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An approach to evaluation of sustainability for Guangzhou's urban ecosystem

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SUMMARY

Guangzhou has ambitions to build itself into a world class metropolis by 2010. Sustainable development is the only way to achieve this magnificent goal. Based on the ecological perspective of sustainable development and the principles of ecosystem integrity, this paper develops an approach for evaluation of sustainable development in Guangzhou between 1986 and 1995. A hierarchical evaluation system of four tiers of sustainability indicators was established. Using the method of fuzzy multistage synthetic evaluation, sustainability development level index, QIx, was calculated for the indicators at the B, C, D, and E tiers. Development stages were identified based on these index values. The coordination degree among the economic, social, and natural subsystems was also computed. Further, an overall sustainability index for each year was computed by combining the development level index and the coordination degree. It was found that the urban ecosystem in Guangzhou had generally become more sustainable, in spite of fluctuations in coordination degree. The development level index of the economic subsystem has surpassed that of social and natural subsystems since 1995. Appropriate measures must be taken to ensure coordinated development among the subsystems for the purpose of sustainable development.

INTRODUCTION

At the 1992 UN Conference on Environment and Development in Rio, UNCED Principle Three characterised sustainable development as, 'the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.' (Agenda 21). UNCED Principle Four further stated that 'in order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be isolated from it.' (Agenda 21). These two principles have produced profound implications for use and stewardship of natural resources, ecology and the environment. In practice, sustainable development is a multifaceted concept which has been viewed from many perspectives, depending upon one's personal experience, viewpoint and discipline.

The ecological perspective represents an essential viewpoint. As we consider sustainable

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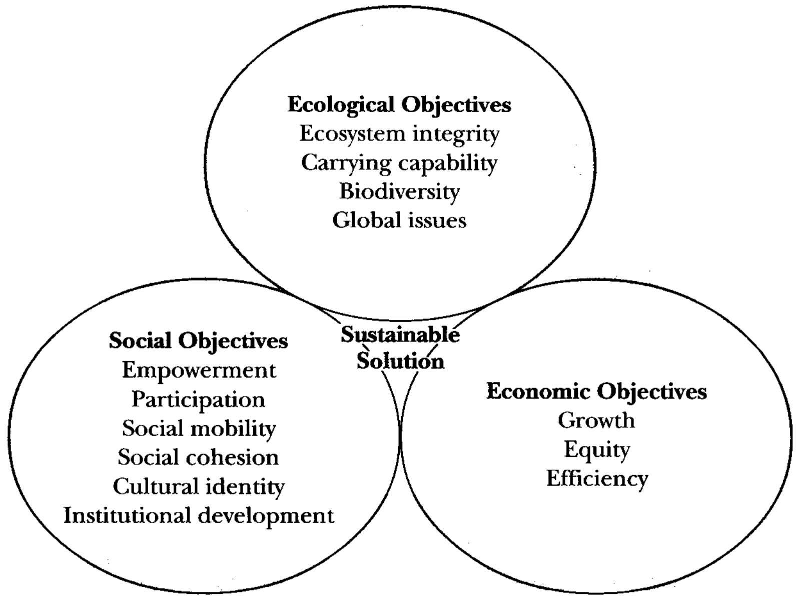

Figure 1 A conceptual illustration of the ecological perspective of sustainable development. Sustainable development is achieved through the integration of three sets of objectives. Although the emphasis given to a set of objectives depends on one's viewpoint, all of the objectives must be in concordance. (After Campbell and Heck, 1997)

development from an ecological perspective, we must have an appreciation of ecosystem integrity. The integrity implies the existence of the system structure and function, maintenance of system components, interactions among them, and the resultant dynamic of the ecosystem (Campbell and Heck, 1997). Shaller (1990) suggests that 'sustainable agriculture over the long term enhances environmental quality and the resource base upon which agriculture depends, provides for basic human food and fibre needs, is economically viable, and enhances the quality of life for farmers and society as a whole'. This definition illustrates well three components of sustainable development: ecological, economic and social objectives (Figure 1). The ecological objective seeks to preserve the integrity of the ecosystem, while the economic objective attempts to maximise human welfare within the existing capital stock and technologies, and uses economic units (i.e. money, or perceived value) as a measurement standard (Campbell and Heck, 1997). The social objective stresses the needs and desires of people, and uses standards of well-being and social empowerment. The ecological perspective for sustainable development balances the ecological, economic and societal values, and falls at the intersection of the spheres that represent the three components (Figure 1). Imbalance among the three components, or recasting of the balance to reflect only one objective, will likely result in failure to achieve sustainability (Zonneveld and Forman, 1990). In addition, temporal and spatial scales are key elements in assessing ecological sustainability because they relate the objective of 'what is it we wish to sustain' to 'over what time and what area and in what location.'

A city is a human-central ecosystem. Cities are the most complex of all human settlements, and differ from rural settlements in that they have greater size and functional complexity. Another obvious difference is that most employed residents of urban centres are engaged in tertiary and secondary occupations, whereas rural people usually support themselves through primary economic activities. Urban centres exist because they are most efficient in providing functions that a society feels are needed. In addition to serving as places of residence for many people, cities commonly possess functions such as manufacturing, trade and commerce, public administration, and personal services (Nelson *et al.*, 1995). Therefore, the economic and societal values are stressed while the ecological value is ignored. The ecological perspective of sustainable development maintains that coordination and balance among the three objectives promises sustainable development for cities. Due to the nature of cities as complex human settlements, urban ecosystems are more integrated, dynamic and multistage in development. The development of an evaluation system and the selection of evaluation methods for sustainability analysis should reflect these characteristics.

