Application Research of Ecological Footprint: Time Sequence and Comparative Analysis of Selected Chinese Cities

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Abstract: In order to evaluate and regulate sustainable development of selected cities in China, ecological footprint (EF) is chosen for its simplicity and international influence from the many different tools and methods developed for sustainability measurement. Based on introduction to elementary concept and research scales of EF, the authors first calculate the EF of Xi’an from 1995 to 2004 with data from statistical yearbooks. The time sequence analysis results show that EF of Xi’an increases gradually and in 2004 the ecological deficit (ED) is 0.845 ha/cap. The high ED indicates the ecological safety of Xi’an is greatly challenged and its ecosystem is seriously overloaded. Then EF and ecological efficiency (EE) of other eight Chinese cities in 2004 are calculated. The comparative analysis results show that EF of Hong Kong (4.8676 ha/cap) is the biggest, 122 times bigger than its biological capacity (0.0399 ha/cap), then come Shanghai, Beijing, Tianjin, Qingdao, Shenyang, Shenzhen and Chongqing. At the same time, the EE of Hong Kong is the highest (39299 yuan/hm2)，then come Shenzhen, Shanghai, Shenyang, Qingdao, Beijing, Tianjin and Chongqing. It is pointed out that EE of the seven Chinese Mainland cities has much improvement space compared with that of Hong Kong.

Key words: urban management; ecological footprint; ecological safety; ecological efficiency

1 Introduction

In modern societies, cities are the main places where people not only use and consume natural resources and all kinds of energies, but produce and discard a lot of pollution harmful to the environment. With global environment and resource problems becoming more and more serious, urban sustainability has now become one of the research focuses in academic field. In recent yeas, China’s urbanization level increases very fast, and the roles of cities in national socioeconomic development becomes much more important. Meanwhile, the economic growth model of China has not been changed essentially, and the situation of high growth rate with high consumption rate and high discharge rate not been controlled effectively yet. Therefor, it is very necessary to reasonably evaluate the sustainability of Chinese cities, in order to offer decision support for building resource-saving and environment-friendly cities.

By far, sustainable development evaluation research often adopts the form of building an index system, while other research angles still include bio-diversity, land use intensity, material flow, energy measurement, environmental space analysis and social statistical analysis, etc.. Among them, ecological footprint analysis (EFA) proposed from the angle of ecological safety by Wackernagel and Rees is paid much attention to and widely accepted for its clear concept and simple calculation. On the other hand, EFA takes a stand of strong sustainability principle in sustainable development evaluation, so it gives a stricter concept of sustainability [1]. For this reason, the authors have chosen EFA in this paper for sustainability measurement of selected Chinese cities.

2Contents and scales of EFA

EFA involves some basic concepts like ecological footprint, biologically productive land, biological capacity, ecological deficit / reserve, etc., which are explained in detail in literature [1]. It should be emphasized that the concept of biologically productive land is the core of EFA. Generally, when EFA is employed, biologically productive land needed by consumption and waste discarding in a certain region is first calculated to present ecological stress (i.e., ecological footprint demand) brought by regional development, then biologically productive land provided by this region is calculated to present regional biological capacity (i.e., ecological footprint supply), and regional sustainability can finally be measured and analyzed by comparing the demand and the supply[2-3].

It should be admitted that EFA still has some limitations. But for its concise principle and convenient operation, EFA has been recognized worldwide, and many scholars have made use of it to implement sustainability evaluation research at different scales.

（1）Global and national scales. Of these researches, serial reports of *Living Planet* published biyearly by WWF and of *EUROPE: The Ecological Footprint* published yearly by EU are typical, which provide regular sustainability tracing and evaluation of the earth and the Continent. National ecological footprint research began soon after EFA was proposed. In *Ecological Footprint of Nations*, Wackernagel calculated 52 countries' ecological footprint [4]. Vuuren calculated and analyzed the ecological footprint of Benin, Costa Rica, Bhutan and Holland [5]. Xu Zhong-min, Chen Min et al measured the ecological footprint of China in one or more years, and put forward some countermeasures for China's sustainability [6-7].

