Computing Simulation and Spatial difference Analysis of Resources and Environment Ecological footprint out of Control

Roulin Chen, Duanmin Zhang, Bo Li*

State Key School of Economics and Management, Changchun Normal University,
Changchun 130022, P. R. China
Email: jiutian898@163.com

Abstract: As a quantitative evaluation method, the ecological footprint theory analysis method (EFA) is a frontier subject in the field of sustainable development. The production activities of human beings will inevitably produce certain consumption, including the occupation of natural resources, consumption of W and the production of waste, which will have a certain impact on the ecological environment, just as one foot on the ground will leave footprints. On the other hand, the ecological environment itself will also provide a certain bearing capacity, supply human material consumption. The ecological footprint theory is to quantitatively convert the material consumption produced by human activities into the biological productive land area, and compare it with the supply area in the study area. Since Rees put forward the theory of ecological footprint, the development of ecological footprint model has gone from one-dimensional model to two-dimensional model, and from two-dimensional model to three-dimensional model. This paper reviews the evolution of ecological footprint model from four aspects: scientific problem, model connotation, interpretation ability and application direction, in order to cause new thinking on ecological footprint model.

Keywords: ecological environment; natural resource accounting; ecological footprint model; sustainable development.

1. Foreword

The sustainable development of the region must take the sustainable development of the ecological environment as the premise and guarantee. The ecological environment is not only the carrying space of the social and economic activities in the region, but also provides the natural material foundation and the space for the waste disposal for the regional development. Therefore, as a decisive factor in regional development, the sustainable development of the region requires comprehensive consideration of the regeneration and substitution capacity of regional resources, the recycling and purification capacity of life support systems and the protection of biodiversity. The ecological footprint model, which has been developing rapidly in recent years, can not only meet the above requirements, but also can be calculated intuitively and has regional comparability[1]. Therefore, the relevant international machines have been quickly obtained. The recognition of government departments and research institutions has become an important method in international sustainable development measurement.

2. Ecological footprint

Ecological footprint (EF (Ecological Footprint),) [1]also refers to the total area of land and water that can continuously provide certain people with all the resources they consume and absorb all the wastes they produce. EF's calculations are based on the following two facts: humans are able to estimate most of the resources they consume, energy and the amount of waste they produce; These resources and wastes can be converted into ecologically productive areas for the production and consumption of these resources and wastes. The main considerations are as follows: fossil energy land, cultivated land,
woodland, pasture land, construction land and water area are weighted to sum up the six kinds of biological production areas with different ecological productivity.

\[ EF = \sum_{i=1}^{n} \left( \frac{r_i c_i}{p_i} \right), \]

and input; \( EF \) is the total ecological footprint; \( N \) is the population number; \( e_f \) is the per capita ecological footprint[2]; it is the average balance factor; it is the per capita consumption of class I commodity; it is the world average living ability of class I consumer goods.

2.1 The basic thought and hypothetical premise of ecological footprint research

Ecological footprint refers to the biological productive land area (hereafter referred to as land area) needed to maintain resource consumption and absorb waste under given population and economic conditions. The basic idea is to convert the "interest" (ecological footprint) of the natural assets needed by human consumption and the "interest" (ecological carrying capacity) generated by the natural assets into the land area which can be compared with each other. The comparison between the two is used to judge the overutilization of natural assets by human beings [4]. To this end, there are six assumptions: (1) the annual consumption of available resources and the amount of waste generated; (2) the consumption and waste of most of the resources The material flow can be converted into land area; (3) various different types of land area can be given a certain weight and converted into a standardized global hectare unit (with the world average productive capacity); (4) all types of land use are exclusive, so the total demand can be obtained by adding up the area of resource utilization and waste absorption; (5) the total interest occupied by human activities can be compared directly with the interest provided by itself; (6) aggregate demand may exceed total supply [1-3].

2.2 Calculation method of ecological footprint

The ecological footprint calculation process is shown in figure 1.

