

Research Article

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Research on the impact of expressway on its peripheral land use in Hunan Province, China

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Abstract: The purpose of this research is to study the scope and magnitude of the impact of expressways and their entrances and exits, as well as the effects of environmental and socio-economic factors on those impacts. Based on multi-period remote-sensing images and land use/land cover change data, the expressway lines and entrances and exits in Hunan Province, China, in 2015 are selected as the research objects. The Urbanization Impact Index (U) and the Impact Strength Index (E) are used to characterize the impact of the expressway on peripheral land use. Geographic information system spatial analysis and correlation analysis methods are also used in this research. The results show that (1) the scope of the expressway impact is 8.4 km and that of the entrances and exits is 8.8 km, of which the impact is considered strong within 0.2 and 3.2 km, respectively; (2) environmental and socio-economic conditions have no obvious effect on the impact scope of the expressways but have a weak effect on the impact scope of the entrances and exits; and (3) regions with more complex terrain and a lower level of socio-economic development have the larger impact scope as well as a stronger impact.

Keywords: expressway effects, environmental and socio-cultural impacts, Hunan Province of China, impact scope, impact strength, peripheral land use

1 Introduction

In road ecology, the impact of roads on land use is defined as the road effect zone, which includes distance, pattern, morphology, impact categories, and impact degree [1,2]. Among these, the spatial orientation and impact degree are research hotspots, and the purpose is to analyze the scope and magnitude of the impact of the road on the surrounding land use. The current studies on the impact of roads on surrounding land use often have a single result, and most of them do not consider the differences in the natural and socio-economic conditions of the areas through which the roads pass. These differences in impact due to different natural and socio-economic conditions can be confirmed by the inconsistent research conclusions of different current studies, and such inconsistency not only manifests in differences of impact scope [3–8] but also in variations of strength within the impact scope [9–11]. Therefore, this study selected an area with a relatively large spatial scope, in which there are obvious differences in natural and socio-economic conditions. Studying the differences in road impacts under different conditions is one of the scientific values of this study. In addition, current studies usually take the road as a whole and lack discussion on the impact relative to different parts of the road (such as expressway routes and entrances and exits). It is necessary to study the impact of different parts of the road on the surrounding land use and analyze their differences.

An expressway is a typical road type. The construction of an expressway has a significant impact on its peripheral land use/land cover change (LUCC) [12–14], and LUCCs will have an impact on ecosystem services [15]; however, due to differences in how different parts of the expressway are accessed (such as the closed management of the roadway and the relatively open management of entrances and exits), this impact varies. This

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study took an expressway in Hunan Province, China, as an example to investigate the impact of roadways and entrances and exits on the peripheral land use, and the differences under different environmental and socio-economic conditions, to provide a research case for future projects and research.

Hunan Province is located in the middle of China, with geographic coordinates of 108°47'E–114°15'E, 24°38'N–30°08'N and a total area of 21.18 million square kilometers. Hunan is located in the transitional area between the Yungui Plateau to the Jiangnan Hills and the Nanling Mountains to the Jiangnan Plain. The geography creates a horseshoe shape with mountains on three sides and an opening to the north. The geomorphic types include semi-alpine, low mountain, hill region, downland, basin, and plain. The Xiangjiang, Zijiang, Yuanjiang, and Lishui Rivers flow into Dongting Lake from south to north along the geography. The gross domestic product (GDP) of Hunan Province in 2015 was 28902.21 billion yuan, while in 2020 it grew to 41781.49 billion yuan; the permanent population was 69.1838 million, and the urbanization rate was 57.22%, ranking 22nd in China. The social and economic development of Hunan is unbalanced, and the northern and central regions are notably more developed than the western and southern regions. The expressway construction in Hunan started late, but it is developing rapidly. By 2020, the expressway traffic mileage within Hunan reached 6,820 km, ranking 4th in China.

