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Evaluation of Intensive Urban Land Use Based on an Artificial Neural Network Model: A Case Study of Nanjing City, China

QIAO Weifeng[1,2,3], GAO Junbo[1,4], LIU Yansui[1], QIN Yueheng[2], LU Cheng[2], JI Qingqing[2]

(1. *Institute of Geographic Sciences and Natural Resources Research*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*; 2. *School of Geography Science*, *Nanjing Normal University*, *Nanjing* 210023, *China*; 3. *Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application*, *Nanjing* 210023, *China*; 4. *School of Geography Science*, *Xinyang Normal University*, *Xinyang* 464000, *Henan Province*, *China*)

Abstract: In this paper, the artificial neural network (ANN) model was used to evaluate the degree of intensive urban land use in Nanjing City, China. The construction and application of the ANN model took into account the comprehensive, spatial and complex nature of urban land use. Through a preliminary calculation of the degree of intensive land use of the sample area, representative sample area selection and using the back propagation neural network model to train, the intensive land use level of each evaluation unit is finally determined in the study area. Results show that the method can effectively correct the errors caused by the limitations of the model itself and the determination of the ideal value and weights when the multifactor comprehensive evaluation is used alone. The ANN model can make the evaluation results more objective and practical. The evaluation results show a tendency of decreasing land use intensity from the core urban area to the periphery and the industrial functional area has relatively low land use intensity compared with other functional areas. Based on the evaluation results, some suggestions are put forward, such as transforming the mode of urban spatial expansion, strengthening the integration and potential exploitation of the land in the urban built-up area, and strengthening the control of the construction intensity of protected areas.

Keywords: urban land; intensive use; functional area; artificial neural network (ANN) model; Nanjing City

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1 Introduction

Since China initiated the economic reform and opening up policy in 1978, the consequent rapid economic development has accelerated the urbanization process, with urban land areas expanding continuously and cultivated land areas decreasing rapidly. The tension between urban occupation and land has gradually emerged (Bai *et al.*, 2014). However, there are many simultaneous problems inside cities, such as the unreasonable utilization of large land resources, the low intensity of land use, and the inadequate development of land use potential. Solving these problems is key to better protecting the land resource and promoting sustainable economic development. The study of intensity of urban land use has been a popular research topic for scholars in recent years. There are many statistical analysis methods and spatial analysis methods used in the field

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Corresponding author: LIU Yansui. E-mail: liuys@igsnrr.ac.cn

of evaluating land use intensity such as the multi-factor comprehensive evaluation method (Yang *et al.*, 2012; Sluisa *et al.*, 2016), the fuzzy comprehensive evaluation method (Luo *et al.*, 2012), the ideal value correction model (Li and Chen, 2013), and evaluation based on Geographic Information System or Remote Sensing technology (Taleai *et al.*, 2007; Wang *et al.*, 2011; Li *et al.*, 2014; Di *et al.*, 2015). Above methods have been widely applied to the evaluation of various types of land, such as agricultural land (Temme and Verburg, 2011; Erb *et al.*, 2013; Kuemmerle *et al.*, 2013; Levers *et al.*, 2016), cultivated land (Xie *et al.*, 2016) and construction land (Gong *et al.*, 2014; Estoque and Murayama, 2015). In the evaluation of intensive urban land use, some scholars have carried out deeper studies based on integrating the above methods, multi-region, multi-type and multi-level (MR-MT-ML) method (Jiang *et al.*, 2008), spatial panel ordered-response probit model (Ferdous and Bhat, 2013), cloud model (Wang and Zhu, 2012) are used in studies in different countries and regions.

Of the methods mentioned above, the multi-factor comprehensive evaluation method is most commonly used. This kind of method, which is based on a comprehensive weighted assessment, is somewhat limited and can not fully reflect the degree of urban land use intensity. The city system is a complex and large system composed of complicated interacting urban individual elements. The land structure, distribution and utilization within the city are the most direct reflections of this system. Traditional simple synthesis and linear fitting are insufficient to meet the needs of the complex and changing pattern of urban land use. Therefore, this study attempts to introduce a neural network model with a strong nonlinear fitting function into the urban land use intensity evaluation framework. Artificial neural network (ANN) model, as a comprehensive evaluation method with self-learning ability, is widely used in ecology (Recknagel, 1997; Khan *et al.*, 2001; Gevrey *et al.*, 2003), geography (Pradhan and Lee, 2009; Pradhan and Lee, 2010) and socio-economic research (Ahn *et al.*, 2000; Guresen *et al.*, 2011). As one of the most widely used ANN models (Salomon and Hemmen, 1996), the Back Propagation (BP) neural network has the best fitting effect. On the basis of the application of multi-factor comprehensive evaluation method, this paper selects the BP neural network model (Pijanowski *et al.*, 2002; Wang *et al.*, 2012) to improve the initial evaluation results, so as to accurately evaluate urban land use intensity. Some researchers have recently used the BP neural network model to evaluate the extent of intensive land use (Li and Yeh, 2002; Almeida *et al.*, 2008), but the scale of evaluation unit in most studies is relatively large (Shi and Huang, 2013; Gong *et al.*, 2014), the integrated application of multi-factor comprehensive evaluation method and BP neural network model and the systematic evaluation of metropolitan built-up area at micro-scale is lacking.

This study selects Nanjing City in China as the demonstration object to evaluate the degree of urban land use intensity at the micro-scale based on the BP neural network model, aiming at improving the existing evaluation methods and making valuable suggestions for improving the urban land use intensity based on the evaluation results.

