Dynamic evaluation and trend prediction of environmental sustainability in Jiangxi Province based on pollution footprint

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Abstract. Based on the calculation results of pollution footprint, environmental carrying capacity and pollution deficit/surplus in Jiangxi Province from 2004 to 2015, the environmental sustainability was dynamically evaluated in Jiangxi Province from 2004 to 2015 based on a designed environmental sustainability standard with the ratio of pollution deficit/surplus to environmental pollution footprint. It was shown that Jiangxi Province was in the pollution surplus status during 2004 to 2015, which was derived from solid waste pollution surplus and atmospheric pollution surplus, while the water environment has been in pollution deficit. It can be seen that the environmental sustainability of Jiangxi was middle from 2005 to 2007 and strong from 2008 to 2015. Meanwhile, a pollution footprint prediction model \( y = -8260.6x^2 + 62750x + 5 \times 10^7 \) was built to predict the pollution footprint trend of Jiangxi Province in the next five years, and that based on the environmental pollution footprint of Jiangxi Province from 2004 to 2015. It showed that the pollution footprint of Jiangxi Province would drop from 4563473.60 hm² in 2016 to 3889286.40 hm² in 2020.

1. Introduction
The ecological footprint was first proposed by Canadian eco-economist William Rees [1] in 1992. His doctoral student Wackernagel [2] developed further into the ecological footprint model in 1996, which became a new measure way of the pressure and influence of human activities on ecosystems. In order to overcome the limitations of traditional ecological footprint theory to eliminate the lack of discharging a pollutant, the pollution footprint had been put forward and applied by domestic and foreign scholars [3-9].

With the rapid development of industrialization and urbanization in Jiangxi province and the rapid growth of population, the environmental sustainability of Jiangxi province was affected. The impact on environmental sustainability in Jiangxi province is worth studying. In this paper, the environmental sustainability of Jiangxi province from 2004 to 2015 was evaluated and the trend of pollution footprint in the next five years was predicted guided by the ecological footprint theory. It will be hopeful to provide a scientific basis for the formulation of environmental policy and pollution prevention plan, and it will promote the sustainable development for Jiangxi Province environment.

2. Dynamic evaluation of environmental sustainability in Jiangxi Province

2.1 current situation of pollution footprint in Jiangxi province from 2004 to 2015
The pollution footprint, environmental carrying capacity and pollution deficit of Jiangxi province from 2004 to 2015 were respectively summarized in table 1, table 2 and table 3.
Table 1. Pollution footprint of Jiangxi Province in 2004-2015

| Time  | Water pollution footprint | Atmospheric pollution footprint | Solid waste pollution footprint | Total pollution footprint |
|-------|---------------------------|-------------------------------|-------------------------------|---------------------------|
| 2004  | 414797.83                 | 3515407.9                    | 598.56                        | 3930804.29               |
| 2005  | 402496.09                 | 4143972.63                   | 642.79                        | 4547111.51               |
| 2006  | 414352.66                 | 4276848.48                   | 678.23                        | 4691879.37               |
| 2007  | 422865.44                 | 4172618.51                   | 713.51                        | 4596197.46               |
| 2008  | 201259.83                 | 3920738.48                   | 751.42                        | 4122749.73               |
| 2009  | 393484.3                  | 3787189.8                    | 816.33                        | 4181490.43               |
| 2010  | 375579.18                 | 3740239.69                   | 863.07                        | 416681.94                |
| 2011  | 577141.06                 | 4012673.71                   | 1043.34                       | 4590858.11               |
| 2012  | 590716.94                 | 3887151.69                   | 1021.41                       | 4478890.04               |
| 2013  | 591591.22                 | 3821629.77                   | 1025.81                       | 4414246.8                |
| 2014  | 597081.01                 | 3716214.51                   | 992.77                        | 4314225.29               |
| 2015  | 548350.61                 | 3683750.76                   | 988.69                        | 4233090.06               |

Table 2. Pollution capacity of Jiangxi Province in 2004-2015

| Time  | Water pollution capacity | Atmospheric pollution capacity | Solid wastes pollution capacity | Total pollution capacity |
|-------|--------------------------|-------------------------------|-------------------------------|--------------------------|
| 2004  | 72766.2                  | 10582037.9                    | 9638074.21                    | 20292878.3               |
| 2005  | 74945.0                  | 10593048.9                    | 9751857.25                    | 20419851.2               |
| 2006  | 75905.2                  | 10604059.9                    | 9884910.9                     | 20564876                |
| 2007  | 79425.55                 | 10615070.9                    | 10920768.8                    | 21615265.3               |
| 2008  | 80411.98                 | 10626081.9                    | 13140779.1                    | 23847273                |
| 2009  | 83411.17                 | 10637092.9                    | 13106281.7                    | 23922363.2               |
| 2010  | 85092.62                 | 10730937.8                    | 13106332.8                    | 23927392.4               |
| 2011  | 85639.26                 | 10730937.8                    | 13111031.9                    | 23927609                |
| 2012  | 86419.56                 | 10730937.8                    | 13106435.1                    | 23927392.4               |
| 2013  | 86645.2                  | 10741948.8                    | 13106486.2                    | 23935080.2               |
| 2014  | 87065.08                 | 10752959.8                    | 13106537.3                    | 23946562.2               |
| 2015  | 86722.56                 | 10763970.8                    | 13106588.4                    | 23957281.8               |

