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Trends Analysis of Ecological Environment Security Based on DPSIR Model in the Coastal zone: A survey study in Tianjin, China

Shao, C.[1*], Guan, Y.[1], Chu, C.[1], Shi, R.[2], Ju, M.[1] and Shi, J.[1]

[1]College of Environmental Science and Engineering, Nankai University, Tianjin 300071, China

[2]Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin, 300071, China

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ABSTRACT: The “Driving force - Pressure - State - Impact – Response” modeling framework is adopted to consider the formation mechanisms of environmental risks and the requirements of ecological environment protection. Moreover, a systematical index system and evaluation model for the measurement of the coastal ecological security level is put forward in this paper to assess the state of coastal ecological environment security. The results show that the security level of the Tianjin coastal ecological environment exhibits an overall downward trend, with the coastal ecological environment security value (E) falling from 0.7491 in 2005 (in good condition) to 0.2773 in 2010 (in a poor state) , and the value will continue to decline into a bad state in the next decade. The increasing use of coastal areas, growing population and increasing emissions of pollutants into the sea are the primary phenomena leading to environmental degradation of coastal ecosystems, which further leads to the degeneration of the ecological and environmental conditions of the coastal zone in Tianjin. The inshore marine ecosystem is always in the sub-healthy and unhealthy state, which has affected the balance of the marine ecosystem and led to poor biomes structure. At present, the marine ecosystem conservation actions, including pollution control, monitoring and surveillance system and emergency management mechanism, are not enough to offset the impacts on the marine ecosystem caused by driving force and pressure changes. It is necessary to establish a coordinated integration management system for the land and sea and an ecological compensation mechanism.

Key words: Driving force-pressure-state-impact-response (DPSIR), Ecological security ssessment, Integrated index, Trends analysis, Tianjin

INTRODUCTION

The coastal zone is a region where the land and sea interact. As one of the most vulnerable and sensitive ecological environments, it is an important part of global change research. According to the China Marine Environment Quality Bulletin, for the most recent 10 years (State Oceanic Administration, 2001-2011), the environmental pollution situation of Chinese ports and offshore areas is very serious. Pollutants carried by the rivers into the sea have been constantly increasing, the frequency and harmful consequences of red tide disasters continue to increase, fishery resources are declining each year, the ecological environment of the estuarine has been damaged, and the marine pollutants flux input from the atmosphere shows an upward trend. To prevent the loss of the ecological environment in the ports and coastal areas, the deterioration of water quality and the depletion of resources, it is necessary to strengthen the management of the ecological environment of the coastal waters and ensure the sustainable development of ports, the coastal ecological environment and the socio-economic system. Necessary components of this change in management include the protection of the coastal ecological environment and biodiversity, restoration of damaged coastal ecosystems and utilization of coastal resources in a sustainable way. The application of a reasonable method for the evaluation and prediction of the coastal ecological environment and natural resources could provide a key decision-making basis for ecological environment management and natural resource utilization in coastal waters. To study the continued development of the composite coastal ecosystem, it is necessary to simulate nutrient dynamics mechanisms, ecosystems and the biological processes of coastal waters through a series of models.

*Corresponding author E-mail: shaocf@nankai.edu.cn

With regard to the dynamic changes in the coastal ecosystem, Wu and Yu (1996) analyzed and classified the feasibility, development situation and development trend of dynamic forecasting of marine ecosystem models. With the application of the Ecopath model, Wang et al. (2009) stimulated the evolution of the marine ecosystem on the continental shelf in the northern part of the South China Sea and revealed fishery resource and ecosystem degradation mechanisms in this region. Jiang et al. (2007) further used the Ecosim model to simulate the impact of coastal water fishing on the change in the number of biological components in the system at the ecosystem level, which provided scientific theoretical guidance for the scientific management of fishery resources and marine ecosystems. In regard to the water eutrophication of coastal waters, Wei et al. (2001) focused on the phytoplankton burden and analyzed the characteristics and performance of different scale phytoplankton dynamics models in coastal eutrophication process simulations under different nutrient loadings. Gao and Wang (2004) built a three-dimensional planktonic ecological dynamics NPZD model and simulated the amount of Bohai Sea phytoplankton and the primary productivity variation characteristics. Moreover, Donald (2009) analyzed and forecasted red tides through large-scale ecological modeling. Lastly, George et al. (2007) and Olivia et al. (2009) studied the relationship between coastal eutrophication, nitrogen and phosphorus loadings with the application of a Bayesian model.

To effectively assess the offshore environmental pollution situation, domestic and foreign scholars studied offshore environmental evaluation and trend prediction. Liu et al. (2002) evaluated the coastal marine water quality status and utilized the monitored value of various marine water quality indicators through the application of a single factor index model. Luo et al. (2004) applied a clustering model in mathematical statistics to study the correlation between the various factors and environmental quality, objectively identified affinities between them, and determined the environmental pollution levels in coastal waters. Fu et al. (2007) applied a gray relational analysis model to evaluate the quality of the marine environment and identify the major pollution sources that need to be treated in the coastal area. Combining a gray prediction model with a fuzzy mathematical model, Wang et al. (2005) evaluated and predicted the pollution load of the coastal area of the Bohai Bay and identified the pollution sources that need to be focused on for governance in the coastal area. Meanwhile, visualization technology and space simulation technology have been used in marine environment evaluation. Chen et al. (2007) solved the visualization problem of large hierarchical ocean monitoring data within a limited display area with the application of hyperbolic visualization technology, applied in the evaluation and analysis of the quality of the marine environment and provided interactive visualization of massive and level node numerous marine statistics and monitoring data, environmental evaluation data and analysis results data.