Fig. 1 schematic diagram of calculation process of ecological footprint method
It can be seen from figure 1 that the calculation method of ecological footprint can be divided into two parts: (1) converting human consumption and waste emissions into corresponding land area; (2) comparing ecological footprint and ecological carrying capacity with common standards. The first part is mainly through the establishment of the consumption-land conversion matrix [6]. It is relatively simple to convert the consumption of biological resources into the corresponding land area, only the embedding of the corresponding land area should be considered, that is, how much land area is needed for a given consumption quantity to produce and supply. The second part is the use of multiplicative equilibrium factor and yield factor. The ecological footprint and ecological carrying capacity are converted into comparable global hectares. In addition, 12% of biodiversity conservation area should be deducted in the calculation of ecological carrying capacity. At the same time, at the national or regional level, due to the impact of trade, the ecological footprint can cross regional boundaries, so the amount of consumption needs to be adjusted to calculate the net consumption [4]

2.3 The key points in the calculation of ecological footprint

Conversion of energy consumption to land area:

Land disposal of fossil energy: usually, the exploitation and utilization of fossil energy means the depletion of stocks and the generation of waste gas. Therefore, in view of the development and utilization of fossil energy, the fossil energy land can be treated from the point of view of flow evaluation and the land area needed to provide the energy consuming substitute and absorb the waste gas. For example, the emission of PCDD (PCB), has no obvious absorption capacity because of nature, although it has obvious influence on natural regeneration ability and is not taken into account in the calculation. Because the natural system has the obvious absorption ability to CO₂, and the data is more abundant, This mainly deals with the waste gas of CO₂ [10]. At present, it is mainly used to estimate the land area needed to absorb the new CO₂ to calculate the demand for fossil energy land. The absorptive capacity of forests is calculated by calculating the average absorptive capacity of 26 different biota. The detailed calculation process is shown in tables 1 and 2 [5]

| Global forest area (Km²) | Aboveground dry matter weight (t/Km²/a) | Underground dry matter weight (t/Km²/a) | Total dry matter weight (t/Km²/a) | Total carbon absorption (tC/km²/a) |
|--------------------------|----------------------------------------|----------------------------------------|----------------------------------|----------------------------------|
| 5120.227×10⁶            | 11612×10⁶                              | 2.27                                   | 2.84                             | 1.42                             |

Note: total dry matter weight includes underground biomass, derived from the third row multiplying the conversion coefficient 1.25.

| Carbon emission factor (tC/Tj) | Global average energy footprint (Cj/Km²/a) |
|-------------------------------|------------------------------------------|
| coal                          | 26                                       | 55                                       |
| oil                           | 30                                       | 71                                       |
| gas                           | 15.3                                     | 93                                       |

Note: the global average energy footprint is derived from column 5 in table 1, divided by column 1 in table 2.

3. Methods
Ecological footprint model, as a method of accounting for natural resources from an ecological point of view, has experienced the development of one-dimensional model.

The results show that: 1) the ecological footprint model is a biophysical tool for natural resource accounting. It makes up for the deficiency of natural resource value accounting in the mainstream national economic accounting system. 2) the one-dimensional model introduces the concept of eco-productive land to carry out the natural resource consumption accounting to calculate the occupation of human activities to the ecology; Based on the dimension of natural resource consumption accounting, the two-dimensional model introduces the dimension of ecological carrying capacity of natural resources and opens up a new field of vision for evaluation of natural resource carrying capacity. Understanding the ecological bearing capacity of natural resources, expressing ecological footprint in cylindrical volume, vividly depicting the ecological pressure of human activities on the region. 3) One-dimensional model is the basis of two-dimensional and three-dimensional models. However, the scientific problems they solve are different, so the applicable research scale and application direction are also different. 4) the ecological footprint model belongs to the static analysis model and cannot explain the dynamic changes of the eco-economic and social system[6]. The two-dimensional and three-dimensional models belong to the closed model, and their calculation results can not accurately reflect the real state of the regional ecology. Finally, the direction of further optimization of ecological footprint model is discussed.

3.1 calculation method of ecological footprint model

The formula for calculating the ecological footprint of the project is as follows:

\[ EF = EFC + EW \]

\( EFC \) (C=Consumption) is the ecological footprint of the consumption invested in the construction, operation and maintenance phase of the project. \( EW \) (W=Waste) is the ecological footprint of the waste produced during the construction of the project.

\[ EFC = N \cdot ef = N \cdot rj \cdot \sum_{i}^{n} (abi) = N \cdot rj \cdot \sum_{i}^{n} \left( \frac{Ci}{P_i} \right) \]

Among them, \( N \) is the population of the project, \( ef \) is the ecological footprint per capita, \( rj \) is the equilibrium factor( \( j=1,2,\ldots,6 \) ) to indicate the land type, and \( abi \) is the per capita bioproductive land area of the class I consumption project. \( Ci \) is per capita consumption for Category \( i \) projects, and \( P_i \) says average global production capacity for Category \( i \) projects[7].

