The Variety and Analysis of Ecological Footprint in Recent Years in Chongqing, China

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ABSTRACT: The urbanization in China has a great impact on environment and the Chinese economic development. The sustainable development has been recognized as the key element to keep China's development with success in the future.

This paper uses ecological footprint and biological capacity as indicators to measure regional sustainable degree. The ecological footprint and the biological capacity of Chongqing municipality with 32 million populations have been calculated from 1999 to 2004. The ecological footprint and the biological capacity in Chongqing municipality had obvious changed from 1999 to 2004. The change degree of ecological footprint affected by social and economic development is more prominent than the change degree of biological capacity. The fossil energy land possesses the most proportion, which exceeds 50% in average. The waste is also an important effect to ecological footprint, which achieves 21% in proportion.

The research results can inform the Chongqing municipality government in more detail to enhance the ecological and environmental protection in the balance of urban development with society, ecology, environment and resource.

Key words: sustainable development, urbanization, ecological footprint, biological capacity, environment and resource

1. INTRODUCTION

In recent years, many researchers use prediction indicators, such as sustainable socio-ecological indicator (Christian AC, 1996), index of sustainable economic welfare (ISEW) (Beatriz E, 1999), genuine progress indicator (GPI) (Anielski, 1999) and genuine savings rates (Ashok D, 2000) to estimate the degree of sustainable development. But these methods have some limitations at measuring the degree of sustainable development (Xu ZM, 2000).

Ecological footprint is a method for measuring sustainable development; it was proposed and developed by William and Wackernagel in 1992 (Wackernagel, 1997, 1999). An ecological footprint is a measurement of the land area required to sustain a population of any size. Under prevailing technology, it measures the amount of arable land and aquatic resources that must be used to continuously sustain a population, based on its consumption levels at a given point in time. To the fullest extent possible, this measurement incorporates water and energy use, uses of land for infrastructure and different forms of agriculture, forests, and all other forms of energy and material "inputs" that people require in their day-to-day lives. It also accounts for the land area required for waste assimilation.

In recent years the ecological footprint experienced a great deal of development and extensive application due to its scientific theory and simple indicator in the world (Borgstroem H, 1999; Helmut H, 2001; et al.). By adopting this method, this paper calculates the ecological footprint and the biological capacity of Chongqing, China from 1999 to 2004.

The aims of this study are: 1) to measure the degree of sustainable development in Chongqing; and 2) to evaluate the environmental impact of the urbanization of Chongqing.

2. MATERIAL AND METHODS

2.1 Study area

Chongqing is located at 28°10' ~ 32°13' north latitude and 105°11' ~ 110°11' east longitude. It is a large commercial and industrial center, and has convenient communications. In 1997, it was granted as the fourth municipality of China. Covering an area of 0.0824 million square kilometers, the municipality is 470 kilometers wide from east to west and 450 kilometers long from north to south. There were a total of 15 districts in Chongqing in 2004. Chongqing's eastern part is lower than the western part, with lots of hills in the northwest and in the middle areas, and Daba Mountain and Wuling Mountain to the southeast. Chongqing has a subtropical humid monsoon climate with four distinct seasons. The summer of Chongqing is hot and the winter is warm, with a long frost-free period. In 2004 annual average temperature of this region was 18.4℃ and its annual precipitation was 1182.1mm.

Chongqing's GDP is 2665.39 hundred million Yuan and its total population is 31.4423 million in 2004. There is a high speed of urbanization in Chongqing, of which growing rate of urban population has increased to 43.5% in 2004 from 31.3% in 1999 (Table 1). This has been also reflected by the data of land resources (see Table 2). The area of cropland is reduced by 499.6 thousand hectare and the area of build-up land increased by 94.4 thousand hectare from 1999 to 2004. In all kinds of land the change of unused land is the most obvious, which reduced about 52%. All change of land resources indicated that the used degree of nature resources is enhancing and the human impact on environment has an increased trend.

