Assessing Land Ecological Security Based on BP Neural Network: a Case Study of Hangzhou, China

Heyuan You
College of Business Administration, Zhejiang University of Finance and Economics, Hangzhou, China
Email: youheyuan@gmail.com

***Abstract*— Due to the increasing stress on the land ecology, the land eco-security suffers damage. In this paper, the BP neural network and PSR framework were adopted to establish the model for assessment of land eco-security, and an empirical study of assessing land eco-security in Hangzhou was done. The results show that the city center district is at serious land eco-security risk; Xiaoshan district and Yuhang district are at high land eco-security risk; and others counties (cities) are at low risk or intermediate risk. In Hangzhou, although some measures are adopted to control the risk of land eco-security, the economic growth still has negative impact on the land ecology. The rapid industrialization and urbanization increase the risk of land eco-security. Therefore the policy constitutors should do something to strengthen the land ecology protection.**

***Index Terms*—land ecological security, pressure-state-response framework, BP neural network, Hangzhou**

I. Introduction

As an essential resource for sustainable development, the land keeps human supplied with basic material and living space. In China, land use is regulated strictly by government since the socialist public ownership of land. However, in order to accelerate the economic growth, the local governments in China excessively exploit and utilize land resource [1], and the sustainable use of land resources is always neglected in many regions. Some serious problems such as soil loss, over-conversion of farmland to construction land, land contamination and deforestation threat the sustainable land use [2, 3, 4, 5]. The scarcity of enough protection for land leads to increased risk of land ecological security (eco-security) [6]. Consequently, the assessment of land eco-security necessarily is done to ascertain ecological state of land use system. And the characteristic analysis of land eco-security can reveal important information for adopting measures to improve the land ecology.

The current literature that related to land eco-security mostly focused on the sustainable use of land resources. The ecological sustainability is considered as a vital feature of sustainable land use [7]. The indicator systems which were applied to assess the sustainable use of land resources included some indicators reflected land eco-security such as soil loss/formation ratio [8], forest cover [9], population density [10], and species loss [11]. Owing to the defects in the accurate analysis of land ecology, the assessment of land ecological security aroused researchers' attention [6, 12].

Back-Propagation (BP) neural network, a method of training a multi-layer feed-forward artificial neural network with the BP algorithm can approximate any nonlinear function [13]. Due to its robust and fault-tolerance, the BP neural network is widely applied in predictor, optimization and classification [14, 15, 16]. Given the subjectivity in the assessment of land eco-security, especially determining the weights of indicators, and the fuzzy relationship among indicators, the BP neural network whose advantage is suitable can be applied to establish model for assessing land eco-security.

The rest of this paper proceeds as follows: Section 2 describes a survey of study area; Section 3 establishes the model for assessment of land eco-security based on BP neural network; Section 4 obtains the original data and pretreats the original date; Section 5 shows the results of the assessment of land eco-security of 8 districts (county-level cities, counties) in Hangzhou; Section 6 summarizes the discussion and conclusion.

II. Study Area

Hangzhou which is administered as a sub-provincial city, with a registered population of 6.8912 million as of 2010, is the capital and largest city of Zhejiang province. Located in Eastern China, Hangzhou sits on the south edge of the Yangtze River Delta economic zone (Figure 1). Hangzhou is the economic, political and cultural center of Zhejiang province. It is an industrial city, and is considered as an important manufacturing base in coastal area of China. The Qiantang River passes through the northeast to the southwest of Hangzhou, and Hangzhou Bay ends at Hangzhou which lies south of Shanghai. Hangzhou extends to the border of the hilly-country Anhui Province on its west and the flat-land Hangzhou Bay on its east. The vast majority of land in Hangzhou is

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Corresponding author: Heyuan You.

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hill and mountain.

Hangzhou city is composed of 8 districts, 3 county-level cities and 2 counties. The city center of Hangzhou is composed of Shangcheng district, Xiacheng district, Jianggan district, Gongshu district, Xihu district and Binjiang district. And Xiaoshan district, Yuhang district, Tonglu county, Chun'an county, Jiande city, Fuyang city and Lin'an city compose the suburban and rural area of Hangzhou. In empirical study, I assumed that the six central urban districts were one integrated region since the six central urban districts were small districts and principal affairs of districts were administered independently of suburban and rural area of Hangzhou by Hangzhou city people's government.