Because of unique characteristics of temporal and spatial scales of an urban centre, sustainable development metrics should be developed with care. Quantitative evaluation of sustainability for cities has been obtained by computing indicators and by finding correlations among the indicators. However, the results of evaluation are often far from satisfactory because the standards for evaluation are difficult to determine. To evaluate any aspect of sustainable development is to try 'measuring the immeasurable' (Bell and Morse, 1999). The ecological perspective for sustainable development necessitates balancing the ecological, economic and societal values, but these values are all 'fuzzy' in nature. Fuzzy logic is therefore attractive for evaluation because of its capability for handling the inexact or fuzzy phenomena. In this paper, a multi-stage evaluation system is adopted to identify, compare and relate each indicator's contribution to the development of the whole ecosystem. This approach is applied to Guangzhou, a major urban centre in South China, for a sustainability evaluation of its ecosystem between 1986 and 1995.

STUDY AREA: GUANGZHOU, CHINA

Since 1978, when the economic reform and open-door policy was implemented, a dramatic social, economic and spatial transformation has occurred in China. This is particularly true in coastal regions such as the Pearl River Delta of Guangdong Province in southern China, where economic growth has exhibited a two-digit increase over the past two decades and has appeared as one of the most advanced regions in the nation (Lo, 1989; Xu and Li, 1990; Lin, 1997; Weng, 1998). The urbanisation process has speeded up due to accelerated economic development. Massive parcels of agricultural land are disappearing each year for urban or related uses. Because of the lack of appropriate land-use planning and measures for sustainable development, rampant urban growth has created severe environmental consequences (Yeh and Li, 1996, 1997, 1999; Weng, 2001 a, 2001b; Weng and Lo, 2001). Fieldworks were carried out in the west side of the delta in 1998 and in Guangzhou in 2001 to provide 'ground truth' data on current land use and land cover, and first-hand data on environmental changes induced by rapid industrialisation and urbanisation. Interviews of city planning officers, visits to contaminated sites and collection of statistics and existing maps and data were also arranged.

Guangzhou, also known as Canton, is located at latitude 23°08' N and longitude 113°17' E, and lies at the confluence of two navigable rivers of the Pearl River system (Figure 2). With a population of 3.99 million and total area of 1444 km^2 (Guangdong Statistical Bureau, 1999), Guangzhou is the sixth most populous city in China. It has been one of the most important political, economic and cultural centres in South China, and in 1992, it became the third largest urban economy in the nation, trailing only Shanghai and Beijing (Guangzhou Municipality Government, 1998). The Guangzhou municipality comprises eight administrative districts in the city proper (Figure 2) and four rural counties (Huadu, Zengchen, Panyu, and Conghua), though this study focuses on the city proper.

As one of the oldest and largest cities in China, Guangzhou has a history of urban development of almost 2000 years (Xu, 1990). Guangzhou originated as a small village in about 300 BC. The city wall was first built in the third century AD, after China was united during the Qin Dynasty. During the Sui, Tang and Song Dynasties, Guangzhou developed into the largest seaport in China as international trade overseas developed rapidly. With economic development and population increase, the city wall was expanded several times toward the east and the north. During the Qing Dynasty, the city was further expanded to the south, approaching the north bank of the Zhujiang River. After the establishment of the People's Republic of China in 1949, Guangzhou's locational advantages became more prominent with the end of the Vietnam conflict and the rising prosperity of

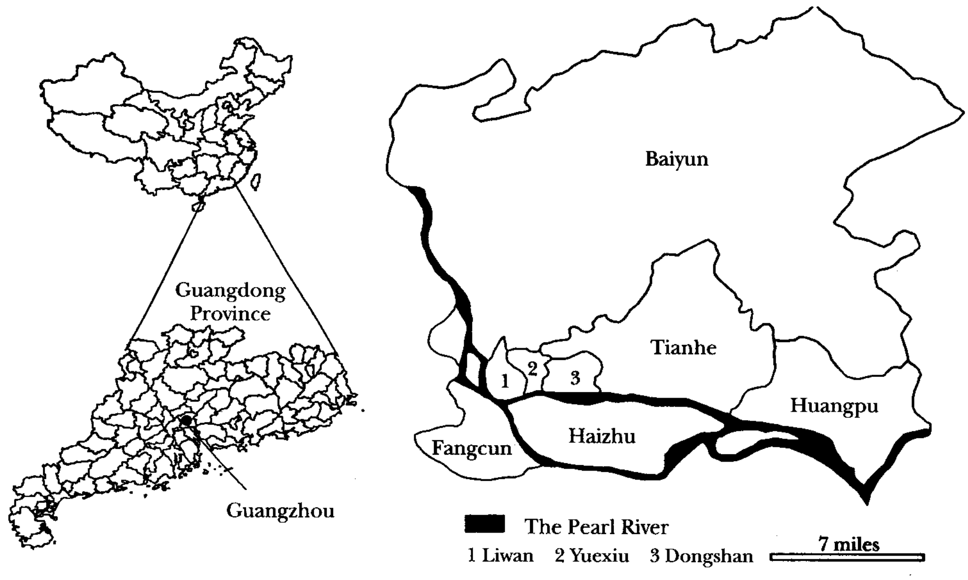

Figure 2 Study area – Guangzhou, China

Southeast Asia. Guangzhou's urban development has progressed at an unprecedented pace and eastward expansion has replaced the traditional southern and western expansion.

