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Spatial and temporal distribution of expressway and its relationships to land cover and population: A case study of Beijing, China

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ABSTRACT

The interaction between urban transport, land cover change and the distribution of population is a typical manifestation of the urbanization process. As high-grade road, expressway plays a significant role in promoting resource circulation and economic development. Based on the road distribution, land cover and population census data, this study specifically probed the relationship between the expressways and the land cover and population of Beijing. The results show that: (1) as the distance from an expressway increases, the amount of built-up land gradually decreased, and the transfer of land cover near the expressway was more intensive and frequent when compared with that of the whole city; (2) In 2010, a district that was less than 3 km from both sides of the expressway and which occupies one-quarter of the entire city had concentrations of 42% industrial land, 58% of settlement land, and 76% transportation land of the entire city; (3) As for Beijing, the population density was positively correlated to road density, and population density declined with a corresponding increase in buffer distance; (4) The ring area between the Fifth and the Sixth Ring Road featured the greatest density of expressways and the most dramatic changes in both land cover and population. According to our study, there's a positive interactive feedback relationship between the expressways, land cover and population of Beijing. Also, due to the concentration of population, industry and transport system around the expressways, special attention should be paid to environmental pollution and the inhabitants' health in this area.

Introduction

Many studies indicate that interactive circular feedback relationships exist between urban transport, land cover and population (Voss and Chi, 2006; Iacono and Levinson, 2009). The construction of transport facilities and an improvement in transport conditions will increase the accessibility of some urban regions, making available the enhanced influences of human activities. Increased access will also promote the emergence of new commercial and residential centers and lead

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to an increase in population (Chi, 2010, 2012; Kotavaara et al., 2011; Ratner and Goetz, 2013). In turn, the changes in land utilization and cover also bring about variations in people's travel activities. Travel demand increases, which in turn induces the formation of transport policies, stimulates road planning and exerts an important influence on the extension and improvement of the transport network (Cervero, 2003; Iacono and Levinson, 2009; Liu, 2009; Wang, 2009). The process of interaction between urban transport, land utilization and cover and population is, in fact, the process of urbanization.

In studies that analyze changes in land cover and population, spatial information technologies, represented by Geographical Information System (GIS) and Remote Sensing (RS), have been commonly used (Weng, 2002; York et al., 2011). Land cover and its changes can be obtained via the interpretation and comparison of remote sensing images taken over time, while GIS provides a spatial statistic tool and mapping tool for the quantitative analysis of such changes (Aljoufie et al., 2013). Meanwhile, GIS not only provides the differences in population in terms of an administrative unit scale, but also shows the distribution and change of the researched population on an even smaller scale (e.g. 1 km or hundreds of meters) (Langford and Unwin, 1994; Gallego, 2010). In addition, when analyzing the influence of transport activities on the natural environment or social economy, the road buffer zone extracted by GIS serves as a common analysis unit. The approach of comparing a specific index within various buffer zones to evaluate whether spatial regularity exists in road influence has been applied in studies of roads on subjects such as ecological influence and heavy metal accumulation, etc. (Larsen and Parks, 1997; Zhang et al., 2002; Schelhas and Sanchez-Azofeifa, 2006).

With the acceleration of China's urbanization process, its urban population has also experienced rapid growth. According to the data obtained from the third to sixth nationwide population censuses, the urban population of China grew from 207 million in 1982 to 666 million in 2010. The latter accounted for 49.68% of the total population of China. As the capital, and also as one of China's largest cities, Beijing is a typical example of the rapid growth of an urban population. By 2010, the urban population of Beijing accounted for 86% of its total population, and had increased in population by 6.336 million people, compared to the year 2000. With the expansion of the city, newly-built urban areas, suburbs and edge cities have become the areas experiencing the most rapid population growth. In order to satisfy the travel demands of people living in these areas, Beijing is striving to develop its rail transit and expressway systems. The improvement in transport conditions has increased the glamour of these areas for more people, leading to increased population concentrations. For the process of interaction between transportation and population, in cases of imbalances and mismatches between transport resources and population distribution, travel demands will not be satisfied, which results in further traffic jams (Aljoufie et al., 2013). Despite the 228 km of metro lines and 900 km of expressways, Beijing still suffers from severe traffic jams (Yu, 2012). The average driving speed on expressways is actually below 20 km per hour during rush hours and on holidays (Beijing Municipal Commission of Transport, http://www.bjjtw.gov.cn/).

As a high-grade road type in the transport system, the expressway exerts obvious influences on both city expansion and population distribution (Wang et al., 1975; Kim, 2007). In this paper, GIS is used to research the spatial and temporal characteristics of expressways in Beijing. The results reveal the basic rules of land cover and the population distribution of the areas around expressways. This study probes the relationship between the expressway and land cover and population. The results of this study are expected to be a theoretical reference for expressway management, urban planning, population sampling surveys and subsequent studies.

Material and methodology

Study area

Beijing is situated at the northern tip of the North China Plain, with its center located at 39°54′20″N and 116°25′29″E. The city covers a land area of 16,411 square kilometers, including 14 districts and 2 counties (Fig. 1). The western, northern and northeastern parts of the area are mountainous and hilly, which accounts for about 61.4% of the city; the remaining part is a plain. According to the urban planning of Beijing, both Dongcheng and Xicheng are traditional inner-city districts. Chaoyang, Haidian, Fengtai and Shijingshan are urban expansion districts. Tongzhou, Shunyi, Fangshan, Daxing and Changping are new urban development districts. Huairou, Pinggu, Mentougou, Miyun and Yanqing are districts dedicated to ecological conservation. According to the fifth and sixth population censuses, the permanent resident population of Beijing in 2000 was 13.57 million people. This increased to 19.61 million by 2010.

