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Evaluation of the Regional Ecological Environment in Central China Based on the Ecological Footprint Model

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Abstract: The ecological footprint is a quantitative biophysical method commonly used to evaluate the status of regional ecological environment and the degree of sustainable development. In this paper, the concept and calculation process of the ecological footprint are introduced by taking a county located in central China as example. Computational analysis and empirical research of the region's ecological footprint is carried out. It turns out that the per-capita ecological footprint and per-capita Biocapacity of the county is $1.207382hm^2$ and $0.506497hm^2$ respectively, so the per-capita ecological deficit of $0.700885hm^2$ appears, which shows that the pressure put by the social development and human activities have exceeded the Biocapacity of the county and the status of the development is unsustainable. Therefore, on the basis of our study, proposals and measures are raised in the end to build a more sustainable development economy.

Keywords: Biocapacity, county ecological environment, ecological environment evaluation, ecological footprint.

1. INTRODUCTION

With the rapid development of the social industrialization and social urbanization, the excessive exploitation of natural resources and emissions of pollutants result in a series of environment problems, such as reduce of arable land, decrease of forest coverage, serious soil erosion, aggravating desertification, degradation of grassland, air pollution and so on. To make the development reasonable and sustainable, the sustainable development concept is developed which suggests that the progress and potential of the regional development are not only indicated by the speed of economic growth but also the resource and environment costs sacrificed. Hence, it is necessary to evaluate the regional ecological environment, which may be a scientific basis and reference for the sustainable development with economic growth and environment protection combined.

As the basic administrative unit of china, the land area, population and total economic output of the county account for about 90%, 80% and 60% of these of the whole country respectively, so the county plays an important role in the national economy and social structure, and the development of the county is the basement of the socio-economic development. However, compared with the development of major cities, the developments of the county obviously lag behind in china. Meanwhile, the problems of natural resources shortage, increasing environment pollution are also encountered. Therefore, to explore the application of ecological footprint theory and the implementation of sustainable development strategy, it is essential to evaluate the ecological environment status of the county [1-5].

In this paper, to analyze the ecological environment status and economic development of Ru yang in Henan province, ecological environment research of the region is conducted by the ecological footprint theory, of which the theoretical model and accounting standards are developed by William Rees in 1992 and widely applied to evaluate the regional ecological environment. The result may be a guideline for the social development and environment protection of the entire county in the central china.

2. THE OVERVIEW OF RUYANG COUNTY

Ru yang county, located in east longitude of 112°8′-112°38′, and north latitude of 33°49′-34°21′, the western Henan province of central china, across the Yellow and Huai River basin, is one of 25 key forestry counties in Henan province. The county-wide total area is about $132807.8hm^2$, and the total population is 473,010, of which the agricultural population is 407 thousands and the non-agricultural population is 66 thousands. The climate is warm temperate continental monsoon climate with abundant sunshine, four distinct seasons, annual average sunshine hours of 2177.3h, annual average temperature of 14°, annual average rainfall of 690mm, and annual average frost-free period 213 days. Three types of geomorphologies are contained in the county with low-lying north south high: mountain, hill and plain. Due to the abundant mineral resources, the county regional economy is developed in a road of new-type industrialization relying on the rich non-ferrous metals. By 2010, the percentage that the industrial added value accounts for the regional GDP increases to be 47%, and contributes more than half of the economic growth, which indicates the industry becomes to be dominant in the regional economy.

Table 1.   The equivalence factor of different categories of spaces.

Type of Ecological Footprint	Arable and Built-up Land	Forest and Fossil Energy Land	Pasture	Sea Space	Non-Productive Land
Equivalence factor	2.8	1.1	0.5	0.2	0.12

Table 2.   The yield factor of different categories of Bioproductive area.

Type of Ecological Footprint	Arable and Built-up Land	Forest	Pasture	Fisheries	Fossil Fuel Land	Non-Productive Land
Yield factor	1.66	1.1	0..19	0.1	0.61	1

3. THE ECOLOGICAL FOOTPRINT

The ecological model is a concept and method used to evaluate the pressure imposed by human on natural capital and offering real bio capacity within a given region or country on the basis of biophysical measure, which is developed by William Rees, a Canadian economist, in 1992, and then modified by doctor Wackernagel, his student, in 1996. The ecological footprint of a region with certain population is commonly defined as the Bioproductive area needed to produce the materials for human's consumption and assimilate the waste production.