METHODS FOR EVALUATING THE SUSTAINABILITY

Establishing an indicator system

Warren (1997) summarises ten criteria for good sustainable development indicators. The indicators must reflect something fundamental to the long-term economic, social or environmental health of a community over the generations and must be simple, quantifiable, sensitive to change across space or within groups and to time, predictive and relatively easy to collect and use. These indicators should also have threshold values available and reveal whether changes are reversible and controllable. In terms of methodologies used to develop an indicator, they must be clearly defined, accurately described, socially and scientifically acceptable and easy to reproduce (Warren, 1997). Indicators also need to be tailored to the scope and scale, such as global, national and local scale. Since cities vary in physical environment characteristics, socio-economic levels and primary functions, indicator systems developed should reflect these differences. After taking into account all the criteria and factors, and the nature of Guangzhou as a multifunctional and comprehensive city in South China, the authors developed a hierarchical evaluation system, which consists of 31 F tier targets (indicators) at the top level, 14 E tier targets at the upper middle, 7 D tier targets in the lower middle, and 3 C tier targets at the bottom (Figure 3). Parametric statistics for the F tier indicators are listed in Table 1.

Methods for evaluation

Evaluation standards

A grading (appraisal) system for evaluation standards was developed according to the unique situation of Guangzhou and China's current development level. Each of the F tier indicators was categorised into four groups, and letter grades I , II, III, and IV were assigned. These letter grades are interpreted as follows: I, Excellent; II, Good; III, Fair; and IV, Poor. Grade I is assigned to those that meet or exceed China's National Standard Level One. In most cases, they are the mid-term or long-term development goals in the nation. Grade II is assigned to those that are comparatively advanced at present and meet the National Standard Level Two. These indicators are the goals of the Ninth Five-Year Plan (1996–2000). Grade III is given to those that are advanced at the province level for the

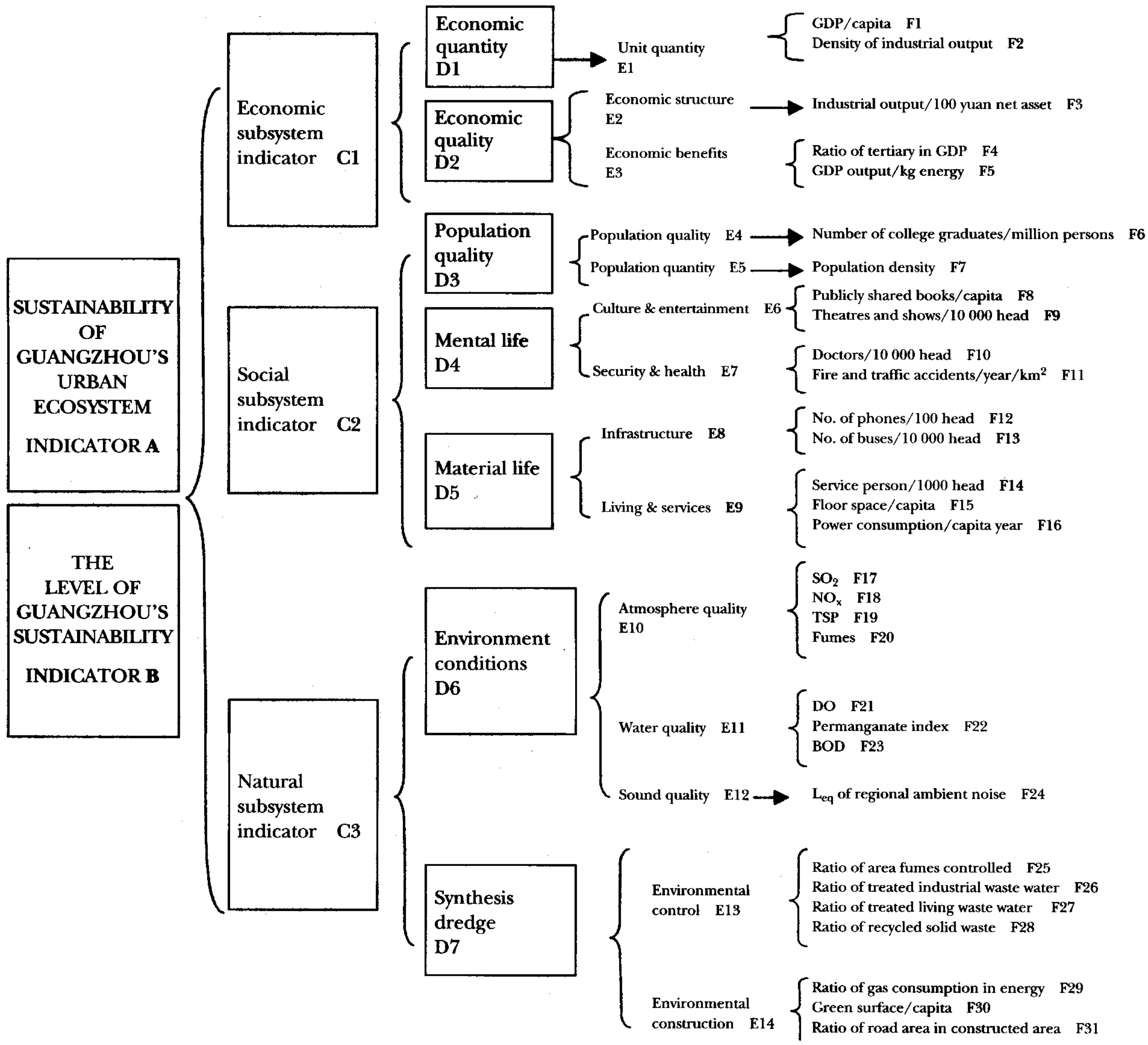

Figure 3 A hierachial evaluation system of sustainability indicators

time being or meet the National Standard Level Three. Grade IV is assigned to those that meet the provincial medium or low levels. The grading criteria for each indicator are displayed in Table 2.

