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Regional sustainability assessment and its sensitivity analysis based on ecological footprint model: A case study of Xingguo County in China

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Based on the Ecological Footprint Model, a Sustainability Index is put forward to measure the degree of regional sustainable development. Using correlation and sensitivity analysis, this study explored the level of sustainable development in the Xingguo County of China from 1996 to 2005, and revealed the driving factors of human activities on sustainable development. The results indicate that the consumption footprint of biological resources in the study area shows a slow, fluctuating upward trend. The increasing ratio of ecological carrying capacity is greater than that of per capita ecological carrying capacity. The values of the sustainable index range from 0.5 to 0.6 (which means unsafe), and it shows a slowly increasing trend. This indicates that the rate of population growth is faster than that of ecological recovery and improvement, which is beyond the bearing capacity of the ecological environment. The Sustainability Index in the study area has a significantly positive correlation with Gross Domestic Product (GDP) urbanization level and this has a significantly negative correlation with the proportion of primary industry. The Sustainability Index in the study area is more sensitive to population growth, followed by a decrease in primary industries.

Key words: Sustainability Index, ecological footprint, sensitivity analysis, regional sustainable development

INTRODUCTION

Since the concept of sustainable development which has been put forward by the World Commission on Environment and Development (WCED) in 1987, there have been a lot of practical applications, and it has become a fundamental thing and a common governmental target for all national and governmental policies to be made (Bleys et al., 2011; Gabrielson, 2013; Choi and Yu, 2014). It is a difficult problem worldwide to measure the degree of regional sustainable development.

The quantitative evaluation and monitoring of regional sustainable development is an important topic in the field of research (Burke, 2011). There have been some valuable evaluation methods and models, such as the Pressure State Response (PSR) framework model proposed by the Organization for Economic Co-operation and Development (OECD) and the United Nations Environment Program (UNEP) (Yang et al., 2011; Babcicky, 2013), and the Index of Sustainable Economic

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Welfare (Gil and Sleszynski, 2003; Lawn, 2003; Clarke et al., 2005; Pulselli et al., 2006; Bleys, 2008, 2013). The "Index of Sustainable Economic Welfare" is applied to Poland, Belgium, Thailand, Italy and other countries (Gil and Sleszynski, 2003; Clarke et al., 2005; Pulselli et al., 2006; Bleys, 2013). Regional sustainable development must depend on sustainable development of ecological environment. On one hand, the ecological environment is the spatial carrier of regional social and economic activities (Duro and Teixido-Figueras, 2013; Stokols et al., 2013). On the other hand, it provides natural resources and assimilates all the wastes for regional development (Jin et al., 2009; Menconi et al., 2013). In the Ecological Footprint Model, the carrying capacity of an ecosystem under the influence of human activities was measured by the ecologically productivity area (Jin et al., 2009; Li et al., 2010; Kissinger et al., 2013; Menconi et al., 2013). This study aims to deal with the relationship between human activities and natural systems from the perspective of biological parameters, a quantitative measure of resource consumption and sustainable development. Ecological footprint analysis is one of the widely used methods for assessing the sustainable development (Ture, 2013). This can quantitatively characterize the state of regional sustainable development through measuring and comparing the profit and loss situation between the material needs of human society development and the natural ecological system of ecological carrying (Ewing et al., 2012; Kissinger, 2013). This helps to monitor the process and to implement the management of sustainable development. The positive features of ecological footprint is that, it clearly shows results and is simpler to calculate. The complicated relationship between human social and economic activities and nature can be simplified in a quantitative way (Wackernagel et al., 1999). Therefore, the ecological footprint method has been recognized by relevant international agencies, government departments and research institutes. It has been a popular method which is important in measuring regional sustainable development in recent years.

China is not only at an important stage of rapid economic development and urbanization, but also is at a turning point for sustainable development (Liu et al., 2014). How to achieve the harmonious development of socio-economic and natural eco systems in China is significant (Dai et al., 2010; Bao et al., 2011; Galli et al., 2012; Liu et al., 2014). Therefore, this study takes a typical region—Xingguo County as a case study and put forward a Sustainability Index based on the ecological footprint to measure the degree of regional sustainable development. Based on a background of small towns' construction in China, we calculated and analyzed the ecological footprint in Xingguo County from 1996 to 2005. The total population, GDP urbanization level and the proportion of primary industry, four social and economic indicators can be measured against the Sustainability Index. The correlation and sensitivity analysis reveals the driving factors of human activities on Sustainability Index. Some targeted suggestions are provided for the planning of regional sustainable development.