Since the rapid economic growth and large population, risk to land ecology in Hangzhou continual increases. Consideration of land eco-security in Hangzhou is required to preserve the land and to draw up measures whose purpose is sustainable utilization of land.

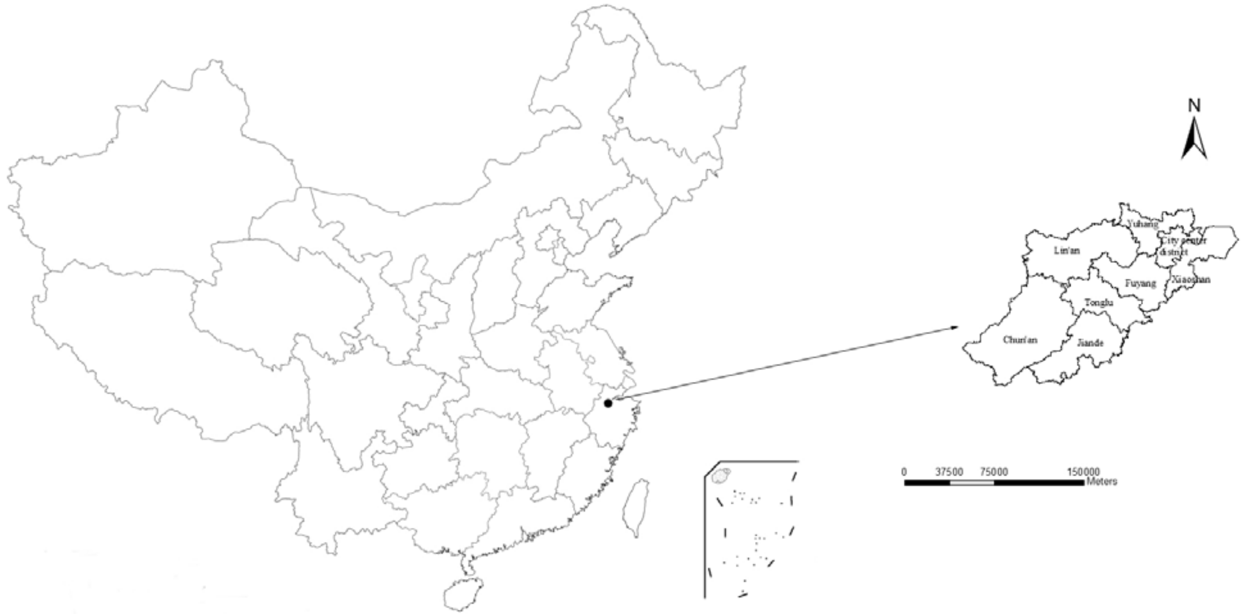

Figure 1. Location of study area

III. METHODS

A. Indicator System for Assessment

The pressure-state-response (PSR) framework has been widely used to describe and quantify the environment [17, 18]. It was accepted to determine indicator to understand complex realities about ecology [6, 19]. In this paper, I focus on the pressures on the land eco-security, the condition of land eco-security which results from these pressures and the actions taken to prevent negative land eco-security impacts. It is apparent that PSR framework can be chosen as a basis for selecting the indicators that compose the indicator system for assessing land ecological security. Complied with the principles in selecting indicators that include substantive, simplicity, universality, consistency and availability, and learnt experience from previous literature, the initial set of 12 indicators was selected. Then indicators were adjusted based on experts' opinions who invited to evaluate the suitability of initial set. Some indicators in initial set were not selected by experts. The reasons for the experts' decision were as follows. (1) Soil erosion modulus was not the representative factor which affected the land eco-security in Hangzhou since the geographical condition of Hangzhou. (2) Natural population growth rate was important indicator of the land eco-security, however the cultivated land area per capita and water resources per capita implied the impact of natural population growth rate on the land eco-security. (3) The original data of energy consumption per unit of GDP could not be obtained. The indicator system applied in study area in this paper is presented in Table 1.

B. Grade Criterion

It is important to grade the land eco-security and determine the grade criterion which used to assess the state of land eco-security in Hangzhou. However, there was no widely accepted grade criterion of land eco-security [6]. The land eco-security should be classified to correspond to local conditions. In this paper, the grade criterion of land eco-security was classified into five grades. The range of land eco-security value was assumed [0, 1], and it can be divided into five grades as no land eco-security risk (0.8, 1], low land eco-security risk (0.6, 0.8], intermediate land eco-security risk (0.4, 0.6], high land eco-security risk (0.2, 0.4] and serious land eco-security risk (0, 0.2].

