2018 International Conference on Educational Research, Economics, Management and Social Sciences (EREMS 2018)

Dynamic Assessment and Regulation of Urban Ecological Security in Jiangsu Province Based on PSR and GM (1,1) Model

Zhao Xicang, Lu Jinlong*

School of Finance and Economics, Jiangsu University, Zhenjiang, 212000, China

*Corresponding Author email: lujinlong_ljl@163.com

Keywords: Environmental Engineering; PSR Model; GM (1,1) Model; Grey Correlation Analysis; Dynamic Evaluation

Abstract: The urban ecological security evaluation system was constructed in Jiangsu province based on PSR model during the period of 2010 and 2016, and entropy-weight method and the analytic hierarchy process (AHP) were used to calculate index weights. Secondly, grey relational analysis was used to analyze the key indicators of the urban ecological security evaluation system. Finally, the GM (1, 1) model was applied to dynamically evaluate the urban ecological security in Jiangsu Province. The following results we obtained: (1) the key indicator of urban ecological security system in Jiangsu province are the comprehensive utilization rate of industrial solid waste, Centralized sewage treatment rate, and the proportion of science and education expenditure in total expenditure of finance; (2) development of Jiangsu province city ecological security exists regional heterogeneity. The Pearson correlation coefficient between urban ecological security assessment and per capita GDP is 0.7745, which indicates that urban ecological security is highly correlated with economic development; (3) During the period of 2010-2016, the development trend of urban ecological security in Jiangsu Province is positive.

1. Introduction

Urban ecological security refers to a series of factors such as the minimum environmental capacity of human beings, a country, a region or urban residents, the minimum per capita possession of strategic natural resources, and the suppression of major ecological disasters.

In the past 40 years of reform and opening up, China has experienced unprecedented large-scale and high-speed urbanization; at present, more than 57% of the people live in cities, and by 2020, this proportion will reach 60%[1]. Therefore, based on the ultimate goal of human survival and sustainable development, systematically explore the root causes of urban ecological environment problems, rationally regulate the relationship between man and nature, formulate urban ecological control programs, and guide the ecological operation of social economic systems. It is of great theoretical value and practical significance to maintain an ecological support system with strong supporting capacity, to construct an urban ecological security pattern, and to implement a sustainable urban development strategy based on the sustainable development of the ecological environment.

At present, there are still differences on the concept and understanding of ecological security. However, there are basically two definitions of broad and narrow definitions based on the definitions of domestic and international. Broadly speaking, the ecological security proposed by the International Institute of Applied Systems Analysis (IIASA) [2] in 1989 was the earliest representative, including natural, economic and social ecological security, to form an artificial safety system. In a narrow sense, the meaning proposed by Rogers [3] in 1997 refers to the safety of natural and semi-natural ecosystems, i.e. the integrity of ecosystems and the reflection of the overall level of health [4,5].

With the deepening of the research on urban ecological security, a series of methods for evaluating ecological security have emerged on the basis of integrating the achievements of relevant disciplines and research fields, such as comprehensive index method [6-10], ecological footprint method [11-14].

  DOI: 10.25236/erems.2018.206

These research methods have different degrees of human activities on the pressure of the environment, the quality of natural resources and human activities.

Generally speaking, whether PSR model or ecological footprint method, urban ecological security assessment technology should continue to study the following aspects: (1) sensitivity analysis of a single indicator to urban overall ecological security and correlation analysis between indicators. (2) Study on the dynamic evolution and development of urban ecological security. (3) Urban ecological security has obvious spatial heterogeneity. In the process of urban ecological security evaluation, it should take into account its spatial heterogeneity and time variability, make the evaluation results more reasonable and help relevant people to take corresponding measures. The article focuses on solving the problems existing in the current research and making the urban ecological security assessment system more perfect.