The expressway data in this study were obtained through visual interpretation of Map World remote sensing (RS) images. Thirty-six expressway lines were analyzed along a total distance of 5,798 km and with 390 entrances and exits that were counted as a pair (Figure 1). The line data obtained through interpretation were linear elements, whereas the entrance and exit data were point elements. To fit the actual situation, the linear and point elements were analyzed with a buffer to form polygonal elements. The buffer radius of the lines and the entrances and exits was set to 50 and 75 m, respectively. The LUCC data in this study come from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (<https://www.resdc.cn/>), obtained through interpretation of Landsat RS images with a resolution of 30 m, with high data accuracy [16]. To better define the macro-characteristics of the impact, the land use was classified into six types according to the first-class classification standard of LUCC classification system in China: cultivated land, woodland, grassland, waters, construction land, and unutilized land (land that is currently unused or difficult to use, including Sand, Gobi area, Saline-Alkali Land, Moorland, Bare Land, and Bare Rock). The topographic data were

obtained from the 1:250,000 topography, and the GDP, population, urbanization rate, etc. were obtained from the statistical yearbook [17]. The timeline for all data was 2015.

2 Research method

2.1 Application of spatial information technology

Geographic information system (GIS) and RS are the most commonly used technical means to study land use patterns and their changes [18,19], and they are also widely used in road ecology [20,21]. In this study, RS was used to obtain the basic expressway and LUCC data; a buffer analysis of GIS data was used to form the impact area of the expressway; overlay analysis of GIS data was used to superpose the impact area and LUCC data on the area map, and spatial statistical analysis of GIS data was used to develop relevant data and related parameters. Data processing and spatial analyses were completed in ArcGIS 10.2, and the tools used included Buffer, Multiple Ring Buffer, Intersect, Summary Statistics, and Zonal Statistics as Table.

2.2 Factor selection and calculation

To analyze the differences in the impact area of an expressway in different environmental and socio-economic conditions (as well as the differences in the impact strength within the impact scope), mean altitude, mean slope, GDP per unit area, population density, and urbanization rate were selected as evaluation factors. The spatial unit for the calculation of statistics for all factors is the city. To calculate the mean altitude and the mean slope of the city, the city was classified as a grid with individual cells of 200 m × 200 m. The formulas for calculating the factors of mean altitude and mean slope are as follows:

$$M_e = \sum_{i=1}^n e_n / n, \quad (1)$$

$$M_s = \sum_{i=1}^n s_n / n, \quad (2)$$

M_e and M_s are the mean altitude and mean slope, respectively, in the region of a city; e_n and s_n are the altitude and slope, respectively, of the n th cell of a city, and n is the total number of cells in the region of a city.