Data collection and processing

In this study, both statistical and spatial data of Beijing were gathered and sorted, including road, land cover, population, administrative boundary and DEM. Spatial and mathematical statistical analysis was carried out in ArcGIS 10.0 (ESRI Inc.) and SPSS 18.0 (SPSS Inc.), respectively.

Road

The road data used in this study is the vector data of roads covering the whole city of Beijing in 2010. It is noteworthy that due to the considerable levels of urban traffic flow, the second, third and fourth ring roads, which have a speed limit of no more than 80 km per hour, are not treated as expressways in this study.

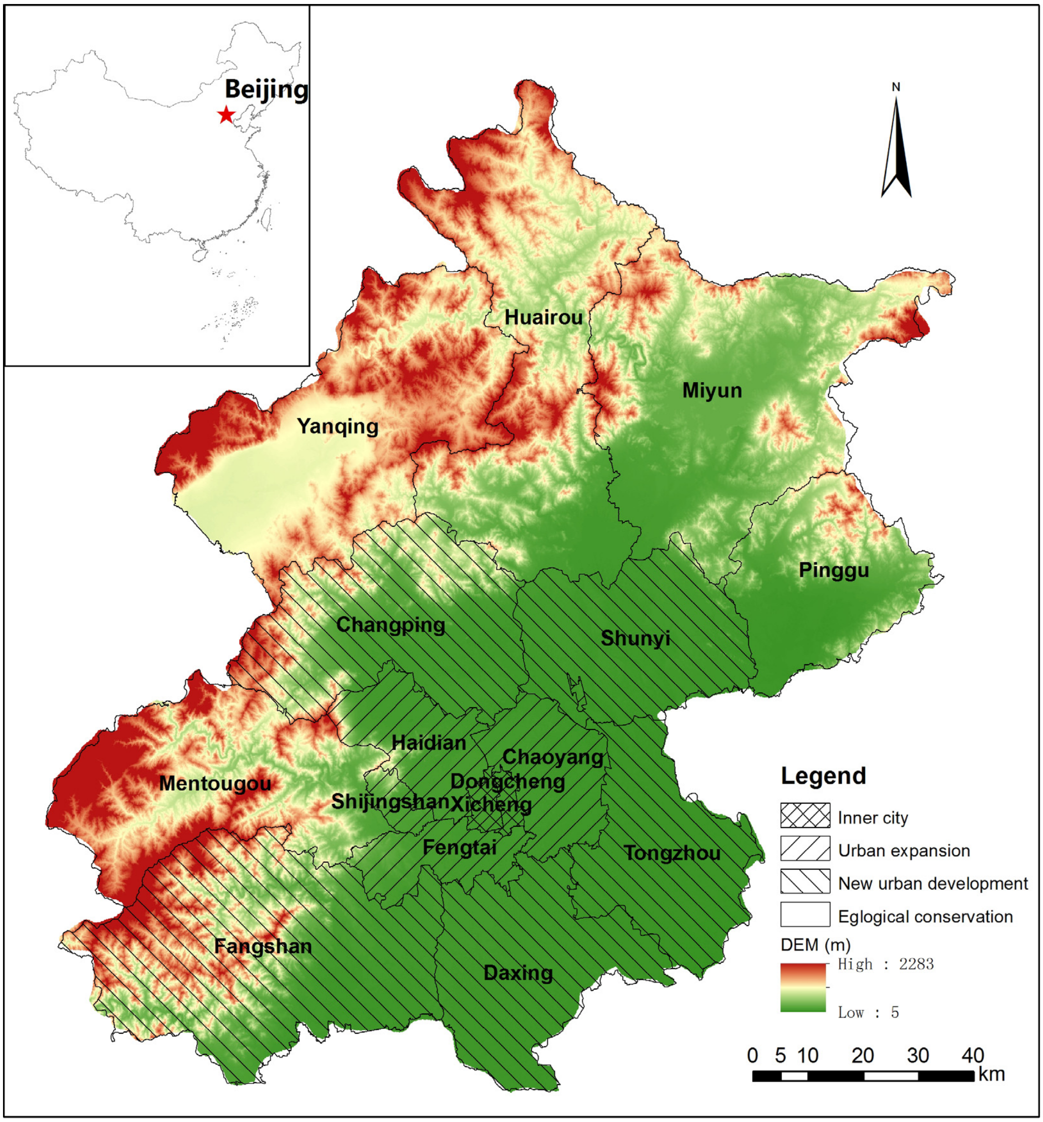

Fig. 1. Districts, counties and DEM of Beijing.

Based on news reports, the time when the expressway was opened to traffic was identified, and the boundaries of the buffer zones within a 10 km scope were also calculated at 1 km intervals on both sides of the expressway (Fig. 2a). In addition, the weighted length of the various roads within a unit area was defined as road density (RD):

$$RD = \frac{\sum_{i=1}^{n}(W_i * L_i)}{S} \quad (1)$$

Where RD is the road density value of a certain unit area; W_i is the weight of road type i; L_i is the length of road type i in the unit area; S is the area of the unit. In this study, roads were classified under administrative grading as being expressways, national roads, municipal roads, first-grade urban roads, county roads and other roads. For the purposes of this study, we set the weight of an expressway as 5, the weight of national roads and the second, third and fourth ring roads as 4, municipal roads as 3, first-grade urban roads as 2, and county roads and other roads as 1. We calculated the road density within a 1 km raster and counted the average road density of each town using the Spatial Analysis Tools of ArcGIS (Fig. 2b).