2 Study Area and Methods

2.1 Study area

Nanjing City (31°14′N–32°37′N, 118°22′E–119°14′E) is located in the southwest of Jiangsu Province in China. In 2012, there are eleven municipal districts and two counties in Nanjing. The total area of eleven municipal districts is 4733 km^2. Approximately 15% of the total area is occupied by low hills. The Yangtze River passes through the central area of Nanjing, and the tributary of the Yangtze River, Qinhuai River and Chuhe River also flow through the city. As one of the three core cities in the Yangtze Delta and the world’s sixth-largest economic center, Nanjing is a typical representative of the rapidly growing and globalizing cities. With total population of 8.16 × 10^6 and urban population of 6.55 × 10^6, Nanjing, after Shanghai, is the second-largest commercial center in the Eastern China region. According to spatial features, the urban space of Nanjing is divided into main city and three vice cities (Dongshan, Xianlin and Jiangbei). Main city is located within urban circle high-way, and its core area is called old city, which is located within city wall built in the Ming Dynasty. The study area in this article is the urban built-up area of Nanjing, with a total area of 536.53 km^2 (Fig. 1).

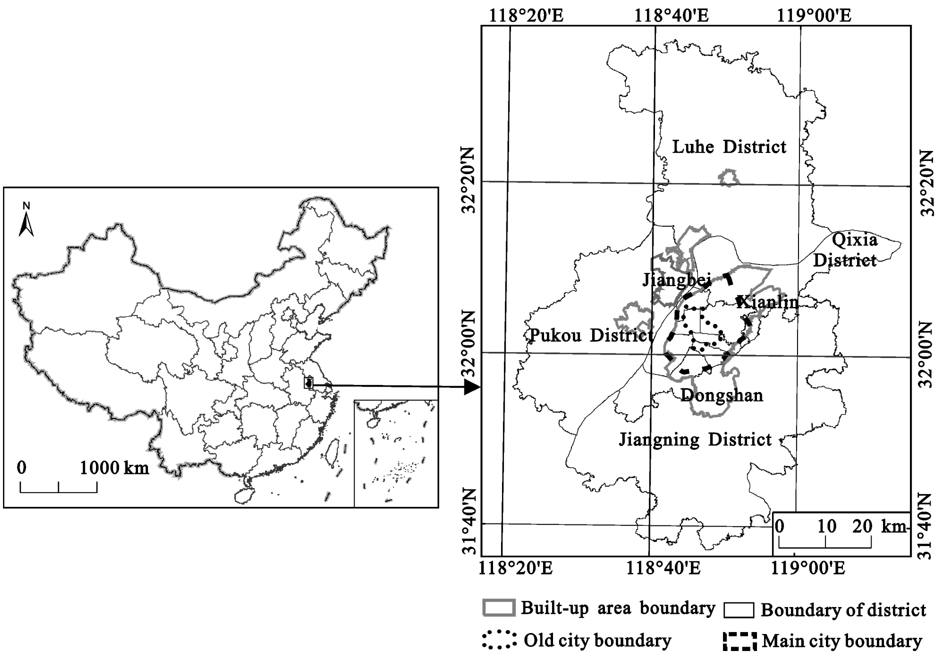

Fig. 1 Map of study area

2.2 Methods

2.2.1 General idea

Making full use of two- and three-dimensional information acquired from multi-source remote sensing images (Qiao, 2013) and considering population, society and economic data, we create a micro-perspective evaluation of land use intensity of Nanjing's built-up area in 2012. The research approach is as follows: firstly, divide the land within the study area into different land use functional areas and determine the representative sample areas of each functional area. Secondly, based on their different positions, construct different index systems for different functional areas. Then, determine the ideal value and weight of each index by using the Delphi method and preliminarily calculate the degree of urban land use intensity of the sample areas using the multi-factor comprehensive evaluation method. Thirdly, use the ANN model to train the preliminary evaluation results and eventually determine the level of land use intensity.

The multi-factor comprehensive evaluation method is actually a method that calculates the intensity score through the weighted summation method. Because of the limitation of the model itself and the influence of the determination of the ideal value and weight, the evaluation results have some deviations. For sample areas for which the preliminary evaluation results are most consistent with the actual situation, we apply the ANN model training to these areas. Finally, according to the ANN model obtained from training, all the sample areas are re-evaluated. The research flowchart is shown in Fig. 2.

2.2.2 Artificial neural network (ANN) model

In this paper, the ANN model is mainly used to describe the fitting and calculation of the degree of land use intensity of the urban land system based on the complex index system. The BP neural network is chosen because, as one of the most widely used ANN models, it is a kind of multilayer feedforward network with a relatively high extreme, and is trained by an error BP algorithm (Pijanowski *et al.*, 2002; Pradhan and Lee, 2009). This network is simple to build, rich in training algorithms, and has strong mapping ability, which is suitable for forecasting, evaluation and optimization. The basic principle of BP neural network is shown in Fig. 3, the input information p passes to the output layer after processing, if the output information a is not the desired output, it is transferred to the reverse propagation, and the error signal is returned along the original neuron connection path. In the process of returning, the weight w which connects different layers of neurons is modified one by one. This process constantly iterates, and finally makes the error within the allowable range. The offset node b can increase the network generalization performance (Li and Yeh, 2002; Zhang and Wu, 2009).

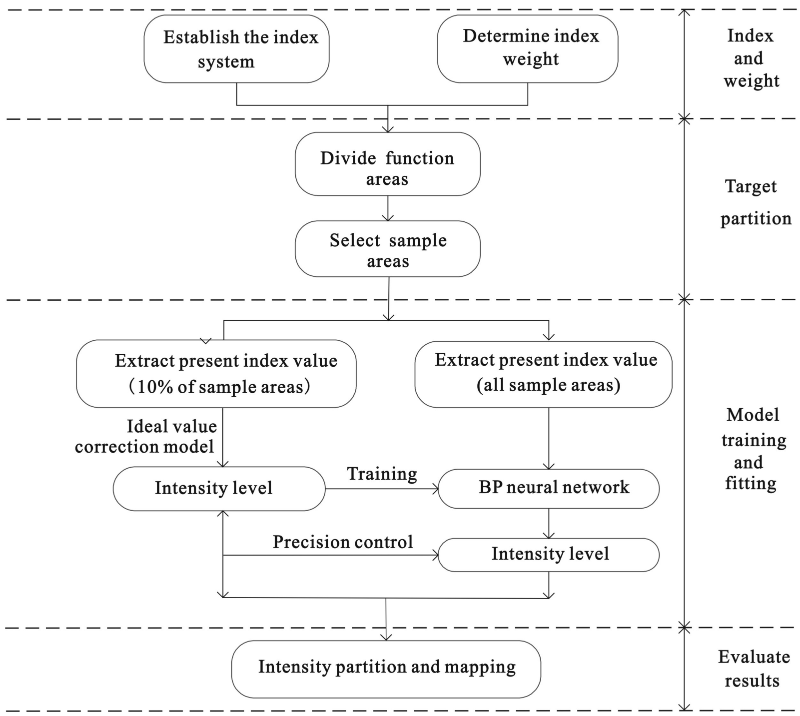

Fig. 2 Framework of artificial neural network (ANN) land intensive use evaluation model