2. Research method

2.1 PSR model

Table 1 Index System of Urban Ecological Safety

Target layer	System layer	Index layer	Unit	Index properties
Urban ecological security	Press	(P1) Per capita daily water consumption	Sheng / Ren	-
		(P2) Domestic electricity consumption of urban and rural residents	KWh/person	-
		(P3) Sulfur dioxide emissions	Ten thousand tons	-
		(P4) Urban Population Density	Man/km2	-
		(P5) Wastewater Discharge	million tons	-
		(P6) Urbanization rate	%	+
	State	(S1) Green Coverage Rate of Built-up Areas	%	+
		(S2) Per capita park green area	Square metre/person	+
		(S3) Per capita Road area	Square metre/person	+
		(S4) Drainage Pipeline Density in Built-up Area	Km/km2	+
		(S5) Per capita GDP	element	+
		(S6) Urban registered unemployment rate	%	-
	Response	(R1) Comprehensive Utilization Rate of Industrial Solid Waste	%	+
		(R2) centralized sewage treatment rate	%	+
		(R3) The proportion of tertiary industry to GDP	%	+
		(R4) The proportion of expenditure on education and science and technology in financial expenditure	%	+
		(R5) Number of beds in medical and health institutions	Individual	+

The Canadian Organization for Economic Co-operation and Development and the United Nations Environment Programme[15] proposed the concept of an environmental PSR indicator system. The indicator system is constructed from three aspects: urban ecological pressure (population growth pressure and environmental resource pressure), ecological environment and countermeasures

(measures and policies to solve ecological problems [16]. On the basis of expert consultation and consulting relevant literature [6-10], the index system of urban ecological security in this paper is established (Table 1).

Urban ecological security system is a complex system. It is a process of interaction and interaction among social, economic, population, resources, environment, culture and nature. At the same time, in the process of the evolution of urban ecological security, it is also a process of multi-factor game. The regulation of urban ecological security can not be separated from the comprehensive regulation of various factors.

2.2 Data Standardization Processing

In order to eliminate the differences of units, orders of magnitude, data properties and other dimensions of each evaluation index, standardized data processing is needed. Since urban ecological security indicators are divided into positive indicators (effectiveness indicators) and reverse indicators (cost indicators), it is necessary to forward the reverse indicators. This paper adopts the maximum and minimum standardization method (very poor standardization method). Since the data will be zero after normalization, it is replaced by an approximate 0.0001 to avoid ln0 meaningless. The maximum and minimum standardization methods are as follows:

Positive indicator: $y_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}$; reverse indicator: $y_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}}$.

2.3 Entropy weight method and analytic hierarchy process

The article uses an analysis method combining entropy weight method and analytic hierarchy process. The entropy method is an objective weighting method. It calculates the weight of the index according to the information entropy of the index and the influence of the relative change degree of the index on the system as a whole. The index with a relatively large degree of change has a larger weight. The comprehensive evaluation using the entropy method mainly consists of the following steps:

First calculate the index information entropy value E and the difference coefficient d:

Use $P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$ to indicate the contribution of the sample A_i of the i item under the index j. Use E_j to represent the total contribution of all samples to the index of the j, that is, the information entropy of the index j:

$$E_j = -K\sum_{i=1}^{m} P_{ij} \ln(P_{ij}), (j = 1, 2, ..., n) \quad (1)$$

Among them, the constant $K = \frac{1}{\ln(m)}$, in this way, can guarantee $0 \le E_j \le 1$, that is, E_j is at most 1. In this way, it can be seen that all sample difference sizes determine the size of the weight coefficient. To this end, d_j can be defined as the degree of difference in the contribution of each sample under the index j. $d_j = 1 - E_j$.

Secondly, the weight of the evaluation index is calculated. The weight W_j of the index j is: $W_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, (j = 1, 2, ..., n)$.

Analytic Hierarchy Process (AHP) weighting is a multi-criteria decision-making and evaluation method which combines qualitative and quantitative analysis. The relevant elements of decision-making are decomposed into target level, criterion level and scheme level, and the decision-making scheme is ranked by people's judgment. On this basis, qualitative and quantitative analysis is carried out. It hierarchically and quantitatively processes people's thinking processes and provides a quantitative basis for analysis, decision making, evaluation, forecasting and control using mathematics. The weight of the analytic hierarchy process is Vj.

After calculating the weights of the entropy weight method and the analytic hierarchy process, the comprehensive weights (Table 3) can be calculated: $h_j = \frac{V_j W_j}{\sum_{j=1}^{m} V_j W_j}$, so that the urban ecological security evaluation values of each city over the years can be calculated (Table 4): $S_i = \sum_{j=1}^{n} h_j p_{ij}$.