Determination of weights for the indicators

Weight expresses different contributions of each indicator to the overall urban ecosystem. The weights of F tier indicators are calculated by using formula (1) or (2). If a higher value of an indicator has a greater negative effect on the urban ecosystem, then formula (1) is used. If a higher value of an indicator has a greater positive effect on the urban ecosystem, then formula (2) is used.

$$W_i = X_i/S_i \quad (1)$$

$$W_i = S_i/X_i \quad (2)$$

Where W_i is the weight; X_i is the average value of the i^{th} indicator in the observed years; and S_i is the standard value of the i^{th} indicator. Grade II standard value is chosen to represent the middle and higher levels. The calculated weights of F tier indicators are original weights. The normalized weights (*ai*) for the F tier indicators are displayed in Table 3, and weights for the C tier, D tier, and E tier indicators are shown in Figure 4.

Table 1 Parametric statistics on sustainable development of Guangzhou's ecosystem

Indicator	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
F_1	3644.4	4198.6	5647.9	6696.8	7342.9	8837.2	1079.3	1485.4	1878.3	2340.8
F_2	506.1	1738.2	2199.8	2276.6	2465.3	3007.7	3743.0	4612.5	5020.4	5956.7
F_3	45.0	48.0	48.6	51.0	54.6	50.2	49.6	50.5	52.2	52.3
F_4	277.8	274.1	272.0	228.9	200.0	277.3	314.7	319.5	297.3	25.8
F_5	2.49	2.96	3.15	3.74	4.07	4.38	4.75	5.28	6.75	7.38
F_6	850	882	938	1008	1000	980	029	1065	1125	1089
F_7	2327	2367	248	2455	2479	2508	2544	2581	2634	2670
F_8	1.12	1.20	1.25	1.3	0.38	1.41	1.40	1.50	1.52	1.52
F_9	0.47	0.61	0.52	0.50	0.50	0.40	0.36	0.46	0.45	0.38
F_{10}	50.6	50.7	51.7	50.0	50.0	50.0	50.0	51.6	50.9	51.5
F_{11}	2.64	3.35	2.69	2.68	3.07	3.14	2.67	2.81	3.44	4.19
F_{12}	3.9	5.2	6.0	7.5	9.3	12.0	14.5	21.0	28.0	42.0
F_{13}	3.8	4.2	4.2	4.1	4.1	4.3	4.7	5.2	6.3	7.2
F_{14}	113	130	137	139	136	126	148	208	255	316
F_{15}	6.9	7.1	7.3	7.6	8.0	8.2	8.5	8.9	9.3	9.6
F_{16}	137.2	128.9	141.1	133.5	169.0	185.9	290.2	356.8	431.4	495.5
F_{17}	0.087	0.085	0.092	0.111	1.097	0.080	0.059	0.049	0.055	0.057
F_{18}	0.100	0.110	0.104	0.130	0.147	0.112	0.107	0.115	0.116	0.123
F_{19}	0.231	0.228	0.288	0.280	0.270	0.260	0.279	0.280	0.300	0.310
F_{20}	13.97	14.60	13.64	13.85	9.56	8.76	9.95	9.59	8.76	9.16
F_{21}	3.61	2.67	3.21	3.14	3.60	3.20	3.40	4.00	4.20	2.80
F_{22}	5.67	6.63	5.38	5.26	5.60	5.35	4.88	5.33	4.57	4.33
F_{23}	2.97	3.45	3.07	2.89	2.72	3.41	3.07	3.11	3.65	3.04
F_{24}	64.1	62.6	62.1	60.5	60.1	58.5	59.0	60.4	58.0	58.0
F_{25}	24.5	36.8	44.2	41.1	55.5	55.3	69.6	98.3	95.3	83.6
F_{26}	34.0	40.6	37.3	40.7	48.3	68.3	67.9	72.7	83.3	85.9
F_{27}	–	–	–	–	14.16	14.16	11.67	16.20	15.99	16.00
F_{28}	57.3	52.0	56.9	55.9	48.6	47.5	56.5	56.3	65.4	67.6
F_{29}	8.8	15.5	20.0	28.6	40.9	42.6	53.8	60.5	85.5	86.6
F_{30}	4.8	4.7	4.6	3.7	3.2	3.4	4.1	4.1	4.0	3.8
F_{31}	2.9	3.5	5.2	5.5	5.8	5.8	5.9	6.7	6.8	7.7

Sources: Guangzhou Statistical Bureau, 1986–1996; Guangzhou Environmental Protection Agency, 1985–1989; Guangzhou Statistical Bureau, 1999; Guangzhou Statistical Bureau and General Labour's Union of Guangzhou, 1992

Table 2 Grading standards for the F tier indicators

Indicator	*I*	*II*	*III*	*IV*	*Indicator*	*I*	*II*	*III*	*IV*
F_1	50 000	20 000	10 000	5000	F_{17}	0.02	0.06	0.010	0.15
F_2	6000	4000	2500	1000	F_{18}	0.05	0.10	0.15	0.20
F_3	70	60	50	40	F_{19}	0.07	0.15	0.30	0.50
F_4	500	400	300	200	F_{20}	6	9	12	15
F_5	60	30	20	10	F_{21}	6	5	3	2
F_6	2000	1500	1000	500	F_{22}	4	6	8	10
F_7	700	5000	10 000	54 000	F_{23}	3	4	6	10
F_8	4.0	1.5	0.3	0.1	F_{24}	50	55	60	65
F_9	5.0	3.0	1.5	0.5	F_{25}	80	60	30	10
F_{10}	100	60	40	20	F_{26}	80	60	30	10
F_{11}	1.2	2.6	5.0	1.3	F_{27}	80	60	30	10
F_{12}	80	60	40	20	F_{28}	80	60	30	10
F_{13}	10	5	3	1	F_{29}	80	60	30	10
F_{14}	400	300	200	100	F_{30}	20	10	5	2
F_{15}	15	12	6	4	F_{31}	20	10	6	2
F_{16}	500	400	200	100					

