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Regional Ecological Security Assessment: A Case Study of Tongling City, Anhui Province

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Abstract

The focus of this study is to assess regional ecological security, based on a method of combining the ecological sensitivity evaluation and the ecosystem services evaluation of Tongling City, China. This approach may reduce the possible errors caused by basing the assessment on only one of these two evaluation methods. The PCA (Principal Component Analysis) and rectified ESV (Ecosystem Services Value) methods were employed in this study with the support of SPSS, RS and ARCGIS. The study showed the following results: the ecological sensitive area is mainly located among the wetland concentrated areas along the river in the north and the forested and green spaces within and around the city, and the area with the highest value is the mountainous areas in the south; the northern wetland area along the river and the southern forested mountain area have high ecosystem services value. Finally, the study identified the ecologically fragile and important services areas, and offered a reliable reference for Tongling's ecological protection and urban growth decisions by dividing the ecological security evaluation areas into areas with low, mid and high ecological security levels.

Keywords: Ecological sensitivity evaluation; Ecosystem services evaluation; Ecological security

Abbreviations: PCA: Principal Component Analysis; ESV: Ecosystem Services Value; SPSS: Statistical Product and Service Solutions; RS: Remote sensing; ARCGIS: Arc- Geographic Information System

Introduction

Since the industrialization period, human impact on the natural environment has proceeded at an unprecedented scale and speed, and put great pressure on the capacity of our resources and environments. This rapid industrialization and urbanization has led to the deterioration of ecosystems and other environmental problems. Ill-considered urban construction projects have led to a series of ecological and environmental issues, such as increased human encroachment on the natural landscape [1] the declining spatial connectivity between ecological patches [2] and the loss and fragmentation of habitats [3] The urban ecosystem is becoming increasingly fragmented, which has seriously threatened both urban biodiversity conservation and ecosystem service maintenance [4]. Only a few non-human species thrive in urban areas [5]. Therefore, it is essential to assess regional ecological security in order to identify and protect important ecological protection areas.

Over the last two decades, Chinese researchers have conducted a series of studies regarding ecological security, such as landscape pattern optimization [6,7]; land use structure optimization [8,9]; ecological sensitivity [10]; ecosystem services value[11]; ecosystem carrying capacity [12]; concept and theoretical basis of ecological security pattern [13] and the designing principles and methods of ecological security [14]. In western countries, concepts such as ecological corridors, ecological networks [15,16], ecological infrastructure[17], and green infrastructure[18] have been proposed to ensure ecological security. Therefore, concepts, connotations and measures ensuring ecological security have been widely discussed both in China and Western Countries.

As it is illustrated in Figure 1, this study focuses on designing a method of regional ecological security assessment, based on evaluating the ecological sensitivity and ecosystem services value of different land use types in a case study of Tongling city. The PCA (Principal Component Analysis) and rectified ESV (Ecosystem Services Value) method were employed in this study with the support of SPSS, RS and ARCGIS.

Materials and Methods

Definitions

There is a wide variety of definitions about ecological security, which may focus on environmental security[19,20], multiple ecosystems including natural system, social system and economic system[21] ,and so on. By analyzing the listed definitions of ecological security, this paper concludes there are two significant elements of ecological security.

The first element represents the security of ecosystem itself, whether ecosystem is threatened or at risk. This paper uses ecological sensitivity to evaluate the risk of ecosystem. The ecological sensitivity reflects the possibility and probability of the occurrence of ecological or environmental problems when an ecosystem and specific ecological process subjected to the impacts of human activities or natural disasters [22].

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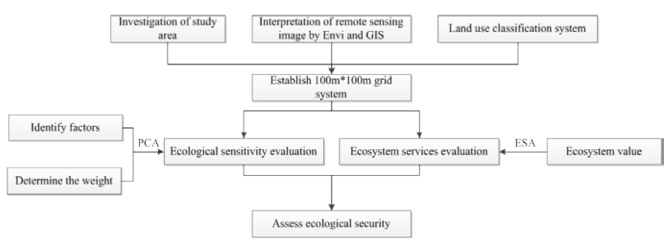

Figure 1: Sketch map of ecological security assessment in Tongling.

The other element emphases the safety for human beings, namely services provided by ecosystem to see whether it can meet the needs of human survival [23-25]. As to the definition of ecosystem services, there are a number of definitions in fact, of which the Daily et al. [26] and Costanza et al. [25] definitions are representative. Daily defines ecosystem services as benefits that ecosystems and their biodiversity confer on humanity through the wide array of conditions and processes, which include the production of goods, life-supporting functions and life-fulfilling conditions [26].

