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Comprehensive Evaluation on Urban Sustainable Development of Harbin City in Northeast China

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Abstract: It is an effective way in realizing urban coordinated and sustainable development to establish a series of indicators and to evaluate urban environmental and socioeconomic development. According to the characteristics of Harbin City in Northeast China, an indicator system including five subsystems and 37 indicators was established for comprehensive evaluation on urban sustainable development. The development indexes of all urban subsystems and complex system were calculated quantitatively using the comprehensively integrated methods composed of Principle Component Analysis, Analytic Hierarchy Process and weighed index method, and then the comprehensive level of urban sustainable development and the degree of urban interior coordination were analyzed. The results indicated that 1) the overall urban development presented an uptrend, however, the interior development was not well balanced from 1996 to 2006; 2) the development in each subsystem presented a strong fluctuation; and 3) the development in resources subsystem showed a downtrend. Based on those results, the suggestions of urban sustainable development were put forward at the end.

Keywords: sustainable development; indicator system; comprehensive evaluation; Harbin City

1 Introduction

Cities are important components of the regional environment. It is an artificial and complex ecosystem composed of society, economy and nature and it has many characteristics such as complicated structure, numerous elements and integrated function (Huang et al., 2001). Human activities are restricted by the laws of natural ecological environment. With the rapid development of a city, the contradiction between the growth of social economy and ecological environment and resources has become a serious issue. Consequently many urban environmental problems emerged (Li, 2006; Borrego et al., 2006). Therefore, the evaluation of the extent of the urban sustainable development (USD) and the level of comprehensive development have become the important directions in the research field of urbanization (Li, 2006; Zhang et al., 2003; Qiao and Xu, 2003; Pulselli et al., 2008).

Taking advantage of the policy that China revives the Old Industrial Base of Northeast China, Harbin City is experiencing rapid urbanization. Since reform and opening-up in China in the late 1970s, Harbin City's economy has developed rapidly and the main economic indictors present an upward trend. The rapid development of economy promotes social progress and raises the living standard of inhabitants; in the meantime, it also gives rise to some environmental problems such as serious water pollution, expanding discharge of exhaust gas and solid waste (Harbin Environmental Protection Administration, 2007). Thus it is very necessary to evaluate the sustainable development of Harbin City. At present, the quantitative approaches on evaluation of USD can be classified into three categories: socioeconomic model (Zhang et al., 2004; Wen et al., 2004; Xiang, 2007), ecological model (Liu and Liu, 2007; Zang et al., 2006; Zhou and Shang, 2004; Gao et al.,

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2006; Moran et al., 2008; Du and Xu, 2006) and system engineering theories and methods (Wu et al., 2005; Zhang and Wen, 2001; Zhang et al., 2003). The former two methods both have disadvantages due to their only focus on some aspects of urban complex system (UCS). However, the third approach is good for comprehensively evaluating the extent of urban development. In this study, we established an indicator system for comprehensive evaluation on USD of Harbin City, calculated comprehensive development indexes of UCS and urban subsystems, and analyzed the coordinated degree of various urban subsystems based on system engineering theories. Finally, the suggestions were provided for decision-maker to manage the urban development of Harbin City.

2 Data and Methods

2.1 Study area

Harbin City (44°04′–46°40′N, 125°42′–130°10′E), the capital of Heilongjiang Province, is located in the north of Northeast China and the south of Heilongjiang Province. It is situated beside the middle-upper reaches of the Songhua River. Its landscape is flat and low-lying with diversiform soil. Its climate is continental monsoon climate of medium latitudes.