Land cover

Land cover data for Beijing of 2000 and 2010, provided by the Data Center for Resources and Environmental Sciences (RESDC), Chinese Academy of Sciences, was interpreted from Landsat/TM images. Land cover was classified into 6 types (forest land, cropland, grassland, wetland, built-up land and other land). Built-up land has been classified into 4 subtypes (land

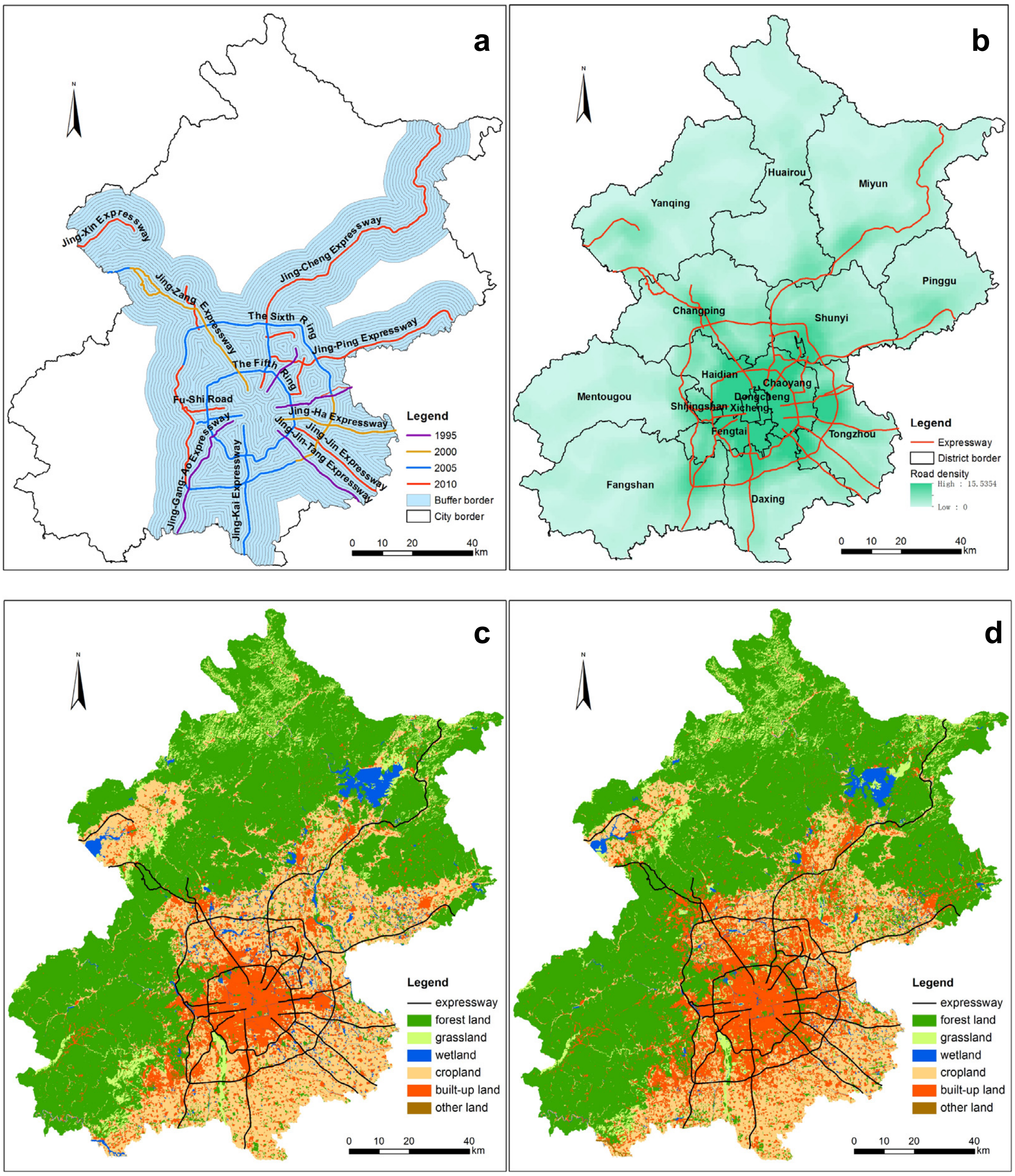

Fig. 2. (a) Expressways of Beijing in 2010 and their buffer zones; (b) Road density (km/km^2), 2010; (c) Land cover of Beijing in 2000 and (d) Land cover in 2010.

for settlement, industry, transportation and mining) in order to study the effect of expressway on human activities (Fig. 2c and d). The data has been widely applied in studies of land cover, with an overall accuracy of 95% for land cover types, 85% for subtypes and a Kappa coefficient above 0.81 validated by intensive field surveys (Liu et al., 2005, 2010; Wang et al., 2013).

In order to make comparisons between various land cover types and buffer zones, in this study we calculated the ratios of the area of a certain land cover type in the buffer zones of the expressway, accounting for the total area of this type in the whole city (RC) and then taking into account the area of the buffer zone (RB):

$$RC = \frac{A_{ij}}{S_i} * 100\% \quad (2)$$

$$RB = \frac{A_{ij}}{R_j} * 100\% \quad (3)$$

Where A_{ij} is the area of the land cover type i in buffer zone j, S_i is the total area of land cover type i in the city, R_j is the area of buffer zone j.

