Application of Ecological Footprint

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Abstract Ecological footprint is a method of measuring how much we use the natural resources and how much the nature provides services for human beings. This paper summarized the application of ecological footprint at different scales and in different fields and different ecological types at home and abroad, analyzed the advantages and disadvantages of ecological footprint method, and made a prediction of the application of ecological footprint.

Key words Ecological footprint, Natural resources, Ecological deficit, Sustainable development

1 Introduction

The ecological footprint (EF) was first put forward by Canadian economist William E. Rees in 1992[1]. His doctoral student Wackernagel elaborated the generation of ecological footprint and the relationship between ecological footprint and sustainable development in *Our Ecological Footprint: Reducing Human Impact on the Earth* published in 1996. Ecological footprint is described as a footprint of giant foot carrying human and human cities, roads, farms, and factories left on the earth. Ecological footprint has become one of the most effective tools to analyze the impact of human beings on nature. Ecological footprint method can not only calculate the ecological footprint of individuals, families, and regions, but also can calculate regional, national and global ecological footprint, so the range of application is wide. The results of ecological footprint can be used as a decision-making tool. Different options or policies are firstly entered as method parameters that can be validated in the ecological footprint. To a certain extent, it can assist decision-makers in their decision to reduce the ecological footprint and make people understand the Impact of personal consumption pattern on the ecological environment.

2 Current situations of application of ecological footprint

2.1 Studies on the application of ecological footprint at different scales In recent years, the study of ecological footprint and its related problems has become a hot spot of many international eco-economists. The World Wildlife Fund (WWF) issues the world's ecological footprint every two years since 1998. With the advocate of Wackernagel and many scholars, the global ecological footprint website (http://www.footprintnetwork.org) was established. At the same time, major industrial countries have incorporated the ecological footprint indicators into the assessment indicator system. Because of its intuitive model, good operability, simple calculation method and wide application range, the ecological footprint analysis method has been widely used in various fields of sustainable development evaluation. In recent years, scholars have carried out extensive studies at different scales and in different industries and regions.

2.1.1 Studies at the global scale. Since 1998, WWF has issued the *Living Planet Report* every two years, to reflect the state of the nation and its impact on human activities. According to *Living Planet Report 2004*, since 1961, the human ecological footprint has increased more than three times. The human occupation of the earth's ecosystem is about 25% more than that of the earth's biosphere. It takes 1.2 years to produce products consumed by the human. According to prediction, at current speed of resource consumption, by 2050, human will consume natural resources about the volume of 2 earths[2]. In 1999, Wackernagel *et al.*[3] calculated the ecological footprints of 52 countries and regions in 1993 using the ecological footprint model. The results showed that the global ecological footprint per capita was 2.8 ha, while the available biological production area was only 2.1 ha and the global ecological deficit per capita was 0.7 ha.

2.1.2 Studies at the national scale. At the national level, McDonald *et al.*[4] calculated and analyzed the ecological footprints of 16 New Zealand regions in 1998. Haberl H *et al.*[5] compared the ecological footprints of Australia in 1926 - 1995, stated the WWF *Report of the Earth's Vitality*, and pointed out that more than half of the world's countries remained in an ecological deficit state. In China, Zhao Xiangui *et al.*[6] conducted a dynamic study on the ecological footprint of China in the past 26 years from 1978 to 2003. The results showed that the ecological footprint per capita in China increased from 0.8992 ha to 2.2522 ha and the per capita ecological deficit increased from 0.127 ha to 1.3702 ha, indicating that China's existing development model is the consumption of natural resources in exchange for economic development, and ecological security is facing a severe test. Liu Moucheng *et al.*[7] calculated the ecological footprint of China since 1949 (1949 - 2008). The results show that the ecological footprint of China per capita in the past 60 years since the founding of the People's Re-

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public of China has been increasing, while the per capita biological carrying capacity constantly declines with fluctuation. In addition, Xu Zhongmin, Chen Chengzhong and other scholars assessed and analyzed China's ecological footprint, the majority of the results show that China is facing more and more serious ecological deficit and remains in an unsustainable state. Since Wackernagel and other scholars applied the theory of ecological footprint in the comparison of ecological carrying capacity between countries, extensive studies have shown that ecological footprints are increasing.

