System Dynamics Simulation of Environmental Resources in Yinchuan Plain

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Abstract. Based on geospatial analysis, this paper studies the relationship between social systems and ecosystems in Yinchuan Plain through the analysis of environmental and resource indicators. Firstly, the ecosystem system configuration model was optimized based on system dynamics (SD). Secondly, different development strategies were analysed through Vensim PLE combined with scenario simulation. Lastly, the environmental impact factors such as air quality, SO2, wastewater, solid waste, energy consumption per unit output value, expenditure for environmental protection and green coverage rate in built-up area, etc were studied. In summary, this paper provides a theoretical basis and realistic basis for the sustainable development of the Yinchuan Plain.

1. Introduction

The Social Ecological System is a complex giant system composed of people, nature and society, and it is a combination of social systems and ecosystems [1-2]. The feedback process of social ecosystem has many characteristics such as unpredictability, self-organization, threshold effect and historical dependence [3]. It is difficult to reflect the feedback process by structural analysis alone. To this end, it is necessary to use experimental methods to study the dynamic mechanism of the feedback process of social ecosystems. Scenario Model-Simulation is an experimental comprehensive technology. Based on system dynamics and using data computing platform as a tool, the scenario model is used to dynamically simulate the feedback process of social ecosystem. It is economical and ultra-real-time. Repetition, convenience and other characteristics are recognized as one of the most effective research methods at home and abroad [4], and thus can be used as an important means to study the feedback process of social ecosystems.

Since the 1960s, scholars have gradually realized that natural systems and socio-economic systems have penetrated each other. The impact of factors such as society, policy, culture, history, consciousness, community organization, and cross-scale linkages on ecosystems has become increasingly apparent. Research has gradually expanded to the field of social ecosystems dominated by human activities. Ma and Zhao proposed the concept of “social-economic-natural complex ecosystem” [5][6], and considered...
social ecosystems to be natural, economic and social. Cumming and other scholars put forward the concept of "social-ecosystems (SESs)" [7]. Elinor Ostrom first proposed in Science, the social ecosystem is decomposed into three parts: natural subsystem, economic subsystem and social subsystem [8]. It has aroused the academic community's high attention to the theory and practice of social ecosystems.

The system dynamics is the way of thinking about the essence of the whole operation. The method of structure, the method of function and the method of history are integrated into a whole, and the feedback relationship among various variables is simulated by computer to reveal the real-world information, ability and material the law of flow [9]. The theory, method and philosophy of system dynamics are applied to the research system. The research object includes management, environmental change, political science, economic behavior, medicine, engineering and other fields [10]. In order to achieve sustainable development, we need to adopt the nonlinear and systematic thinking mode instead of the linear and mechanical thinking mode [10]. System dynamics as a tool for studying the complex feedback relations in the system has been applied in urban planning [11]. In addition, system dynamics is used as a tool for urban residential sustainable development evaluation [12].

In this paper, the system dynamics is used to study the sustainable development of cities in northwest China. The sustainable development model of Yinchuan city in the capital city of northwest China was established by using Vensim PLE software. The model mainly analyzes the interaction between population, environment and economy, and analyzes the influence of different development strategies on the three.

2. System dynamics model

This paper takes Yinchuan City, the capital of Ningxia Hui Autonomous Region as the object of study, and establishes the system dynamics model from 2001 to 2020, taking the whole city as a system, taking into account the interaction of population, economy and environment.

Using methods in geography and sociology, we combine multi-year satellite remote sensing maps with demographic data. With the help of computer drawing tools (Fig 1), which is supported by the Joint Research Centre (JRC) and the DG for Regional Development (DG REGIO) of the European Commission.

![Figure 1. The Methodology of Global Human Settlement Layer](https://ghs1sys.jrc.ec.europa.eu/index.php)
After 25 years of urbanization, the five cities in the Yinchuan Plain are cohesive and expansive. We can find that the migration footprint of the urban population is accompanied by the expansion of artificial canals; the discovery and utilization of new resources; the medium-sized cities continue to attract the surrounding countryside with the accumulation of population (fig 2). Water resources interact with fossil resources, mineral resources and biological resources. Each block represents 250 to 5,000 sq. meters. Taller blocks represent more people. This picture wields data from the Global Human Settlement Layer, which use “satellite imagery, census data, and volunteered geographic information” to create population density maps.

2.1. Social ecosystem modeling based on system dynamics

The system dynamics model includes state variables, auxiliary variables and variable rate variables. Among them, the state variables reflect the main state of each subsystem in the system.

Auxiliary variables and rate variables are the change speed and influence factors of state variables, and the relationship between state variables is established through logistics and information flow to form an interactive system network.

This paper established the system dynamics model, the population indicators for the total population of the region and economic indicators for the region's gross domestic product, and the annual gross domestic product is divided into primary industry (agriculture) in gross domestic product (GDP), the second industry output value, agricultural and construction), the third industry (other than the first and second industry other walks of life).