With the construction of the project going on, there will be some waste. Every 1m\(^2\) construction project in our country will produce about 60kg waste. However, due to the lack of strict supervision and management of the treatment of Lakzaka in our country, Construction waste is usually disposed of by direct stacking or landfill. The construction waste of each 1000kg will occupy the land of 0.067m\(^2\), so the calculation formula of the ecological footprint of construction waste is as follows:

\[ EFW = SBA \times 60 \times 0.067 \times 10^{-3} \]

The calculation formula of ecological carrying capacity of the project is as follows:
Among them, \( ec \) is the per capita ecological carrying capacity, \( ej \) is the equilibrium factor, \( yj \) is the yield factor, and \( bj \) is the per capita biological productive land area.

According to the proposal of the (WCED) of the World Commission on Environment and Development, 12% of the area of bio-productive land should be set aside for biodiversity conservation, and the actual ecological capacity of the project should be multiplied by a coefficient of 0.88. Namely:

\[
EC = 0.88N.ec
\]

Calculation of ecological surplus:

The concept of surplus (ecological deficit) is defined as follows:

\[
ES = EC - EF
\]

If \( ES > 0 \), there is ecological surplus, and the ecological carrying capacity of the project is higher than that of the sustainable improvement of the project. If \( EF < 0 \), there will be ecological deficit, the ecological carrying capacity of the project is not as good as the ecological footprint, the sustainability of the project is poor, and the project is in a critical state between sustainability and unsustainability, such as \( ES = 0 \). [8]

3.2 One-dimensional ecological footprint model

3.2.1 Scientific issues

At present, mankind is facing the problem of how to coordinate the relationship between economic development and ecological protection. "all human activities on Earth are carried out in the biosphere and have an impact on the biosphere", This is consistent with the evolution of the ecological footprint model of natural resource accounting and its comment law 1 proposed by Hardin. It can also be explained by the second law of thermodynamics [8]. The economic system is only a sub-system under the ecosystem. In order to maintain the orderly state of the economic system, it is necessary to continuously absorb low-entropy substances and release high-entropy substances from the ecosystem. To maintain economic growth Increased ecosystem disorder (or entropy value) at the cost of [9]. If the economic system demands more from the ecosystem than it can regenerate, the entropy of the ecosystem will increase, and the ecosystem will change to a disordered state (such as climate change). As a subsystem of the biosphere, the human economic society in a certain region may have broken through the upper limit of the natural resources that the region can provide, and the ecological environment of the region and the whole world is facing severe challenges. How to trace the source of natural resource consumption and its decomposition and assimilation after use, and put forward a kind of self-directed ecological protection. However, the accounting method of resource consumption, which reveals the occupation of human activities to the ecology, has become a hot issue in academic circles, various organizations and government departments. As a biophysical tool for natural resource consumption accounting, the ecological footprint model provides a unique way to solve this scientific problem.

3.2.2 connotation and characteristics of models

Rees defines ecological footprint as the ecological productive land area needed to support the natural resource consumption of a certain population and assimilate the waste produced in a given area. He likened the ecological footprint to "a city, factory, and farmland loaded with human creation." The
footprints left by the giant feet on the earth "[30]." From this definition, ecological footprint is only a quantitative concept, not limited to specific space. Therefore, this paper calls it a one-dimensional ecological footprint model (hereinafter called one-dimensional model). Rees). The one-dimensional model classifies the biological products and ecological services consumed by human beings into 23 categories, respectively. According to the six types of eco-productive land, the human consumption of natural resources is converted into the corresponding eco-productive land area by land productivity data, and the equilibrium factor is proposed to balance the productivity difference among different types. The regional area data can be added and summarized after the correction of the equilibrium factor, and the ecological footprint of regional human activities can be obtained. One-dimensional model is based on its calculation. The result is the value of land area and does not consider the concept of space. Therefore, the one-dimensional model can be applied to the measurement of ecological footprint on any scale. At present, some people try to measure the ecological footprint on various scales, which are summed up by scholars as global [10-12], and national macro scale. Provincial and urban meso scale [12], institutional group activity and individual [10] microscale. At the same time, the calculation of ecological footprint at different scales requires different calculation methods (for example, Table 3) due to the difference of data acquisition methods and regional characteristics.

| Study area scale         | computational method                              |
|--------------------------|--------------------------------------------------|
| Global, regional         | method of synthesis                               |
| country                  | Input-output method                               |
| economize                | Integrated method, input-output method, emergy method |
| City, county             | Synthesis method, input-output method, emergy method, component method |
| Institutions, group activities and individual | Component method                                 |

