Dynamic evolutions of ecological carrying capacity in poor areas using ecological footprint model at Ruyang County of China

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Abstract: In this study, the ecological footprint (EF) from 2004 to 2013 of a poor county chosen from Central China was measured and analyzed by using the methodology and theory of EF. The results showed that in the past 10 years, the county's ecological footprint per capita was growing gradually, increasing from 0.7053 hm^2 in 2004 to 1.4473 hm^2 in 2013, with growth clearly accelerated in recent years. During the same period, the ecological carrying capacity per capita reduced from 0.6351 hm^2 to 0.5018 hm^2. Additionally, regional development had been in a state of ecological deficit, per capita ecological deficit increased from 0.0702 hm^2 to 0.9456 hm^2. This led to contradictions between regional socio-economic development and sustainability of natural ecosystems, meaning the development of the region is unsustainable. Measures to reduce the ecological deficit were proposed to coordinate regional industrialization, urbanization, ecological environmental protection, and to promote the sustainable development in the region (e.g. adjusting industrial structure and consumption structure, promoting economic transformation, scientific planning and management of land). The results could provide a scientific basis for studies on ecological carrying capacity of the poor areas in Central China.

Keywords: ecological footprint, ecological carrying capacity, ecological deficit, sustainable development, poor areas in China
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1 Introduction

With the rapid development of the urbanization and industrialization process in China, ecological and economic development is increasingly prominent. The five development concepts, "innovation, coordination, green, open, sharing" were put forward in the fifth plenary session of the 18th Congress of the Chinese Communist Party. Thereinto, coordination means to promote the coordinated development between urban and rural areas, between material progress and cultural and ideological progress. Coordinating the relationship between social/economic development and resource protection plays an essential role in the sustainable development of the region. Therefore, it is of great practical significance to evaluate and analyze the dynamic eco-environmental situation and to monitor sustainable development of the region.

Since the ecological footprint (EF) theoretical model

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and calculation method was proposed by William Rees in 1992[1], it has attracted extensive attention, recognition and application from academia. This theory and methodology can be used to calculate the degree of natural resource use and the life-support services provided by nature for humans. It can evaluate and analyze carrying capacity and evolution states of the regional ecological environment, as well as sustainable regional development. Antonio and Manuel[2] evaluated ecological footprint in 771 regions of Spain Andalusia. Debrupa and Joyashree[3] found that the industry based on the data set is beneficial to the sustainable development of social production strategy by evaluating ecological footprint. Hao et al.[4] assess the ecological footprint in the farm and animal husbandry of Inner Mongolia in northern region of China.

County regions, an important part of the national economy and social structure, are the basic administrative unit, and play an important role in the support and foundation of China’s social/economic development[5]. At present, there are 592 counties meeting the standards for poverty established by the Chinese government. Poverty populations in China have concentrated continuous distribution. There are 11 concentrated continuous poor areas in China, as divided by the government. The total area of concentrated continuous poor areas is 3.92 million km^2, accounting for 40.8% of the country's land area[6]. In recent years, the Chinese government has made poverty alleviation in contiguous poverty-stricken areas a priority. The new policies have been combining socio-economic development in poor areas, an increase in support and financial investment, and implementing infrastructure and livelihood projects. The Government’s welfare work has made great progress, rapidly developing the poor areas and reducing the poverty population. Meanwhile, the struggle between socio-economic development and carrying capacity of eco-environment in poor areas increased, with regional ecological pressure increasing.

Ruyang County was determined as one of state-level poverty-stricken countries by the Chinese government. It is located in the central region of China, and is the traditional agricultural mountainou area. This county has big mountain areas, poor natural conditions, inconvenient traffic, and lagging social and economic development for a long time. So it was determined a concentrated especially poor areas in Qinba mountain areas by the Chinese government. This study has a certain reference value for eco-environmental construction and poverty alleviation in poor Qinba mountain areas in central China. According to statistics of social and economic development released by the Chinese government, in seven state-level poverty-stricken counties in Luoyang areas of Henan province, natural geographical conditions and regional development in Ruyang County are belong to the intermediate level, and this county has certain representativeness of the poor areas in Qinba mountain areas. At the same time, the data about the economic development and poverty alleviation in Ruyang County are complete, so we selected Ruyang County as the sample in the research on the development in the poor areas of Central China.