2.1.3 Studies at the regional scale. For the studies at the regional scale of ecological footprints, in foreign countries, Kautsky *et al.* [8] calculated the fishery ecological footprint of 29 major cities in the Baltic Sea basin in Europe, and Wackernagel *et al.* [9] analyzed and calculated ecological footprint of Vancouver, Canada, and Baglian *et al.* [10] studied the province of Siena, Italy, and Muniz *et al.* [11] studied ecological footprint of Barcelona, Spain. For Chinese scholars, Xie Gaodi *et al.* [12] used the ecological footprint method to evaluate the consumption of ecological services in China during the 1950 – 1995, and the results show that at the provincial scale, more than 85% provinces are in the form of ecological deficit , and only Tibet, Hainan, and Fujian remain at the ecological surplus. Wang Zhijie *et al.* [13] compared and calculated the ecological footprints of East China, Central China and Southwest China from 2001 to 2010, and the results show that ecological footprints of these regions are basically in the form of ecological deficits. Li Guangjun *et al.* [14] studied the application of ecological footprint in urban development of China and calculated the ecological footprint of different cities in China in 2004. The results show that the ecological footprint of Hong Kong was 4.8676 ha / person and its ecological carrying capacity was only 0.0399 ha / person, the demand was 122 times of the supply, followed by Shanghai, Beijing, Tianjin, Qingdao, Shenyang, Shenzhen and Chongqing. The above studies show that with the rapid development of human society and the increase in personal consumption, the demand for natural resources has exceeded the carrying capacity of the earth. Most of the regions are maintaining the existing economic growth through the overdraft of ecological capital.

2.1.4 Studies at the small scale. The early researches on ecological footprint were mainly focused on the national, provincial and municipal administrative regions, and there were few studies at the small scale. Nicholson *et al.* [15], taking the operation of Anglian Water Services in 1998 as an example, introduced the calculation method of enterprise ecological footprint and how to apply the ecological footprint method into the enterprise's evaluation analysis system. Li Bing *et al.* [16], introduced the idea of life cycle assessment, and studied the ecological footprint and ecological efficiency of an enterprise in Chengdu. The ecological footprint of the enterprise was 230.66 ha, the energy, raw materials and water were the highest and accounted for 93.5% of the total ecological footprint; the ecological efficiency the enterprise was 472384 yuan / ha, showing relatively high ecological efficiency. This study quantitatively reveals the ecological efficiency of enterprises and its influencing factors. In contrast, the application of ecological footprint at the domestic small scale is more concerned about the ecological footprint of university campus. Jiang Li *et al.* [17] calculated the ecological footprint of Lanzhou University (Panxuan Road Campus) in 2003 and obtained that the ecological footprint was 0.892 ha/person. The per capita ecological footprint of male and female students was 0.976 ha and 0.788 ha, respectively. These data were relatively lower than that of national or western regions. However, the overall ecological footprint was 4119.3 ha, which was 73.7 times of the campus area.

2.2 Application of the ecological footprint in different fields

2.2.1 Industrial field. Industry is the main source of national economic income, but also the main source of environmental pollution, especially the chemical industry. In 2008, Beynon *et al.* [18] first calculated the ecological footprint of a dairy processing factory. Since then, many scholars in some other industries started carrying out ecological footprint researches. Robert *et al.* [19] used the life cycle method to calculate the ecological footprint of the Antarctic, and Herva *et al.* [20] introduced the calculation and evaluation of ecological footprints in enterprises taking textile industry in Spain as an example. Yu Hongmin *et al.* [21] carried out an empirical study on the ecological footprint and composition and changes in the steel industry. The results show that with the rapid growth of steel production, the ecological footprint of the steel industry has increased significantly because the main body of the ecological footprint of the steel industry is the indirect occupation of energy. Cui Weijun *et al.* [22] comprehensively analyzed the formation mechanism of ecological footprint of heavy chemical industry, divided the formation ecological footprint of heavy chemical industry into two stages: resource consumption and environmental discharge, and tried to apply ecological footprint method to sustainable development evaluation of the heavy industry, in the hope of guiding the development of China's heavy chemical industry.