Table 3 Initial and normalised weights for the F tier indicators

Indicator	W_i	a_i	*Indicator*	W_i	a_i	*Indicator*	W_i	a_i
F_1	2.05	0.614	F_{11}	1.13	0.487	F_{21}	1.45	0.468
F_2	1.29	0.386	F_{12}	4.33	0.803	F_{22}	0.87	0.281
F_4	1.46	0.172	F_{13}	1.06	0.197	F_{23}	0.78	0.251
F_5	7.03	0.828	F_{14}	1.82	0.365	F_{25}	1.07	0.147
F_6	1.53	0.754	F_{15}	1.50	0.301	F_{26}	1.07	0.147
F_7	0.5	0.246	F_{16}	1.66	0.334	F_{27}	4.08	0.560
F_8	1.12	0.149	F_{17}	1.30	0.237	F_{28}	1.06	0.146
F_9	6.38	0.851	F_{18}	1.12	0.203	F_{29}	2.46	0.252
F_{10}	1.19	0.513	F_{19}	1.81	0.330	F_{30}	2.45	0.422
			F_{20}	1.26	0.230	F_{31}	1.89	0.326

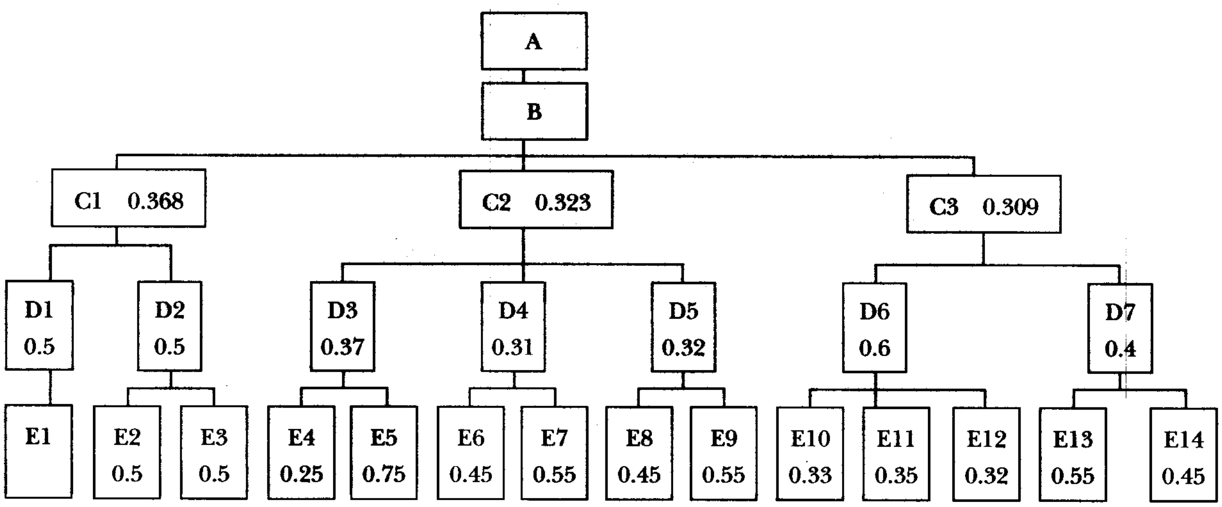

Figure 4 Weights for the C, D, and E tier indicators

Construction of the fuzzy correlation matrix

Semi-trapezoid probability functions are used to compute the probability of each indicator value belonging to each grade category (i.e. I, II, III, and IV). If greater values will cause a greater negative effect on the urban ecosystem for an indicator, then an ascending semi-trapezoid probability function will be used for this indicator. If greater values will cause a greater positive effect on the urban ecosystem for an indicator, descending semi-trapezoid probability function will be used for this indicator. For n indicators and m grading categories, an indicator set $X = \{X_1, X_2, ..., X_n\}$, and an appraisal set $Y = \{Y_1, Y_2, ..., Y_m\}$ can be defined. For any indicator $X_i \in X$, the possibility value R_{ij} can be computed to indicate the likelihood that an indicator belongs to an appraisal set $Y_j \in Y$ using the semi-trapezoid probability functions. Therefore, each X_i has a probability vector RR_i $(R_{i1}, R_{i2}, ..., R_{im})$, where i = 1,2,... n, which is called the appraisal set for a single indicator. For n indicators, a fuzzy correlation matrix $RR = (RR_{ij})_n \times m$ is established.

