Chin. Geogra. Sci. 2013 Vol. 23 No. 3 pp. 378–388
doi: 10.1007/s11769-012-0582-5

Springer Science Press
www.springerlink.com/content/1002-0063

Impacts of Transportation Arteries on Land Use Patterns in Urban-rural Fringe: A Comparative Gradient Analysis of Qixia District, Nanjing City, China

ZHANG Runsen[1], PU Lijie[1, 2], ZHU Ming[1]

(1. *School of Geographic and Oceanographic Sciences*, *Nanjing University*, *Nanjing* 210093, *China*; 2. *Key Laboratory of Land Use*, *Ministry of Land and Resources*, *Beijing* 100029, *China*)

Abstract: Integrated transportation and land use studies are of major interest to planners because they consider the interaction between transportation development and land use change. Quantifying the impact of transport infrastructure on land use change is necessary for evaluating the role of transportation development in the process of land use and land cover change in the urban-rural fringe. Taking Qixia District of Nanjing City, Jiangsu Province, China as a typical urban-rural fringe area, this paper analyzes the patterns and characteristics of land use change along three major transportation arteries using land use data from 2000 and 2008. We examine the spatial differentiation and gradient of land use pattern around railway, expressway, and highway corridors to investigate whether land use change in the urban-rural fringe is related to distance from transportation arteries and to clarify the varying impacts of different forms of transport infrastructure on land use patterns. We find that construction land generally tends to be located close to major transportation arteries, and that railways have the most obvious influence on land use change in the urban-rural fringe, while the impact of expressways was not significant. We conclude that there exists a causal relationship between the presence of transportation arteries and land use change in the urban-rural fringe, but this relationship varies across different types of linear transport infrastructure.

Keywords: land use change; transportation arteries; gradient analysis; land use dynamic degree; urban-rural fringe

Citation: Zhang Runsen, Pu Lijie, Zhu Ming, 2013. Impacts of transportation arteries on land use patterns in urban-rural fringe: A comparative gradient analysis of Qixia District, Nanjing City, China. *Chinese Geographical Science*, 23(3): 378–388. doi: 10.1007/s11769-012-0582-5

1 Introduction

In the process of rapid urbanization and industrialization, urban built-up areas have been expanding continuously, leading to the extension of urban socioeconomic activities to suburban and rural areas. This has led to the emergence of a distinctive urban-rural fringe region surrounding the core areas of many major cities (Andrews, 1942; Wehrwein, 1942; Pryor, 1968; LeSage and Charles, 2008). Because the urban-rural fringe is a transitional zone between city and country, its development is affected by the interaction of industrial, residential, transport, commercial, and agricultural activities from both urban and rural areas (Gollege, 1960). Consequently, land use in urban-rural fringe areas often changes rapidly and it always exhibits patterns and dynamics which quite different from those observed in urban or rural areas (Chen, 2000; He *et al.*, 2011).

Along with economic development and urbanization in China, the urban sprawl has changed the land use structure in urban-rural fringe through farmland undergoing conversion to different uses and urban land area

Received date: 2012-04-12; accepted date: 2012-07-25
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 40871255), Scientific Research Foundation of Graduate School of Nanjing University (No. 2010CL12)
Corresponding author: PU Lijie. E-mail: ljpu@nju.edu.cn

growing (Lopez *et al.*, 2001; Xiao *et al.*, 2001; Tan *et al.*, 2005). This change in land use has led to social problems such as growth in the number of landless farmers, diminishing food security, and various environmental problems. Given that the urban-rural fringe has become a key locus of urban land expansion, rural land conversion, population mobility, and environmental protection efforts (Chen and Wu, 1998), there has been a large amount of research on land use monitoring, planning, and policies in urban-rural fringe (Nkambwe and Arnberg, 1996; Crossman *et al.*, 2007; Nick and Dave, 2007; Ganta *et al.*, 2011).

Integrated study of transportation development and land use change in the urban-rural fringe can contribute not only to research on land use and urban planning, but also to research on transportation development. Transport infrastructure plays a pivotal role in urban and regional development. By enhancing accessibility and easing the movement of people and goods, improvement in transportation systems accelerates urban land expansion and regional economic growth (Hawbaker *et al.*, 2006). Several studies have found that transport infrastructure development contributes to land use and land cover change, producing urban growth (Handy, 2005; Jha and Kim, 2006), deforestation (Chomitz and Gray, 1996; Cao, 2006), landscape fragmentation (Geneletti, 2004; Zhu *et al.*, 2006), and other ecological effects (Miller *et al.*, 1996; Forman and Alexander, 1998; Trombulak and Frissell, 2000; Zhang *et al.*, 2002).

Buffer zone and gradient analysis (Whittaker, 1975; McDonnell *et al.*, 1997; Luck and Wu, 2002) provide a powerful spatial analytic technique for detecting the impact of transport infrastructure on land use by investigating the spatial distribution and gradient of land use patterns along transport corridors (Zhu *et al.*, 2006; Mueller *et al.*, 2010). Previous research usually has only investigated the impact of transport infrastructure on land use patterns in metropolitan zones and typically has considered only basic transport infrastructure such as motorways (Mueller *et al.*, 2010), urban roads (Mao and Yan, 2004; Zhu *et al.*, 2006), or road networks (Lausch *and* Herzog, 2002; Saunders *et al.*, 2002; Serranoa *et al.*, 2002). Against a backdrop of rapid urbanization and industrialization, the urban-rural fringe has gradually become a hotspot for urban development and land resource utilization, as well as a focal point for urban environmental protection efforts. However, there has been little research examining the impacts of different types of transportation arteries on land use patterns in the urban-rural fringe.