2.2.2 Energy field. It has proved that the massive use of fossil fuels by human is the main factor leading to an increase in atmospheric CO_2 concentration and global warming. Zou Yanfen *et al.* [23] calculated the per capita energy ecological footprint of China from 1980 to 2007, and calculated the efficiency of energy ecological footprint. The results showed that the ecological footprint efficiency of energy has been increasing. They also studied the influence of scientific and technological progress on energy ecological footprint, indicating that scientific and technological progress can reduce the energy ecological footprint[24].

2.2.3 Transport field. After Holden *et al.* [25] introducing the concept of transport ecological footprint, many countries have made extensive calculation of the ecological footprint in the transport field. In China, Zong Gang *et al.* [26] calculated the ecological footprint of public transport in Beijing from 2005 to 2010, indicating a growing trend. The average annual growth rate was about 12.3% , and the proportion of public transport ecological footprint to total ecological footprint is low, conforming to the requirements

of sustainable development. Therefore, it is required to further promote the development of public transport, especially the rail transport. Li Jie *et al.* [27], taking Wuhan City as an example, made a systematic introduction of the calculation method of ecological footprint for urban passenger transport and evaluated the influence of passenger transport on urban ecological environment in Wuhan. According to their results, in the type of occupied land, fossil energy took up the largest part (95.13%), followed by water footprint (accounting for 4.75%), while the construction land only accounting for 0.12%; in the structural analysis of the ecological footprint, private cars accounted for 55.85%, the ecological footprint of bus, taxi and motorcycle accounted for 18.26%, 15.21%, and 6.36% respectively, electric vehicles only accounted for 3.08%, and bicycles and other travel mode were very small and could be ignored.

2.2.4 Life field. With the acceleration of the modernization process, people are increasingly concentrated in urban areas. When the population gets relatively concentrated, the consumption of life is gradually increasing. Using the ecological footprint test technology system for housing consumption of urban residents, Li Feng *et al.* [28] studied the ecological footprint of housing consumption of urban residents in Chongqing, to reveal the characteristics and mechanism of their changes. At the same time, they made a dynamic comparative study on the ecological footprint of housing consumption in the central cities of the Yangtze River Basis, including Wuhan, Nanjing and Shanghai[29].

2.2.5 Recreation field. With the continuous improvement of people's living standards in recent years, outdoor recreational activities are increasing rapidly, which brings the climax of ecotourism. As early as in 2002, Gossling *et al.* [30] applied the ecological footprint as a tool to the tourism industry to evaluate its sustainability. Taking Huangshan City as an example, Zhang Jinhe *et al.* [31] built the tourism ecological footprint model, including 6 calculation sub-models, namely, transport, accommodation, catering, shopping, entertainment and sightseeing, and analyzed the tourism ecological footprint and its efficiency in 2002. Zhen Yi *et al.* [32] divided the tourism ecological footprint into two types: movable ecological footprint and immovable ecological footprint. Taking Zhangjiajie as an empirical study object, they analyzed the tourism ecological footprint of Zhangjiajie in 2006. The results showed that the immovable ecological footprint was 221069 ha, movable ecological footprint of 123904 ha. Yang Lifang *et al.* [33], through combining the ecological footprint analysis and scenario planning, analyzed the impact of outdoor recreational sports on the environment and tried to translate them into various types of resource consumption. They built four scenario scenarios using scenario planning method and calculated the energy consumption of each scenario. Ecological footprint has been applied to many more fields, to better guide the various human behavior.

2.3 Application in different ecological types

2.3.1 Agricultural ecosystem. Due to excessive use of chemical fertilizers and pesticides, agricultural ecosystem has suffered serious environmental pollution problem. Liu Hongli *et al.* [34] analyzed the ecological footprint of farmland in Hubei Province from 1990 to 2004, and its ecological deficit fluctuated slightly from 0.1956 ha to 0.1571 ha. Chen Chunfeng *et al.* [35], taking the farmland resource of Heilongjiang as an example, studied the ecological footprint of farmland in Heilongjiang. The results show that the per capita ecological footprint of farmland in 2005 was 1.358 ha, and the per capita ecological carrying capacity was 0.829 ha. These indicate that the ecological footprint of farmland in most suitable arable land in China is also in a state of deficit. Therefore, it is required to strengthen the management and planning of farmland.