The land eco-security was relative. The assessment standards of eco-security in the literature were classified into four grades [12]. The numbers ranging from 1 to 4 were assigned to "insecure", "relatively insecure", "relatively secure" and "secure". Two grade criterions of land eco-security were similar in the method

TABLE I.
INDICATOR SYSTEM FOR ASSESSING LAND ECO-SECURITY AND GRADE CRITERION OF LAND ECO-SECURITY

Element	Indicators	Grade criterion of land eco-security				
		(0.8, 1][a]	(0.6, 0.8]	(0.4, 0.6]	(0.2, 0.4]	[0, 0.2]
Pressure	Cultivated land area per capita(mu/person)x_1[b]	>1.4	0.8-1.4	0.7-0.8	0.6-0.7	0.6-0.5&<0.5 [c]
	Water resources per capita (m^3/person) x_2	>2500	2000-2500	1500-2000	1000-1500	500-1000&<500
	Pesticide application per farmland area (kg/hm^2) x_3[d]	<5	5-15	15-20	20-25	25-30&>30
	Chemical fertilizer application per farmland area (kg/hm^2) x_4	<220	220-300	300-400	400-500	500-600&>600
State	Cultivated land proportion (%)x_5	>12	10-12	8-10	6-8	5-6&<5
	Forests land proportion (%)x_6	>30	25-30	20-25	15-20	10-15&<10
	Cultivated land gradient＞25°proportion (%)x_7	<1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-4.0&>4.0
	Population density(person/km^2) x_8	<450	450-500	500-550	550-600	600-650&>650
Response	Area of stable yields despite drought or excessive rain proportion (%)x_9	>65	50-65	40-50	30-40	20-30&<20
	Tertiary industry proportion (%)x_{10}	>70	60-70	50-60	40-50	30-40&<30
	Investment in fixed assets per land area (10^4yuan/hm^2) x_{11}	>30	25-30	20-25	15-20	10-15&<10
	Environment protect expenditure of local financial budgetary expenditure proportion (%)x_{12}	>5	4-5	3-4	2-3	1-2&<1

a. (0.8, 1]- no land eco-security risk; (0.6, 0.8]- low land eco-security risk; (0.4, 0.6]- intermediate land eco-security risk; (0.2, 0.4]- high land eco-security risk; (0, 0.2]- serious land eco-security risk . b. "mu" is a Chinese measuring unit for land and 1 mu=667 m^2. c. "0.6-0.5&<0.5"= "<0.6", the reason of this translation will be explained in "Ⅳ. ORIGINAL DATA AND PRETREATMENT". d. the farmland is composed of cultivated land and garden land.

of classification. The suitability of the grade criterion in the literature was tested [12], and the grade criterion in this paper was acceptable to be used in the empirical study.

The relationship between indicators applied to assess land eco-security and classes of land eco-security should be established. The perfect values of indicators that reflected one part characteristic of no land eco-security risk in study area were determined by the evidences from investigation, criterion recognized by government or international organization and the average value of Zhejiang province. Then the perfect value was fallen to other grade point values logically if the indicators positive effect on the land eco-security, otherwise the perfect value was risen to other grade point values logically if the indicators negative effect on the land eco-security. The five grades of 12 indicators are showed in Table 1.

C. BP Neural Network

A BP neural network consists of three types of neuron layers: input, hidden, and output, and the signal flow is from input to output units, strictly in a feed-forward direction. The topological structure of BP neural network should be designed to determine the number of neurons and layers. The BP neural network applied to assess the land eco-security in Hangzhou consists of one input layer, one hidden layer and one output layer. The input layer takes inputs which are the values of indicators, and forwards inputs to hidden layer. Therefore the number of input neurons corresponds to the number of indicators in indicator system. The output of the assessment model for land eco-security in Hangzhou is the land eco-security values of different districts, and consequently the number of output neurons is 1. The number of neurons in hidden layer can be decided by the equation (1) in general.

$$m = \sqrt{i + j} + a \tag{1}$$

Where m is the number of neurons in the hidden layer, i is the number of neurons in the input layer, j is the number of neurons in the output layer, α is the constant between 1 to 10. Then the suitable number of neurons in the output layer was found by trial and error, and finally, the number of neurons in the output layer was set to 12. The BP neural network for the land ecological security assessment model with the structure of 12-12-1 was established. The topological structure of BP neural network is shown in Figure 2.

