Pol. J. Environ. Stud. Vol. 30, No. 3 (2021), 2935-2946
DOI: *10.15244/pjoes/128584* ONLINE PUBLICATION DATE: 2021-01-28

Original Research

Impact of Expressways on Land Use Changes, Landscape Patterns, and Ecosystem Services Value in Nanping City, China

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Received: 12 July 2020
Accepted: 18 October 2020

Abstract

Even as it promotes economic development, the rapid development of expressways has important effects on its surrounding land use, landscape patterns, and ecological environment. In this study, we took the 10 km buffer zone of the expressways network in Nanping City as the study area with the support of GIS. Changes in land use, landscape patterns, and ecosystem-services value along expressways were analyzed using buffer zone analysis, statistical analysis, model of changes in land use and landscape indices, and ecosystem services value model. The results showed that forest land was the main land-use type along expressways in Nanping City from 2005 to 2015. The construction land area increased significantly when it was closer to the expressways, while the area of cultivated land decreased significantly when it was closer to the expressways. For the temporal changes, the increase in the area of forest land and construction land was mainly due to the transfer of grassland and cultivated land. The patch density and shape of construction land showed increasing and complex trends, respectively, while the patch density and shape of other land types showed decreasing and simple trends. The patch distribution of construction land and forest land was more concentrated, while other land types tended to be scattered, especially unused land. The influence of expressway on the surrounding landscape pattern was about 4 km. Expressway mainly caused the increase of landscape patch density and diversity index, and the decrease of landscape shape index and aggregation index. The value of ecosystem services in forest land and water gradually decreased and increased, respectively when they were closer to the expressways. Four kilometers was the range of influence of the expressway network on ecosystem-services value in Nanping City. The study provides a decision-making reference for regional ecological environment management, rational use of land resources, and sustainable economic development.

Keywords: buffer zone, landscape indices, ArcGIS, Northern Fujian Province

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Introduction

Land use is the most intimate link between humans and nature. Change in land use is a process by which humans constantly change the surface environment of the land in order to survive and develop [1]. Eventually, it results in changes in land cover. Land use/land cover changes (LUCC) inevitably affect landscape patterns and the structures and functions of ecosystems. Furthermore, it also has a major impact on regional climate, hydrology, biogeochemical cycles, and biodiversity [2-7]. Ecosystem services refer to the environmental conditions and utilities formed by ecosystems, which are necessary for the survival and development of human beings [8]. It not only provides human beings with food, medicine, and raw materials for industrial and agricultural production, but also maintains the life-support system that human beings depend on for survival and development [9-10]. The essence of expressways construction is the conversion of natural and semi-natural ecosystems such as the transition of forests, grasslands, farmlands and rivers into transportation facilities [11]. The conversion affects regional landscape patterns and ecosystem-services value by changing land use types. Environmental impact assessments of expressways construction mainly analyze the functions changes in land use caused by land occupation for expressways construction, and then analyze the impact of expressways on landscape patterns and regional ecological-services value.

According to the "Expressways Engineering Technique Standard" of the China Transport Bureau, "expressway" refers to roads with more than four lanes, two-way separation, full control of entrances and exits, all adopting three-dimensional intersections [11]. At the same time, they are capable of adapting to an annual average day and night passenger traffic of more than 25,000 vehicles, exclusively for automobiles on divided expressways at high speed. Along with China's rapid economic development, the pace of expressway development is unmatched by projects elsewhere. Statistically, the total mileage of expressways in China reached 14.26×10^4 km by 2019 [12], which is far more than most developed countries. However, while promoting regional economic development, the expressways also have a non-negligible impact on the ecological environment [13-15]. The constructions and operations of expressways seriously changed the topography and land use types and caused the changes of the regional landscape patterns. Therefore, it had a lot of negative effect on the ecosystem such as the deterioration of natural environment [16-18]. Meanwhile, these effects will continue to expand with the formation of the expressways network. In response to the current pressure of environmental degradation and the shortage of land resources, land use/land cover research has become an important breakthrough for scholars to resolve current contradictions, especially in environmental protection along expressways. Land use changes along the expressways and its impact on landscape patterns and ecosystem-services value have significant spatial variation [19], due to the influence of expressways corridor effects.

At present, the relevant researches mainly focused on the influence of expressways on the ecological environment [20-21], land use changes and landscape pattern [22], and economic development [23]. In addition, the economical and intensive use of land along expressways [24] and the restoration of land damage caused by expressway construction [25] were also studied. However, the impact of expressways on land use, landscape patterns and ecosystem services is still not studied systematically.

The Economic Development Zone on the west side of the Strait is mainly located in Fujian Province, with some cities in Jiangxi Province and Zhejiang Province. The study area for our research is Nanping City, which is the main location of the economic construction in the Economic Development Zone. In recent years, increase in urban area along with the expansion of population, expressways, and infrastructure construction have caused extreme shortage of land resources and deterioration of the environment in Nanping City. In the new urban planning, the current contradictions should be urgently addressed by finding a scientific way. Therefore, with the support of GIS, in this study, we use the 10 km buffer zone of the Nanping City expressway network as the study area, and utilize spatial analysis and statistical analysis to study the impact of expressways on the changes in its surrounding land use, landscape patterns, and ecosystem-services value. This study is expected to find out the characteristics of changes of land use, landscape pattern and the ecosystem service value along the expressway, and determine the influencing distance of the expressway on the land along the expressway. It provides a reference for the rational development and utilization of land resources and the sustainability of the ecological environment.