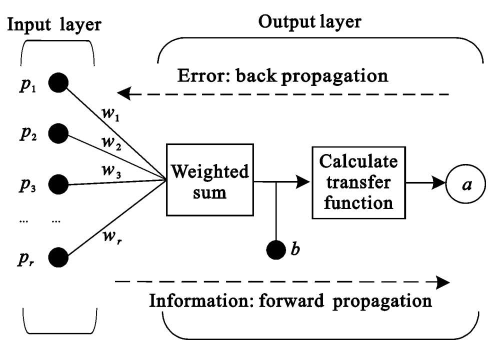

Fig. 3 Neuron structure of Back Propagation (BP) network. *w* is weight, *b* is node, *p* and *a* are input and output information

3 Evaluation Progress of Intensive Land Use Level

3.1 Division of evaluation units

According to general idea, based on the consistency of terrain, feature boundary and relative integrity of the administrative division, Nanjing's built-up area is divided into five kinds of functional areas: residential, commercial, industrial, educational, and special purpose functional areas. Among them, the special purpose functional area includes idle land and other land that needs daily land use management. The five kinds of functional areas are seamlessly connected to each other and generate the evaluation function area distribution map of the study area (Fig. 4).

This study intends to choose representative sample areas from different functional areas to evaluate and use the evaluation results of the sample areas as representatives of the land use intensity of the corresponding functional areas. It significantly influences the actual land use evaluation results of the different functional areas in Nanjing's urban built-up area. Therefore, this study makes use of the spatial analysis function of ArcGIS, combined with the relative evaluation process and expert opinion, and determines the basis for the selection of the sample study areas. As shown in Fig. 4, this study delineates a number of planar sample areas, based on the determined division rules. This delineation takes the secondary rivers, residential district roads, and parcel shape as the main references to determine the boundary divisions of the sample areas. By Measuring on the distribution map of evaluation function areas and sample areas, the total area of the sample areas accounts for 51.34% of the total area of the functional areas.

3.2 Construction of index system

The urban ecosystem is an organic whole where nature, society and economy couple, provide mutual feedback, and interact with each other. The complexity and functional diversity of the urban ecosystem contains numerous

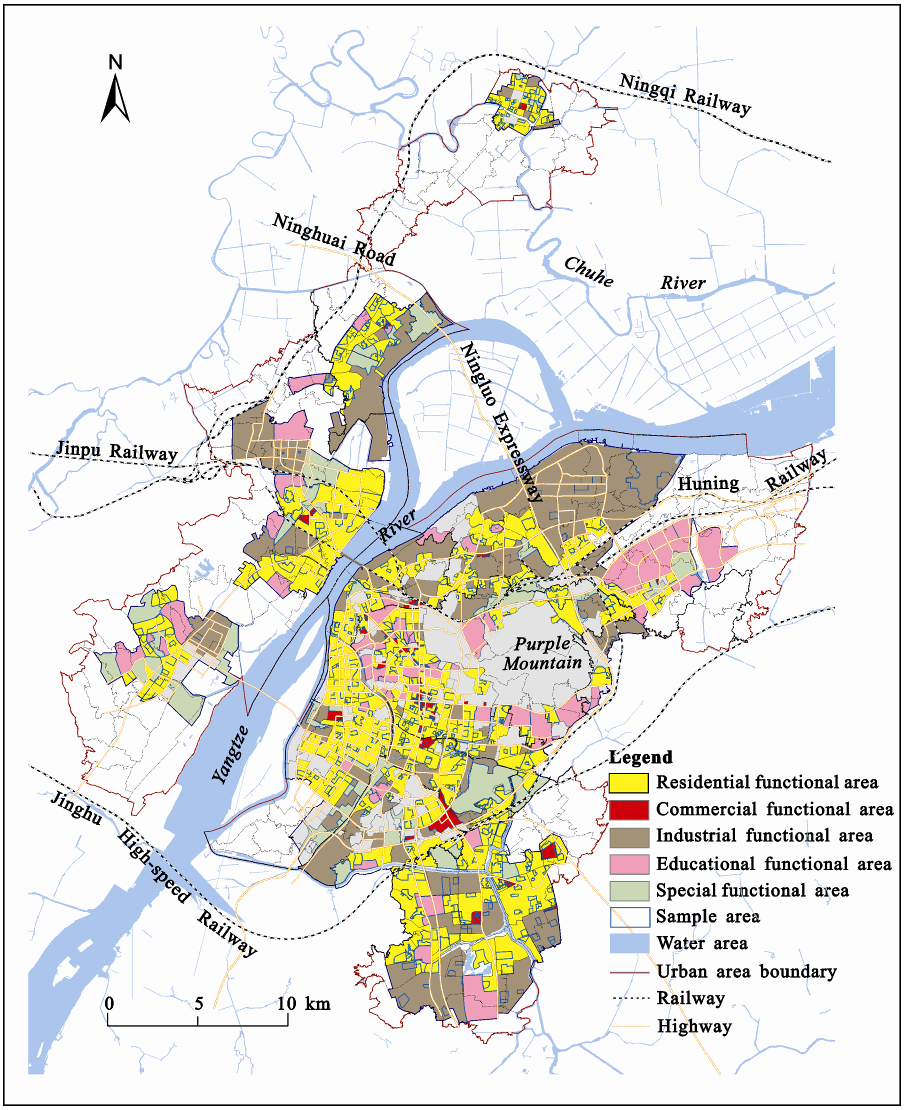

Fig. 4 Distribution map of urban land evaluation function areas and sample areas

accidental changes and trend evolution factors. Consequently, it is necessary to establish a comprehensive index system for the assessment of urban land use intensity. The construction of an index system should be based on science, hierarchy, and flexibility, as well as be comprehensive, simplified, comparable, quantifiable and dynamically oriented. According to the positional differences of the functional areas, different evaluation index systems of land use intensity are constructed to meet future development needs (Table 1).