3.3 Two-dimensional ecological footprint model

3.3.1 Scientific issues

The one-dimensional model proposed by Rees constructs an eco-system-based natural resource consumption accounting method. The calculation results represent the ecological occupation of human activities in the form of eco-productive land area. However, the one-dimensional model is only the accounting of resource consumption, how to define and calculate the supply capacity of regional natural resources, and compare the consumption of natural resources with the supply of natural resources. To evaluate whether the natural resource consumption of the region is within its ecological carrying capacity, to establish a set of evaluation system for sustainable development, to judge whether the economic, social and ecological environment are developing harmoniously, which has become the academic circle's view of one-dimensional model to two-dimensional [11].

3.3.2 the connotation and characteristics of the model

Wackernagel improved the one-dimensional model, introduced the concept of ecological carrying capacity to characterize the supply capacity of regional natural resources, and formed a two-dimensional ecological footprint model [12] (hereinafter referred to as two-dimensional model). By calculating the ecological footprint of a region and comparing it with the ecological carrying capacity of a region, the two-dimensional model measures the occupation of natural resource flow by
human natural resource consumption, and analyzes the regional ecological deficit or surplus. The calculation of ecological carrying capacity by two-dimensional model is essentially the accounting of natural resource flow. The so-called flow of natural resources means that a certain area of land in the region can be produced in one year [17]. The two-dimensional model represents the ecological carrying capacity of the region by the ecologically productive land area provided by the region, which in fact endows the ecological.

3.4 Three-dimensional ecological footprint model

3.4.1 Scientific issues

Ecological economist Daly proposed that the sustainable use of natural resources should follow three guidelines [13]: 1) Non-renewable resources, Jin Xiangmu et al.: evolution of ecological footprint model of natural resources accounting and its consumption rate of comments The degree should not be faster than its regeneration speed; 2) the consumption rate of non-renewable resources should not be faster than the replacement rate of corresponding renewable resources, and 3) the rate of pollution and waste emission should not be higher than that of ecosystem assimilation. Accordingly, once the consumption rate of non-renewable resources is higher than its regeneration rate or the replacement speed of corresponding resources, the stock of natural resources will be consumed, and the natural resources will be overdrawn. State. Although both one-dimensional and two-dimensional models recognize the importance of natural resources in sustainable development, their focus is on the consumption and flow of natural.

3.4.2 Model connotation and characteristics

On the basis of two-dimensional model, Niccolucci has introduced two new indexes, footprint depth and footprint breadth, to describe the ecological footprint by the volume of the cylinder, so as to explain the human occupation of the natural resource flow and the natural resource stock. The plane analysis of the two-dimensional model is extended to the stereoscopic analysis of the three-dimensional model, and the longitudinal expansion of the ecological footprint research is realized [14]. Compared with the two-dimensional model, the concept of natural resource stock is introduced in the three-dimensional model. The stock of natural resources is relative to the flow of natural resources, when the flow of natural resources cannot meet human consumption, Additional consumption comes from the stock of natural resources. The evolution of the ecological footprint model from two to three dimensions is shown in figure2.

![Figure 2. Evolution of ecological footprint model from two to three dimensions](image)

There are the following relationships in the 3D model:

\[ EF = BC + ED \]
In the formula: $EF$ is ecological footprint; $BC$ is the area of ecologically productive land that can be provided by region; $ED$ is ecological deficit.

In a three-dimensional model, there are the following relationships:

$$0 < EF_{\text{Size}} \leq BC$$

$$EF = EF_{\text{Size}} \times EF_{\text{Depth}}$$

$$EF_{\text{Depth}} = 1 + \frac{EF - BC}{BC}$$

$EF_{\text{Size}}$ for footprint breadth, $EF_{\text{Depth}}$ for footprint depth.

In the three-dimensional model, when the ecological footprint is smaller than the ecological carrying capacity, the footprint breadth is used to characterize the extent of human activity occupying the natural resource flow, and the footprint breadth is equal to the ecological footprint (for example, the formula (2)). When the ecological footprint is larger than the ecological carrying capacity, a footprint depth index will be introduced to characterize the extent to which human activities occupy natural resource stocks (e.g. formula (3)). Footprint depth is equal to the ratio of ecological footprint to ecological carrying capacity (e.g. formula (4)). The ratio can represent the number of years required to meet regional development needs, reproduce the consumption of human resources in 1a, or, in theory, how many times as much ecological production as is required Land area can meet the demand of natural resources consumption. It can be concluded that footprint depth is an indicator of regional ecological pressure on a time scale [14-16].