2.4 Urban ecological security level

The comprehensive evaluation value of urban ecological security can approximate the conformity and closeness of urban ecological security status and development goals. The closer the indicator value is to 1, the better the urban ecological security situation. On the contrary, the closer the value is to 0, the worse the urban ecological security status. The comprehensive evaluation value of ecological security can be graded to determine the level of regional ecological security. According to the existing research results [17-20], the urban ecological security level of Jiangsu Province can be classified (Table 2). Here, we consider not only the existing security level of urban ecological security, but also its development trend.

Table 2 Grade Division of Urban Ecological Security Evaluation

Security classification	Evaluation value interval	Safe state	Early-warning leve
I	$S \geq 0.75$	Security	No warning
II	$0.55 \leq S < 0.75$	Safer	
III	$0.45 \leq S < 0.55$	Critical safety	Mild warning
IV	$0.35 \leq S < 0.45$	Unsafe	Moderate early warning
V	$S < 0.35$	It's not safe	Severe early warning

2.5 Grey Relational Analysis and Grey Prediction

Urban ecological security can be regarded as a huge grey system (between white system and black system, there is a lot of uncertainty in information). The use of grey correlation analysis can evaluate the key elements and key indicators of ecological security in cities in Jiangsu Province, and provide a scientific basis for urban ecological security management. Through the formula (2) and the formula (3) [here, the Deng's gray correlation degree combining the gray correlation analysis and the maximum fuzzy entropy is adopted.] The gray correlation degree of the three system layer indices of the P, S, and R 2000-2016 time series (comparison columns) for the comprehensive index S2000-2016 time series (reference column) can be calculated (Table 5).

$$\gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \xi \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \xi \max_i \max_k |x_0(k) - x_i(k)|} \tag{2}$$

$$\gamma(X_0, X_i) = \frac{1}{n} \sum_{k=1}^{n} \gamma(x_0(k), x_i(k)) \tag{3}$$

The GM(1,1) residual model can effectively predict the time series data of a small sample. Grey predictions identify differences in the trends between system factors. That is to say, the correlation analysis is carried out, and the original data is generated and processed to find the law of system variation, and the data sequence with strong regularity is generated, and then the corresponding differential equation model is established to predict the future development trend of things. This paper forecasts the individual index values of Jiangsu Province and its 13 cities from 2017 to 2020, and calculates the urban ecological security evaluation values of Jiangsu Province and its 13 cities from 2017 to 2020 (Figure 2).

3. Case analysis

3.1 Data sources

The research data are from Jiangsu Statistical Yearbook (2011-2017), Jiangsu Municipal Statistical Yearbook (2011-2017), Jiangsu Municipal Environmental Status Bulletin (2010-2016), Jiangsu Municipal Statistical Bulletin of National Economic and Social Development (2010-2016). A total of 18 indicators for 13 cities from 2010 to 2016 were collected, totaling 91 samples and 1638 records. In the dataset, there are 16 missing values, and the article uses the moving average window method to process missing values.

3.2 Result analysis

According to the method proposed in the second section, the weights of Jiangsu's urban ecological security index system (Table 3) and the comprehensive evaluation value of urban ecological security over the years (Table 4) were calculated. The grey relational degree of each element in the urban ecological security evaluation system of Jiangsu Province (Table 5) and the evolution trend of urban ecological security in Jiangsu Province (Figure 2).

(1) Comprehensive Evaluation and Analysis of Urban Ecological Security

Table 3 Weight of Urban Ecological Security Rating Index System

		Weight of AHP (V_j)	Weight of entropy method (W_j)	Comprehensive weight (h_j)
Pressure layer (0.1714)	P1	0.0149	0.0574	0.0181
	P2	0.0149	0.0233	0.0074
	P3	0.0635	0.0304	0.0410
	P4	0.0163	0.0584	0.0202
	P5	0.0743	0.0375	0.0591
	P6	0.0163	0.0741	0.0256
State layer (0.2033)	S1	0.0564	0.0100	0.0119
	S2	0.0404	0.0618	0.0529
	S3	0.0380	0.0100	0.0081
	S4	0.0404	0.1059	0.0908
	S5	0.0114	0.0930	0.0225
	S6	0.0135	0.0597	0.0171
Response layer (0.6253)	R1	0.1804	0.0253	0.0968
	R2	0.1804	0.0459	0.1755
	R3	0.0878	0.0376	0.0700
	R4	0.0624	0.0833	0.1102
	R5	0.0496	0.0784	0.0825
	R6	0.0394	0.1079	0.0901

Note: The weights of bold fonts in each column in the table are the top three weights in each weighting method.