Table 1: The change of population in ChongQing from 1999 to 2004.
Unit: million

Years	1999	2000	2001	2002	2003	2004
Total Population	30.72	30.90	30.97	31.07	31.15	31.44
Urban Population	9.61	10.22	10.75	11.31	11.87	13.68
Rural Population	21.11	20.68	20.22	19.76	19.28	17.76

Table 2: The change of various land area in Chongqing from 1999 to 2004.
Unit: Ten thousand hectare

Years	1999	2000	2001	2002	2003	2004
Cropland	278.7	277.1	251.7	246.6	34.76	228.7
Garden land			23.81	18.25	21.00	22.09
Forest	297.1	297.4	297.8	303.0	319.0	325.1
Pasture	23.71	23.86	23.84	23.85	23.84	23.81
Fisheries	26.67	26.74	26.73	26.73	26.73	26.73
Build-up Land	46.45	48.27	49.92	51.95	54.00	55.89
Unused Land	151.4	150.6	150.0	77.32	73.30	72.39

2.2 Analytical methods

There two types of analytical methods , which are compound and component-based methods. This research uses the component-based method. The component-based approach sums the Ecological Footprint of all relevant components of a population's resource consumption and waste production. The content of research is divided into two parts: the ecological supply (or bioproductive areas) and the demand on nature (or ecological footprint). The bioproductive areas can be divided into five distinct types: cropland, forest, pasture, fisheries and built-up land, which provides economically useful concentrations of renewable resources. And the ecological footprint accounts express the use of built-up areas, and the consumption of energy and renewable resources. It can be divided into six types: cropland, forest, pasture, fisheries, built-up land and fossil energy land. The calculation of fossil energy land is for solving this research question 'how much regenerative capacity is required to maintain the throughput of fossil fuel through the human economy?' (Monfreda C, 2004). All process of calculation is as follows:

The first step is to calculate the ecological footprint of each consumption item. The computational forms can be defined as:

$$A_i = C_i / Y_i = (P_i + I_i - E_i) / (Y_i \times N)$$

where i is the item type of consumption, Y_i is annual average yield of the item (kg / hm^2) ,C_i is per capita consumption of the item(kg/capita), A_i is the per capita ecological footprint of the item(hm^2 / capita), P_i is annual yield of the item(kg), I_i is annual importation of the item (kg) , E_i is annual export of the item (kg) , and N is the population of research region. The ecological footprint of energy consumption can be calculated through the constant conversion factor. For instance, the constant conversion factor of coal is 55GJ / hm^{2}a, and the constant conversion factors of oil and gas are 71 GJ / hm^{2}a and 93 GJ / hm^{2}a (Wackernagel, 1997).

The second step is to calculate the ecological footprint of research region. The computational forms can be presented as:

$$ef = \sum r_j A_i = \sum r_j (P_i + I_i - E_i) / (Y_i \times N)$$

(j=1,2,…,6)

Where ef is per capita ecological footprint of research region(hm^2 / capita), j is bioproductive area, it can be divided into six types: cropland, forest, pasture, fisheries, built-up land and fossil energy land. The meanings of i, A_i, Y_i , P_i , I_i , E_i and N are same to that in the first step. And the r_j are equivalence factors. Equivalence factors represent the world's average potential productivity of a given bioproductive area relative to the world average potential productivity of all bioproductive areas (Monfreda, C, 2004). Cropland, for example, is more productive than pasture, and so has a larger equivalence factor than pasture. The equivalence factors of each bioproductive area are listed as follows: cropland is 2.9, forest is 1.1, pasture is 0.6, fisheries are 0.2, built-up land is 2.9 and fossil energy Land is 1.1.

The total ecological footprint of research region can be defined as:

$$EF = N \times (ef)$$

Where EF is the total ecological footprint (hm^2), and N is the population of research region.

The third step is to calculate the biological capacity of research region. Biocapacity is the counterpart of the ecological footprint, or the demand side. A region's total Biocapacity is the sum of its bioproductive areas. The computational forms of per capita Biocapacity can be presented as:

$$ec = a_j \times r_j \times y_j \qquad (j=1,2,\ldots,6)$$

Where *ec* is the per capita Biocapacity (hm^2 / capita) , a_j are per capita bioproductive area, r_j are equivalence factors, y_j are yield factors. Yield factors describe the extent to a biologically productive area in a given country or region, which is more (or less) productive than the global average of the same bioproductive area. Each country or region has its own set of yield factors (Monfreda, C, 2004). The yield factors of each bioproductive area in Chongqing are listed as follows: cropland is 1.82, forest is 0.61, pasture is 0.98, fisheries are 1.0, and built-up land is 1.82.

The total Biocapacity of research region can be defined as:

$$EC = N \times (ec)$$

Where *EC* is the total Biocapacity of research region (hm^2) , *N* is the population of research region.

The fourth step is to calculate ecological deficit. A comparison of the footprint and Biocapacity reveals whether existing natural capital is sufficient to support consumption. An ecological deficit means that a region whose footprint exceeds its Biocapacity. The computational forms of ecological deficit can be presented as:

Ecological deficit (hm^2) = Footprint (hm^2) - Biocapacity (hm^2)

2.3 Data sources

In this paper all consumption of resident has been divided into six kinds of items: food, residence, traffic, merchandise, service and waste. The total footprint comes from the summation of each item; Biocapacity has been deducted by 12% for the protection biological variety. All data come from the Chongqing statistical yearbook 2000-2005.