The purpose of this study is to present the evidence of how different types of transportation arteries affect land use patterns in the urban-rural fringe, and to compare the effects of these different types of transportation arteries on land use in the urban-rural fringe. We address the following questions: 1) What are the spatiotemporal features of land use change in the urban-rural fringe? 2) How does land use change along transportation arteries in the urban-rural fringe? 3) Is land use change related to distance from transportation arteries? and 4) Does the gradient of land use change vary for different kinds of transport infrastructure?

We assess the influence of transportation arteries on land use patterns by using gradient analysis of the area, structure, and distribution of land use change, and then we explore whether different types of transportation arteries have varying impacts on land use patterns by comparing land use change characteristics in zones surrounding railway, expressway, and highway corridors. We believe that our findings can contribute to the integrated study of transportation and land use, and provide a reference for land use planning and transportation development in the urban-rural fringe.

2 Materials and Methods

2.1 Study area

One of the core cities of the Changjiang (Yangtze) River Delta, Nanjing City is located in the Nanjing-Zhenjiang-Yangzhou hill area of the lower reaches of the Changjiang River, and has a subtropical monsoon climate, with annual average temperature of 15.4℃. Qixia District (32°02′–32°15′N, 118°46′–119°14′E) is situated in the northeastern part of Nanjing City (Fig. 1). Qixia has a surface area of 376.09 km^2 and had approximately 516 000 inhabitants in 2008. According to 2008 land use data, 34.28% of the district is arable land, 8.16% is forest, 1.67% is grassland, 18.12% is water area, 28.10% is urban land, 6.20 % is rural settlements, 3.42% is independent construction land, and 0.04% is other land. Nanjing is one of most urbanized and industrialized city regions in Jiangsu Province and China, but the land use pattern of Qixia District in suburban Nanjing includes substantial amounts of both agricultural land and urban land. Against the backdrop of rapid urbanization in Nanjing, this district can be seen as a typical example of an urban-rural fringe area. In addition, as the important transportation hub in Nanjing, Qixia contains numerous transport routes and networks, which have enormous influences on land use patterns in the district. This study focuses on railway, expressway, and highway as three representative types of transportation arteries in Qixia District to examine the impacts of different types of transport infrastructure on land use pattern in the urban-rural fringe (Fig. 1).

2.2 Data acquisition and pretreatment

This paper examines land use patterns during the period from 2000 to 2008. Land use data is based on historical Landsat TM satellite images in 2000 and 2008, the sampling time of which was between September and November of each year, and the spatial resolution is 30 m × 30 m. Land use was classified as arable land, forest, grassland, water area, urban land, rural settlements, or independent construction land, according to the basic principles of land use and land cover features (Fig. 1). Next, a land use database was built using ArcGIS 9.3 software to extract the land use and land cover information for Qixia District in 2000 and 2008. Data on the three major types of transportation arteries in Qixia District were obtained from the Database of the Second National Land Survey of Qixia District (2008).

2.3 Methods

In order to analyze the spatiotemporal variation in land use pattern caused by transportation development, we applied the techniques of buffer zone analysis. We constructed buffers of 1000 m along the three major types of transportation arteries and extracted the land use information in buffer zones. The area of Qixia District is so narrow and small that the major transportation arteries are close to one another, resulting in the overlap of buffer zones. Therefore, we selected the non-overlapping portions of buffers rather than using the whole buffers of the three major transportation arteries in order to distinguish the impacts of different transportation routes. As shown in Fig. 2, ten buffers of railway, expressway, and highway corridors can be set up at 100-m intervals on the south side, north side, and both sides of corridors, respectively. Next, by overlaying buffer zones with land