2.3.2 Forestry ecosystem. The function of forestry ecosystem is well known in protecting the ecological environment. Hu Xiaofei *et al.* [36] studied the ecological footprint of China's forestry in 1973 – 2003. Ji Chunyi *et al.* [37], with the aid of the ecological footprint model, measured the movement of forest ecological footprint caused by import of Chinese logs from 1995 to 2007, and compared the ecological footprint of import of Chinese logs and the global forest ecological footprint and carrying capacity.

2.3.3 Grassland ecosystem. Xie Hongyu *et al.* [38] revised the calculation of grassland ecological footprint. In the process of analysis, they found that China's livestock husbandry takes separate breeding as main mode of production. Therefore, when calculating the ecological footprint of grassland, it is required to consider the composition of livestock feed. According to this, it can be induced that pork, poultry and egg footprints mainly come from feed, while beef, lamb and milk footprint come from forage and feed. Based on the grain consumption per unit livestock product and the average milk production of grassland in China, we calculated ecological footprint of various livestock products and obtained following results: 1 kg of poultry footprint was 7.6687 ha, the bird footprint was 8.0106 ha, pork footprint was 9.7859 ha or 11.7326 ha, the beef footprint was 139.704 ha, the mutton footprint was 232.0662 ha, and the milk footprint was 37.2368 ha.

2.3.4 Water ecosystem. At present, water resource utilization is a major issue concerning people's livelihood in all over the world. In 2004, Chapagain *et al.* [39] studied the establishment and calculation of water footprint account of a country. Hoekstra *et al.* [40] proposed the concept of water footprint and applied the concept of ecological footprint to the calculation of water resources. Huang Linnan *et al.* [41] considered other functions of the groundwater and surface water as water resources, and calculated the ecological footprint of water resources of Jiangsu Province in 1998 – 2003, showing a slight rising trend, but the water use efficiency had significant increase. Wang Wenguo *et al.* [42] analyzed the ecological footprint and ecological carrying capacity of water resources in Chongqing in 2000 – 2009, and the water resources carrying capacity was higher than the ecological footprint and had certain ecological surplus. Zhang Yi *et al.* [43] introduced the current situation of the basic theory and basic models of water ecological footprint research in China, and analyzed the existing shortcomings and deficiencies.

3 Prospects of application of ecological footprint

Ecological footprint transforms the demand for eco-environment of human social and economic activities into the area demand according to the global average production[44], realizing the possibility of evaluating the ecological footprint and ecological carrying capacity using the bio-productive land area, and the results could be compared among different countries[45]. Therefore, the ecological footprint has been widely concerned and applied at various levels. Besides, based on the application of ecological footprint, some scholars have put forward the concepts of water footprint[46] and carbon footprint[47], making the calculation of the footprint more pertinent. At present, however, ecological footprint is only considered as a calculation and communication tool, and there is no much significance in decision analysis. In addition, its calculation reflects the impact of human needs and activities on the environment, but it does not make a comprehensive evaluation of all demands and activities of the human beings. Furthermore, sometimes it is difficult to obtain data for calculation, thus not all aspects can be included in the calculation. In view of the above shortcomings, we made following prospects for the development of ecological footprint: when it is used as part of a series of indicators, the combination with other indicators will play a greater role. Therefore, it is required to strengthen the connection with the existing accounting system (GDP, for instance) and increase the possibility of acceptance by decision makers. Also, it is required to broaden the scope of the possible influencing factors, to ensure that the conclusions reflecting the local ecological situation can be obtained ultimately. Finally, it is required to increase the openness of data access and the scope, to ensure comprehensive calculation items.

References

[1] REES WE. Ecological footprints and appropriated carrying capacity: what urban economics leaves out[J]. Environmental and Urbanization, 1992, 4(2):121 – 130.

[2] ZHANG ZQ. The earth is difficult to carry human burden——Interpretatating "Life Planet Report 2004"[J]. Earth Science Progress,2005,20(4):378 – 383. (in Chinese).

[3] WACKERNAGEL M, LEWAN L. Evaluating the use of natural capital with the ecological footprint[J]. Ambio, 1999, 28(7):604 – 612.