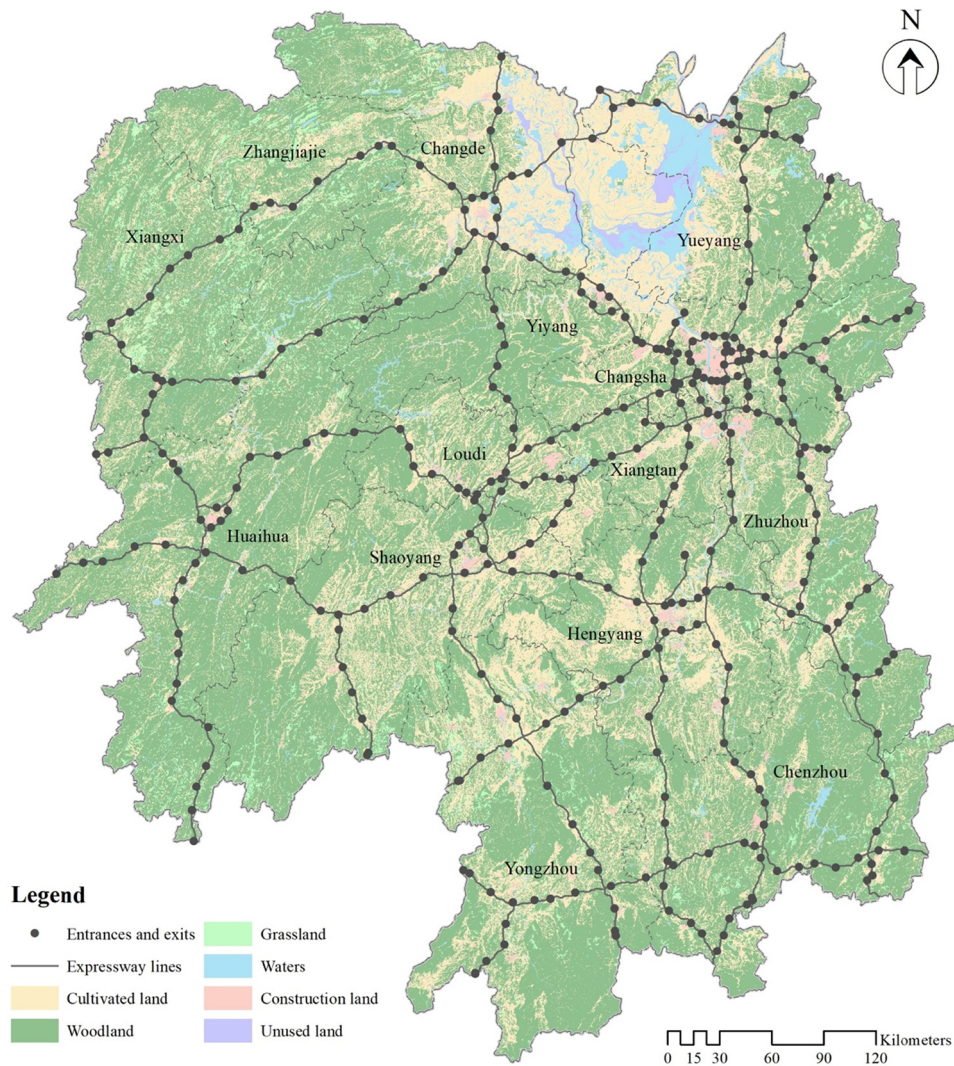


Figure 1: Research area and data from 2015.

The formulas for GDP per unit area and population density are as follows:

$$D_{\text{GDP}} = T_{\text{GDP}}/S, \quad (3)$$

$$D_p = T_p/S, \quad (4)$$

D_{GDP} and D_p are the GDP per unit area and population density, respectively, in a city; T_{GDP} and T_p are the total GDP and population, respectively, in the region of a city, and S is the area of the target region.

2.3 Calculation of urbanization impact index

First, multi-ring buffer analysis was carried out for expressway lines and entrances and exits. According to relevant conclusions from previous research, the radius of the buffer rings was set to 200 m and the number of buffer

rings was set to 50, which exceeded the impact scope of 8 km obtained in existing research [7,8]. The buffer results were superposed on LUCC data, and then the area of each type of land use was calculated. To analyze the degree of the impact of the expressway on land use, the urbanization impact index U proposed by Hall and Tian [22] and Liu and Cui [23] was used as a quantitative index. The formula for U is as follows:

$$U = A_p / \sum_{i=1}^n A_n, \quad (5)$$

A_p is the area of the built environment in a buffer ring, and A_n is the remaining area of other land types. In this study, n was set to 5, representing cultivated land, woodland, grassland, waters, and unutilized land. The calculation of U included buffer rings covering provincial and municipal regions of a city.

A buffer ring was determined to be part of the expressway impact scope if the value of U was higher than the regional mean value of U , and the area was determined to be strongly impacted by the expressway when the value of U was three times the regional mean value of U .