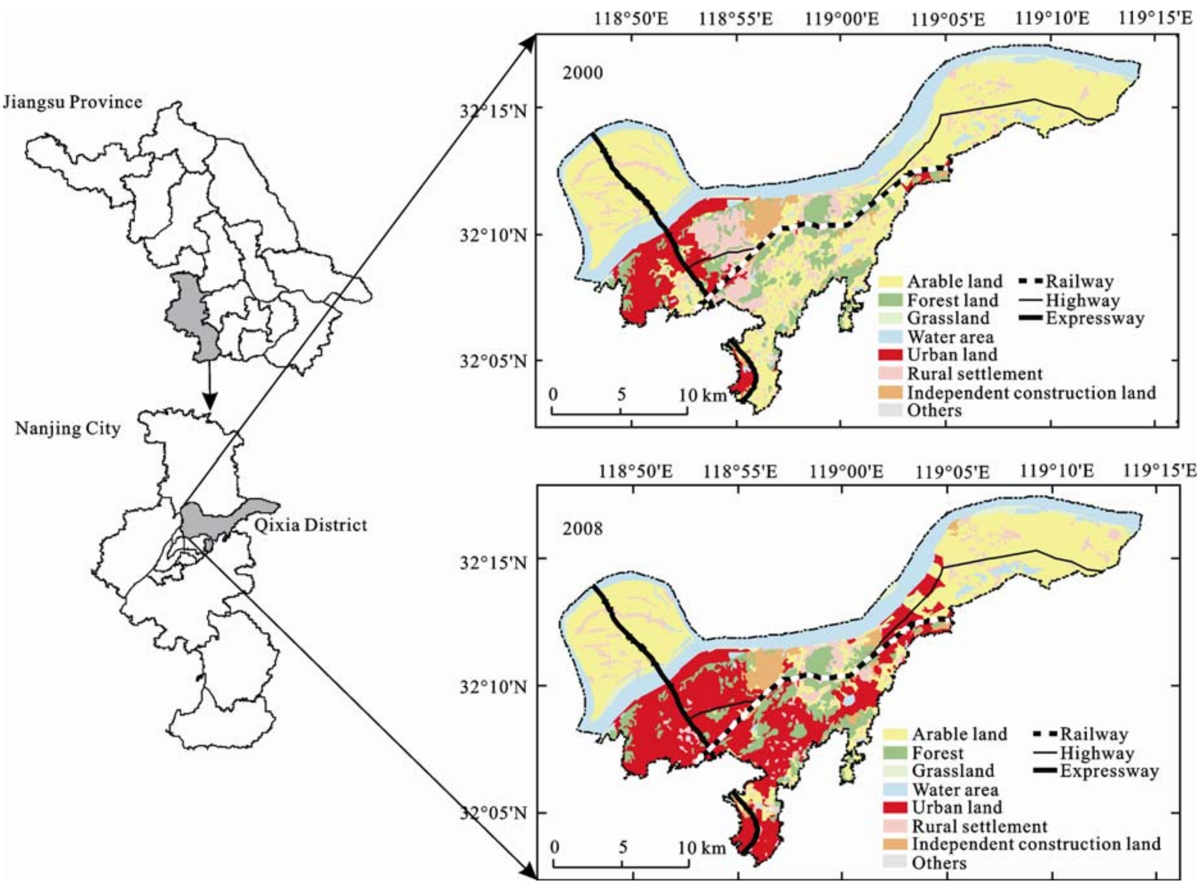

Fig. 1 Location, land use pattern, and major transportation arteries of Qixia District, Nanjing City

use maps from different points in time, we can investigate the extent and rate of land use change at different distances from transportation arteries.

Calculations of land use dynamic degree (*LUDD*) can be used to measure the speed of regional land use change so as to compare the spatial and temporal differentiation and forecast the tendency of variation in land use patterns. Measures of *LUDD* include the single land use dynamic degree (*SLUDD*) and the comprehensive land use dynamic degree (*CLUDD*). Single land use dynamic degree (*SLUDD*) is used to indicate the rate of change in one kind of land use during a given time interval in a certain area. The formula for computing *SLUDD* is as follows:

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

where U_a is the area of one land use type at the initial time; U_b is the area of that land use type at the later time; T is the length of the time interval.

The *CLUDD* measure can be calculated to show the comprehensive rate of change in regional land use and assess spatiotemporal variation of land use patterns. The formula for computing *CLUDD* is as follows:

$$CLUDD = \left(\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \right) \times \frac{1}{T} \times 100\% \tag{2}$$

where LU_i is the area of land use type i at the first stage; LU_{i-j} is the absolute value of the area of land use of type i changing to land use of type j during the study phase; and T is the time interval.

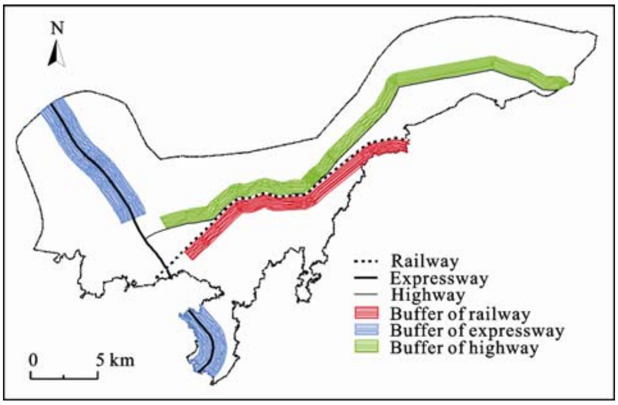

Fig. 2 Buffers of railway, expressway and highway in Qixia District, Nanjing City

3 Results

3.1 Characteristics of land use change in Qixia District

As shown in Table 1, arable land was the major land use type in Qixia District in 2000, covering an area of 18 374 ha and occupying 48.22% of the total area, followed by water area, rural settlements, and urban land, with shares of 18.14%, 10.87%, and 9.49%, respectively. By 2008, arable land still accounted for the highest proportion of 34.28%, while urban area had risen to second place, making up 28.10% of the total land area. Moreover, in terms of land use dynamic degree, the rate of expansion of urban land area (24.52%) is the highest, and far greater than the rate of expansion of grassland and independent construction land. Meanwhile, the rate of contraction of rural settlements area (–5.36%) is the highest, followed by the rate of contraction of arable land of –3.61%. The rate of change in forest area and water area are relatively low, which means the transformation of these types of land use areas is not apparent.

Overall, the area of arable land, forest, water, and rural settlements decreased between 2000 and 2008, while the area of grassland, urban land, and independent construction land increased. The most obvious characteristic of land use change is the dramatic expansion of urban land and the decline in rural settlements and arable land. Though urban land area expanded sharply and arable land area dropped substantially, agriculture land continued to make up the largest proportion of total area in 2008, accounting for 34.28% in that year. Thus, Qixia District clearly exhibits a dual urban- rural land use mode, a pattern characteristic of the urban-rural fringe.