To quantify the vulnerability of the coastal ecological environment, relevant experts conducted studies investigating the comprehensive evaluation of the ecological environment, combining coastal ecology with environmental factors. This study is mainly about the determination and evaluation of pollution indicators, e.g., heavy metals in coastal fish and benthic organisms and model simulations of pollution processes for marine pollution to eutrophication. Yuan et al. (2005) and Maria and Giuseppe (2005) calculated the impact of the heavy metal accumulation coefficient on the pollution level of coastal waters through the determination of the heavy metal content in the bodies of coastal benthos and plankton. Based on this work, Agnese and Carlo (2006) applied a model to evaluate the heavy metal changes in coastal benthic organisms and then evaluated the marine ecological environment quality based on these changes. Focusing on the interaction between marine water quality indicators and marine phytoplankton growth, Artioli et al. (2005) applied a model to simulate the change in the marine eutrophication-indicating organisms in the coastal area and evaluated the marine ecological environment. A comprehensive model of factors including the interaction between land, waterpower and biology was proposed and applied in the simulations to investigate the influence of nitrogen nutrients and organic carbon on phytoplankton. Thus, the coastal eutrophication process was evaluated.

Ecological environment security refers to the supporting conditions of regional ecological environment, the state that ecological and environmental problems do not pose a threat to human survival and that ecological vulnerability can be constantly improved, i.e., ecosystem functionality could meet the needs of its continued existence and development. When the regional ecosystem is disturbed, humans take active measures to improve the degenerated ecological environment and protect and restore the ecological service functions of the system. In regard to ports and the coastal ecological environment impact assessment, the current study focuses on the environmental assessment of a single factor without taking the port and the coastal ecosystem as a whole. Consequently, environmental issues cannot be fully identified and judged. Therefore, the environmental decision-making behavior is affected. Based on the Driving forces–Pressure–State–Impact–Response model (referred to as the DPSIR model), this paper establishes a complete set of index systems and evaluation methods to systematically measure the security level of coastal ecology. For illustrative purposes; the security status of the Tianjin coastal zone ecological environment is assessed over the last several years. Meanwhile, in accordance with the targets and scenarios set forth in the socio-economic development plan of Tianjin and the Bohai Sea Environmental Protection Plan, this paper predicts and analyzes the ecological environment safety level for 2010 and 2020, assesses the effectiveness of the efforts made to improve the quality of the regional environment and aims to provide a basis for decision making to promote regional environmental management.

MATERIALS & METHODS

The driving forces–Pressure–State–Impact–Response model (referred to DPSIR model) is a management model established by the European Environment Agency (EEA) that integrates the PSR (Pressure - State - Response) and DSR (Driving forces - State - Response) models to solve environmental problems. The DPSIR model has gradually become an effective tool to determine the state of the environment and environmental issue causality (the basic principle is shown in Figure 1) and has produced a set of indicators that provide a framework widely used in the field of environmental protection and sustainable development in the international world (Gervem *et al.,* 2007; Svarstad *et al.,* 2008; Niemeijer *et al.,* 2008).

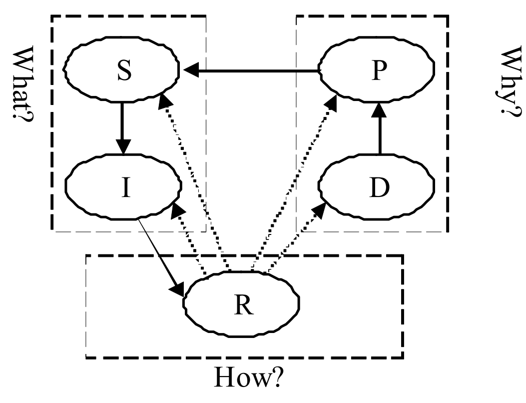


Fig. 1. DPSIR framework

(1) What

"What happened" is what the evaluator first addresses and is reflected in the DPSIR model by the S (state) and I (impact) indicators. The state of the core object of concern is described by S (state); this is the focal point of the evaluation. The state of the core object may affect some other factors that concern the evaluators. These impacts are described as I indicators, which is a complement and refinement to S (status). If S (status) is the direct reason and result of P (pressure) and D (driving forces), I (impact) is visualized as an indirect effect and result.

(2) Why

After "what happened" is clear, it is necessary to analyze why it happens because it can guarantee and guide evaluators about what happens, which is to guarantee and guide core objects that the evaluator needs and provide important information. It is also a necessary condition to understand "how to address it". The DPSIR model depicts "why it happened" through P (pressure) and D (driving force) indicators. The P (pressure) indicator describes the factors that directly apply to the core object and force its status changes. Moreover, the D (driving force) indicator describes factors that prompt pressure change and cause a state change in the concerned core object. The D (drive force) and P (pressure) indicators will affect S (status) and I (impact). However, the role of the D (drive force) indicator occurs indirectly through P (pressure). The effects of P (pressure) on S (status) are clear, while the effects of D (driving force) on S (status) are unclear. For example, if the quality of the environment is taken as the core object (S) and pollution emissions is P (pressure), the increase in P will inevitably lead to the deterioration of environmental quality S. Furthermore, economic growth is represented by D (driving force), also having important effects on the environmental quality S. On one hand, the impact on environmental quality is embodied in the driving force that increases pollution emissions P. However, on the other hand, it is also likely to bring more environmental investments to improve the quality of the environment S, which will bring both positive and negative effects. Therefore, if P is the direct and surface reason that causes S and I, D is the indirect and underlying reason.

(3) How

After knowing why it happened, we can and should further analyze "how to deal with it". The purpose of dealing with a problem is generally to guarantee and guide the transformation of the core object to the state required by the evaluators, or to improve the state to reduce adverse effects. There are many ways to achieve this goal, either directly through S or I, or acting on P or D.