Material and Methods

Study Area

Nanping City is also known as Northern Fujian Province, on the southeast coast of China, covers an area of 26,300 km^2. It consists of two municipal districts, three county-level cities, and five counties. At the end of 2019, the total registered household population was 3.18 million, of which 2.69 million were permanent residents [26]. Hills and mountainous regions constitute the main areas of Nanping City. It has a subtropical monsoon climate. The total mileage of expressways in Nanping City was up to 1045 km by 2019, including Fuyin Expressway, Punan Expressway, Ningwu Expressway, Songjian Expressway, and Longpu Expressway [26]. Most of these expressways were

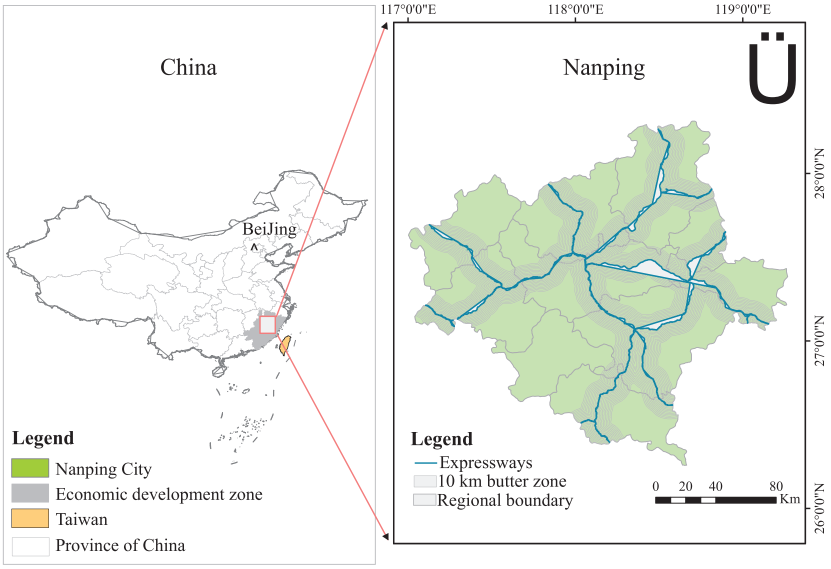

Fig. 1. Distribution map of the buffer zone along the expressways.

opened before 2005. Therefore, they had a distinctive influence on land use changes in Nanping from 2005 to 2015, as shown in Fig. 1.

Data Collection

Our study used remote sensing images for two time periods (2005 and 2015) from Landsat 5 and 7, downloaded from the Chinese geospatial data cloud (http://www.gscloud.cn/). The detailed information of these remote sensing images can be found in Table 1. The preprocessing of these data included radiation correction, geometric correction, and mosaic and clipping.

The land use classification was performed via the object-oriented classification method. This method focuses on the object instead of pixels compared to other classification methods. Furthermore, it can make full of the information of object and classify the land use according to the differences of the spatial and the spectral characteristics of selected object. It is a complement to the classification based on pixels. Therefore, the information of land use can be obtained more intelligently and accurately using this method. In this study, this method was used to classify the land use of study area based on ENVI 5.2 software. After experiments and comparisons, the Scale Level and Merge Level was set to 20 and 80, respectively, in

Table 1. Detailed information of remote sensing data.

Data source	Shooting time	Description
Landsat-5 TM	2005-10	Path and rows were 120/40, 119/40, 119/41, 119/42, 120/42, 121/41, 120/41, respectively. Bands 5, 4, and 3 were used for color synthesis and the rate of cloud coverage was less than 10%.
Landsat-7 ETM	2015-10	

Table 2. Accuracy evaluation of the classification results in Nanping City.

Year	Indices	Forest land	Cultivated land	Grassland	Water	Unused land	Construction land
2005	User accuracy	88.74%	97.41%	97.78%	92.42%	75%	85.71%
	Producer accuracy	97.10%	86.92%	93.62%	95.31%	75%	92.31%
	Overall accuracy	92.50%	-	-	-	-	-
	Kappa coefficient	0.89	-	-	-	-	-
2015	User accuracy	86.62%	97.37%	97.82%	92.31%	100%	84.62%
	Producer accuracy	98.55%	85.38%	95.74%	93.75%	62.50%	84.62%
	Overall accuracy	92%	-	-	-	-	-
	Kappa coefficient	0.89	-	-	-	-	-

Table 3. Landscape indices and their calculating equations.

