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To cite this article: Qinghuan Qian et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 108 032063

View the article online for updates and enhancements.
Ecological balance between supply and demand based on cultivated land ecological footprint method in Guizhou Province

Qinghuan Qian¹, ², ³, Dequan Zhou¹, Xiaoyong Bai², ³, ⁷, Jianyong Xiao¹, ², ³ and Fei Chen¹, ², ³, Cheng Zeng¹, ², ³

¹School of Geography and Environmental Sciences, GuiZhou Normal University, Guiyang 550001, Guizhou Province, PR China
²State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, 99 Lincheng West Road, Guiyang 550081, Guizhou Province, PR China
³Puding Karst Ecosystem Observation and Research Station, Chinese Academy of Sciences, Puding 562100, PR China

*Corresponding author e-mail: baixiaoyong@126.com

Abstract. In order to construct the indicators of the balance between supply and demand of the cultivated land ecological carrying capacity, basing on the relation of the cultivated land ecological carrying capacity supply and demand, applying the model of Cultivated Land Ecological Footprints and the method of CIS and considering the factors of cultivated land production, taking the statistical data of 2015 as an example, and then made a systematic evaluation of the balance between supply and demand of the cultivated land ecological carrying capacity in Guizhou Province. The results show that (1) the spatial distribution of supply and demand of cultivated land ecological carrying capacity in Guizhou is unbalanced, and the northern and eastern parts are the overloading area, the middle, the south and the west parts are the balance area. (2) From the perspective of cultivated land structure, the crops with ecological carrying capacity surplus were rice, vegetables and peanuts, among which rice was the highest and the ecological balance index was 0.7354. The crops with ecological carrying capacity overload were potato, wheat, maize, rapeseeds, soybeans and cured tobacco, of which the index of potato up to 7.11, other types of indices are less than 1.5. The research can provide the ecological security early warning, the overall plan of land use and sustainable development of the area cultivated land with scientific evidence and decision support.

1. Introduction

With the rapid development of social urbanization and economic industrialization, the regional economic structure and the change of ecological environment structure, the exploration of sustainable development and the evaluation of sustainable development have become the hotspot of social research. Human society to maintain the sustainability of development, we must maintain the stock of
natural assets and sustainable benefits [1]. Sustainable development requires that we must live within the biosphere's ability to regenerate [2].

Rees and Wackernagel [3-4] in 1992 proposed the concept of ecological footprint and the evaluation of indicators, by measuring the survival of the natural ecological services and natural ecosystem services can provide the gap between the services, to understand the use of ecosystems in human society. The ecological footprint focuses on the consumption of natural capital, which is used to assess the survival and development of human ecosystems and reflect the consumption of ecosystems [5]. It can be in the global, national and regional standards on human society compared to the natural consumption and natural capital carrying capacity [6]. The ecological carrying capacity refers to the sum of all the areas of biological production land that a region actually provides to human beings [7]. It is an important basis for judging the coordination between resource development intensity and environmental carrying capacity [8]. Stuart [9] uses the ecological footprint as one of the key indicators for describing global biodiversity. World Wide Fund for Nature released in 2014, Living Planet Report shows that the need for 1.5 earth to carry the current human ecological footprint, China to 3 billion global hectares of ecological footprint total ranked first in the world [10]. Guizhou Province, as a world-famous mountain tourism destination, national ecological civilization test area, and inland open economic test area, there is construction land tension, land scarcity, fragile ecological environment and other issues.

Based on the GIS and the ecological footprint model of cultivated land, this paper studied the ecological supply and demand balance of cultivated land in Guizhou Province, and analyzed the status of cultivated land protection, ecological security and economic development from the perspective of cultivated land supply and demand. It is of great significance to maintain the sustainability of ecological services in cultivated land and promote the rational development and utilization of cultivated land resources and the coordinated development of human and natural environment. The research can provide the decision-making basis for the adjustment of agricultural industry structure, the ecological security of cultivated land, the sustainable development of regional economy and the compilation of land use planning.