In addition, a land cover change detection matrix and dynamic index were introduced to indicate variations in land cover in the city and buffer zones of the expressways (Berlanga-Robles and Ruiz-Luna, 2002). The land cover change detection matrix could demonstrate the mutual transformation among the various types of land cover intelligibly. Land Cover Dynamic Index (LCDI) and Bilateral Land Cover Dynamic Index (BLCDI) are good indicators of the intensity of land cover change:

$$LCDI_i = \frac{(U_{ia} - U_{ib})}{U_{ia}} * \frac{1}{T} * 100\% \tag{4}$$

$$BLCDI_i = \frac{(\sum U_{ij} + \sum U_{ij})}{U_{ia}} * \frac{1}{T} * 100\% \tag{5}$$

Where U_{ia} is the area of land cover type i in the beginning of the study period, U_{ib} is the area of type i at the end of the period; ΣU_{ij} is the total area of type i converted into other types, ΣU_{ji} is the total area of type i converted from other types; T is the study period; $LCDI_i$ and $BLCDI_i$ are dynamic index and bilateral dynamic index of land cover type i, respectively (Wang and Bao, 1999; Wang et al., 2002; Liu et al., 2010).

Population

The population data for this study came from the fifth and sixth population censuses and was processed at two scales, which were town and 1 km raster. For the town scale, on the basis of the total area and area of settlement land that was obtained from the land cover data, population density of the town and population density of settlement land were calculated for 2000 and 2010. SPSS was adopted to calculate the correlation coefficients between the road density of each town in 2010, the overall population density and the population density of the settlement land in 2010. Then, a significance level test was conducted. We also calculated the population growth rate (PGR) in each town in the period 2000–2010.

$$PGR = \frac{(P_{2010} - P_{2000})}{P_{2000}} * 100\% \tag{6}$$

Where P_{2000} and P_{2010} are populations in 2000 and 2010, respectively.

Conversely, for the 1 km raster scale, the correlation between population and land cover was employed to calculate the population coefficient of each type of land cover. Spatial distribution of the population was computed and modified with DEM data, and then the 1 km raster for the population of Beijing in the years 2000 and 2010 were obtained (Jiang et al., 2002; Huang et al., 2007). We counted the average population density of each buffer zone using the Spatial Analysis Tools in ArcGIS.

Results

Distribution of expressways and road density

The expressways of Beijing were mainly concentrated in the central and southeastern parts of the city. Prior to 1995, the mileage of the four expressways extending out of Beijing to the east and southwest was only 126 km. Between 1995 and 2000, 140 km of new expressways were added. The additional roads included the Beijing–Harbin Expressway in the southeast and the Beijing–Tibet Expressway in the northwest. Between 2000 and 2005, 300 km of new expressways were added, including the Fifth and Sixth Ring Roads and the Beijing–Kaifeng Expressway. Between 2005 and 2010, 372 km of new expressways were added, including the Beijing–Chengde Expressway, the Beijing–Pinggu Expressway and the Beijing–Urumqi Expressway in the northeast and west, which had fewer expressways to that point.

In 2010, the road density of Beijing could be spatially divided into three sections. The first is the urban area within the Fifth Ring Road, including inner-city districts and parts of urban expansion districts, where the overall road density is higher. The second is the area outside the Sixth Ring Road, including the new urban development districts and the ecological conservation districts, where the overall road density is lower. The third is the area between the Fifth Ring Road and the Sixth Ring Road, which is effectively the interface between the urban expansion districts and the new urban development districts. The road density here is somewhere between the other two and is higher in the areas around the expressways. As for the average road density of the various districts and counties, 13 km per square kilometer refers to the inner-city districts, 5–9 is for the urban expansion districts and 1–4 is for the new urban development districts, while that of most of the areas in the ecological conservation districts and counties is less than 1 (Table 1).

Analysis of land cover and expressways

Land cover of buffer zones of expressways in 2010

The land cover of Beijing was dominated by forest, cropland and built-up land. The forest land was mainly distributed in the western and northern mountainous areas, while the cropland and built-up land were mainly distributed on the central

Table 1
Road density of districts/counties of Beijing in 2010 (km/km^2).

Name (Inner city and urban expansion districts)	Road density	Name (New urban development districts)	Road density	Name (Ecological conservation districts)	Road density
Dongcheng	13.45	Tongzhou	3.42	Huairou	0.77
Xicheng	12.94	Shunyi	2.90	Pinggu	1.36
Haidian	6.07	Fangshan	1.22	Mentougou	0.72
Chaoyang	8.48	Daxing	2.82	Miyun	1.00
Fengtai	6.59	Changping	2.04	Yanqing	0.87
Shijingshan	5.64				