3.2 Land use change along three major transportation arteries

In the 1000-m buffers of Qixia′s railway routes, the major land use types in 2000 were arable land and forest, with proportions of 33.63% and 27.67%, respectively. By 2008, land use was dominated by urban land and forest, with proportions of 44.03% and 24.60%, respectively (Table 2). The rates of change of each land use type varied widely in the buffers of railway routes. The *SLUDD* of urban land was the highest, at 32.68%, while water area had no change, with *SLUDD* of 0. In addition, the rate of decrease of arable land area was also con-

Table 1 Land use change in Qixia District in 2000 and 2008

Land use type	2000		2008		*SLUDD* (%)
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	
Arable land	18374.00	48.22	13062.71	34.28	–3.61
Forest	3298.68	8.66	3110.24	8.16	–0.71
Grassland	635.13	1.67	638.14	1.67	0.06
Water area	6912.30	18.14	6902.77	18.12	–0.02
Urban land	3615.10	9.49	10706.09	28.10	24.52
Rural settlements	4140.49	10.87	2363.55	6.20	–5.36
Independent construction land	1111.33	2.92	1303.54	3.42	2.16
Other land	14.99	0.04	14.99	0.04	0.00
Total	38102.02	100.00	38102.02	100.00	0.00

spicuous, with a *SLUDD* of –8.75%. Land use change in the buffers of railways thus shows that railways are associated with urban land expansion and arable land reduction.

Arable land is the largest land use type in the 1000-m buffers of expressways, with proportions of 61.35% and 49.42% in 2000 and 2008, respectively, followed by urban land and water area (Table 2). Urban land area expanded from 15.00% in 2000 to 28.26% in 2008, and the area of independent construction land remained unchanged, while the area of all other land use types decreased between 2000 and 2008. With regard to *SLUDD* in the buffers of expressways, the rate of change of urban land area is also highest absolute value, with a *SLUDD* of 11.05%, followed by arable land with *SLUDD* of –2.43%. The absolute values of *SLUDD* measures for other land use types are all below 1%, indicating that urban land and arable land area were both changing rapidly while other land use types had no remarkable change.

Arable land made up a large share of the 1000-m buffers of highways in 2000, accounting for 61.48% of total area (Table 2). Although arable land area fell to 45.99% by 2008, it remained the land use type with the largest proportion, indicating that large stretches of arable land persisted along the highway. In addition to change in land use areas, *SLUDD* varied across different land use types. The rate of change of urban land in highway buffers was far higher than that of other land use types and far higher than that of urban land in the buffers of railways and expressways, with a *SLUDD* of 780.77%. This rapid change was a product not only of striking urban land expansion along highways, but also of the small base value for urban land area in highway buffers of 0.38% in 2000. Thus, the land use pattern in highway buffers is dominated by arable land and rural settlements because of low urbanization along highway routes.

3.3 Spatial gradients of land use in buffers of three major transportation arteries

In 2000, the proportion of arable land decreased from 43.19% at 100 m to a minimum of 22.61% at 600 m and then gradually increased to the maximum of 53.76% at

Table 2 Land use change in 1000-m buffers of three major transportation arteries (%)

	Item	Arable land	Forest	Grassland	Water area	Urban land	Rural settlements	Independent construction land
Railway	Proportion in 2000	33.63	27.67	0.00	0.58	12.18	16.11	9.82
	Proportion in 2008	10.07	24.60	0.00	0.58	44.03	11.85	8.86
	SLUDD	–8.75	–1.39	–	0.00	32.68	–3.31	–1.23
Expressway	Proportion in 2000	61.35	1.32	0.00	13.68	15.00	5.36	3.30
	Proportion in 2008	49.42	1.25	0.00	12.74	28.26	5.03	3.30
	SLUDD	–2.43	–0.62	–	–0.86	11.05	–0.76	0.00
Highway	Proportion in 2000	61.48	11.23	3.06	2.81	0.38	14.68	6.35
	Proportion in 2008	45.99	11.41	0.74	1.77	24.41	6.57	9.11
	SLUDD	–3.15	0.20	–9.47	–4.64	780.77	–6.91	5.43

1000 m, forming a 'U' shape. Forest presented a typical inverted 'U' shape: the proportion increased from a minimum value of 9.73% at 100 m to the maximum of 40.72% at 600 m, and then decreased to 23.95% at 1000 m. The share of urban land, rural settlements, and independent construction land all tended to decline as distance from railways increased (Fig. 3a). In 2008, the spatial distribution of arable land and forest remained similar to those of 2000, forming a 'U' shape and an inverted 'U' shape, respectively. Rural settlements and independent construction land also showed the same declining tendency evident in 2000. The spatial distribution of urban land, however, revealed a tendency opposite that seen in 2000: though urban land areas in each buffer zone at different distances in 2008 were bigger than those of 2000, the spatial distribution pattern in 2008 was first fluctuating then gradually increasing to a peak of 52.48% at 900 m (Fig. 3b).

As shown in Fig. 3c, in 2000 arable land was the dominant land use type, accounting for a proportion of around 60% for each distance in the buffers of expressways, resulting in relatively even spatial distribution of arable land. A similarly even spatial distribution was observed for water area, with the lowest value of 11.87% seen within 100 m and the highest value of 15.83% observed at 700 m. This is a result of the orientation of the expressway corridor, which runs from the south to the north of Qixia District. The expressway runs through the Changjiang River and Baguazhou Town in Qixia District, where the most water areas lie. In addition, there was a relatively smooth spatial distribution for urban land and rural settlements due to the lower rate of urbanization and greater share of agriculture land along the expressways as well as the low absolute values of urban land and rural settlement areas. In 2008, arable land still accounted for the largest share of total area, and forest, water area, rural settlements, and independent construction land showed the spatial distribution similar to those seen in 2000. Urban land exhibited an inverted 'U' shape: its proportion increased from a minimum value of 25.48% at 100 m to a peak of 32.70% at 500 m, and then gradually decreased (Fig. 3d).