The mean value of SO\(_2\) years in air is the environmental index. The total population, the total output value of the three industries and the mean value of SO\(_2\) years in air are state variables. The system kinetic flow diagram is shown in figure 3.
The data used to build the model came from the Yinchuan statistical yearbook (2001-2016). In Figure 3, the Yinchuan City Social Ecosystem Optimization Configuration Model consists of three parts: population system, economic system and ecological environment system. The SD model indicator consists of 15 state variables, 45 auxiliary variables, and 90 rate-varying variables.

The core state variables are the annual average of SO2 in total population, GDP, and air. The simulation period is 2005-2025 and the raw data is from the Yinchuan Statistical Yearbook (2005-2017). The original parameters of the model from 2005 to 2017 are mainly obtained through statistical data. The model parameters after 2017 are mainly obtained by the following methods: arithmetic average method to determine birth rate, mortality, water resources change, and oasis area change. Multiple regression analysis determines forest area, cultivated land, domestic water, ecological water, production water supply, GDP growth rate, and population policy coefficients. The grey correlation forecasting method corrects parameters such as environmental quality, per capita GDP, birth population, death, and net migration.

The calculation formula for some state variables is as follows:

Population= INTEG (population change rate)  \( (1) \)

Daily Mean Content of SO\(_2\)= INTEG (SO\(_2\) change rate\(^9\))  \( (2) \)

Output Value of Primary Industry= INTEG (increase of output value of primary industry)  \( (3) \)

Output Value of Secondary Industrial= INTEG (increase of output value of secondary industrial)  \( (4) \)

Output Value of Tertiary Industry= INTEG (increase of output value of tertiary industry)  \( (5) \)

Average GDP=gross domestic product/ Population  \( (6) \)

Other auxiliary variables establish the quantitative relation between variables through multiple regression analysis.

2.2. Test of Social Ecological System model

Before the established ecosystem optimization configuration model is run, it should be tested first. This paper verifies the rationality of subsystem module design through error analysis. If the error of the data
is within ±6%, according to the historical retrospective test, it can be shown that the social ecosystem optimization configuration model established in this paper is reasonable [13]. The model test of Yinchuan sewage system and solid waste system is mainly divided into two steps: operation test and historical data comparison test:

1. Operational inspection
   Check the model structure and model unit monitoring, run the Check Model and Units Check commands under the Vensim software Model window.

2. Historical data comparison test
   The social ecosystem has historically dependent characteristics [14], so it is necessary to analyze the error between the simulated data and the historical data to judge the accuracy and rationality of the model. In this paper, the error analysis of the sewage and solid waste selection data in the model is carried out. The results are shown in Figure 4 and Figure 5.

![Net sewage production simulation test](image1)

**Figure 4. Net sewage production simulation test**

![Net solid waste production simulation test](image2)

**Figure 5. Net Solid waste production simulation test**

To make Model can better reflect the evolution of the population-economy-environment system of Yinchuan, the article USES the Vensim PLE Check in simulation software Model Units and the Check of the established Model structure of the system dynamics Model of suitability test good dimensional consistency Check.

3. Scenario setting and simulation analysis of social ecosystem
   Set variables is presented in this paper, the number of auxiliary variables to time as the independent variables in the form of a table function, according to table function according to the statistical data of 2001-2010 function value, the 2011-2020 function values determined according to the average value of a function in the preceding ten years.

   Proportion of expenditure for environmental protection is 0.0037143.

   The above development model is defined as the basic model.
In addition, different development modes are set up:

**Pattern 1**: priority to the development of the model for the pattern of the second industry, as China belong to economic underdeveloped regions in Ningxia region, developing the second industry is regarded as rapidly improve the economic strength, improvement of people's life, the effective way to promote the competitiveness of the region.

When adopting pattern 1, it is assumed that since 2011, the annual output value of the second industry is 30% higher than the previous year when other variables have not changed.

**Pattern 2**: the model of priority to the development of the tertiary industry, due to the third industry to service industry and transportation is given priority to, also the development of the third industry less disturbance to the environment, and the ability to develop regional economy, increase employment, but the development of the tertiary industry is restricted by the primary industry and second industry development level.

When adopting pattern 2, it is assumed that the annual output value of the third industry is 21% higher than that of the previous year, since 2011, when the other variables have not changed.

**Pattern 3**: the model for economic and social development pattern, this pattern mainly includes promotes the development of the second industry, increase the science and technology expenditure, expenditure on health, environmental protection, promote social development will help to enhance the social fairness, maintaining social stability, improve people's health, to promote economic and social progress in an all-round way.

Using pattern 3, assuming other variables are unchanged, since 2011, the second industry increased by 30% over the previous year, every year every year, proportion of expenditure for science and technology over the previous year increased by 5%, annual proportion of expenditure for health increased by 5% over the previous year, the proportion of expenditure for environmental protection, to 0.85%. The simulation results are shown below in figure 6 to figure 11:

![Figure 6. Population change trend chart](image1.png)

![Figure 7. Daily means content of SO2 trend chart](image2.png)
Figure 8. Green coverage rate in built-up area.

Figure 9. SO$_2$ change rate.

Figure 10. Energy consumption per unit output value.

Figure 11. Expenditure for environmental protection.
According to simulation results, the model 1, Gross domestic product relatively rapid growth in 2010 and beyond, and several other development model of Gross domestics’ product broadly similar growth speed.