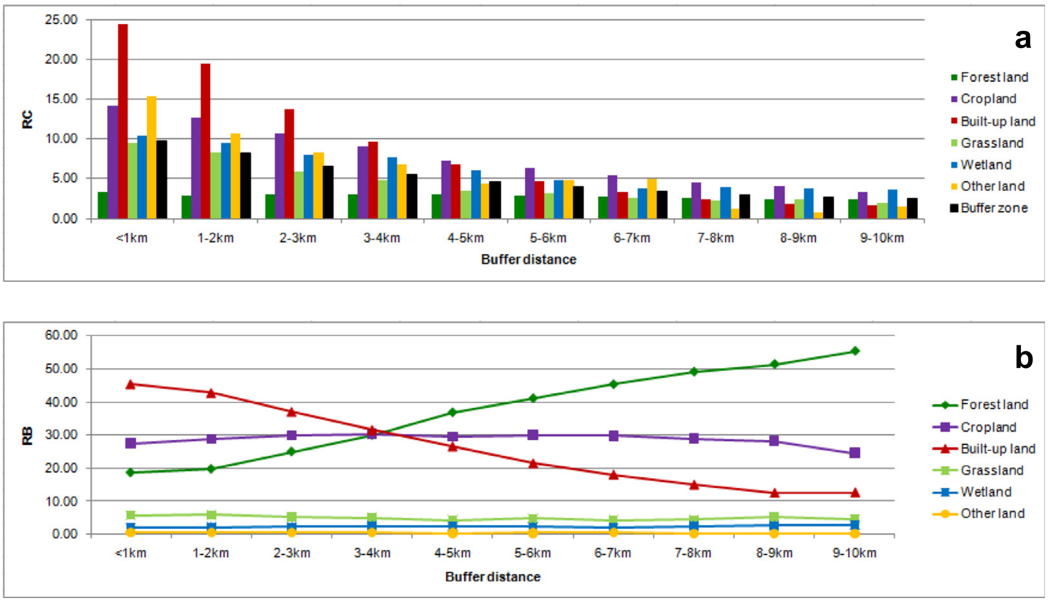

Fig. 3. (a) Ratios of the area of land cover type in the buffer zones of the expressway, accounting for the total area of this type in the whole city (RC) and (b) taking into account the area of the buffer zone (RB) of various land cover types in 2010.

and southeastern plains (Fig. 2c and d). The area of expressway buffer zones decreased with the increase in buffer distance, so the RC of the buffer zones showed a trend of gradual decline (Fig. 3a). The RC of the land covered by forest remains stable in various buffer zones, and in no case exceeded 5%. Except for forest land, the RCs of the other five land cover types all declined with increase in buffer distance. The RC of built-up land within a range of 3 km was obviously higher than that of other types of land cover and rapidly declined with increase in buffer distance.

Cropland, forest land and built-up land were the three primary land cover types in all buffer zones, and the sum of the RBs of the three combined has exceeded 90% (Fig. 3b). In the various buffer zones, as the buffer distance increases, the RBs of built-up land and forest land, respectively, presented an obvious declining trend and an obvious rising trend; the RB of forest land exceeded that of the built-up land in 3–4 km buffer zones, and the RB of the cropland changed insignificantly in all the buffer zones and remains consistent at approximately 30%.

Land cover change in buffer zones of expressways and Beijing in the period 2000–2010

Statistics were respectively made on the land cover change detection matrix, LCDI and BLCDI for Beijing and buffer zones within the range of 10 km from the expressways, during the period from 2000 to 2010 (Table 2). On the whole, the LCDI of wet land and cropland was below 0, and their area was decreasing. The LCDI of forest land, grassland and built-up land was above 0, and their area was increasing. The BLCDI of forest land, grassland and other land were far higher than their LCDI. In a decade, the transfer of land with an area of more than 100 square kilometers included the transfer from cropland to built-up land, from cropland to forest land, from cropland to grassland and from grassland to cropland. Particularly, the transfer from cropland to built-up land accounted for 24% of the total area of built-up land in 2010. The transfer from wetland and other land to different types of land cover were low in quantity but high in proportion, so the LCDI and BLCDI of the two was higher than those of the other types of land cover.

In the buffer zones of the expressway, the land cover dynamic index represented an area of increasing or decreasing trends that were consistent with that of the whole city (Table 3). However, the LCDI and BLCDI reached from two to five

Table 2
Land cover change detection matrix and dynamic index of Beijing in the period 2000–2010 (km^2).

2000	2010						
	Forest land	Grassland	Wetland	Cropland	Built-up land	Other land	Sum
Forest land	8339.49	20.32	3.32	86.28	55.46	1.30	8506.17
Grassland	128.65	631.90	1.84	12.31	18.92	3.41	797.03
Wetland	31.38	41.45	271.43	56.05	41.88	14.14	456.34
Cropland	552.83	227.89	21.73	2900.37	699.47	15.90	4418.18
Built-up land	12.63	27.98	0.62	2.83	2141.23	0.25	2185.53
Other land	3.10	1.93	0.62	5.58	5.42	25.93	42.57
Sum	9068.08	951.46	299.56	3063.42	2962.37	60.93	16405.82
LCDI	0.66	1.94	−3.44	−3.07	3.55	4.31	–
BLCDI	1.05	6.08	4.67	3.80	3.96	12.13	–

Table 3
Land cover change detection matrix and dynamic index of the buffer zones of expressway in the period 2000–2010 (km^2).

2000	2010						
	Forest land	Grassland	Wetlands	Cropland	Built-up land	Other land	Sum
Forest land	2075.54	17.41	2.71	72.60	48.01	0.84	2217.12
Grassland	35.68	189.74	1.51	11.20	14.90	2.88	255.91
Wetland	19.42	28.28	158.89	45.65	39.83	6.15	298.21
Cropland	445.72	156.60	20.21	2238.67	647.66	13.34	3522.20
Built-up land	12.14	27.93	0.57	2.23	1855.45	0.21	1898.52
Other land	2.85	1.61	0.62	3.75	4.07	12.60	25.49
Sum	2591.35	421.57	184.51	2374.08	2609.92	36.02	8217.46
LCDI	3.38	12.95	−7.63	−6.52	7.49	8.26	–
BLCDI	5.93	23.29	11.06	8.06	8.40	28.49	–