2. Study area
Guizhou Province is located in the southwest of China, at the range of 24°37'N–29°13'N, 103°36'E–109°35'E. It is part of the eastern Yunnan-Guizhou Plateau, belonging to the national terrain of the second Step. It is the provinces with the highest mountainous areas in China. The territory is complex and diverse, including four types of plateau, mountain, hills and basins, of which 92.5% are mountainous and hilly areas. The climate is humid subtropical monsoon, with an annual mean temperature of 15.5°C and mean annual precipitation of 1170 mm. Guizhou Province land area of 17.62×104 km2, under the jurisdiction of six cities, and three minority autonomous prefectures. In 2015, the total population of 35.30 million people, of which agricultural population of 20.47 million, accounting for 57.77% of the total population, and per capita GDP of 29847.25 yuan. The total area of cultivated land is 4.54 million ha, per capita arable land of 0.1287 ha, and the contradiction between people and land is outstanding.

3. Materials and methods

3.1. Materials
The research data are derived from the Statistical Record 2015 of Guizhou Province, the Statistical Statement of Guizhou Province for National Economy and Social Development, and the Statistical Record of Cities (State) in Guizhou Province. The global average production data comes from the FAO Statistical Database (FAOSTAT). The data of cultivated land resources and administrative divisions in Guizhou Province were provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC).
3.2. The model of cultivated land ecological carrying capacity

3.2.1. Demand model: The ecological footprint of cultivated land. According to the definition and calculation method of ecological footprint, the ecological footprint of cultivated land refers to the spatial area of cultivated land resources needed to produce its consumption and to absorb the waste caused by its consumption. It compares the human consumption of cultivated land resources and the carrying capacity of cultivated land resources by measuring the gap between the demand for ecological services for cultivated land and the ecological services provided by the area. The formula as follows:

\[ EF = N \times ef \]

\[ ef = \sum_{i=1}^{n} rA_i = \sum_{i=1}^{n} r \frac{C_i}{P_i} \]

Where EF is the total ecological footprint of the cultivated land; N is the total population of the region; ef is the ecological footprint of per capita arable land in the region; i is the equilibrium factor of cultivated land; i is the type of consumption item; A_i is the bio-productive area of the regional per capita the type of consumption; C_i is the regional per capita annual consumption items; P_i is the regional average productivity of consumption items.

The study on the ecological footprint of cultivated land and the ecological carrying capacity of cultivated land in Guizhou Province will be carried out. The research will involve the biological products of cultivated land: rice, wheat, corn, soybean, potato, rapeseeds, peanut, cured tobacco and vegetables. In this study the equilibrium factor is 2.17 modified by Wackernagel [11], since the equilibrium factor is only slightly adjusted in the long-term time series.

3.2.2. Supply model: the ecological carrying capacity of cultivated land. The ecological carrying capacity of cultivated land is the area of bio-productive cultivated land which is truly owned in the region, which reflects the supply of cultivated land ecosystem to human activities. The formula for calculating the ecological carrying capacity of cultivated land is:

\[ EC = N \times ec \]

\[ ec = \sum_{i=1}^{n} a_i \cdot r \cdot Y_i = \sum_{i=1}^{n} a_i \cdot r \cdot \frac{Y_i}{Y_{ni}} \]

Where EC is the total ecological carrying capacity of the cultivated land in the region; ec is the ecological carrying capacity of per capita arable land; a_i is the production area of the crops; Y_i is the yield factor of the crops; Y_n is the average productivity of the regional crops; Y_{ni} is the world average productivity for crops.