Table 3. The pollution deficit/surplus of Jiangxi Province in 2004-2015

| Time  | Water pollution deficit | Atmospheric pollution surplus | Solid waste pollution surplus | Total pollution surplus |
|-------|------------------------|------------------------------|------------------------------|-------------------------|
| 2004  | 342031.63              | -7066630                     | -9637475.65                  | -16362074               |
| 2005  | 327551.09              | -6449076.27                  | -9751214.46                  | -1587239.6              |
| 2006  | 338447.46              | -6327211.42                  | -9884232.67                  | -15872996.6             |
| 2007  | 343439.89              | -6442452.39                  | -10920055.3                  | -17019067.8             |
| 2008  | 120847.85              | -6705343.42                  | -13140027.7                  | -19724523.3             |
| 2009  | 310073.13              | -6849903.1                   | -13105465.3                  | -19645295.3             |
| 2010  | 290486.56              | -6990698.09                  | -13105469.7                  | -19805681.3             |
| 2011  | 491501.08              | -6718264.07                  | -13109988.6                  | -19367509.9             |
| 2012  | 504297.38              | -6843786.09                  | -13105413.6                  | -19444902.4             |
| 2013  | 504946.02              | -6920319.01                  | -13105460.4                  | -19520833.4             |
| 2014  | 509952.93              | -7036745.27                  | -13105544.5                  | -19632336.9             |
| 2015  | 461628.05              | -7080220.02                  | -13105599.7                  | -19724191.7             |

It can be seen from the table 3 that Jiangxi Province was pollution surplus in 2004-2015. It was derived from solid waste pollution surplus and atmospheric pollution surplus, it indicated that Jiangxi Province had an excellent atmospheric environment. The water environment had been in a state of pollution deficit, which indicated that the water environment in Jiangxi province was polluted and...
exceeded the requirement of water environmental function zone and the self-purification ability of water. It showed that the overall environment in Jiangxi Province was improved when pollution surplus and solid waste pollution surplus rose from 2008. The minimum of pollution surplus was 15872739.64 hm² in 2005, while the maximum was 19805681.25 hm² in 2010. It was 19724191.71hm² in 2015.

2.2. Environmental sustainability evaluation of Jiangxi province

2.2.1. Environmental sustainability evaluation criterion

Based on the principle of equity, sustainability and intercommunity, the criterion for environmental sustainability evaluation was established and presented in table 4.

| Pollution footprint index | [-1, -0.8) | [-0.8, -0.5) | [-0.5, 0) | ≥0 |
|---------------------------|-------------|-------------|-----------|-----|
| Sustainability            | Strong sustainability | Middle sustainability | Weak sustainability | Unsustainable |

2.2.2. Environmental sustainability evaluation method

The environmental sustainability of Jiangxi Province was accessed by the ratio of deficit/surplus and pollution capacity (defined as pollution footprint index). The results were shown in table 5.

| Time | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Water pollution footprint index | 4.70 | 4.37 | 4.46 | 4.32 | 1.50 | 3.72 | 3.41 | 5.74 | 5.84 | 5.83 | 5.86 | 5.32 |
| Atmospheric pollution footprint index | -0.67 | -0.61 | -0.60 | -0.61 | -0.63 | -0.64 | -0.65 | -0.63 | -0.64 | -0.64 | -0.65 | -0.66 |
| Solid waste pollution footprint index | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| Total pollution footprint index | -0.81 | -0.78 | -0.77 | -0.79 | -0.83 | -0.82 | -0.83 | -0.81 | -0.82 | -0.82 | -0.82 | -0.82 |

From table 4 and table 5, it can be seen that the environmental sustainability of Jiangxi was strong in 2004-2015 except the middle sustainability in 2005-2007. The water environment had been in an unsustainable condition while the atmosphere had been in a middle sustainable condition. On the environmental pollution, the effects of atmospheric pollutants and solid wastes in Jiangxi Province were still acceptable, but the impact of water pollutants had exceeded the water environmental capacity. Measures must be taken to prevent water pollution.

3. Trend prediction of pollution footprint from 2016 to 2020 in Jiangxi Province

Based on the pollution footprint of Jiangxi Province from 2004 to 2015, the trend of pollution footprint of Jiangxi Province in the next five years was predicted by date fitting forecasting model which excluded the abnormal data in 2008, it was shown in figure 1.

