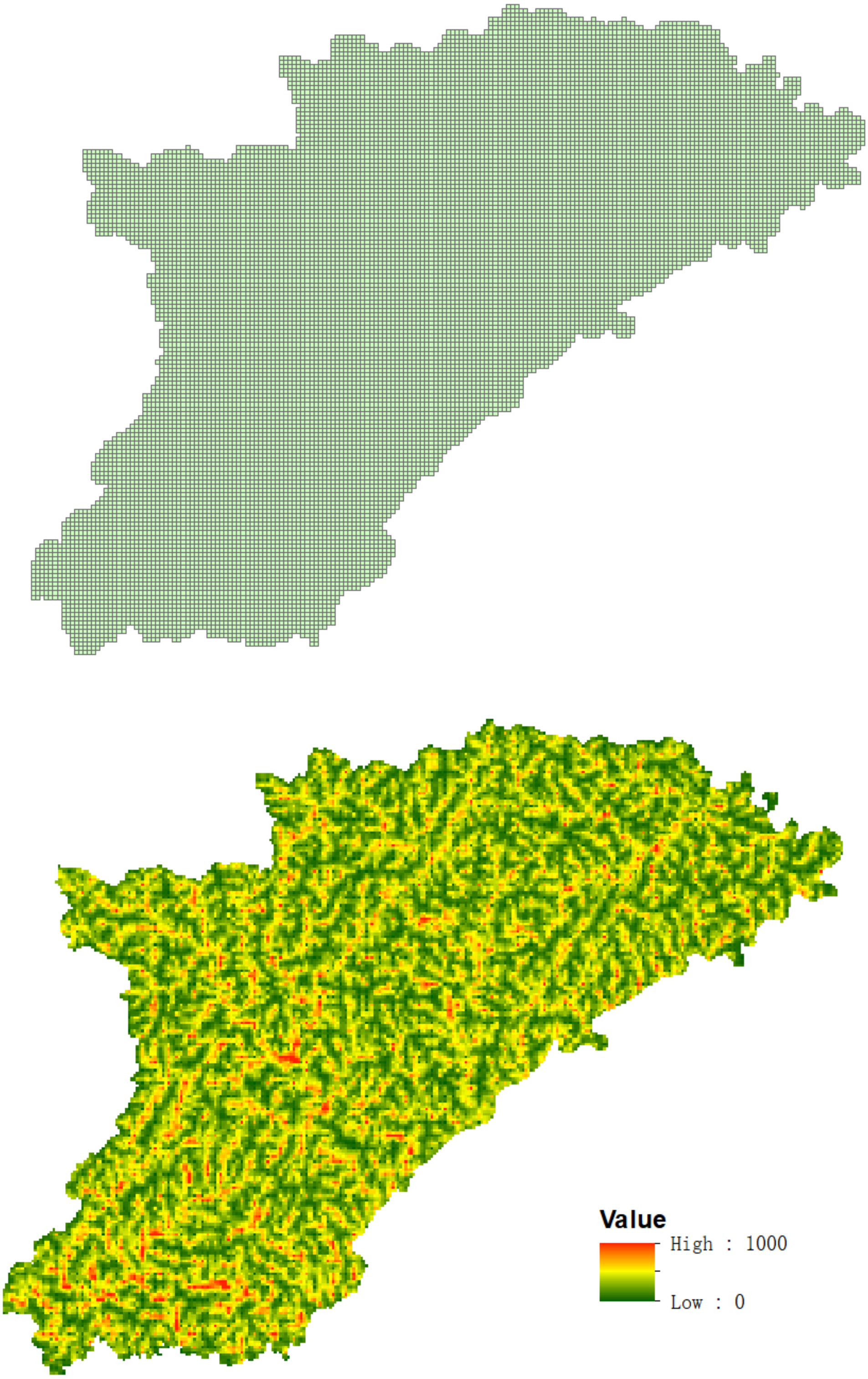


Figure 4.4 Covering grid and standardized trench density data

Population density: It is calculated directly by using the population source data and the area of each district in GIS. The calculation result is [72.3,2787.07], as shown in Figure 4.5.