Study area and data source

The chosen study area of Tongling is located in Anhui Province (latitude, 30°45'12 "N to 31°07'56"N; longitude, 117°42 '00 "E to 118°10'06"E), as shown in Figure 2. The city is situated on the south bank of the Yangtze River, near the most developed urban agglomeration of the Yangtze River Delta. The three reasons for choosing Tongling as a representative case for our study are as follows.

First, in spite of being a small city, Tongling has a large variety of species and a broad spectrum of land-use types. Located in a subtropical humid monsoon climate, Tongling has more than 600 plant species and 88 families. It is located on the list of 11 National Modern Forestry Model Cities which were approved by China's National Forestry Administration in 2009. Tongling is located on hilly plains along a river, in an area which belongs to the Yangtze River water system. The river, estimated to be 55 km, flows from the southwest to the north, then turns east, and surrounds half of the city's border. The mountains in Tongling belong to the Huangshan Mountain range. The overall terrain slopes from south to north, and there are embedded small landscapes such as plains, plateaus, hills, low mountains, small rivers, and lakes.

Second, city sprawl and long-tern mining have put great pressure on Tongling's ecological security. The city is rich in mineral resources, including copper, sulfur, iron, gold, silver, coal, limestone, etc., giving it the name "bronze city". However, mining has caused a deterioration of the ecological environment. Many ecological and environmental problems have emerged, such as destruction of vegetation, soil erosion, ground collapse, and topography change. Meanwhile, Tongling has seen continuous urban growth in the last decade. Its central city building area rose from 54.29 km^2 in 2002 to 61.86 km^2 in 2008, and by 2010 reached the control targets of its Urban Mater Plan issued in 2003, i.e. 64 km^2. The contradiction between economic development and ecological protection has become an increasingly prominent issue.

The third reason is the recent national policy of transferring industry from coastal areas, such as the Yangtze River Delta, to inland areas. Due to its location, the city of Tongling is on the frontline to undertake the industrial spillover and population migration from the Yangtze River Delta. With this background in mind, the rapid economy growth will cause increasing land-use demands, which conflicts with the ecological protection requirement. This will become a typical problem for almost all the cities in the middle-eastern region of China. Tongling is just a representative case among them. Therefore, the rapid urban sprawl, the deterioration of the ecological environment caused by mining and the undertaking of industrial spillover and population migration have all necessitated the assessment of the ecological security in the city of Tongling.

In this study, the basic data-set is Tongling's land-use change investigation data from 2010, obtained from the Tongling Land and Resources Bureau, who organizes the annual investigation of land-use changes. The land-use change investigation is an annual survey conducted by the government of China at all levels. The survey looks into the annual changes in land use and ownership within each jurisdiction. Tongling's land-use data for 2010, which are used in this study, include farmland (paddy fields, irrigated land); forested land (forest, shrub land, other woodland, as well as orchards, tea plantations, landscaped land); grass land (natural, artificial, and other grasses); constructed land (cities, towns, villages, mining land, ditches, hydraulic construction sites, railway, highways, rural roads, ports, pipeline transportation, facilities); water areas (river, lake, reservoir, and pond waters); wetlands (inland beaches, marshes); and bare ground (bare ground, sand). The survey contains seven categories of land use, 36 sub-categories, and each has detailed information of the location, parcel shape, and area, etc. The analysis was mainly based on ARCGIS10.0, and this analysis method may also be applied in other cases.

Evaluation Methods

Ecological sensitivity evaluation method

In this study, by consulting the *Interim Regulations on Ecological Function Zoning Techniques,* published by China's Ministry of Environmental Protection, along with previous study results, an indicator system for ecological sensitivity evaluation was first established. Then the grading standards for each indicator were set. The principal component analysis (PCA) was applied in order to obtain the ecological sensitivity evaluation results.