（2）Regional and urban scales. Folke et al gave the ecological footprint results of 29 cities in the European Baltic sea drainage area [8]. Ecological footprint of London, Liverpool and York had been researched by Best Foot Forward and Stockholm Environment Institute [9-11]. In China, Beijing, Shanghai, Nanjing, Hangzhou and other cities' ecological footprint had been researched [12-14], and some scholars improved EFA and employed it to ecological planning of cities [15].

（3）University campus and family scales. Colorado College in U.S. and Newcastle University in Australia researched ecological footprint of themselves [16-17]. In China, GU Xiao-wei et al studied the ecological footprint of Northeastern University in 2003 [18]. Besides, He Yuhong et al got the ecological footprint and ecological rucksacks of cars to discuss their environmental influences after entering families [19].

Implementing ecological footprint researches at different scales can evaluate and analyze the environmental influence brought by actions of units at different levels (nations, cities and families), which will help to find specific sustainable development measures for units at each level.

3 Time sequence analysis: ecological footprint of Xi'an city from 1995 to 2004

3.1Data preparation

Based on the available data from the statistical yearbooks of Xi'an city, the consumption items of biologic resources and energy needed in EFA of Xi'an city are ascertained objectively. Among them, there are 17 consumption items of biologic resources, including corn, legume, potato, fruit, vegetable, oil plants, nuts, cotton, aquatic products, wine, sugar, pork, beef and mutton，fowls, eggs, milk and lignum, and 11 consumption items of energy, including original coal, cleaned coal, coke, gasoline, diesel oil, kerosene, fuel oil, LPG, other petroleum products, natural gas and electric power.

To calculate ecological footprint, the average global output of each biologic resources consumption item is ascertained according to data published on FAO's website, and equivalence factor of each kind of biologically productive land according to literature [20]. Besides, the average global land output ratio of each energy consumption item is ascertained according to Wackernagel's research, which can help to convert consumed caloric to a certain amount of fossil energy land. To calculate biological capacity, yield factor of each kind of biologically productive land is again ascertained according to literature [20]. By now, all the data needed in EFA have been prepared, but will not appear in this paper with restrictions of length.

3.2 Calculation results and analysis

The EFA results of Xi'an city from 1995 to 2004 are shown in table 1 to table 3, and figure 1 compares the ecological footprint per capital, biological capacity per capital and ecological deficit per capital of Xi'an city from 1995 to 2004. It can be seen that there is ecological deficit in each of these ten years and it increased a lot in 2004, while in the other years the ecological deficit per capital stayed at the range of 0.65-0.71hm^2. Of ecological footprint per capital, data from 1995 to 2003 stayed at the range of 0.89-0.94hm^2, while in 2004 it reached the level of 1.07hm^2. Of biological capacity per capital, except a certain amount of increasing in 2000, data of the other years presented a gradual decreasing trend in general, which stayed at the range of 0.25-0.22hm^2.

In the six kinds of biologically productive lands corresponding to ecological footprint per capital of Xi'an city, data value of cropland ranges from 0.55 to 0.64hm^2/cap, contributing to 54-69% of the whole ecological footprint; and data value of fossil energy land ranges from 0.20 to 0.40hm^2/cap, contributing to 24-37% of the whole ecological footprint. These two components together contribute to 88-92% of the whole ecological footprint, which indicates that food consumption and energy consumption are main factors forming the ecological footprint of Xi'an city. Further, in the 10 years, data value of fishing ground indicates that there was a fast increase in relative consumption, while of grazing land, forest, and built-up land, there were no obvious increase in relative consumptions. In the five kinds of biologically productive lands corresponding to biological capacity per capital of Xi'an city (here CO_2 land is neglected), supply of cropland and water area decreases gradually in general, supply of forest and built-up land increases gradually in general, and that of grazing land has no change in general.