Landscape indices	Equations	Meanings
Patch Density (*PD*)	$PD = N/A$	On landsacpe scale, *N* represents the number of plaques in the landscape, and *A* is the total area of the landscape. On plaque type level, *N* represents the number of plaques in a certain type of landscape, and *A* is the total area of a certain type of the landscape plaques. *PD* reflects the fragmentation of the overall landscape plaques. High value of *PD* indicates plaque size per unit area is small, and landscape heterogeneity is high.
Fractal Dimension of the Perimeter Area (*PAFRAC*)	$PAFRAC = \frac{2}{\frac{\left[n_{ij}\sum_{j=1}^{n}\left(\ln p_{ij} - \ln a_{ij}\right)\right] - \left[\left(\sum_{j=1}^{n} p_{ij}\right)\left(\sum_{j=1}^{n} a_{ij}\right)\right]}{\left(n_i \sum_{j=1}^{n} \ln p_{ij}^2\right) - \left(\sum_{j=1}^{n} \ln p_{ij}\right)}}$	a_{ij} is the area of the plaque *ij*, p_{ij} is the perimeter of the plaque, and n_i denotes the number of plaques. *PAFRAC* close to 1 indicates that the shape of the plaque tends to be simple. *PAFRAC* close to 2 means the shape of the plaque tends to be complex.
Splitting Index (*SPLIT*)	$SP_i = D_i \cdot A / A_i, \; D_i = \left(\frac{1}{2}\right) \cdot \sqrt{n_i} / \sqrt{A}$	A_i is the area of the *i*-th landscape, n_i is the number of patches of the *i*-th landscape, and *A* is the total area of the landscape. *SPLIT* represents the degree of fragmentation of the landscape, the complexity of the spatial structure of the landscape, and the degree of human disturbance to the landscape, to some extent. Therefore, it can reflect the impact of humans on the natural ecosystem. In general, value of *SPLIT* is positively correlated with human impact on the ecosystem.
Landscape Shape Index (*LSI*)	$LSI = P\sqrt{\pi A}$	*P* represents the total length of all plaque boundaries. A is the area of all plaques in the landscape. *LSI* reflects the complexity of the plaque shape.
Shannon's Diversity Index (*SHDI*)	$SHDI = -\sum_{i=1}^{m}\left(P_i \times \mathrm{h}\;\, p_i\right)$	*i* is the plaque number, p_i is the ratio of type *i* in the landscape area, and *m* is the total number of plaque types. *SHDI* reflects the richness and complexity of the landscape types.
Aggregation Index (*AI*)	$AI = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[\left(P_i\right)\left[\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right]\right]\left[\ln\left(p_i\right)\left[\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right]\right]}{2\ln m}\right]\left(100\right)$	p_i is the proportion of *i*-type plaques in the landscape, g_{ik} denotes the number of polygons adjacent to plaque *i* and plaque *k*, m is the total number of plaque types in the landscape. The value of *AI* is the lowest when there is no common boundaries among all pixels.

order to segment the objects with flat boundary changes and ensure that the same objects were not divided into several parts to the maximum extent. After repeated experiments, 250 samples of each land use type can achieve optimal classification results. In keeping with research requirements, land use types were divided into six categories: forest land, cultivated land, grassland, unused land, construction land, and water.

The accuracy of the classification results was evaluated in order to ensure the quality of data [27]. The indices of the accuracy evaluation include user accuracy, producer accuracy, overall accuracy, and kappa coefficient, as shown in Table 2. The random sampling method was used to evaluate the accuracy. Firstly, 400 points were randomly generated in each period of the image, and then the accuracy was evaluated. From Table 2, in addition to the producer accuracy of unused land in 2015, the user accuracy and producer accuracy of each land use types in 2005 and 2015 were all higher than 75%. The overall accuracy of the interpretation results in 2005 was 92.50%, and its Kappa coefficient was 0.89; the overall accuracy of the interpretation results in 2015 was 92%, and its Kappa coefficient was 0.89. Therefore, the accuracy of the two periods meets the relevant requirements and can be used as the basic data for follow-up research. In addition, the expressways vector data were collected from the resource and environmental science data center of the Chinese Academy of Sciences.

Buffer Analysis

After analyzing the known research results [19, 28], we used the buffer function of ArcGIS to create a buffer of 10 km distance on both sides of the expressways at intervals of 1 km. The purpose was to explore the spatial distribution laws of land use changes along the expressway and impact of expressways on the landscape patterns.

Landscape Pattern Index Analysis

We analyzed the landscape pattern changes around the expressways from the scale of the landscape and plaque type. The landscape indices of the landscape scale include *PD*, *LSI*, *SHDI*, and *AI*. The landscape indices of the plaque type scale include *PD*, *PAFRAC*, and *SPLIT*. The equations are shown in Table 3.

Changes in Land Use and Landscape Indices

We used the dynamic degree of single and bidirectional land use types to reflect the dynamic process of changes in land use types [29]. The dynamic degree of single land use type characterizes the changing rate of land use types of the study area during the study period. It emphasized the change in single land use types (see Equation 1) [30]. The bidirectional dynamic degree of a single type of land use can better express the changing process and direction of a certain type of land use, which is a supplement to the single dynamic degree (refer to Equation 2). The equations are as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

$$BK = \frac{\left(\sum U_{ij} + \sum U_{ji}\right)}{U_i} \times \frac{1}{T} \times 100\% \tag{2}$$

...where K is the dynamic degree of a certain land use type, U_b and U_a are the area of the land use type at the end and beginning of study, and T is the length of the study. *BK* denotes the bidirectional dynamic degree of a certain type of land use, $\sum U_{ij}$ represents the sum of the area of a land use type to other land use types during the study period, $\sum U_{ji}$ is the sum of the area of other land use types to a certain land use type, and U_i indicates the area of a certain type of land use at the beginning of the study period. Excel software was used to calculate the dynamic degree of single land use and bidirectional dynamic degree of a certain type of land use in this study.