METHODS

Study area

The study area (115°01′–115°51′E, 26°03′–26°41′N) (Figure 1) is Xingguo County in Jiangxi province of China, which is located in the mid-southern areas and lies to the North of Ganzhou City, at the headwaters of Pinggu River. It is surrounded by mountains in the east, north and west. There is a valley basin centered in the County in the south-central, mostly low mountains and hills. In 2005, the GDP of Xingguo totaled 3.32 billion Yuan. The proportion of three industrial structures is 39.3:31.3: 29.4, and the rural per capita net income is 2,376 Yuan in 2005. The study area covers an area of 15.5 km^2, and the resident population was 121,000. The County belongs to the subtropical South East monsoon climate, with an annual average temperature of 18.9°C, an extreme maximum temperature of 39.9℃, and an extreme minimum temperature of under 6.3°C.The annual average frost-free period amounts to 248 days. The average annual rainfall is 1516 mm, which is concentrated in April and June, with rainfall from April to June, this accounts for 48.5% of annual precipitation.

Data

The data of land were collected from the current land use database of Xingguo County during 1996 to 2005. And the social and economic data mainly came from the statistical year book of Xingguo County from 1996 to 2005.

Ecological footprint model

The ecological footprint was first put forward by the Canadian ecological economist William Rees in 1992. Thereafter, it was improved and developed into the ecological footprint model by his student, Mathis Wackernagel in 1999, who was studying for his Doctorate degree. The ecological footprint model is a method which is used to measure the degree of sustainable development and a set of quantitative indicators based on land area. It consists of three parts: first is the ecological footprint, second is the ecological carrying capacity or biocapacity and third is ecological deficit or ecological surplus. The ecological footprint of an entity is defined as the sustainably biologically productive land and water area, required to provide resources consumed and assimilate waste produced (Wackernagel et al., 1999). Its computation formula is as follows:

$$EF = N \times \left(ef\right) = N\sum_{i=1}^{n}\left(r_i C_i / P_i\right) \quad (1)$$

where i is the type of consumer goods and investment, EF is the total ecological footprint, N is the population, ef is the per capita ecological footprint, r_i is the type i's equivalence factor, C_i is the consumption per head of type i's goods, P_i is the world's average productive capacity of type i's consumer goods. The calculation of ecological footprint can be divided into two parts: biological resource consumption and energy consumption. Because the data

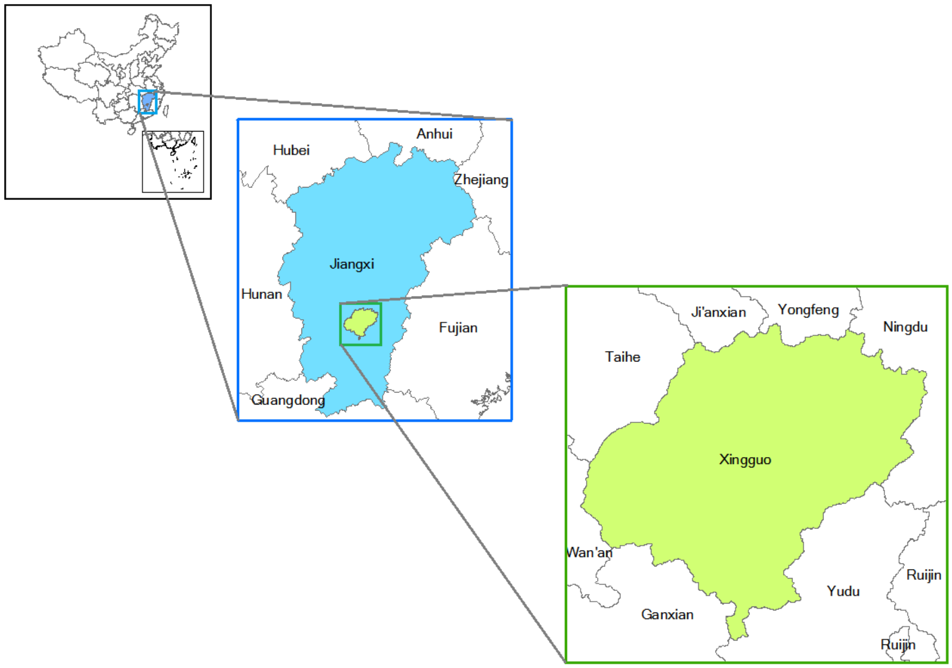

Figure 1. Study area.

needed for calculating the ecological footprint model in Xingguo County is not comprehensive, and it is on the basis of the actual local situation, this study should first state the following instructions:

1) The trade adjustment estimation was not formed due to lack of detailed information on import-export and the domestic and foreign trade. The quantity of energy trade was not taken into account when calculating the quantity of the energy consumed.
2) Replace production with total consumption because the data of consumption per head or total consumption for the past years have not been collected.
3) The type of garden plot was introduced through six types of biological productive land (fossil energy land, arable land, forest land, grassland, construction land and waters). Despite some researchers pointing out in their studies (Wackernagel et al., 1999)that, the soil quality of a garden plot is closer to arable land than forest land and that it belongs to the arable land, the garden plot was separated from the arable land in Xingguo County. In view of this paper we regard the balanced factor and production factor of the garden plot as the average value of the cultivated land and forest land, which is 1.98 and 1.285 respectively.
4) So the ecological footprint calculation formula after adjustment takes this form:

$$EF = \sum C^*_i \, r_i / P_i \qquad (2)$$

where C^*_i is the output of type *i*, other parameters are same as the formula (1).