3.3 Further discussion

For higher ecological footprint per capital generally reflects higher economic development level, the fact that ecological footprint per capital of Xi'an is lower than that of the nation (in 2001, ecological footprint per capital in China is 1.5hm^2) shows that to some extent, the economy of Xi'an is far from developed and still needs to be strengthened. Because food consumption and energy consumption are main factors forming the ecological footprint of Xi'an city, so it is more important that in the future, population size of the city should be properly controlled and energy (resource) has to be saved and made better use of. Moreover, protection of the city's natural environment should be paid much attention to; for existing cropland and water area are decreasing, so protection of cropland, rivers and riverheads must be strengthened.

The fact that ecological footprint per capital of Xi'an is lower than that of the nation also indicates that in this region, the population's demanding and snatching degree to the natural eco-system is relatively lower, and influence made to the environment is relatively less, which is in favor of future eco-construction of the city. Meanwhile, it can be seen that in the ten years, the ecological footprint per capital of Xi'an had always been 3.5 times over the biological capacity per capital of itself, and in 2004, the former was even 4.7 times over the latter. This indicates that socioeconomic development of Xi'an needs extra ecological footprint coming from its neighboring regions, leading a substantial decrease in biological capacity of theses regions, which will do harm to the whole area's sustainability. Therefore, economic growth model and people's consumption model should be changed as soon as possible, and building a resource-saving and environment-friendly society in Xi'an should be carried out in an all-around way.

Under the situation that the ecological footprint per capital was 4.7 times over the biological capacity per capital in Xi'an in 2004, the city still operated normally. The reason for this normal operation is the input of the outside resources and energy. As we all know, when material and energy exchange between a system and its environment has not been broken, the system keeps its dynamic stability. But when this exchange is broken, development of the system will be badly affected. In an extreme situation, i.e., once Xi'an cannot obtain the outside resources and energy as supplementary supply, then the whole city will break down in few days. From this aspect we can say that adopting EFA to do early warning for urban eco-safety is of special importance. Undoubtedly, developing an operational system of eco-safety early warning of Xi'an based on theory and procedures of EFA is an important and urgent research task to be finished.

4Comparative analysis: ecological footprint of 8 Chinese cities in 2004

4.1 Data preparation

The 8 Chinese cities selected in this paper are Beijing, Shanghai, Tianjin, Chongqing, Shenzhen, Qingdao, Shenyang and Hong Kong. Among them, Beijing is the capital, Shanghai is the economic center, Chongqing has the biggest population, Tianjin and the three above cities are all municipalities, Shenzhen is a special economic zone, Shenyang is a heavy industry city, Qingdao is a port city and Hong Kong is a special administrative region.

Because categories in the statistical yearbooks (2005) of the cities are not the same, so the authors had tried their best to sort out the common categories from the yearbooks (2005) of the cities to compare their ecological footprint. The categories include 16 consumption components of biologic resources and 4 energy consumption components. Moreover, except the yield factors consult Wackernagel's work, the other factors are identical to that of 3.1.

4.2 Calculation results and analysis

The EFA results of the 8 cities in 2004 are shown in table 4. It is easy to know from table 4 that the ecological footprint per capital of Hong Kong is the biggest, 4.8676hm^2/cap, while Chongqing's is the smallest, 1.3210hm^2/cap. Except Chongqing, the ecological footprints per capital of other cities are all bigger than 2hm^2/cap. Of biological capacity per capital, Shenyang's is the biggest, 0.7356 hm^2/cap, next is Chongqing's, and Hong Kong's is the smallest, only 0.0399hm^2/cap. Of ecological deficit per capital, Hong Kong's is the biggest, 4.8277hm^2/cap, next is Shanghai's, and Chongqing's is the smallest, 0.6628hm^2/cap.

