CHINESE GEOGRAPHICAL SCIENCE
Volume 12, Number 3, pp. 282 – 287, 2002
Science Press, Beijing, China

QUANTITATIVE DESCRIPTION OF TAIYUAN URBAN COORDINATED SUSTAINABLE DEVELOPMENT

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ABSTRACT: As the economic, political and cultural center of a nation or a region, cities are the carriers of human activities. In a sense, only cities take the path of the coordinated sustainable development, it is possible for a country or a region, even the whole world , to develop coordinately and sustainbly. Today, how to describe the urban sustainable developing level and measure the coordinated degree of environment, economy and society, has attracted more and more attentions of urban managers and researchers. City is assumed to be a big system composed by 3 subsystems of environment, economy and society, a set of indicators for urban coordinated sustainable development of Taiyuan have been designed according to the thought of coordinated sustainable development and the reality of Taiyuan development. In this indicator set there are three levels, which can be called as target level, indicator level and statistic indicator level. Among them, target level includes three high-generalized grade-1 indicators, representing the development standard of economy, society and environment subsystems. In this paper, according to the ideas of system theory and QIAN Xue-sen's theory of meta-synthesis methodology from qualitative analysis to quantitative analysis, the level, the sustainable degree and the coordinated degree of urban development were set up, which described the urban coordinated sustainable development scientifically and quantitatively. The above indicator system and the method of quantitative description were applied to Taiyuan. Through calculating, we have got the economic developing level, social developing level, environmental quality situation and the overall developing level, of Taiyuan from 1986 to 1995. Also, we worked out the sustainability of the whole development, the respective coordinatabilities of the subsystems of economy and society, society and environment, and environment and economy, and the coordinatability of the overall development of Taiyuan in the same period of time. The coordinated sustainable development situation was quantitatively described, and the low development level was comprehensively analyzed , and suggestions were raised for its future coordinated sustainable development.

KEY WORDS: Taiyuan; coordinated sustainable development; indicator system; quantitative description

CLC number: F292 Document code: A Article ID: 1002-0063(2002)03-0282-06

1 INTRODUCTION

As the economic, political and cultural center of a nation or a region, cities are the carriers of human activities, in which human being can effectively utilize natural, economic and social resources(KUANG and SUN, 1998), and create of material and spiritual civilization. The urban development has an important position in the sustainable development of human residence.

The sustainable development refers to the development, which can not only meet the needs of the present generation, but also not weaken the next generation's ability to meet their needs. And there are two distinctive factors about it: one is the sustainability of the development, which means the development should sustainedly meet the needs of present and future generations so as to reach the unity of their interests; the other is the coordinatability of the development, which implies that the development of economy and society must take the bearing capacity of resources and environment into consideration, pursuing the coordinated development among economy, society, resources and environment. Today, how to describe the urban

Received date: 2002-04-10
Foundation item: Under the auspices of the fund for studying abroad of Shanxi Province(9)1) and the special fund for high science and technology of the Education Department of Shanxi Province (9)47).
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sustainable developing level and measure the coordinated degree of environment, economy and society, has attracted more and more attentions of urban managers and researchers.

2 EVALUATION INDICATOR SYSTEM AND QUANTITATIVE DISCRIPTION

City is assumed to be a big system composed by 3 subsystems of environment, economy and society, a set of indicators for urban coordinated sustainable development of Taiyuan have been designed according to the thought of coordinated sustainable development and the reality of Taiyuan development(YU, 1998; FENG, 2000), according to the design rules of indicator system.

As shown in Table 1, in this indicator set there are three levels, which can be called as target level(A), indicator level(B) and statistic indicator level(C). Target level includes three high-generalized grade-1 indicators, representing the development standard of economy, society and environment subsystems. And the three subsystems are indicated by L_1, L_2 and L_3, in which L_1 is the function of economic development standard; L_2 is the function of social development standard and L_3 is the function of quality situation of environment. Indicator level(B) is composed of 17 grade-2 indicators, shown as I_1, I_2, ⋯, I_{17}, which are feature indicators of urban development and certain individual features like economic structure, basic facilities, atmospheric quality, etc. Statistic indicator level (C) has 45 statistic indicators expressed by X_1, X_2, ⋯, X_{45}.

