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Research Article

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Study on the system dynamic model of sustainable development of the island: A case study on Pingtan

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ABSTRACT

Due to the special geographical position and the fragile ecological environment, it is necessary to attach great importance to the analysis of the sustainable development in the sea island city. Based on the system dynamic theory and method, a system dynamic model of sustainable development of Pingtan Island is constructed. The model consists of four subsystems: economic, social, resources, environmental. Several plans are formulated for simulation prediction and research. Simulation result shows that the sustainable development ability of Pingtan can be improved gradually in the aspects of the conditions of transportation, health care and education; implementing the project of water diversion from outside the island; controlling the population size, improving the environmental quality of the island, and increasing the investment index of environmental protection. According to the results, some control measures are proposed, which can be used as the scientific basis for the environmental policy making oriented by sustainable development.

Keywords: Island; sustainable development; system dynamics; simulation; regulation

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INTRODUCTION

Island is an important part of China's territory. It is the "bridge" connecting the land and the sea. It is also an important base of oceanic developments. However, island usually has a small area, and is relatively independent from the mainland. Hence, the connections between islands and between island and the mainland are difficult to established, and the islands are vulnerable to natural disasters [1]. Moreover, the resources of an island are limited, especially the land resources, forest resources and freshwater resources. Besides, the economy of island has a less diverse composition; the ecosystem is fragile, and the environmental capacity is small [2]. Thus, the island is challenged by the contradiction of economic development and environmental degradation. If an island is developed inappropriately or overdeveloped, its society, economy and environment would suffer greatly.

In order to realize ecological balance, good environment, healthy social and economic development, and sustainable use of the resources, it is of great importance to study on the sustainable development of the island. The complexity and speciality of island give rise to the features of multiple feedback, high orderness, nonlinearity and long time lag. In terms of the ability of analyzing complex systems such as society, economy, ecosystem and environment and of solving practical problems, the theory and method of system dynamics (SD) is mature.

SD is widely applied in the macroscopic fields, project management, learning-oriented organization, logistics and supply chain [3]. In the aspect of sustainable development, Moffatt [4] and Cannon [5] et al performed studies on the structural analysis, modeling and applications of economy-resource-environment model or sustainable development model.

In China, system dynamics involves the micro management of enterprises and institutions, regional planning on meso level and national economy on the macro level [6]. Studies have been performed on the sustainable development on national level (Huang Zhenzhong et al. [7]), on regional level (Shi Tian [8], Yang Jie et al. [9], and Liu Yaobin et al. [10]) and on industry level (Luo Geping [11], Sun Cheng'ai et al. [12], Li Xiujun et al. [13]).

General Situation of the Research Area

Pingtan Island (originally Pingtan County, and now is Pingtan integrated experimental area) is located in the east coastal area of Fujian Province. To the east of Pingtan Island is Taiwan Strait, and to the west is Fuqing City and Changle City, divided by Haitan Strait. There are 156 islands with no residents. The land area is 371.91 km^2, and the area of the main island Haitan Island is 267.13km^2. Haitan Island is the fifth largest island of China, and the largest in Fujian Province. At the end of 2009, there were 7 towns and 8 villages in the county, with a total population of 384785. In 2009, the GDP of the whole county was 7.358 billion yuan, and the gross industrial output value was 187,000 yuan. In 2009, the visitor reception was 3.853 billion, and the annual gross tourism income was 138 million yuan. The main industries of the island are marine aquaculture and planting industry (primary industry), seafood processing, wind power generation, ship building and sand mining (secondary industry), and tourism & trade (service industry).

The sea area of Pingtan Island belongs to typical south subtropical ocean monsoon climate. The winter here is warm, and the summer is cool. The Island has adequate sunshine, and clear monsoon, with frequent droughts in summer and autumn. The annual average temperature is 19.4 ℃, annual average precipitation is 1196.2 mm, and annual average wind speed is 9.0m/s.

EXPERIMENTAL SECTION

Principle of Research

System dynamics [14] deals with the analysis and research of information feedback, with the stress on systematic and holistic viewpoint, and relational, developing and dynamic perspectives. Model simulation in system dynamics is a type of structure-function function. It is most appropriate to be used to study the dialectical relationships between the structure, function and behavior of a complex system. In system dynamics, the combined use of qualitative and quantitative approach benefits the solving of complex system problems based on systematic inference. The model established according to the principle and method of system dynamics studies the problems of a system in a qualitative and quantitative way with the help of computer simulation.