From Table 3, we can see that in the weight allocation of PSR model, the response layer occupies the largest weight (0.6253). Among all the individual indicators, the top three indicators with the largest weight are (R1) the comprehensive utilization rate of industrial solid waste: 0.0968. (R2) centralized sewage treatment rate: 0.1755. (R4) The proportion of expenditure on education and science and technology in financial expenditure is 0.1102. The most important concern for urban ecological security in Jiangsu Province is to respond to these changes through policies, decision-making or management measures such as environment, economy and land, and to alleviate the pressure on the environment due to human activities and maintain environmental health.

It can be seen from Table 4 that both the overall situation in Jiangsu Province and the comprehensive evaluation value of urban ecological security in all cities (except Changzhou) are on the rise. Since 2010, the urban ecological security of Jiangsu Province has developed better.

It can be seen visually from Figure 1 that the overall ecological security levels of the cities and Jiangsu are rising. There are two exceptions here: one is the ecological security value of Suqian City. In 2011, the urban ecological security value dropped a lot. This was mainly due to the decline in the proportion of education and science and technology expenditures to fiscal expenditures by key indicators (R4). The other is that the ecological safety value of Changzhou City does not rise and fall after reaching its peak in 2014. By comparing its individual indicators over the years, it is found that the indicators of the main pressure layer and the state layer are worth changing. The comprehensive index value of pressure layer in Changzhou decreased from 0.1232 in 2014 to 0.0722 in 2016, and the comprehensive index value of state layer decreased from 0.154 in 2014 to 0.1077 in 2016.

Table 4 Comprehensive Evaluation of Urban Ecological Safety in Jiangsu

Region	2010	2011	2012	2013	2014	2015	2016
Nanjing	0.6658	0.6884	0.7099	0.7186	0.6990	0.7411	0.7699
Wuxi	0.4457	0.5057	0.5432	0.6001	0.6534	0.6539	0.6978
Xuzhou	0.4111	0.4906	0.5070	0.5201	0.5517	0.5801	0.5949
Changzhou	0.4721	0.5150	0.5641	0.5944	0.6671	0.6228	0.5989
Suzhou	0.5141	0.5364	0.5510	0.6265	0.6670	0.6871	0.7095
Nantong	0.4415	0.4657	0.4772	0.5202	0.5556	0.6092	0.6236
Lianyungang	0.4190	0.4505	0.4811	0.5241	0.4964	0.5424	0.5896
Huaian	0.4557	0.4348	0.4532	0.4878	0.6234	0.6031	0.6281
ynz	0.3686	0.3813	0.4312	0.5260	0.6169	0.6135	0.6394
Yangzhou	0.5176	0.5550	0.6376	0.6416	0.6704	0.6650	0.6901
Zhenjiang	0.4608	0.4802	0.5283	0.5684	0.6109	0.6360	0.6449
Taizhou	0.4054	0.4533	0.5103	0.5468	0.5706	0.5659	0.6289
Suqian	0.4484	0.3622	0.4862	0.4580	0.5137	0.5379	0.5233
Jiangsu Province	0.4635	0.4861	0.5293	0.5640	0.6074	0.6199	0.6414