The following is the procedure of gaining feature indicators(I_1, I_2, ⋯, I_{17})and horizontal functions(L_1, L_2 and L_3). Firstly, the statistical indicators are collected and sorted out, that especially come from the statistical yearbook, environmental monitoring yearbook, environmental quality reports and so on. Secondly, the statistical indicators are non-dimension. As for the statistical data that have unit and unified standard values, the unified standard values are used as the

Table 1 Taiyuan's set of indicators for urban coordinated sustainable development

Level A	Level B	Level C
Economic developing standard	Economic strength index	GDP
	Economic structure index	Secondary industrial GDP proportion, tertiary industrial GDP proportion, secondary industrial employing proportion, tertiary industrial employing proportion
	Economic benefit index	GDP per person, GDP per unit area, the labor productivity of independent accounting industrial enterprise
	Economic intensive index	GDP per unit power consumption, GDP per unit water consumption, GDP per unit science and technology personnel, waste gas emission per unit GDP, waste water emission per unit GDP, solid waste emission per unit industrial output value, comprehensive utilization ratio of solid waste
	Economic export-oriented index	Foreign capital utilization per person, GDP proportion of industrial enterprise exporting
	Economic flourishing index	Total volume of retail sales per person
Social developing standard	Population index	Population density
	Housing condition index	Living space per person, public green space per person, green covering ratio on built area
	Infrastructure index	Road length per person, road area per person, power consumption per person, water for daily use per person, gasification ratio , possession of telephone set per 100 persons
	Living standard index	Engle's coefficient
	Medical and health condition index	Hospital beds per 10000 persons
	Public order condition index	Public security cases per 10000 persons, criminal cases per 10000 persons, traffic incidents per 10000 persons
	Cultural standard index	Cultural and entertaining consumption per person
	Educational standard index	The number of students in school per 10000 persons
	Scientific and technical standard index	Scientific and technological personnel per 10000 persons, GDP proportion of expense on study and development
Environmental quality situation	Atmosphere pollution index	TSP, SO_2, dust
	Surface water pollution index	Petroleum, volatile phenolphthalein, NH_3-N, CODcr

reference indicators to deal with them. Taking the atmosphere and surface water as examples, we respectively use the GB3095-1996 grade-2 standard and GBZB1-1999 grade-3 standard as reference values. As far as the statistical indicators concerned, which have unit but not the unified standard value, they are non-dimension, by using the best three average values in national same indicators of 1995 as the reference values(SGSD , 1999). The GDP per person, GDP per unit area and GDP proportion of per unit power consumption are all the cases in point. The third step is to decide the respective weight by means of hierarchical analysis(JIANG, 1994), combined with experts' consultation.

The formula of feature indicators of economic and social subsystem is

$$I_i = \sum_j \alpha_{ij} X_{ij} \tag{1}$$

where X_{ij} is the jth non-dimension statistical datum under the ith feature indicator; α_{ij} is the relevant proportion and $i = 1, 2, \cdots, 15$.

The formula of feature indicators of environmental subsystem is

$$I_i = \sum_j \alpha_{ij} \ (X_{1j} + X_{2j}) + X_0 \tag{2}$$

where $X_{ij} = \rho_j / \rho_{j0}$($\rho_j$ and ρ_{j0} refer to the measured density of the jth pollutant and the unified standard value, respectively), $X_{2j} = N / N_0$ (N and N_0 refer to the extra-standard number and the total number of samples, respectively), $X_0 = M / M_0$(M and M_0 refer to the number of extra-standard items and the total number of monitoring items, respectively), α_j is the relevant proportion and $j = 16, 17$.

The formula of economic and social developing level and environmental quality situation is

$$L_k = \sum_i \beta_i I_i \tag{3}$$

where I_i is the ith feature indicator under the kth level of hierarchical function, β_i is the relevant proportion and $i = 1, 2, 3$. L_1 and L_2 respectively refer to the functions of the economic and social developing levels and the bigger, the better. And L_3 is the function of environmental quality situation and the smaller, the better (at this time I_i are all negetive indicators).

The core of sustainable development is development, while its key is coordination. Urban economic, social or environmental system's development at any section of time, always has a developing level, the sustainability of development and the coordinated degree among the subsystems. Therefore, we designed the level function, the sustainability and the coordinatability of urban development, which described the urban coordinated sustainable development scientifically and quantitatively.

The function of urban developing level is

$$L = \frac{\sum k_i L_{+i}}{\sum k_i L_{-i}} \tag{4}$$

where L_{+i} is the ith positive indicator function, such as the L_1 in the economic subsystem and the L_2 in the social subsystem; L_{-i} is the ith negetive indicator function, such as the L_3 in the environmental subsystem, and k_i is the relevant weight. The high value of L shows the high level of urban development and the low one represents the low level. Also, the developing situation of urban system can be more carefully divided into 5 levels(Table 2).