3.3 Preliminary calculation of intensive land use degree based on multi-factor comprehensive evaluation method

In this paper, the preliminary assessment selects the sample areas for specific accounting on the basis of dividing Nanjing's urban built-up area into different functional areas. The data source of each index is shown in Table 1. Among them, the data of volume rate and building density in the index system is extracted from urban 3D data (Qiao, 2013). The determination of the ideal value of each index is mainly based on current national and local laws and regulations, in combination with the technical indices in the local general land use planning and urban planning. In the absence of the above criteria and standards, the relevant ideal value is determined through the typical regional survey and expert advice. The selected typical area is a region that reflects the actual situation and represents higher degree of intensive land use in Nanjing. The weight of each

Table 1 Evaluation index system of urban land use intensity in Nanjing City, China

Type of functional area	Index	Data source
Residential functional area	Volume rate	Urban 3D data
	Building density	Urban 3D data
	Proportion of green land	Remote sensing data
	Population density	Map of population density
	Level of Infrastructure completeness	Urban land grading information
	Level of life service facilities completeness	Urban land grading information
	Level of residential land price	Map of standard land price and investigation
Commercial functional area	Volume rate	Urban 3D data
	Level of Infrastructure completeness	Urban land grading information
	Level of commercial land price	Map of standard land price and investigation
Industrial functional area	Volume rate	Urban 3D data
	Total amount of fixed assets per unit land	Industrial land survey data
	Level of Infrastructure completeness	Urban land grading information
	Total industrial output value per unit land	Industrial land survey
	Industrial profits and taxes per unit land	Industrial land survey
Educational functional area	Volume rate	Urban 3D data
	Building density	Urban 3D data
	Student number per unit land	Student number survey data
	Level of Infrastructure completeness	Urban land grading information
Special functional area	Volume rate	Urban 3D data
	Building density	Urban 3D data

index is determined by an analytic hierarchy process. To eliminate the influence caused by different index units on the effectiveness of the ultimate calculation results, this study standardizes the index data and uses this standard index. The region's degree of land use intensity (λ) can be defined as:

$$\lambda = \sum_{i=1}^{n} (\beta_i \times F_i) \times 100 \tag{1}$$

where λ is the regional intensive land use degree; β_i is the weight of the index i ($0 \le \beta_i \le 1$), the sum of the weights of n indexes is 1; and F_i is the standardized value.

By means of the ArcGIS software platform, we adjust the attribute lists for all sample areas and preliminarily calculate the degree of land use intensity of the different functional areas in urban built-up area of Nanjing City. This is done according to the multi-factor comprehensive evaluation method mentioned above. It can be observed from the calculated results that the highly intensive use regions in Nanjing are mainly concentrated in the core urban areas such as the Gulou District, Baixia District, and Xuanwu District, and the degree of land use intensity of the peripheral Luhe District and Qixia District is low. As a whole, the degree of land use intensity of Nanjing's urban built-up area shows the radial gradient extension as gradually reducing from the centre to the outside of the city. However, it is noted that there are differences between the actual situation and the evaluation results, such as the result that the urban village in the main urban area lies in the excessive land use intensity region, which is inconsistent with reality. This is also a concrete manifestation of the problem that the multi-factor comprehensive evaluation model cannot reflect the object's structure and situation at parcel scale. Therefore, there is an urgent need to develop a new evaluation model.

3.4 Evaluation of intensive land use based on ANN model

The multi-factor comprehensive evaluation method is used to calculate the intensity level of each evaluation unit, and most of the results are satisfactory. However, there are also some deviations due to the limitation of the model itself and the determination of the ideal value and weight. So, based on the real situation of the sample areas and expert judgement, this study selected 10% of the sample areas whose evaluation results are most consistent with the actual situation; then, these evaluation units are used as the training samples for the neural network training and all the evaluation units are re-evaluation. The introduction of the neural network model is used to describe the intensive degree fitting and calculation of the urban land system under the complex index system. This study used the BP neural network model for the calculations. The model is built in MATLAB software, and the detailed process is shown in Fig. 5.

The quantitative indexes used in this article cannot be calculated directly because of their different units. So, the collected index data have to be normalized using MATLAB software. Using the premnmx function in MATLAB, the change range of the data is controlled as [−1, 1], and the dimensional effect is well eliminated, making the evaluation of the land use intensity of the study area more practical. The normalized function used in the premnmx function can be defined as:

$$T_j = \frac{P_j - P_{j\min}}{P_{j\max} - P_{j\min}} \quad (2)$$

where T_j is the standardized value of P_j; $P_{j\min}$ and $P_{j\max}$ are the minimum and maximum of the pre-established index j, respectively, and j is the number of the indexes.

After the neural network training, the normalized indexes of all sample areas can be input into the trained network. The output value is the normalized comprehensive index value of each sample area. The final evaluation score of each unit is obtained by the inverse normalized treatment. According to the total score frequency curve chart method, the degree of land use intensity of the sample areas for different functional areas is divided into several score sections. The score sections of over-exploited, intensive-used, moderated-used and low-used regions are 95–100, 75–95, 50–75 and 0–50, respectively. These sections determine the standard of

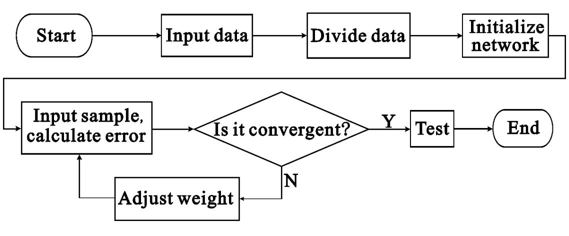

Fig. 5 Flow chart of BP neural network construction

differentiating four types of land use intensity. By comparison, the evaluation values of the neural network model and the degree of land use intensity determined by it match the actual situation.