3.5 Research Progress in Ecological footprint Model

It was first proposed by Canadian ecological economist William Rees et al in 1992 and improved in 1996 by his Ph.D. Wackernagel et al. Ecological footprint model has become a frontier field in the research of resource development and environmental protection because of its theory, method innovation and practical maneuverability. At home, the concept and model of ecological footprint have been introduced into China since 2000. According to the full text database of CNKI Chinese Journal of Science and Technology and The number of full text of VIP Chinese scientific and technological journals is based on the library "Ecological footprint", "Ecological occupation" (title / keyword / abstract) interactive retrieval (Nov. 7, 2005). At present, 175 related papers have been published in China. According to the retrieval of CNKI Chinese excellent doctoral thesis database, there are four doctoral papers on ecological footprint. The study of ecological footprint has been paid more and more attention by domestic scholars, and the number of papers has been increasing rapidly year by year. From figure 3, it can be seen that the number of papers on ecological footprint in China from 2000 to 2002 was small and the increase was small, and the number of papers increased significantly after 2003, indicating that ecological footprint research is a frontier field.
According to 175 related research papers which have been retrieved at present, the research on ecological footprint in China is mainly focused on three aspects (Fig. 4), that is, model review, scale footprint research and specific industry / sector footprint analysis.

**Fig. 4 comparison of content and quantity of ecological footprint studies in China**

- a-Review of research  
- b-Provincial footprint  
- c-Municipal footprint  
- d-County footprint  
- e-Town footprint  
- f-Family footprint  
- g-Tourism footprint  
- h-Agricultural footprint  
- i-Project footprint  
- j-School footprint  
- k-Traffic footprint

4. **Experiment**

Spatial and temporal Analysis of Ecological footprint and Ecological carrying capacity of Water Resources in China.

China has a vast territory and is affected by many climatic types, and there is a serious
phenomenon of uneven distribution of water resources in time and space. In recent years, water pollution is becoming more and more serious. Under the influence of monsoon climate, the total amount of water resources is abundant in most areas of China, but there is a serious imbalance in spatial distribution, which decreases from the southeast coast to the northwest inland. The difference in time distribution is also large, most areas have less spring and winter rain, and more summer and autumn rain. The spatial and temporal differences of ecological footprint and ecological carrying capacity of water resources in China from 1997 to 2010 were studied in order to improve the planning and management of water resources in China. For a certain reference basis, promote the sustainable development of China’s social and economic environment.

4.1 Ecological footprint model of water resources

It is divided into three major users: domestic water, production water and ecological and environmental water supply (including only urban environmental water supplied by artificial measures and some rivers and lakes, wetland water). The calculation model is as follows:

\[ EF_W = N \times \text{ef}_W = \gamma_w \times W / P_w \]
\[ \text{ef}_W = \gamma_w \times W\text{cap} / P_w \]

\( EF_W, N, \text{ef}_W, \gamma_w, P_w, W, W\text{cap} \) are the total ecological footprint of water resources (hm\(^2\)), the number of population, the ecological footprint of water resources per person (hm\(^2\) / person), the global equilibrium factor of water resources, and the global average production energy of water resources (m\(^3\)/hm\(^2\)). Total water consumption (100m\(^3\)), per capita water consumption (m\(^3\)) [15].

4.1.1 Ecological carrying capacity model of water resources

The ecological carrying capacity of water resources refers to the ability of the highest value of water supply to maintain the normal operation of economic system and ecosystem in a certain period of time and in a certain region. It also has natural attributes, social attributes and spatial attributes.

\[ EC_w = N \times \text{ec}_w = 0.4 \times \psi \times \gamma_w \times Q / P_w \]

As 60% of the water carrying capacity of a region and a country is used to maintain the ecological environment, the water carrying capacity must be multiplied by a factor of 0.4; \( EC_w, \text{ec}_w, \gamma_w, \psi, Q, P_w \), \( N \) are water resource carrying capacity (hm\(^3\)), per capita water resource carrying capacity (hm\(^3\) / person), global equilibrium factor of water resources, output factor of regional water resource source, total water resource amount (m\(^3\)). Global average water production capacity (m\(^3\) / hm\(^2\)), population [9]

