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The changes of densities and patterns of roads and rural buildings: a case study on Dongzhi Yuan of the Loess Plateau, China

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Abstract Roads and buildings are considered as primary causes of rural landscape changes. In this study, linear regression models were used to analyze the dynamic influences of environmental factors and variables on roads and rural buildings from 1979 to 2005 in Dongzhi Yuan (tableland) of the Loess Plateau, China. The relationship between roads and rural buildings and their effects on Dongzhi Yuan are discussed also. The results showed that three environmental factors (topography, land cover, and development level) explained roads better than rural buildings referring densities and patterns. The environmental variables significantly related to roads have decreased, whereas those related to rural buildings have increased over time. Among these significant variables, percent of farmland mostly determined the densities and patterns of both roads and rural buildings. There was significant correlation between roads and rural buildings in terms of density and pattern. In addition, roads and rural buildings have increased greatly in gully areas of this region. Therefore, more attention should be paid to planning of roads and rural buildings in Dongzhi Yuan.

Keywords Density · Pattern · Road · Rural building · Dongzhi Yuan

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Introduction

Roads and buildings have been recognized as primary causes of anthropogenic landscape changes (Forman 1998; Forman and Alexander 1998; Hammer et al. 2004; Hawbaker and Radeloff 2004; Hawbaker et al. 2005, 2006; Gonzalez-Abraham et al. 2007a), which have strongly altered the land surface at various scales (Miller et al. 1996; Penteriani et al. 2001; Saunders et al. 2002; Schnaiberg et al. 2002; Miller et al. 2003). They cause destruction of natural vegetation, soil erosion, invasion of exotic species, fragmentation of wildlife habitats, etc. (Brown 2003; Kirch et al. 2004), and they eventually influence landscape structures and ecosystem functions

(Sanders et al. 1991; Miller et al. 1996; Hawbaker and Radeloff 2004, 2006). Meanwhile, there is a correlation between roads and buildings due to their similar landscape functions, such as removing habitats and creating edges (Miller et al. 1996; Hawbaker et al. 2006).

Many aspects have determined densities and patterns of roads and buildings. In addition to socioeconomic and cultural characteristics (Buntgen et al. 2006), natural factors, including topography (Turner et al. 1996), soil (Dale et al. 1993), water and lakes (Schnaiberg et al. 2002; Walsh et al. 2003), visibility (Sevenant and Antrop 2007), and land cover (Hawbaker et al. 2005; Martinuzzi et al. 2007), largely control their densities and patterns at the regional and landscape scales (Banaszuk and Wysocka 1998; Gonzalez-Abraham et al. 2007b; Jenerette et al. 2007). Recently, roads and buildings have increased not only in urban and suburban areas, but also in rural areas with higher ecological values (Meigs and Sauber 2000; Schnaiberg et al. 2002; Gonzalez-Abraham et al. 2007b; Sevenant and Antrop 2007). Hence, understanding the temporal and spatial relationships between environmental factors and roads or buildings in rural areas is very helpful for the planning of roads and rural buildings and the restoration of the disturbed ecosystems.

The Loess Plateau has been suffering from serious soil erosion and population expansion for about 2,000 years (Chen et al. 2007a; Fu et al. 2007), where most land with lower natural vegetation cover is used for agriculture production (Fu and Chen 2000). Dongzhi Yuan, the largest tableland in the Loess Plateau, is a typical rural landscape (Zhu 1954), and has been densely settled for more than 2,000 years, where human activities are particularly intense. Due to the fertile and thick loess, it has historically been the main base for grain and flax production in the Loess Plateau, and even for Northeast China (Li et al. 2000). With social development in this tableland, a larger amount of cultivated land has been converted into roads or buildings. As a result, patterns of land cover and land use have been changed greatly, and the natural landscapes have been fragmented also. Since the 1970s, roads and rural buildings have expanded, especially around farmland or at the verge of gullies, which not only wasted large amounts of land resources, but also caused heavy soil erosion (Chen et al. 2007b). Therefore, those unique characteristics make this region an appropriate place to explore the relationship between roads and buildings with environmental variables. Though the local government has realized the problems and carried out a series of policies to solve them, the present condition is still dissatisfying.