According to simulation results, the model 3, the population growth in 2010 and beyond is greater than the other two modes, ideally, can reach more than 10 million people in 2020, this is mainly because on the one hand, rapid industrial development, gathered to a large number of population, in addition, due to the increased health, science and technology, environmental protection investment, improve the quality of life of residents, improve the natural population growth rate to the attraction of the floating population and cities.

The adoption of model 1 shows a decline in population after 2018, mainly due to the poor quality of the natural environment and the decline of population.

With the simulation results, before 2013, the daily mean the content of SO$_2$ all showed a trend of gradual decline, after that, if take the model 1, the daily mean the content of SO$_2$ is gradually increased, mainly because the large-scale industrial development for deterioration in air quality, using the model 3 is the daily mean the content of SO$_2$, fastest decline in industrial development at the same time, should be increased spending on health care, technology and environmental protection, but after 2018, the daily mean the content of SO$_2$ increased, pertaining to the industrial development of the environmental pollution caused by need more funding for governance.

With model 2, the daily mean content of SO$_2$ has been declining, indicating that the third industry has fewer disturbances to the environment.

4. Conclusion

This paper analyzes the most important control indicators in the future development of Yinchuan Plain, population, environment and ecological resources. Through the system dynamics method to study the ecosystem of Yinchuan Plain, the following main conclusions are obtained:

1. The results of the ecosystem optimization configuration model test show that the error of population and GDP data and simulation data are within 6%, indicating that the ecosystem model of this paper can reflect the changing law of population and economic data.

2. From the scenario setting and simulation results, it can be seen that urban resources show different results with construction and development. By rationally utilizing urban and regional resources, environmental protection planning and continuous investment, avoiding the waste of ecosystem-oriented resources and pollution direction. For Yinchuan City, the central city of Yinchuan Plain, the transition from a balanced development model to a three-product priority development model is conducive to the sustainable development of the city. The three-product priority development model is the best choice among the four development programs because it has relatively small local ecological damage and mineral resource consumption, and can maintain rapid development in the middle and later stages, and ultimately achieve sustainable urban development.

However, cities are artificial ecosystems with dynamic, multi-level and nonlinear characteristics [15]. The simulation can only simulate the dynamics of a certain time period, and the choice of the elements has certain subjectivity. Secondly, although the system dynamics model is more reliable in judging the macro direction, it cannot be accurately predicted. Therefore, in future research, the SD model can be combined with cellular automata and genetic algorithms to optimize the simulation model.

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References

[1] YU Z Y, LI B, ZHANG X S. Social ecological system and vulnerability driving mechanism analysis. Acta Ecologica Sinica,2014,34(7): 1870-1879.

[2] Folke Carl. Resilience: The emergence of a perspective for social–ecological systems analyses[J].
Global Environmental Change, 2006(3): 253-267.

[3] Begum R-A, Siwar C, Pereira J-J, et. al. Attitude and behavioral factors in waste management in the construction industry of Malaysia[J]. Resources, Conservation & Recycling, 2009(6): 321-328.

[4] Deakin Mark, Reid Alasdair. Sustainable urban development: Use of the environmental assessment methods[J]. Sustainable Cities and Society, 2014: 39-48.

[5] MA Shi jun, WANG Rusong. The social-economic-natural complex ecosystem[J] Acta Ecologica Sinica, 1984,4(1):1-9.

[6] Allen Craig-R., Holling Crawford-S.. Columbia University Press[M]: Columbia University Press, 2008.

[7] G. s. cumming . An Exploratory Framework for the Empirical Measurement of Resilience[J]. Ecosystems, 2005(8): 975-987.

[8] Ostrom Elinor. A general framework for analyzing sustainability of social-ecological systems.[J]. Science, 2009, 325(5939): 419-422.

[9] LI Fujia, LI Yu, LI Zehong, et al. Comprehensive benefit evaluation on the circular agricultural system based on system dynamics[J]. Journal of Arid Land Resources and Environment, 2015(6): 45-50

[10] Yin K, Wang R, An Q, et al. Using eco-efficiency as an indicator for sustainable urban development: A case study of Chinese provincial capital cities[J]. Ecological Indicators, 2014, 36: 665-671.

[11] Hjorth P, Bagheri A. Navigating towards sustainable development: A system dynamics approach[J]. Futures, 2006, 38(1): 74-92.

[12] Fong W K, Matsumoto I, Lun Y F. Application of System Dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities[J]. Building and Environment, 2009, 44(7): 1528-1537.

[13] Xu Z, Coors V. Combining system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development[J]. Building and Environment, 2012, 47: 272-287.

[14] GUO Wei-feng,WANG Wu-ke. A SD-based Study on Simulated Calculation of Man-earth Areal System in Guanzhong Plain [J] Journal of Northwest A&F University(Social Science Edition), 2010(1): 47-52.

[15] Cumming G.-S., Barnes G., Perz S., et al. An Exploratory Framework for the Empirical Measurement of Resilience[J]. Springer-Verlag, 2005, 8(8): 975-987.