Before 2000, because of traffic block, investment promotion and capital introduction of Ruyang were serious influenced by poor traffic, and the economic development was slow. After 2000, with improving of regional traffic condition and increasing of the national poverty alleviation and development strength, society and economy of Ruyang entered a rapid development stage, Ruyang County entered a rapid transformation of economic development, and the economic strength of the county enhanced obviously. The development path and characteristics of Ruyang County has certain typical significance the seven mountainous counties of Luoyang, Henan province, even in Qinba mountain areas, designated poor areas by the Chinese government. During the study, the latest comprehensive regional social and economic development data of 2013 years in Ruyang County was obtained, but the related data about 2000 years ago were incompleted. The study on ecology is often selected the time of five or ten years for the basic research time, and from 2004 to 2013, ecological environment change in Ruyang County was the biggest, so this study selected the data of the 10 years for research and analysis.

Ruyang County, as a key county of state-level county and the national poverty alleviation, is a traditional agricultural county, the county economy is dependent on the consumption of resources, energy resources, and the leading industries are processing of mineral resources, building materials and chemical industry. During the period of the tenth five-year plan, the average annual growth rate of GDP in Ruyang County was 21%. GDP in 2004 was 2.32857 billion Yuan (RMB), and increased to 11.55195 billion Yuan (RMB) in 2013, the average annual growth rate of GDP was 17.37%. County economic output per capita was 5518 Yuan (RMB) in 2004, was increased to 24320 Yuan (RMB) in 2013, and 10 years of average annual growth of economic output per capita was 16%. The local fiscal revenue of Ruyang County had a high-speed increase, the local financial general budget revenue was only 83.66 million Yuan (RMB) in 2004, and reached 567 million Yuan (RMB) in 2013, which increased 6.8 times in 10 years.

As a traditional agricultural county, agriculture has an important role in the economic structure in Ruyang County for a long time. Since the reform and opening, Ruyang County has accelerated the process of industrialization, and achieved significant results. The total output value of first industry was 0.6569 billion Yuan (RMB) in 2004, and increased to 1.565 billion Yuan (RMB) in 2013. The total output value of second industry was 0.96 Yuan (RMB) in 2004 and increased to 6.953 billion Yuan (RMB) in 2013. Total output value of the tertiary industry was 712 million Yuan (RMB) in 2004, and increased to 3.033 billion Yuan (RMB) in 2013. Transformation and upgrading in regional economic structure is obvious, and the development situation of industry leading county economy had formed.

The main problems of Ruyang County economy was industry transformation and upgrading. In Ruyang County, industrial supporting ability was not strong, agriculture foundation was weak, the third industry development was lags, and the rural poverty was difficult. The overall level of industry was low, and high added value of leading enterprises was lack. The problems of industry development was facing the multiple pressures of efficiency gains, transformation and upgrading. The task, which speeded up the transformation of the mode of economic development, was very difficult. Starting from the supply and demand relationship of ecological carrying capacity and applying the ecological footprint model, Ruyang County, a representative impoverished county located in the Henan province, Central China, is chosen to conduct the research. The research will evaluate and analyze the dynamic evolution of the ecological environment and sustainable development of social economy in this region in the past 10 years by ecological footprint theory and methodology. This will result in a fuller understanding of the balance between social-economic development and ecological environmental protection in the central county.

2 Overview of the study area

Ruyang County, located at longitude 112°8'-112°38'E, latitude 33°49'-34°21'N, in the west of Henan Province in Central China (Figure 1), is 74 km away from Luoyang, which is the ancient capital of nine dynasties in Chinese history. Ruyang County is one of 25 key forestry counties in Henan province, also is a government established poverty-stricken county and a key county for national poverty alleviation and development. This county is also representative of concentrated continuous areas.