The ecological footprint components of the 8 cities are shown respectively in figure 2.It is easy to know from figure 2 that fossil energy footprint is the primary component of the whole footprint for all the cities except Chongqing. The proportions of fossil energy footprint in Shanghai, Beijing, Tianjin and Shenzhen are all over 70% of their own footprints, the proportions in Shenyang and Qingdao are 60.64% and 63.65% respectively, and the proportions in Hong Kong and Chongqing are

37.01% and 34.45%. Energy footprints in Beijing, Shanghai and Tianjin are all over $2hm^2$/cap, because in calculation the temporary population of the 3 cities is not included. The following component of the whole footprint for all the cities except Chongqing is the cropland footprint (the cropland footprint in Chongqing is the primary component, accounting for 48.28% of its footprint), and the proportions range from 12% to 24%, among which Hong Kong is at the top, i.e. 23.26%, Shenyang the second, 21.06%, and then come Qingdao, Tianjin, Beijing, Shanghai and Shenzhen (its proportion is only 11.96%).

The ecological footprints of the 8 cities can be classified to three levels. In the first level, there is only Chongqing, for its primary footprint component is cropland and energy the second. As we all know, Chongqing has the most population in the 8 cities, and its economic level is quite lower, so life consumption here is dominant, and next is the industry consumption. In the second level, there are Shanghai, Beijing, Tianjin, Qingdao, Shenyang and Shenzhen, for energy footprints are all their primary components (proportions over 60%) and cropland the second. Of the 6 cities, their economic development is faster and industrialization and urbanization level much higher, so much more energy consumption is needed, while life consumption has become less important. In the third level, there is only Hong Kong. For Hong Kong, though energy footprint is the primary component, but its proportion is less than 40%, similar to that of cropland, and other components' proportions are close except that of built-up land. It is clear that Hong Kong has a developed economy and the highest urbanization level in the 8 cities and people here pay much attention to life quality, which is the reason that all the footprint components' proportions are close to some extent and the total ecological footprint is higher than that of the other cities.

4.3Further discussion

For a certain region, the production potential of its biologically productive land decides the population size this region could sustain under some economic and technological conditions (especially under some consumption level and life quality). When we consider a region's ecological footprint and GDP together, we can get the concept of ecological efficiency (EE) of regional economy, which is defined as the economic output (GDP) "produced" by ecological footprint of 1 hectare. The reciprocal of EE is called ecological footprint intensity. The ecological footprint intensity and EE of the 8 cities in 2004 are shown in table 5.

It is obvious that EEs of the 8 cities differ with each other. The EE of Hong Kong was the highest (39299 yuan/hm^2), while that of Chongqing was the lowest (6461 yuan/hm^2). That indicates the EE of Hong Kong was 6.07 times over that of Chongqing. Besides, The EE of Shenzhen was lower than that of Hong Kong, but higher than that of the other 6 cities. This illuminates that EE of a city has a close relationship to its industry structure, i.e., regions and cities with dense high-tech industry and developed service industry have higher EE, while regions and cities with heavy industry and underdeveloped service industry have lower EE. Compared with Hong Kong, there is much room for the Chinese mainland cities to promote their EEs. In this course, adjusting industry structure and heightening resource use factor is the only way for their future development.

5 Conclusions

By adopting EFA, this paper first gives a time sequence study to ecological footprint of Xi'an from 1995 to 2004, discovering that the city's ecosystem has been overloaded and its eco-safety is facing big challenge. To deal with that, it is needed for the city to positively change its economic growth model and try his best to build a resource-saving and environment-friendly society, at the same time, an effective and feasible system of eco-safety early warning has to be set up as soon as possible to meet the supervision and regulation demands in the process of the city's sustainable development. Moreover, this paper also offers a comparative analysis to ecological footprints of other 8 Chinese cities in 2004, which discovers that the size and composition of a city's ecological footprint have close relations with its economic development status, urbanization level and population. Further study points out that EE of the mainland cities in China has much room for improvement. Unless industry structure is adjusted, resource use factor heightened and people's consumption model changed in these cities, the expected improvement will not be realized.