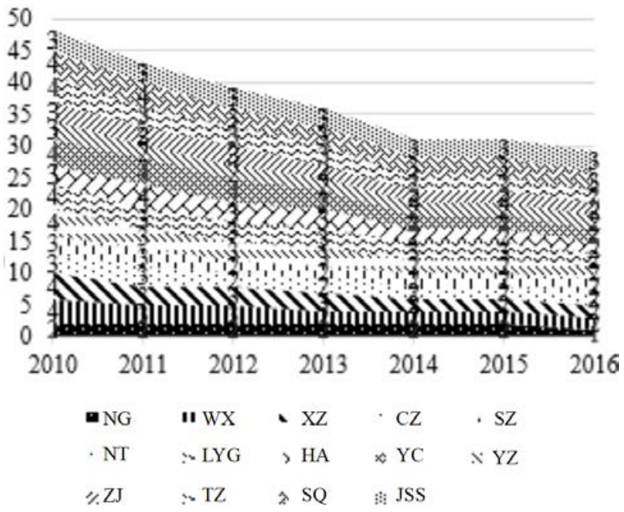

Figure 1 Change of Urban Ecological Safety Grade in Jiangsu

Compared with table 4, the safety levels of Jiangsu Province and its 13 cities were classified (Fig. 1). It is found that the overall urban ecological security in Jiangsu Province is in a relatively safe state of level II, and the corresponding early warning level is "no early warning". However, there are obvious regional differences in the urban ecological security level of 13 cities in Jiangsu Province. The best performers were Nanjing, Suzhou and Yangzhou (Southern Jiangsu). The urban ecological security level of Nanjing increased from the earlier safety level (Level II) to the 2016 safety level (Level I). Suzhou and Yangzhou are in addition to the critical safety level in 2010 (Level III) (Suzhou also includes 2011), and the rest of the years are safer (Level II).

(2) Grey relational analysis of urban ecological security in Jiangsu Province

Table 5 shows the grey correlation degree of the three system-level indices of P, S and R for the 2010-2016 time series (comparative column) of each city to the time series (reference column) of the composite index S2000-2016. From the perspective of the entire Jiangsu Province, the largest correlation with the comprehensive indicator value is the response layer index value, and the development of the single indicator corresponding to the response layer is the main driving force for the development of urban ecological security in Jiangsu Province.

Table 5 Grey Correlation Degree of Urban Ecological Security Elements in Jiangsu

	Press	State	Response
Nanjing	0.6526	0.6874	0.7182
Wuxi	0.8000	0.7534	0.7672
Xuzhou	0.6140	0.5216	0.8290
Changzhou	0.8934	0.7626	0.7946
Suzhou	0.5472	0.6293	0.6720
Nantong	0.9403	0.6537	0.6569
Lianyungang	0.7323	0.5380	0.6826
Huaian	0.8628	0.6512	0.6232
ynz	0.6739	0.6026	0.8312
Yangzhou	0.6435	0.7713	0.5075
Zhenjiang	0.5575	0.5602	0.7055
Taizhou	0.7416	0.6103	0.7659
Suqian	0.9021	0.6527	0.6230
Jiangsu Province	0.6884	0.6124	0.8294

Note: The table is thick and inclined, and the number of underlined lines is the maximum of each row, that is, the maximum of grey correlation degree between P, S, R and composite index S of each city.

At the same time, we found that the grey correlation degree between the index values of response layer and the comprehensive index values of Nanjing, Suzhou, Xuzhou, Yancheng, Zhenjiang and Taizhou was the greatest (0.7182, 0.6720, 0.8290, 0.8312, 0.7055 and 0.7659, respectively). The key of urban ecological security control in these cities lies in the control of response layer, and the main impetus of urban ecological security development is also accomplished by response layer. The pressure-related index values of Wuxi, Changzhou, Nantong, Huai'an, Lianyungang and Suqian are the most correlated with the comprehensive index values (0.8000, 0.8934, 0.9403, 0.7323, 0.8628 and 0.9021, respectively). It shows that the development of ecological security in these cities in recent years is mainly driven by energy conservation and emission reduction (pressure indicators are reverse indicators, which have been positive). Yangzhou is different. The highest correlation with the comprehensive indicator value is the state layer (0.7713), indicating that Yangzhou's urban ecological environment is better, which is the main driving force for the city's ecological security and healthy development.

(3) Dynamic Evaluation of Urban Ecological Security in Jiangsu Province

The GM (1,1) model was used to evaluate the urban ecological security of Jiangsu Province. The commonly used accuracy test of GM (1,1) model is posterior error test. Table 6 gives the accuracy test results of GM (1,1) models in various provinces and cities. It is found that except for the qualified accidents of Changzhou and Suqian, the prediction accuracy of all other provinces and cities is good, which shows that it is feasible to use GM (1,1) model to dynamically assess urban ecological security.