4.1.2 Correlation coefficient between precipitation and ecological carrying capacity of water resources

The correlation coefficient is a statistical analysis indicator of the degree of correlation between variables, and its formula is as follows:

\[ R_{ER} = \frac{\sum (EC_w - \overline{EC_w})(RF - \overline{RF})}{\sqrt{\sum (EC_w - \overline{EC})^2 \cdot \sqrt{\sum (RF - \overline{RF})^2}}} \]

\( R_{ER}, EC_w, RF \) is the correlation coefficient between the ecological carrying capacity of water resources and precipitation, the ecological carrying capacity of water resources (hm\(^3\)), the mean value of ecological carrying capacity of water resources (hm\(^3\)), and the value of precipitation (mm), in
each year. Mean precipitation per year (mm).
RMB 413,000 GDP Water Resources Ecological footprint

This indicator can be used to measure the utilization of water resources, with the following formulas:

Water resources ecological surplus (deficit)  =  $EC_w - EF_w$

When the results of $EC_w - EF_w$ are greater than, equal to, less than 00:00, the water resources show ecological surplus, ecological balance and ecological deficit respectively.

4.2 Results

The ecological footprint and ecological carrying capacity of water resources in China are calculated. The results are shown in fig. 5. It can be seen from the figure that the annual variation of the ecological carrying capacity of water resources in China is great, and the maximum value of the ecological carrying capacity of water resources appears in 1998, reaching 21.1. A minimum of 100 million hm²; was seen in 2004 and 2009, with only 1.5 billion hm², down 28.5%. By calculation, the ecological carrying capacity of water resources has a great correlation with precipitation, and the correlation coefficient is 0.5%. During the analysis period, China’s water resources showed a certain ecological surplus (fig. 5), and there was also a certain amount of growth. State space is available for use. The ecological footprint of GDP water resources in China has declined (Fig. 6), from 1.5% in 1997. 2hm² fell to 0.5% in 2010. 25hm², an annual decrease of 11.1%. The utilization rate of water resources in China is increasing year by year.

Figure. 5  Ecological footprint and ecological carrying capacity of water resources in China 1997-2010
The water resource utilization of a region or a country can be judged by comparing the relationship between the ecological carrying capacity of water resources per capita and the ecological footprint (hm$^2$) (Fig. 6). The ecological footprint of water resources per capita in China from 1997 to 2010 was maintained at 0.68 ~ 0.76hm$^2$/person showed the trend of first decreasing and then rising, the highest value appeared in 1997, and the lowest value appeared in 2003. The relative change of ecological carrying capacity of water resources per capita is relatively large, which is closely related to the amount of precipitation in the current year. The highest value appeared in 1998, reaching 1.569hm$^2$/person, this It was mainly affected by three heavy precipitation processes in the Yangtze River basin in that year, and the lowest value appeared in 2009, which was only 1.5%. The change trend of ecological surplus of per capita water resources is close to the trend of ecological carrying capacity, and the highest value appears in 1998, reaching 0.5% 97hm$^2$/person, the lowest in 2009, was just 0.5%. 39hm$^2$/person, still have ecological surplus, can further develop and utilize. The per capita ecological surplus of water resources has generally shown a downward trend, indicating that China's water demand is increasing, while climate change leads to changes in precipitation and water pollution. Changes in vegetation have also reduced the amount of water available in China.

In the ecological footprint account of water resources in China from 2003 to 2010, the agricultural water consumption was the largest, and the ecological footprint was maintained at 0.44hm$^2$/person and 0. The per capita ecological footprint of water resources fluctuated greatly between 46hm$^2$/person, which was the largest in 2006 and 2009, which was 0.5%. 46hm$^2$/person, the smallest in 2003, was just 0.5%. 44hm$^2$/person, accounting for an average of 62.2% of the total water account. Industrial water and domestic water accounted for 23.3% respectively. 175 percent and 12.5 percent. The ecological footprint of industrial water use is maintained at 0.15hm$^2$/person and 0. Between 18hm$^2$/person, domestic water is maintained at 0.5%. 081hm$^2$/person and 0. 094hm$^2$/person, showing a slow upward trend, ecological and environmental water supply only 1.5%. The range of changes over the years is 0. 1%. 01hm$^2$/person to 0. 015hm$^2$/person. In general, the ecological footprint of water resources of each production account is increasing (Fig. 7), and the water demand of each account is increasing.[15]
The ecological footprint of ten thousand yuan GDP water resources can reflect the utilization rate of water resources. It can be seen from figure 9 that GDP water resources of ten thousand yuan are the lowest in Beijing and Tianjin, and the water resources have been fully utilized. Xinjiang is the highest, mainly because of the economic structure and other factors, one of the characteristics of water use in Xinjiang is that the proportion of agricultural water use is too high, accounting for 95% of the total water consumption; Tibet took the second place, which was mainly related to industrial structure, water-saving level and water resources.[16]
5. Discussion