3.2.3. Ecological carrying capacity index: The supply and demand balance of cultivated land. Based on the study of the ecological supply and demand of cultivated land in Guizhou Province, this paper introduces the ecological carrying capacity index (ECI) to study the balance of ecological supply and demand in cultivated land. ECI refers to the ratio of ecological footprint of per capita cultivated land and the ecological carrying capacity of per capita arable land, which reflects the relationship between supply and demand of cultivated land resources. The formula as follows:

\[ ECI = \frac{ef}{ec} \]
When ECI is equal to 1, it indicates the regional ecological service balance of cultivated land. When ECI is greater than 1, it indicates the regional deficit of cultivated land ecological service. When ECI is less than or equal to 0.85 for the ecological surplus area, and the ECI is greater than or equal to 1.15, and the ECI is more than or equal to 1.15 in the karst area. According to the ECI range of cultivated land ecological balance area, surplus area and deficit area, the ecological supply of cultivated land is subdivided into five levels. The specific classification criteria are shown in Table 1.

| Type                      | Bearing capacity status | ECI             |
|---------------------------|-------------------------|-----------------|
| The area of ecological deficit | Serious overshoot        | $1.45 \leq ECI$ |
|                           | Overshoot               | $1.15 \leq ECI < 1.45$ |
| The area of ecological balance | Balance                 | $0.85 \leq ECI < 1.15$ |
|                           | Surplus                 | $0.55 \leq ECI \leq 0.85$ |
| The area of ecological surplus | Affluence               | $0.55 < ECI$    |

4. Results

4.1. Cultivated land ecological footprint

The ecological footprint of total cultivated land in Guizhou Province was $96.86 \times 10^6$ ha, and the ecological footprint of cultivated land per capita was $0.2744$ ha, in 2015. According to the first ratio of the ecological footprint of the cultivated land and the average ecological footprint of the cultivated land in the cities and states. The second ratio of the ecological footprint of per capita cultivated land in the cities (states) and the average ecological footprint of per capita cultivated land in the province. Calculate the total and per capita arable land ecological footprint of nine cities (states) in Guizhou Province, respectively. The total ecological footprint is dominated by median and high value areas (Fig. 1a). The high value areas are located in Bijie City, Zunyi City and Tongren City. The low value areas are located in Liupanshui City, Anshun City, and Guiyang City. The ecological footprint of per capita cultivated land is dominated by low and high value areas (Fig. 1b). The high value areas are located in Zunyi City and Tongren City. The low value areas are located in Guiyang City, Liupanshui City, and Anshun City. The ecological footprint of the total cultivated land and the ecological footprint of the per capita arable land in the cities are well consistent in space. The reason is that where the per capita arable land ecological footprint is large usually distributed more population, resulting in a larger total ecological footprint.

![Figure 1. The total ecological footprint (a) and the per capita ecological footprint (b)](image-url)
From the structure of cultivated land (Fig. 2), several crops with high ecological footprint were vegetables, potatoes, maize, wheat and rapeseeds, accounting for 85.59% of the total ecological footprint. Among them, the ecological footprint of vegetables was the highest, accounting for 21.98% of the total; the potatoes was the second, accounting for 20.04% of the total; the grain crops were the highest in maize and rice, accounting for 17.3% and 14.86% of the total; and Rapeseeds accounted for 11.41% of the total.

Figure 2. The ecological footprint of different crop types

4.2. Cultivated land ecological carrying capacity
The ecological carrying capacity of total cultivated land in Guizhou Province was $78.39 \times 10^5$ ha, and the ecological carrying capacity per capita was 0.2569 ha, in 2015. From the regional point of view (Fig. 3), the cities (states) per capita arable land ecological carrying capacity is generally lower than the province's per capita value. There are five cities (states) in which the ecological carrying capacity of cultivated land is lower than that of the whole province. Among them, the lowest in Guiyang City, the second of Liupanshui City, both of them are less than 0.2. There are four cities (states) in which the ecological carrying capacity of cultivated land higher than that of the whole province, of which the highest in Qiannan state, followed by Zunyi City, both are greater than 0.3. The ecological carrying capacity of total cultivated land and the ecological carrying capacity of per capita arable land in cities (states) are heterogeneous in space. The reason is that the size of the total carrying capacity cultivated land depends mainly on the area of cultivated land, the larger the cultivated land area, the greater the total ecological carrying capacity. While the size of per capita ecological carrying capacity in addition to cultivated area is also closely related to population density, the greater the population density, the smaller the per capita ecological carrying capacity. The non-matching between the spatial distribution of the population and cultivated land in the province is the main reason for the ecological carrying capacity of the per capita arable land and the total cultivated land.