The changing rate of landscape indices refers to the relative changing rate of the landscape indices of the study area. The following formula can be used:

$$Y = \frac{X_2 - X_1}{X_1} \times \frac{1}{T} \times 100\% \tag{3}$$

...where Y represents the changing rate of a certain landscape index, X_1 and X_2 are the landscape indices at the beginning and end of the study period, respectively, and T is the length of the study.

Ecosystem Services Value

A table of the equivalent value per unit area of terrestrial ecosystem services in China slightly modified to create a table of the equivalent value per unit area value of ecosystem services in Nanping City according to the actual situation of this study, as shown in Table 4 [31]. In this study, we did not calculate the value of construction land because this activity greatly damages the environment. However, the value of ecosystem services reflects positive influence on the needs of human beings.

The average grain yield of Nanping City (5700 kg/hm^2) in 2015 and the average grain price in China (5.24 yuan/kg) were obtained by consulting statistical yearbook of Nanping. The value of cultivated land ecosystem services per unit area in Nanping City was determined using Equation 4:

$$E_a = \frac{1}{7} \cdot T_a \cdot T_b \tag{4}$$

...where E_a denotes the service value per hectare of cultivated land in the study area (yuan/hm^2), T_a is the average grain yield (kg/hm^2), and T_b represents the average purchase price of grain in China.

The unit area value of a specific ecosystem service (CV_{ij}) can be obtained using Equation 5 and Table 4. Equation 5 is as follows:

$$CV_{ij} = E_a \cdot f_{ij} \tag{5}$$

...where CV_{ij} is a specific ecosystem service unit area value (yuan/hm^2·year) and f_{ij} is the equivalence factor of a specific ecosystem service of a specific land use type.

Lastly, using Equation 6 and Table 5, the *ESV* in Nanping City was obtained. Equation 6 is as follows:

$$ESV = \sum_{i=1}^{n} \sum_{j}^{m} A_i \times CV_{ij} \tag{6}$$

...where the *ESV* denotes the total ecosystem service value (yuan) and A_i represents the area of a specific land use type.

Table 4. Equivalent value per unit area of terrestrial ecosystem services in Nanping City.

Types	Forest land	Cultivated land	Grassland	Water	Unused land	Construction land
Gas regulation	3.50	0.50	0.80	0.00	0.00	0
Climate regulation	2.70	0.89	0.90	0.46	0.00	0
Water conservation	3.20	0.60	0.80	20.38	0.03	0
Soil formation and protection	3.90	1.46	1.31	0.01	0.02	0
Waste treatment	1.31	1.64	1.95	18.18	0.01	0
Biodiversity conservation	3.26	0.71	1.09	2.49	0.34	0
Food production	0.10	1.00	0.30	0.10	0.01	0
Supply of raw materials	2.60	0.10	0.05	0.01	0.00	0
Entertainment and culture	1.28	0.01	0.04	4.34	0.01	0

Table 5. Value per unit area of ecosystem services related to landscape types in Nanping City (Ten thousand yuan/hm^2).

Types	Forest land	Cultivated land	Grassland	Water	Unused land
Gas regulation	1.49	0.21	0.34	0.00	0.00
Climate regulation	1.15	0.38	0.38	0.20	0.00
Water conservation	1.37	0.26	0.34	8.70	0.01
Soil formation and protection	1.66	0.62	0.56	0.01	0.01
Waste treatment	0.56	0.70	0.83	7.76	0.01
Biodiversity conservation	1.39	0.30	0.47	1.06	0.15
Food production	0.04	0.43	0.13	0.04	0.01
Supply of raw materials	1.11	0.04	0.02	0.01	0.00
Entertainment and culture	0.55	0.01	0.02	1.85	0.01
Total	9.32	2.95	3.09	19.63	0.20

Results and Discussion

Temporal Variation in Land Use in Buffer Zone

Taking the completed main expressways network of Nanping City as the study subject, the buffer zone of 10 km was established using the buffer analysis of ArcGIS 10.1, as shown in Fig. 2. The buffer zone of 10 km was characterized by a network structure. Forest land was the most prevalent land use type in the area. In the past 10 years, the area of construction land increased significantly along the expressways, while the area of cultivated land decreased sharply. Fig. 3 shows that forest land was the main matrix of the study area. During the study period, the proportion of forest land to the total area of the study area increased from 51.51% to 68.69%, and the proportion of construction land increased from 3.49% to 11.56%. Contrastingly, other land use types decreased, of which cultivated land area had the greatest reduction with from 13.60% to 3.69%. The government added the construction land such as newly built house and related supporting infrastructure to improve people's living conditions, while they has always paid attention to the protection of the ecological environment. Therefore, the construction area increased, while the forestland area also continued to increase during the study period.