The consumption of biological resources is mainly divided into four categories: agricultural products, animal products, aquatic products and forest products. Each of this categories has the following detailed classification, this study adopts the world's average output data about biological resources which was calculated in 1993 by the United Nations Food and Agriculture Organization (Wackernagel et al., 1999), converts the biological resources consumption to biological production area, providing the consumption needs and energy consumption part which considers several kinds of energy: raw coal, gasoline, kerosene, diesel oil, electric power, liquefied petroleum gas and other fuels. Using the average calorific per unit of fossil fuel in the production of land area in the world value as standard (Wackernagel et al., 1999), this translates the Xingguo County's calories of consumed energy in 2005 into a certain amount of fossil fuel land area. The ecological carrying capacity or biocapacity means the amount of biological productive land in the inner region, the computation formula is as follows:

$$EC = N \times (ec) = N \sum_{j=1}^{6} \left(r_j \times a_j \times y_j \right) \qquad (3)$$

where: *j* is the type of biological productive land (fossil energy land, arable land, forest land, grassland, construction land and water), *EC* is the total ecological carrying capacity, *N* is the population; *ec* is the ecological capacity of per capita; a_j for biological production area per capita, r_j is proportional factor; y_j is the yield factor. In this study, the proportional factors and yield factors which are used to calculate the ecological footprint and ecological carrying capacity or biocapacity are shown in Table 1. Ecological deficit (ED) or ecological surplus (ER) refers to the difference between the ecological carrying capacity or biocapacity and the ecological footprint. The computation formula is as follows:

$$EP = EC - EF \qquad (4)$$

where the *EP* represents the ecological deficit or surplus. If the *EP* is negative, *EF>EC*, then an ecological deficit is formed, which works against the regional sustainable development; if the *EP* is positive, *EF* < *EC*, then an ecological surplus is formed, which is conducive to the regional sustainable development. For a study object, the observation gap between the ecological footprint and

Table 1. Proportional factors and yield factors.

Land type	Proportional factor (Wackernagel et al., 1999)	Yield factor (Wackernagel et al., 1999)
Arable land	2.82	1.66
Forest land	1.14	0.91
Grassland	0.54	0.19
Water	0.22	1
Construction land	2.82	1.66
Fossil fuel land	1.14	0

ecological carrying capacity or biocapacity, to reflect the state of sustainable development, is the most direct application of the ecological footprint model.

Sustainability index (SI)

In the traditional models of ecological footprint, the ecological surplus or deficit indexes can reflect how regional development depends on the ecological environment, but to what degree is the environmental resources are utilized cannot be well shown. Ecological footprint evaluates the impact of human activities on the regional ecological environment from the perspective of specific biological parameters. Therefore, in this study the ecological footprint acts as a Sustainability Index (SI), the computation formula based on it, is as follows:

$$SI = \frac{EF}{EF + EC} \tag{5}$$

SI ranges from 0 to1, when SI = 0.5, the ecological footprint is equal to the ecological carrying capacity or biocapacity, which means the sustainable development of the region is right on the edge, when SI is between 0 and 0.5, we know the area is in a sustainable state, and when SI is nearly equal to zero, the ecological footprint is negligible and the ecological carrying capacity is high, there is a great opportunity for the region to develop sustainably. When SI is between 0.5 and 1, the area is in an unsustainable state. And when SI tends to be 1, the ecological footprint is much greater than the ecological carrying capacity or biocapacity, and the sustainable development of the regional situation is not good.

Sensitivity coefficient (SC)

According to the Principle of Elastic Analysis in Economics, we canconclude that the elastic value can be used to represent the sensitivity between dependent variable and independent variables as long as there is a functional relation existing between the dependent and independent variables. In this study, the quantified Sustainability Index will be used to analyze the degree of sensitivity factor of social and economic development, by defining the sensitivity coefficient of the Sustainability Index. The formula of the sensitivity coefficient of Sustainability Index is as follows:

$$\mathrm{SC}_{\mathrm{ij}} = \left| \frac{\left(SI_{i+1} - SI_i\right)/ SI_i}{\left(IF_{(i+1)j} - IF_{ij} / IF_{ij}\right)} \right| \tag{6}$$

where, SC_{ij} is the sensitive coefficient of the social and economic in *j*, which is effected by *i* year's Sustainability Index. SI_{i+1} and SI_i are the Sustainability Index of *i*+1 and *i* year. $IF_{(i+1)j}$ and IF_{ij} are *j* kinds of the social economic factor influencing the change of the Sustainability Index in *i*+1 and *i* years. If the sensitivity coefficient is greater than 1, it indicates that the large changes of the independent variable are caused by a small change of the dependent variable.