[4] MCDONALD, GW, PATTERSON MG. Ecological footprints and interdependencies of New Zealand regions[J]. Ecological Economics, 2004, 50(1 – 2): 49 – 67.

[5] HABERL H, ERB KH, *et al.* How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926 – 1995[J]. Ecological Economics, 2001, 38(1): 25 – 45.

[6] ZHAO X G, GAO L F, MA C H, ZOU X M. Dynamics of ecological footprint in China[J]. Chinese Journal of Eco-Agriculture, 2007,15(1): 149 – 152. (in Chinese).

[7] LIU M C,WANG B,LI W H. Analysis and dynamic prediction of China's development based on the ecological footprint method[J]. Resources Science, 2010, 32(1): 163 – 170. (in Chinese).

[8] KAUTSKY N, BERG H, FOLKE C, *et al.* Ecological footprint for assessment of resource use and development limitations in Shrimp and Tilapia aquaculture[J]. Aquaculture Research. 1997, 10: 753 – 766.

[9] Global Footprint Network. Ecological footprint atlas 2010[R]. Global Footprint Network, Oakland B Ewing, D Moore, S Goldfinger, A Oursler, 2010.

[10] BAGLIAN M, FERLAINO F, *et al.* Ecological footprint and input-output methodology: The analysis of the environmental sustainability of the economic sectors of piedmont region (Italy)[A]//Proceedings of the 14th International Conference on Input-Output Techniques [C]. MontrÉAl, Canada, 2002, 10: 10 – 15.

[11] MUNIZ I, GALINDO A. Urban form and the ecological footprint of commuting: The case of Barcelona[J]. Ecological Economics, 2005, 55: 499 – 505.

[12] XIE GD, CAO SY, LU CX, *et al.* Human's consumption of ecosystem services and ecological debt in China[J]. Journal of Natural Resources, 2010,25(1):43 – 51. (in Chinese).

[13] WANG ZJ, GAO J. Energy ecological footprint comparative study on the regional sustainable development status in our country[J]. Journal of Southwest Normal University (Natural Science Edition), 2013, 38(2): 54 – 60. (in Chinese).

[14] LI GJ, WANG Q, GU XW, *et al.* Application of ecological footprint in Chinese Cities' development[J]. Journal of Northeastern University (Natural Science), 2007, 28(10): 1485 – 1488. (in Chinese).

[15] NICHOLSON IR, CHAMBERS N, GREEN P. Ecological footprint analysis as a project assessment tool proceedings of the Institution of Civil Engineers Engineering Sustainability[J]. Engineering Sustainability, 2003, 156(9): 139 – 145.

[16] LI B, ZHANG JQ, QUAN JM. The ecological footprint and ecological efficiency research[J]. Environmental Engineering, 2007, 25(6): 85 – 88. (in Chinese).

[17] JIANG L,CHENG ZJ, SHEN XJ. Lanzhou University (circle road campus) ecological footprint analysis in 2003[J]. Journal of Geography and Geographic Information Science, 2005, 21(2): 82 – 85. (in Chinese).

[18] BEYNON MJ, MUNDAY M. Considering the effects of imprecision and uncertainty in ecological footprint estimation: An approach in a fuzzy environment[J]. Ecol Econ, 2008, 67: 373 – 383

[19] ROBERT WRP. Measuring and characterizing in the ecological footprint and life cycle environmental costs of Antarctic Krill (Euphausia Superb) products[D]. Dalhousie University Halifax, Nova Scotia, 2011.

[20] HERVA M, FRANCO A, *et al.* An approach for the application of the ecological footprint as environmental indicator in the textile sector[J]. Hazard Mater, 2008,156: 478 – 487.

[21] YU HM, WANG Q, YU XF, *et al.* Ecological footprint of China's iron and steel industry[J]. Journal of Northeastern University (Natural Science), 2008, 29(6): 897 – 900. (in Chinese).

[22] CUI WJ, ZHOU FX, XU CP. Method study of ecological footprint calculating of heavy and chemical Industry in China[J]. China Population, Resources and Environment, 2010, 20(8): 137 – 141. (in Chinese).