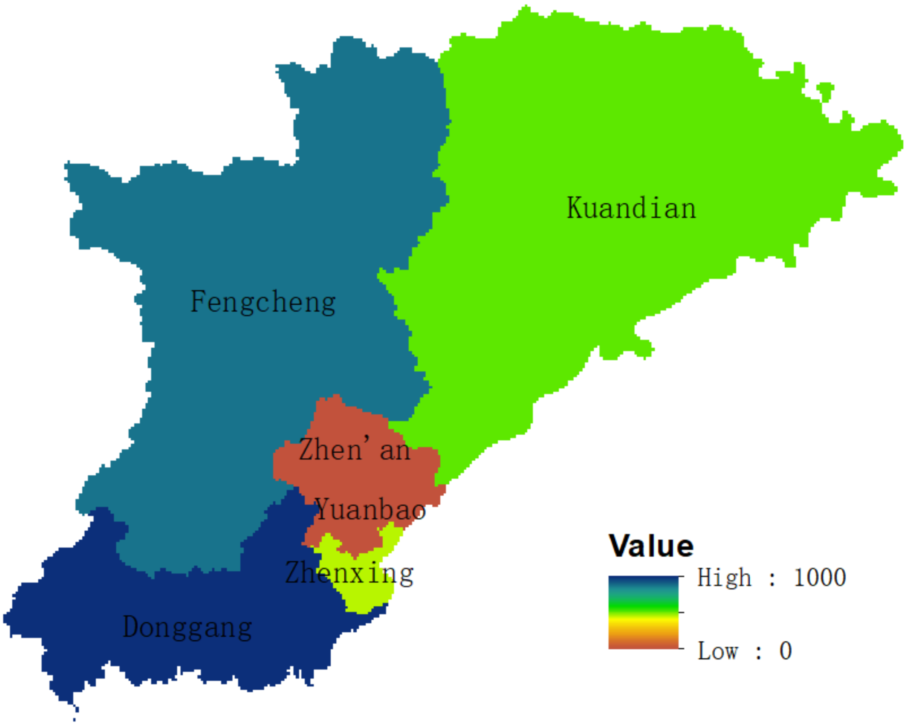


Figure 4.5 Standardized population density data

GDP per capita: The method is same with the population density. The range of values is between [232.65,7778.47]. The results after standardization are shown in Figure 4.6.