2.4 Calculation of impact strength

After determining the impact scope of expressways, to analyze the relative impact strength within the impact scope on the peripheral land use, the index E was used as a quantitative index. The formula for E is as follows:

$$E = U_a / U_r. \quad (6)$$

E is the impact strength; U_a is the urbanization impact index calculated for a buffer ring within the municipal region using equation 5, and U_r is the mean urbanization impact index in the region of a city. The greater the value of E was, the greater was the relative impact strength of an expressway on peripheral land use.

2.5 Calculation of correlation coefficient

Taking 14 cities of Hunan as samples, the Pearson correlation coefficients of each factor with the impact scope and impact strength were calculated using the statistical package for social sciences. It is generally believed that parties are highly correlated when $|r| \geq 0.7$ ($P < 0.01$), moderately correlated when $0.3 < |r| < 0.7$ ($P < 0.05$), and poorly correlated or uncorrelated when $|r| \leq 0.3$ ($P > 0.05$) [24].

3 Results

3.1 Impact scope and correlation

U values of expressways in Hunan Province, which are shown in Figure 2, and all cities were calculated. Within 5 km, the U value of the entrances and exits was higher than that of the expressway line, and beyond 5 km, the U values of the two were basically the same. Within 3.2 km, the U value of the entrances and exits was larger for all buffer rings; whereas beyond 8.8 km, it was smaller than the mean U value for Hunan Province. The U value of the line itself was larger than its average value within 0.2 km, decreased rapidly beyond 0.2 km, and tended to become stable. Beyond 8.4 km, the U value fell below the mean value for Hunan Province. The U value of the expressway buffer rings and the mean U value of the municipal region of the city were calculated. According to the classification of the U value, the expressway impact scope on Hunan Province and each city was determined (Table 1).

The correlation coefficient of the strong impact of the lines was not calculated because the scope values were zero and relatively flat. The correlation coefficients of other parts and each factor are shown in Figure 3. The impact of the lines was not related to each factor. The impact scope of entrances and exits was moderately positively correlated with mean altitude, moderately negatively correlated with GDP per unit area and urbanization rate, and was not correlated with other factors. The strong impact scope of entrances and exits was moderately correlated with all factors; it was positively correlated with topographic factors and negatively correlated with socio-economic factors.

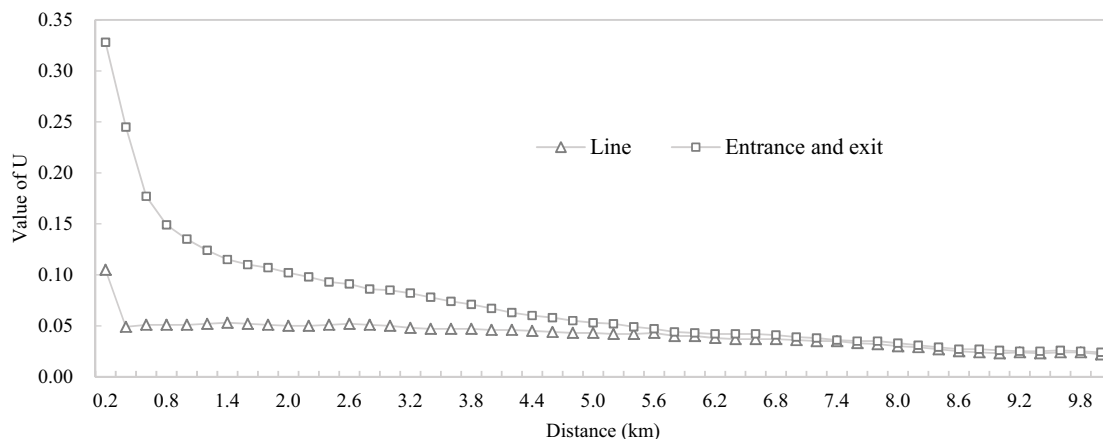


Figure 2: Changes of U value in 10 km buffer ring of expressways in Hunan Province.