Appraisal

Multiplication of the weight set A with the fuzzy correlation matrix RR results in a decision set B = A ∩RR, B = (b1, b2, ..., bm), where b1, b2, ..., bm stands for the coefficient of possibility of each decision in the appraisal set, and can be calculated as:

$$b_j = \min\left[1, \sum_{i=1}^{n} ai \times R_{ij}\right] \tag{3}$$

A computer program has been written for the

Table 4 QIx values in the B, C, D and E tiers

Year	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
E_1	0.130	0.221	0.389	0.537	0.665	0.987	1.368	1.802	1.122	2.448
E_2	0.500	0.800	0.860	1.100	1.460	1.020	0.960	1.050	0.220	1.230
E_3	0.134	0.127	0.124	0.050	0.000	0.132	0.196	0.205	0.169	0.027
E_4	0.700	0.764	0.876	1.016	1.000	0.960	1.058	1.130	1.250	1.178
E_5	2.622	2.612	2.600	2.592	2.586	2.580	2.571	2.563	2.550	2.542
E_6	0.251	0.355	0.284	0.274	0.283	0.287	0.286	0.289	0.299	0.299
E_7	1.751	1.610	1.769	1.727	1.648	1.634	1.729	1.742	1.596	1.460
E_8	0.276	0.315	0.315	0.305	0.305	0.325	0.364	0.442	0.766	1.365
E_9	0.518	0.603	0.638	0.635	0.763	0.794	1.086	1.436	1.805	2.256
E_{10}	1.295	1.211	1.411	0.913	1.283	1.609	1.621	1.673	1.653	1.567
E_{11}	1.971	1.426	1.903	1.500	1.979	1.817	2.017	2.084	2.102	1.634
E_{12}	0.178	0.480	0.580	0.900	0.980	1.290	1.200	0.920	1.400	1.400
F_{13}	0.551	0.632	0.677	0.673	0.863	0.975	1.039	1.340	1.381	1.397
E_{14}	0.467	0.571	0.753	0.759	0.821	0.865	1.065	1.188	1.428	1.473
D_1	0.130	0.221	0.389	0.537	0.665	0.987	1.368	1.802	1.122	2.448
D_2	0.317	0.463	0.492	0.575	0.500	0.576	0.628	0.695	0.695	0.629
D_3	1.173	1.219	1.301	1.404	1.390	1.359	1.331	1.482	1.569	1.513
D_4	1.076	1.045	1.101	1.073	1.034	1.028	1.080	1.092	1.013	0.938
D_5	0.409	0.451	0.493	0.487	0.558	0.584	0.761	0.990	1.555	1.855
D_6	1.175	1.052	1.316	1.267	1.431	1.580	1.625	1.576	1.729	1.538
D_7	0.514	0.605	0.711	0.981	0.845	0.927	1.050	1.432	1.401	1.432
C_1	0.224	0.332	0.441	0.519	0.698	0.782	0.782	1.215	1.408	1.539
C_2	0.900	0.919	0.981	1.007	1.012	1.009	1.107	1.267	1.323	1.443
C_3	0.910	0.874	0.822	1.023	1.197	1.320	1.396	1.455	1.596	1.496
B	0.653	0.690	0.734	0.852	0.954	0.984	1.076	1.285	1.438	1.495

computation of decision sets for the four grading categories. The fuzzy synthetic progression method (Zhang, 1992) was further used to calculate a sustainable development index, *I*, as follows:

$$I = I_{max} \pm b_i \pm 2\, b_{i\pm 1} \pm 3\, b_{i\pm 2} \qquad (4)$$

Where I_{max} is the grade with maximum subordination, b_i is the grade with the second subordination, $b_{i\pm1}$ the grade with the third subordination, and $b_{i\pm2}$ the grade with the fourth subordination. In order to have larger values of indices, the authors constructed another index (QI_x), which is used for the evaluation of sustainability at the B tier, C tier, D tier, and E tier levels.

$$QI_x = 4 - I \qquad (5)$$

The value of QI_x varies between 1 and 3. The higher the QI_x value, the higher the level of sustainable development. The value of QI_x at the B tier, C tier, D tier and E tier is displayed in Table 4. The values of *I* and QI_x are further classified into four major sustainability types according to the criteria listed in Table 5.

Computation of the coordination degree and sustainable development index

Sustainability of an urban ecosystem depends not only upon the development level of economic, social and natural subsystems, but also the coordination among the three components. A coordination degree is therefore developed to measure the degree of coordination among the three subsystems in the urban ecosystem. The formula for calculating the coordination degree is as follows:

$$C_x = 1 - \sqrt{\frac{\Sigma (C_i - C)^2}{N}} \qquad (6)$$

Where C_x is the coordination degree of the system, C_i the index value of sustainable development level for the i^{th} subsystem at the C tier, *C* is the average index value of the i^{th}

Table 5 Criteria for classification of sustainability types and stages

Sustainability Type		*I value*	*QI_x value*
Unsustainable		≥ 4	≤ 0
Primary sustainable	Early stage	3.999~3.6	0.001~0.4
	Middle stage	3.599~3.3	0.401~0.7
	Late stage	3.299~3.0	0.701~1.0
Secondary sustainable	Early stage	2.999~2.6	1.001~1.4
	Middle stage	2.599~2.3	1.401~1.7
	Late stage	2.299~2.0	1.701~2.0
High sustainable	Early stage	1.999~1.6	2.001~2.4
	Middle stage	1.599~1.3	2.401~2.7
	Late stage	1.299~1.0	2.701~3.0

subsystem at the C tier, and *N* is the number of the subsystems.

Based on the coordination index C_x and the sustainable development level index *QIx*, an overall sustainable development index (SI_x) is calculated:

$$SI_x = QI_x * C_x \tag{7}$$

Where SI_x is the index of sustainability, QI_x the index of development level, and C_x the coordination degree among the three subsystems. The result of computation is shown in Table 6. Considering the multistage nature of urban development in Guangzhou and for convenience of analysis, the overall sustainability index is classified into five categories using the data classification scheme of equal distance. They are: $0 \leq SI_x < 0.6$, extremely weak sustainabilily; $0.6 \leq SI_x < 1.2$, weak sustainability; $1.2 \leq SI_x < 1.8$, medium sustainability; $1.8 \leq SI_x < 2.4$, strong sustainability; $2.4 \leq SI_x < 3.0$, extremely strong sustainability.

