CSCanada
Canadian Social Science
Vol. 16, No. 2, 2020, pp. 18-24
DOI:10.3968/11540

ISSN 1712-8056[Print]
ISSN 1923-6697[Online]
www.cscanada.net
www.cscanada.org

Research on Sustainable Development of Xi'an City Based on Ecological Footprint Model

ZHANG Li[a],*

[a] Lecturer, Ph.D, School of Humanities and Economics, Northwestern Polytechnical University, Xi'an, China.
*Corresponding author.

Received 21 December 2019; accepted 1 February 2020
Published online 26 February 2020

Abstract

This paper evaluates the sustainable development of Xi'an city with the ecological footprint method. Based on the ecological footprint method, it calculates the per capita ecological footprint of Xi'an city from the year 2000 to 2017. With the calculation result, the paper forecasts the per capita ecological carrying capacity and per capita ecological deficit, and draws the following conclusion: during the study period, ecological deficit occurs every year, and the ecological deficit in each year exceeds global average per capita ecological deficit. Besides, both ecological footprint and ecological deficit have a tendency to increase year by year, and the growth rates of both are higher than the growth rate of ecological carrying capacity. According to the calculation results of ecological footprint, ecological carrying capacity and ecological deficit of Xi'an city from the year 2000 to 2017, the GM (1, 1) model is used to predict the above three indicators. The predicted results show that the load of ecological environment in Xi'an region is over the ecological carrying capacity caused by the production and living activities of human beings. The resources and environmental system are under great pressure, and the regional development mode is in an unsustainable state. It is a necessity to reduce ecological footprint by improving industrial economic efficiency, cultivating the consumption habits of energy saving and environmental protection, promoting investment in environmental protection and stimulating technological progress, so as to promote the sustainable development of Xi'an city.

Key words: Ecological footprint; Ecological carrying capacity; Ecological deficit; Sustainable development; Xi'an city

Zhang, L. (2020). Research on Sustainable Development of Xi'an City Based on Ecological Footprint Model. *Canadian Social Science, 16*(2), 18-24. Available from: http://www.cscanada.net/index.php/css/article/view/11540
DOI: http://dx.doi.org/10.3968/11540

City is a crucial part of human civilization. With the expansion of cities, the urban resources, environment and sustainable development are overburdened. The protection of urban ecological environment and the guarantee of urban sustainable development are significant issues of global urban development. The quantitative evaluation of urban ecological footprint aims to measure whether the resources and environment can bear the development of urban economy and society, so as to provide references for the urban development plan considering economic growth, social development and ecological environment protection, for the rational urban development scale, and for the realization of regional sustainable development.

In the 1990s, Canadian ecologist William Rees (Rees, 1992) proposed the concept of ecological footprint for the first time, aiming to assess the impact on ecosystems by measuring the amount of natural capital consumption of people to meet their own needs in a certain region. As an index of evaluating sustainable development, ecological footprint has always been focused by scholars. At present, scholars have conducted extensive research on ecological footprint, including the research on the ecological footprint of a certain country or region (Peng, et al, 2019; Anass, Youness, & Abderrahmene, 2019), the research and analysis on a specific industry, such as agriculture (Diao, et al, 2012), industry (Dilawar, et al, 2019), tourism (Imran, et al, 2019), etc., and the research on the influencing factors of ecological footprint (Lin, 2017; Rong, et al, 2019).

Based on the research of previous scholars, this paper, taking Xi'an city as the target region, analyzes the change of the ecological footprint, ecological carrying capacity and ecological profit and loss (surplus or deficit) from the year 2000 to 2017 with the ecological footprint model. Besides, it predicts the ecological footprint and ecological carrying capacity to assess the sustainable development capacity of Xi'an city, so as to provide theoretical basis for government departments to make regional development policy.