Table 1: The impact scope of expressway in Hunan Province and each city

Cities	Strong impact scope of lines (km)	Impact scope of lines (km)	Strong impact scope of entrances and exits (km)	Impact scope of entrances and exits (km)
Hunan	0.2	8.4	3.2	8.8
Changsha	0.0	6.8	2.0	5.8
Zhuzhou	0.0	8.6	0.8	8.6
Xiangtan	0.0	9.6	1.5	6.8
Hengyang	0.2	8.2	1.2	8.4
Shaoyang	0.2	7.8	4.4	9.0
Yueyang	0.0	7.0	2.6	7.6
Changde	0.2	9.8	1.2	9.6
Zhangjiajie	3.8	6.0	4.2	8.6
Yiyang	0.2	5.4	4.0	5.8
Chenzhou	0.2	7.6	1.4	8.0
Yongzhou	0.2	12.0	0.4	11.6
Huaihua	0.2	5.2	5.0	7.4
Loudi	0.0	11.8	1.0	11.4
Xiangxi	0.2	6.0	3.4	7.2

3.2 Impact strength and correlation

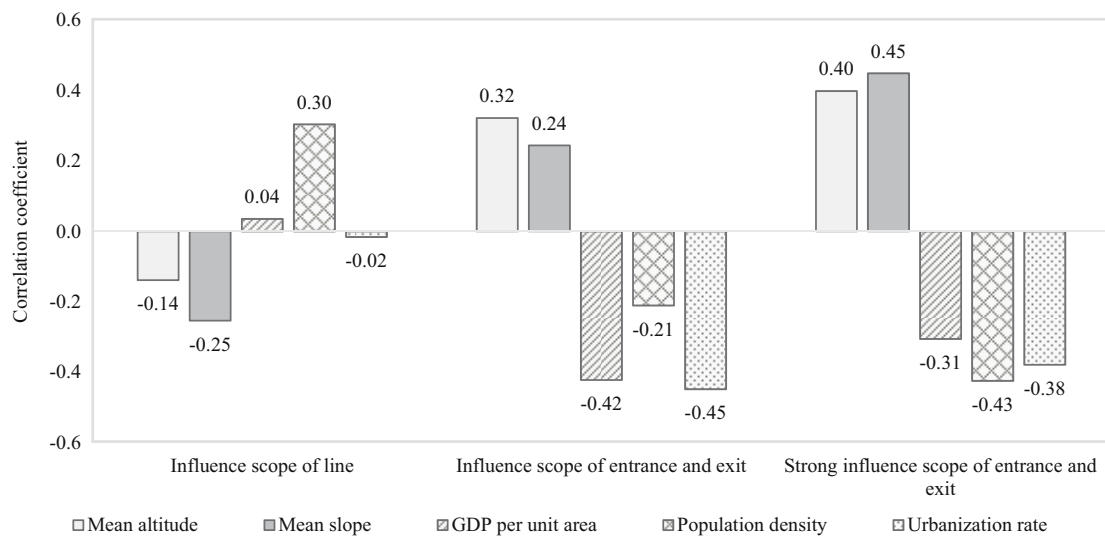
The correlation coefficient between the impact strength and each factor within the impact scope of the expressway is shown in Figure 4. The impact strength of lines and entrances and exits was positively correlated with topographic factors and negatively correlated with socio-economic factors. The line was highly correlated with the mean slope and moderately correlated with other factors.

Entrances and exits were moderately correlated with all factors.