Principle Component Analysis (PCA) is the simplest of the true eigenvalue-based multivariate analyses, where it is used to reduce the number of variables and transform into new variables that are mutually orthogonal, or uncorrelated, as well as to determine, dominant multivariate relationships [27,28]. Principal Components (PCs) contain most of the information from the original variables [29]. Meanwhile, PCA could also determine the weight of each indicator according to its variance contribution, and achieve a multi-indicator

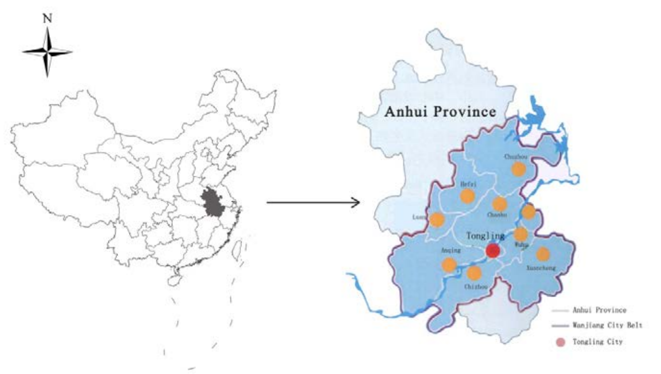

Figure 2: Geographical location of Tongling.

comprehensive evaluation. The weights computed by the principal component analysis process are objective, and only determined by a data-set structure, while other methods such as the Delphi method and the Analytic Hierarchy Process (AHP) method cannot avoid the influence of subjective factors. Such a data-driving evaluating method is suitable for a large data-set. As this study uses a GIS digital data-set with a large quantity of evaluating units, the principal component analysis results are reliable.

In mathematical terms, PCA involves five major steps: (1) select factors of ecological sensitivity evaluation and normalize the measurements. The normalization formula is

$$S_i' = \frac{S_i - min(S_i)}{max(S_i) - min(S_i)} \times 100 (i = 1, 2, ..., n),$$

where S_i' is the normalized ecological sensitivity score; (2) calculate the covariance matrix (F_{ij} (i=1, 2,…, n; j=1,2,…,m))

;(3) find the eigenvalue (λ_κ (k=1,2,…,m)) and the corresponding eigenvectors(L_K (k=1,2,…,m)); (4) discard any components that only account for a small proportion of the variation in datasets; (5) develop the factor loading matrix and perform a varimax rotation on the factor loading matrix to infer the principle parameters.

Ecosystem services evaluation method

Costanza referred to ecosystem services as benefits that humans obtain directly or indirectly from ecosystem functions. He estimated the value per unit area of each ecosystem service for each ecosystem type and then multiplied the value times the surface area of each ecosystem to arrive at global totals. Costanza used a static partial equilibrium model in order to evaluate the ecosystem services of the global ecosystem, introducing scientific principles and methods for estimating the value of the ecosystem services [25]. The ecosystem's service valuation formula is as follows:

$$ESV = \sum_{i=1}^{m} \sum_{j=1}^{n} A_j E_{ij} (i = 1, 2, \ldots\ldots m; j = 1, 2, \ldots\ldots n)$$

Where ESV is the total ecosystem services value; E_{ij} is the ecosystem services value unit area of ecological function *i* in a certain ecosystem type *j*; and A_j is the total area of ecosystem type *j*.

Compared to Costanza who aimed to evaluate the global ecosystem services value, Chinese scholar Xie [30,31] Figured out Ecosystem Services Value (ESV) unit area of the Chinese ecosystem based on a questionnaire about Chinese ecosystem services value among 200 leading ecologists and Costanza's work. This study used a rectified Ecosystem Services Value (ESV) for Anhui [32] and thus determined Tongling's ecosystem services value.

Results

Ecological sensitivity evaluation results

Ecological sensitivity evaluation index and single-factor evaluation: In order to ensure the authenticity, suitability and operability of the evaluation, the area was divided into 100 m × 100 m units. Based on the analysis of the ecological characteristics and its influencing factors, six factors were selected in order to assess the ecological sensitivity in Tongling City. These included the slope of the landform, vegetation coverage (Vegetation coverage was calculated based on Tongling's land-use change investigation data from 2010. The research area was divided into 1000*1000 grids. Following the division of the area of land type (orchards, tea plantations, forest, shrub land, and other woodland) within each grid by the grid area, then the percentage of vegetation coverage could be obtained), biodiversity conservation, water, road traffic, and geologic hazards(Data regarding the geologic hazard were extracted from the Tongling Urban Master Planning (2011-2030)). After analyzing the sensitivity of each factor, each of the factors was classified into five grades (insensitive, slightly sensitive, moderately sensitive, highly sensitive, and extremely sensitive). Then the five grades were assigned scores of 1, 3, 5, 7 and 9, respectively. The higher the score, the greater the ecological sensitivity, which indicated it may not be appropriate for urban construction. The grading criteria of each factor and the evaluation results of each factor are shown in Table 1 and Figure 3.