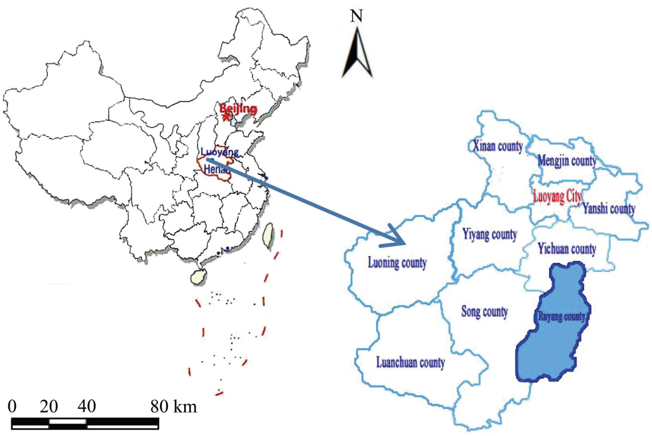

Figure 1 Site map of the research area

The total area of the county is 132807.8 hm^2. The 2013 census-registered population is 475 000, the resident population is 414 000, and the rural area population and non-rural area population are 399 000 and 76 000, respectively. In 2014, there was 14 800 recorded households in this region, 51 900 people whose annual per capita net income are less than 2736 Yuan (RMB), and a poverty incidence rate of 13%. The region has a warm temperate continental monsoon climate, with sufficient sunlight, mild climate, and four distinct seasons. The annual average temperature is 14 degrees centigrade and the average annual rainfall is 690 mm. Ruyang is made up of mountainous areas, hills, and plains. The area is also rich in mineral resources; more than 10 kinds of minerals have been discovered in the county. The superposition of three characteristics, resource-rich, economic poverty and areas of ecological protection, make the relationship between economic development and ecological environment in these areas more complex.

China's reform and opening up policy has spurred governments at all levels to push hard for poverty alleviation and development. Since the reforms, the county's economy has maintained steady and rapid development. The county's GDP increased from 2328.57 million Yuan (RMB) in 2004 to 11 551.95 million Yuan (RMB) in 2013, with an average annual growth rate of 17.37%. Meanwhile, key ecological restoration projects (e.g. returning farmland to forest, soil management, and water conservation), were implemented by China in Ruyang. The county has resolved a large part of the food and shelter problems that plagued it in the past and has moved into to the next phase of development. The next steps include accelerating poverty eradication, improving the ecological environment, enhancing the capacity of development, and narrowing the development gap with developed countries.

Potential land resources of Ruyang are limited. During the study period, the potential land resources, which belongs to less investment, quick effects, and high benefit, has gradually get the development and utilization, and the difficulty of land development and consolidation is getting intensified year by year. Land use exist extensive and inefficient phenomenon in this area. Resource of new construction land is limited, the contradiction between supply and demand of land becomes apparent.

Table 1 Land use of change during 2004-2013 in Ruyang County

Land types	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Arableland	33 641.33	33 619.96	33 568.26	33 558.65	33 532.15	33 520.05	33 509.32	33 492.5	33 483.90	33 470.40
Woodland	63 816.90	63 858.10	63 870.70	63 886.90	63 902.40	63 922.10	63 937.70	64 287.93	64 367.30	64 517.60
Grassland	14 928.70	14 931.20	14 939.90	14 947.50	14 954.00	14 946.90	14 962.50	15 023.10	15 145.60	15 096.70
Water areas	4 557.69	4 550.37	4 537.27	4 533.67	4 549.27	4 569.57	4 714.70	4 412.03	4 323.17	4 222.93
Buildings land	10 836.10	10 828.50	10 878.20	10 873.60	10 868.10	10 857.50	10 706.90	10 686.23	10 605.40	10 565.10
Unused land	5 027.10	5 019.70	5 013.50	5 007.50	5 001.90	4 991.70	4 976.70	4 906.03	4 882.47	4 935.10

3 Methods

3.1 Related theory and calculation of EF

3.1.1 Theory of EF

The concept of EF was first presented by Canada ecological Economist William Rees in 1992[1], and later he improved his theory and method with the help of Wackernagel[7]. Based on the measurement of biophysical quantity, EF can be used to evaluate the utilization of natural resources by humans and the life-supporting services provided by nature for humans[7]. This methodology judges quantitatively whether regional developments are within the scope of its ecological carrying capacity. EF also analyzes and studies the region's ecological environment and sustainability of development by converting regional resources and energy that people consumed into the biologically productive land area necessary to supply these materials. This area is then compared with the biologically productive land area supplied by the region.

The research method of EF is to calculate the amount of resource and energy demand necessary to develop the regional social economy, and calculate the ecological carrying capacity supplied by the region. Then the sustainability of regional development can be analyzed by comparing the two quantities.