We thus highlighted the influences of environmental factors on roads and rural buildings and assumed that agriculture and topography should have more influence on roads than rural buildings in this region. The main objectives are to (1) identify the environmental variables that can explain the densities and patterns of roads and rural buildings; (2) explore the differences when these variables explained roads and rural buildings; (3) examine whether there was significant correlation between roads and rural buildings; and (4) analyze environmental effects of roads and buildings on Dongzhi Yuan, especially in the gully areas.

Materials and methods

Study area

Dongzhi Yuan, with an area of approximately 90 km^2, is located in Qingyang County in eastern Gansu Province, China (35°40′N, 107°51′E, elevation 1,298 m above sea level) (Fig. 1), and the climate is characterized by cold, dry winters and warm, wet summers, with an annual precipitation of 551 mm. As one of the most important agriculture regions, the average yields of crops in 2003 were 3.5 t ha^{-1} for winter wheat, 6.5 t ha^{-1} for maize, and 1.8 t ha^{-1} for soybean (Nolan et al. 2008). Because Dongzhi Yuan is the richest region in the Losses Plateau, roads and rural buildings have developed rapidly in recent years. A rectangle-shaped region (20 × 24 km) was selected in Dongzhi Yuan, where only two small towns, Dongzhi and Pengyuan, were located and the influences of urban (Xifeng City) and suburban areas were almost ignored. It was divided into 120 samples with cell lengths of 2 × 2 km for spatial analysis (Fig. 1).