1. OVERVIEW OF THE RESEARCH REGION

Xi'an city is located in the midsection of the Guanzhong plain which lies in the middle of Shaanxi province, on the edge of southern part of the Loess Plateau in the northwest region of China, between 107.40 to 109.49 degrees east longitude and 33.42 to 34.45 degrees north latitude. It has jurisdiction over 11 districts and 2 counties, also in charge of the Xixian New District. Xi'an city covers a total area of 10752 square kilometers. By the end of 2018, it has a resident population of 10.0037 million people and 74.01% urbanization rate, with its GDP totaling 834.986 billion yuan. The overall supply of land resources in Xi'an city is insufficient. With the process of urbanization and the increase of population, the urban construction land continues to expand and the cultivated land decreases sharply year after year, resulting in the shortage of land resources. As a water resources shortage city, Xi'an has been listed as one of the most seriously water-shortage cities in China. The resources and environment are extremely fragile in Xi'an city. From the aspects of air environmental quality, water environmental quality and solid waste emission, the pollution in these three aspects is quite serious. For the further development of Xi'an city, how to balance the relationship between industrial development, urbanization and environmental protection needs a coordinated resolution. As the core area of B&R(the Belt and Road initiative) and the important central city in western China, the ecological safety of Xi'an city is of great significance.

2. BASIC MODEL

Among so many methods to evaluate ecological carrying capacity, the ecological footprint method refers to calculating the biological productive land area which can meet the needs of resource consumption and waste degradation according to the scale of population and economy. Indicators with strong comparability are used in this method, which can realize the quantitative comparison between the current ecological demand of the human production and life and the ecological services provided by natural ecosystem. It can also make the quantitative evaluation of the human impact on natural ecosystems, which can reflect whether human activities are within the range of the ecological carrying capacity of natural ecosystem. The ecological footprint method can be used to analyze the sustainability of industrial development in a certain region and the coordination of industrial development, resources and environment (Zhang, et al, 2001). Therefore, this paper uses the ecological footprint method to quantitatively evaluate the ecological carrying capacity of industrial ecosystem in Xi'an city.

The survival and development of human must depend on the natural ecosystem. The survival and development of any individual, city or country must consume the products and services provided by nature, which have a certain impact on the ecosystem. The ecological footprint method assesses the impact of human activities on the ecosystem by measuring the amount of natural resources occupied by human beings for their survival currently. The calculation is based on two basic facts: first, the amount of resources consumed for human survival and the amount of waste produced by human can be determined; Second, the above resources and waste degradation can be converted into the corresponding biological production area.

At a certain technological level, the ecological footprint of the population within a certain region refers to the biological production area supporting natural resources and waste degradation to sustain human survival and consumption, mainly including two parts: land and water (Zhang, et al, 2001). It can be measured on a variety of scales, ranging from individuals, cities, countries or the whole body of mankind.

Ecologically productive land refers to the land or water area with ecological productive capacity, which is mainly divided into six types: fossil energy land, construction land, farmland, forest land, grassland and water area. The six types of ecologically productive land have different roles. They are: fossil fuels absorb CO_2 released by humans; Cultivated land produces crops; Forest land provides woods and forest products; Grassland provides livestock products; Construction land provides places for human production and life; Water area provides aquatic products. However, in practice, humans have not set aside land for CO_2 absorption. The ecological footprint can measure the essential area of ecologically productive land for the human survival.

The ecological carrying capacity can be measured by the area of ecologically productive land for human survival in a certain area (Jammazi & Aloui, 2015). By calculated the difference between ecological footprint and ecological carrying capacity, in a certain area, whether the impact of human production and life on the ecological environment is within the limits of the ecological environment can be evaluated (Aşici, 2013). Accordingly, the basic models of ecological carrying capacity evaluation include ecological footprint model, ecological carrying capacity model, ecological surplus and ecological deficit model.

2.1 Ecological Footprint Calculation Model

Component calculation of per capita ecological footprint of each consumption items:

The calculation formula of biological consumption items is (Kuznets, 1949):

$$B_i = \frac{C_i}{Y_i} = \frac{P_i + I_i - E_i}{Y_i \times N}$$

In the formula, i is the type of consumption item. B_i is the per capita biological production area converted by the i-th consumption item. C_i is the per capita consumption of the i-th consumption item. Y_i is the annual global output of the i item. P_i is the annual production of the i-th consumption item. I_i is the annual import of the i-th consumption item. E_i is the annual export of the i-th consumption item. N is the population.