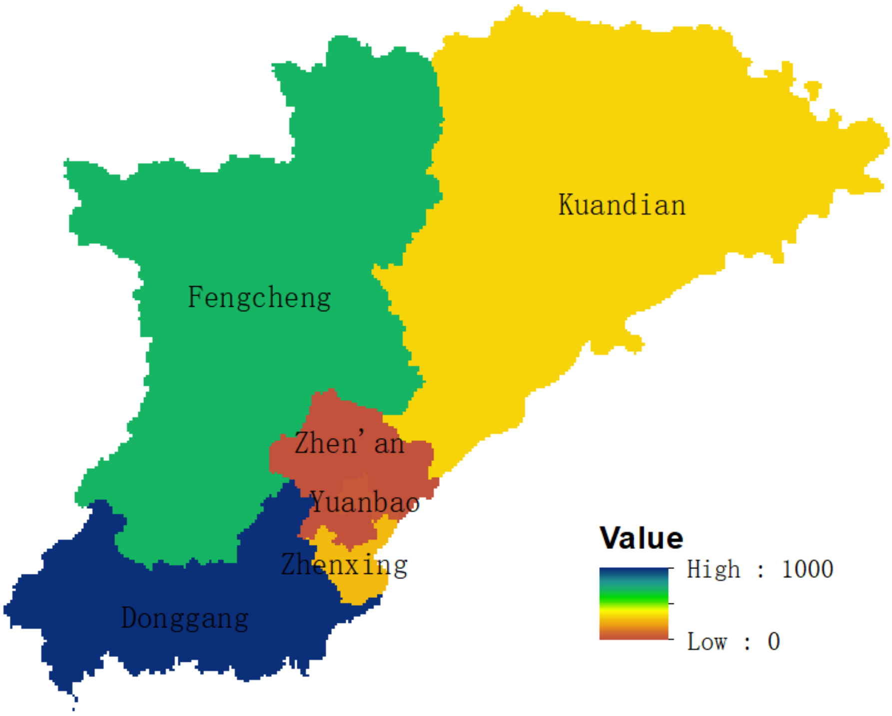


Figure 4.6 Standardized average GDP data (Please use English for any legend and texts in the figure!)

4.5. Construction and Operation of Assessment Model

The comprehensive indicator method is used to calculate and measure the final sea level rise vulnerability of Dandong. Based on the source data, the assessment indicator data is extracted. After standardization, the weights of indicators calculated by the analytic hierarchy process are substituted as follows:

$$idx=\sum_{i=1}^{n} C_i \times w_i$$

In the formula: idx - index value; w - index weight; C - index magnitude; i - the number of indicators of a factor. Then the comprehensive index of sea level rise vulnerability in the assessment area can be obtained.

All standardized indicator data is stored in the form of a grid, and the calculation is conducted on ArcGIS grid computing platform. The result is shown in Figure 4.7.

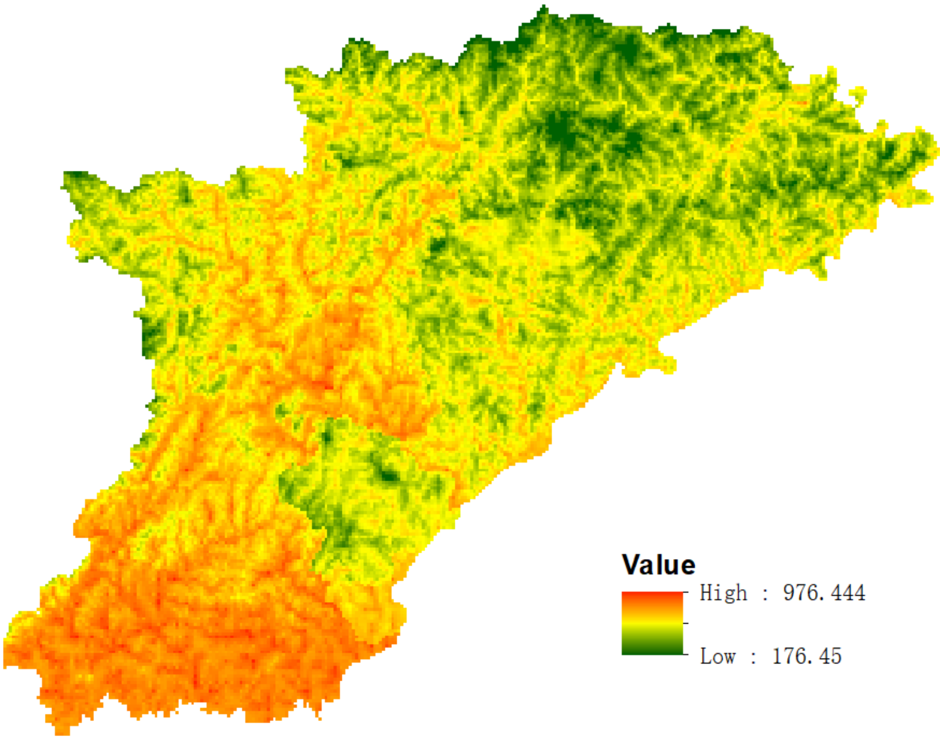


Figure 4.7 Spatial map of sea level rise vulnerability in Dandong

Chapter V Results and Analysis

5.1. Evaluation Results

According to the normalized value and weight of each evaluation index, the weights are summed in the GIS. Finally the numerical values of grid elements of Dandong sea level rise vulnerability are obtained after calculation. The result values range from 176.45 to 976.444 with an average of 654.74 and a standard deviation of 108.97. And from the grid statistical histogram (Figure 5.1), it can be seen that Dandong sea level rise vulnerability grid value obeys the normal distribution, that is, the vulnerability basically floats above the middle line.