In the DPSIR conceptual model, the driving forces are the potential causes that lead to environmental changes, for example, the region's socio-economic activities and development of industry. "Pressure" refers to the direct impact of human activities on the natural environment, which represents the direct pressure of ecological environment change caused by resource and energy consumption and pollutant emissions. Furthermore, “status” refers to the state that the ecological environment system is in when under the pressure, mainly evaluated by the status of the ecological environment and health. “Impact” refers to the effect of the ecological environment system state on the natural systems and socio-economic status. Lastly, the “response” process indicates the countermeasures and positive policy utilized in the promotion of sustainable development processes, e.g., improving the efficiency of resource use, reducing pollution, increasing investment and other measures. At present, attempts have been made to apply the DPSIR model in such areas as the sustainable use of water resources, environmental management capacity analysis, sustainable development of agriculture and soil and water conservation benefits (Atkins *et al.,* 2011; Hong and Chan, 2011; Maxim *et al.,* 2009). These studies show that the DPSIR model emphasizes the relationship between the functionality of the economy and its impact on the environment and is comprehensive, systematic, integrative and flexible. The model can also reveal the causal relationship between the environment and the economy and effectively integrate resources, development and environment and human health.

Based on the principles of the DPSIR model, and with top-down, layer-by-layer decomposition, this paper divides coastal ecological environment security into three levels with each level respectively choosing elements reflecting its main features from the evaluation index. The first layer is the target layer (O), taking the composite index of the coastal ecological environment security as the core object to measure the overall level of ecological environment safety of inshore areas. The second layer is the criterion layer (C), including the driving force, pressure, state, impact and response. Lastly, the third layer is the indicator layer. This paper considers the regional characteristics of the Tianjin offshore region and proposes to establish the Tianjin offshore region ecological environment safety assessment index system (Table 1) based on systematic, scientific and practical features; the availability and ease of quantifying indicators from basic data; and incorporating results of domestic and international ecological standards and requirements from expert recommendations.

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then (Saaty, 1987). It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education (Saaty *et al.,* 2008).

Selecting the key indicators for assessing the ecological environment security in the coastal zone involves analyzing the ecology, environment, society, and economy of the area, with each category containing several indicators with hierarchical characteristics. Figure 2 shows a hierarchy system for the key indicator selection to assess the ecological environment security with three hierarchies. The overall objective of the ecological security assessment lies at the top of the hierarchy (Level 1), and the Criterion indicators (Cs) and the specific indicators (Is), which represent grey sequences, lie at descending levels of this hierarchy (Levels 2 and 3, respectively) (Table 1. Five Cs (driving force, pressure, state, impact, and response) constitute the second level. The Is, which can be classified into five groups corresponding to the Cs, are at the bottom level.

The regional comprehensive assessment of environmental risks based on the DPSIR model involves a multiple evaluation index. Therefore, the goal is to determine the contribution of each evaluation index or evaluation factor on regional environmental risk, i.e., weights. Considering the characteristics of various weight-determining methods and the combined features of environmental assessment uncertainties and intricate weight values, we choose the fuzzy comprehensive evaluation method (Tian *et al.,* 2011).

The factors are the evaluation indexes involved in the evaluation. In the evaluation, the factor set is the fuzzy subsets composed by the actual measured values of n factors involved in the evaluation, i.e.,

$$U=\{u_1 \quad u_2 \quad u_3 \quad \dots \quad u_n\} \tag{1}$$

Where u_i is the i-th factor.

Because of the complex types of evaluation indexes in the evaluation index system, the dimensions of the coefficients are not necessarily identical. Therefore, the indexes are often not comparable. It is not feasible to use them directly in the evaluation; therefore, the indexes need to be standardized. To reflect the effects and obtain interval annual rates of change for each indicator, we used the maximum difference normalization method to standardize the data and eliminate the dimensionless impact caused by different ranges and units of indicators.

For positive indicators:

$$x_{ij}=\frac{x_{ij}-\min\{x_{ij}\}}{\max\{x_{ij}\}-\min\{x_{ij}\}} \tag{2}$$

Table 1. The ecological environment safety assessment index system in the coastal zone based on DPSIR model

Target layer O	Criterion layer C	Indicator layer I	Significance of indicators
Ecological environment system security	Driving forces C_1	Total output value of coastal areas I_{11}	Indicate the level of economic development of the region
		Total output value of marine industries in coastal areas I_{12}	Indicate the development and utilization levels of marine resources
		Mari-culture production I_{13} Reclamation area I_{14}	Indicate the degree of development and utilization of coastal waters
		Coastal port throughput I_{15}	Indicate of port size and vessel traffic conditions
		Coastal populations I_{16}	Indicate regional development demand
	Pressure C_2	Fresh water inflow amount I_{21}	Indicate the pressure of salinity changes in coastal waters
		Fluxes of COD discharged into the sea I_{22} Fluxes of DIN discharged into the sea I_{23} Fluxes of phosphorus nutrient discharged into the sea I_{24} Fluxes of petroleum hydrocarbons discharged into the sea I_{25}	Indicate the pressure of water pollutants that caused by coastal areas socio-economic development on marine ecosystems
	State C_3	Proportion of the contaminated waters in coastal waters I_{31}	Means the area which water quality is inferior to the second water quality requirements of "Sea water quality standard (GB 3097-1997)", indicate the water pollution of the coastal waters functional areas
		Inshore marine ecosystem health index I_{32}	Indicate environmental quality, biological community structure, spawning function and impact of development activities on the ecosystem of the coastal waters. Calculated by methods recommended by the State Oceanic Administration of China
		Seawater eutrophication I_{33}	Indicate the level that seawater affected by inorganic nitrogen and active phosphate, calculated by the proportion the eutrophication waters area account the total sea area
		Inshore and coastal wetland area reduction I_{34}	Indicate the degradation degree of inshore terrestrial ecosystem
		The sediment contamination ecological risk index I_{35}	Indicate the level that sediments affected by petroleum, heavy metals, arsenic, sulfides and organic carbon pollutants, Calculated by methods recommended by the State Oceanic Administration of China
	Impact C_4	Loss of marine disasters in coastal areas I_{41}	Indicate the impact of environmental pollution on marine ecosystems
		Sea-level change status I_{42}	Indicate the impact of climate change on marine ecosystems
		Seawater intrusion area I_{43} Soil salinization range I_{44}	Indicate the impact of changes in the marine ecosystem on inshore terrestrial environment
		Marine biodiversity I_{45}	Indicate the species number of coastal waters and assigned uniformity of the individuals number among species. Calculated by Shannon-Wiener diversity index
	Response C_5	Water quality compliance rate of sewage into the sea I_{51}	Response to environmental pollution, refers to the measure of the response that made to improve the quality of the marine environment, indicate the practical action for marine Ecological Environment Security