[23] ZOU YF. Evaluating Chinese efficiency of energy ecological footprint [J]. China Mining Magazine, 2009, 18(8): 57 – 64. (in Chinese).

[24] ZOU YF. Effects of technological advance on energy ecological footprint in China[J]. Resources Science, 2010, 32(7): 1280 – 1288. (in Chinese).

[25] HOLDEN E, HOYER KG. The ecological footprints of fuels[J]. Transportation Research Part D: Transport and Environment, 2005, 10(5): 395 – 403.

[26] ZONG G, LI YF. The Beijing public traffic ecological footprint[J]. Urban Problem, 2013, 4: 54 – 60. (in Chinese).

[27] LI J, HU G J, GAO J, *et al.* Calculation and analysis of urban passenger traffic ecological footprint in Wuhan[J]. Journal of Wuhan Institute of Technology, 2013, 35(3): 1 – 7. (in Chinese).

[28] LI F, QIU DC, LI XG, *et al.* Chongqing urban residents' housing consumption classification study ecological footprint[J]. Journal of Southwest University (Natural Science Edition), 2013, 35(3): 1 – 7. (in Chinese).

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source phosphorus pollution load in 2015 was in the order of Zouping County > Bincheng District > Boxing County > Yangxin County > Huimin County > Zhanhua County > Wudi County; it was highest (8000 t) in Zouping County and lowest (1000 t) in Wudi County. It was also found that the spatial distribution of non-point source nitrogen and phosphorus pollution load was not even in Binzhou City in 2015.

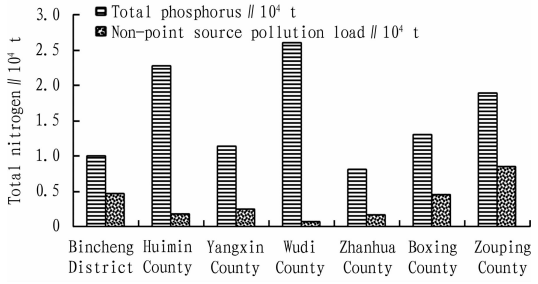

Fig. 4 Non-point source pollution load in Binzhou City in 2015

4 Conclusions and discussions

(i) The agricultural non-point source nitrogen and phosphorus pollution in Binzhou City changed from 114400 t and 28800 t in 2008 to 110600 t and 24400 t in 2015, respectively. Due to heavy use of nitrogen fertilizer in Binzhou City in 2009 and 2010, the non-point source nitrogen pollution in 2009 and 2010 was significantly higher than in other years. (ii) For the non-point source nitrogen pollution sources, the proportion of chemical fertilizer, manure and domestic sewage changed from 80.41%, 10.47% and 9.13% in 2008 to 82.94%, 4.77% and 12.29% in 2015, respectively; for the non-point source phosphorus pollution sources, the proportion of chemical fertilizer, manure and domestic sewage changed from 89.29%, 8.32% and 2.39% in 2008 to 91.6%, 4.78% and 3.62% in 2015, respectively. On the whole, the contribution rate of chemical fertilizer phosphorus tended to increase, while the contribution rate of manure phosphorus tended to decrease; the contribution rate of domestic sewage phosphorus did not change much. (iii) In 2015, the non-point source nitrogen pollution was most serious in Wudi County and Huimin County and least serious in Zhanhua County; the non-point source phosphorus pollution was most serious in Zouping County and least serious in Wudi County; the spatial distribution of non-point source nitrogen and phosphorus pollution load was not even in Binzhou City in 2015.

References

[1] HUANG J, ZHANG X, PENG J, *et al.* Temporal and spatial distribution and transportation of nitrogen and phosphorus in stormwater runoff[J]. Journal of Agro-Environment Science, 2004, 23(2):255 - 258. (in Chinese).

[2] HUANG MX, ZHANG S, ZHANG GL, *et al.* Losses of nitrogen nutrient in overland flow from farmland in Beijing under simulated rainfall conditions [J]. Acta Geographica Sinica, 2003, 58(1): 147 - 154. (in Chinese).

[3] FANG LP, ZHANG HM, ZHANG MK. Spatio-temporal changes of agricultural non-point source N and P and its potential effect on surface water quality in Zhejiang Province[J]. Journal of Zhejiang Agricultural Sciences, 2008 (5):577 - 582. (in Chinese).