Actually, a variable rate equation is set to conduct dynamics simulation of a series of causal feedback loops in a system to quantify the behaviors of the whole system. Available mathematical expression is

$$y_{(ti)} = y_{(ti-1)} + R_{(ti)}\, ti$$

where $y_{(ti)}$ is the amount at ti; $y_{(ti-1)}$ is the amount of at the end of ti -1; $R_{(ti)}$ is the variation rate from the end of ti -1 to the end of ti. A variable rate equation represents the basic unit of system dynamics.

The specific procedures for solving problems by system dynamics [15] are as follows: (1) determine the objectives of system simulation; (2) analyze system structure and causal relation; (3) establish system dynamics model; (4) determine and input system parameters; (5) model validation (6) system simulation study.

Determination of the Boundary of Model System

According to the features of society, economy and ecological environment in Pingtan Island, the administrative division boundary of Pingtan Island is used as the main basis when establishing the model and choosing variables and parameters.

Division of Subsystems and Predictive Range of the Model

(1) Division of Subsystems

Based on the goals and constraining factors of the sustainable development of Pingtan Island, the total system is divided into two four subsystems: resource subsystem, economy subsystem, society subsystem and environment subsystem. The subsystems are connected with the input and output of materials and information. Thus, a model feedback structure is formed with 3 status variables, 5 rate variables, 83 auxiliary variables and initial variables.

(2) Predictive Range of the Model

The predictive range of the model is from the year 2005 to 2030; 2005 is the base year, and 2006 ~ 2009 the validation years of the model, with the step size of one year.