From reform and opening-up, Harbin's economy has developed rapidly. Gross domestic product (GDP) reached 209.4×10^9 yuan (RMB) in 2006 and it is on the intermediate level among three capital cities of provinces in Northeast China. In the urban complex system of Harbin, the rapid development of economy promotes social progress continually, thus living standard of inhabitants is rising step by step and social and economic development ability is strengthened increasingly. Environmental system is influenced while society and economy develop speedily, and the main problems are as follows. First, water pollution is serious. In 2006, there were only two tributary streams whose water quality was better than the criterion of plan among all the 12 first-degree tributary streams. Water quality of the other 10 tributary streams was lower than the criterion or just reached the mark, and among them, the water quality of the Ashi River, the Lalin River and the Wuyue River was much lower than the standard of category Ⅴ in *Quality Standard of Surface Water Environment of China* (*GB3838-2002*). Second, atmospheric pollution is aggravated. The discharge amount of waste gas increases yearly and the atmospheric pollutants are SO_2 and TSP mainly. Harbin is faced with dual pressure of coal smoke pollution and petroleum pollution. Third, the situation of solid waste pollution is severe. With the development of industry and the expansion of activity range, the amount of industrial solid waste is elevated yearly.

2.2 Data sources

The socioeconomic and environmental data of 11 years from 1996 to 2006 were adopted, which included the data in the 10 years of "the Ninth Five-Year Plan" and "the 10th Five-Year Plan", and the first year of "the 11th Five-Year Plan" in China. Those data can represent and reflect the latest development progress of Harbin City. The original data were from *Statistical Yearbook of Harbin City* (*1997–2007*) (Harbin Statistic Bureau, 1997–2007). Some data were obtained from existing research results (Cai and Shang, 2009). Those data of indicators that were used to compare with other cities were from *China Statistical Yearbook* (*2007*) (National Bureau of Statistics of China, 2008).

2.3 Multilevel indicator system of evaluation

Under the system engineering theories, combining numerous indicator systems of evaluation on sustainable development (Zhang et al., 2003; Zhang and Wen, 2001) and the real situation of social, economic and ecological environment, an indicator system of evaluation on USD of Harbin City was established including five subsystems and 37 indicators (Table 1).

2.4 Models of sustainable development indexes of various subsystems

For satisfying the basic requirements of statistic analysis method, the formula of Z-score was chosen to standardize the indicators (Equations 1–3).

$$x_i' = \frac{x_i - \bar{x}}{s} \tag{1}$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \tag{3}$$

where x_i presents initial value of indicator *i*; x_i' presents the standardized one; $\bar{x}$ presents the average of sample data; *s* presents the standard deviation of sample data; *n* presents the number of indicators of subsystems.

Table 1 Indicator system of evaluation on urban sustainable development of Harbin City

Subsystem		Indicator
Economy (EC)	EC_1	GDP (×10^8 yuan (RMB))
	EC_2	Per capita GDP (yuan)
	EC_3	Total investment in fixed asset (×10^8 yuan)
	EC_4	Gross output value of agriculture (×10^8 yuan)
	EC_5	Per capita gross output value of agriculture (yuan)
	EC_6	Growth rate of GDP (%)
	EC_7	Gross output value of industry (×10^8 yuan)
	EC_8	Per capita gross output value of industry (yuan)
	EC_9	Value-added of tertiary industry (×10^8 yuan)
	EC_{10}	Per capita value-added of tertiary industry (yuan)
Society (S)	S_1	Per capita annual net income of rural households (yuan)
	S_2	Per capita annual disposable income of urban households (yuan)
	S_3	Engle coefficient of rural households (%)
	S_4	Number of certified (assistant) doctors per 10^4 persons (person)
	S_5	Level of urbanization (%)
	S_6	Per capita floor space of residential building (m^2)
	S_7	Per capita public green area (m^2)
	S_8	Engle coefficient of urban households (%)