3.1.2 The calculation of the EF

The EF is the amount of biologically productive area necessary to supply the resources a human population consumes, and to incorporate associated waste[8]. Biologically productive area is the land/water that has the ability to generate the materials necessary for the survival and development of living things, and it is classified into six types[7]. These types are Fossil energy land, Arable land, Grassland, Woodland, Buildings, and Water areas. The ecological and biological productivity of the six types of land varies considerably. In order to translate the calculated results into comparable values, each type of land is multiplied by an equivalence factor. Then the regional EF can be calculated by with the weighted sum of the equivalent bio-productive land areas. The globally consistent equivalent factors are used in this paper (i.e. Arable land and Buildings areas is 2.8, Woodland and Fossil energy land is 1.1, Grassland is 0.05, and Water areas is 0.02[7]). The calculation formula is as follows:

$$EF = N \cdot ef = N\sum_{i=1}^{n} A_i = N\sum_{i}^{n}(r_i c_i / p_i) \qquad (1)$$

where, *EF* is total ecological footprints; *N* is population, *ef* is per capita ecological footprints; A_i is the per capita ecological footprint component converted by the *i*th type of consumption; *i* is the input type of consumption of goods and resources; *N* is the number of consumption items; r_i is the equivalence factor corresponds to the *i*th type of land; *c* is per capita consumption of goods; *p* is average productivity of goods consumed by people; p_i is the average world production corresponds to the *i*th type of goods or services, kg/hm^2; c_i is per capita consumption corresponds to the *i*th type of goods, kg.

3.2 Calculation of ecological carrying capacity

Ecological carrying capacity, also called ecological supply footprint, is the total bio-productive land area necessary to supply resources and energy, and to assimilate associated waste. The difference of resources endowment and land productivity between different countries and areas leads to the big difference of production per unit in the six area types. To compare and summarize the real area of the same type of bio-productive land from different countries and regions, standardization with a yield factor for different types of bio-productive land is used. Yield factor is a parameter that can convert the same type of bio-productive land from different countries and regions into a comparable area[9]. We can define yield factor as the ratio of average productivity of a certain country or region to the world average productivity of the same type land.

When calculating the ecological carrying capacity, all types of bio-productive land area studied in the region shall be multiplied by the corresponding equivalence factor and yield factor and sum them. The expression is as follows:

$$EC = N \cdot ec = N\sum_{j=1}^{n}(a_j r_j y_j) = N\sum_{j=1}^{n}(E_j / P_j) r_j y_j \qquad (2)$$

where, *EC* is the total regional carrying capacity; *N* is the population; *ec* is the per capita ecological carrying capacity; *j* is the bio-productive land type; a_j is the total real areas of the bio-productive land corresponding to the ith type; r_j is the equivalence factor; y_j is the yield factor; E_j is the total production of the bio-productive land corresponding to the ith type, kg; P_j is the production of per unit of world bio-productive land corresponding to the ith type, kg/hm^2.

Yield factor is the common yield factor value in China at present calculated by Wackernagel, namely: Arable land and Buildings is 1.66, Woodland is 0.91, Grassland is 0.19, Water is 1.0, and Fossil energy land is 0.61[7].

The World Commission on Environment and Development (WCED) released a report called ‘Our Common Future’. According to the proposals in the report, 12% bio-productive land area should be deduced in the calculation of regional ecological carrying capacity for the protection of biodiversity in the region[10].

3.3 Ecological deficits and remainder

Ecological footprint and ecological capacity are quantified through biological indicators of the bio-productive land area, so that it has a certain degree of comparability. After comparing calculation results of the regional ecological footprint and ecological carrying capacity, we refer to difference in area as ecological remainder (ER) if the EF is less than the EC. Similarly, we refer to difference in area as ecological deficits (ED) and its development is unsustainable if the EF exceeds the EC. We refer to a region as ecologically balanced

(EB) if its development is in a critical state; the EF is equal to the EC. The regional ED and ER represents the utilization of natural resource by human population in this region, which can be used to comprehensively judge whether the production and consumption activities are within the EC, and to measure the sustainability of regional development. It can be expressed by the following equation:

$$ED(ER) = EC - EF = N \cdot (ec - ef) \quad (3)$$

where, N, ec, and ef are population, net per capita EC, per capita EF, respectively.

4 Results of regional EF

4.1 Regional EF

According to the principle and method of calculating EF, the regional EF of the study area is calculated from 2004 to 2013. Calculation of EF in this paper includes biological resource consumption and energy consumption. Consumption of biological resources is classified into varieties of agricultural products, forest products, livestock products, and seafood consumption. Using the world average yield of the biological resources calculated by the United Nations Food and Agriculture Organization, consumption of biological resources of the study area can be converted into biologically productive land area (Arable land, Grassland, Woodland) and biologically productive water areas. The calculation of Energy consumption includes select raw coal, gasoline, diesel, kerosene, and electric energy consumption items[11]. This consumption of energy in the area is converted to the area of fossil fuel energy consumption, using the average calorific value of the world's fossil fuel-producing land area per unit as a standard[12].