Table 6 Dynamic Evaluation of the Urban Ecological Security in Jiangsu

Region	C value	Prediction accuracy	Region	C value	Prediction accuracy
Nanjing	0.3220	Good	Huaian	0.2978	Good
Wuxi	0.1023	Good	ynz	0.1975	Good
Xuzhou	0.0558	Good	Yangzhou	0.1979	Good
Changzhou	0.4123	Qualified	Zhenjiang	0.1214	Good
Suzhou	0.1310	Good	Taizhou	0.1235	Good
Nantong	0.0943	Good	Suqian	0.3520	Qualified
Lianyungang	0.2011	Good	Jiangsu Province	0.1244	Good

Figure 2 shows the comprehensive evaluation value and trend line of urban ecological security in Jiangsu Province over the years. The horizontal dashed line is the lower safety limit value, and the virtual frame is the predictive evaluation value. It is found that the future development of urban ecological security in Jiangsu Province is optimistic, and the safety level will reach the safety level in 2018. The evaluation value of urban ecological security in Nanjing will increase slightly in the next four years, while that of Suqian City will be the lowest, but it will also reach a safer level after 2017.

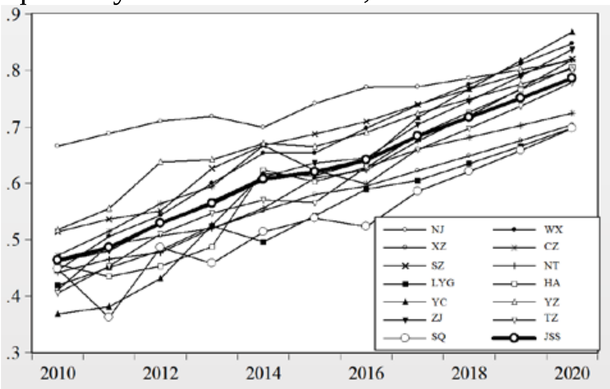

Figure 2 Trend of comprehensive evaluation value of urban ecological security in Jiangsu

4. Conclusion and discussion

Based on the PSR model, this paper constructs the urban ecological security evaluation system of Jiangsu Province from 2010 to 2016, and uses the entropy weight method and the analytic hierarchy process to determine the weight of the index system. The gray system is used to analyze the key indicators and development trends. The main empirical results are as follows:

(1) In selecting the key indicators affecting urban ecological security in Jiangsu Province, in addition to considering the weights determined by the entropy weight method and the analytic hierarchy process, the gray correlation degree is also used. The comprehensive utilization rate of industrial solid waste, the centralized treatment rate of sewage, and the proportion of education and science and technology expenditures in fiscal expenditure in the response layer of its key indicators were found. It shows that Jiangsu Province should focus on the improvement of these three aspects in the process of promoting the development of urban ecological security. But the key indicators are different from city to city. For example, Wuxi, Changzhou, Nantong, Huai'an, Lianyungang and Suqian have the greatest grey correlation with the comprehensive index values. The key to promote the development of urban ecological security in these cities is to improve the pressure index. The focus of Yangzhou is to improve the indicators at the state level.

(2) In the process of analyzing the comprehensive evaluation values of urban ecological security of Jiangsu Province and Jiangsu Province, there is obvious regional heterogeneity in urban ecological security of Jiangsu Province. Pearson correlation coefficient between urban ecological security evaluation value and per capita GDP is 0.7745, and the corresponding t-test probability value is less than $0.0000 < 0.05$, which indicates that there is a significant high correlation between urban ecological security and urban economic development. Urban ecological security is developing from north to south of Jiangsu in space. The GM (1,1) model is used to predict the dynamic evaluation of urban ecological security in Jiangsu Province and various cities. The development of Jiangsu's urban ecological security situation in the next few years is optimistic. The warning level is no warning, and the security level is basically level II (more security level).).

(3) In the urban ecological security evaluation system of Jiangsu Province, the following various control measures are proposed: 1) Establish a comprehensive management system in Jiangsu Province to improve the level of environmental governance integration. 2) Establish new methods of ecological compensation, such as increasing employment opportunities and high-level human resource compensation, and increasing scientific and technological innovation compensation for science and technology investment. 3) Promote traditional compensation methods, such as environmental tax. 4) Innovation of natural ecological protection model and so on.

(4) There are also some shortcomings in this paper. The early warning mechanism of urban

ecological security in Jiangsu Province is based on the deduction of existing data, which is limited by the lack of data. It is expected that the early warning mechanism will be more perfect in the future.