Subsystem		Indicator
Population (P)	P_1	Total population (×10^4 persons)
	P_2	Natural growth rate of population (‰)
	P_3	Population density (person/km^2)
	P_4	Total enrollment of vocational senior secondary schools (×10^4 persons)
	P_5	Total enrollment of specialized secondary schools (×10^4 persons)
	P_6	Total enrollment of primary schools (×10^4 persons)
	P_6	Total enrollment of secondary schools (×10^4 persons)
Resources (R)	R_1	Water consumption per unit GDP (t/10^4 yuan)
	R_2	Energy consumption per unit GDP (t(SCE)/10^4 yuan)
	R_3	Per capita ecological footprint (ha)
	R_4	Forest coverage rate (%)
	R_5	Per capita ecological carrying capacity (ha)
	R_6	Per capita ecological deficit (ha)
Environment (EN)	EN_1	Volume of industrial waste gas emission (×10^8 Nm^3)
	EN_2	Total volume of industrial waste water discharged (×10^{4}t)
	EN_3	Rate of industrial solid waste utilized (%)
	EN_4	Volume of industrial solid waste produced (×10^{4}t)
	EN_5	Rate of industrial waste water meeting discharge standard (%)
	EN_6	Average value of regional environment noise (db(A))

The contribution rate of variances were calculated using the module of Principle Component Analysis in Statistical Package for the Social Science (Lu, 2006; Bastianoni et al., 2008), and all of the principal components were selected if their corresponding latent roots are greater than 0.5 and their cumulative contribution rate of variance are greater than or equal to 85%. The weighing factors of indicators were obtained from the component score coefficient matrices of the subsystems. The evaluation models of each subsystem were then given as follows (Equations 4–8):

$$\begin{aligned}F_{EC} = {} & 0.89535(0.113EC_1' + 0.112EC_2' + 0.106EC_3' + 0.093EC_4' + 0.092EC_5' - 0.170EC_6' + 0.146EC_7' + \\ & 0.147EC_8' + 0.119EC_9' + 0.119EC_{10}') + 0.0949(0.005EC_1' + 0.008EC_2' + 0.034EC_3' + 0.091EC_4' + \\ & 0.099EC_5' - 0.968EC_6' - 0.161EC_7' - 0.166EC_8' - 0.023EC_9' - 0.024EC_{10}')\end{aligned} \tag{4}$$

$$\begin{aligned}F_S = {} & 0.85349(0.506S_1' + 0.197S_2' - 0.211S_3' + 0.411S_4' + 0.068S_5' - 0.139S_6' + 0.523S_7' + \\ & 0.210S_8') + 0.07859(-0.327S_1' + 0.005S_2' + 0.010S_3' - 0.597S_4' + 0.116S_5' + 0.340S_6' - \\ & 0.351S_7' - 0.413S_8')\end{aligned} \tag{5}$$

$$\begin{aligned}F_P = {} & 0.42633(0.329P_1' - 0.233P_2' + 0.329P_3' - 0.036P_4' + 0.095P_5' - 0.04P_6' - 0.24P_7') + \\ & 0.2707(0.08P_1' + 0.053P_2' + 0.072P_3' + 0.053P_4' + 0.474P_5' + 0.538P_6' + 0.211P_7') + \\ & 0.21126(0.005P_1' + 0.294P_2' + 0.011P_3' + 0.559P_4' + 0.021P_5' - 0.055P_6' - 0.469P_7')\end{aligned} \tag{6}$$

$$\begin{aligned}F_R = {} & 0.54173(0.278R_1' + 0.314R_2' - 0.212R_3' + 0.078R_4' - 0.059R_5' - 0.336R_6') + \\ & 0.33227(0.041R_1' + 0.038R_2' + 0.231R_3' + 0.440R_4' + 0.449R_5' - 0.118R_6')\end{aligned} \tag{7}$$

$$\begin{aligned}F_{EN} = {} & 0.60817(0.358EN_1' - 0.300EN_2' - 0.146EN_3' + 0.465EN_4' - 0.079EN_5' - 0.033EN_6') + \\ & 0.27241(-0.184EN_1' - 0.180EN_2' + 0.607EN_3' - 0.186EN_4' + 0.579EN_5' - \\ & 0.310EN_6') + 0.0873(0.335EN_1' + 0.194EN_2' - 0.208EN_3' - 0.108EN_4' - \\ & 0.244EN_5' + 1.083EN_6')\end{aligned} \tag{8}$$

where F_{EC}, F_S, F_P, F_R and F_{EN} represent the sustainable development indexes of subsystems respectively; EC_{n1}', S_{n2}', P_{n3}', R_{n4}' and EN_{n5}' represent the standardization value of indicators of subsystems respectively ($n1$=1, 2, 3…10, $n2$=1, 2, 3…8, $n3$=1, 2, 3…7, $n4$=1, 2, 3…6, $n5$=1, 2, 3…6).