We calculated the transfer matrix of land use within 10 km of the expressways from 2005 to 2015 to study further the changing trend of various land use types in the buffer zone with time. It can be seen from Table 6 that the area of other land use types transferred to forest land were larger, of which the increase of forest land area mainly came from the transfer of grassland and cultivated land. Furthermore, the transfer of forest land, grassland and cultivated land was the main reason for the increase in the area of construction land. Therefore, the reduction in grassland and cultivated land mainly transferred to forest land and construction land. It can be seen that the increased construction land area mainly occupied forest land, grassland, and cultivated land. In this process, the rapid expansion of construction land caused the sharp decline of cultivated land area and

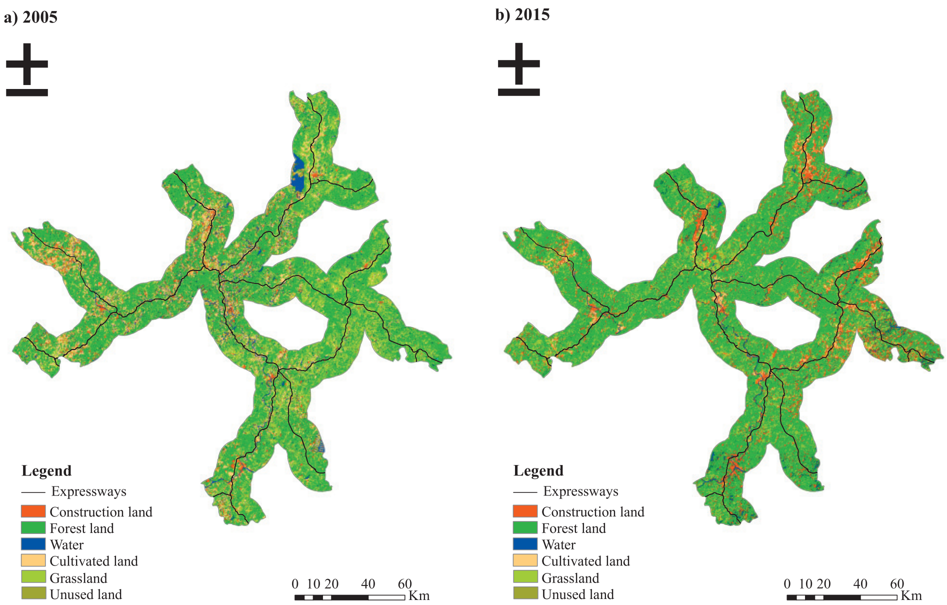

Fig. 2. Distribution of land use types along expressways in Nanping City from 2005 to 2015.

even the obstruction of natural ecological functions, which should be paid enough attention.

Additionally, compared to other land use types, the single dynamic degree of construction land was the highest with a value of 23.10%. It indicates that the area of construction land in the buffer zone increased rapidly during the 10 years. Meanwhile, the bidirectional dynamic degree of construction land was also the highest with a value of 69.35%, which points out that the rate of switching-in and switching-out of construction land was fast. The main reason for this phenomenon is that the Chinese government published a policy that bungalows with safety hazards were demolished in cities and towns, and high-rise buildings were built on the original site or in other surrounding areas after the demolition during the study period. The roads, squares, education, commerce and other infrastructure facilities have also been built in surrounding the new buildings. At the end of 2018, about 100 million people in China have moved into new buildings, and

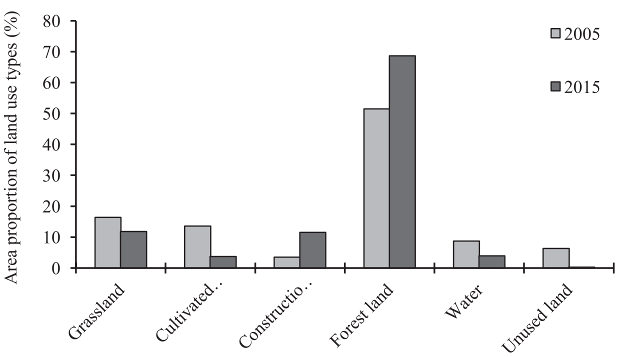

Fig. 3. Area proportions of land use types along expressways in Nanping City from 2005 to 2015.

their housing conditions have been greatly improved [32]. The Nanping Municipal Government has actively implemented this national policy, which has increased the total construction output value of Nanping City from 1.86 billion yuan in 2005 to 15.01 billion yuan in 2015 with an increase of more than 8 times in 10 years [33-34].

Spatial Variation in Land Use in Buffer Zone

In order to analyze the spatial variation in land use in the 10 km buffer zone, we calculated the proportion of different land use types in every buffer zone in 2005 and 2015, respectively, as shown in Fig. 4. As can be seen from Figs. 4a) and 4b), the proportion of forest land area was significantly higher than other land use types, and it rose slowly as the increased distance from the expressways. The proportion of forest land area increased rapidly within 4 km of the buffer zone, which indicated that the impact of expressways on forest land was more severe in this range. In 2005, the forest coverage rate in the study area was as high as 75.6%. The construction of expressways inevitably occupied a large amount of forest land, so expressways had a greater impact on forest land.

The expressway had a strong impact on grassland and cultivated land within 1-2 km in 2005 (Fig. 4a). The influence of the expressway on grassland and cultivated land gradually increased when they were closer to expressway. Expressway generally enters the city from the mountainous area through the suburbs, and the cultivated land is generally distributed near the suburbs. Therefore, a large amount of cultivated land was distributed around the suburban section of the expressway.

Table 6. Transfer matrix of land use along expressways in Nanping City from 2005 to 2015 (km^2).