(From page 60)

[29] LI F, QIU DC, LI XG, *et al.* Comparative study center city housing consumption in Yangtze River Basin Ecological footprint-Chongqing, Wuhan, Nanjing, Shanghai, for example[J]. Journal of southwest university (natural science edition), 2013, 35(6): 149 - 155. (in Chinese).

[30] GOSSLING S, BORGSTROM CH, HORSTMEIER O, *et al.* Ecological footprint analysis as a tool to assess tourism sustainability[J]. Ecological Economics, 2002, 43: 199 - 211.

[31] ZHANG JH, ZHANG J. Touristic ecological footprint model and analysis of Huangshan City in 2002[J]. Acta Geographica Sinica, 2004, 59 (5): 763 - 771. (in Chinese).

[32] ZHEN Y, KANG WX. A modified ecological footprint model and analysis of Zhangjiajie[J]. Issues of Forestry Economics, 2008, 28(4): 306 - 309. (in Chinese).

[33] YANG LF. Based on the perspective of ecological footprint analysis of the outdoor leisure sports consumption[J]. Journal of Beijing Sport University, 2013, 36(1): 41 - 45. (in Chinese).

[34] LIU HL, HUANG CX. Hubei Province farmland ecological footprint dynamic analysis[J]. Resources and Industry, 2007, 9(3): 72 - 76. (in Chinese).

[35] CHENG CF, WANG HY, XIAO DN, *et al.* Based on the ecosystem services and ecological compensation mechanism of ecological footprint——In order to cultivated land resources in Heilongjiang Province as an example[C], In 2008 the National Ecological Compensation Proceedings of International Conference, 2008: 89 - 95. (in Chinese).

[36] HU XF, DAI LM, GU HY, *et al.* Chinese forestry ecological footprint in 1973 - 2003 study[J]. Journal of Forestry Research, 2006, 17(2):87 - 92. (in Chinese).

[37] JI CY, YANG HQ, NIE Y. China imported iog intercontinental forest ecological footprint impact[J]. Journal of Forestry Economy, 2010, (2): 104 - 108. (in Chinese).

[38] XIE HY, CHENG XS, YANG MZ, *et al.* Ecological footprint analysis unit of China animal husbandry products[J]. Acta Ecologica Sinica, 2009, 29(6): 3264 - 3270. (in Chinese).

[39] CHAPAGAIN AK, HOEKSTRA AY. Water footprints of nations[R]. Value of Water Research Report Series 16; UNESCO-IHE: Delft, the Netherlands, 2004.

[40] HOEKSTRA AY, CHAPAGAIN AK. Water footprints of nations: Water use by people as: A function of their consumption pattern[J]. Water Resource Managem, 2007, 21: 35 - 48.

[41] HUANG LL, ZHANG WX, JIANG CL, *et al.* Water ecological footprint calculation method[J]. Acta Ecologica Sinica, 2008, 28(3): 1279 - 1286. (in Chinese).

[42] WANG WG, GONG JP, QIN P, *et al.* Chongqing water ecological footprint and ecological carrying capacity analysis[J]. Ecological Economy, 2011 (7): 159 - 162. (in Chinese).

[43] ZHANG Y. Based on the preliminary study on the ecological footprint of ecosystem services of water[J]. Journal of Resources and Environment in Yangtze River Basin, 2013, 22(4): 502 - 507. (in Chinese).

[44] LIU M, HU Y M, CHANG Y, *et al.* Ecological footprint method and its application in regional sustainable development research[J]. Journal of Ecology, 2007, 26(8): 1285 - 1290. (in Chinese).

[45] WACKERNAGEL M, YOUNT JD. Footprint for sustainability: the next step[J]. Environment, Development and Sustainability, 2002(2): 21 - 42.

[46] HOEKSTRA AY, CHAPAGAIN AK. Water footprints of nations: Water use by people as a function of their consumption pattern[J]. Water Resource Management, 2007, 21: 35 - 48.

[47] KENNY T, GRAY NF. Comparative performance of six carbon footprint models for use in Ireland[J]. Environmental Impact Assessment Review, 2009, 29(1): 1 - 6.