RESULTS AND ANALYSIS

Development stages and sustainability of the ecosystem

Table 4 displays the values of development indices (QI_x) at different tiers. The last row of Table 4 shows the development index values at the B tier, an indication of the overall development level of the ecosystem. Figure 5 illustrates the trend of the development index at this tier, as well as at the C tier, from 1986 to 1995. It is clear that the value of QI_x progressed continuously from 0.653 in 1986 to 1.495 in 1995, implying an overall improvement in the quality of the ecosystem. By comparing Table 4 with Table 5, different stages of the sustainable development can be identified. Between 1986 and 1987, the values of QI_x were below 0.7, implying a middle Primary Sustainability stage. The value of QI_x was 0.734 in 1988 and continued to increase in 1989 and 1990, levelling up to 0.984 in 1991. Table 5 indicates that these years were at the late stage of Primary Sustainability. The value of QI_x was over 1.0 from 1992, signalling the arrival of the Medium Sustainability stage. However, a careful examination shows that both 1992 and 1993 were at the early stage of Medium Sustainability, while 1994 and 1995 were at the middle stage of Medium Sustainability. Apparently, Guangzhou's urban ecosystem is developing towards higher stages of sustainable development.

The sustainability index, SI_x, reflects the development level in the economic, social, and natural subsystems and their coordination. A plot of SI_x by year is given in Figure 6, showing that the value of SI_x continued to grow during the study period. From 1986 to 1988, Guangzhou witnessed an extremely weak period of sustainability with an average value of 0.506. However, the sustainability index increased to 0.652 in 1989 and to 1.153 in 1993, implying that the ecosystems moved away from this extremely Weak Sustainability. During 1994 and 1995, the sustainability index was 1.306 and 1.437, respectively.

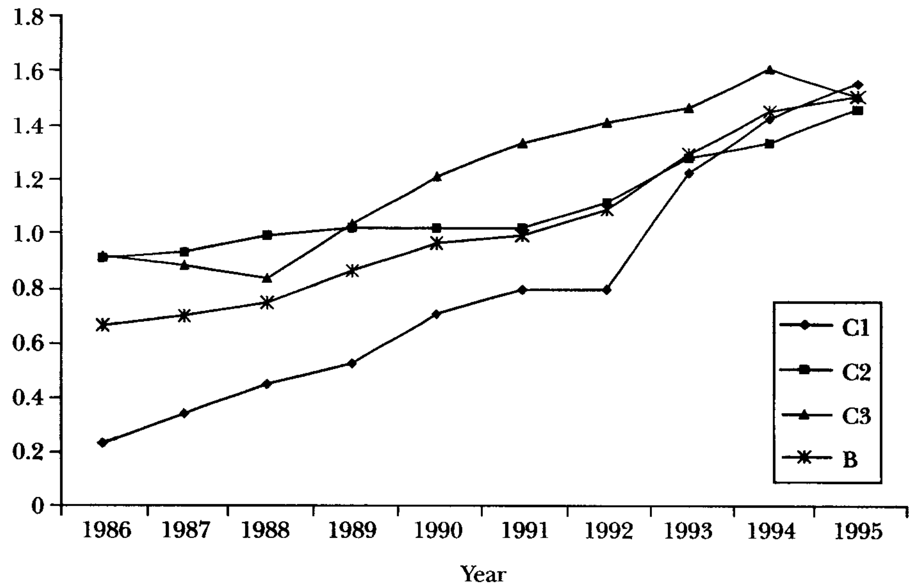

Figure 5 QI_x values for the C and B tier indicators

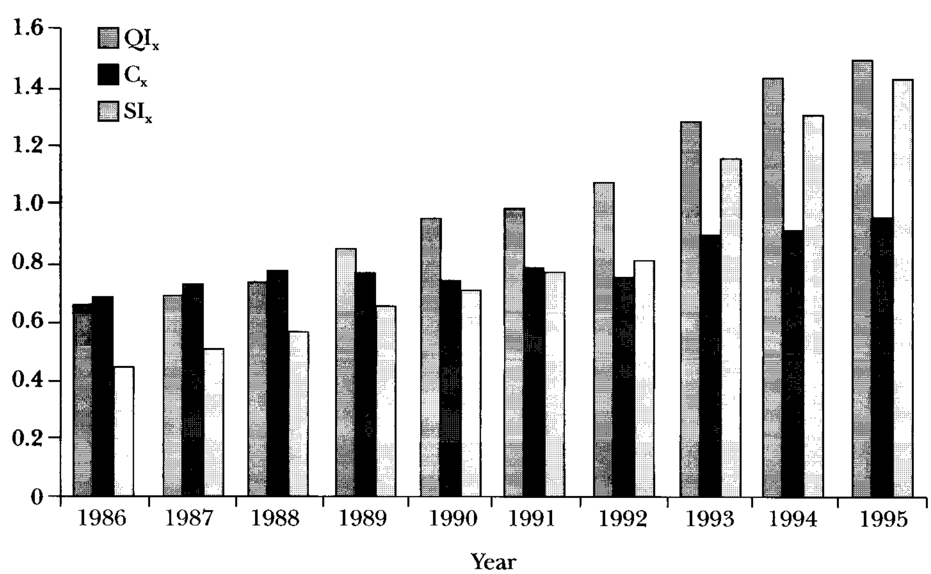

Figure 6 Sustainable development indices by year in Guangzhou

In other words, Guangzhou's urban ecosystem had a Medium Sustainability. It can be concluded that Guangzhou's sustainability was getting stronger year by year.