In 2000, arable land in the highway buffers formed an inverted 'U' shape: the proportion increased from 60.50% at 100 m to a peak of 68.62% at 300 m, and then gradually decreased to 50.09% at 1000 m. The distribution of forest was similar. Grassland and water area were only found between 500m and 1000 m, and gradually fluctuated and rose as distance from the highway increased. There was almost no urban land in the highway buffers in 2000, except at 200 m and 300 m. Highways appeared to exert an attractive force on rural settlements, which were widely distributed nearby the highway. On the other hand, independent construction land was repelled by the highway, with land area proportion rising with increasing distance from the highway (Fig. 3e). In 2008, arable land exhibited two peaks, at 400 m and 800 m, respectively, forming an 'M' shape. The spatial distribution of forest, grassland, water area, rural settlements, and independent construction land remained similar to those observed in 2000. The share of urban land at each distance expanded dramatically and had a clear spatial tendency: the proportion peaked at 28.44% at 100 m, and decreased gradually thereafter with increasing distance from the highway (Fig. 3f).

We next turn to spatial gradient analysis of comprehensive land use dynamic degree in the buffers of the three types of transportation arteries in order to examine the influence of different transport routes on land use patterns as a whole. As shown in Fig 4, the *CLUDD* in railway buffers showed a fluctuating but increasing tendency, with its minimum value of 1.30% occurring at 200 m and its peak of 3.06% at 1000 m. Compared with what is observed in railway buffers, *CLUDD* in the buffers of expressways and highways varied within a much more limited range. *CLUDD* in expressway buffers remained between 0.50% and 1.00%, and with no obvious spatial trend. *CLUDD* in the buffers of highways remained between 1.50% and 2.00%, exhibiting a tendency of gradual decline, whereby it decreased from a maximum of 1.96% at 100 m to a minimum of 1.50% at 1000 m. In general, land use change along expressways was the least conspicuous of all: *CLUDD* at each distance was lower than that observed along railways and highways.

4 Discussion

Past research employing gradient analysis techniques to study urban growth, arable land conversion, and forest degradation along roads has found clear distance trends (Cao *et al.*, 2006; Zhu *et al.*, 2006; Mueller *et al.*, 2010). This general hypothesis has also found support in study