Calculation of energy consumption items:

Energy consumption mainly calculates gasoline, diesel, coal, coke, fuel oil, crude oil and electric power project. According to the energy conversion coefficient and the equivalence factor, all the specific consumptions of each energy are converted into unified unit of energy, and the required fossil energy land and construction land can be calculated. Among them, the electric power consumption is converted into construction land area and the rest items are converted into fossil energy land area. The following is the specific algorithm formula:

$$EF_i = \frac{Q_i}{EW_i} \times Z_i$$

In the formula, EF_i is the single per capita ecological footprint of the i -th energy account. Q_i is the per capita annual consumption of the i project. EW_i is the global average energy footprint of the i -th energy, and Z_i is the conversion coefficient of the i -th energy.

The calculation formula of regional ecological footprint is as follows:

$$EF = N \times ef$$

In the formula, EF is the total ecological footprint of the region, and N is the population of the region, and ef is the per capita ecological footprint of the region.

The calculation formula of per capita ecological footprint is as follows (Rees, 1992):

$$ef = \sum_{j=1}^{6} r_j B_i = \sum_{j=1}^{6} r_j (P_i + I_i - E_i) / (Y_i \times N)$$

In the formula, i is the category of resource consumption items and r_j is the equivalence factor of the j -th ecologically productive land, which are converted into a unified ecologically productive land area for comparison.

2.2 Calculation Model of Ecological Carrying Capacity

The calculation formula of regional ecological carrying capacity is as follows:

$$EC = N \times ec$$

In the formula, EC is the total actual ecological carrying capacity of the region. N is the population in the region and ec is the per capita ecological carrying capacity of the region.

The calculation formula of per capita ecological carrying capacity is as follows:

$$ec = \sum_{j=1}^{6} a_j r_j y_j \quad (j = 1,2,3.....6)$$

In the formula, j is the category of ecologically productive land. a_j is the per capita area of the j -th ecologically productive land. r_j is the equivalence factor of the j -th ecologically productive land, and y_j is the yield factor of the j -th ecologically productive land.

According to the recommendation of the World Commission on Environment and Development (WCED), 12% of the area is deducted from the calculation of EC and ec for biodiversity conservation, and the actually available EC and ec are obtained after deduction.

2.3 Ecological Surplus and Ecological Deficit Model

ER and er respectively represent the total ecological surplus and the per capita ecological surplus ED and ed respectively represent the total ecological deficit and the per capita ecological deficit, then:

$$ER(ED) = EC - EF$$

$$er(ed) = ec - ef$$

In the formula, if the calculation is positive, it indicates the ecological surplus; If the calculation is negative, it indicates the ecological deficit.

3. CALCULATION AND ANALYSIS OF ECOLOGICAL CARRYING CAPACITY OF INDUSTRIAL ECOSYSTEM

3.1 Data Sources

The ecological footprint method aims to measure the amount of natural resources consumed by human to maintain their current production and life. According to the main material types of consumer goods, each item of the human production and living consumption is converted into corresponding biological productive land area. Then, through the results of the comparison between human demand of the ecological footprint and ecological carrying capacity of natural ecosystem, whether industry and population development of a region is within the limits of resources and environment system can be estimated.

The data in this paper are mainly from Xi'an City Statistical Yearbook and Shaanxi Province Statistical Yearbook from 2001 to 2018. In the accounting of biological consumption, the consumption of agricultural products, livestock products, aquatic products and other items are covered, specifically including grain, vegetable oil, vegetables, fruits, meat, eggs, milk, wine and aquatic products. Accordingly, the area of biologically productive land is divided into four categories, namely, cultivated land, forest land, grassland and water area. The consumption items in production and life are divided into two categories, namely the consumption of biological resources and the consumption of fossil energy, and the ecological footprint of Xi'an city in the past 18 years is calculated. According to the statistical yearbook of Xi'an city over the years, each section includes the subdivision of various items. Synthesizing the availability of data and the actual situation of production and consumption in Xi'an city, the import and export data are not taken into consideration in the calculation of ecological footprint.