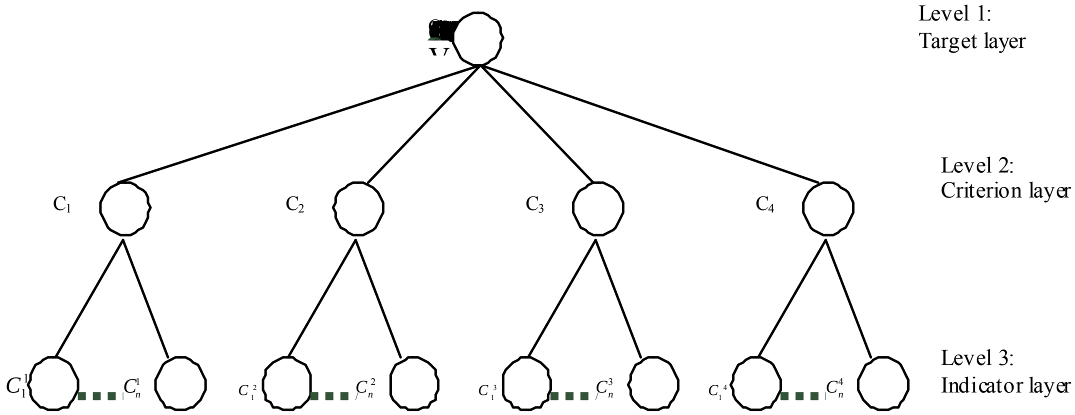


Fig. 2.Basic framework of the analytic hierarchy process

For negative indicators:

$$x_{ij} = \frac{\max\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (3)$$

After this standardization, the maximum value is normalized to 1, the minimum value is normalized to zero, and the rest of the values are between zero and one.

In the fuzzy comprehensive evaluation, weight coefficients reflect the status and the role of the various factors in the integrated decision-making processes, which can directly affect the results of the comprehensive evaluation (Zou *et al.*, 2006). Usually, the degrees of importance of the various factors are different. Therefore, a corresponding weight value a_i (i=1, 2, … , n) is assigned to each factor ui and compose a weight set A=(a_1, a_2,…, a_n). An analytic hierarchy process (AHP) and the Delphi method are adopted to determine the weights of the evaluation factor and construct a judgment matrix as follows:

$$S = \begin{bmatrix} u_{11} & u_{11} & \cdots & u_{1m} \\ u_{21} & u_{22} & \cdots & u_{2m} \\ \vdots & \vdots & & \vdots \\ u_{m1} & u_{m2} & \cdots & u_{mm} \end{bmatrix} \quad (4)$$

Where, u_{ij} is the importance of the i-th factor relative to the j-th factor.

According to the judgment matrix, the eigenvector corresponding to the largest eigenvalue is obtained, i.e., the weight distribution A=(a_1, a_2,…, a_n). The analysis was performed for the 26 indicators identified in Table 1. Moreover, 20 experts in different parts of Tianjin, including environmental management, environmental impact assessment and development of marine resources were consulted. Lastly, the indicators were assigned values. The statistical results are shown in Table 2.

To test the reliability of the weight coefficient, it is necessary to check the consistency of judgment matrix, the formula is as follows.

$$CR = {CI}/{RI} \quad (5)$$

Where, *CR* is the coefficient of consistence (when *CR*<0.1ÿthe consistency of judgment matrix is acceptable), *CI* is the coincident indicator, *RI* is the average random consistency index. Firstly, we calculated the coefficient of consistence of O-C judgment matrix, and the result is 0.0395, which is less than 0.10. This indicated the weight distribution of the criterion layer is reasonable. For the weight distribution of the index layer by the same method, the coefficient of consistence of the five C-I judgment matrixes were calculated respectively, and the five values were less than 0.010.Consequently the results of the analytic hierarchy were very satisfied, which showed that the weight distribution of all index is reasonable.

The method of comprehensive evaluation is based on the assigned index weights and standardized indicators. This study uses the ecological environment security composite index (E) to characterize the regional ecological security situation, namely,

$$\boldsymbol{E} = \sum_{i=1}^{n} W_i \times X_i \quad (6)$$

Where, *E* is the eco-environment safety index, W_i is the weight of each index and X_i is assigned results for each indicator.The *E* value is in [0,1] and the greater its value, the higher the degree of ecological environment security. Ecological environment composite indexes are sorted from highest to lowest; the results of the

Table 2. Coastal eco-environment safety evaluation index weight

Target layer O	Criterion layer C	O-C weight	Indicator layer *I*	C-I weight
Comprehensive evaluation of the ecological environment security	Driving forces C_1	0.1155	I_{11}	0.0835
			I_{12}	0.1592
			I_{13}	0.1787
			I_{14}	0.1592
			I_{15}	0.2408
			I_{16}	0.1787
	Pressure C_2	0.1439	I_{21}	0.1429
			I_{22}	0.2857
			I_{23}	0.2857
			I_{24}	0.1429
			I_{25}	0.1429
	State C_3	0.2718	I_{31}	0.1728
			I_{32}	0.2280
			I_{33}	0.1728
			I_{34}	0.1985
			I_{35}	0.2280
	Impact C_4	0.2506	I_{41}	0.2589
			I_{42}1	0.2254
			I_{43}	0.1487
			I_{44}	0.1708
			I_{45}	0.1962
	Response C_5	0.2182	I_{51}	0.1244
			I_{52}	0.1244
			I_{53}	0.2166
			I_{54}	0.2488
			I_{55}	0.2858

evaluation are divided into five equally spaced levels: [0.8, 1.0] is the ideal state, [0.6, 0.8] represents good conditions, [0.4, 0.6] is an alert state, [0.2, 0.4] is a poor state and [0, 0.2] is a bad state.