Coordination among the subsystems

The coordination index, C_x, has a value between 0 and 1. When the C_x value = 1, the three subsystems are completely coordinated; when the C_x value = 0, the three subsystems are not coordinated at all. Therefore, the larger the C_x value, the higher degree of coordination. The results of the coordination index analysis reveal a continual increase in the degree of co-ordination from values of 0.679 in 1986 to over 0.7 in the late 1980s and early 1990s, with a sharp increase in 1993 to 0.897, levelling out to over 0.9 in 1994 and 1995 (Figure 6). This increase in the index indicates a general improvement in the coordination among the economic, social and natural subsystems in Guangzhou's ecosystem. From 1987 to 1992, the coordination degree fluctuated with small amplitudes. Beginning in 1993, the coordination degree increased rapidly, which can be explained by more balanced development in the three subsystems. Vigorous economic development was accompanied by the emergence of numerous environment regulations and increased social benefits. By 1995, the development index of the economic subsystem (C1 = 1.539) had surpassed that of the social (C2 = 1.443) and the natural (C3 = 1.496) subsystems, as indicated in Figure 5. In the future, if the importance of economic development is over-emphasized, and if the investment and improvement in both social and natural subsystems is ignored, the coordination degree will decline. This would bring a negative impact on the sustainability of the urban ecosystem in Guangzhou.

Analysis of the subsystems

Unbalanced development exists among the three subsystems of the urban ecosystem in Guangzhou, as shown in Table 4 and Figure 5. In terms of the economic subsystem, there had always been an imbalance between economic quantity (D1) and economic quality (D2). The largest disparity of QI_x occurred in 1995 (difference = 1.819). Before 1989, the development level index of economic quality was larger than that of economic quantity. However, the situation reversed after 1989, and the disparity became larger and larger. While the QI_x value for economic quantity increased rapidly (from 0.13 in 1986 to 2.448 in 1995), the QI_x value for economic quality remained relatively unchanged. A close examination of the two components of economic quality, i.e. economic structure (E2) and economic efficiency (E3), indicates that the QI_x value for economic structure (E2) had remained stable for most of the time. The QI_x value for economic benefits (E3) had always been low, levelling out in 1990 to 0. This indicates that rapid economic growth resulted heavily from investment and that economic efficiency had not improved simultaneously. It would be difficult for Guangzhou to maintain economic prosperity if the economic structure is not adjusted and the economic efficiency is not maximised in the future.

In terms of the social subsystem, the general trend of population quality (D3) increased in spite of fluctuation during the periods from 1989 to 1992 and from 1994 to 1995. The changing tendency of mental life quality (D4) was consistent with that of population quality. However, the development level of population quality changed approximately one year behind that of mental life, suggesting that mental life may have an impact on population quality. By comparing the development level of mental life and material life (D4 and D5 in Table 4, respectively), it becomes clear that the level of material life had overtaken the level of mental life after 1994. When the level of material life rose, the level of mental life did not go up accordingly. Instead, the QI_x value dropped below the level of 1986. Analysis of the two components of the mental life (entertainment, E6, and security and health, E7) reveals that the QI_x value of entertainment was much lower than the QI_x value of security and health. Moreover, the QI_x value of entertainment had remained nearly constant from 1986 to 1995, while the level of security and health had a general trend of declining, a result of the decrease in the social security indicator (F11) (the reciprocal of the frequency of accidents). In contrast, both components of material life (living facilities, E8, and infrastructure, E9) enjoyed sizeable increases between 1986 and 1995, although living facilities increased more rapidly than infrastructure.

The natural subsystem had been improved due predominantly to more investment in environmental protection and enforcement measures in environmental management. The level of the natural subsystem (C3) had a general tendency of moving upward, as indicated in Table 4. Among air quality, water quality, and noise levels, the QI_x value of noise (E12) ranked lowest, air (E10) second and water (E11) was highest. Although the air and water quality kept improving most of the time, the level of water quality decreased substantially in 1995, suggesting increased water pollution.

CONCLUSION

The ecological perspective of sustainable development suggests that sustainability of an urban ecosystem depends upon coordinated and harmonised development among economic, social, and natural subsystems. Based on this theory of sustainable development and the principles of ecosystem integrity, the authors have developed an evaluation system and approach for sustainable development in Guangzhou, China. Fuzzy multistage synthetic evaluation methods were adopted for appraisal of sustainability. The results revealed that the urban ecosystem in Guangzhou had gone through different stages of sustainable development from 1986 to 1995 and had generally become more sustainable.

Coordinated development among economic, social, and natural subsystems must be guaranteed to maintain Guangzhou as a vital modern metropolis. Due to rapid development in the economic subsystem in recent years, the QI_x values for both the social and natural subsystems were dropping below that of the economic subsystem. Effective measures should be taken soon to ensure sustainability in the city. While the overall sustainability was increasing, the coordination degree fluctuated annually. The components of each subsystem, therefore, must be carefully examined.

Urban ecosystems are complex and dynamic, and have a characteristic of multistage development, therefore sustainable development metrics and indicators should be developed with care. Although a large number of indicators may be adopted, data availability is a key element for consideration. This paper presents a general approach, and further improvement in the methods is necessary. This is particularly true when considering the fact that urban ecosystems are diverse in terms of geographic setting, topography, urban development history and patterns, and socio-economic conditions. For a specific application, the evaluation methods may be modified for different settings and times.

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