Since the productivity of the six types ecologically productive land is not the same, according to the calculated biological production areas, the land areas of six types should be converted into areas of the same ecological productivity with equivalence factors in order to facilitate calculation. The calculation formula of the r_j equivalence factor of the j -th biological productive land area is as follows:

$$r_j = \frac{h_j}{H} \quad (j = 1,2,3,K,6)$$

In the formula, h_j is the global average ecological productivity of the j -th type of land, and H is the global average ecological productivity of all types of biological productive land areas.

The yield factor y_j of the j -th type of land is calculated as follows:

$$y_j = \frac{l_j}{L_j}$$

In the formula, l_j is the average productivity of the j -th type of land in a certain area, and L_j is the global average productivity of the j -th type of land.

When and yield factor are selected, the global uniform unit of measurement, namely the global hectare (ghm^2), can be used to calculate and the result can be compared with that of other countries or regions. D_1 represents fossil energy land and D_2 represents construction land. The values of equivalence factor r_j and yield factor y_j of ecological production land in Xi'an city are shown in Table 1:

Table 1
r_j and y_j of ecological productive land in Xi'an city (Zhang, et al, 2001)

	S_1	S_2	S_3	S_4	D_1	D_2
r_j	2.8	1.1	0.5	0.2	1.1	2.8
y_j	1.66	0.91	0.19	1.00	1.66	0

3.2 Calculation Process and the Analysis of Calculation Results

The energy consumption of Xi'an city is converted into a certain land area of fossil fuels. The correlation coefficient of energy consumption calculation is shown in Table 2:

Table 2
Correlation coefficient y_j of energy consumption calculation (Zhang, et al, 2001)

	Natural gas	Kerosene	Gasoline	Diesel	Fuel oil	Liquefied petroleum gas	Coal	Coke	Electricity
Productive land type	D_1	D_1	D_1	D_1	D_1	D_1	D_1	D_1	D_2
Conversion coefficient	38.977GJ/t	41.619 GJ/t	43.124 GJ/t	42.705 GJ/t	50.20 GJ/t	50.20 GJ/t	20.934 GJ/t	28.470 GJ/t	0.0036 GJ/KW.h
Global average energy footprint G/hm^2	93	93	93	93	71	71	55	55	1000

The calculated results of *ef*, *ec* and *ed* of Xi'an city from 2000 to 2017 are shown in bar Figure 1. From the chart, *ef* is over *ec* from 2000 to 2017. *ec* Ecological deficit *ed* occurs every year. From the absolute value of *ef*, *ec* and *ed*, *ef* and *ed* show a trend of growth year by year, thus the contradiction between *ef* and *ec* is expanding. *ef* of 2017 is 0.61 more than that of 2000, with an increase of 75%. *ec* fluctuates greatly in the study period, with the value of 2017 increasing by 43% as compared with that of 2000. *ed* of 2017 is 0.18 more than that of 2000, with an increase of 94.8%. Moreover, *ed* of each year in the study period exceeds the global warning level of 0.4 hm^2. The annual increase of ecological deficit indicates that the load of human in the industrial ecosystem exceeds the ecological capacity of the region. Natural capital consumed by economic and social development outreaches the natural supply capacity. The natural system is under great pressure and the regional development mode is in an unsafe and unsustainable state.

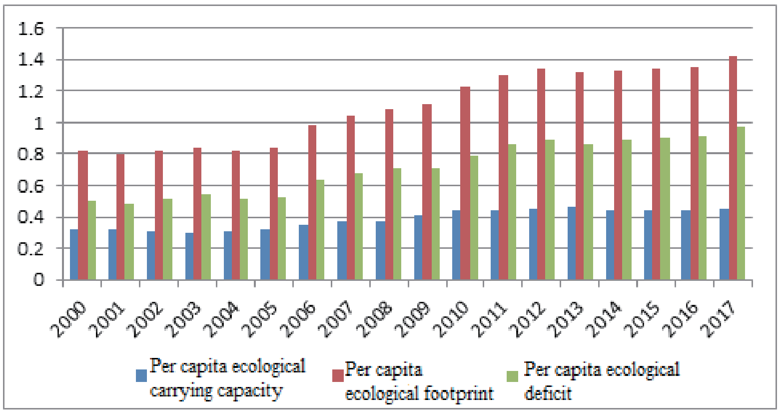

Figure 1
Ecological carrying capacity and ecological footprint of Xi'an city from 2000 to 2017 (hm^2 per capita