Land use types	Grassland	Cultivated land	Construction land	Forest land	Water	Unused land	Total	Switching-out rate (%)
Grassland	474.80	283.97	46.16	435.93	121.17	136.44	1498.46	77.12
Cultivated land	133.61	142.22	28.98	70.83	37.57	55.70	468.91	91.76
Construction land	339.80	322.00	129.25	374.77	158.47	142.51	1466.79	70.83
Forest land	1074.94	906.26	216.81	5444.93	631.46	442.90	8717.30	16.71
Water	43.13	61.10	19.97	203.47	152.10	22.02	501.79	86.22
Unused land	9.04	10.60	1.93	7.66	3.05	5.18	37.47	99.36
Total	2075.32	1726.15	443.09	6537.59	1103.81	804.74	-	-
Switching-in rate (%)	68.31	69.67	91.19	37.54	69.69	86.18	-	-
Dynamic degree of single land use	-2.78	-7.28	23.10	3.33	5.45	-9.53	-	-
Dynamic degree of bidirectional land use	12.64	13.14	69.35	6.54	21.58	26.08	-	-

In contrast, the expressways had a strong influence on construction land within 2 km in 2015. It showed the the area proportion of construction land increased significantly when it was closer to the expressways. From 2005 to 2015, the permanent population of Nanping City increased from 2.88 million to 3.20 million with an increase of 0.32 million in 10 years. In order to relieve the pressure of overpopulation in the city, the government has planned to shift the population from the center to the suburbs. For example, the government demolished houses with safety hazards in the city center, and arranged the residents in the new houses near expressway in the suburbs of the city. Therefore, 2 km of the buffer zone was the most active regions of the impact of expressways on land use changes. Contrastingly, expressways had less impact on unused land and water. The area of unused land and water area were small, so they were less affected by expressways.

Changes in Landscape Types Along Expressways

Studies of landscape pattern mainly described the characteristics of plaques and explored the temporal and spatial variability of these characteristics [35]. In this study, we selected *PD*, *PAFRAC*, and *SPLIT* to analyze the landscape patterns of the buffer zone, as shown in Table 7. The results of the study showed that except construction land, the *PD* of other land use types showed a downward trend, which indicated that the plaques of construction land in the buffer zone tended to be fragmented and the distribution tended to be dispersed. In contrast, other plaques clustered significantly.

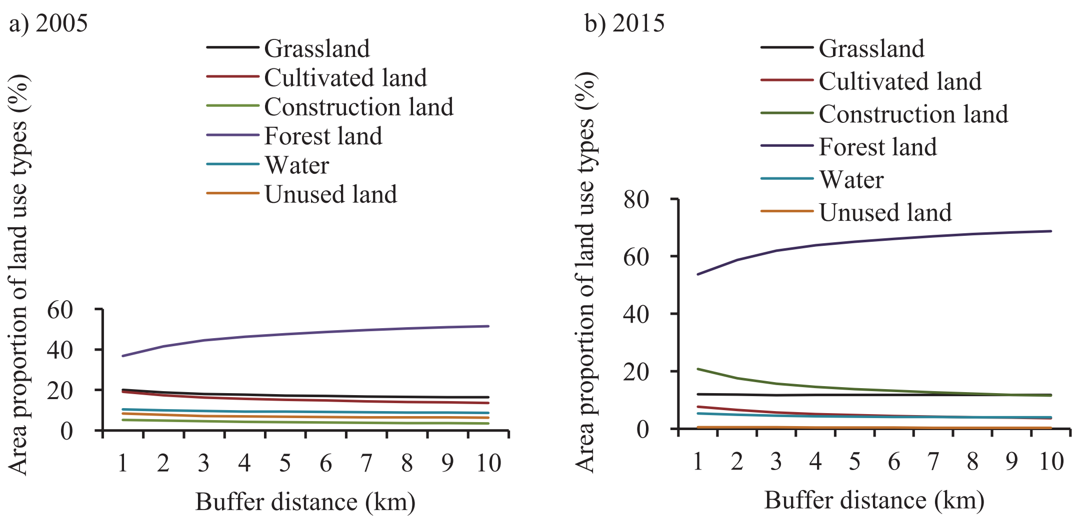

Fig. 4. Area proportions of land use types along expressways in every buffer zone in Nanping City from 2005 to 2015.

Table 7. Analysis of landscape types in 10 km buffer zone along Nanping City expressways from 2005 to 2015.

	PD			*PAFRAC*			*SPLIT*		
Landscape types	2005	2015	Rate of change (%)	2005	2015	Rate of change (%)	2005	2015	Rate of change (%)
Grassland	1.604	1.166	-2.729	1.381	1.358	-0.164	31480.458	168112.599	43.402
Cultivated land	0.924	0.768	-1.687	1.365	1.302	-0.461	59107.779	333173.892	46.367
Construction land	0.492	1.019	10.718	1.323	1.346	0.169	839975.701	42424.016	-9.495
Forest land	0.379	0.300	-2.063	1.400	1.338	-0.443	119.245	6.951	-9.417
Water	2.165	0.766	-6.465	1.392	1.366	-0.190	32002.600	338809.153	95.869
Unused land	0.857	0.152	-8.223	1.338	1.299	-0.294	917052.246	56256516.711	603.449

PAFRAC showed that other land use types rather than construction land presented a downward trend. It indicated that the plaque shape of construction land was more complex, while the plaques of other landscape types were more regular.

It can be seen from *SPLIT* that construction land and forest land had a declining trend, while other land use types showed an increase. This indicated that the distribution of plaques in construction land and forest land was more concentrated due to human activities. The distribution of other plaques, especially for unused land, was relatively more dispersed. The distance among plaques significantly increased under the disturbance of human activities.