Table 2 The grades of urban sustainable development

L <0.1	0.1≤ L <0.8	0.8≤ L <1.6	1.6≤ L <2.5	L> 2.5
Very low	Low	Middle	Relatively high	High

The sustainable degree of urban development is

$$S = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \tag{5}$$

where L and L_0 refer to the functions of urban developing level in the present year and last year, respectively. In this formula, when $S > 0$, the development is sustainable and the bigger S is, the better the sustainability is; on the contrary, when $S < 0$, it isn't sustainable development and the smaller S is, the worse; when $S = 0$, it shows that there is not a change between the adjacent two years, and such state is called the critical state.

The urban coordinated sustainable development requires that the subsystems, composing the cities, should develop coordinatedly, high effectively and balancedly at any time. To make the urban development be coordinated sustainable, the developments of the economic, social and environmental subsystems must have positive benefits at the same time. L_1 and L_2 are positive indicator functions, and so the bigger they are, the better; while L_3 is negetive indicator function and the smaller it is, the better. As a result, the combination of $\Delta L_1 > 0$, $\Delta L_2 > 0$, and $\Delta L_3 < 0$, is the only coordinated sustainable development, whose degree of coordination can be described by coordinatability D.

$$D = \sqrt{\left(\left| \frac{\Delta L_1}{L_1} \right| - \left| \frac{\Delta L_2}{L_2} \right| \right)^2} + \sqrt{\left(\left| \frac{\Delta L_2}{L_2} \right| - \left| \frac{\Delta L_3}{L_3} \right| \right)^2} + \sqrt{\left(\left| \frac{\Delta L_3}{L_3} \right| - \left| \frac{\Delta L_1}{L_1} \right| \right)^2} \tag{6}$$

where $\Delta L_1 = L_1' - L_1$, and L_1' and L_1 refer to the

functions of the economic developing standard of the present and the previous years, respectively; $\Delta L_2 = L_2' - L_2$, and $L_2'$and L_2 respectively refer to the functions of the social developing standard of the present and the previous years; $\Delta L_3 = L_3' - L_3$, and $L_3'$and L_3 respectively refer to the functions of the environmental quality situation of the present and previous years.

We define

$$D_{12} = \sqrt{\left(\left| \frac{\Delta L_1}{L_1} \right| - \left| \frac{\Delta L_2}{L_2} \right| \right)^2} \tag{7}$$

as the coordinatability between the economic and social subsystems and

$$D_{23} = \sqrt{\left(\left| \frac{\Delta L_2}{L_2} \right| - \left| \frac{\Delta L_3}{L_3} \right| \right)^2} \tag{8}$$

as the coordinatability between the social and environmental subsystems, and

$$D_{31} = \sqrt{\left(\left| \frac{\Delta L_3}{L_3} \right| - \left| \frac{\Delta L_1}{L_1} \right| \right)^2} \tag{9}$$

as the coordinatability between the environmental and economic subsystems.

It is obvious that the bigger D is, the bigger the coordinatability of urban development is. If no one of the economic, social and environmental developments has a negative benefit($\Delta L_1 < 0$, $\Delta L_2 < 0$, $\Delta L_3 < 0$) and one of them has zero benefit ($\Delta L_1 = 0$ or $\Delta L_2 = 0$, $\Delta L_3 = 0$), like the combination ($\Delta L_1 > 0$, $\Delta L_2 > 0$, $\Delta L_3 = 0$) and ($\Delta L_1 > 0$, $\Delta L_2 = 0$, $\Delta L_3 < 0$), ($\Delta L_1 > 0$, $\Delta L_2 = 0$, $\Delta L_3 = 0$) and so on, we call them the partial coordinated state. And we regard the combination ($\Delta L_1 = 0$, $\Delta L_2 = 0$, $\Delta L_3 = 0$) as the critical state.

3 APPLICATION

The above indicator system and the method of quantitative description have been applied to Taiyuan, the capital of Shanxi Province. Through calculating, we've got the function of economic developing standard L_1, the function of social developing standard L_2, the function of environmental quality situation L_3 and the function of whole developing standard L, of Taiyuan from 1986 to 1995. Also, we worked out the sustainability of the whole development S, the coordinatabilities of economy-society, society-environment and environment-economy, D_{12}, D_{13}, D_{31}, and the coordinatability of the whole development D, of Taiyuan in the same period of time(Table 3).