Comprehensive evaluation results of the ecological sensitivity: The results of the ecological sensitivity evaluation based on the Principal Component Analysis (PCA) are depicted in Table 2. The sufficiency of the data for factor analysis was assessed using the Kaiser-Meyer-Olkin Measure (KMO) and Barlett's Test of Sphericity. The KMO test (0.619) which are greater than 0.5 show that the date is adequate [33] and Barlett's test of sphericity ($p<0.001$) shows a high degree of relationship between the six parameters, and the data are suitable for factor analysis. The four principal components were extracted according to the cumulative contribution rate, which was 83.89%. Also, in order to make a clear affiliation between the variables and components, a regressive orthogonal rotation method was used. The eigenvalues, variance contribution, and cumulative variance contribution are as shown in Table 2. In Table 3, the eigenvectors matrix for rotated PCA results was reported. Each row of this matrix represents one eigenvector and each column contains the loadings (relationship weights) of each principal component on each original variable.

By evaluating the ecological sensitivity of the principal component analysis above, we can calculate the ecological sensitivity evaluation scores for each of the evaluation units. The higher the score, the greater the likelihood of interference the evaluation unit may suffer from human activities. That is to say, the units with high scores might not be appropriate for land development and urban construction. As can be seen from Figure 4, units with high ecological sensitivity evaluation scores were mainly located in the southern area of Tongling, where low mountains dominate the landscape. A number of ecological protection areas and scenic spots are situated in this location such as the Bailang Lake scenic spot, Shilichangchong forest park, and Phoenix Mountain etc., where the forest coverage is high and the biological resources are rich. Also, several important ecologically sensitive areas are distributed along the river to the north of Tongling. There are many wetlands, thus the ecological environment is relatively stable. The National Nature Reserve of Freshwater Dolphin is also located in the north. The parks and green spaces within and surrounding the city are also highly ecologically sensitive areas. Since these parks and green spaces are small, scattered and surrounded by built-up urban areas, they were considered to be easily disturbed and eroded by human activities. However, they play important roles in the protection of the regional biodiversity, and the maintenance of the regional ecological security.

Ecosystem services evaluation results

Ecosystem services per unit area

Ecosystem services is a general term regarding the nature of ecosystems and ecological processes which maintain human survival and include provisioning, regulating, cultural, and supporting services. By evaluating the value of the ecosystem services, it is helpful to have a direct understanding of the ecosystem service functions, to identify

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Factor	**Insensitive (1)**	**Slightly sensitive (3)**	**Moderately sensitive (5)**	**Highly sensitive (7)**	**Extremely sensitive (9)**
Slope of landform	≤2°	2°-6°	6°-15°	15°-25°	>25°
Vegetation coverage	≤10%	10%-30%	30%-45%	45%-60%	>60%
Biodiversity	Residential andindustrial land	Traffic land	Arable land	grassland, water	Landscape ground
Waters	≥500 m	350-500 m	200-350 m	100-200 m	<100 m
Road traffic	≥200 m	150-200m	100-150 m	50-100 m	<50 m
Geologic hazard	Other places	——	——	——	High incidence of geologic disaster

Table 1: Grading of ecological sensitivity evaluation factors.