The transfer function determines the output of the BP neural network. The logsig transfer function as shown in equation (2) was selected to apply between input layer and hidden layer which can limit the output to a narrow range. And the purelin transfer function as shown in equation (3) was selected to apply in the output layer.

$$\log sig(x) = 1\big/(1 + e^{-x}) \tag{2}$$

$$purelin(x) = x \tag{3}$$

The BP neural network was trained by gradient descent with momentum (GDM) that updates weight and bias values according to gradient descent with adaptive learning rate since the GDM can slide through small features in the error surface to improve the training speed and stability. The GDM train the BP neural network as:

$$w_{ij}(k+1) = w_{ij}(k) + \eta[(1-\beta)D(k) + \beta D(k-1)] \tag{4}$$

Where $w_{ij}(k+1)$ is the new vector of weight and bias, $w_{ij}(k)$ is the current vector of weight and bias, $D(k)$ is the negative gradient of $w_{ij}(k)$ at time k, $D(k–1)$ is the negative gradient of $w_{ij}(k)$ at time $k–1$, η is the learning rate, β is the momentum constant which is a number between 0 and 1.The learning rate usually is trialed with a range of 0.1 to 0.3, if the learning rate is too high, the algorithm may oscillate and becomes unstable. And the momentum constant usually is trialed with a range of 0.9 to 1 since the low momentum may prevent the network from learning. In empirical study, the values of η and β were selected as 0.3 and 0.94, respectively.

The performance measure adopted in empirical study was mean-squared error (MSE) function. The MSE function is as follows:

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(q_k(t) - s_k(t))^2 \tag{5}$$

Where MSE is net error. $q_k(t)$ is kth network node desired output of tth training pattern and $s_k(t)$ is kth network node actual output of tth training pattern.

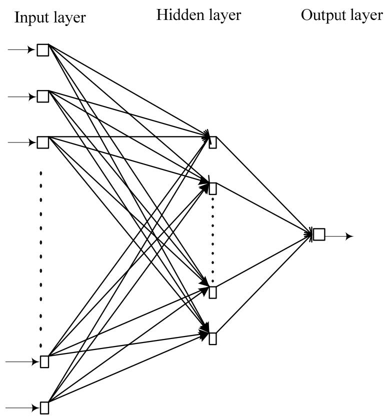

Figure 2. Topological structure of BP neural network for assessment

IV. ORIGINAL DATA AND PRETREATMENT

The original indicator values of 8 districts (county-level cities, counties) applied to assess the land eco-security of Hangzhou were obtained from the statistical yearbooks and local municipal bureau of land and resources. The descriptive statistics of original indicator values is showed in Table Ⅱ.

In order to improve the convergence rates and enhance the estimation accuracies since the feature of logsig transfer function. The original indicator values and original grade criterion of land eco-security presented Table Ⅰ were normalized between 0 and 1. The land eco-security grade is determined by the particular combination of indicator values. Therefore the BP neural network should be trained to learn the nonlinear relationship from the learn samples. The endpoints of the interval of land eco-security and indicator values whose correspondence relationship was showed in Table Ⅲ were selected. Although the range of land eco-security values is assumed [0, 1], the values of land eco-security in Hangzhou that will be assessed by BP neural network may greater than 1 or less than 0. So as to prevent the assessment values of land eco-security to break the limitation of an interval and enhance the distinguishability of assessment values of land eco-security, some proper endpoints were selected to reflect the correspondence relationship between the indicator values and land eco-security whose value was 0.

There are a variety of methods for normalization. In this empirical study, the equation for normalization is as follows:

$$S_n' = (S_n - \min_{n.value}) / (\max_{n.value} - \min_{n.value}) \tag{6}$$

Where $\max_{n.value}$ is maximal value in input vector n, and $\min_{n.value}$ is minimal value in input vector n. S_n is the original input in input vector n. S_n' is the normalized value of the original in input vector n.