Then, the results are mapped using the spatial map spot data. With the help of the spatial analysis and statistics function of ArcGIS, this study analyses and maps the evaluation results of the typical sample areas. On this basis, the sample area map and the functional area map data are processed by spatial join. We then obtain the degree of land use intensity within the study area's different functional areas (Fig. 6). The area and proportion of the functional areas with different degrees of land use intensity can be simultaneously calculated (Table 2).

4 Analysis of Evaluation Results

4.1 Overall situation of intensive land use

Evaluation results show that the overall land use intensity of Nanjing is good, the area of intensive and moderate use land accounts for 64.60% of the total evaluation area. Considering different urban districts, the proportions of over-exploited land area of Gulou District, Xuanwu District and Qinhuai District are higher in all districts, reaching 25.69%, 11.95% and 11.38%, respectively, the proportions of the rest districts are all less than 10%. The proportions of intensive use land in Jiangning District and Gulou District are higher, reaching 66.68% and 62.46%, respectively, the proportions of the rest districts are all less than 25%. The proportions of moderate utilization area are higher in Yuhuatai District, Liuhe District, Xuanwu District and Jianye District, reaching more than 30%, the proportion of moderate utilization area in Qinhuai District is the lowest, only 3.21%; The proportions of low use land in Qinhuai District, Xiaguan District and Qixia District are higher, reaching more than 40%, the proportion of low utilization area of Gulou District is the lowest, only 3.37%. Comparing the sum of the over- exploited area and intensive use area with the sum of the moderate utilization area and low utilization area, the ratios of Gulou District, Jiangning District and Xuanwu District are larger, the ratios of Qixia District, Qinhuai District and Baixia District are lower, which indicates that the overall intensive use level of the former is better, the intensive use level of the latter is lower.

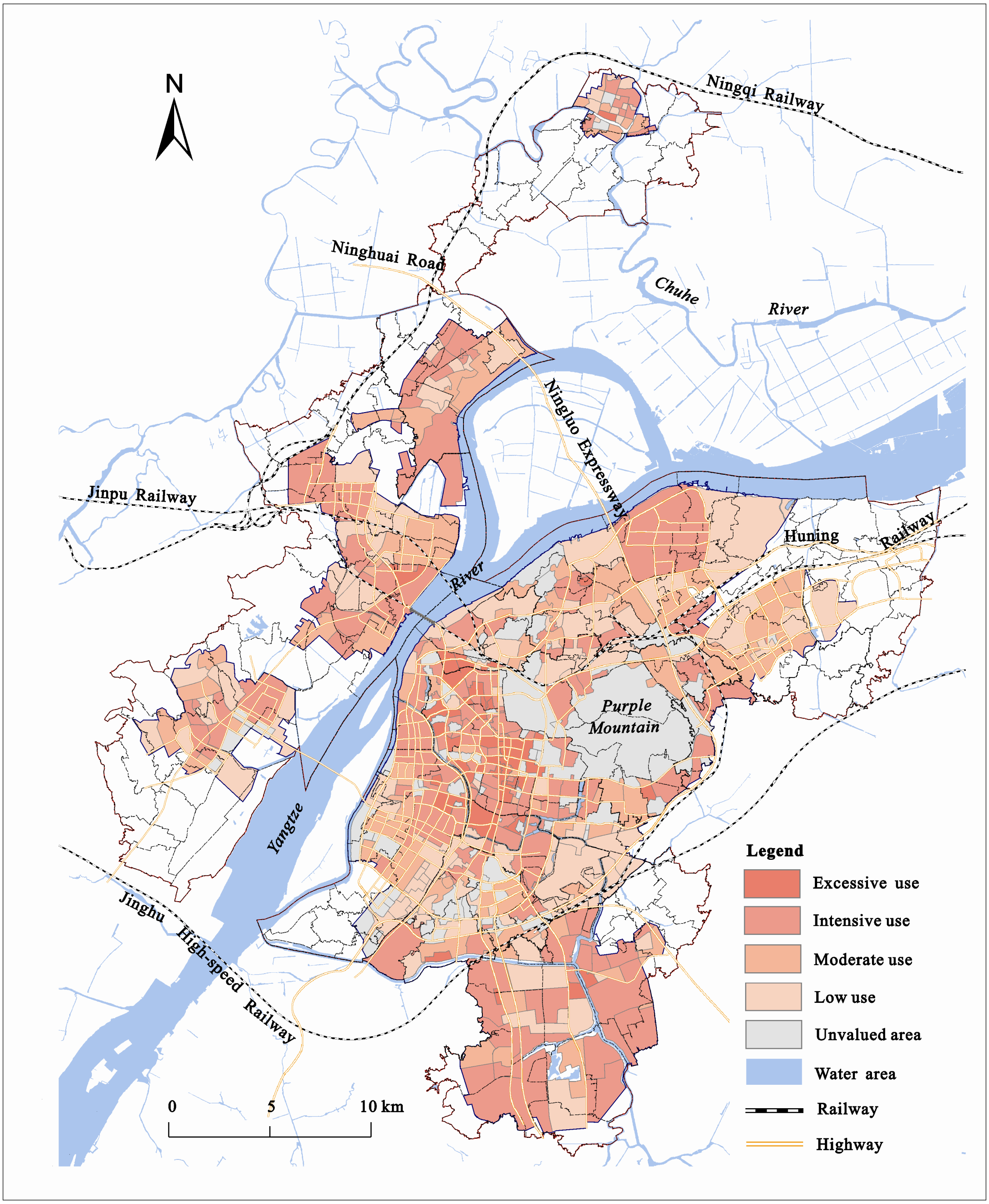

Fig. 6 Intensive land use condition of different functional areas in the urban built-up area of Nanjing City, China

4.2 Urban land use intensity situation of different functional areas

Evaluation results show that the residential functional area generally exhibits an intensive state of utilization. From the quantitative point of view, the number of sample map spots reaching the intensive use level is 198, accounting for 56.6%. In terms of area, the intensive use sample area accounts for 43.92% of the whole area. The intensive use level of residential functional areas in the urban built-up area is higher than that of other parts and gradually decreases from the centre to the outside. The over-exploited areas centre on the old city, mainly in the Gulou District, Xuanwu District and Xiaguan District. Some residential functional areas with low density and low volume rate are distributed over the suburban districts such as the Qixia District, Jiangning District and Yuhua District. Parts of the residential villa areas are with moderate or low utilization.