Based on EF theory and calculation method above and according to Henan Statistical Yearbook and Luoyang Statistical Yearbook of 2004-2013[13], and literature data, the EF of study area for the past ten years are calculated (Tables 2-4).

Table 2 EF per capita of the biotic resource during 2004-2013 in Ruyang County

Year	Grain	Cotton	Oil	Vegetable	Tobacco	Fruit	Pork	Beef&lamb	Poultry	Milk	Egg	Fish	Total
2004	0.4116	0.0006	0.0102	0.0101	0.0103	0.0017	0.0358	0.0156	0.0167	0.0103	0.0035	0.0012	0.5278
2005	0.4132	0.0007	0.0108	0.0102	0.0115	0.0026	0.0536	0.0187	0.0218	0.0107	0.0052	0.0016	0.5606
2006	0.4153	0.0008	0.0114	0.0102	0.0126	0.0038	0.0765	0.0256	0.0265	0.0114	0.0050	0.0020	0.6010
2007	0.4106	0.0008	0.0126	0.0103	0.0135	0.0040	0.1068	0.0272	0.0327	0.0106	0.0060	0.0022	0.6373
2008	0.4115	0.0009	0.0137	0.0106	0.0156	0.0041	0.1166	0.0317	0.0457	0.0113	0.0071	0.0025	0.6714
2009	0.4107	0.0008	0.0277	0.0117	0.0217	0.0042	0.1239	0.0440	0.0490	0.0122	0.0124	0.0029	0.7211
2010	0.4256	0.0010	0.0315	0.0126	0.0213	0.0050	0.1279	0.0455	0.0501	0.0124	0.0131	0.0031	0.7491
2011	0.4362	0.0009	0.0316	0.0114	0.0216	0.0052	0.1364	0.0477	0.0511	0.0138	0.0153	0.0021	0.7732
2012	0.4661	0.0009	0.0335	0.0141	0.0225	0.0065	0.1400	0.0530	0.0572	0.0174	0.0177	0.0032	0.8320
2013	0.4165	0.0009	0.0363	0.0131	0.0257	0.0072	0.1779	0.0528	0.0657	0.0322	0.0188	0.0054	0.8522
Average	0.4217	0.0008	0.0219	0.0114	0.0176	0.0044	0.1095	0.0362	0.0417	0.0142	0.0104	0.0026	0.6926
Ratio	60.89%	0.12%	3.16%	1.65%	2.55%	0.64%	15.82%	5.22%	6.01%	2.05%	1.50%	0.38%	100.00%

Table 3 EF per capita of energy consumption during 2004-2013 in Ruyang County

Year	Coal	Gasoline	Diesel oil	Coal oil	Power	Total
2004	0.1630	0.0033	0.0107	0.0001	0.0004	0.1775
2005	0.1730	0.0051	0.0128	0.0001	0.0006	0.1917
2006	0.2065	0.0062	0.0137	0.0001	0.0007	0.2273
2007	0.2573	0.0076	0.0151	0.0001	0.0009	0.2810
2008	0.2769	0.0092	0.0161	0.0002	0.0009	0.3033
2009	0.2653	0.0110	0.0192	0.0002	0.0011	0.2968
2010	0.3167	0.0121	0.0214	0.0002	0.0013	0.3517
2011	0.3374	0.0132	0.0254	0.0002	0.0016	0.3778
2012	0.3817	0.0190	0.0284	0.0003	0.0017	0.4311
2013	0.5157	0.0472	0.0311	0.0004	0.0018	0.5961
Average	0.2894	0.0134	0.0194	0.0002	0.0011	0.3234
Ratio	89.47%	4.14%	5.99%	0.06%	0.34%	100.00%