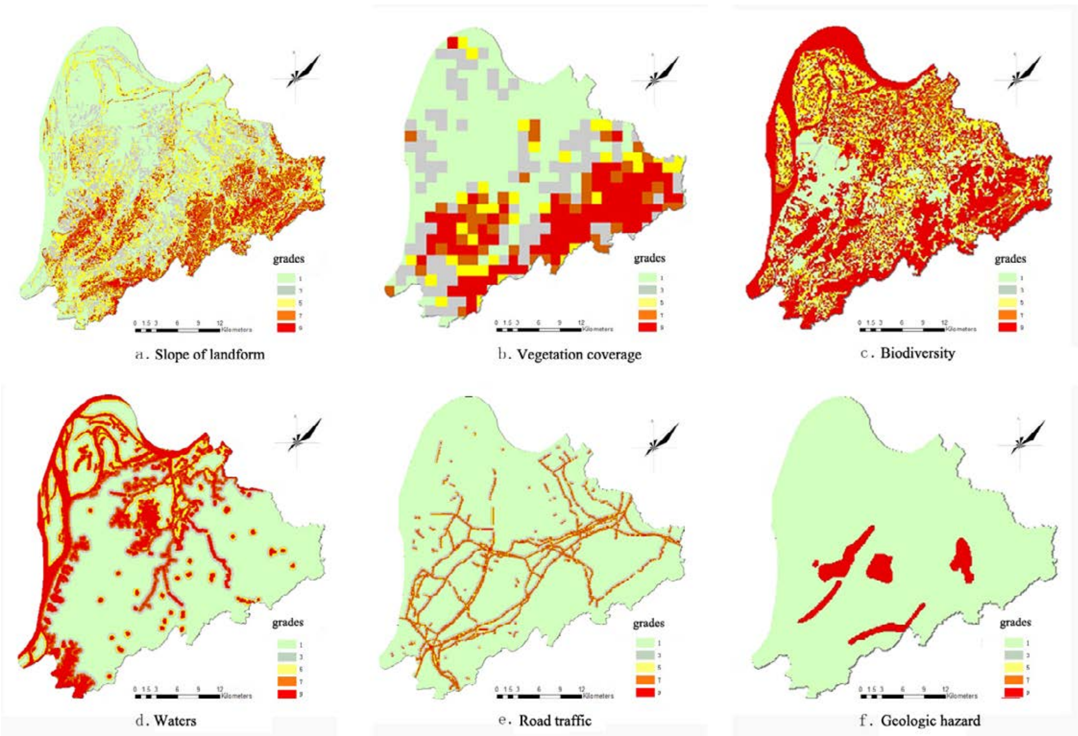

Figure 3: Spatial distribution of ecological sensitivity evaluation factors.

Component	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% Variance**	**% Cumulative**	**Total**	**% Variance**	**% Cumulative**
1	1.986	33.101	33.101	1.935	32.253	32.253
2	1.308	21.8	54.901	1.089	18.153	50.407
3	0.964	16.072	70.974	1.01	16.827	67.234
4	0.775	12.914	83.887	0.999	16.653	83.887
5	0.583	9.711	93.598			
6	0.384	6.402	100			

Table2: Eigenvalues and Explained Variance for PCA on Ecological Sensitivity Evaluation.

Original variables	**Principal components**			
	1	**2**	**3**	**4**
Slope of landform	0.814	0.133	-0.03	0.085
Vegetation coverage	0.86	0.14	-0.07	0.052
Biodiversity	0.077	0.94	-0.099	-0.06
Waters	-0.719	0.393	-0.084	-0.017
Road traffic	-0.026	-0.102	0.993	-0.009
Geologic hazard	0.093	-0.059	-0.009	0.993

Table3: Rotated Eigenvectors Matrix for PCA on Ecological Sensitivity Evaluation.

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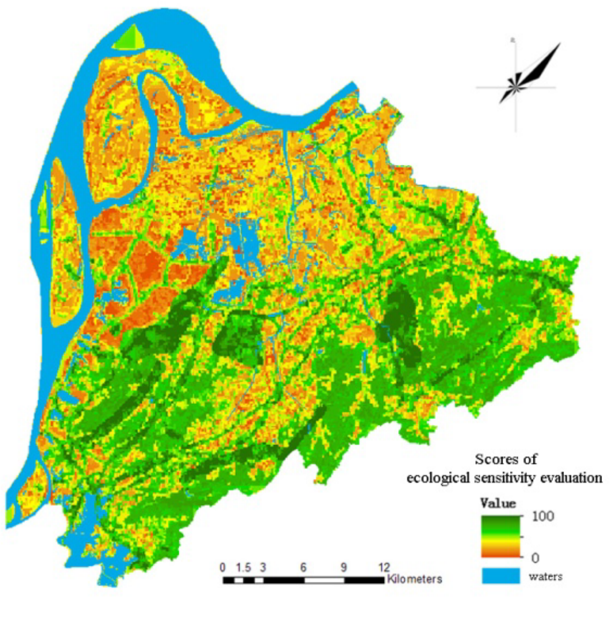

Figure 4: Scores of the ecological sensitivity evaluation in Tongling.

the high-value regions in the city, and to provide these with the proper protection in order to maintain a healthy and sustainable urban ecosystem.