Table 2 Intensive land use condition of different administrative regions in Nanjing City, China

District	Excessive use (ha)	Proportion (%)	Intensive use (ha)	Proportion (%)	Moderate use (ha)	Proportion (%)	Low use (ha)	Proportion (%)
Baixia District	162.98	8.37	821.83	42.21	271.43	13.94	690.71	35.48
Gulou District	539.29	25.69	1311.46	62.46	178.07	8.48	70.75	3.37
Jianye District	123.40	5.19	693.93	29.21	728.13	30.65	830.00	34.94
Jingning District	132.12	1.76	4998.42	66.68	953.25	12.72	1411.86	18.84
Luhe District	30.76	0.96	1424.54	44.27	999.17	31.05	763.08	23.72
Pukou District	99.63	1.18	3598.46	42.77	2115.90	25.15	2598.56	30.89
Qixia District	25.94	0.28	2829.10	30.39	2403.96	25.83	4048.78	43.50
Qinhuai District	241.06	11.38	656.51	31.00	67.97	3.21	1152.41	54.41
Xiaguan District	153.51	7.92	577.46	29.78	345.56	17.82	862.52	44.48
Xuanwu District	349.84	11.95	1076.78	36.78	903.36	30.85	597.78	20.42
Yuhuatai District	50.34	2.09	862.00	35.76	768.76	31.90	729.14	30.25
Total	1909	4.31	18850	42.60	9736	22.00	13756	31.09

The commercial functional area generally shows a relatively high intensity of use. From a quantitative point of view, the number of the sample map spots of the intensive use level is 35, accounting for 50.7%. In terms of area, the intensive use and over-exploited sample areas account for 63.3%. The intensive use level of the commercial functional area in the centre city is higher than that of other areas and gradually decreases from the centre to the outside. The over-exploited areas centre on the old city, mainly in the Gulou District, Baixia District and Xuanwu District. The moderate-exploited areas mainly centre on the Jiangning District and Pukou District. The reason why the sample areas with low utilization mainly centre on the Jiangning District and Pukou District because these districts' commercial areas are in development, and at the point of the evaluation, the facilities were imperfect.

The study evaluates only the enterprises outside the ring road. The quantity of the intensive use areas is more than half, but the total area only accounts for 20%. Moreover, though the number of moderate use areas and low utilization areas is few, the total area is large, mainly centred on the Jiangning District and Qixia District. The industrial enterprises inside the ring road are all of low utilization, and since they ought to be entirely moved away and transformed, they are not evaluated here. The industrial enterprises mainly centre on the new area, giving priority to the national and provincial development zones within the jurisdiction. The low-utilization areas are mainly distributed in the Jiangning District and Qixia District.

The overall educational functional area presents a relatively high intensive use situation. The number of the intensive use and over-exploited sample areas is 49, accounting for approximately 73.9% of the educational functional areas. The intensive use and over-exploited area of the sample areas account for approximately 47.3% of the area of the sample areas. The degree of intensity of the city centre's educational functional area is apparently higher than that of the suburbs. There are a many old campuses in the Xuanwu District and Gulou District, and most of them are in an over-exploited or intensive use state. Some universities' new campuses are located in the Qixia District, Jiangning District and Pukou District, and at the point of evaluation, they are in a state of moderate or low utilization.

The number of special functional areas is 43 and that their area reaches 4719.11 hm^2, accounting for approximately 10.3% of the entire evaluation region. From the quantitative point of view, special functional areas have increased the most in Pukou District and Jianye District. Only one of the 43 special functional areas is excessive use, and the rest is low use.

5 Discussion

The purpose of intensive urban land use is to develop the land use potential, use land efficiently and save valuable land resources (Meng *et al.*, 2008). The premise of achieving the goal of intensive urban land use is to make an objective and accurate assessment of urban land use. In the previous studies, the scales of the evaluation units were often larger: some studies took the whole city as an evaluation unit (Hui *et al.*, 2015), some took the administrative regions, such as district or sub-district as evaluation units (Meng *et al.*, 2008; Yang *et al.*, 2012), and some took the large functional areas in the city, such as the development zone or university district as evaluation units (Shao and Wang, 2008; Liu and Gao, 2011; Shi and Huang, 2013). This paper evaluates the degree of intensive urban land use in a hot study city from microcosmic perspective, which is more practical. The comprehensive evaluation method is widely used in the actual evaluation work. In this paper, the ANN model is used to correct the evaluation results of the comprehensive evaluation method. It solves the problems of normalization of different dimension indicators and artificial determination of index weights to a certain extent. Compared with the results of the comprehensive evaluation method, the calculated values of the ANN model and the determined level of intensive land use are more realistic. At present, China's urban construction land intensive use evaluation project is widely carried out in all cities and all counties, this research method has certain promotional value.

The evaluation results of this paper are in line with the laws of urban expansion and urban land price distribution. The degree of land use intensity presents a gradually decreasing trend from the core districts to the outside. Overall intensive land use degree is good, but the proportion of land with low utilization reaches 31.09%, which is just behind the intensive use land. So, the land use potential is also great. There are obvious spatial differences in the distribution of intensive use types: the residential, commercial and educational functional areas show an intensive centre with a low utilization periphery; the industrial functional areas in the main urban area are low utilization and are gradually improving because of Nanjing's 'reduce the secondary industry and increase the tertiary industry' policy.