RESULTS AND DISCUSSION

Measurement of sustainability level

The consumption of biological resources in the study area is divided into four categories including agricultural, animal, fish and forest products. Using the world average yield data calculated by FAO in 1993, the consumption of biological resources of the study area in 2005 has been used to measure the biologically productive area provided by such consumer. The results of ecological footprint of the consumption of biological resources are shown in Table 2. Using the average calorific value of the world's fossil fuel production on the unit of land area as the standard, we have made the heat of energy consumption of fossil fuels in study area in 2005 converted into certain land areas of fossil fuels. The results of ecological footprint of the consumption of energy are shown in Table 3. According to the type of biological production area and the related data from Xingguo County in 2005, the ecological carrying capacity or biocapacity in the study area is calculated. And then we get the results of the ecological footprint and the Sustainability Index for Xingguo County in 2005. These results are listed in Table 4. As shown in Table 4, there is obvious asymmetry between the supply structure of ecological productive land and the demand structure of social and economic development in 2005.

From Table 4, we can conclude that per capita ecological deficit of arable land is the largest, amounting to 0.229 hm^2 per capita and the supply is less than half of demand. The supply of garden plot can just meet the needs of social and economic development. The supply of forest land is adequate and has a considerable part of the ecological surplus. And the state of construction land is between them. There is no supply, but demand for grassland and fossil energy land in the study area. Also, the footprint of cultivated land per capita is the largest,

Table 2. Ecological footprint of the consumption of biological resources of study area in 2005.

Land type	Item	Global average yield (kg/hm^2)	Biological production (t)	Ecological footprint (hm^2)	Per capita ecological footprint ((hm^2/per capita)
Arable land	Food categories	2744	258931	266102.5583	0.3647
	Oilseeds	1856	5614	8529.8922	0.0117
	Melons	18000	466	73.0067	0.0001
	Cane	18000	52000	8146.6667	0.0112
	Tobacco leaf	1548	1959	3568.7209	0.0049
	Vegetables	18000	234217	36693.9967	0.0503
Grass	Meat	265.5	74429	151381.0169	0.2074
	Eggs	400	5127	6921.45	0.0095
	Honey	50	54	583.2	0.0008
Garden plot	Teas	566	171	598.19788	0.0008
	Fruits	3500	20192	11422.9029	0.0157
Forest land	Timber	1.99(m^3/hm^2)	1.888(10^{4}m^3)	10815.6784	0.0148
	Bamboo	1.99(m^3/hm^2)	0.24(10^{4}m^3)	1374.8744	0.0019
	Tung tree seeds	1600	50	35.625	4.88E-05
	Tea seed oil	1600	33	23.5125	3.22E-05
	Chinese tallow tree seeds	1600	8200	5842.5	0.0080
	Turpentine	1600	750	534.375	0.0007
	Dried bamboo shoots	3000	100	38	5.21E-05
	Chestnut	3000	135	51.3	7.03E-05
Water	Aquatic products	29	15302	116084.1379	0.1591

Table 3. Ecological footprint of the consumption of energy of study area in 2005.

Energy type	Global average energy footprint (GJ/hm^2)	Conversion coefficient (GJ/t)	Total consumption (t)	Ecological Footprint (hm^2)	Per capita ecological footprint (hm^2/per capita)	Production area type
Raw coal	55	20.934	64537.74	28003.23	0.0384	Fossil fuels land
Gasoline	93	43.124	1736.667	918.03	0.0013	Fossil fuels land
Kerosene	93	43.124	36.25	19.16	2.62589E-05	Fossil fuels land
Diesel fuel	93	42.705	254.2933	133.12	0.00018	Fossil fuels land
Electricity (10 kWh)	1000	36.00#	10657.3	1081.93	0.00148	Building land
LPG	71	50.2	4	3.22	4.41812E-06	Fossil fuels land
Other fuels (tce)	55	36.19	4265.867	3199.91	0.00438	Fossil fuels land

#Power conversion coefficient units GJ/10^{4}kwh.

accounting for almost 49% of the total, followed by grassland, water, fossil energy land, forest land and construction land (Figure 2). This indicates that the agriculture, forestry and fishing is the main mode of economic development in the study area at present, which is a typical mountainous area economy. The low level of industrial development is evident, and social and economic development is relatively lacking, but there is still a great potential to develop. The ecological deficit in the study area is 0.325 hm^2 per capita, which means that the existence of the social and economic system has gone beyond the threshold value of ecological environment. The study areas is in a state of unsustainable development. Conclusively, in Xingguo County there are opportunities to develop its economy but challenged by the ecological deficit. The government should ensure that the ecosystem and the development of the economy are balanced at all times. As can be seen

Table 4. Ecological Footprint and Sustainability Index of Xingguo County in 2005 (hm^2/per capita).