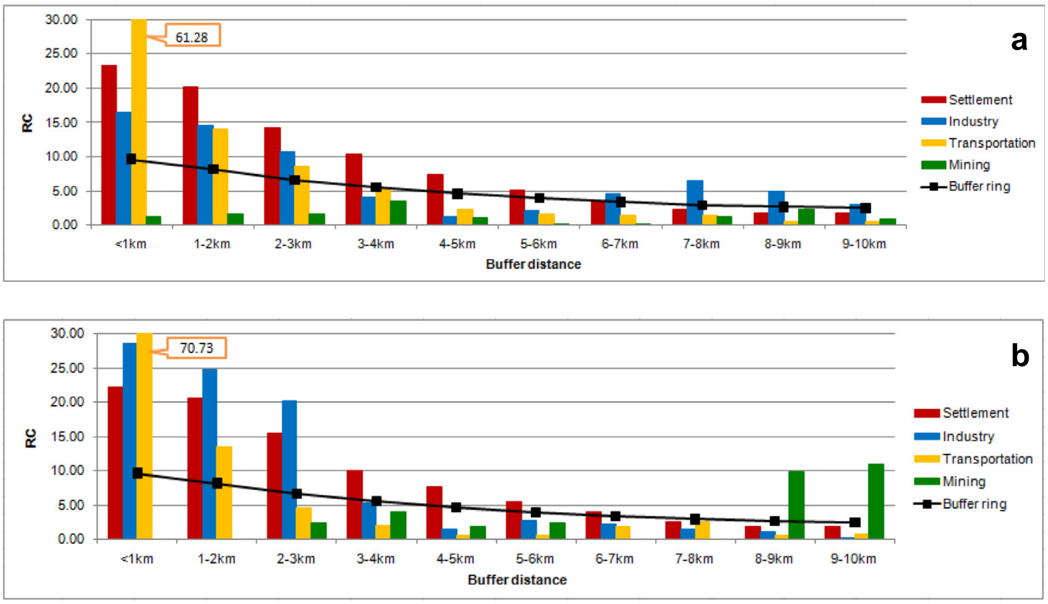

Fig. 4. (a) Ratios of the area of land cover type in the buffer zones of the expressway, accounting for the total area of this type in the whole city (RC) of the subtypes of built-up land in 2010 and (b) RC of the increased area of the subtypes of built-up land in the period 2000–2010.

times those of the entire city, and the BLCDI of grassland and other land were far higher than the LCDI. The transfer of more than 100 square kilometers included transfer from cropland to built-up land, from cropland to forest land and from cropland to grassland.

Built-up land in buffer zones of expressways

The changing trends of the RCs of the four subtypes of built-up land with increased buffer distances in 2010 are shown in Fig. 4a. The RCs of settlement land and transportation land gradually declined with increases in buffer distance. The PC of transportation land exceeded 60% in buffer zones <1 km and declined to below 15% in the 1–2 km buffer zones. The RC of industrial land showed a fluctuating trend of first declining and then rising, and reached its minimum in the 4–5 km buffer zones. The RC of mining land was lower than the RC of the buffer zones in each buffer zone, and its distribution area was smaller.

The built-up land of Beijing in 2010 represented an increase of about 821 square kilometers over that of 2000. This accounted for 38% of the built-up land in 2000. Fig. 4b depicts the proportions of the increased areas of the four subtypes of land cover in the entire increased area of these subtypes in the entire city (RC). It could be observed that the RCs of the newly-added settlement land, industrial land and transportation land all declined with increases in the buffer distance, and the RC of the newly-added transportation land exceeded 70% in buffer zones of less than 1 km. The RC of the increased industrial land no longer showed any fluctuation, and it exceeded the settlement land in buffer zones of less than 3 km. The RC of the increased mining land increased in the 8–10 km buffer zones.

What is noteworthy is that the sum of the 10 km buffer zones around expressways accounted for only one-half of the total area of the entire city. However, in 2010, the areas of settlement land, industrial land and transportation land, respectively, in the buffer zones accounted for 90%, 68% and 98% of the whole city. Particularly within 3 km on both sides of the expressway, an area of one-quarter of the total area of the whole city had a concentration of 58% of the settlement land, 42% of the industrial land and 76% of the transportation land of the entire city. Besides, in the built-up land added between 2000 and 2010, the areas of the increased settlement land, industrial land and transportation land, respectively, concentrated in the 3 km buffer zones accounted for 58%, 74% and 89% of the entire city.

Analysis of population and expressways

Statistical analysis of population in buffer zones of expressways

It was noted that the average population density in the buffer zones of the expressways declined with an increase in the buffer distance in both 2000 and 2010 (Fig. 5). The density fell below the average population density of the entire city when the distance exceeded 6 km. It was obvious that population density increased in the period 2000–2010 in the 7 km buffer zone, especially in 1–5 km buffer zone.

As shown in Table 4, the Pearson correlation analysis of the town scale showed that the average road density of the towns was significantly and closely correlated to total population, population density as a whole and population density on residential land was at a level of 0.01, and the highest correlation coefficient occurred between road density and population density.