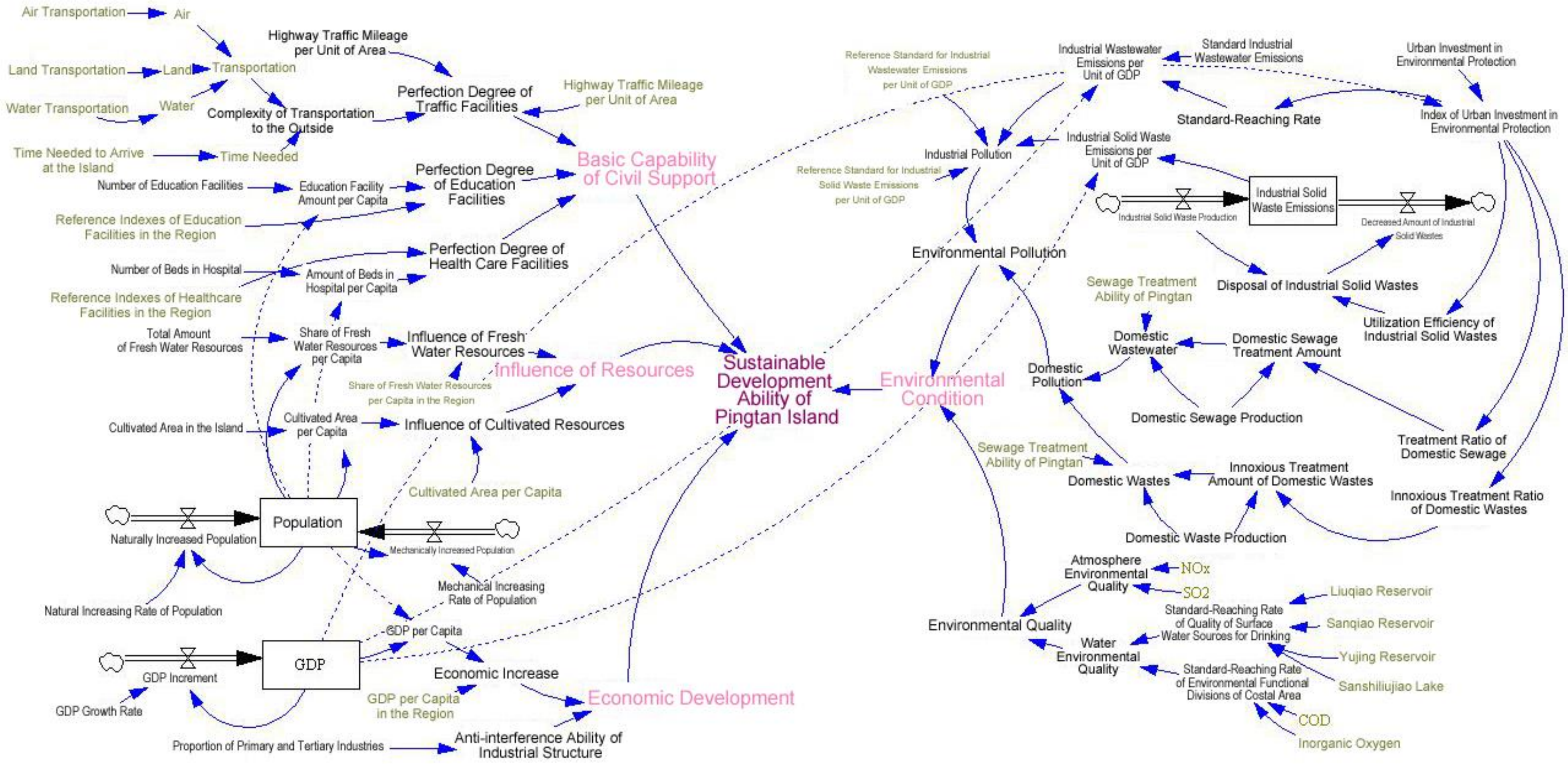

Figure-1 system dynamic model of sustainable development of PingTan Island

Flow Chart of the Model

VENSIM software is used to simulate the system behavior. The flow chart of the model is shown in Figure-1.

Effectiveness Validation of the Model

After the establishment of the model, the effectiveness of the model should be validated to ensure that the model results conform to reality. It represents the operating effect of the model. The validation years are 2006 ~ 2009, and the test variables are the population and GDP of Pingtan Island, which are shown in Table-1 and Table-2. It can be known by analyzing the relative error that the absolute value of error between simulated value with the model and the historical value is smaller than 5%. This means that the operating results highly match the actual data, and the simulation and policy analysis is reliable and correct.

Table-1 Error Statistics of the Historical and Simulation Values of Population of Pingtan Island

Index / Year	Simulation Value	Historical Value	**Error (%)**
2006	384392	382876	0.396
2007	386175	380721	1.432
2008	387967	384785	0.827
2009	389767	389722	0.012

Table-2 Error Statistics of Historical and Simulation Values of GDP of Pingtan Island

Index / Year	Simulation Value (10000 Yuan)	Historical Value (10000 Yuan)	**Error (%)**
2006	414807	434150	4.455
2007	468732	479361	2.217
2008	529667	531903	0.420
2009	598524	593072	0.919

Plan Design

The system dynamics simulation experiment on the sustainable development of Pingtan Island is carried out by changing the parameters of the system. In this study, 7 plans are designed by dividing the subsystems based on plan 0 (maintaining the status quo). Finally, 4 comprehensive plans are derived, as shown in Table-3.

Table-3 Table of the Sustainable Development Ability Plan of Pingtan Island

S. No.	*Plan*		**Scenario**
1	Plan 0		Sustainable development ability of the experimental area with current developing condition
2	Plan 1		Sustainable development ability of the experimental area by assuming that the traffic, health care and educational facilities are approaching perfection
3	Plan 2		Sustainable development ability of the experimental area if the project of water diversion from outside the island (scale 518,000 m3/d) is implemented, and the population is controlled at 1,000,000 [16]
4	Plan 3		Sustainable development ability of the experimental area if the project of water diversion from outside the island is implemented and the population is controlled at 830,000 (per capita share of water resources 500 m3)
4	Plan 4		Sustainable development ability of the experimental area if the project of water diversion from outside the island is implemented, with reclaimed water recycling (20% in 2015, 20% in 2020 and 30% in 2030), and the population is controlled at 1,000,000
6	Plan 5		Sustainable development ability of the experimental area if the project of water diversion from outside the island is implemented, with reclaimed water recycling (20% in 2015, 20% in 2020 and 30% in 2030), and the population is controlled at 920,000
7	Plan 6		Sustainable development ability of the experimental area considering that the pollution would be greatly aggravated after the implementation of the plans in the experiment area, under the existing investment index of environmental protection, and for the situation that the environmental quality is maintained at the current status or improved
8	Plan 7		Sustainable development ability of the experimental area based on Plan 6, with the changes in investment index of environmental protection (increasing to 1.7% in 2015, 2.0% in 2020, and 3.0% in 2025)
9	Comprehensive Plan	Plan A	Sustainable development ability of the experimental area as determined by combining plan 1, plan 2 and plan 7
10		Plan B	Sustainable development ability of the experimental area as determined by combining plan 1, plan 3 and plan 7
11		Plan C	Sustainable development ability of the experimental area as determined by combining plan 1, plan 4 and plan 7
12		Plan D	Sustainable development ability of the experimental area as determined by combining plan 1, plan 5 and plan 7

RESULTS AND DISCUSSION

Result Analysis

The sustainable development ability of the island based on plan 1 to plan 7 is shown in Figure-2, and that of the Pingtan Integrated Experimental Area based on comprehensive plan A to plan D is shown in Figure-3.