3. CALCULATION RESULTS AND DISCUSSION

3.1 Calculation result and discussion of Chongqing's ecological footprintThe result (Table 3) indicated that the ecological footprint of Chongqing has a decreasing trend. From 1999 to 2004, the per capita footprint of Chongqing has reduced by 4.4%. Hereinto, the footprint of fossil energy has reduced by 12%, the footprint of cropland has reduced by 1.6%, but the footprint of pasture has increased by 142%, the footprint of forest has increased by 112.5%, the footprint of build-up land has increased by 50%, and the footprint of fisheries has increased by 50%. The main reason is that the demand structure of resident in Chongqing had an obvious change from 1999 to 2004. As the demands of residents to residence, traffic, merchandise, service and animal product have obvious increase, so do the footprints of pasture, forest, build-up and fisheries have a great increase. The decreasing reason of fossil energy's footprint is environmental reform, for example, the ecological footprint of solid waste has reduced about 60%.

Table 3: The calculation result of the per capita ecological footprint in Chongqing from 1999 to 2004

	Ecological Footprint (hm^2/capita)					
Type	1999	2000	2001	2002	2003	2004
Fossil Energy	0.955	0.851	0.721	0.712	0.728	0.840
Cropland	0.560	0.537	0.534	0.574	0.539	0.551
Forest	0.008	0.008	0.010	0.012	0.013	0.017
Pasture	0.026	0.019	0.038	0.042	0.053	0.063
Fisheries	0.006	0.006	0.007	0.008	0.008	0.009
Build-up Land	0.006	0.006	0.009	0.009	0.009	0.009
Total	1.558	1.427	1.319	1.357	1.350	1.489

In composing of ecological footprint in Chongqing, the footprint of fossil energy land possesses the most proportion, which has achieved by 57% on average. The footprint of cropland is the second, which has achieved by 40%. But the footprint of pasture, forest, fisheries land and build-up land is very small on proportion. So the footprint changes of fossil energy land and cropland have great effect on the total footprint in Chongqing.

The ecological footprint of Chongqing is less than the average of China, it is also less than the ecological footprint of developed countries and regions, but it is greater than that of India, as is shown in Fig.1(Zhang KM, 2003).

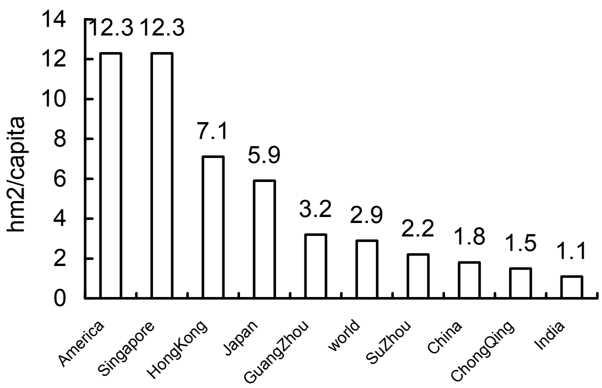

Figure 1: The compare of ChongQing's ecological footprint with other country or region.

3.2 Calculation result and discussion of Biocapacity in Chongqing

The result (Table 4) indicated that the Biocapacity of Chongqing has a decreasing trend. From 1999 to 2004, the per capita Biocapacity of Chongqing has reduced by 6%. Hereinto, the Biocapacity of cropland has reduced by 12.1%, but the Biocapacity of pasture and fisheries does not change; the Biocapacity of forest has increased by 6.2%, and the Biocapacity of build-up land has increased by 20%. The main reason is that there is a fast speed of urbanization in

Chongqing from 1999 to 2004 (Table 1). More and more residents start to live in the urban areas, so that the build-up area has a great increase.

Table 4: The calculation result of the per capita Biocapacity in Chongqing from 1999 to 2004.

	Biocapacity (hm^2/capita)					
Type	1999	2000	2001	2002	2003	2004
Cropland	0.480	0.475	0.470	0.449	0.433	0.422
Forest	0.065	0.064	0.064	0.066	0.068	0.069
Pasture	0.005	0.005	0.005	0.005	0.005	0.005
Fisheries	0.002	0.002	0.002	0.002	0.002	0.002
Build-up Land	079	0.084	0.084	0.090	0.090	0.095
Total	0.631	0.630	0.625	0.612	0.598	0.593
After deduction 12% for protection biological variety:						
	0.555	0.554	0.550	0.539	0.526	0.522

The biological capacity of Chongqing is small, which does not achieve 0.6 ha/capita and that is less than the average of world and China (see Fig.2). But it is breater than the biological capacity of east China (Zhang KM, 2003).