2.5 Model of sustainable development index of UCS

The weights of various subsystems in UCS were calculated by using Analytic Hierarchy Process. The weights of economy, society, population, resources, and environment subsystem were calculated as 0.169, 0.169, 0.154, 0.237, and 0.271 respectively. Those weights are reasonable after testing the consistency of decision matrix.

Equation (9) expresses the model of sustainable development index of UCS in Harbin City.

$$F = F_{EC} \times W_{EC} + F_S \times W_S + F_P \times W_P + F_R \times W_R + F_{EN} \times W_{EN} \quad (9)$$

where W_{EC}, W_S, W_P, W_R and W_{EN} represents the weight of each subsystem in UCS; and F is the sustainable development index of UCS.

3 Results and Discussion

3.1 Trends of USD in Harbin City

The trends of sustainable development of urban subsystems and complex system of Harbin City over the years from 1996 to 2006 are shown in Fig. 1. The results show that the overall trends are upward.

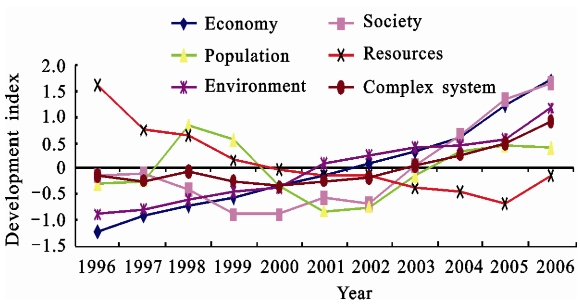

Fig. 1 Development trends of urban complex system and subsystems of Harbin City in 1996–2006

During 1996–2006, the development level of economy subsystem increased annually and the growth rate was relatively stable. The level of economy subsystem was the highest one among all the subsystems in 2006. The developments of society and population subsystems fluctuated. The former reached the lowest point in 1999 and then increased during the following years apart from 2002, while the latter showed the biggest fluctuation due to a great change in the number of school enrollments during this period. The level of environment subsystem upward steadily due to the decrease in discharge amounts of industrial waste and the increase in the recycling and treatment rate of waste water and solid waste. The level of resources subsystem decreased gradually from 1996 to 2005, but increased a bit in 2006. The mainly reasons for this are as follows: 1) various natural resources were consumed greatly during the process of urban development, but the availability of resources increased slowly; 2) the ecological carrying capacity decreased step by step, which is in accord with the conclusions about the level of supply and demand of ecological system in Harbin City of Cai and Shang (2009); and 3) in 2006, the small increase was due to the improvement of ecological carrying capacity.

3.2 Coordination among urban subsystems in Harbin City

The indexes of urban development can be used not only to evaluate the level of USD but also to monitor the coordination among urban subsystems (Zhang et al., 2003). The relative plots in Fig. 2 indicate the degree of coordination among urban subsystems in Harbin City from 1996 to 2006.

The results indicate that the coordination level of development among each subsystem in Harbin City is overall on the low side and the fluctuation is relatively large. From 1996 to 1997, the development of economy and environment was poor and the urban development focused on society, population and resources subsystems, and the level of resources subsystem was highest. The development placed extra emphases on population, environment and economy subsystems when resources subsystem developed rapidly from 1998 to 2002. From 2003 to 2006, all the others developed quickly apart from resources subsystem. Since 2001, society and economy have developed quickly under the guidance of the policy that China revives the Old Industrial Base of Northeast China; meanwhile, Harbin City went through the first overall boosting stage of constructing the ecological city from 2001 to 2005 and then has been stepping into a propulsion stage. While from 2000 to 2002, the resources, environment and economy developed harmoniously, and after 2003, the environment, economy, society and population developed relatively harmoniously, meanwhile, the extent of coordination between the resources and the other subsystems decreased due to the consumption of natural resources when society and economy developed rapidly.