Table 4 EF per capita during 2004-2013 in Ruyang County

Year	Arable land	Woodland	Grassland	Water areas	Fossil energy land	Buildings land	Total
2004	0.4429	0.0017	0.082	0.0012	0.1771	0.0004	0.7053
2005	0.4464	0.0026	0.1100	0.0016	0.1910	0.0006	0.7522
2006	0.4503	0.0038	0.1450	0.0020	0.2266	0.0007	0.8284
2007	0.4479	0.0040	0.1833	0.0022	0.2801	0.0009	0.9183
2008	0.4523	0.0041	0.2126	0.0025	0.3024	0.0009	0.9748
2009	0.4726	0.0042	0.2414	0.0029	0.2957	0.0011	1.0179
2010	0.4920	0.0050	0.2490	0.0031	0.3504	0.0013	1.1008
2011	0.5016	0.0052	0.2643	0.0021	0.3762	0.0016	1.1510
2012	0.5371	0.0065	0.2852	0.0032	0.4294	0.0017	1.2631
2013	0.4924	0.0072	0.3472	0.0054	0.5933	0.0018	1.4473
Average	0.4735	0.0044	0.2120	0.0026	0.3222	0.0011	1.0159
Ratio	46.61%	0.45%	20.87%	0.25%	31.72%	0.11%	100%

4.2 Regional ecological capacity

According to survey data in Ruyang County of 2004-2013, and using the calculation model of ecological capacity (EC) described above, the EC per capita in Ruyang County can be calculated by multiplying bio-productive land area per capita by equivalence factor and yield factor, then subtracting 12% area of biodiversity protection (Table 5).

Table 5 Ecological capacity per capita during 2004-2013 in Ruyang County

Land types	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Arableland	0.396152	0.375261	0.332573	0.327512	0.301562	0.299312	0.297615	0.290716	0.289544	0.28715
Woodland	0.111353	0.111752	0.112137	0.112531	0.11367	0.113561	0.118731	0.119675	0.119871	0.12352
Grassland	0.002012	0.002013	0.002067	0.002094	0.002175	0.002115	0.002316	0.002569	0.002677	0.002637
Water areas	0.003215	0.003165	0.002535	0.002516	0.003132	0.00352	0.006782	0.001637	0.001609	0.001573
Buildings land	0.120758	0.118357	0.150679	0.149963	0.149371	0.130296	0.099906	0.097629	0.091708	0.085171
Unused land	0.001636	0.001587	0.001573	0.001511	0.001415	0.001377	0.001365	0.001136	0.00109	0.00171
Total	0.635126	0.612135	0.601564	0.596127	0.571325	0.550181	0.526715	0.513362	0.506496	0.501761

4.3 Regional ecological reserves/ecological deficit

Based on the calculations described above, using ecological reserves/ecological deficit (ER/ED) calculation Equation (3), the ED and ER in Ruyang County from 2004 to 2013 can be acquired by comparing the EF with EC (Table 6).

Table 6 Ecological deficit and reserves during 2004-2013 in Ruyang County

Year	Per EC	Per EF	Per ED
2004	0.6351	0.7053	-0.0702
2005	0.6121	0.7522	-0.1401
2006	0.6016	0.8284	-0.2268
2007	0.5961	0.9182	-0.3221
2008	0.5713	0.9748	-0.4034
2009	0.5502	1.0179	-0.4677
2010	0.5267	1.1008	-0.5741
2011	0.5134	1.1510	-0.6376
2012	0.5065	1.2631	-0.7566
2013	0.5018	1.4473	-0.9456
Average	0.5615	1.0159	-0.4544

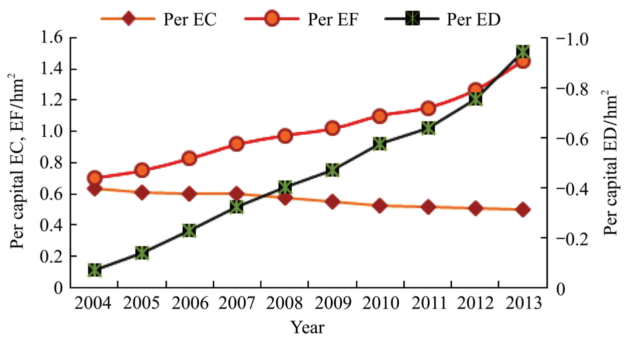

Figure 2 Dynamic change of ecological footprint in Ruyang County (2004-2013)

5 Results analysis

5.1 Structure and trends of EF per capita

In terms of EF trends, the EF per capita was growing from 2004 to 2013 in Ruyang County, from 0.7053 hm^2 in 2004 to 1.4473 hm^2 in 2013. The rate of increase reached 0.7402 hm^2, with an average annual growth rate of 12.86%. This meant that ecological land occupancy of human activity was increasing during the study period in Ruyang County.