4. GREY SYSTEM PREDICTION OF ECOLOGICAL CARRYING CAPACITY

In order to provide better decision-making reference for the future economic and social development of Xi'an city, the time series trend analysis of ecological footprint and ecological carrying capacity of Xi'an city is conducted by the prediction model based on the dynamic research results of ecological footprint from 2000 to 2017, and the per capita ecological deficit of Xi'an city from 2018 to 2029 can be predicted.

Grey system prediction model is one of the most widely applied prediction models of grey system, with the advantage of forecasting grey and uncertain problems in the real world. Even if available and valid data is not enough, the model can combine these data with the grey and uncertain data to predict the future trend of development by using the accumulated generating sequence. The model possesses some merits like easy solution and high prediction accuracy, and it only needs the existing time series data of the object to make prediction. *ef* and *ec* of the region are affected by a lot of factors and have the characteristics of grey system. Therefore, grey model can be used for prediction.

(1) Establishment method and steps of GM(l, 1) model (Yao & Gong, (2014):

The first step:

Let the original time series be:

$$X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), \cdots, X^{(0)}(n)\}$$

The original sequence is accumulated according to the above formula, and then the accumulated generating sequence is:

$$X^{(1)}(i) = \sum_{m=1}^{i} X^{(0)}(m), \; i = 1, 2, \ldots n$$

The second step:

The original time series is one-accumulated to generate the sequence:

$$X^{(1)} = \{X^{(1)}(1), X^{(1)}(2), \ldots, X^{(1)}(n)\}$$

According to the above formula, the least square method is used to determine the model parameters:

$$\hat{a} = \begin{pmatrix} \hat{a} \\ \hat{\mu} \end{pmatrix} = (B^T B)^{-1} B^T y_N$$

In the formula:

$$B = \begin{bmatrix} -\frac{1}{2}\left[X^{(1)}(1) + X^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[X^{(1)}(2) + X^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\left[X^{(1)}(n-1) + X^{(1)}(n)\right] & 1 \end{bmatrix}$$

$$y = (x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(N))^T$$

The third step:

The differential equation model is established according to the accumulated generating sequence:

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = u$$

To solve the accumulation sequence, the discrete description form of the solution is:

$$X^{(1)}(k+1) = \left[X^{(1)}(1) - \frac{u}{a}\right] e^{-ak} + \frac{u}{a}$$

The fourth step: test the model by residual analysis. The specific testing method is as follows: first, the accumulated sequence is calculated based on the established model, then reduced by IAGO (Inverse Accumulated Generating Operation). After that, the reduced result is compared with the original sequence to find the difference value between the two sequences, which is the residual. Then the relative accuracy is calculated to determine the relative accuracy of the model.

Let $X^{(0)}(n)$ be the original time series and $e^{(0)}$ be the residual sequence, then the mean value of $X^{(0)}$ is:

$$\bar{x} = \frac{1}{k}\sum_{n=1}^{k} x^{(0)}(n)$$

Variance of $X^{(0)}$ is:

$$S_1^2 = \frac{1}{k}\sum_{k=1}^{n}(x^{(0)}(n) - \bar{X})^2$$

The mean and variance of residuals $e^{(0)}$ are as follows:

$$\bar{e} = \frac{1}{k}\sum_{n=1}^{k} e^{(0)}(n)$$

$$S_2^2 = \frac{1}{k}\sum_{k=1}^{n}(e^{(0)}(n) - \bar{e})^2$$

$$C = \frac{S_2}{S_1}$$

The above formula is the ratio of standard deviation, and the minimal error probability is:

$$p = P(|e(n) - \bar{e}| < 0.6745 S_1)$$

The prediction accuracy level is shown in Table 3:

Table 3
Table of prediction accuracy grade

Prediction accuracy grade	Good	Qualified	Barely qualified	Unqualified
P	>0.95	>0.80	>0.70	≤0.70
C	<0.35	<0.45	<0.50	≥0.65

The fifth step, the model conducts the prediction after passing the test.