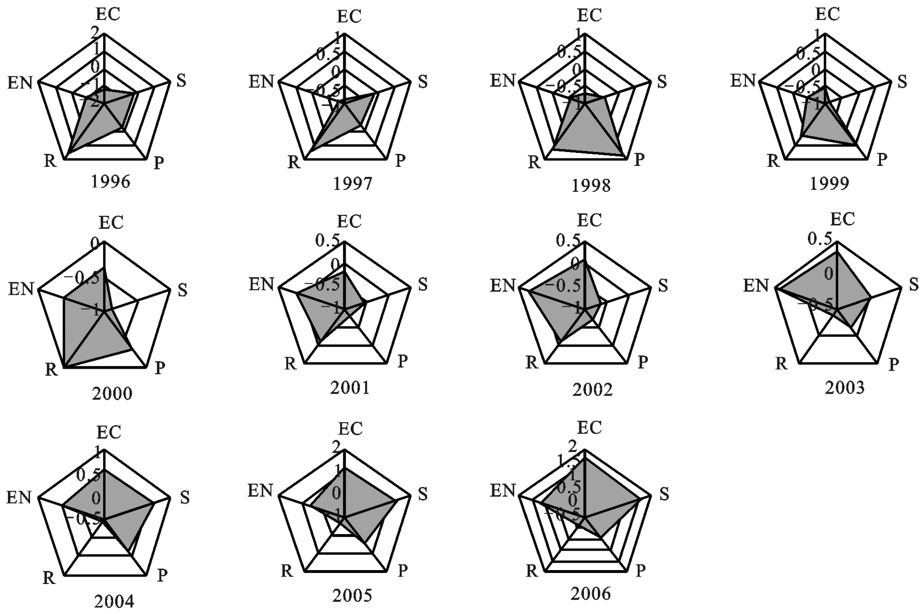

Fig. 2 Coordination among urban subsystems in Harbin City from 1996 to 2006

3.3 Influencing factors of sustainable development in Harbin City

The influencing factors can be obtained by analyzing the component matrix of urban subsystems (Table 2).

Table 2 shows that the indicators which have the largest contribution rate for the level of sustainable development of various subsystems are EC_7, EC_6, S_1, S_4, P_3, P_6, P_4, R_6, R_5, EN_4, EN_3 and EN_6 respectively. Those indicators are the main factors to influence comprehensive capability of USD.

Table 2 Component matrix of urban subsystems in Harbin City

Subsystem	Component	Factor loading									
EC		EC_7	EC_8	EC_9	EC_{10}	EC_1	EC_2	EC_3	EC_5	EC_4	EC_6
	1	0.991	0.988	0.985	0.984	0.980	0.980	0.971	0.952	0.951	0.148
	2	0.032	0.027	0.167	0.166	0.194	0.197	0.221	0.282	0.273	0.986
S		S_1	S_7	S_3	S_2	S_4	S_8	S_6	S_5		
	1	0.913	0.905	–0.771	0.766	–0.288	–0.481	0.523	0.619		
	2	0.375	0.341	–0.616	0.629	–0.908	–0.858	0.809	0.635		
P		P_3	P_1	P_2	P_6	P_5	P_4	P_7			
	1	0.967	0.966	–0.741	–0.144	0.247	–0.203	–0.645			
	2	0.108	0.121	0.170	0.939	0.834	0.212	0.290			
	3	–0.022	–0.031	0.533	0.028	0.117	0.934	–0.685			
R		R_6	R_2	R_1	R_3	R_5	R_4				
	1	–0.958	0.931	0.819	–0.752	–0.040	0.023				
	2	–0.100	–0.068	–0.043	0.617	0.970	0.940				
EN		EN_4	EN_1	EN_2	EN_3	EN_5	EN_6				
	1	0.986	0.889	–0.869	0.110	0.244	0.054				
	2	–0.051	0.280	–0.468	0.919	0.889	0.369				
	3	–0.116	0.350	–0.071	0.288	0.246	0.927				

4 Countermeasures

On the basis of above analyses, more effective measures in economy, society, population, resources and environment should be carried out for promoting harmonious development among urban subsystems and for increasing the sustainable comprehensive level of UCS.