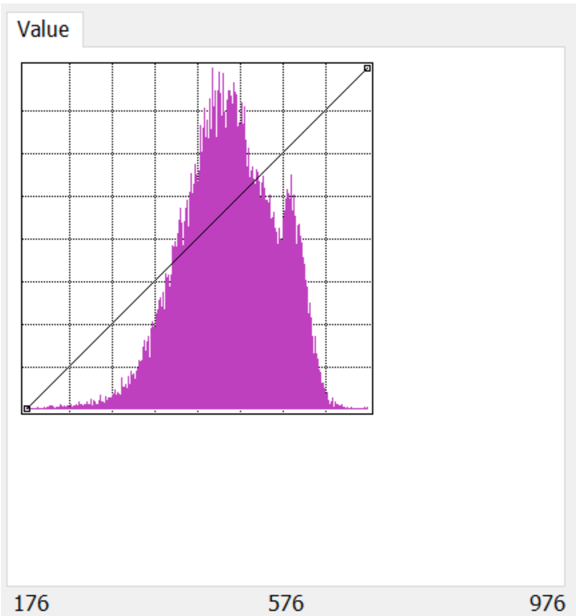


Figure 5.1 Statistics of the vulnerability grid for sea level rise in Dandong

5.2. Results Analysis

Based on data distribution characteristics of the final result, the natural discontinuous point segmentation method is used to classify the results. The obvious "fracture" in the distribution map is used as the boundary point, and finally Dandong sea level rise vulnerability is divided into 5 degrees (Figure 5.2).

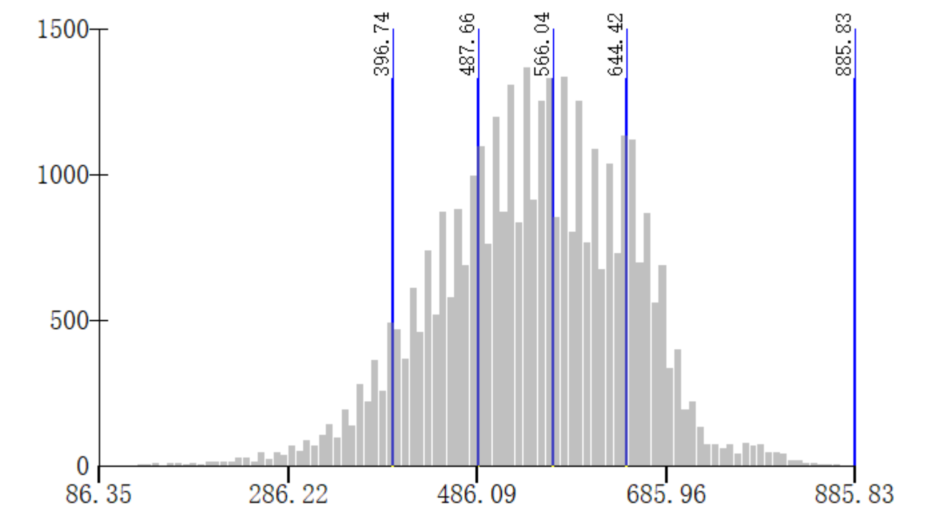


Figure 5.2 Statistics of the vulnerability grid for sea level rise in Dandong

According to the segmentation interval, the results are divided into five vulnerable degrees: extremely vulnerable (>644.43), severely vulnerable (566.05-644.42), moderately vulnerable (487.67-566.04), vulnerable (396.75-487.66), and low vulnerable (<396.74). See figure 5.3.