Though angles of EFA made to Xi'an and other 8 Chinese cities are different, but results gained support each other. This again shows the effectiveness of EFA as a mainstream method for sustainability evaluation. As a quantitative tool for environment load analysis and sustainability research, EFA can help to discover the interactions between urban development and ecological stress, find the main contradictions faced by regional sustainable development, and provide decision support for regional development strategy and economic policy making. By far indeed, EFA has not properly embodied the positive influence to sustainable development brought by factors like restoration ability of ecology, technology improvement and trade. Therefor, combination of EFA and other sustainable development index systems should be strengthened to make the calculation results more reliable, which will in turn strengthen EFA's application effects.

Table 1 Ecological footprint per capital of Xi'an（1995-2004）

Unit: hm^2/cap

Year	Cropland	Forest	Grazing land	Fishing ground	Fossil energy land	Built-up land	EF per capital
1995	0.557523	0.047653	0.027913	0.001107	0.27131699	0.00402255	0.90953554
1996	0.57701	0.028024	0.059485	0.004447	0.26630895	0.00406551	0.93934046
1997	0.568207	0.027099	0.037794	0.008986	0.261085	0.005229	0.9084
1998	0.568679	0.051461	0.031937	0.013073	0.258389	0.010682	0.934221
1999	0.58556	0.035576	0.027763	0.01642	0.222701	0.005261	0.893281
2000	0.639014	0.036149	0.029587	0.01197	0.206871	0.005557	0.929148
2001	0.596759	0.034212	0.027916	0.013512	0.253811	0.005634	0.931844
2002	0.623285	0.035654	0.034443	0.015071	0.22267009	0.0070655	0.93818859
2003	0.586285	0.035528	0.035369	0.017523	0.24430926	0.00609293	0.92510719
2004	0.58042	0.034888	0.039192	0.014884	0.397022	0.008112	1.074518

Table 2 Biological capacity per capital of Xi'an（1995-2004）

Unit: hm^2/cap

Year	Cropland	Forest	Grazing land	Fishing ground	CO_2 land	Built-up land	Usable bio-capacity
1995	0.22179122	0.04739805	0.00019318	0.00111668	0	0.0106124	0.247378148
1996	0.21363886	0.04691569	0.00019121	0.00110531	0	0.0105044	0.239672823
1997	0.21371492	0.04640651	0.00018914	0.00109332	0	0.01137327	0.240043892
1998	0.21174509	0.04597878	0.00018739	0.00108324	0	0.01126844	0.237831391
1999	0.20707617	0.04556087	0.00018565	0.00121572	0	0.0128842	0.234891895
2000	0.22872864	0.06072208	0.000182	0.00093889	0	0.01263114	0.266818426
2001	0.19251117	0.06012557	0.00018021	0.00092967	0	0.01250706	0.234303239
2002	0.18719708	0.06265736	0.00017822	0.00091941	0	0.01340694	0.232635932
2003	0.17895469	0.06143456	0.00017475	0.00090145	0	0.0132173	0.224120816
2004	0.17303709	0.07214689	0.00017271	0.00089097	0	0.01421567	0.229207733

Table 3 Ecological deficit per capital of Xi'an（1995-2004）

Unit: hm^2/cap

Year	Eco-deficit	Year	Eco-deficit
1995	0.6622	2000	0.6623
1996	0.6997	2001	0.6975
1997	0.6684	2002	0.7056
1998	0.6964	2003	0.7010
1999	0.6584	2004	0.8453