At present, the contradiction between people and land has stood out due to rapid urbanization in large and medium cities in China. The evaluation of urban land use can guide the transformation of urbanization and provide the basis for the formulation of urban and land use planning, as well as the relevant laws and regulations on land use intensity. This paper attempted some new evaluation methods. However, for many steps of the evaluation, such as data acquisition of each evaluation index, the division of functional areas, the choice of index system, the determination of the reference value of the indicators and the calculation model, further study is required to obtain more objective and applicable results. In the application of the evaluation results, efforts should be made to explore the potential of low and moderate intensive land use regions and strengthen the adjustment and integration of over-exploited land. Urban construction should be rationally directed towards liveable habitats and in accordance with areas reserved for protection. It is important to strengthen the rational allocation of land use functional areas, scientifically distribute the urban and rural construction land, and coordinate the layout of the city's internal production and living areas to achieve the concentration and agglomeration of development.

6 Conclusions

In this study, the multi-factor comprehensive evaluation method and neural network model are used synthetically, and both can reflect the actual situation. Compared to the former, the neural network model has a stronger nonlinear fitting function between the independent variable and the dependent variable. The trained neural network can distinguish the special evaluation unit and make the evaluation results of the neural network model more scientific and practical, which can be effectively applied to an evaluation of urban land use intensity.

The overall urban land use intensity of Nanjing City is good, the sum of intensive use and moderate use land area accounts for 64.60% of the total area of the evaluation area. The degree of land use intensity gradually decreases from the urban core area to the outside. Considering the overall spatial distribution of the degree of land use intensity of the urban built-up area in Nanjing, the excessive and intensive use levels are mainly concentrated in Gulou District, Jiangning District, Baixia District and Xuanwu District, Among them, the proportions of the sum of over-exploited and intensive use land area in Gulou District and Jiangning District reach 88.15% and 68.44%, respectively. The moderate use and low utilization level is mainly concentrated in the Qixia District, Jianye District, Xiaguan District and Yuhuatai District, the proportions of the sum of moderate and low use land area in the four districts are all more than 60%. Between them, the proportion of Qixia District reaches 69.33%. In terms of different functional areas, the commercial functional area is generally in a state of relatively high intensive use, the residential and educational functional areas are generally in state of relatively intensive use, and the industrial functional area is in a state of relatively low utilization.

Nanjing is now in the transition period of urbanization. The city should aim for an intensive expansion mode. For the residential functional area, Nanjing should appropriately increase the building density and volume rate of the residential areas, especially the newly developed area around the city. For the industrial functional area, the industry in the main urban area ought to be moved out to industrial parks, according to the 'reduce the secondary industry and increase the tertiary industry' policy. It is better to gradually increase the comprehensive volume rate of the industrial land development zones and improve the land use efficiency and industrial development capacity of existing and planned industrial land. It is also advisable to raise the construction standards of newly built factory buildings, gradually transform the original factory buildings, and avoid the extension of the development zones. For the commercial functional area, Nanjing should add or extend several regional commercial centres and increase the average building density and volume rate of commercial land. Finally, for the historical and cultural protection areas in the inner city, the intensity of control and protection should be strengthened.

References

Ahn B S, Cho S S, Kim C Y, 2000. The integrated methodology of rough set theory and artificial neural network for business failure prediction. *Expert Systems with Applications*, 18(2): 65–74. doi: 10.1016/S0957-4174(99)00053-6

Almeida C M, Gleriani J M, Castejon E F *et al.*, 2008. Using neural networks and cellular automata for modelling intra-urban land-use dynamics. *International Journal of Geographical Information Science*, 22(9): 943–963. doi: 10.1080/13658810701731168

Bai X M, Shi P J, Liu Y S, 2014. Society: Realizing China's urban dream. *Nature*, 509(7499): 158–160. doi:10.1038/509158a

Di Xianghong, Hou Xiyong, Wang Yuandong *et al.*, 2015. Spatial-temporal characteristics of land use intensity of coastal zone in China during 2000–2010. *Chinese geographical science*, 25(1): 51–61. doi: 10.1007/s11769-014-0707-0

Erb K H, Haberl H, Jepsen M R *et al.*, 2013. A conceptual framework for analysing and measuring land-use intensity. *Current Opinion in Environmental Sustainability*, 5(5): 464–470. doi: 10.1016/j.cosust.2013.07.010

Estoque R C, Murayama Y, 2015. Intensity and spatial pattern of urban land changes in the megacities of Southeast Asia. *Land Use Policy*, 48: 213–222. doi: 10.1016/j.landusepol.2015.05.017

Ferdous N, Bhat R C, 2013. A spatial panel ordered-response model with application to the analysis of urban land-use development intensity patterns. *Journal of Geographical Systems*, 15(1): 1–29. doi: 10.1007/s10109-012-0165-0

Gevrey M, Dimopoulos I, Lek S, 2003. Review and comparison of methods to study the contribution of variables in artificial neural network models. *Ecological Modelling*, 160(3): 249–264. doi: 10.1016/S0304-3800(02)00257-0

Gong J Z, Chen W L, Liu Y S, 2014. The intensity change of urban development land: Implications for the city master plan of Guangzhou, China. *Land Use Policy*, 40: 91–100. doi: 10.1016/j.landusepol.2013.05.001

Guresen E, Kayakutlu G, Daim T U, 2011. Using artificial neural network models in stock market index prediction. *Expert Systems with Applications*, 38(8): 10389–10397. doi: 10.1016/j.eswa.2011.02.068

Hui E C M, Wu Y Z, Deng L J *et al.*, 2015. Analysis on coupling relationship of urban scale and intensive use of land in China. *Cities*, 42: 63–69. doi: 10.1016/j.cities.2014.09.002

Jiang Hai, Qu Futian, Ou Minghao *et al.*, 2008. Evaluation methods and application of regional Land-use intensity. *Transactions of the Chinese Society of Agricultural Engineering*, 24(1): 117–123. (in Chinese)