The following is the analysis of the coordinated sustainable development situation of Taiyuan in 1986 – 1995, based on the calculated results of Table 3 and their combined statistical data.

(1) Generally speaking, the urban sustainable developing standard of Taiyuan was low level. In 1986 – 1987, it was at a extreme low level, $L < 0.10$. In 1986 – 1995, the average value, $\bar{L} = 0.139$, the maximum value, $L_{max} < 0.28$. While in the same period, the average value of Beijing, Shanghai, and Tianjin, $\bar{L} = 0.81$. Compared with this value, we can see that Taiyuan only made up 17 percent of it. Judged by the economic development, the level of Taiyuan's economic development, at most of time, was low. In 1986 – 1991, $L_1 < 0.4$, $L_{1min} = 0.2$. Only in the year of 1995, a better situation was owned, $L_{1max} = 0.71$. At the same time, the average value of Beijing, Shanghai and Tianjin, $\bar{L} = 0.79$, while Taiyuan's value made up 54 percent of the average one. The social development of Taiyuan was at a middle level. L_2 ranged from 0.42 to 0.64 and the average value, $\bar{L}_2 = 0.52$. Meanwhile, the average value of the 3 cities, $\bar{L}_2 = 0.72$, and the Taiyuan's value was not too far from it. As to the environmental situation, Taiyuan's environmental

Tabel 3 The calculation results of sustainable development Level, sustainable degree and coordinated degree for Taiyuan City

Year	L_1	L_2	L_3	L	S	D_{12}	D_{23}	D_{31}	D
1986	0.22	0.42	8.49	0.075					
1987	0.24	0.42	9.17	0.072	-0.04	0.091	×	×	×
1988	0.28	0.44	5.90	0.122	0.69	0.119	0.309	0.190	0.620
1989	0.32	0.46	7.69	0.101	-0.17	0.097	×	×	×
1990	0.33	0.51	7.07	0.119	0.18	0.077	×	×	×
1991	0.37	0.54	7.25	0.126	0.06	0.062	×	×	×
1992	0.48	0.57	5.84	0.180	0.43	0.242	0.139	0.103	0.480
1993	0.59	0.59	5.92	0.199	0.11	0.194	×	×	×
1994	0.60	0.61	5.54	0.218	0.10	0.017	0.030	0.047	0.090
1995	0.71	0.64	4.90	0.276	0.27	0.134	0.066	0.068	0.270
Average	0.42	0.52	6.78	0.139					

"×" presented non-coordinated.

quality were extremely bad. The maximum value of the function of environmental situation, $\bar{L}_3 = 6.78$. In the meantime, the average value of the 3 cities, $\bar{L}_3 = 1.86$. And Tainyuan's value was 3.64 times of it. But we've noticed that the standards of economic and social development have been rising year by year and the environmental quality is also improving. Moreover, the sustainable degree of Taiyuan development was not only very low(the maximum value of it, $S_{max} < 0.5$), but also unstable(unsustainable in 1986 – 1987; sustainable in 1987 – 1988; unsustainable in 1988 – 1989; progressively sustainable since 1989). But in general its sustainability has been becoming better year after year. Another, the Taiyuan big urban system, including environment, economy and society, the subsystems of environment-economy and environment-society were all at a non-coordinated developing state in 1986 – 1993, and they became coordinated step by step since 1994.