The calculation of the ecological footprint is based on the two basic facts: 1) It is possible to track the annual amounts of resources consumed and wastes generated by countries; 2) The majority of these resource flows can be related to the Bioproductive area necessary for their regeneration and the assimilation of their waste [2].

From the demand side, the ecological footprint is represented by the Bioproductive area required for the material and resource consumption. From the supply side, the Biocapacity is shown by the Bioproductive area the region can provide. All mutually exclusive resource and waste-assimilating demand can be aggregated to six different Bioproductive area: arable land, pasture, forest land, built-up land, fossil energy land and fisheries. The evaluation of the regional environment and sustainable development status is conducted by the comparison of the two sides.

3.1. The Calculation of Ecological Footprint

As mentioned above, the Bioproductive area on the earth is divided into six categories: arable land, pasture, forest land, built-up land, fossil fuel land and fisheries. It is clear that the biological production capacity of each category of area differs greatly. Therefore, to aggregate the different categories of space to a total footprint and make the calculation results be comparable, the area of each category of area is multiplied by a 'equivalence factor', which represents the world average potential productivity of a given Bioproductive area relative to the world average potential productivity of all Bioproductive areas and will relate the different categories of area to the footprint in global hectares. Then the regional ecological footprint will be obtained by the weighted summation of the Bioproductive areas by (1). The equivalence factors utilized in our study are shown in Table 1 [2, 3]. Meanwhile, the Non-productive land including the

desert, saline land, tideland and so on, are not counted in the ecological footprint calculation, for they are unable to provide human consumption products directly. However, these lands should be contained when the Biocapacity is assessed due to the ecological value.

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

In which EF is the total ecological footprint, N is the population, ef is the per-capita ecological footprint, i represents different types of consumption and resource, A_i is the per-capita ecological footprint aggraded from each type of resource consumption, n is the number of the consumption items, r_i is the equivalence factor of different Bioproductive areas, and c is the per-capital consumption of all goods while c_i is the per-capital consumption of each kind of goods (kg). p and p_i represent the world average production capacity of all goods and the world average yield of each goods or services(kg/hm^2) respectively.

3.2. The Calculation of Biocapacity

The Biocapacity is embodied by the total Bioproductive area in the county. It is no doubt that the production capacity of the same land in different regions varies considerably, so the Bioproductive area of different categories have to be multiplied by the equivalence factor and yield factor shown in Table **2** [2], which informs about the category's relative yield (measured in primary or green biomass productivity) as compared with the world-average area. The Biocapacity is calculated by (2).

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

where EC is represented as the regional Biocapacity, N is the population, ec is the per-capital Biocapacity, j represents different categories of Bioproductive area in the county, a_j is the area, r_j is the equivalence factor, y_j is the yield factor, E_j is the production of Bioproductive area j(kg), and P_j is the world-average per unit yield of Bioproductive area j(kg/hm^2).

3.3. Ecological Overshoot and Ecological Deficit

A comparison of the Footprint and Biocapacity reveals whether existing natural capital is sufficient to support con-

Table 3.   The ecological footprint of biology resource of Ruyang County in 2012.

Types	EF Category	Global Average Yield (kg/hm²)	Total Production	Total EF	Per-Capital EF	Equivalence Factor	Per-Capital EF after Adjustment
Farm products							
Grain	Area land	2744	198186	72225.219	0.152693		0.427540
Legume	Area land	1856	7886	4248.922	0.008982		0.025152
Potato	Area land	12607	28587	2267.550	0.004794		0.013423
Oilseed	Area land	1856	10502	5658.405	0.011963	2.8	0.033945
cotton	Area land	1000	158	158	0.000334		0.000935
tobacco	Area land	1548	5876	3795.866	0.008025		0.022470
vegetable	Area land	18000	39663	2203.500	0.004658		0.013044
Melon	Area land	18000	3229	179.389	0.000379		0.001062
Forest product							
Walnut	Forest	3000	600	200	0.000423		0.000465
Chestnut	Forest	3000	330	110	0.000233	1.1	0.000256
Fruit	Forest	3500	8767	2504.857	0.005296		0.005825
Animal products							
Pork	pasture	74	9800	132432.432	0.279978		0.139989
Beef	pasture	33	1355	41060.606	0.086807		0.043404
Mutton	pasture	33	299	9060.606	0.019155		0.009578
Poultry	pasture	33	1786	54121.212	0.114419	0.5	0.057209
Eggs	pasture	400	6682	16705.000	0.035316		0.017658
Milk	pasture	502	790	1573.705	0.003327		0.001664
Wool	pasture	15	65	4333.333	0.009161		0.004581
Honey	pasture	50	526	10520.000	0.022241		0.011120
aquatic products	Fisheries	50	217	7482.759	0.015309	0.2	0.003164