The trend analysis is simulation exercises based on the law of history. Consider the objective things, the representation of system complexity and data messy, we predicted and analyze through gray forecasting model GM (1,1).

Set there are n observation values in time sequence $X^{(0)}$,

$$X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n)\},$$

and generated new series by accumulating,

$$X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \cdots, x^{(1)}(n)\},$$

among

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \qquad (i = 1,2,3,\cdots,n)$$

which:

The corresponding differential equation for GM (1, 1) model is:

$$\frac{dx^{(1)}}{dt} + \alpha x^{(1)} = \mu$$

Among whichÿα is the development of gray number; μ is the endogenous control gray number.

Set: $\partial = \begin{pmatrix} \alpha \\ \mu \end{pmatrix}$

Obtained from least-squares solution:

$$\partial = (B^T B)^{-1} B^T Y_n \tag{7}$$

Among which:

(8)

$$B = \begin{bmatrix} -[x^{(1)}(1) + x^{(1)}(2)]/2 & 1 \\ -[x^{(1)}(2) + x^{(1)}(3)]/2 & 1 \\ -[x^{(1)}(3) + x^{(1)}(4)]/2 & 1 \\ \cdots & \\ -[x^{(1)}(n-1) + x^{(1)}(n)]/2 & 1 \end{bmatrix} Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ x^{(0)}(4) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}$$

Solving differential equations can obtain prediction model:

$$\hat{x}(k+1) = [x^{(0)}(1) - \frac{\mu}{\alpha}]e^{-\alpha k} + \frac{\mu}{\alpha} \tag{9}$$

RESULTS & DISCUSSION

The Bohai Sea is a semi-enclosed inland sea that undertakes the Haihe, Yellow and Liaohe River basins and connects the Yellow Sea to the East China Sea ecosystem (see Fig. 3). It is the most fragile ecological environment in the Chinese coastal waters. Bohai rim areas, including Tianjin, Liaoning Province, Hebei Province and Shandong Province, are high-speed economic and social development areas (see Fig. 4). In recent years, due to declining land resources, environmental water quality and other factors, the Bohai Sea has partially lost its ecological and economic functions. Environmental protection of the integrated land and sea interface is facing a grim situation.

China's third largest city, Tianjin, sits at the east end of the Bohai Sea, is the largest open coastal city and is the earliest-opened modern city in northern China. In March 2006, Tianjin was positioned as "the economic center of the Bohai Sea region and an international port city and a northern eco-city economic center". "Promote the development and opening of the Tianjin Binhai New Area" is written into China's "Eleventh Five-Year Plan" and the national strategy. The Chinese government wanted to establish Tianjin as a national comprehensive reform pilot area and make it "China's economic third growth pole". At present, the Bohai economic zone, with the Tianjin Binhai New Area at its core, has rapidly formed and developed. The Tianjin Binhai New Area is in the eastern coastal areas of Tianjin, covering an area of 2270 km^2 and coastline length of 170 km (see Fig. 5). The area is one of the fastest developing areas of economic growth in China with gross domestic products increasing at an average rate of more than 20% in the past five years. With the acceleration of urban construction in Tianjin and large-scale development of the Tianjin Binhai New Area, a large number of coastal areas and seashores have been occupied and the total amount of pollutant emissions into the sea remain high. This results in a highly fragmented coastline and atrophy of coastal wetland area, which seriously affects and damages the continuity of the waters - shoals - swamp ecological corridor and further exacerbates the situation of ecological security of coastal waters in Tianjin. Improving the ecological environment of Tianjin coastal waters to achieve regional sustainable development has become an urgent problem. To analyze the Tianjin coastal ecological environment security trends, the identification of the main factors affecting the Tianjin coastal ecological environment security is a necessary precondition for Tianjin coastal ecological environment protection work.

To obtain the raw data for the safety evaluation indexes of the Tianjin coast eco-environment, we first gained access to a large number of statistics including the Tianjin Statistical Yearbook 2006-2011, Binhai New Area Statistical Yearbook, Statistical Yearbook of the China National Inshore, Tianjin Environmental Quality Reports, Tianjin Marine Environmental Quality Bulletins, China Marine Environment Quality Bulletins, China Sea Level Bulletins and the Bulletin of the Chinese Marine Disasters. The raw data for some indicators also made reference to the research results of the "Environmental impact report of the Tianjin Port and overall plan" and "Strategic environmental impact assessment report of the Tianjin Binhai New Area". Second, based on a remote sensing (RS) survey supplemented by ground ecological data collection and sentinel surveillance of important ecological functions, we combined geographic information systems (GIS) and global positioning systems (GPS) to conduct a regional ecological environment survey. Key standardized findings are shown in Table 3.