Spatial distribution of population change and expressways

In 2010, the largest population and smallest population reported by individual Beijing towns were 359,415 and 2472, respectively. The most densely populated towns were mainly concentrated in the urban expansion districts (Fig. 6a). It can be seen in Table 5 that the towns of Beijing witnessed population decreases and increases, respectively, that accounted

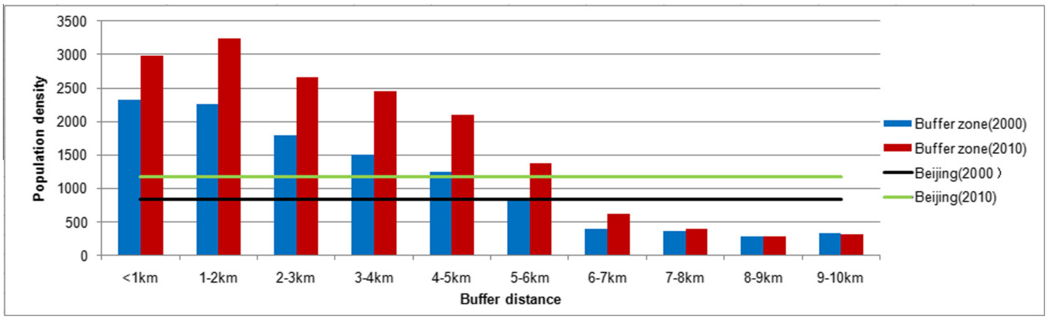

Fig. 5. Population density (person/km^2) of the buffer zones of expressway and that of the whole city.

Table 4
Correlation analysis between road density and population indicators in town-scale in 2010.

	Population density	Population density in settlement land
Pearson correlation	.845**	.775**
Kendall's tau_b	.762**	.453**
Spearman's rho	.927**	.659**
Sig. (2-tailed)	.000	.000
Number of counties	311	311

** Means correlation is significant at the 0.01 level.

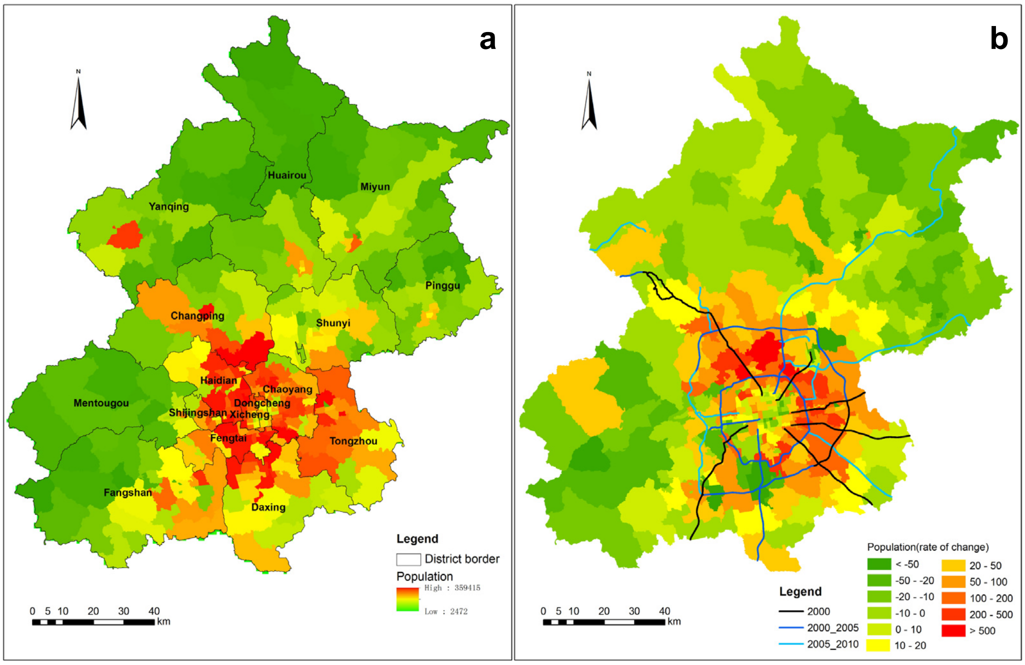

Fig. 6. (a) Population of towns in 2010 and (b) population growth rate (PGR) of towns in the period 2000–2010.

Table 5
Population growth rate (PGR) in the period 2000–2010.

PGR	Less than −50%	−50%∼0	0–50%	%50∼%100	More than %100	Sum
Number of towns	16	119	110	38	42	325
Ratio to all the towns (%)	4.92	36.62	33.85	11.69	12.92	100

for 41% (PGR < 0) and 59% (PGR > 0) of all towns. Of these, about one-quarter of the towns witnessed a population increase of more than 50%. In fact, 42 towns saw their populations double.

Most towns experienced a population increase distributed in the urban expansion and new urban development districts. The towns with a population increase of more than 50% were mostly concentrated within the ring area between the Fifth Ring Road and the Sixth Ring Road, especially within the northern and eastern parts of the area (Fig. 6b). Some of these towns even had an increase in excess of 500%. In addition, outside of the Sixth Ring Road, the towns distributed along the expressways also showed a trend toward population increases.

For the towns through which the expressways opened before 2000, their population has significantly increased. Around the expressways opened between 2000 and 2005, the towns experienced population increases proportionally lower than those along expressways that opened before 2000. Around the expressways opened between 2005 and 2010, only a few towns showed a trend of increasing population. As for the towns distributed along the expressways to the northeast and east of Beijing, many even showed a trend of decreasing populations.

Discussions

Development of expressways and variation of land cover

Since the first expressway was built and opened to traffic in 1990, the total number of expressway kilometers in Beijing has exceeded 900 in just two decades. Centered on the inner city, an expressway framework with a combination of ring and radial expressways was formed. Blocked by the mountainous areas to the west and north, and attracted by cities like Tianjin and Tangshan, as well as the seaports to the east and south, the expressways of Beijing mainly extended out to the southeast and south in the early days. With improvements in the developmental plan for the districts and counties of Beijing, on the one hand, expressways built after 1990 were still densely constructed in the southeast and south to improve the ties between Tianjin, Beijing and Hebei. On the other hand, the northwest and northeast were also emphasized. The opening of the Beijing–Tibet and Beijing–Chengde expressways incorporated several districts and counties along the way into the "One-Hour Economic Circle of the inner city". This has significantly strengthened the connections of these areas with the adjacent urban districts.