At present, domestic ecological footprint research has made gratifying progress, but there is still a big gap compared with outside countries. According to the study of domestic ecological footprint, comparing with the frontier research fields and trends of ecological footprint abroad, the research on domestic ecological footprint and sustainable development in the future should be strengthened in the following four aspects. The main contents are as follows:

(1) on the time scale, the study on the time series of ecological footprint is increased to reveal the internal interaction mechanism between the characteristics of regional ecological footprint and the evolution of regional development, as well as the corresponding coupling relationship between the change of regional ecological footprint and the regional sustainable development.

(2) on the spatial scale, we should increase the comparative study of the ecological footprint in the east, middle and west regions of China, large, medium, small cities, cities and villages, and analyze the structural hierarchy of the ecological footprint. The differences of validity rate, temporal dynamics, spatial superposition and spatial diffusion reveal the relationship between regional development and interregional, intercontinental and even global, and discuss the spatial segmentation scale and degree of regional ecological footprint spillover and transfer. The "mark value" of ecological footprint under the ecological ethics equity of regional development can better reveal the inner nature of regional development and regional and even global sustainable development. Relationship.

(3) on the one hand, we should strengthen ecological footprint and ecological compensation, ecological footprint and ecological security, ecological footprint and environmental ethics, the time series of ecological footprint, the different spatial scale comparison of ecological footprint. The ecological footprint of waste materials, the limiting factors of regional development capacity, the ecological footprint of circular economy and so on; On the other hand, we should strengthen the relationship between different consumption patterns, consumption level, ecological footprint in the
context of consumption culture and regional sustainable development, international trade. The inter-regional migration of ecological footprint caused by domestic trade and the inter-regional diffusion of ecological responsibility, energy, transportation, aquaculture, industry, The research on ecological footprint of specific industries and departments, such as agriculture and tourism, will expand the research field of ecological footprint.

(4) on the one hand, the improvement of ecological footprint calculation method should be strengthened, such as regional hectare, yield factor, equilibrium factor, land type, trade adjustment, energy consumption, waste absorption and so on. On the other hand, the ecological footprint analysis method should be combined with other indicators that can reflect the sustainable development of the region in terms of social economy and economy, and the index system and the analysis frame of the regional sustainable development based on the ecological footprint should be established. Vigorously developing HANPP (human appropriation of net primary pro Duction) analysis, strengthen the ecological footprint based on PIOTs (physical input_output tables) rather than MIOTs (monetary input_output tables), ecological burden research, promote regional and global sustainable development.

Acknowledgements: Supported by the National Social Science Foundation of China (Grant No. 15BGL086); Foundation of Jilin Science and Technology Committee (Grant No. 20200101086FG); Research Fund for the Doctoral Program of Changchun Normal University

List of abbreviations

(EFA) Exploratory Factor Analysis

Declarations

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

declares that he has no conflict of interest.
* Research involving human participants and/or animals
Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

* Informed consent
All authors agree to submit this version and claim that no part of this manuscript has been published or submitted elsewhere.

Funding

Supported by the National Social Science Foundation of China (Grant No. 15BGL086); Foundation of Jilin Science and Technology Committee (Grant No.
**Authors' contributions**

Roulin Chen is responsible for the writing of the paper, duanmin Zhang is responsible for the collection of experimental data, and Bo Li is responsible for the design of the experimental process.

**Acknowledgements**

Supported by the National Social Science Foundation of China (Grant No. 15BGL086); Foundation of Jilin Science and Technology Committee (Grant No. 20200101086FG); Research Fund for the Doctoral Program of Changchun Normal University.

**References:**

[1] William E. Rees. Ecological footprints and appropriated carrying capacity: what urban economics leaves out [J]. Focus, 1992, 6(2):121-130.

[2] XU Z M, CHENG G D, ZHANG Z Q. A resolution to the conception of ecological footprint [J]. China Population, Resources and Environment, 2006, 16(6): 69-78.

[3] Daniel D. Moran, Mathis C. Wackernagel. Trading spaces: Calculating embodied Ecological Footprints in international trade using a Product Land Use Matrix (PLUM) [J]. Ecological Economics, 2009, 68:1938-1951.