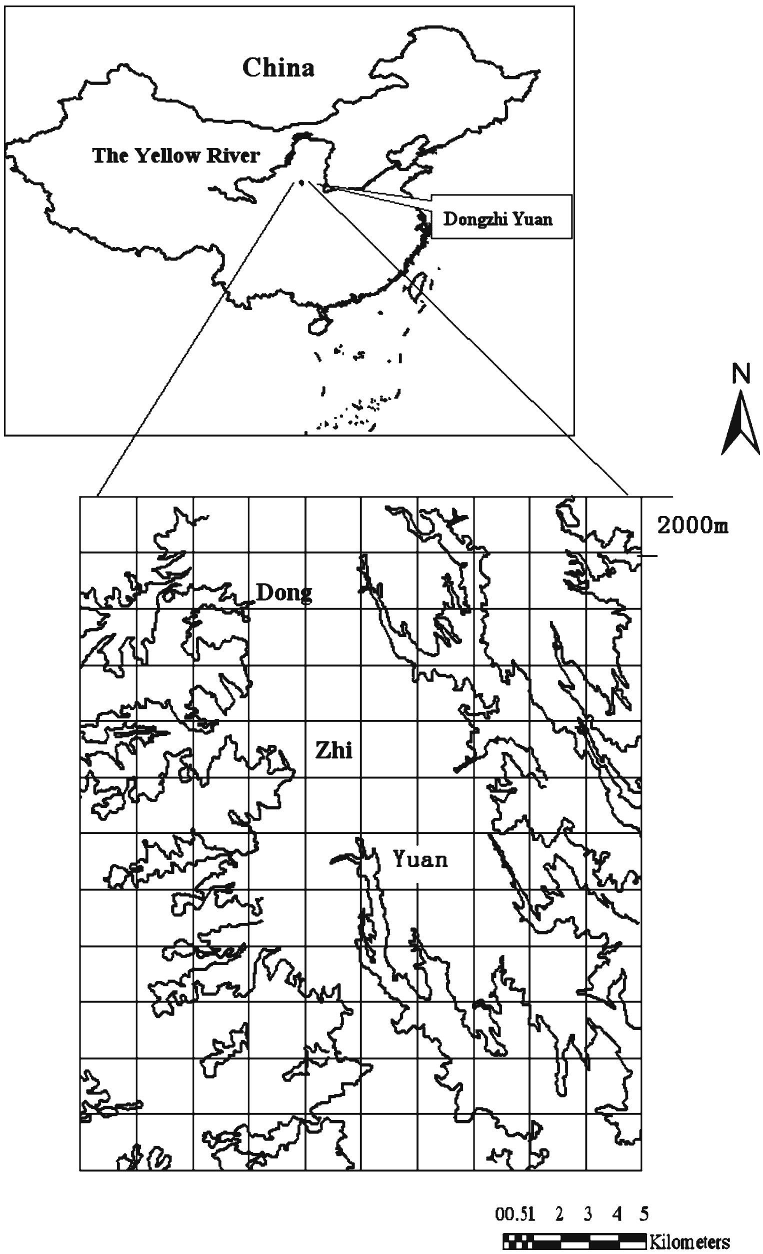

Fig. 1 Location of Dongzhi Yuan in the Loess Plateau, China

Data sources

Based on sequential stereo pairs of the black and white aerial photographs in 1979 (1:39,000-scale), 1993 (1:45,000-scale), and a topographical map (1:10,000-scale), the digital orthophoto maps and digital elevation models were generated with 0.5- and 2-m pixel resolution, respectively (Greenfeld 2001). SPOT images in 2005 with 5-m pixel resolution were mapped by visual interpretation. Roads and rural buildings were digitized separately from those images in ERDAS 8.6. Here, roads were characterized by white lines and rural buildings were characterized by black, shaded, or white squares (Gonzalez-Abraham et al. 2007b). They were not subclassified due to the lack of more information, although the classification is very important (Kalwij et al. 2008). In addition, several environmental variables were derived directly from the images. For example, a gully, a typical landscape characteristic in Dongzhi Yuan, greatly affected by roads and buildings, was digitized as line layers; a town, which determined the patterns of roads and rural buildings to some extent, was digitized as point layers; and farmland, forest, shrub, and grassland were digitized as polygon layers. Farmland, accounting for more than 80% of the region, was easily identified because of the normal shape and distribution characteristics. Forest and shrub, usually distributed at both sides of the roads, around rural buildings, or on the hill areas, were combined together because it was difficult to distinguish them only by black and white aerial photographs. Grassland was easily identified due to the scattered distribution.

Definition of variables

Three environmental factors (topography, land cover, and development level) and their variables were chosen to explain the densities and patterns of roads and rural buildings from 1979 to 2005. Elevation, determining slope, aspect, etc., is the main feature of topography, which influences spatial distribution of roads and buildings at the local scale; gully line, another feature of topography, changed quickly at the fringe of Dongzhi Yuan and was closely related to the rate of soil erosion (Wang 2007). Thus, coefficient of variation (CV) of elevation (Zhang et al. 1999; Gustafson et al. 2005; Wang et al. 2008) and gully line density (the ratio of gully line length to sample area) in 120 samples were selected as independent variables of topography. Land cover in Dongzhi Yuan is relatively simple, mainly including farmland, forest, shrub, and grassland (Chen et al. 2007b), so the percents of areas of these types were directly calculated as independent variables of land cover. While towns usually represented higher levels of economic development, gullies represented negative development level due to their effects on soil erosion. Therefore, distance to town and distance to gully were considered as independent variables of development level. All of the calculations were conducted by spatial analysis tools in ArcInfo 9.0.

We then chose densities and patterns of roads and rural buildings as dependant variables. Road density (km/km^2) and rural building density (building number/km^2) were directly calculated in 120 samples. The influences of roads and rural buildings on landscape occur at a variety of scales, so two particular grids were chosen to describe the scale issue of pattern: one with cells of 50 × 50 m and the other with cells of 400 × 400 m, which represented average rural building size and the disturbed extension, respectively (Gonzalez-Abraham et al. 2007b). The variable of rural building pattern is the proportion of occupied cells per sample with at least one rural building point, and a value closer to 1 represented a higher dispersed pattern. This pattern index was chosen because it can simply describe dispersed pattern, which may cause higher landscape fragmentation at a given density (Theobald et al. 1997; Gonzalez-Abraham et al. 2007b). Similarly, we used the same two grids and the pattern index, which is just the proportion of occupied cells per sample with at least one road line to describe road patterns.