(2) The serious environmental situation of Taiyuan City is the important reason of its low sustainable developing standard. As far as its air quality monitoring (1986 – 1995) concerned, all of its 12 monitoring sites were over-standard (GB3095-1996 grade-2 as the reference and the following is the same) and 5 out of its 6 monitoring items were over-standard. In the above items, the highest over-standard rate of TSP is 98%, the lowest one is 77% and its average one is 87%; the highest over-standard time of TSP is 2.47, the lowest is 0.9 and the average one is 1.46. As far as SO_2 concerned, the highest over-standard rate is 68%, the lowest is 36% and the average is 52%; its highest over-standard time is 5.50, the lowest is 1.83 and the average is 3.4. And the dust' s highest over-standard rate is 96%, the lowest is 60% and the average is 71%; its highest over-standard time is 2.07, the lowest is 0.42 and the average is 0.92. About the surface water of environmental quality observation (1986 – 1995), all of its 10 monitoring sites and 12 out of its 20 monitoring items were over-standard(GBZB1-1999 grade-3 as the reference and the following is the same). Among them, the petroleum's highest, lowest and average over-standard rates are 95%, 60% and 80%, respectively; the highest, lowest and average over-standard times are 271.0, 77.6 and 131.16. The volatile phenolphthalein's highest, lowest and average over-standard rates are 79%, 52% and 66%, and the highest, lowest and average over-standard times are 175, 27 and 95. The highest, lowest and average over-standard rates and over-standard times of NH_3-N are 84%, 51% and 74%, 33.2, 13.78 and 23.71. The 3 over-standard rates and 3 times of chemical oxygen consumption are 88%, 61% and 74%, 25.4, 1.6 and 8.78. The highest, lowest and average over-standard rates and times of biological oxygen consumption are 83%, 42% and 50%, 10.5, 2.58 and 6.29. Also, the suspended substance's highest, lowest and average over-standard values and times are 62%, 40% and 62%, 12.4, 2.1 and 6.25, respectively. Besides, NO_2-N、Pn、Hg、XF, Fe so on are all badly over-standard. In addition to all above, the under ground water is also seriously polluted (not being taken into consideration for lack of data).

(3) It's also the key reason for low urban sustainable developing level of Taiyuan that there is an unrational structure of industries and the low content of science and technology in it. Taiyuan is a heavy industry city mainly based on coal, metallurgy, machinery and chemical industry. Therefore, the high energy-consumption industrial structure is based on energy, with low utilization rate and serious wasting. And the energy products have single structure, poor quality and low additive value, especially the energy structure based on coal. As for it, lots of waste has been produced and the environment has been seriously polluted during its exploiting, processing, transporting and utilizing periods. For instance, the energy concentrative degree in 1995 (yuan/t of standard coal): Guangdong was 10 154.19; Shanghai, 5863.26; Beijing, 3985.40; and Taiyuan was 2089.43. So we can see that Taiyuan's values were 0.52, 0.36 and 0.21 times, compared with Beijing, Shanghai and Guangdong, respectively. Even worse, the energy concentrative degree of Taiyuan in 1986 was even as low as 526.76 yuan/t of standard coal, which could prove how low its energy utilization ratio was. Another example is the whole labor productivity in 1995(yuan/person): Beijing was 26 067.8; Shanghai, 33 155.7; Tianjin, 22 974.5; and Taiyuan was 11 211.27, which was only 0.43, 0.34 and 0.49 times of Beijing, Shanghai and Tianjin respectively. And the whole labor productivity of Taiyuan in 1986 was only 2916.41 yuan/person. In addition, of Taiyuan exporting energy products, raw coal holds over 70% and the ratio of energy transforming and processing is only about 45%. And the rate of coal still constitutes 63% in the terminal consuming structure. Also, the waste density of Taiyuan in 1986 and 1995: the drains of waste gases per GDP were 3.84 m^3/yuan and 0.38 m^3/yuan, the drains of waste water per GDP were 27.15kg/yuan and 5.43kg/yuan, and the drains of waste solid per GDP were 1.47kg/yuan and 0.33 kg/yuan, all of which were far higher than the average value of Beijing, Shanghai and Tianjin.

From above analysis, it is clear that the only way to the urban coordinated sustainable development of Taiyuan is to adjust the industrial structure, to build high-beneficial and clean energy producing system, and to improve the utilizing benefit of energy sources and the science and technology consent in products.

4 DISCUSSION

In the late 1980s and the earlier 1990s people made great efforts to study the coordinated development between environment and economy, and people turned to the studies of the sustainable development again since the mid 1990s. However, there still wasn't a definite and public-admitted conclusion about the relationship between the sustainable development and the coordinated one, and how to describe them quantitatively. As our paper has discussed, we know that if the whole system can develop sustainably, it must be required that all the subsystems also need the sustaining among them. In short, the coordination and sustainability are "you are in me, I am in you, cause and effect each other", and this is just the relationship between the coordinated development and the sustainable development.

In the end, it must be pointed out that because of the difficulties to quantification, the indicators of this paper didn't reflect the indicators about the governmental management and policy decision(including the standards of policy decision and management, construction of laws and regulations, etc.), which are important and sometimes even vital. For instance, the undulation of urban environmental quality of Taiyuan in 1986 – 1991 was caused by unclear recognition, un-perfect laws and regulations and powerless management.

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