Acknowledgements

Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX17_1737); 16th batch of student research projects of Jiangsu Univesity (16C067).

References

[1] Chen W C, Li X D. Low braking index of PSR J1734-3333: an interaction between fall-back disk and magnetic field?. Monthly Notices of the Royal Astronomical Society Letters, 2016, 455(1): L87-L90.

[2] Liu X W, Li X D. A Fallback Disk Accretion-Involved Formation Channel to PSR J1903+0327. Astrophysical Journal, 2008, 692(1):723-728.

[3] Kumar P, Quataert E J. On the Orbital Decay of the PSR J0045?7319 Binary. The Astrophysical Journal, 1998, 493(1):412-425.

[4] Yao M, Wang X. Electricity Consumption Forecasting Based on a Class of New GM (1, 1) Model. Lecture Notes in Electrical Engineering, 2014, 237:947-953.

[5] Zhou W, He J M. Generalized GM (1,1) model and its application in forecasting of fuel production. Applied Mathematical Modelling, 2013, 37(9):6234-6243.

[6] Hongbo Z, Yanji M A. Study on early-warning model based on variable weight-matter element analysis for ecological security in old industrial bases: a case study of Jilin Province. Acta Ecologica Sinica, 2014, 34(16):4720-4733.

[7] Mclachlan J C, Finn G M, Tiffin P A. Evaluating professionalism in medical undergraduates using selected response questions: findings from an item response modelling study. BMC Medical Education, 2011, 11(1):1-9.

[8] Anderson G M, Castet S, Schott J, et al. The density model for estimation of thermodynamic parameters of reactions at high temperatures and pressures. Geochimica Et Cosmochimica Acta, 1991, 55(7):1769-1779.

[9] Li X, Tao Y, Zheng Y. Model GM (1,1,\r, β\r,) and its applicable region. Grey Systems: Theory and Application, 2013, 3(3):266-275.

[10] Zeng B, Luo C, Liu S, et al. Development of an optimization method for the GM (1, N) model. Engineering Applications of Artificial Intelligence, 2016, 55:353-362.

[11] Shi-Wei L, Lei X, Xian-Dong W, et al. Adaptive GM (1,1) model based on residual recurrence. Systems Engineering & Electronics, 2013, 35(10):2141-2144.

[12] Luo D, Sun Y L, Song B. AIP Conference Proceedings [AIP 11TH INTERNATIONAL CONFERENCE OF NUMERICAL ANALYSIS AND APPLIED MATHEMATICS 2013: ICNAAM 2013 - Rhodes, Greece (21–27 September 2013)], - Optimization of GM (1,1) power model[C]// 2013:1756-1761.

[13] Zhao J, Yang S, Liu X. Stepwise Ratio GM (1, 1) Model for Image Denoising. Grey Systems Theory & Application, 2011, 2(1):659 - 663.

[14] Li Y, Hua X, Yao Z, et al. Application of dynamic GM (1,1) model modified by fourier series in subsidence prediction. Journal of Geomatics, 2017, 42(1):30-33.

[15] Datta T, Chatterjee N, Pal A K, et al. Application of Metabolic GM (1,1) Model in Deformation Monitoring Data Processing. Site Investigation Science & Technology, 2014, 29(1):61-63.

[16] Pohl, M. A Variability and Localization Study of the Galactic Center Gamma-Ray Source 3EG J1746?2851. The Astrophysical Journal, 2005, 626(1):174-182.

[17] Wu-Yong Q, Yao-Guo D. GM (1,1) model based on oscillation sequences. Systems Engineering-Theory & Practice, 2009, 29(3):149-154.

[18] Wu-Yong Q, Yao-Guo D, Si-Feng L. Grey GM(1,1,t~α) model with time power and its application. Xitong Gongcheng Lilun Yu Shijian/system Engineering Theory & Practice, 2012, 32(10):2247-2252.

[19] Malhotra R. Three-body effects in the PSR 1257+12 planetary system. Astrophysical Journal, 1993, 407:266-275.

[20] Perrier N, Langevin A, Campbell J F. A survey of models and algorithms for winter road maintenance. Part IV: Vehicle routing and fleet sizing for plowing and snow disposal. Computers & Operations Research, 2007, 34(1):258-294.