From the perspective of cultivated land (Fig. 4), The types of crops with high ecological carrying capacity were vegetables, rice, maize and rapeseeds, accounting for 82.11% of the total ecological carrying capacity. Among them, the ecological carrying capacity of vegetables was the highest, accounting for 31.14% of the total; followed by rice and maize in grain crops, accounting for 23.25% and 17.49% of the total respectively. The rapeseeds oil content accounted for 10.24% of the total.
Figure 3. The total ecological carrying capacity (a) and the per capita ecological carrying capacity

Figure 4. The ecological carrying capacity of different crop types

4.3. The balance of supply and demand of cultivated land ecological carrying capacity

According to the ecological supply and demand balance index and grading standard of cultivated land, the ECI of cultivated land in Guizhou Province was studied, as shown in Fig. 5. There are only two types of ecological deficit (ECI > 1.15) and ecological balance (0.85 < ECI < 1.15) in the ecological carrying capacity of cultivated land in Guizhou Province, and there is no ecological surplus area (ECI < 0.85) in Guizhou province.

In terms of the population, the ecological deficit area of cultivated land accounts for 19.41 million people, accounting for 54.98% of the total population of the province. The ecological balance area of cultivated land occupies 15.89 million people, accounting for 45.02% of the total population of the province. In terms of land area, the cultivated area of cultivated land ecological deficit area is 3.08 million ha, accounting for 67.91% of the total cultivated land area of the province. The cultivated area of cultivated land ecological balance area is 1.45 million ha, accounting for 32.09% of the total cultivated area of the province. Overall, there are obvious differences in the spatial supply and demand of cultivated land ecological capacity in Guizhou Province, showing that the northern and eastern parts are overloaded, and the southern and western regions are balanced.

The perspective of the crop structure (Fig. 6), there are ecological surplus crop types with rice, vegetables and peanuts, these supply and demand balance index is less than 1. There are ecological
overload crop types are potato, wheat, corn, rapeseeds, soybean and cured tobacco, of which the index of potato up to 7.11, other types of indices are less than 1.5.

![Figure 5. The ecological carrying capacity index of the cities](image)

![Figure 6. The ecological carrying capacity index of different crop types](image)

5. Conclusion
It is an effective method to evaluate the ecological security status of cultivated land in the region by using the ecological footprint model of cultivated land to measure the utilization degree of cultivated land resources and the sustainable development of human. However, the study on the balance of supply and demand of cultivated land in southwest hills and mountains, especially in Guizhou Province, has not been seen. Therefore, this study takes the relationship between supply and demand of cultivated land ecological capacity as the starting point, and uses the cultivated land ecological footprint model to study the balance of supply and demand of cultivated land in Guizhou. The conclusions are as follows: (1) The spatial distribution of supply and demand of cultivated land in Guizhou Province showed a significant imbalance, which showed that the northern and eastern parts were overloaded zone, and the southern and western regions were the balance area. There is an
imbalance between supply and demand of cultivated land in Guizhou Province, and the ecological overloading area of cultivated land is not consistent with the distribution of main urban area. (2) In terms of cultivated land structure, the types of crops with ecological surplus were rice, vegetables and peanuts, among which rice was the highest and the ECI was 0.7354. The crops with ecological overload were potato, wheat, maize, rapeseed, Soybeans and cured tobacco, of which the index of potato up to 7.11, other types of indices are less than 1.5.

Acknowledgments
This research work was supported jointly by National Key Research Program of China (No.2016YFC0502300, 2016YFC0502102, 2014BAB03B02), International cooperation research projects of the national natural science fund committee (No. 41571130074 & 41571130042), Science and Technology Plan of Guizhou province of China (No.20126015), Agricultural Science and Technology Key Project of Guizhou province of China (No.2014-3039), Science and technology cooperation projects(No.2014-3), Science and Technology Plan Projects of Guiyang Municipal Bureau of Science and Technology of China (No.2012-205). The National Natural Science Fund (No.41461041).

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