First, we reclassified the different land use types in Tongling into: farmland, forested land, grassland, constructed land, water areas, wetland, and bare land. The results of this reclassification are as shown below in Table 4. Then, according to the correction coefficient of Anhui Province by Xie [32], we calculated the ecosystem services value of each land use type, presented in Table 5. Table 5 illustrates in detail the ecosystem services value of each land use type per unit area. It was clear that the wetland and water areas could provide the highest ecosystem services value per unit area, followed by the forested land, grassland and farmland, while the bare and constructed lands' ecosystem services values were much lower.

Evaluation results of ecosystem services

The ecosystem services evaluation was based on the specific ecological structure and function of the ecosystem. The land is the carrier of various ecosystems, and changes to the land use type will directly change the surface structure of the landscape, thereby directly affecting the function and processes of the ecosystem services. Therefore, the assessment of the ecosystem services value and the identification of important regional ecosystem service areas have great importance in maintaining the health of the existing natural ecosystems, as well as the sustainability of regional ecosystem services.

According to the estimation of the ecosystem services value per unit area, as illustrated in Table 5, each land parcel in the study area received a score for its ecosystem services value. The spatial distribution of the ecosystem services value scores is as shown in Figure 5. As it can be seen in Figure 5, the regions with the highest value of ecosystem services are mainly located along the river in the northern wetland areas of Tongling, which includes the rivers, lakes, river sandbars and wetlands. These locations are important sources of ecosystem services, as well as the ecological barrier in the west and north of Tongling. Also, the southern mountain regions are important ecosystem services protection areas, along with being the ecological barrier in the south and east of Tongling, and are rich in biological resources with a high forest coverage rate.

Ecological security assessment

Through the evaluation of the ecological sensitivity and ecosystem services values, the two sets of evaluation scores could be obtained. With the help of an ARCGIS10.0 spatial analysis tool, a disjunction operation was carried out between the results of the ecological sensitivity evaluation and the ecosystem services value. In other words, the maximum score between the score of ecological sensitivity evaluation and the score of the ecosystem services value was selected as the final comprehensive score of each unit area in order to maximize the identification and protection of the ecologically fragile and important ecosystem services areas. On this basis, according to the results of the comprehensive evaluation scores presented in Figure 6 combined with the consideration of the environmental features of Tongling City, the ecological security level grading was finally identified as shown in Figure 7. Tongling City was classified as areas of low level, moderate level and high level ecological security.

As is illustrated in Figure 7, areas with low level of ecological security value in Tongling are areas that should be protected and put on strict restrictions against urban construction, followed by areas with moderate level of ecological security value, which should also be protected but not necessarily as strictly. That is to say, areas with moderate level of ecological security value could be used for urban construction sometimes but had better not be developed on a large scale. However, areas with high level of ecological security value are places that can be used for urban construction and urban growth, where protection of the ecosystem is not so important.

Conclusions

This paper, taking Tongling as the study case area, assessed the ecological security and identified the ecological protection areas using the PCA and rectified ESV methods with the support of SPSS, RS and ARCGIS. The potential errors of this assessment were reduced by combining an ecological sensitivity evaluation and an ecosystem services evaluation. The main conclusions of this study are as follows.

(1) Following the indicator selection and an indicator grading and principal component analysis, the multi-indicator evaluation results show that the ecological sensitive area is mainly located among the wetland concentrated areas along the river in the north, the forested and green spaces within and around the city, and the area with the highest value is the mountainous areas in the south. Among these, the southern area is the most concentrated location of important ecologic resources for Tongling. These include many ecological protection areas

Number	Type	Land use types in Tongling
01	Farmland	Paddy fields, irrigated land
02	Forested Land	Forest land , shrub land , other woodland, orchards, tea plantations,
03	Grassland	Grassland
04	Constructed land	Cities, towns , villages, mining sites, scenic and special land , ditches , hydraulic construction sites , railways, highway, rural roads , ports, pipeline and transportation land
05	Waters	Rivers, lakes, reservoirs, ponds
06	Wetland	Inland beaches, marshes
07	Bare land	Bare land

Table 4: Land-use type classification designed for ecosystem services.