In order to disperse the urban pressure, the government built infrastructure, residential houses, commercial office areas, schools, etc. near the expressways in the suburbs of the city, which led to the increasing patch density, complex shapes, and more concentrated patch distribution of construction land within a certain area of the expressway. The forest land in the buffer zone was severely fragmented due to the impact of the expressway, which resulted in reduced patch density and simple shape of the forest land. However, larger forest land area caused its patches to show an aggregated distribution. The smaller area and the serious fragmentation of other land use types resulted in reduced patch density, simple shape, and scattered distribution of patches.

Changes of Landscape Pattern in the Buffer Zone at the Landscape Scale

At the regional landscape scale, the landscape pattern characteristics reflect the ecological process of the overall landscape structure [36-37]. In this study, we calculated the *PD*, *LSI*, *SHDI*, and *AI* in every buffer zone to describe the landscape pattern changes (Fig. 5). Compared to 2005, other landscape indices decreased except the *AI* in 2015. Furthermore, all indices had the same tendency in 2005 and 2015. *PD* and *SHDI* showed a decrease with the increase of distance from the expressways in the buffer zone, while *LSI* and *AI* showed an increase.

Fig. 5a) shows that *PD* increased rapidly with a decrease in the distance from the expressways within 4 km. This indicates that the number of plaques per unit area was greater and the distribution was more dispersive when they were closer to the expressways. In Fig. 5b), the value of *LSI* was lessened gradually when it was closer to expressways within the 10 km buffer zone. It indicates that as it was closer to the expressways, the shape of the plaques showed more regular and simple. As can be seen from Fig. 5c), the value of *SHDI* rose slowly as the decreasing distance from the expressways, which indicated that the number of land use types in the buffer zone showed an increasing trend when they were closer to the expressways. Regarding Fig. 5d), the value of *AI* decreased more rapidly when it was closer to the expressways within 4 km of the buffer zone. It pointed out that the degree of aggregation of the landscape plaques decreased when it was closer to the expressways in the buffer zone. In summary, the impact of the expressways on the surrounding landscape pattern was the most remarkable within 4 km of the expressways.

The expressway caused the fragmentation of its surrounding patches, which resulted in scattered patches with complex shapes. The expressway led to an increase of edge effect which resulted in an increase in landscape diversity. Forest land and construction land were main land use types near the expressway. As the patch was closer to the expressway, the proportion of forest land with lower density decreased, while the proportion of construction land with higher density increased. Therefore, the density of patches around the expressway showed an increasing trend when the patches were closer to the expressways.

Changes in Ecosystem-Services Value Along Expressways

We further studied the changes in the value of ecosystem services influenced by land use changes in order to fully understand the impact of expressways on the surrounding ecological environment (Fig. 6). However, we did not calculate the value of ecosystem services in unused land, the main reason being that

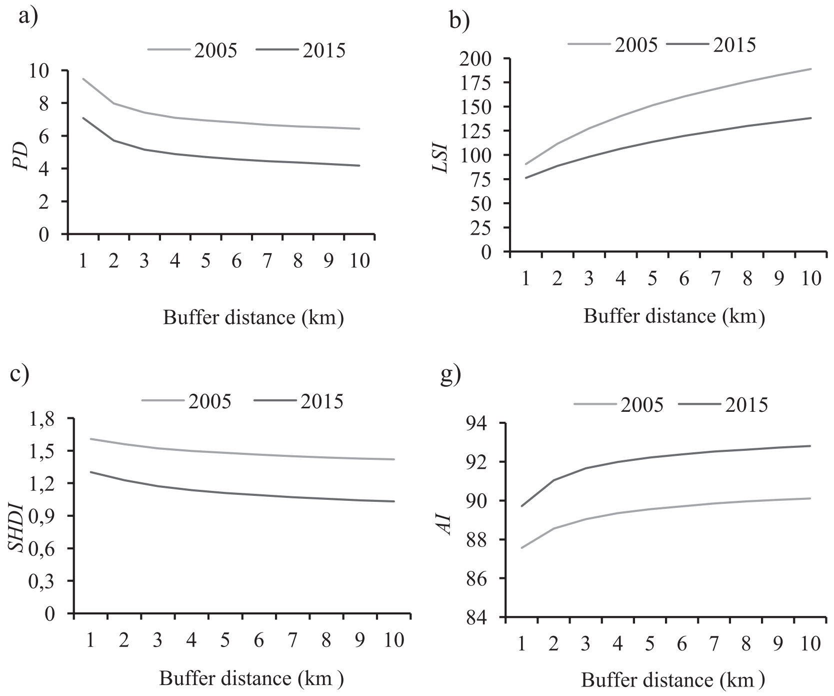

Fig. 5. Various landscape indices in each buffer zone in Nanping City from 2005 to 2015.

the value was very small. Comparing 2015 to 2005, the value of ecosystem services of different land use types showed basically the same trend with the increase in distance from the expressways.

The changes in the ecosystem-services value in grassland and cultivated land were not obvious with increase in distance from expressways. It indicated that the impact of expressways on the two land use types was less. Nevertheless, the value of ecosystem services in forest land and water gradually decreased and increased, respectively when they was closer to the expressways. Especially within 4 km, the impact of expressways on the service values of forest and water ecosystems was quite severe. Therefore, 4 km was the main region where the expressways affected the value of ecosystem services in Nanping City.