Note: EF-ecological footprint

sumption and production patterns. If the ecological footprint is less than the Biocapacity, which is called as Ecological overshoot(ER) and indicates that the development of society and human demand on the environment does not go beyond the bearing capacity of the environment. The development of the region is in a sustainable state. On the contrary, when the ecological footprint becomes larger than the Biocapacity, the ecological deficit(ED) appears in the region and the development of the region is unsustainable. The Ecological overshoot or ecological deficit can be obtained by (3).

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

N is the population, ec is the per-capital Biocapacity, and ef is the per-capital ecological footprint.

4. THE ECOLOGICAL FOOTPRINT OF THE RUYANG COUNTY

The biological resource consumption includes farm products, animal products, forest products, and aquatic prod-

ucts. According to the criteria about the global-average yield of the biological resource from FAO (Food and Agriculture Organization), the biological resource flows of the county in 2012 are all related to the Bioproductive area needed. Meanwhile, the ecological footprint of the trade is ignored because of the low volume of import and export (Table **3**).

4.1. The Ecological Footprint of Ruyang Energy Consumption

Not only the biological products are contained in the people's consumption, the energy is also a essential part of human life. Therefore, it is necessary to assess the footprint of energy consumption consisting of the raw coal, fuel oil, gasoline, diesel and electricity. The biomass substitution approach, which calculates the area needed to replace fossil fuels with their energy equivalent in fuel wood, is used to calculate the energy footprint of the county. Fuel wood is chosen as the default replacement as it has been the historically dominant fuel for most societies and the primary fuel

Table 4.   The ecological footprints of energy of Ruyang County in 2012.

Type	EF Category	Global Average Energy Footprint (GJ/hm^2)	Converting Efficient (GJ/T)	Consumption (T)	Total Footprint (hm^2)	Per-Capital Footprint (hm^2)	E- Factor	Adjusted Per-Capital EF (hm^2)
Raw cocal	Fossil fuel	55	20.934	375595	142598.286	0.302231	1.1	0.332454
Gasoline	Fossil fuel	93	43.124	14291	6626.721	0.014010	1.1	0.015411
fuel oil	Fossil fuel	93	43.124	223	103.405	0.000219	1.1	0.000240
diesel	Fossil fuel	93	42.705	21741	9983.327	0.021106	1.1	0.023217
electricity	built-up	1000	3.6(1)	62615(2)	225.414	0.000477	2.8	0.001334

Note: (1) has units of GJ/million kwh, and (2) has units of million kwh. The data in the Table **4** is from Luoyang statistical yearbook in 2013 and the sales volume of county oil company in 2012.

Table 5.   The Biocapacity of Ruyang County in 2012.

Type	Area (hm^2)	Per-Capital Area	Y- Factor	E-Factor	Gross Per-Capital Biocapacity (hm^2)	Net Per-Capital Biocapacity (hm^2)
Arable	33843.91	0.070789	1.66	2.8	0.329027	0.289544
Forest	64367.31	0.136080	0.91	1.1	0.136216	0.119871
Pasture	15145.55	0.032020	0.19	0.5	0.003042	0.002677
waters	4323.17	0.009140	1	0.2	0.001828	0.001609
Built-up	10605.39	0.022421	1.66	2.8	0.104213	0.091708
Unused	4882.47	0.010322	1	0.12	0.001239	0.001090
Total					0.575565	0.506497

Note: Y-factor—yield factor, E-factor—equivalence factor

Table 6.   The ecological status of Ruyang County in 2012.