TABLE II.
DESCRIPTIVE STATISTICS OF ORIGINAL DATA IN HANGZHOU

	Min.	Max.	Mean	Std.Deviation
x_1	0.05	0.82	0.61	0.25
x_2	527.04	14001.76	4426.24	4454.91
x_3	10.37	45.29	25.59	11.29
x_4	117.55	554.03	338.03	149.02
x_5	3.89	38.31	16.01	11.54
x_6	14.69	76.86	51.39	26.79
x_7	0.04	5.47	2.18	2.01
x_8	103.00	3209.00	730.25	1037.25
x_9	6.79	87.43	49.02	26.13
x_{10}	30.58	63.27	38.04	10.73
x_{11}	1.69	190.31	34.87	64.00
x_{12}	1.29	8.56	3.76	2.20

TABLE III.
ENDPOINTS OF THE INTERVAL OF LAND ECO-SECURITY AND CORRESPONDING INDICATOR VALUES

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	values of land eco-security
1.4	2500	5.00	220	12	30	1.0	450	65	70	30	5	0.8
0.8	2000	15.00	300	10	25	1.5	500	50	60	25	4	0.6
0.7	1500	20.00	400	8	20	2.0	550	40	50	20	3	0.4
0.6	1000	25.00	500	6	15	2.5	600	30	40	15	2	0.2
0.5	500	30.00	600	5	10	4.0	650	20	30	10	1	0.0

V. RESULTS

The BP neural network that was established to assess the land eco-security was performed under MATLAB version 7.0 by using Neural Network Toolbox [20, 21]. In the empirical study, performance goal of the BP neural network was set to 0.001 or if number of epoch reaches 2000. The learn samples which were normalized were input, and the Figure 3 showed that the training error falls down to 0.001 within 62 epochs. Therefore the BP neural network was accepted, and applied to assess of land eco-security in Hangzhou.

The normalized indicator values of city center district, Xiaoshan district, Yuhang district, Tonglu county, Chun'an county, Jiande city, Fuyang city and Lin'an city were put into the BP neural network which had been trained, then the values of land eco-security of 8 districts (county-level cities, counties) were calculated by the BP neural network. The result of assessment was showed in Table Ⅵ, and the spatial distribution of land eco-security of Hangzhou was presented in Figure 4.