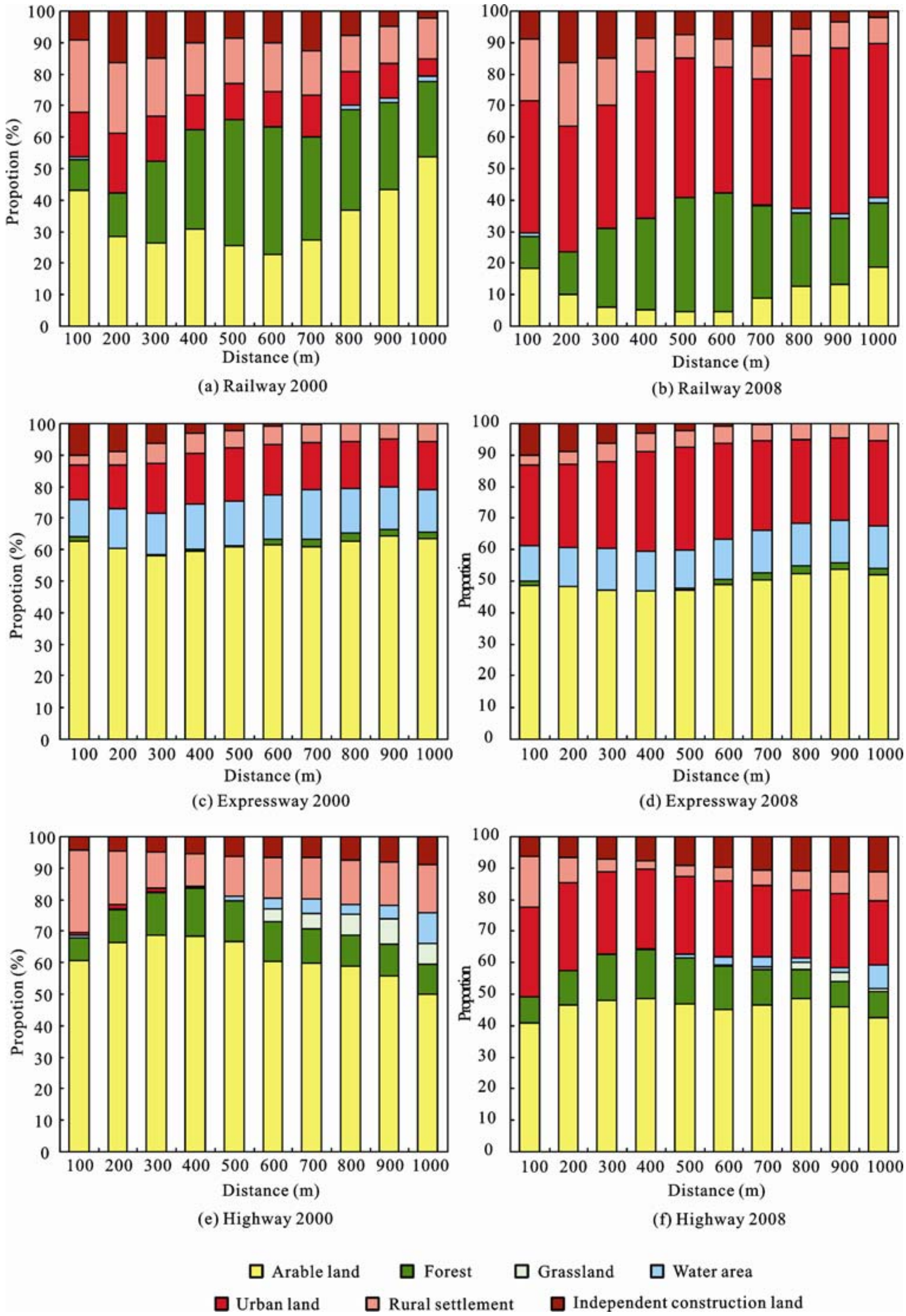

Fig. 3 Spatial distribution of land use pattern along railway, expressway and highway

of the urban-rural fringe, so we can thus put forward an answer to the question of whether land use displays a clear distance-related trend: in general, construction land tends to be located nearby major transportation arteries, while the distribution of agriculture land has no obvious distance trend. This suggests that transport infrastructure indeed has significance for promoting urbanization in the urban-rural fringe. However, it must be pointed out that this distance trend exists only in general, because patterns of land use change along different types of transportation arteries display distinct spatio-temporal features. The analysis of distance trends, therefore, is not sufficient to clarify the interaction of transport infrastructure and land use patterns; it is nec-

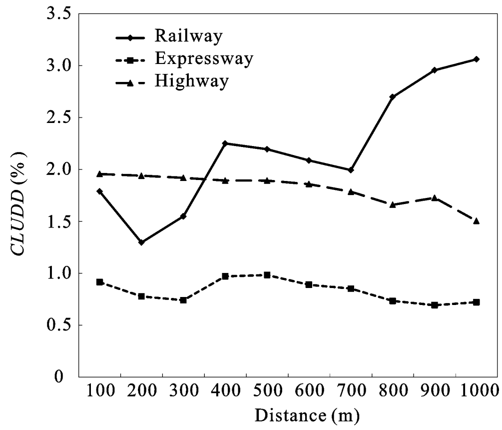

Fig. 4 Comprehensive land use dynamic degree (*CLUDD*) in buffers of railway, expressway and highway

essary to examine how land use change varies along different kinds of transportation arteries. To our knowledge, this is the first study that considers different types of transport infrastructure in examining land use change analysis. We turn now to a discussion of the gradient differences among land use changes seen in the buffers of railways, expressways, and highways.

Spatial gradient analysis of land use patterns in the buffers of three major types of transportation arteries indicates that railways, expressways, and highways drive land use change, and in particular that they bring about the expansion of construction land nearby. There is no conclusive pattern, however, when it comes to the spatial distribution of arable land, forest, and other agricultural land use types. Spatial distribution of land use patterns along railways suggests that railways exert a strong attractive force on all kinds of construction land including urban land, rural settlements, and independent construction land, all of which tended to be located nearby railways, but this tendency gradually weakened over time. Highways also attracted urban land and rural settlements, but independent construction land consisting of independent industrial, transportation, and water conservancy land areas was repelled by highways. In contrast, gradient analysis of the land use distribution along expressways revealed a strong attracting force only for independent construction land; urban land and rural settlements tended to be located farther from expressway.

As is clear from the varying impacts of railways, expressways, and highways on land use patterns, respectively, the attracting force of railways on construction land was far stronger than that of either expressways or highways. Thus, we can conclude that different types of transportation arteries have different influences on land use. The railway appears to have the most significant positive influence on urbanization and the expansion of construction land. This is not entirely surprising. The Beijing–Shanghai railway, which was completed in the early 20 century, is the most important transportation artery in Nanjing City, and perhaps in all of China, and the opening of a high-speed rail line in recent years has further enhanced its function as a key piece of transport infrastructure. The highways serve as the primary transport infrastructure for Qixia District, and have attracted an agglomeration of urban residential and economic activity due to its open characteristics, so it played a basic and indispensable part in the process of urbanization in urban-rural fringe. As a result of its closed nature, expressways are not effective enough for driving construction land expansion inside the urban-rural fringe, because they usually can only facilitate regional urban and industrial agglomeration.

Past studies have typically used urban growth rate (Mueller *et al.*, 2010), forest degradation rate (Cao *et al.*, 2006), landscape density (Zhu *et al.*, 2006), and other simple indices to evaluate the impact of roads on land use pattern and landscapes. In this study, by contrast, we employ gradient analysis of comprehensive land use dynamic degree to measure the distance trends of comprehensive land use change. Our findings indicate that land use patterns nearby railways have tended to remain stable because of the mature urbanization around railways; *CLUDD* nearby railway was low. *CLUDD* along highways tended to decline with growing distance, indicating that highways drive land use change only in their immediate vicinity. The impact of expressways on land use change, meanwhile, was not as conspicuous as for the other two types of transport infrastructures, and lacked any obvious spatial gradient characteristic. *CLUDD* also can be used to investigate the different roles and effects of three different types of transportation arteries. We find that highways are a driving force for land use change, whereas expressways have no evident impact on local land use patterns. However *CLUDD* in the buffers of railways exhibited a rising distance trend, which did not conform to the general rule that geographic interactions should decline with increasing distance. The reasons for this anomalous finding, we suspect, are related to the location of the Xianlin

University Town development zone to south of the railway line, resulting in high *CLUDD* on the outer edge of the railway buffers.