Unit: hm^2/cap

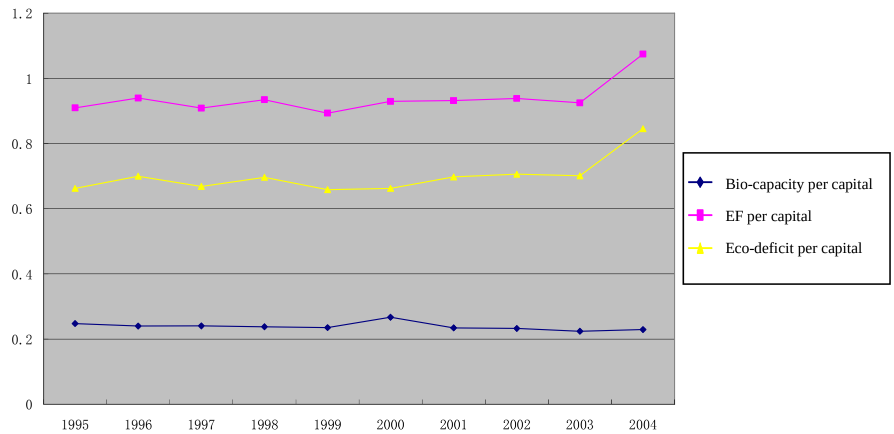

Figure 1 EFA of Xi'an city form 1995 to 2004

Table 4 EFA of the 8 cities in 2004

Unit: hm^2/cap

City	Population （10,000）	EF	Bio-capacity	Eco-deficit
Hong Kong	688.3000	4.8676	0.0399	4.8277
Shanghai	1352.3900	3.4236	0.2131	3.2105
Beijing	1162.9000	3.0680	0.3381	2.7299
Tianjin	932.5500	2.9598	0.4917	2.4681
Qingdao	731.1228	2.2581	0.5444	1.7137
Shenyang	693.8708	2.0401	0.7356	1.3045
Shenzhen	597.5500	2.0157	0.1035	1.9122
Chongqing	3144.2300	1.3120	0.6492	0.6628

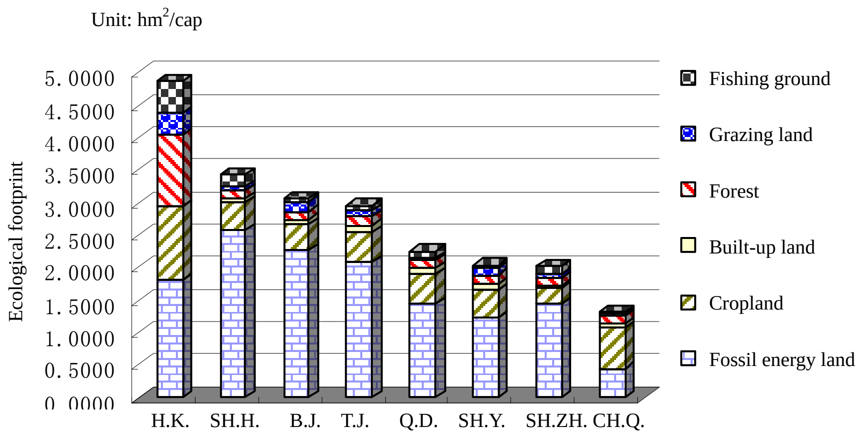

Figure2 Ecological footprint components of the 8 cities in 2004

Table 5 Ecological footprint intensity and ecological efficiency of the 8 cities in 2004

City	GDP per capital （10,000 yuan）	EF per 10,000 yuan GDP	GDP per unit EF
Hong Kong	19.0951	0.2549	3.9229
Shanghai	5.5090	0.6215	1.6091
Beijing	3.6833	0.8330	1.2006
Tianjin	3.1439	0.9414	1.0622
Qingdao	2.9596	0.7630	1.3106
Shenyang	2.7393	0.7448	1.3427
Shenzhen	5.7280	0.3519	2.8417
Chongqing	0.8477	1.5477	0.6461

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