Khan J, Wei J S, Ringner M *et al.*, 2001. Classification and diagnostic prediction of cancers using gene expression profiling and artificial neural networks. *Nature Medicine*, 7(6): 673–679. doi: 10.1038/89044

Kuemmerle T, Erb K, Meyfroidt P *et al.*, 2013. Challenges and opportunities in mapping land use intensity globally. *Current Opinion in Environmental Sustainability*, 5(5): 484–493. doi: 10.1016/j.cosust.2013.06.002

Levers C, Butsic V, Verburg P, 2016. Drivers of changes in agricultural intensity in Europe. *Land Use Policy*, 58(15): 380–393. doi. 10.1016/j.landusepol.2016.08.013

Li Guangdong, Fang Chuanglin, Pang Bo, 2014. Quantitative measuring and influencing mechanism of urban and rural land intensive use in China. *Journal of Geographical Sciences*, 24(5): 858–874. doi: 10.1007/s11442-014-1125-z

Li Kongqing, Chen Yinrong, 2013. Evaluation on the intensity of urban land use based on low-carbon concept: a case study of Nanjing City. *China Land Sciences*, 27(1): 61–66. (in Chinese)

Li X, Yeh A G O, 2002. Neural-network-based cellular automata for simulating multiple land use changes using GIS. *International Journal of Geographical Information Science*, 16(4): 323–343. doi: 10.1080/13658810210137004

Liu X D, Gao J, 2011. Discussion on the index system of intensive land use evaluation in development area. *Asian Agricultural Research*, 3(2): 91–96.

Luo H C, Li X M, Zheng S J *et al.*, 2012. Study on synthesis evaluation of intensive land use and growth pattern transformation of towns. *Journal of Computers*, 7(8): 1959-1966. doi: 10.4304/jcp.7. 8.1959–1966

Meng Y, Zhang F R, An P L *et al.*, 2008. Industrial land-use efficiency and planning in Shunyi, Beijing. *Landscape and Urban Planning*, 85(1): 40–48. doi: 10.1016/j.landurbplan.2007.09.004

Pijanowski B C, Brown D G, Shellito B A *et al.*, 2002. Using neural networks and GIS to forecast land use changes: a land transformation model. *Computers*, *Environment and Urban Systems*, 26(6): 553–575. doi: 10.1016/S0198-9715(01)00015-1

Pradhan B, Lee S, 2009. Landslide risk analysis using artificial neural network model focussing on different training sites. *International Journal of Physical Sciences*, 4(1): 1–15.

Pradhan B, Lee S, 2010. Delineation of landslide hazard areas on Penang Island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models. *Environmental Earth Sciences*, 60(5): 1037–1054. doi: 10.1007/s12665-009-0245-8

Qiao Weifeng, 2013. *Study on Urban Spatial Multidimensional Expansion of Nanjing Based on Land Use Perspective*. Nanjing: Nanjing Normal University. (in Chinese)

Recknagel F, 1997. ANNA: Artificial Neural Network model for predicting species abundance and succession of blue-green algae. *Hydrobiologia*, 349(1): 47–57. doi: 10.1023/A:1003041427672

Salomon R, Hemmen J, 1996. Accelerating back propagation through dynamic self-adaptation. *Neural Networks*, 9(4), 589–601. doi: 10.1016/0893-6080(95)00144-1

Shao Xiaomei, Wang Jing, 2008. Appraisal of intensive land use of development zones in small towns: a case study of Cixi in Zhejiang Province. *Progress in Geography*, 27(1): 75–81. (in Chinese)

Shi Y S, Huang Y C, 2013. Relationship between morphological characteristics and land-use intensity: empirical analysis of shanghai development zones. *Journal of Urban Planning and Development*, 139(1): 49–61. doi: 10.1061/(ASCE)UP.1943-5444.0000134

Sluisa T, Pedrolia B, Kristensen S, 2016. Changing land use intensity in Europe: recent processes in selected case studies. *Land Use Policy*, 57(30): 777–785. doi: 10.1016/j.landusepol.2014.12.005

Taleai M, Sharifi A, Sliuzas R, 2007. Evaluating the compatibility of multi-functional and intensive urban land uses. *International Journal of Applied Earth Observation and Geoinformation*, 9(4): 375–391. doi:10.1016/j.jag.2006.12.002

Temme A J A M, Verburg P H, 2011. Mapping and modeling of changes in agricultural intensity in Europe. *Agriculture*, *Ecosystems and Environment*, 140(1–2): 46–56. doi: 10.1016/j.agee.2010.11.010

Wang F, Antipova A, Porta S, 2011. Street centrality and land use intensity in Baton Rouge, Louisiana. *Journal of Transport Geography*, 19(2): 285–293. doi:10.1016/j.jtrangeo.2010.01.004

Wang J, Chen Y, Shao X *et al.*, 2012. Land-use changes and policy dimension driving forces in China: present, trend and future. *Land Use Policy*, 29(4): 737–749. doi: 10.1016/j.landusepol.2011.11.010

Wang Mingshu, Zhu Ming, 2012. Evaluating intensive land use situation of development zone based on cloud models. *Transaction of the Chinese Society of Agricultural Engineering*, 28(10): 247–252. (in Chinese)

Xie Hualin, He Yafen, Zou Jinlang *et al.*, 2016. Spatio-temporal difference analysis of cultivated land use intensity based on emergy in the Poyang Lake Eco-economic Zone of China. *Journal of Geographical Sciences*, 26(10): 1412–1430. doi: 10.1007/s11442-016-1335-7

Yang J Y, Yang Y, Tang W, 2012. Development of evaluation model for intensive land use in urban centers. *Frontiers of Architectural Research*, 1(4): 405–410. doi: 10.1016/j.foar.2012.07.006

Zhang Y D, Wu L N, 2009. Stock market prediction of S&P 500 via combination of improved BCO approach and BP neural network. *Expert Systems with Applications*, 36(5): 8849–8854. doi: 10.1016/j.eswa.2008.11.028