Table 2 indicates that food consumption per capita EF occupies the largest area (60.89% on average) among all average consumption terms of biotic resources in Ruyang County. The consumption trend of biotic resources shows that food consumption of ecological footprint of the region occupies a constant area[14]. Food consumption EF is further dived into several categories, with grain and other plant foods taking up the largest proportion. Pork, poultry, red meat occupies a moderate proportion, while consumption per capita EF area of cotton, oilseed, vegetable and fruit is the least. Interestingly, pork, poultry, beef, vegetables, fruit, dairy consumption of EF occupies the fastest growing area. With the development of economy, the proportion of grain and other plant foods consumed daily is reduced, while the proportions of meat, dairy, and other animal foods consumed daily is increased[15]. As the economy shifts and standard of living improves, the shift in diet will be evident in the EF. Since animal food production requires more EF, the demand for EF of biotic resource consumption is increasing[16].

The rapidly expanding ecological footprint of fossil energy had an average EF area of 31.72%, and the percentage of arable land and grassland's area of EF was 67.5% on average. This suggests the acceleration of urbanization and industrialization in Ruyang, albeit still relatively low compared with the developed regions in China.

It can be seen from table 3 that coal consumption per capita ecological footprint occupies the largest area among all the energy consumption terms, with the average being 89.47%. This energy consumption dominated by coal has caused tremendous stress on the region's ecological environment. The EF area of all the energy consumption terms has gradually increased in recent years, suggesting that Ruyang is in a stage of rapid development at present, and that the pace of development is accelerating, with an increasing demand for energy[17].

From Table 4, we can identify that fossil energy land occupies the largest area (31.72%) among all kinds of ecologically productive land area in Ruyang County except arable land, followed by grassland, the ecological footprint per capita of which covers an area of 20.87%. During the study period, the grassland, woodland, Buildings, and fossil energy land per capita occupy an increasing EF area, with the largest increase in fossil fuel land.

5.2 Analysis of ED

According to Figure 3, per capita ecological footprint of Ruyang County showed an upward trend overall, while the per capita ecological carrying capacity had a gradually decreasing trend during 2004 to 2013. In the study period, per capita ecological footprint in Ruyang County expanded greatly, but the change in per capita ecological carrying capacity was small, so per capita ecological deficit increased with per capita ecological footprint[18,19].

Socio-economic development of Ruyang County was rapid from 2004 to 2013. The County's GDP increased from 2.3 billion Yuan (RMB) in 2004 to 11.5 billion Yuan (RMB) in 2013, with an average annual growth rate of 17.37%. The EF per capita increased from 0.7053 hm^2 in 2004 to 1.4473 hm^2 in 2013 (per capita), with a net increase of 0.7420 hm^2. Meanwhile the regional EC per capita showed a declining trend, decreasing from 0.6351 hm^2 in 2004 to 0.5018 hm^2 in 2013, a net decrease of 0.1334 hm^2. The absolute value of ED per capita increased over the study period, with rates of growth accelerating in later years. The ED per capita increased from 0.0702 hm^2 in 2004 to 0.9456 hm^2 in 2013, a net increase of 0.8754 hm^2. This suggests that the regional development is not sustainable and is getting worse. In order to achieve long-term development of the region and to adapt to China's economic growth, Ruyang County must change from extensive high-speed development of the past, into a more efficient, low cost, sustainable development.

The EF results calculated in this paper reflects the effects of economic development on ecological environment in study area, but is not all encompassing. The data does not take into account other important factors in land use, such as land degradation caused by pollution, erosion, and rapid industrial enterprise. Therefore, its calculation results may overestimate regional ecological status, and the estimation of the regional ecological footprint and ecological deficit are optimistic.

As one of poverty-stricken counties in China targeted by the poverty alleviation and development program, the government of Ruyang County has a strong desire to develop the economy and surmount poverty. Ruyang County has made great strides in poverty alleviation and development; regional rural poverty population has been reduced significantly, income levels has steadily increased, and infrastructure was substantially improved. In the decade of 2001-2010, 160 million Yuan (RMB) anti-poverty funds were invested in Ruyang County for rural infrastructure construction. The money was used to build 521 km of village roads and construct 472 safe drinking water projects. The stimulus lifted 78000 people out of poverty, and the county's per capita net income rose from 1897 Yuan (RMB) in 2001 to 4028 Yuan (RMB) in 2010, with an annual growth of 17.56%. Then, in 2011-2013, 33.57 million Yuan (RMB) was invested in the county. This funding provided 71.5 km of new road that connected villages, 750 new methane-generating pits, 9 chain supermarkets, 15 green ecological projects, 7 irrigation/water conservancy projects, as well as medical resources in the poor villages. The average income of the poverty-stricken population increased by more than 1500 Yuan (RMB), and the region's poverty population dropped by 14 100 people.