Firstly, the population size should be controlled and the development level of society and economy should be increased steadily and ceaselessly. Among the four central cities (Changchun, Harbin, Shenyang and Dalian) in Northeast China, Harbin City has the largest population, but the smallest number of 'Number of certified (assistant) doctors per 10^4 persons' and 'Total investment in fixed assets' compared with Changchun City, Shenyang City and Dalian City (National Bureau of Statistics of China, 2007), which indicates that the economic reproductive capacity, living standard of inhabitants and infrastructure construction of Harbin City are backward; moreover, the total industrial output value of Harbin City in 2006 only placed the third among the four central cities which shows that the productivity per worker and availability of resources are on the low side as well. Thus several effective ways could be done to improve these laggard fields including to strengthen the guidance of macro policies, to adjust the industrial structure, to complete social welfare systems of education and medical treatment, and to increase income per capita.

Secondly, in order to change the downtrend of sustainability in resources subsystem, on the one hand, the availability of resources should be increased and the diversity of ecological footprint must be raised for utilizing and developing various kinds of land proportionately and decreasing per capita ecological footprint by the help of progress of science and technology; on the other hand, the quality of ecological environment should be recovered actively for improving the carrying capacity of ecological system.

Thirdly, the development of environment subsystem should focus on increasing the capabilities of purifying industrial waste gas, limiting discharge of waste water to meet the criteria and utilizing solid waste comprehensively. Environment subsystem should be developed nicely by bringing new ideas into the manufacturing techniques, equipments, process flow, etc.

Therefore, it is the necessary tendency to reinforce the research of science and technology for improving the level of coordinative development among various subsystems and realizing sustainable development of UCS in Harbin City. Generally, the sustainable development can be effectively promoted by applying the economic benefit gained during the process of urbanization into the development of society, population, resources and environment subsystem, and by controlling and decreasing the influences of limiting factors.

5 Conclusions

Comprehensive development indexes of urban subsystems and complex system were calculated by establishing the indicator system for comprehensive evaluation on USD of Harbin City and using various methods. Based on these results, the coordinated degree of urban subsystems were analyzed. The main conclusions are as follows:

(1) The capability of sustainable development in complex system of Harbin City presented an obvious uptrend from 1996 to 2006. The trend of every subsystem fluctuated variously. The sustainable level of resources subsystem decreased, while that the society and population subsystems increased slowly. The economy and environment subsystems grew steadily. The main influence factors for these are the indicators including 'Gross output value of industry', 'Growth rate of GDP', 'Per capita annual net income of rural households', 'Number of certified (assistant) doctors per 10^4 persons', 'Population density', 'Total enrollment of primary schools', 'Total enrollment of vocational senior secondary schools', 'Per capita ecological deficit', 'Per capita ecological carrying capacity', 'Volume of industrial solid wastes produced', 'Rate of industrial solid wastes utilized' and 'Average value of regional environment noise'.

(2) The coordination level of development among each subsystem in Harbin City is overall on the low side and the fluctuation is relatively large. The key points of development diverted from population, resources and society subsystems to economy and environment subsystems and then to society and population subsystems from 1996 to 2006; finally, in 2006, the environment, economy, society and population developed relatively harmoniously, meanwhile, the extent of coordination between the resources and the other subsystems decreased due to the consumption of natural resources when society and economy developed rapidly.

To realize harmonious and sustainable development in Harbin City well, the countermeasures were put forward as well. Strengthening management of environment and resources, innovating techniques and making macro-economic control policies scientifically are important ways to raise the level of USD and the degree of harmonious development among subsystems in Harbin City.

The results of this paper prove that the indicator system and methods for comprehensive evaluation on USD of Harbin City are highly applicable and effective, and can provide references for the practical application of systematical engineering theories and approaches in the field of USD in China.

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