Statistical and spatial analysis

We hypothesized that the three environmental factors and their independent variables could be used to predict different densities and patterns of roads and rural buildings (Gustafson et al. 2005; Gonzalez-Abraham et al. 2007b). For example, topography was supposed to be negatively related to distribution patterns of roads and rural buildings (Liang and Zhao 2001), and land cover was positively related (Table 1). Six simple linear regression models with backward selection procedures were used to explore the changes of densities and two spatial patterns (50 and 400 m) of roads and rural buildings as functions of the topography, land cover, and development level in 1979, 1993, and 2005, respectively. The R^2 values of the regression models were used to compare the importance of the three factors in explaining roads and rural buildings, and further to test whether roads were explained better than rural buildings (Gustafson et al. 2005; Gonzalez-Abraham et al. 2007b). Based on the regression models mentioned above, the t value of each significant

Table 1 Excepted correlations between roads or rural buildings and environmental variables

Variable	Road		Rural building	
	Density	Pattern (50 and 400 m)	Density	Pattern (50 and 400 m)
Topography				
CV of elevation	–	–	–	–
Gully line density	–	–	–	–
Development level				
Distance to town	–	–	–	–
Distance to gully	+	+	+	+
Land cover				
% of farmland	+	+	+	+
% of forest and shrub	+	+	+	+
% of grassland	+	+	+	+

+ positive correlations, – negative correlations

variable was used to compare the importance of variables in determining roads and rural buildings (Gustafson et al. 2005; Gonzalez-Abraham et al. 2007b). To satisfy the assumptions of normal distributions for the regression models, the data were log or square root transformed before analysis (Gonzalez-Abraham et al. 2007b). For example, the areas of farmland, forest shrub, and grassland and the densities of road, rural building, and gully line were log transformed. The distances to gully line and town were square root transformed. CV of elevation and the patterns of roads and buildings did not require transformation.

Due to the spatial autocorrelation of the independent variables and the misspecification of the ordinary least squares models, we examined the spatial autocorrelation in the residuals derived from a principal spatial lag model by Moran's *I* and tested all of the hypotheses (Chatterjee et al. 2000; Gustafson et al. 2005).

In addition, another three linear regression models were conducted to analyze the relationship between roads and rural buildings referring to density and pattern. Further, to examine if roads can be better explained by rural buildings with combination of those environmental variables, or the same for buildings, we added road or rural building variables to the six linear regression models mentioned above to examine the relationship between roads and rural buildings again. Finally, spatial analysis was conducted by building a series of buffer zones with distances to gully lines