The area and ecosystem service value of grassland and cultivated land were less, so the expressway had little impact on their ecosystem service value. Forest land occupied a larger area and its overall ecosystem services value was high, so the expressway had a greater impact on its ecosystem service value. The water area accounted for a less proportion, but it had a larger value of ecosystem service per unit area. Therefore, the expressway had a greater impact on ecosystem service value of water area, although the expressway had a less impact on distribution of water area in general.

In this study, we explored the impact of expressways on its surrounding landscape patterns and ecosystem-services value, based on the characteristics of land use changes. We only considered the impact of a single expressways on them. However, the factors affecting the land use changes, landscape patterns, and ecosystem-services value were comprehensive and diverse, such natural and social and economic factors. The latter has the greatest impact on land use, landscape patterns

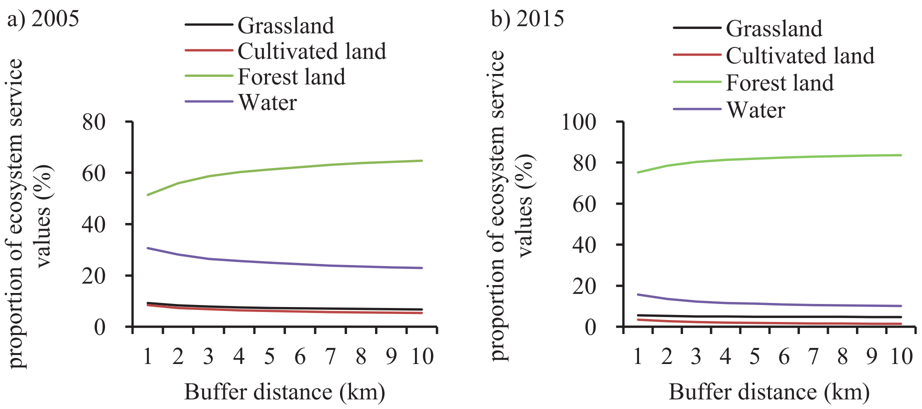

Fig. 6. Proportions of ecosystem-service values along expressways to every buffer zone in Nanping City from 2005 to 2015

and ecosystem services value. If the road section of expressway is located near the urban area, the land use, landscape pattern and ecosystem service value along the part will be mainly affected by the expressway and the urban economy. If the road section is located in a mountainous area, the land use, landscape pattern and ecosystem service value along this part will be mainly affected by expressway. It requires a progressive study that how to simply study the impact of expressways on land use, landscape patterns and ecosystem service values without being disturbed by other influencing factors.

The 10 km buffer zone of the Nanping expressway network covered nearly 50% of the urban area and it is the key planning area of the whole city. Therefore, we suggest protecting cultivated land by limiting its conversion to other land use types, and rationally planning the regional road network structure. The expansion boundary of construction land should be defined, and the ecological maintenance and management of forest land should be strengthened to promote the rational use of land resources.

Conclusions

In this study, we used remote sensing images for two time periods (2005 and 2015) from Landsat 5 and 7 as data sources and extracted the LUCC data around the expressways of Nanping City. The impact of expressways on land use changes, landscape patterns, and the value of ecosystem services were studied using the methods of statistical analysis and buffer analysis. The main conclusions are as follows:

(1) Within the 10 km buffer zone, the proportion of forest land area was the largest, and it gradually increased from 2005 to 2015. Meanwhile, the proportion of construction land area also increased, while cultivated land decreased. Cultivated land was mainly transferred to forest land and construction land, which was the major reason for the reduction in cultivated land area. Except for the contribution of cultivated land, the transfer of forest land to construction land was also the main reason for the increase in the proportion of construction land area. The increase in the proportion of forest land was closely related to the large-scale conversion of grassland to forest land.

(2) The impact of expressways on unused land and water was the lowest, while it had the most severe for forest land, especially within 4 km. Regarding construction land, the impact of expressways on the area distribution of construction land was low in 2005, while there was an increase in the proportion of construction land as it was closer to the expressways in 2015. Four kilometers was the affected ranges of expressways on forest land, grassland, cultivated land, and construction land.

(3) Compared to other land use types, only the *PD* of construction land showed an increase, while the *PD* of other land use types showed a decrease during the 10 years. The shape of construction land tended to be more complex, while others were more regular. The distribution of construction land and forest land were more concentrated under the influence of human activities, while other land use types tended to be dispersed. The spacing among plaques increased significantly, especially for unused land.

(4) The range of influence of the expressways network of Nanping City on the surrounding landscape patterns extended to about 4 km, which mainly led to the decline of *AI* and *LSI*, and the increase of *SHDI* and *PD*.

(5) The impact of the expressways on the value of ecosystem services in grassland and cultivated land was less. In contrast, the expressways had a significant impact on the ecosystem-services value of forest land and water within 4 km.

In conclusion, the range of influence of expressways on land use changes, landscape pattern changes, and ecosystem-services value in Nanping City was a distance of about 4 km.

Acknowledgments

This work was supported by the Education Department of Hunan Province (No.19C1670), the Specialized Research Fund for the Doctoral Program of Shaoyang University (No. 17ZX03), and the National Science and Technology Major Project of the Ministry of Science and Technology of China (Fund No. 2017YFD0601304). The authors wish to thank the referees for providing helpful suggestions for improving this manuscript.

Conflict of Interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication.

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