More generally, there is no question that land use change in the urban-rural fringe is driven not only by transport infrastructure, but also by urban planning, land use policy, local geomorphology, previous land use patterns, population, and other factors. The proportion of flat areas and the amount of previously developed urban areas have also been included in research into urban growth along motorways in Switzerland, and such research has concluded that local topography and previous urban areas have obvious impacts (Mueller *et al.*, 2010). In our research, we have found that land use and urban planning authorities encouraged construction land expansion in already developed areas, while locations planned as arable land in the Principal Agricultural Land Protection Planning as well as forest, water area, and other ecological land use types in the General Land Use Planning used as urban ecological buffers did not change even though they were close to roads. This may help explain why expressways had the smallest observed influence on land use change, insofar as the expressway in question passes through the Changjiang River and Baguazhou Town, which is the principal agricultural land protection area in Nanjing and there are large distributions of agriculture land and water area within the buffers of the expressway. In addition, complicated population distribution and flows between urban and rural areas related to China′s dualistic society may also increase the complexity of transportation, residential, and production behavior. Accordingly, land use patterns along transportation arteries are likely affected by various social factors.

This study selected linear buffers of three major arterial traffics to analyze the comparative gradient features of land use change. Likely due to the closed nature of expressways, there was no obvious land use change along the expressway corridor; expressways are more likely to affect land use patterns through the location of interchanges and stations. Furthermore, we find that Nanjing′s urban-rural fringe has its own particular characteristics different from those observed in metropolitan centers such as Guangzhou City (Mao and Yan, 2004) or sparsely populated regions such as the Qinghai-Tibet Plateau (Zhang *et al.*, 2002). Although land use change in the urban-rural fringe of Qixia District was affected by transport infrastructure, it was also driven simultaneously by the presence of nearby urban centers and by other factors under the broad heading of urban sprawl because Qixia District is narrow and small. Consequently, figuring out how to distinguish from the impacts of transportation corridors from those of other geographic variables, and figuring out how to build proper buffers, will be a key emphasis for further research.

5 Conclusions

Taking Qixia District as a typical urban-rural fringe area, our study has assessed land use characteristics in the urban-rural fringe and spatiotemporal features and the gradient of land use change in the buffers of railways, expressways, and highways from 2000 to 2008. We have identified dual urban-rural land use characteristics in urban-rural fringe, and have shown that transportation arteries had obvious and important influences on land use pattern as drivers of urbanization. Our aim was not only to demonstrate the impact of transportation arteries, but also to compare the varying spatial effects of three major types of transport infrastructure on land use patterns in the urban-rural fringe. Our findings imply that railways and highways have the strongest impact on arable land conversion and urban land expansion, whereas the driving force of expressway was relatively weak.

This research casts a new light on research into the interaction between transport infrastructure and land use. For land use and urban planning authorities, our research shifts the focus to the role of different types of transport infrastructure in land use in the urban-rural fringe, and gives an assessment of the distinct effects of railways, expressways, and highways on land use change. In fact, as discussed above, comparative gradient analysis using linear buffers is not enough, and land use change in urban-rural fringe is likely affected by a variety of factors. In further research, we will build buffers for expressway interchanges, stations, and other point geographic elements, and will take into consideration the interaction of various influence factors including urban policy, location, geomorphology, population, and behavior for conducting workable quantitative transportation-land use modeling, so as to strengthen our understanding about the factors driving land use and land cover change in the urban-rural fringe, and to improve our capability in transportation planning and urban development.

Acknowledgements

We thank Dr. Kyle Jaros from Harvard University for his thoughtful assistant.

References

Andrews R B, 1942. Elements in the urban-fringe pattern. *Journal of Land and Public Utility Economics*, 18(2): 169–183. doi: 10.2307/3158863

Cao Zhiwei, Ma Youxin, Li Hongmei, 2006. Amendatory comprehensive land use dynamic degree model and its application: A case study of impact of road on LUCC in Xishuangbanna. *Journal of Yunnan University*, 28(S1): 224–228. (in Chinese)

Chen Youqi, Wu Wei, 1998. An analysis on the man-land system and its dynamics in urban-rural interlocking belt. *Scientia Geographica Sinica*, 18(5): 418–424. (in Chinese)

Chen Youqi, 2000. Land use in the anternate region of urban and rural. *Journal of China Agricultural Resources and Regional Planning*. 21(5): 22–25. (in Chinese)

Chomitz K M, Gray D A, 1996. Roads, land use, and deforestation: A spatial model applied to Belize. In: Jaime de Melo. *World Bank Economic Review*. Oxford: Oxford University Press, 487–512.