Land use type	Per capita ecological footprint	Per capita ecological carrying capacity	Per capita Ecological footprint surpluses or deficits	Sustainability Index
Arable land	0.443	0.214	-0.229	0.674
Garden plot	0.017	0.018	0.001	0.486
Forest land	0.026	0.350	0.324	0.069
Grassland	0.218	0	-0.218	1.000
Water	0.159	0.002	-0.157	0.988
Construction land	0.002	0.026	0.024	0.071
Fossil fuel land	0.044	0	-0.044	1.000
Total	0.907	0.582*	-0.325	0.609

* 12% of biodiversity conservation area is deducted.

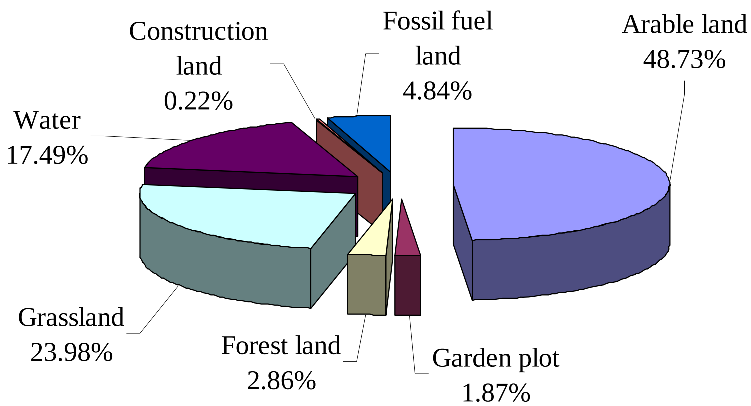

Figure 2. The proportion of ecological footprint per capita for different land use types in 2005.

from Table 4, in terms of measuring the degree of regional sustainable development, the Sustainability Index (SI) based on the ecological footprint is better than the indicator of ecological surplus or deficit. The ecological deficit per capita of grassland is less than that of cultivated land, but its Sustainability Index is larger than that of arable land. From the investigated data of land use in Xingguo County, we can conclude that there are no data for grassland due to the area being scattered and small. From this perspective, the ecological carrying capacity of grassland in Xingguo County is less than which necessary meet the needs of its social and economic development, being in a completely unsustainable state. The situation also occurred in water land and fossil energy land. This shows that the ecological footprint model of ecological surplus or deficit only reflects the status of regional development demand for ecological environment, but can not reflect the degree of regional sustainable development very well. For the parts with ecological surplus or the area whose Sustainability Index is less than 0.5, there is a principle which goes like this: the larger the ecological surplus, the smaller the Sustainability Index, but the rates at which each changes are different.

Analysis of time series

According to the same methods and steps, the per capita ecological footprint and ecological carrying capacity in Xingguo County from 1996 to 2005 were calculated. The detailed results are listed in Table 5; Figure 3 shows the changing trends of per capita ecological footprint of different land use types from 1996 to 2005 in the study area. From Figure 3, we can conclude that arable land, grassland and water occupied a major share, and combined measure 90.41%. The state of arable land kept constant before 1999.The value was decreasing during the years 1999 to 2003. Then it was steadily increasing. Overall, it showed a declining trend, though contributing the most. The footprint per capita of grassland and water were increasing year by year. The value of Sustainability Index (SI) increased from 0.527 in 2005 to 0.609 in 1996. In addition to the slow increase in the ecological carrying capacity or biocapacity per capita of garden land, ecological

Table 5. Supply and demand of Per Capita Ecological Footprint in Xingguo County (hm^2 per capita).