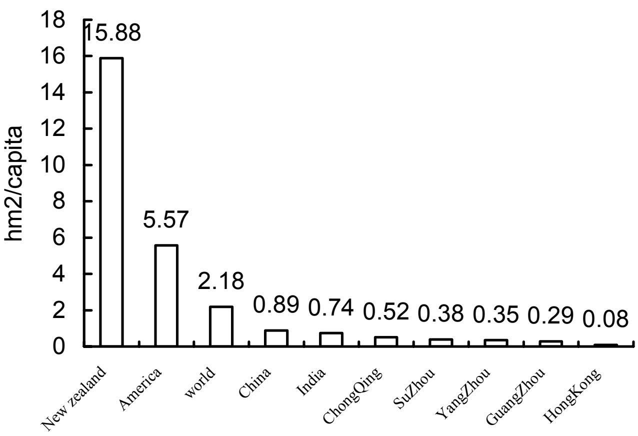

Figure 2: The compare of Chongqing's biological capacity with other country or region.

3.3 Change and discussion of ecological deficit in Chongqing

As is shown in Fig.3, the ecological deficit of Chongqing has an increasing trend from 2001 to 2004, but it has a decreasing trend from 1999 to 2001. The increasing reason is the influence of fast speed of urbanization (Table 1), and the decreasing reason is that the reform of environment diminished the ecological footprint in Chongqing.

The per capita ecological deficit of Chongqing was 0.967 ha in 2004. It is very great with the biological capacity. The main reasons are shown as following:

Firstly, Chongqing is lack of land resource. The cropland was 2.2874 million hectare in 2004, but there was a great population in Chongqing, so the per capita biological capacity is relatively small and the ecological deficit was great.

Secondly, in composing of ecological footprint of Chongqing, the footprint of fossil energy land possesses the most proportion, it has achieved 57% on average (Table 3). The footprint of fossil energy reflects the condition of energy consumption, so there is great energy consumption in Chongqing, and the ecological deficit is great for the great energy consumption.

In addition, environmental pollution is a crucial problem too. Though the condition of environmental pollution has a reform trend, it has an important effect on the ecological deficit in Chongqing yet. The footprint of waste item is a bigger proportion in all consumption items; it has reduced from 34.8% in1999 to 16.0% in 2004. So the environment pollution has improved the ecological deficit of Chongqing.

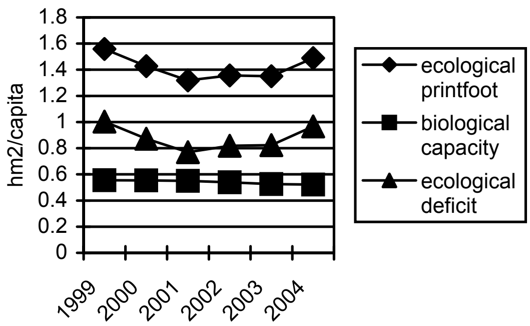

Figure 3: The change of ecological footprint, biological capacity and ecological deficit in Chongqing from 1999 to 2004.

3.4 Reliability and validity analyse of calculation result

As for any scientific measurement tool, the results need to be scrutinized on its reliability and validity. To minimize data inaccuracies or calculation errors that might distort the ecological footprint accounts, we have some quality assurance procedures. It includes comparing calculation results of Chongqing to other correlative region. Furthermore, we have revised some illogical data. The calculation result is relative credible.

The potential errors are reflected as follows:

a). systematic errors in assessing the overall demand on nature. Some demands, such as freshwater consumption, soil erosion and toxic release are excluded or incompletely covered in the calculations. This typically leads to underestimates of ecological deficit.

b). data errors in statistical sources for one particular year. With our improved ability to compare across time, significant errors in this category are largely eliminated as they are detected by looking at time trends. Smaller errors of this kind may still exist in calculations and affect overall results.

c). Systematic misrepresentation of reported data in Chongqing statistics.

4. CONCLUSIONS

The ecological footprint is a useful method with simple indicator for measuring regional sustainable development. This paper describes the condition of regional sustainable development using ecological footprint method. Based on the calculation and analysis of ecological footprint, a regional developmental aim and countermeasure can be established. The method of ecological footprint can be used in sustainable research extensively in China's sustainable development.

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