Crossman N D, Bryan B A, Ostendorf B *et al.*, 2007. Systematic landscape restoration in the rural-urban fringe: Meeting conservation planning and policy goals. *Biodiversity and Conservation*, 16(13): 3781–3802. doi: 10.1007/s10531-007-9180-8

Forman, R T T, Alexander L E, 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29(1): 207–231. dio: 10.1146/annurev.ecolsys.29.1.207

Ganta R L, Robinson G M, Fazal S, 2011. Land-use change in the 'edgelands': Policies and pressures in London's rural-urban fringe. *Land Use Policy*, 28(1): 266–279. doi: 10.1016/j.landusepol.2010.06.007

Geneletti D, 2004. Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. *International Journal of Applied Earth Observation and Geoinformation*, 5(1): 1–15. doi: 10.1016/j.jag.2003.08.004

Gollege R G, 1960. Sydneys metropolitan fringe: A study in urban-rural relations. *Australian Geographer*, 7(6): 243–255. doi: 10.1080/00049186008702353

Handy S, 2005. Smart growth and the transportation—Land use connection: What does the research tell us? *International Regional Science Review*, 28(2): 146–167. doi: 10.1177/0160017604273626

Hawbaker T J, Radeloff V C, Clayton M K *et al.*, 2006. Road development, housing growth, and landscape fragmentation in northern Wisconsin: 1937–1999. *Ecological Application*, 16(3): 1222–1237. doi: 10.1890/1051-0761(2006)016[1222:RDHGAL]2.0.CO;2

He C Y, Wei A N, Shi P J *et al.*, 2011. Detecting land-use/land-cover change in rural–urban fringe areas using extended change-vector analysis. *International Journal of Applied Earth Observation and Geoinformation*, 13(4): 572–585. doi: 10.1016/j.jag.2011.03.002

Jha M K, Kim E, 2006. Highway route optimization based on accessibility, proximity, and land-use changes. *Journal of Transportation Engineering-ASCE*, 132(5): 435–439. doi: 10.1061/(ASCE)0733-947X(2006)132: 5(435)

Lausch A, Herzog F, 2002. Applicability of landscape metrics for the monitoring of landscape change: Issues of scale, resolution and interpretability. *Ecological Indicators*, 2(1): 3–15. doi: S1470-160X(02)00053-5

LeSage J P, Charles J S, 2008. Using home buyers' revealed preferences to define the urban-rural fringe. *Journal of Geographical System*, 10(1): 1–21. doi: 10.1007/s10109-007-0055-z

Lopez T D, Aide T M, Thomlinson J R, 2001. Urban expansion and the loss of prime agricultural lands in Puerto Rico. *AMBIO*, 30(1): 49–54. doi: 10.1639/0044-7447(2001)030[0049:UEATLO]2.0.CO;2

Luck M, Wu J G, 2002. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology*, 17(4): 327–339. doi: 10.1023/A:1020512723753

Mao Jiangxing, Yan Xiaopei, 2004. Corridor effects of the urban transport artery on land use: A case study of the guangzhou avenue. *Geography and Geoinformation Science*, 20(5): 58–61. (in Chinese)

McDonnell M J, Pickett S T A, Groffman P *et al.*, 1997. Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystem*, 1(1): 21–36. doi: 10.1023/A:1014359024275

Miller J R, Joyce L A, Knight R L *et al.*, 1996. Forest roads and landscape structure in the southern Rocky Mountains. *Landscape Eco*logy, 11(2): 115–127. doi: 10.1007/BF02093743

Mueller K, Steinmeier C, Kuechler M, 2010. Urban growth along motorways in Switzerland. *Landscape and Urban Planning*, 98(1): 3–12. doi: 10.1016/j.landurbplan.2010.07.004

Nick G, Dave S, 2007. Spatial planning, area action plans and the rural-urban fringe. *Journal of Environmental Planning and management*, 50(5): 617–638. doi: 10.1080/09640560701475188

Nkambwe M, Arnberg W, 1996. Monitoring land use change in an African tribal village on the rural-urban fringe. *Applied Geography*, 16(4): 305–317. doi: 10.1016/0143-6228(96)00014-8

Pryor R J, 1968. Defining rural-urban fringe. *Social Forces*, 47(2): 202–215. doi: 10.2307/2575150

Saunders S C, Mislivets M R, Chen J Q *et al.*, 2002. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. *Biological Conservation*, 103(2): 209–225. doi: 10.1016/S0006-3207(01)00130-6

Serrano M, Sanz L, Puig J *et al.*, 2002. Landscape fragmentation caused by the transport network in Navarra (Spain)-Two-scale analysis and landscape integration assessment. *Landscape and Urban Planning*, 58(2): 113–123. doi: 10.1016/S0169-2046(01)00214-6

Tan M H, Li X B, Xie H *et al.*, 2005. Urban land expansion and arable land loss in China : A case study of Beijing-Tianjin-Hebei region. *Land Use Policy*, 22(3): 187–196. doi: 10.1016/j.landusepol.2004.03.003

Trombulak S C, Frissell C A, 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, 14(1): 18–30. doi: 10.1046/j.1523-1739.2000.99084.x

Wehrwein G S, 1942. The rural-urban fringe. *Economic Geography*, 18(3): 217–228. doi: 10.2307/141123

Whittaker R H, 1975. *Communities and Ecosystems*. New York: MacMillan.

Xiao J Y, Shen Y J, Ge J F *et al.*, 2001. Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. *Landscape and Urban Planning*, 75(1): 69–80. doi: 10.1016/j.landurbanplan.2004.12.005

Zhang Yili, Yan Jianzhong, Liu Linshan *et al*., 2002. Impact of Qinhai-Xizang highway on land use and landscape pattern change: From golmud to tanggulashan pass. *Scientia Geographica Sinica*, 57(3): 253–266. (in Chinese)

Zhu M, Xu J G, Jiang N *et al.*, 2006. Impacts of road corridors on urban landscape pattern: A gradient analysis with changing grain size in Shanghai, China. *Landscape Ecology*, 21(5): 723–734. doi: 10.1007/s10980-005-5321-z