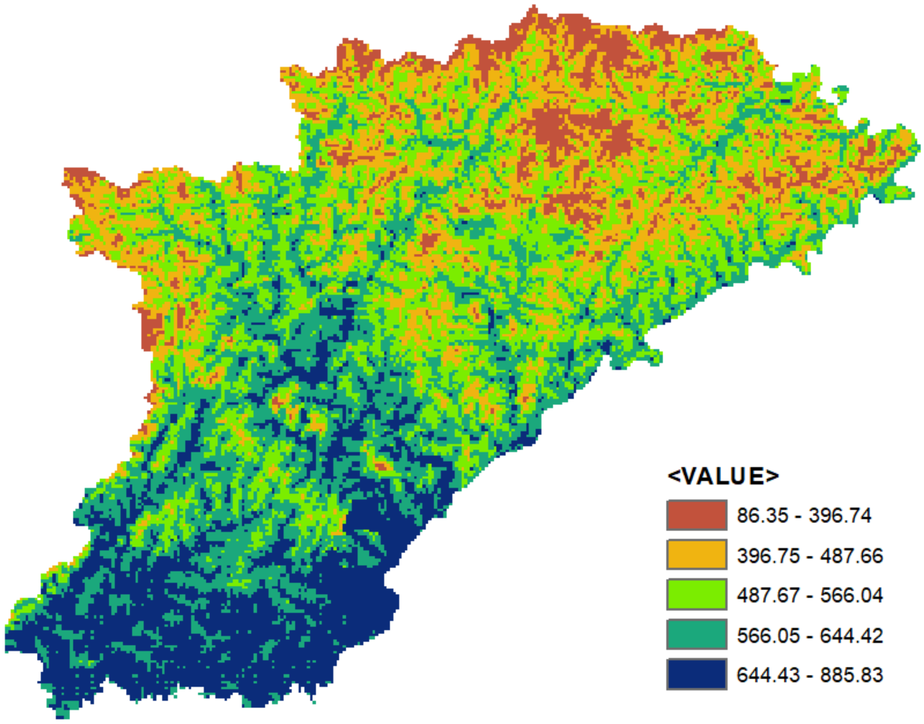


Figure 5.3 Spatial distribution map of vulnerable areas at all levels

The areas of each vulnerable degree and their proportions are shown in Figure 5.4. The largest proportion covered by the moderately vulnerable area (4167.45 km^2) and severely vulnerable area (3875.33 km^2), accounting for 28.64% and 26.63% of the total area of Dandong, followed by the vulnerable area (2912.45 km^2) and extremely vulnerable area (2505.63 km^2), accounting for 20.01% and 17.22% of the total area of Dandong. The smallest vulnerable area is the low vulnerable area, which is 1091.48 km^2, accounting for only 7.5% of the total area.

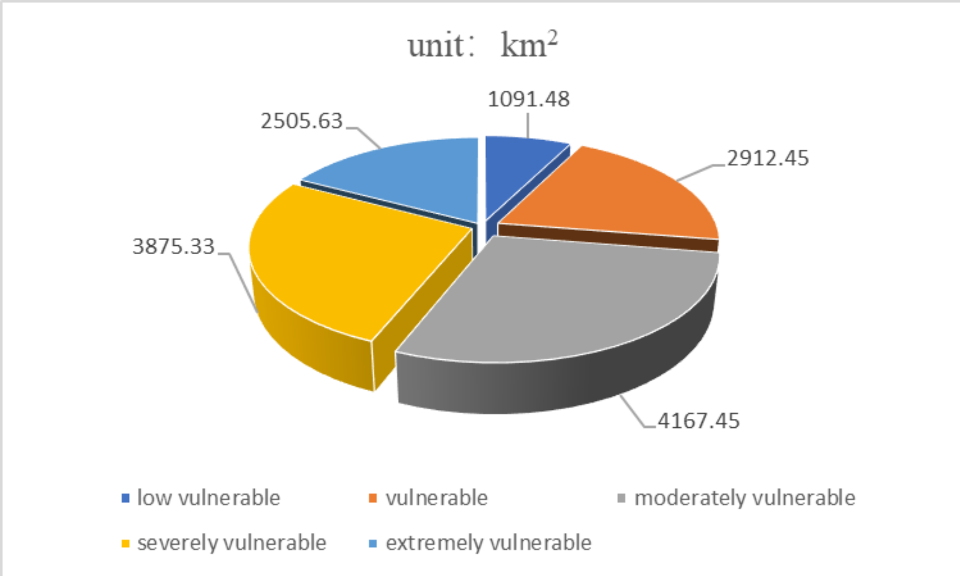


Figure 5.4 Distribution of areas of vulnerable areas at all levels

Table 5.1 shows the distribution of areas and counties of different vulnerable degrees:

Table 5.1 Distribution statistics on vulnerable areas in each district and county

Vulnerability level	**District（km²）**					
	Zhenxing	Zhen'an	Yuanbao	Donggang	Kuandian	Fengcheng
low vulnerable	0	2.78	0	0	797.68	283.62
vulnerable	0	17.09	0	8.38	1877.82	1004.53
moderately vulnerable	0.45	110.61	0.37	66.84	2208.12	1777.99
severely vulnerable	2.31	325.42	1.47	508.85	1165.13	1865.52
extremely vulnerable	186.92	232.66	77.04	1372.45	117.18	515.24

Although Yuanbao District and Zhenxing District are small in size, they are in the immediate vicinity of the estuary of the Yalu River with high population density and GDP per capita. The two districts are almost completely extreme vulnerable areas (>97%) and have no low vulnerable and vulnerable areas, as shown in Figure 5.5. This indicates that these two districts are most threatened by sea level rise among all districts and counties. Donggang County features extremely vulnerable areas (70.15%) and followed by severely vulnerable areas (26.01%). It has no low vulnerable areas. For Zhen'an District, the severe and extremely vulnerable areas account for 81.05% of its total area, which cannot be ignored. Fengcheng County and Kuandian Manchu Autonomous Counties are the most inland counties of China and their vulnerability is relatively low. From southern parts to northern parts, it can be seen that the vulnerability shows a diminishing trend, and the low vulnerable and extremely vulnerable areas are relatively small.

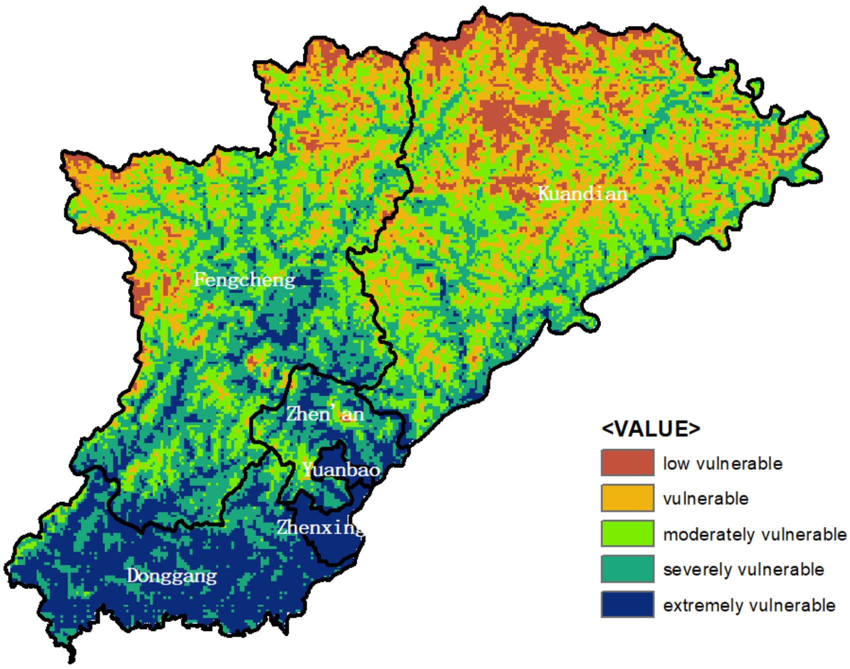


Figure 5.5 Spatial distribution of vulnerability in each district and county

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