According to the pollution footprint trend chart, the fitted trend function was 

\[ y = -8206x^2 + 62750x + 5 \times 10^6 \]

Where X was time and Y was the pollution footprint of according time. \( R^2 = 0.9389 \), with a significant correlation, so the fitted trend function can be used to forecast the development trend of pollution footprint in the next five years in Jiangxi Province. The results were shown in table 6.
Figure 1. Trend of pollution footprint changes in Jiangxi Province from 2004 to 2015.

Table 6. Prediction of pollution footprint’s development trend in Jiangxi Province in the next five years

| Time | 2016        | 2017        | 2018        | 2019        | 2020        |
|------|-------------|-------------|-------------|-------------|-------------|
| footprint | 4563473.60 | 4419708.60 | 4259422.40 | 4082615.00 | 3889286.40 |

Based on figure 1 and table 6, the pollution footprint of Jiangxi Province would decline in the next five years. Total pollution footprint would drop from 4563473.60hm² in 2016 to 3889286.40hm² in 2020. It was consistent with the trend chart (Figure 1.) of pollution footprint in Jiangxi Province which showed that the environmental pollution problem will be improved in the next five years. With the improvement of environmental awareness, as well as the strengthened control of the environment and pollution at all levels, the phenomenon was happened. Under the strict environmental governance situation, enterprises and institutions improved the efficiency of resource utilization. It reduced the pollutants from the source and reduced the emissions of pollutants from the terminal which caused a result that decrease pollution footprint gradually.

4. Conclusion
The temporal dynamic analysis of pollution footprint in Jiangxi Province was researched by using the pollution footprint model and the forecasted pollution footprint of Jiangxi Province will decline in the next five years. From 2004 to 2015, the state of Jiangxi Province’s total pollution footprint was surplus. However, the water environment had been in the state of pollution deficit. Besides the year of global subprime crisis, the water pollution footprint of Jiangxi Province gradually increased year by year trend. To constantly improve the environment of Jiangxi Province, first it should develop eco-industry, improve water recycling and reuse rate to reduce water pollutant emissions. It should also build clean enterprises and use clean energy to reduce air pollutant emissions. Then, water environmental capacity should be improved by protecting the water area and regulating the water system comprehensively; atmospheric pollution capacity would be improved by increasing the area of forest land and the proportion of greening. The last, strict environmental administrative supervision system should be established and implemented to make sure the pollution emissions of all enterprises meet the requirements of the sewage permit and the total control index.

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References

[1] Rees, W.E. (1992) Ecological footprint and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization, 4:120-130.

[2] Wackernagel, M., Rees, W.E. (1996) Our Ecological Footprint: Reducing Human Impact on the Earth. New Society, Gabriola, B C, Canada.

[3] Muradian, R., O’Connor, M., Martinez-Alier, J. (2002) Pollution in trade: estimating the environmental load displacement of industrialized countries. Ecological Economics, 41:51-67.

[4] Pu Wu, Peihua Shi. (2011) An estimation of energy consumption and CO2 emissions in the tourism sector of China. Journal of Geographical Sciences, 21: 733-745.

[5] Wenjun Jiao, Qingwen Min, Shengkui Cheng, et al. (2011) Pollution footprint and its application in regional water pollution pressure assessment: a case study of Huzhou City in the upstream of Taihu Lake Watershed. Acta Ecologica Sinica, 31:5599-5606.

[6] Qingwen Min, Wenjun Jiao, Shengkui Cheng. (2011) Pollution footprint: a type of ecological footprint based on ecosystem services. Resources Science, 33: 195-200.

[7] Xiaobai Zhou, Ninghong Zhang, Yong Zhang, et al. (2012) Pollution water footprint calculation based on the pollutant consumption theory: Taking the chemical oxygen demand index as the pollutant characteristic index. Ecology and Environmental Sciences, 21: 1975-1979.

[8] Jing Li, Qingwen Min, Wenhua Li, et al. (2014) Pollution Assessment of Rice Agriculture in the Taihu Lake Watershed Based on the Pollution Footprint: A Case Study of Changzhou City and Yixing City, China. Journal of Agricultural Resources and Environment, 31:372-380.

[9] Haixia Zhao, Songjun Xu. (2015) Discussion on Compensation Standards at the Regional Level Based on Pollution Footprint: A Case Study of Guangzhou. Journal of South China Normal University(Natural Science Edition), 47: 116-121.

[10] Tao Zhou, Yunpeng Wang, Jianzhou Gong, et al. (2015) Ecological footprint model modification and method improvement. Acta Ecologica Sinica, 35:4592-4603.

[11] The national economic statistics department of Jiangxi Provincial Statistic Bureau. (2017) Statistical bulletin of Jiangxi Province on the 2016 National Economic and Social Development. http://www.jxstj.gov.cn/News.shtml?p5=9457204.

[12] Statistic Bureau of Jiangxi. Jiangxi statistical yearbook(2004-2015). China Statistics Publishing House Publishing:2004-2015.

[13] Jie Wu, Wei Meng, Mingzuo Wu, et al. (2007) The Ecological Footprint of Xinxiang City from 1997 to 2005. Henan Science, 25:1063-1067.