Year	Demand of ecological footprint								Supply of ecological footprint						The per capita ecological footprint surpluses or deficits	Sustainability Index
	Arable land	Garden plot	Forest land	Grassland	Water	Fossil fuel land	Construction land	Total	Arable land	Garden plot	Forest land	Grassland	Water	Fossil fuel land		
1996	0.449	0.007	0.025	0.158	0.060	0.039	0.000	0.737	0.254	0.006	0.407	0.002	0.081	0.661	-0.076	0.527
1997	0.439	0.010	0.031	0.159	0.071	0.042	0.000	0.753	0.250	0.006	0.403	0.002	0.081	0.654	-0.099	0.535
1998	0.442	0.009	0.034	0.127	0.088	0.057	0.002	0.759	0.248	0.006	0.398	0.002	0.081	0.648	-0.111	0.539
1999	0.446	0.011	0.012	0.163	0.096	0.053	0.000	0.780	0.245	0.006	0.394	0.002	0.081	0.641	-0.139	0.549
2000	0.419	0.008	0.026	0.192	0.130	0.078	0.000	0.854	0.242	0.006	0.390	0.002	0.081	0.635	-0.219	0.574
2001	0.391	0.012	0.015	0.180	0.150	0.035	0.000	0.784	0.226	0.006	0.364	0.002	0.077	0.594	-0.190	0.569
2002	0.359	0.016	0.014	0.181	0.134	0.034	0.001	0.739	0.223	0.009	0.359	0.002	0.076	0.589	-0.150	0.556
2003	0.335	0.015	0.030	0.187	0.137	0.036	0.001	0.741	0.214	0.012	0.350	0.002	0.076	0.575	-0.166	0.563
2004	0.417	0.015	0.026	0.196	0.145	0.039	0.001	0.841	0.211	0.015	0.346	0.002	0.076	0.572	-0.269	0.595
2005	0.443	0.017	0.026	0.218	0.159	0.044	0.002	0.907	0.214	0.018	0.350	0.002	0.078	0.582	-0.325	0.609

* 12% of biodiversity conservation area is deducted.

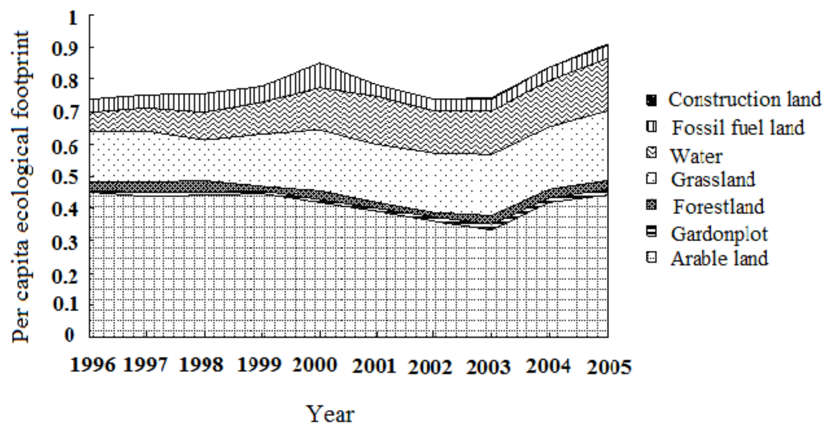

Figure 3. Changing trends of per capita ecological footprint of different land use types from 1996 to 2005.

carrying capacities or biocapacity for other land use types were either slowly decreasing or keeping unchanged.

The changing trend of the ecological footprint, ecological carrying capacity or biocapacity per capita and the Sustainability Index were shown in Figure 4. Between 1996 and 2005, the ecological footprint per capita in Xingguo County showed a fluctuating upward trend and the per capita ecological carrying capacity or biocapacity is reduced (Figure 4). The changing trend of the Sustainability Index and the per capita ecological footprint is the same, and the change is small. The value of the Sustainability Index was between 0.5 ~ 0.6 (insecurity interval of the Sustainability Index) and increases slowly, over 0.6 for the first time in 2005. This illustrates that the social and economic activities are beyond the ecological

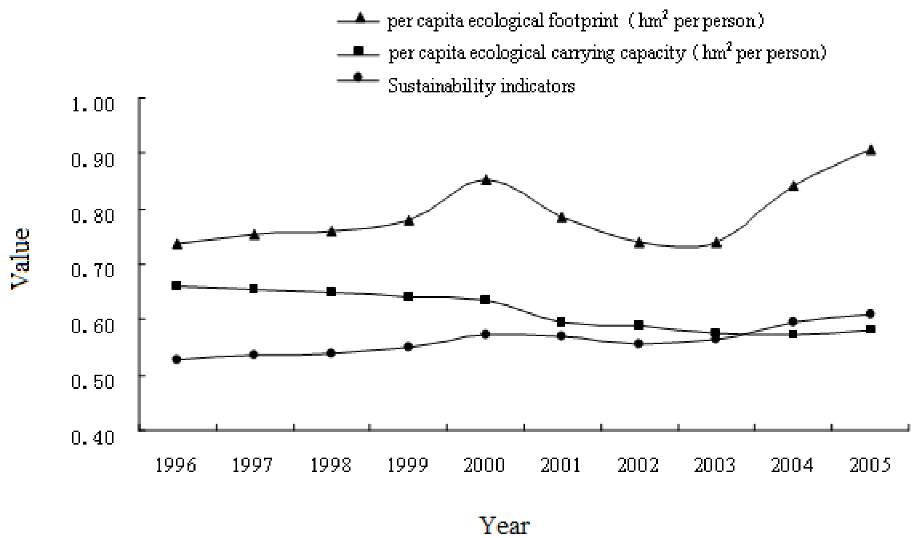

Figure 4. Changing trend of ecological footprint, ecological carrying capacity per capita and Sustainability Index from 1996 to 2005.