4 Discussion

4.1 Impact scope

Current studies by scholars show that the impact scope of an expressway on peripheral land use is approximately 8 km [7,8], but these studies have not considered the variations in impact scope related to different components of the expressway. According to the calculated impact strength and its classification in this study, the impact scope of lines and entrances and exits in Hunan was 8.4 and 8.8 km, respectively, within which the impact scope was considered strong for 0.2 and 3.2 km, respectively. Generally, there was little difference in impact scope between the lines and entrances and exits, but the impact scope strength of lines was significantly larger than the entrances and exits, which was mainly due to the accessibility of the two. The line was completely closed and had little contact with the peripheral land, so it was difficult to directly change the peripheral land-use type. Construction that did occur was limited to close proximity to the expressway. In contrast, the expressway affected the land in a relatively distant location through the nearby entrances and exits. Entrances and exits are expressway access. On the one hand, the construction of entrances and exits dramatically increased the flow of people and

**Figure 3:** The correlation coefficient between the impact scope of expressway and each factor.

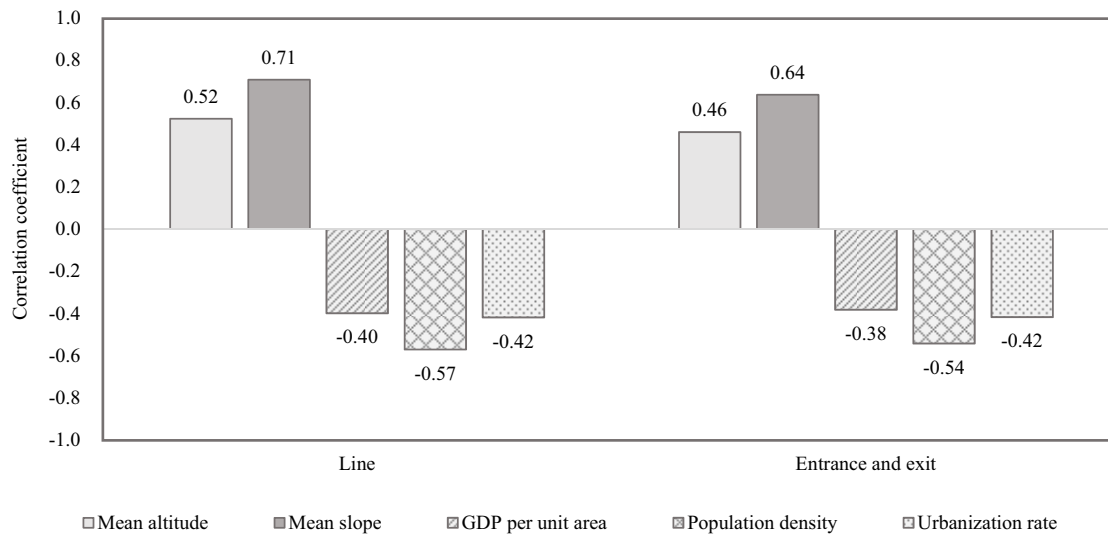


Figure 4: The correlation coefficient between impact strength and factors.

logistics around them; on the other hand, the advantages of convenient external transportation and lower transportation cost increased around them. As a result, the peripheral cultivated land, woodland, and waters were transformed into commercial, industrial, and residential land [14,25].

The impact of the expressway line on the peripheral land use was small, so the regional topography and socio-economic conditions did not experience a positive or negative effect from the impact scope of the line. The strong impact scope of entrances and exits is positively related to the topographic conditions. The more complex the topographic conditions, the larger the influence scope, and *vice versa*. This is related to the suitability of urban construction. In areas with complex topographic conditions, the suitability of urban construction is low [26,27], and there is relatively little land suitable for construction around entrances and exits. To make use of the external transportation advantages and the stream of people and logistics at the entrances and exits, the construction land will be arranged in a “mosaic” layout around the entrances and exits. Compared with the “continuous” layout, this layout will form a larger spatial scope, thereby expanding the scope of impact of entrances and exits. The strong impact of entrances and exits is negatively related to socio-economic conditions. The better the socio-economic conditions, the smaller the impact scope, and *vice versa*. On the one hand, areas with good socio-economic conditions have relatively good topographical conditions, and the construction land around the entrances and exits is laid out in a “continuous” manner, thereby reducing the scope of impact. On the other hand, in areas with good socio-economic conditions, other forms of transportation

(national trunk highways, intercity trunk lines, high-grade highways, railways, etc.) are relatively more developed, and their dependence on the expressway is relatively reduced. Relying on a relatively convenient transportation system, it can still have a convenient connection with the expressway in areas relatively far from the entrances and exits, reducing the willingness of human activities to aggregate at the entrances and exits. Relatively low dependence and willingness have led to a reduction in the total amount of construction land around the entrances and exits, reducing the scope of impact of the entrances and exits.