(2) Use *GM*(1,1) model to predict

According to the calculation results *ef* and *ec* of Xi'an from 2000 to 2017, *GM*(1,1) model is established by the grey system analysis method. The ecological carrying capacity is calculated by the software MATLAB as α =−0.028462, μ =0.2934246, and ecological footprint α =−0.038518, μ =0.7603762. The equations of ecological carrying capacity and ecological footprint are as follows:

$$x^{(1)}(k+1) = 10.62435 \cdot e^{0.0285k} - 7.32789$$

$$x^{(1)}(k+1) = 20.55687 \cdot e^{0.038518k} - 19.7408$$

After the test, the test indexes of P and C meet the requirements, as shown in Table 4:

Table 4
Test values of grey prediction model

	Mean	Variance S1	Mean of residual	Variance of residual	Posterior error ratio C	Prediction accuracy grade
ec	0. 3845333	0. 062488	-0.000299	0.0247338	0.3958153	Qualified
ef	1.0999158	0.233808	-0.001646	0.0658382	0.281591	Good

It can be seen from Table 4 that the prediction equations of both ecological footprint and ecological carrying capacity meet the standards, so the predicted values of ecological footprint and ecological carrying capacity are calculated respectively by the above ecological footprint model and ecological carrying capacity model.

According to the predicted results, the development trends of per capita ecological carrying capacity, per capita ecological footprint and per capita ecological deficit are shown in the bar Figure 2:

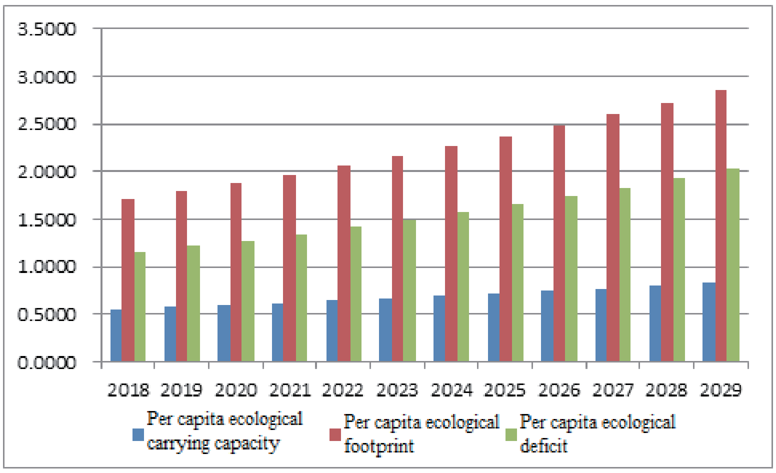

Figure 2
Predicted results of per capita ecological deficit in Xi'an city in 2018-2029 (hm² per capita)

From the above chart, per capita ecological footprint of Xi'an city will witness a substantial growth if the current economic and social development patterns are sustained, with an average increase of 6.1% a year during predicting period. Due to scientific and technological progress and environmental protection measures, the per capita ecological carrying capacity will also increase, with the average annual growth rate of 4.6%, which is lower than the growth rate of per capita ecological footprint. Accordingly, the per capita ecological deficit will gradually increase, with an average annual growth of 6.8%.In the case of existing ecological deficit, the growth rate of *ec* is lower than that of *ef*, which suggests that the current model of development is not sustainable. To reverse the tendency of unsustainable development, measures must be taken to slow down the increase of ecological footprint and increase the growth rate of ecological carrying capacity at the same time. Therefore, it is essential to optimize the industrial structure, improve economic efficiency, cultivate the consumption habits of energy saving and environmental protection, reduce resources consumption. Also, increasing investment in environmental protection and improving the disposal rate and recycling rate of pollutants are needed to reduce our ecological footprint. At the same time, it is crucial to increase investment in science and technology and promote technological progress. In the case of limited natural resources and environmental capacity, scientific and technological progress is the only way to increase ecological carrying capacity of the region, and improve the condition of low or negative growth of the ecological carrying capacity.