These developments were reinforced by an influx businesses and investments. Infrastructure was constructed to support industrial projects. The number of large industrial enterprises (annual revenues are above 5 million Yuan) increased from 20 in 2004 to 62 in 2013. The industry and infrastructure occupies large portions of land, especially arable land, which has a highest ecological supply among all kinds of land[20,21]. Therefore, the increase in occupying arable land is bound to lead to the reduction of regional ecological supply. Additionally, due industrial expansion, the local government introduced a number of energy-intensive mining operations in order to expedite the production of mineral resources. Several heavy industry projects have also been built (e.g. steel works, coking plants, and cement plants), creating a growing need for coal, oil, and electricity. The region's coal consumption has increased from 224 000 t in 2004 to 334 000 t in 2013, and electricity consumption increased from 211.75 million kW·h to 736.94 million kW·h.

The simultaneous reduction of ecological supply and the increase in ecological footprint has led to rapid increase in regional ecological deficit and an increasingly evident struggle between socio-economic development and environmental resource management.

6 Conclusions and suggestions

6.1 Conclusions

Ruyang County is developing rapidly, and showing signs of early stage industrialization and urbanization. Its most striking feature is its resource-intensive industries whose economic output depends on regional energy and resource consumption. Through EF and EC calculations in the study area, we can see that while socio-economic development, poverty relief, and development work in Ruyang County have been very successful, it puts great strain on the region's ecological environment. This is glaringly evident in the large ecological deficit that is rising rapidly. The existence of ED indicates that consumption demand for human life and production exceeds the carrying capacity of the ecosystem. The ecosystems are under the pressure of excessive exploitation by humans, and the social-economy development is unsustainable. This indicates the need to adjust the manner in which development is taking place. The development of Ruyang County has resulted in rapid growth of regional EF and aggravated ED, caused by industrialization and urbanization. Balancing between the development with decreasing the EF, and sustainably expanding Ruyang County are critical problems.

6.2 Suggestions

In order to ensure the safety of regional ecosystem, and achieve sustainable long-term social and economic development, effective measures should be taken in Ruyang County:

(1) Government environmental policy needs to be strengthened. This can be achieved by refining the relevant taxation and environmental policies,

strengthening the regulations on environmental pollution treatment, and increasing government and business investment in ecological environment protection. Pollution treatment should also be implemented by law. The implementation of such policies and regulations have an important influence on handling the relationship between resource exploitation, economic development, and ecological protection during the development process of resource-rich economically-poor areas like Ruyang County.

(2) Modern agriculture needs to be actively developed[22]. Developing agriculture that is more effective and adjusting conditions to improve biological production per unit area of land will enhance the ecological supply capacity of land. The government should develop sustainable agriculture by combing the use of modern science, technology, and management tools with useful experience of traditional agriculture. Agricultural resources need to be used reasonably to restore the environment, while increasing productivity within the region. The carrying capacity in the region would be improved, while simultaneously bestowing economic benefits, energy efficiency, and environmental protection.

(3) The structure of energy consumption in the region needs to be optimized[23]. The coal-dominated energy consumption ought to be converted to electric power, natural gas, and other clean energy. Once the region's social-economic status is stabilized, and poverty has been greatly alleviated, industrial projects with high-energy consumption can be limited. Traditional high energy-consuming industry should be substituted with conservation-oriented low carbon industrial projects. Shutting down the industrial projects with high-energy consumption and heavy pollution will improve energy efficiency, save resources, and thereby reduce the ecological footprint of energy.

(4) Management of land resources needs to be rational and scientific. Industry and infrastructure occupy large plots of land, usually on the most ecologically productive area—arable land. The construction planning should take EF into consideration by protecting existing arable land area and utilizing undeveloped land such as sand, saline, and nude land. Land-intensive operations should be encouraged to improve the productivity of land and EC.

(5) Urbanization and development needs to be planned more efficiently. The local government should systematically plan region layout of urban and rural areas, combining urban construction with the implementation of returning farmland to forest/grassland. Rural populations who live in ecologically fragile areas should be concentrated into cities and towns, and funding should actively support 'ecological migration'.

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