[4] Jin Xiangmu, Liu Qiankun. Evolution of Ecological footprint Model in Natural Resources Accounting and its Review [J]. Journal of Natural Resources, 2017, 32(1): 163-176.

[5] Xie G D, Feng Z M, Shen L, et al. Research Progress in Natural Resources and Environmental Security [J]. Journal of Natural Resources, 2010, 25(9):1424-1431.

[6] Guang-Cai X U, Kang M Y, Shi Y J. A Review of Adaptive Management Research on Natural Resources [J]. Journal of Natural Resources, 2013, 28(10):1797-1807.

[7] GAO X Y, GUO Y. Study on price structure of natural resources from the point of view of sustainable development [J]. Resources & Industries, 2010, 12(2): 129-133.

[8] HAMBIRA W L. Natural resources accounting: A tool for water resources management in Botswana [J]. Physics and Chemistry of the Earth, 2007, 32(15): 1310-1314.

[9] ZHANG Z Q, XU Z M, CHENG G D, et al. The ecological footprints of the 12 provinces of west China in 1999 [J]. Acta Geographica Sinica, 2001, 56(2): 599-609.

[10] Wang Y, Wang L. A review of research on ecological footprint [J]. Science of Soil & Water Conservation, 2011, 09(3):114-120.

[11] CHEN C Z, LIN Z S. Debate and development of ecological footprint model during the last 10 years [J]. Acta Ecologica Sinica, 2008, 28 (12): 6252-6263.

[12] Duan Jin, Kang Muyi, Jiang Yuan. Improved ecological footprint model based on freshwater resource accounts and pollution accounts [J]. Journal of Natural Resources, 2012, 27 (6): 953-963.

[13] DUAN J, KANG M Y, JIANG Y. Improvement of ecological footprint model based on fresh water resource account and pollution accounts [J]. Journal of Natural Resources, 2012, 27(6):953-963.

[14] LI J C, ZHONGZ X, GAO Z G. Theory and method of natural resource accounting. [J] Journal of Quantitative and Technical Economics, 1991(1): 30-35.
Figure 1:
Title: schematic diagram of calculation process of ecological footprint method
Legend: Figure 1 shows schematic diagram of calculation process of ecological footprint method

Figure 2:
Title: Evolution of ecological footprint model from two to three dimensions
Legend: Figure 2 shows Evolution of ecological footprint model from two to three dimensions

Figure 3:
Title: Time distribution of ecological footprint research papers (2000-2005 / 11)
Legend: Figure 3 shows time distribution of ecological footprint research papers (2000-2005 / 11)
Fig. 3: Time distribution of ecological footprint research papers (2000-2005 / 11)

Figure 4:

Title: Comparison of content and quantity of ecological footprint studies in China

Legend: Figure 4 shows comparison of content and quantity of ecological footprint studies in China

Fig. 4: Comparison of content and quantity of ecological footprint studies in China

Figure 5:

Title: Ecological footprint and ecological carrying capacity of water resources in China 1997-2010

Legend: Figure 5 shows Ecological footprint and ecological carrying capacity of water resources in
Figure 5: Ecological footprint and ecological carrying capacity of water resources in China (1997-2010)

Figure 6: Ecological footprint of GDP water resources in China from 1997 to 2010

Legend: Figure 6 shows Ecological footprint of GDP water resources in China from 1997 to 2010

Figure 7:
Title: Ecological footprint, ecological carrying capacity and ecological surplus of per capita water resources in China, 1997-2010

Legend: Figure 7 show Ecological footprint, ecological carrying capacity and ecological surplus of per capita water resources in China, 1997-2010

Figure 7: Ecological footprint, ecological carrying capacity and ecological surplus of per capita water resources in China, 1997-2010

Figure 8:

Title: Ecological footprint of water resources per capita in different production accounts in China, 1997-2010

Legend: Figure 8 show Ecological footprint of water resources per capita in different production accounts in China, 1997-2010
Figure 8: Ecological footprint of water resources per capita in different production accounts in China, 1997-2010

Figure 9:
Title: GDP water resources ecological footprint and ecological surplus of 31 provinces (autonomous regions, municipalities directly under the Central Government) of China from 2010 to 2010

Legend: Figure 9 show GDP water resources ecological footprint and ecological surplus of 31 provinces (autonomous regions, municipalities directly under the Central Government) of China from 2010 to 2010

Fig. 9 GDP water resources ecological footprint and ecological surplus of 31 provinces
(autonomous regions, municipalities directly under the Central Government) of China from 2010 to 2010