With increasing emission of land-based pollutants and the continuous development and utilization of coastal areas, natural coastal wetland areas have been greatly reduced, leading to the loss of many habitats for species which are economically important and decreasing species diversity. Statistics in Table 3 for six consecutive years show that inshore water in the Bohai Bay has been in a serious eutrophication and sub-healthy state and demonstrates a deteriorating trend. Correspondingly, the deterioration of coastal ecosystems leads to increasing harm. In accordance with the ecological environment safety evaluation index system and the comprehensive evaluation model established in this paper, we derive the Tianjin coastal areas ecological environment security index (Fig. 6). From 2005 to 2010, relevant administrative departments continued to take positive measures to perform ecological protection work. However, the E value fell from 0.7491 in 2005 (in good condition) to 0.2773 in 2010 (in poor condition), and the coastal ecological environment security level also shows a general downward trend.

Based on the environmental protection goals and requirements of Tianjin, and the trends of ecological environment security in the coastal zone of Tianjin between 2005and 2010, the time series $X^{(0)}$ was set up, which is $X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(6)\}$. We generated a new sequence by adding, which is $X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \cdots, x^{(1)}(6)\}$. By the method of GM(1,1), the development of gray

Fig. 3. Map showing the location of Bohai Sea and Tianjin city in China

Fig. 4. Distribution of cities and ports in Bohai rim areas

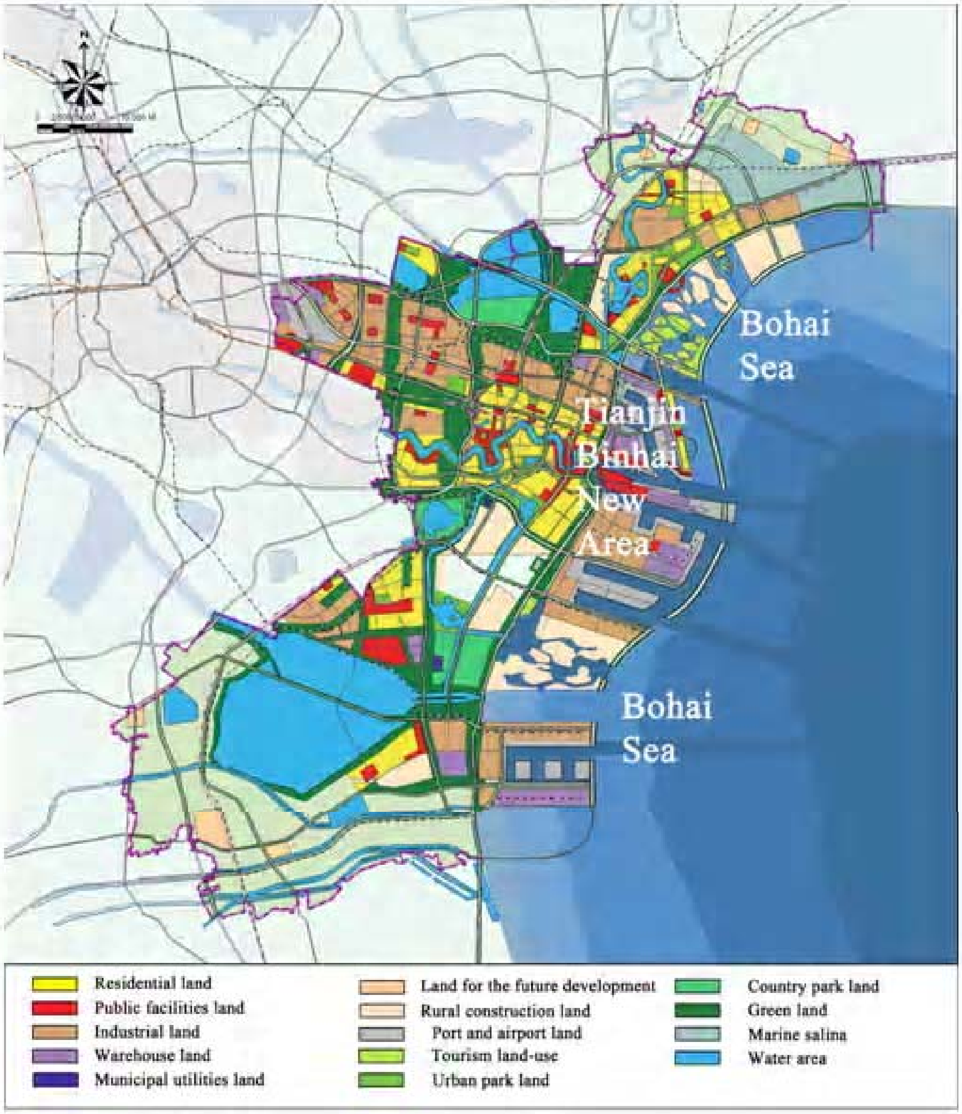


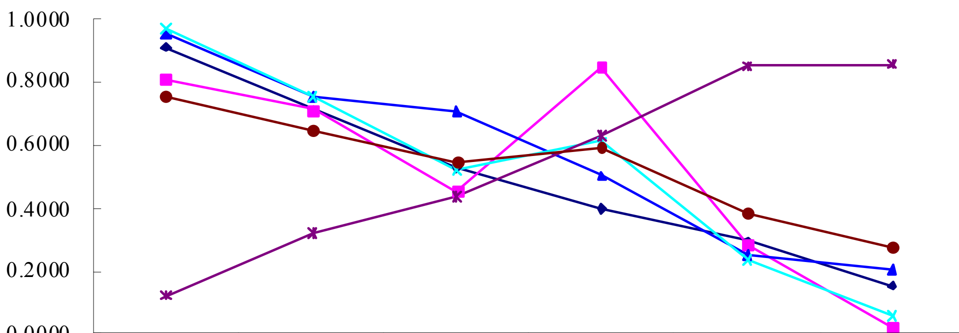
Fig. 5. Coast exploitation and development plan of Tianjin Binhai New Area

number(α) and the endogenous control gray number(μ) can be obtained. Solving differential equations can obtain prediction result which is $x^{(0)}(2015) = 0.18, x^{(0)}(2020) = 0.27$. In the next decade, the value will continue to decline into a bad state. New protection countermeasure is necessary, such as optimizing the pattern of economic development, curbing the development of Marine resources, reducing pollutants into Bohai Sea, strengthening the ecological protection in the coastal zone area.