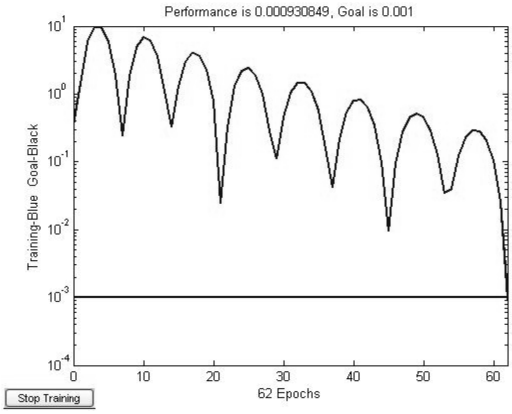

Figure 3. Training error trend of BP neural network

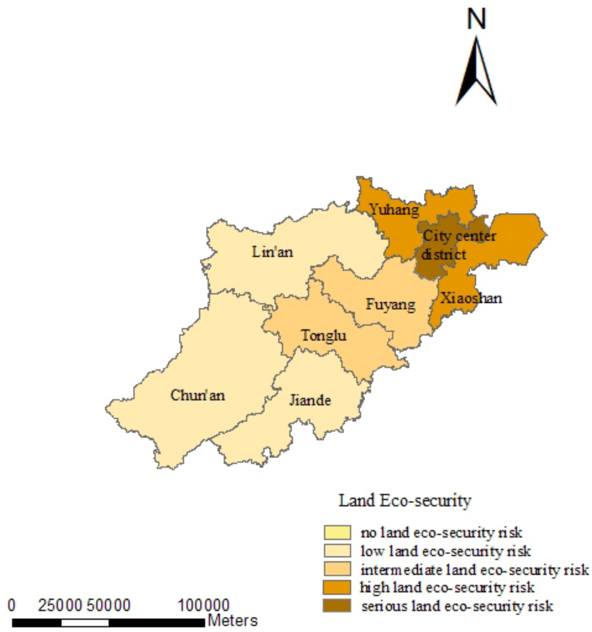

Figure 4. Spatial distribution of land eco-security of Hangzhou

TABLE IV.
NORMALIZED INDICATOR VALUES AND THE LAND ECO-SECURITY OF DISTRICTS IN HANGZHOU

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	values of land eco-security	
City center district	0.000	0.002	0.133	0.216	0.202	0.070	0.000	1.000	0.000	0.832	1.000	0.072	0.070	serious land eco-security risk
Xiaoshan	0.456	0.014	1.000	0.905	1.000	0.094	0.000	0.245	0.943	0.112	0.170	0.283	0.274	high land eco-security risk
Yuhang	0.423	0.042	0.507	0.525	0.731	0.265	0.122	0.193	1.000	0.249	0.147	0.411	0.382	high land eco-security risk
Tonglu	0.555	0.313	0.544	0.305	0.228	0.914	0.503	0.038	0.436	0.015	0.025	0.839	0.599	intermediate land eco-security risk
Chun'an	0.383	1.000	0.139	0.000	0.000	0.892	1.000	0.000	0.373	0.224	0.000	0.566	0.708	low land eco-security risk
Jiande	0.535	0.404	0.509	0.677	0.217	0.873	0.497	0.038	0.447	0.064	0.009	0.778	0.612	low land eco-security risk
Fuyang	0.390	0.167	0.610	0.271	0.286	0.844	0.236	0.082	0.595	0.061	0.047	0.689	0.574	intermediate land eco-security risk
Lin'an	0.570	0.384	0.645	0.757	0.155	1.000	0.791	0.021	0.396	0.053	0.009	1.890	0.601	low land eco-security risk

VI. DISCUSSION AND CONCLUSIONS

Districts whose land eco-security values are above 0.4 and below 0.8 account for 60% of the entire region. It indicates that the land ecology of districts in Hangzhou suffers damage, whereas the risk of land eco-security in Hangzhou is in control. Actually the local government adopts some measures to administer the land use and land ecology since the ecological consciousness. These measures principally refer to farmland protection, intensive and economical utilization of construction land, forests land preservation, contamination emission control, family planning, ect. Therefore the condition of land eco-security in Tonglu county, Chun'an county, Jiande city, Fuyang city and Lin'an city is at low risk or intermediate risk.

The economic growth has negative impact on the land ecology of the land ecology in Hangzhou. The city center district has a population of 226.74 million which accounts for 33% of the total population of Hangzhou, and the city center district produces largest GDP of Hangzhou which accounts for over 85% of Hangzhou GDP. A great deal of service industry and manufacturing centralize the city center district. For example, biological medicine industry, mechanical manufacturing industry and food and beverage industry is geographically concentrated Hangzhou Economic & Technological Development Zone whose purpose is to attract the global investment. The local governments currently consider GDP as a most important indicator of economic progress, however the improvement of land ecology dose not directly tied to the growth of GDP. Much farmland is converted to construction land for industrial and residential uses, and high population density increases the ecological frangibility.

Xiaoshan district and Yuhang district locate in the surrounding area fringed city center district of Hangzhou. The development plan of Hanghzhou proposes that concentrated distribution area of heavy industry locate in Xiaoshan district and Yuhang district. Rapid industrialization and urbanization increase the stress on the land ecology, in spite of the fact that original ecological condition of land in Xiaoshan district and Yuhang district is appropriate to maintain the relatively security of land ecology since the large cultivated land area per capital, large proportion of cultivated land, low population density, ect.

One goal of this paper is to provide a method to assess the land eco-security. The BP neural network and PSR framework were adopted to establish the model for assessment of land eco-security. Then the original date was pretreated, and the training error of BP neural network was acceptable. The values of land eco-security of 8 districts (county-level cities, counties) in Hangzhou were evaluated by the BP neural network which was trained. The results showed that the city center district was at serious land eco-security risk; Xiaoshan district and Yuhang district were at high land eco-security risk; Tonglu county and Fuyang city were at intermediate land eco-security risk; Chun'an county, Jiande city and Lin'an city were at low land eco-security risk. This phenomenon reveals that although some measures are adopted to control the risk of land eco-security, the economic growth still has negative impact on the land ecology in Hangzhou, and the rapid industrialization and urbanization increase the risk of land eco-security. Therefore the policy constitutor should do something to strengthen the land ecology protection.

The method for assessing land eco-security in this paper is flexible enough to be modified to applied in other areas according to the local factors. The purpose of assessment of land eco-security is not only obtaining the state of the land eco-security but also understanding of the factors affect the land eco-security. Consequently the similar research about land ecology in the areas where the land ecology may suffer damage should be done.

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Heyuan You, he was born in Wenzhou City, Zhejiang Province of China in 1983. He received the PhD degree in land resource management from Institute of Land Science and Property Management, Zhejiang University in 2012.

He is currently working as a lecturer in the College of Business Administration, Zhejiang University of Finance and Economics, Zhejiang, China. His research area centers on land use simulation and land ecology management.