CONCLUSION

Ecological footprint method is used to evaluate the ecological carrying capacity of industrial ecosystem of Xi'an city in this paper. The per capita ecological carrying capacity *ec* of Xi'an city from 2000 to 2017 is calculated with the ecological footprint method, and the per capita ecological footprint *ef* and per capita ecological deficit *ed* are predicted based on the calculated results. The major conclusion is as follows:

In the study period, ecological deficit occurs every year and *ed* of each year exceeds the global per capita ecological deficit warning level of 0.4 hm^2. *ef* and *ed* show an increasing tendency year by year, and the growth rates of are higher than the growth rate of *ec*. It can be indicated that the load of human life and production in the industrial ecosystem exceeds the ecological capacity of the region. Natural capital consumed by economic and social development outreaches the natural supply capacity. The resource and environmental systems are under great pressure and the regional development mode is in an unsafe and unsustainable state.

According to the calculation results of ecological footprint, ecological carrying capacity and ecological deficit of Xi'an city from 2000 to 2017, the *GM*(1,1) model is used to predict these three figures. The predicted results show that the current development mode is not sustainable, and it is essential to reduce the ecological footprint and improve the ecological carrying capacity of the industrial ecosystem by improving the industrial economic efficiency, cultivating the consumption habits of energy saving and environmental protection, increasing investment in environmental protection and promoting technological progress.

REFERENCES

Anass, B., Youness, L., & Abderrahmene, G. (2019). Ecological footprint accounting: A multi-scale approach based on net primary productivity. *Environmental Impact Assessment Review*, (7), 136-144.

Aşici, A. A. (2013). Economic growth and its impact on environment: A panel data analysis. *Ecological Indicators, 1,* 324-333.

Diao, W. Y., Tian, B. P., Ma, P., et al. (2012). Trade ecological footprint analysis of China's agricultural. *Advanced Materials Research* (pp.2340-2343).

Dilawar, H., Pulkit, G., & Ravi, P. (2019). Ecological footprint assessment and its reduction for industrial food products. *International Journal of Sustainable Engineering.*

Imran, W. M., Elashkar, E. E., et al. (2019). Measuring the ecological footprint of inbound and outbound tourists: evidence from a panel of 35 countries. *Clean Technologies and Environmental Policy, 11*, 1949-1967.

Jammazi, R., & Aloui, C. (2015). Environment degradation, economic growth and energy consumption nexus: A wavelet-windowed cross correlation approach.Statistical Mechanics and its Applications, 2015, 10:110-125.

Kuznets, S. (1949). National Income and Industrial Structure. *Econometrica* (pp.205-241)

Lin, U. R. (2017). Persistence of policy shocks to Ecological Footprint of the USA. *Ecological Indicators*, *9*, 337-343.

Peng, B. H., Li, Y., Ehsan, E., et al. (2019). Dynamic evolution of ecological carrying capacity based on the ecological footprint theory: A case study of Jiangsu province. *Ecological Indicators,* (4), 19-26.

Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environment andUrbanization, 4*(2), 121-130.

Rong, Q. Q., Cai, Y. P., Su, M. R., et al. (2019). Identification of the optimal agricultural structure and population size in a reservoir watershed based on the water ecological carrying capacity under uncertainty. *Journal of Cleaner Production*, (10), 340-352.

Yao, T. X., & Gong, Z. W. (2014). *Gray prediction theory and its application* (in Chinese). Beijing: Science Press.

Zhang, Z. Q., Xu, Z. M., Cheng, G. D., et al. (2001). The ecological footprints of the 12 provinces of west China in 1999. *Acta Geographica Sinica, 5,* 599-610.