As shown in Fig.6, the ecological and environmental conditions of the coastal zone of Tianjin fell from 0.9494 in 2005 to 0.2027 in 2010. The ecological environment is deteriorating, and the inshore marine ecosystem is always in a sub-healthy or unhealthy state primarily because of increasing emissions of land-based pollutants (e.g., nitrogen and phosphorus) that have led to the deterioration of the eutrophication level of coastal waters. Because of the increased pollution levels, the clean sea area of the Tianjin coastal waters fell from 1260 km^2 in 2005 to 400 km^2 in 2010 (Cui *et al.*, 2013; Wang and Zhang, 2011). Continued large-scale reclamation projects caused a substantial reduction of the coastal natural wetland area, which decreased from 58,090 hectares in 2005 to 37,856 hectares in 2010 (Tianjin Bureau of Statistics, 2011; Zhai *et al.*, 2012) and led to the loss of many important economic biological habitats and the continual reduction of

Table 3. Assignment Tianjin inshore area ecological environment security trend indicators

Indicators	2005	2006	2007	2008	2009	2010
I_{11}	0.000	0.103	0.230	0.505	0.641	1.000
I_{12}	0.953	1.000	0.860	0.686	0.522	0.000
I_{13}	1.000	0.000	0.405	0.429	0.431	0.405
I_{14}	1.000	0.950	0.196	0.129	0.039	0.000
I_{15}	1.000	0.901	0.605	0.308	0.186	0.000
I_{16}	1.000	0.974	0.688	0.411	0.164	0.000
I_{21}	1.000	0.881	0.681	0.310	0.155	0.000
I_{22}	0.751	0.579	0.345	1.000	0.020	0.000
I_{23}	0.667	0.572	0.000	1.000	0.354	0.075
I_{24}	1.000	0.946	0.812	0.787	0.554	0.000
I_{25}	0.827	0.853	1.000	0.821	0.513	0.000
I_{31}	1.000	0.655	0.414	0.172	0.172	0.000
I_{32}	0.778	0.556	1.000	0.889	0.000	0.889
I_{33}	1.000	0.875	0.678	0.452	0.318	0.000
I_{34}	1.000	0.775	0.589	0.472	0.352	0.000
I_{35}	1.000	0.912	0.758	0.429	0.417	0.000
I_{41}	0.875	0.772	0.358	1.000	0.000	0.229
I_{42}	1.000	0.676	0.500	0.412	0.382	0.000
I_{43}	1.000	0.796	0.583	0.417	0.285	0.000
I_{44}	1.000	0.813	0.652	0.468	0.339	0.000
I_{45}	1.000	0.722	0.605	0.590	0.248	0.000
I_{51}	0.000	0.179	0.464	0.607	1.000	0.821
I_{52}	1.000	0.808	0.769	0.731	0.731	0.000
I_{53}	0.000	0.186	0.308	0.605	0.901	1.000
I_{54}	0.000	0.335	0.458	0.652	0.857	1.000
I_{55}	0.000	0.269	0.357	0.586	0.792	1.000



	2005	2006	2007	2008	2009	2010
D	0.9090	0.7101	0.5282	0.3961	0.2941	0.1559
P	0.8090	0.7118	0.4547	0.8455	0.2817	0.0215
S	0.9494	0.7529	0.7064	0.5021	0.2497	0.2027
I	0.9676	0.7512	0.5222	0.6093	0.2351	0.0593
R	0.1244	0.3232	0.4362	0.6271	0.8501	0.8534
E	0.7491	0.6479	0.5445	0.5934	0.3868	0.2773

Fig. 6. Evaluation results of Tianjin coastal ecological environment safety

biodiversity. Water pollution affected the balance of the marine ecosystem and the biological community structure, causing a downward trend in the number and density of life forms.

The decline of the ecological and environmental conditions causes the eco-environmental impact consequence of the Tianjin coastal zone to continually increase; the eco-environmental impact value (indicator I in Fig.6) has declined from 0.9676 in 2005 (in a slightly affected state) to 0.0593 in 2010 (in a serious impact state). An example of the effect of such changes follows. The degradation of the marine ecosystem and increased traffic results in an increased number red tides and oil spills, intensified impact of marine disasters to coastal areas and elevated sea levels in conjunction with the impact of climate warming (uplift of 34 mm from 2005 to 2010). Combined with the disabled original dike and the lack of coastal mudflats to buffer the reclamation area, these effects ultimately lead to an increased risk of storm surges in large areas of the reclamation section and along the Tianjin coastline. According to the prediction analysis through a gray prediction model GM (1, 1) established in this paper, the inshore sea level of Tianjin will continue to rise by 76 mm by 2020; the impact on Tianjin coastal areas will also continue to increase. Coastal areas of Tianjin are muddy silt plains. Land subsidence in parts of Tianjin coastal areas is obvious due to certain factors, e.g., reduced groundwater level and ground compaction. As of 2010, the ground elevation of some streets in the Tianjin Binhai New Area is already below sea level. With the continual expansion of seawater intrusion, the spillway capacity of the Haihe River is declining, municipal drainage problems are getting serious, and the storm surge hazard is intensifying. There are 243 township level administrative regions, 782 km of railway and 14832 km of highway in Tianjin. It is estimated that by 2020, 64 township-level settlements will be affected (26% of the city), 256 km of railway will be affected (33% of the city) and about 1418 km of roads will be affected (10% of the city). The total area of affected inland waters and the total length of affected rivers will be 316 square km and 457 km, respectively.