Convenient and efficient transport accelerated the process of urbanization of suburban districts and counties. One of the main manifestations is the change in land cover. Between 2000 and 2010, both Beijing as a whole and the buffer zones of the expressways presented a decreasing trend in cropland and wetland, and an increasing trend in forest land, grassland, built-up land and other land. However, the LCDI and BLCDI of the buffer zones were obviously higher than those of the entire city, which suggested more intensive and frequent transfers occurred among various types of land cover. Meanwhile, the transfer from cropland to other types of land cover accounted for the greatest area in terms of volume. In particular, the transfer from cropland to built-up land became the most important source of the newly-added built-up land. The amount of this kind of transfer that occurred in the buffer zones accounted for 93% of the total area of all such transfers in the entire city. This phenomenon suggests that this kind of transfer mostly occurred around the expressways. All these phenomena have reflected close associations between expressways and land cover changes, as well as the attraction of expressways to built-up land.

Development of expressways and population distribution and change

After several decades of development, the population of the inner-city districts of Beijing has basically stabilized. Expensive house prices are continuously forcing large sections of the population to migrate from inner-city districts to the suburbs. Meanwhile, the relatively lower land prices and rents in the suburbs have attracted logistics, high-tech and other enterprises to migrate out of downtown and form new industry, commerce and residential centers. In the current study, the significant correlation between road density and population density proves the close spatial association between transport conditions and population distribution. Most settlement land and transportation land across the city is concentrated on both sides of the expressways. The settlement land area and population density both declined with an increase in distance away from the expressways. This all suggests that the development of the expressway not only improves regional transport conditions, but also increases transport accessibility and attracts concentrations of population around the expressways.

As shown in this study, the Fifth Ring Road and the Sixth Ring Road are connected to all expressways extending out of Beijing. In addition, the ring area between the two ring roads contains the expressways most heavily used and serves as an effective interface between the urban expansion districts and the new urban development districts. Viewed from the perspective of changes in land cover, the ring area is an important place for the transition from suburbs to inner-city districts. From a travel perspective, the ring area features convenient transport conditions, through which people can enter the urban districts or go out to the surrounding provinces and cities via the radial expressways. Alternatively, they could rapidly transit to other radial expressways via the two ring roads. As for population increases, between 2000 and 2010, the towns that witnessed the greatest population increases were all distributed within the ring area. Therefore, this area is the place with the densest distribution of expressways and that which has experienced the most intensive changes in both land cover and population. In addition, the interaction and circular feedback among the three areas is worthy of further study.

Development of expressways and traffic congestion and environment pollution

During the period from 2000 to 2012, the number of motor vehicles parking in Beijing increased from 1.4 million to 5.2 million. The improvements in both economic levels and transport conditions significantly changed the means of travel for many millions of people. These changes also imposed huge pressures on the transport systems and infrastructure of Beijing. In the current study, the northern and eastern urban districts of Beijing have witnessed the most rapid population growth, and they were also the most densely populated Beijing districts in 2010. To the east, there are many expressways extending out of Beijing, and the road density is also very high. However, in the north, the road density is only at a moderate level throughout the city. In particular, on the northwestern side of the city, only one radial expressway, that being the Beijing–Tibet Expressway, has opened in the past decade. This places a heavy transport burden on the area and the expressway.

In addition, the effects of vehicle exhaust can cause a higher risk of cardiovascular and cerebrovascular diseases, respiratory system diseases and reproductive system diseases in the residents living near the busy roads (vanVliet et al., 1997; Brugge et al., 2007; Hazenkamp-von Arx et al., 2011). This has already been proven by many studies. Further studies are also needed on the issue of whether or not the frequently-jammed expressway sections adjacent to massive concentrations of settlement land, industrial land and transportation land would lead to super-imposed pollution through industrial discharges and vehicle exhausts, thus imposing even greater health risks on the residents.

Limitation

A few limitations of this study warrant mentioning. For example, subway plays an important role in the transport system of Beijing and has great impact on the distribution of settlement land, especially in the suburban area outside the Fifth Ring Road. Due to the lack of subway data, the spatial distribution of the subway lines and their relationship with the expressways were not discussed currently. Further research will be carried out to improve this study. For the temporal analysis of land cover and population, only years 2000 and 2010 have been considered same as the limitation of data. Data of land cover of Beijing could only be obtained in 2000 and 2010, and Chinese government conducted the national census every ten year. In addition, it is remarkable that, as shown in Fig. 5b, the earlier the expressway opened, the higher its influence on population concentration. It can also be seen that such influence has a certain lag effect. In our study, comparisons were made between the distribution of expressways, land cover and population during the same period. In the future, more historic data can be employed to analyze the interactive relationship between expressways and the land cover and population from the perspective of an established timescale.

Conclusion

In this study, the distribution characteristics of land cover and population in the buffer zones of the expressways from Beijing in 2010, and the land cover transfer and population changes between 2000 and 2010 were analyzed. The results showed that the transfer of land cover near expressways was more intensive and frequent compared to that in the rest of the city, as these regions near the expressways not only contained the greatest concentrations of settlement land, industrial land and transportation land in Beijing, but these same regions also witnessed the most rapid rates of population growth. The ring area between the Fifth and Sixth Ring Roads was the region with the most significant interactions between expressways, land cover and population, and needs to be studied further. Meanwhile, the environmental pollution and health risks to the residents living nearby expressways are also important issues that cannot be ignored.

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