Type	Per-capital Biocapacity	Per-Capital EF (hm^2)	ED/ER (hm^2)
Arable	0.289544	0.537120	-0.247576
Forest	0.119871	0.006546	0.113325
Pasture	0.002677	0.285202	-0.282525
Waters	0.001609	0.003164	-0.001555
Built-up	0.091708	0.001334	0.090374
Fossil fuel	0	0.374016	-0.374016
Unused	0.001090	0	0.001090
Total	0.506497	1.207382	0.700885

the biosphere supplies without human modification. The rate of fuel wood used in this part is production equals the growth rate of fuel wood production for unit area.

4.2. The Calculation of the Ruyang County Biocapacity

The Bioproductive area of different categories is multiplied by the equivalence factor and yield factor after 12% of it subtracted for the biodiversity protection. Then by (2), the county Biocapacity in 2012 is obtained as illustrated in Table **5**.

4.3. The Calculation of Ecological Overshoot/Ecological Deficit

By (3), the ecological status of Ruyang is determined as shown in Tabel VI

4.4. Discussion

As illustrated by the Table **6**, in 2012, the per-capital ecological footprint of Ruyang county is 1.207382hm^2, and per-capital Biocapacity available is 0. 506497, so the ecological

deficit of the county is 0.700885, which is mainly from the consumption of the arable-land products, pasture products and energy. The ecological deficit of the county indicates that the regional development exceeds the bearing capacity of the nature. The proportion that each category of Bioproductive areas accounts for the county ecological footprint is calculated from Table **6**. The proportion of arable land footprint and pasture footprint are 44.49% and 23.62% respectively, which is the major part of the county ecological footprint while the proportion of the forest footprint, fisheries footprint and built-up land footprint are much less, 0.54%, 0.26% and 0.11% respectively. Therefore, the Bioproductive area for the grain and meat has high demand. Especially, with the rapid economic development, people's living standards are improved, the consumption of animal products, such as meat and milk, increases greatly.

From the perspective of energy consumption, the per-capital ecological deficit of the fossil fuel land is $0.374016hm^2$, and the per-capital Bioproductive area for the raw coal consumption occupies 88.57% of the total ecological area of the energy consumption, which results from the fast developing heavy industry supported by the resource preponderance. However, such energy relying consumption structure has caused enormous pressure on the pasture ecology and sustainable development of the county.

Due to the abundant forest resource in the county with a forest coverage rate of 44.7%, the per-capital ecological overshoot of forest is $0.113325hm^2$. With the development of social economy, more attention has been paid on the construction and protection of the ecological environment. For example, 'Grain for Green project' has been implemented in Henan province since 2002, and as the key county of forest, the forest area of Ruyang is expanded by 12,000 hm^2, which provides the county with effective ecological supply.

CONCLUSION

The comparison of the ecological footprint and Biocapacity reveals that the existing natural capital is not sufficient to support consumption and production patterns in the county. The pressure put on the ecological environment mainly comes from the high energy consumption, and high demand of arable land and pasture to satisfy people's increasing need of life and consumption.

To guarantee the safety of the regional ecosystem, and the sustainable development of the society, measures to decrease the regional ecological footprint and increase Biocapacity are shown as follow:

(1) Improve the agricultural science and technology to rise per unit biological yield and increase the land utilization efficiency. Then the ecological deficit of arable land will be reduced.

(2) To reduce the ecological footprint of energy consumption, it is essential to decrease the volume the fossil fuel consumption and optimize the energy consumption structure of the county by replacing the raw coal with electricity and gas, *etc*.

(3) Due to the 'Grain for Green project', the traditional forestry industry for which the timber trade is dominating is limited. However, with the improvement of people' life, the ecotourism is being greeted with increasing approval and developed rapidly in the world for its significant synthetically benefits and the nature of sustainable development. Therefore, the government of the county should take the advantage of the abundant forestry resource to develop the unique ecotourism industry in the region. By transforming the resources superiority as the economical superiority, the balance of regional ecological environment and economy development can be realized.

(4) To lessen the pressure of population upon the limited land resource, it is essential to control the regional population within the ecological tolerances.

(5) From the supply structure of the ecological footprint, it is found that the ecological supply of the arable land accounts for almost 57.06%, which indicate that the regional Biocapacity relies largely on arable land. Hence, the occupation of the arable land has to be controlled and reduced by the rational use of land resources during city construction and development.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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