Table 6. Correlation coefficient between SI and social economic indicators.

	Population ($\times 10^3$)	GDP($\times 10^{10}$)	Urbanization level (%)	Primary industry proportion (%)
Correlation coefficient	0.796**	0.766**	0.847**	-0.847**
Significance level	0.006	0.010	0.002	0.002

** Pearson correlation coefficient (P<0.01).

carrying capacity and the ecological capacity or biocapacity cannot sustain current human activities. Humans in the study area had to rely mostly on other resources. Regional development is in a state of being relatively unsustainable, which is going to become more serious.

Correlation analysis

Although the ecological footprint model has the characteristics of ecological bias, actually a time series evolution of the ecological footprint has a particularly close connection to the social and economic development. Based on the calculation principles of the Sustainability Index and considering that Xingguo County is a typical hilly mountain area, four indicators of the social-economic system were used to analyze the correlation using the software SPSS17.0. The results of correlation analysis between the Sustainability Index and social-economic indicators are listed in Table 6. And the Changing trend of correlation between SI and the total population, GDP, urbanization level and proportion of primary industry can be seen from Figure 5.

From Table 6 and Figure 5, we can conclude that the Sustainability Index was significantly positively related with total population, GDP and urbanization level. That means that population growth, economic development and urbanization level had a negative effect on regional sustainable development in the study area. With the development of society and the economy, the quality of the ecological environment declined. There is a strong negative correlation between the Sustainability Index and the proportion of primary industry. As a large agricultural County, the ecological footprint of biological resources consumption in Xingguo County accounted for 95.15% in 2005.The larger the proportion of primary industry, the more the corresponding biological resources consumption. With the current production model unchanged, it is harmful for regional sustainable development.

Sensitivity analysis

Using the formula (6), we calculated the sensitivity coefficients of the Sustainability Index related to total population, GDP, level of urbanization and primary industry proportion (Table 7). From Table 7, we can see that in most years the sensitivity coefficients of the Sustainability Index related to the four social and economic