4.2 Impact strength

In regions with different environmental and socio-economic conditions, the impact strength of the expressway on peripheral land use varied within the impact scope. In Hunan Province, the mean altitude and mean slope were positively correlated with the impact strength, which indicates that the higher the mean altitude and mean slope are, the faster large proportions of cultivated land, woodland, waters, and so on around the expressway are transformed into construction projects. The GDP per unit area, population density, and urbanization rate were negatively correlated with the impact strength, which indicates that, in the regions with a higher socio-economic development level, the speed of the transformation from cultivated land, woodland, and waters around the expressway to construction decreased. The reason for this result is similar to the relevance of the impact scope and natural and socio-

economic factors (Section 4.1). The regions with higher mean altitude, especially with higher mean slope, have relatively harsh natural conditions, provide less suitable space for urban construction, and have a relatively lower level of socio-economic development and urban construction. The construction of an expressway plays a significant role in promoting regional economic development, leading to the rapid growth of construction around the expressway. In areas with relatively good topographic conditions, there are relatively more areas suitable for urban construction, and other traffic situations are relatively developed. In areas far from expressways, convenient connections can still be made with expressways. Within the impact area around the expressway, the land used for urban construction and development is relatively reduced, and the intensity of land development is relatively reduced, resulting in a relatively low impact intensity of the expressway. In addition, in the regions with a relatively higher level of socio-economic development, the layout of construction land is affected by other factors besides the expressway. The driving effect of the expressway itself is weakened; the degree of centralization and the proportion of peripheral construction land is reduced, and the impact strength is relatively small. Factors such as GDP per unit area, population density, and urbanization rate reflect the level of regional socio-economic development. Regions with a lower level of socio-economic development are more dependent on expressways. The urban construction land in the expressway area can be affected quickly and may generate localized area agglomeration.

5 Conclusion

Through the study of the impact scope and strength of the expressway in Hunan Province, as well as their correlation with environmental and socio-economic factors, the following conclusions were drawn:

- (1) The impact scope of Hunan expressway lines and entrances and exits was 8.4 and 8.8 km, respectively, and the strong impact within that scope was 0.2 and 3.2 km, respectively. The main reason for the great difference in the impact scope strength was the accessibility of the two.
- (2) Environmental and socio-economic conditions had no obvious effect on the scope of impact of the lines but had a weak effect on the scope of impact of the entrances and exits. Complex terrain conditions promoted the expansion of the scope of impact, whereas a higher level of socio-economic development made the scope of impact relatively small.
- (3) Within the impact scope of expressways, the strength of the effect on peripheral land use was relatively greater in the areas with complex terrain conditions and was relatively smaller in the areas with higher socio-economic development level.
- (4) In the planning of an expressway and the layout of urban construction land, as well as in the protection and governance of urban ecology, the impact of expressway construction on peripheral land use should be fully considered, and scientific planning and management should be carried out according to local conditions.

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Author contributions: Based on the expressway data and the spatial analysis method, Li Zhixue calculated the *U* values of different buffer zones for lines and entrances and exits and determined the impact scopes on its peripheral land use. On this basis, Li Zhixue also calculated the *E* values within the impact scope and analyzed the relevance between impact scope, impact strength, and environmental and socio-economic factors. Finally, he also analyzed and discussed the research results. Huang Zhongxiang guided the research content and methods. Zhou Songlin obtained and processed data on expressway lines and entrances and exits, as well as data on environmental and socio-economic factors.

Conflict of interest: Authors state no conflict of interest.

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