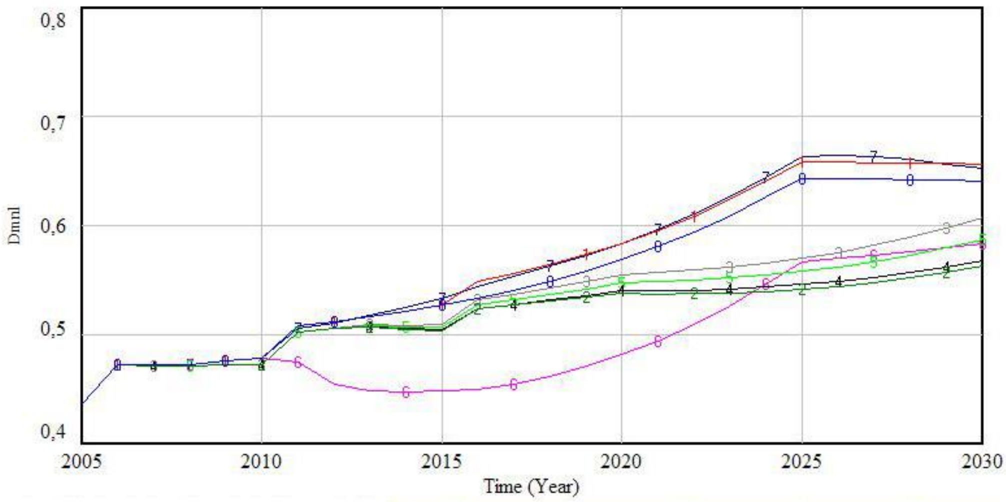

Figure-2 Sustainable Development Ability of Pingtan Island Based on Plan 1 to Plan 7

It cam be seen from Figure 2 that the influence of water resources constraint and environmental pollution on the sustainable development ability of the experimental area is large. Plan 1 greatly improves the infrastructures of the area under the current conditions compared with plan 0; it enhances the sustainable development ability of Pingtan Island. In plan 2, there is a large population burden, with the share of water resources per capita being only 417 m^3, which is far lower than the average level of the province, the negative standard of livable city and even lower than that of the integrated experimental area presently. According to internationally recognized standard, this area is an extremely water-deficient area, which would restrict the sustainable development of Pingtan Island, bringing tremendous pressure to the industrial development and economy. In plan 3, a project of water diversion from outside the island is implemented, and the population is controlled at a reasonable size. Thus, the crisis of low share of water resources per capita is alleviated to some extent, and the sustainable development ability is improved more efficiently than plan 2. Reclaimed water recycling is strengthened in plan 4, but the contribution of the increased use of reclaimed water to the sustainable development ability of the experimental area is not significant due to the large increase of the population. In Plan 5, besides the enhancement of reclaimed water recycling, the population is controlled at a reasonable size, which makes the sustainable development ability under plan 5 superior to that under plan 4. By improving the investment index of environmental protection, plan 7 decreases the influences of the greatly increased pollutants caused by the development in this area on the environment of Pingtan Island. Hence, the sustainable development ability is higher than that under plan 6.

It can be seen from Figure 3 that the sustainable development ability of Pingtan Island is gradually increasing by combining plan A to D. Plan B and plan D concentrate on the harmonious development of economy, society, resources and environment, which contributes to the sustainable development ability, and these two plans are far better than plan A and plan C. Reclaimed water recycling is implemented in plan D, and the population size is also higher. But it can be seen from Figure 3 that the sustainable development ability under plan D is not as good as that under plan B. Hence, the recommended plan for environment impact assessment is plan B, which includes improving the traffic, health care and education facilities and conditions gradually, implementing the project of water diversion from outside the island, and controlling the population at the size of 830,000. Meanwhile, the environmental quality of the experimental area should be constantly improved, and the investment index of environmental protection should be increased (to 1.7% in 2015, 2.0% in 2020 and 3.0% in 2025). Therefore, the sustainable development ability of the experimental area will increase gradually. Since the water resource constraint has a considerable impact, the reclaimed water recycling needs to be further strengthened in this plan.