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Services	Detailed service	Farmland	Forested land	Grassland	Constructed land	Waters	Wetland	Bare land
Provisioning services	Food production	525.45	163.68	198.13	——	238.02	161.68	0
	Raw material production	204.93	1478.14	165.88	——	157.19	107.78	0
Regulating services	Air regulation	378.32	2142.81	691.16	——	229.04	1082.33	
	Climate regulation	509.69	2018.81	718.81	——	925.15	6085.31	
	Hydrological regulation	404.6	2028.73	700.37	——	8429.61	6035.9	29
	Waste disposal	730.37	853.15	608.22	——	6669.14	6467.04	9.7
Supporting services	Soil protection	772.41	1994	1032.12	——	184.13	893.71	19.4
	Biodiversity conversation	535.95	2237.05	861.65	——	1540.41	1657.18	329.2
Cultural services	Entertainment culture	89.33	1031.73	400.87	——	1994	2106.28	9.7
	Total	4151.04	13948.11	5377.2	0	20366.69	24597.21	397

Table 5: Estimation of ecosystem services value per unit area(yuan·hm^{-2}·a^{-1})"——"indicates that this type of land provides no such services.

Figure 5: Scores of the ecosystem services evaluation in Tongling.

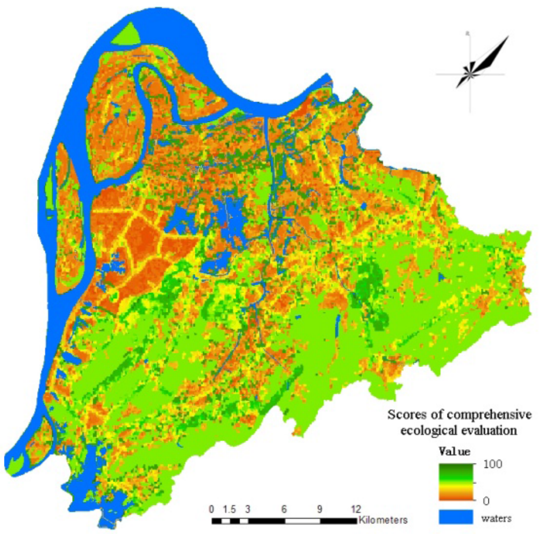

Figure 6: Scores of the comprehensive ecological evaluation in Tongling.

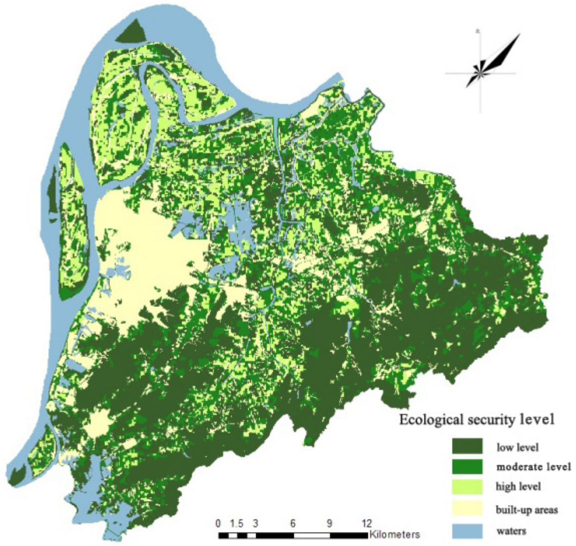

Figure 7: Ecological security level grading of Tongling.

and scenic spots, such as the Bailang Lake Scenic Area, Shilichangchong Forest Park, and Phoenix Mountain Forest Park.

(2) The northern wetland area along the river and the southern forested mountain area have high ecosystem services value. According to the local correction coefficients of Anhui Province and the biomass of the different ecosystems of Tongling, this study lists a Table of the ecosystem service value per unit area of Tongling's various ecosystems. It was found that the different ecosystems' service value can be put into the following descending order: wetland and waters > grass land, forested land and farmland > bare land and constructed land. The land with the highest service value is mainly distributed in the north, including rivers, lakes, river sandbars, wetlands, and other areas along the river. This is followed by the southern mountainous region, with rich biological resources and a high forest coverage rate.

(3) This research study proposed an ecological protection area identification procedure based on an ecological sensitivity evaluation and an ecosystem services evaluation. The results identified the ecologically fragile and important services areas, as well as offer a reliable reference for Tongling's ecological protection and urban growth decisions by dividing the ecological security evaluation areas into areas with low, mid and high ecological security levels. However, there are still some limits in this study's evaluation. For example, the

ecological sensitivity evaluation indicators were sorted into five grades whereas a different number of grades could also have been chosen; the range of each grade could also have been adjusted differently. Future studies are suggested.

Acknowledgments

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