Freshwater flooding of Tianjin by the Haihe River into the sea has obviously decreased, leading to yearly reductions in the environmental base conditions. Because of the reduction of marine ecological water consumption in the Bohai Bay, the average runoff, which was 14.4 billion cubic meters in the 1950s, had decreased to 8.2, 4.5, 1.0 and 2.4 billion cubic meters in the 1960s, 1970s, 1980s and 1990s, respectively. In recent years, the average runoff has fallen from 0.952 billion cubic meters in 2005 to 0.623 billion cubic meters in 2010. This situation has not only led to the obvious increase in salinity, changes in the estuary environment and degeneration and disappearance of spawning space for most aquatic organisms but also led to expansion of the invading seawater area, elevated degree of mineralization and increased concentration of chloridion in ground water, fresh water salinization and water quality deterioration, ultimately leading to the continual expansion of soil salinization in coastal lands.

In recent years, Tianjin has been taking positive action to protect the marine ecosystem and has improved the marine ecosystem management level. Meanwhile, Tianjin has established and improved the marine supervision, monitoring and inspection system, implementing supervision and monitoring into marine environmental protection construction (e.g., the South Port Industrial Zone, Tianjin Port (Group) Co., Ltd., the Harbor Industrial Zone, the Harbor Industrial Zone and the Binhai New City). Moreover, the supervision and management of marine engineering has been strengthened. Furthermore, Tianjin has increased investments in environmental protection efforts, constructed sewage treatment facilities and promoted the governance of urban sewage and garbage disposal, ecological fisheries, ecological farming, ecological construction and agricultural non-point source management, which made the sea water quality compliance rate increase from 28% in 2005 to 51% in 2010. Tianjin has also formulated "Tianjin red tide disaster contingency plans", "Tianjin storm surge, waves, tsunamis and sea ice disaster contingency plans", established a marine disaster prevention and mitigation system, improved port emergency capacity and met the construction requirements of the "*Equipment requirements for port oil spill emergencies (JT/T 451-2009)*". However, due to the excessive density and use of coastal waters, coastal wetlands have degraded, the capacity of the wetland environment has continued to decrease, and the purification capacity has declined. With the expansion of Tianjin Port, especially the continued increase of handling capacity for oil and chemicals, the risk of major oil spills from ships will also increase. Emissions of nitrogen and phosphorus pollutants from expanding coastal water farming have provided nutrient conditions conducive to red tides. The inshore environmental protection work has not been systematic, has not yet formed comprehensive land and sea management mechanism and has not yet formed coordination mechanisms between departments of land, sea and river basins. Overall, the response measures are not enough to offset the impact of the driving force and pressure changes to the marine ecosystem, which has led the Tianjin coastal ecosystem health status to deteriorate and the impact of the consequences to increase. In brief, the Tianjin coastal ecological environment security level is showing a downward trend.

Rapid socio-economic development of Tianjin coastal areas causes an increase of discharged water, which thereby causes a significant pressure on the environment. Meanwhile, coastal water ecological protection and land usage for social development have sharp contradictions. Consequently, the Tianjin inshore environment and ecological problems have become constraints on the sustainable development of Tianjin coastal areas. According to the goals of societal and economical development, environment protection and ecological construction set by the "*Bohai Sea Environmental Protection Master Plan (2008 - 2020)*", the "*Tianjin City Master Plan (2005 - 2020)*", "*Tianjin Eco-City Construction Plan*" and the "*Tianjin Binhai New Area Master Plan (2009-2020)*", Tianjin will format an ecological sustainable development model, Tianjin coastal ecological environment security should gradually improve, Tianjin will convert the coastal ecosystems to a healthy state by 2020, and Tianjin will continue to improve the inshore land area ecological environment quality. From the results of the 2005-2020 Tianjin coastal ecological environment security trends analysis, it is quite difficult to achieve the predetermined goals for the protection of the Tianjin coastal ecosystem and environment. Therefore, there is an urgent need for positive and effective response measures.

CONCLUSION

Bohai Sea is China's only semi-closed inland sea with poor seawater exchange ability and fragile marine ecosystems. A comprehensive assessment of the coastal ecological environment security, understanding of the situation and the extent of inshore marine ecological damage, and identification of key factors that affect coastal ecological environment security can provide scientific basis for the identification of land-based pollution sources and management of the inshore marine environment.

At present, the Tianjin coastal ecological environment security level shows a declining trend, the environmental state is poor, the inshore ecosystem faces environmental pollution and habitats are decreasing. Because of the poor environmental quality of coastal waters, the increasing intensity of coastal water usage, the increase of pollutant emissions into the sea and the polluted coastal ecosystem, ecosystems have been in a long-term sub-healthy or unhealthy state, biodiversity is being destroyed, and the ecological environment is relatively fragile. There is a large gap between the current situation and the Bohai Sea marine environmental protection goals. There are more "unsafe" factors and there is a long way to go for inshore marine ecological environment security building.The expansion of reclamation activities, the population growth and the increase of pollutants into the sea are the primary causes for environmental degradation of coastal ecosystems. Existing scientific and technological support are not sufficient to meet environmental governance and ecological protection of the coastal waters. The lack of a scientific and rational environmental management system is also a key factor restricting the improvement of the quality of the marine environment. It is necessary to continue to enhance the security level of the coastal ecosystems and promote the sustainable use of the marine environment. Moreover, the establishment of emergency response mechanisms for sudden accidents in the coastal ecological environment, marine engineering ecological damage compensation and coastal restoration works, accounting for the impact of rising sea levels in regional development planning are also necessary. Lastly, comprehensive promotion of saving and utilization of water, energy, land and materials in the planning of ports, logistics, heavy equipment manufacturing and development process of petrochemical industry, are required to ensure that the introduced projects consist of low consumption, low emission, low pollution and high efficiency enterprises and products, thus upgrading the industry level of environmental performance.

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