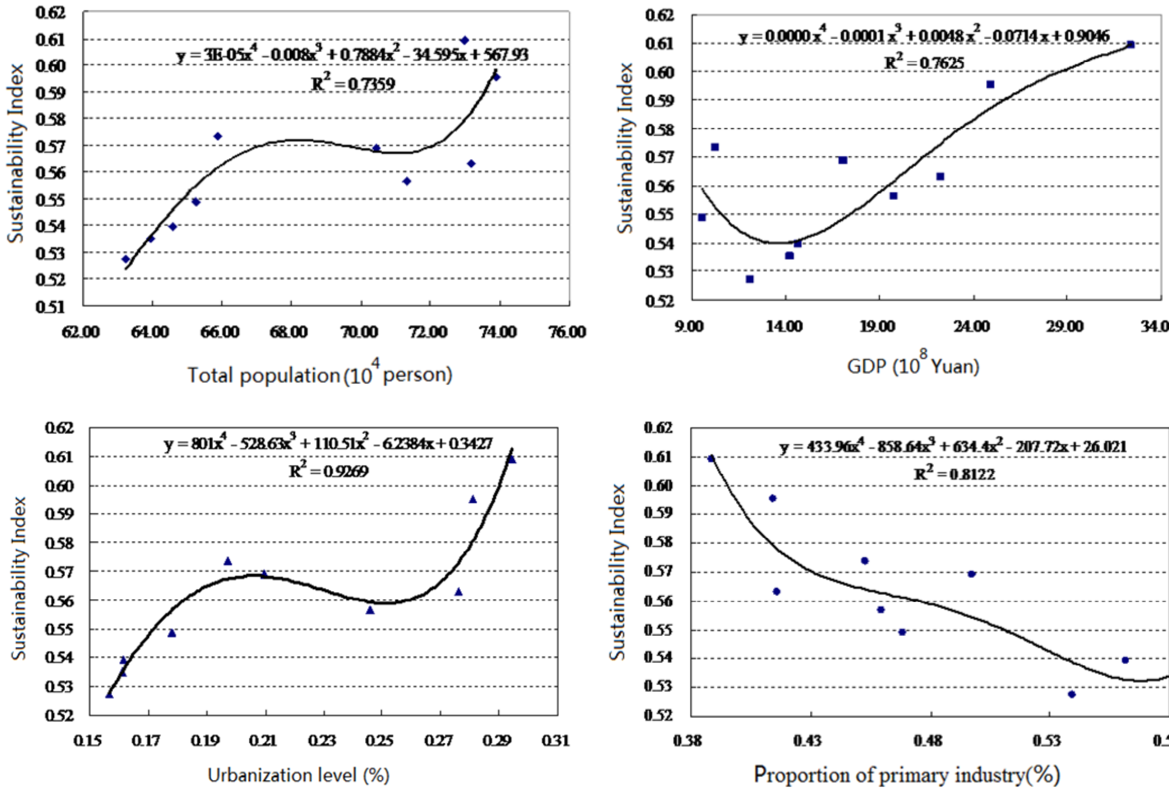

Figure 5. Changing trend of correlation between the SI and the total population, GDP, level of urbanization and proportion of primary industry.

Table 7. Sensitivity coefficient of the Sustainability Index related to the total population, GDP, level of urbanization and primary industry proportion.

Year	$SC_{Total\ population}$	SC_{GDP}	$SC_{Urbanization\ level}$	$SC_{Primary\ industry\ proportion}$
1996	1.3911	0.0871	0.5807	0.1759
1997	0.8145	0.2452	1.8327	0.1935
1998	1.6654	0.0502	0.1730	0.1061
1999	4.5635	0.5795	0.4184	1.3363
2000	0.1158	0.0122	0.1275	0.0818
2001	1.7538	0.1380	0.1262	0.2873
2002	0.4588	0.0945	0.0962	0.1261
2003	5.7804	0.4706	3.3532	14.3077
2004	1.8940	0.0791	0.4914	0.3768
2005	1.0108	0.0929	0.1774	0.5575

indicators are less than 1. This indicates that in the social - economic - natural complex system, the ecological environment is the order parameter. When the complex system is unbalanced, ecological environment plays a key role on the system. Therefore, in the process of developing the social economy, we should pay more attention to the protection of ecological environmental at the large scale. From Table 7, we concluded that the Sustainability Index (SI) is most sensitive to population growth, followed by the decline in the proportion of primary industry. This is mainly because with the increasing population growth, the consumption of food and energy increase, which is the major factor effecting an increasing ecological footprint. As a typical hilly mountain area, the largest ecological footprint in the study area is the consumption footprint of biological energy. With the rate of primary industry in China reduced, the consumption of biological resources will decrease the ecological footprint to a large extent, thereby reducing the Sustainability Index. On one hand, urban expansion makes the transition from arable land, forest land, grassland and other types of land to construction land, conversely, it increases the demand on regional material energy level and waste disposal space, which will make the Sustainability Index rise. Therefore, the Sustainability Index also has a relatively high sensitivity to the level of urbanization.

Conclusion

Based on the ecological footprint model, this article used a Sustainability Index to measure the level of sustainable development in Xingguo County in China. Through the correlation and sensitivity analysis, we reveal the driving factors of human activities on the regional sustainability in the study area. The consumption of biological resources in the study area, accounted for the vast majority in the footprint, and its proportion showed a somewhat slowly upward trend of fluctuations from 1996 to 2005. It illustrates that economic development in the Xingguo County is still mainly dependent on agriculture and forestry production the typical mountain economic model has not changed from 1996 to 2005. The increasing ratio of the ecological carrying capacity is greater than the per capita ecological carrying capacity, which indicates the rate of population growth is much faster than that of the ecological recovery and improvement, and it is beyond the bearing capacity of ecological environment. The values of the Sustainable Index range from 0.5 to 0.6 (which means unsafe), and show a slowly increasing trend. This means that the development of Xingguo County is in a state of relative unsustainability, and the unsustainability has a further expanding trend. The value of the Sustainability Index shows a significantly positive correlation with GDP and the level of urbanization. And it has a significantly negative correlation with the proportion of primary industry. The change of the Sustainability Index is most sensitive to the population growth, followed by decreases in primary industries.

To improve the ability of sustainable development in study area, we put forward the following corresponding suggestions: first is to keep control of the population growth rate, second is to carry out strict farm land protection system and improve the quality of forest land, third is to accelerate the transformation of agricultural economic development mode, to improve the utilization rate of resources, to develop ecological agriculture, and to realize the development cycle of social and economic systems and the last is to develop ecological tourism and to raise the proportion of tertiary industry. In terms of measuring the degree of regional sustainable development, the Sustainability Index in this article is better than the index of ecological surplus or deficit. When evaluating the area at the small scale (such as county), we should establish the model of county hectare. But we can s ,,ensure the balanced factor and yield factor according to local condition, to reflect the supply of natural capital more fairly at the small scale, and then optimize the ecological footprint model in the application of the measurement of sustainable development at the small scale.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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