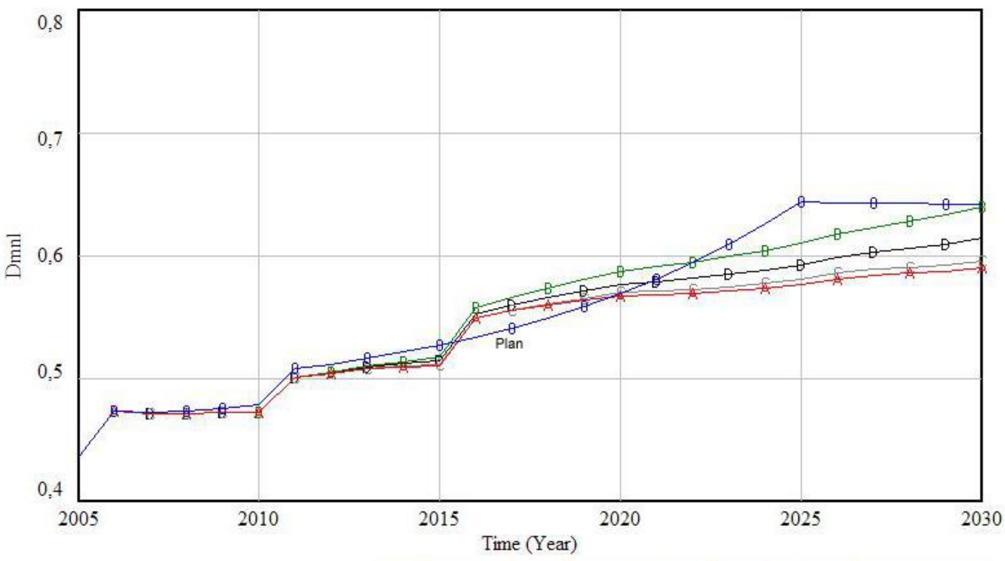

Figure-3 Sustainable Development Ability of Pingtan Island by Combining Plan A to Plan D

Control Measures

(1) Control the population in Pingtan Island It is suggested that the population does not exceed 830,000 while ensuring that the long-term water diversion amount is 518,000 m3/d, so that the harmonious development of resources, environment and economy will be achieved, and the area be developed sustainably.

(2) Guarantee the water supply in Pingtan Island The construction of water supply infrastructures should be strengthened to assure the implementation of regional water resources distribution. The water resources should be exploited reasonably, the resource utilization ratio be improved, and wastes and pollutant emissions be decreased. Moreover, the reclaimed water recycling rate should be further improved, by stepping up the construction of reclaimed water recycling projects and reclaimed water pipeline network.

(3) Reinforce environmental pollution control and improve the investment index of environmental protection.

First, multiple approaches and measures must be taken against industrial pollution. The pollutant emissions by the enterprises should be monitored and cut down. The pollutant emissions by industrial enterprises should reach the standard, and the total pollutant emissions should be controlled.

Second, the domestic pollution should be reduced from the origin. The construction of environmental protection infrastructures should be reinforced.

Third, the investment in environmental protection should be increased to improve the environment of the area, so that the self-purification capacity of the environment will be strengthened, and the sustainable development of the area will be promoted.

(4) Strengthen the construction of traffic infrastructures The external transportation in the experimental area should be improved. The traffic constraints should be addressed immediately, and the improvement of external transportation for island where there are residents should be considered.

(5) Optimize the industrial structure The historical opportunity that the nation is accelerating the construction of the economic zone on the west coast of the strait should be grasped. It is of great importance to facilitate the optimization and upgrading of industrial structure, to control the proportion of primary, secondary and tertiary industries, to follow the policy of land, energy and water saving, emissions reduction, and low carbon, so that the industrial structure of this area would develop towards the direction of low energy, low pollution and low carbon emissions.

CONCLUSION

The sustainable development of the island involves economy, society, resource and environment development. Studies in this respect must be conducted from the system view. Based on system dynamics, a model is established with the consideration of both internal and external factors of a complex system. The dynamic behavior of the complex system with the variation of time can be reflected by model simulation. In this study, the principle and method of system dynamics is applied to construct a system dynamics model of the sustainable development of Pingtan Island, and the simulation result serves as the basis for the general environmental impact assessment of Pingtan integrated experimental area. This provides the scientific basis for policy makers in formulating environmental protection measures from the perspective of sustainable development.

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