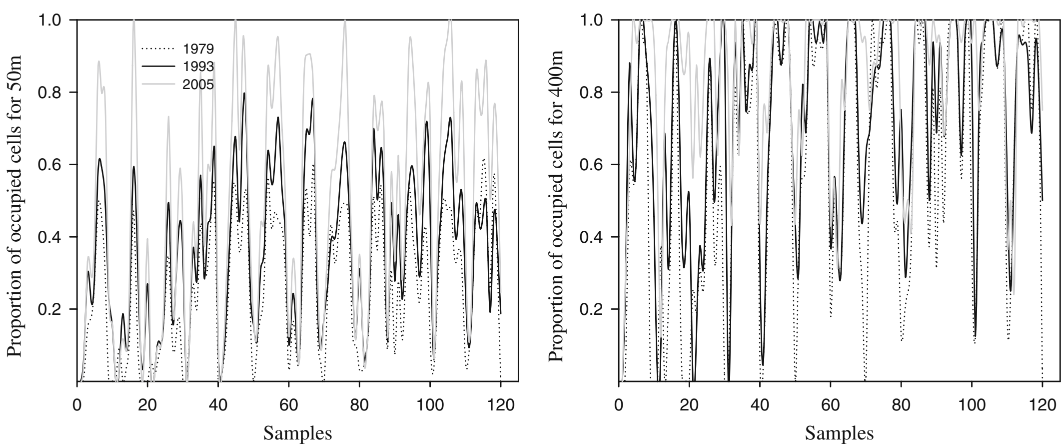

Fig. 2 Spatial patterns of roads

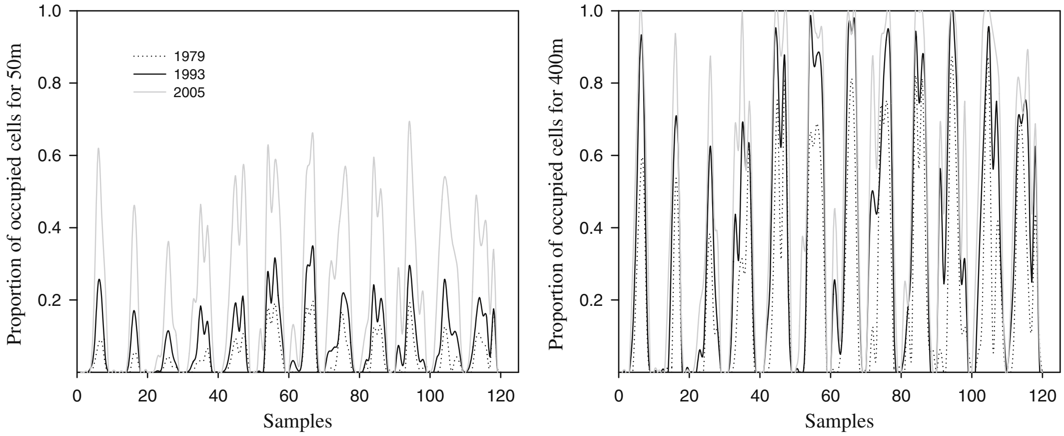

Fig. 3 Spatial patterns of buildings

of 100, 200, 300, 400, and 500 m, respectively, to analyze the changes of roads and rural buildings in gully areas from 1979 to 2005.

Results

Changes of densities and spatial patterns of roads and rural buildings

In Dongzhi Yuan, road densities were 1.5, 2.61, and 2.80 km/km^2 and rural building densities were 1.51, 2.61, and 2.80 per square kilometer in 1979, 1993, and 2005, respectively. The spatial distributions of roads and rural buildings appeared to be increasingly dispersed patterns at both grid cells, especially at the 50-m grid. During the whole period, dispersed patterns of roads had increased in 109 samples (90.83%) at 50-m grid cell scale, compared to 105 samples (87.5%) at 400-m grid cell scale, and that of rural buildings had increased in 116 samples (96.67%) at 50-m grid cell scale, compared to 115 (95.83%) at 400-m grid cell scale. The values of dispersed index from 1993 to 2005 increased more than that from 1979 to 1993 (Figs. 2 and 3).

Influences of environmental factors and variables

We did not find significant spatial autocorrelation in any of the models. The R^2 value of each model for roads was higher than that for rural buildings (Table 2), which suggested that the three environmental factors explained roads better than rural buildings either by density or by pattern. And the R^2 values for roads gradually increased over time, whereas that for rural buildings changed irregularly. In addition, there were differences when regression models explained densities and spatial patterns (50 and 400 m) of roads and rural buildings. Especially, regression models explained spatial patterns of rural buildings (50 and 400 m) better than density (Table 2).

In regression procedures, the variables that had P values greater than 0.05 or that showed 60% of correlations with other variables were removed, so they did not appear in t values in Tables 3, 4,

Table 2 R^2 values from regression models for roads and rural buildings

Year	Road			Rural building		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
1979	0.84	0.86	0.79	0.65	0.74	0.75
1993	0.88	0.89	0.81	0.59	0.72	0.74
2005	0.89	0.90	0.84	0.62	0.74	0.71

Table 3 *t* Values from regression models for roads and rural buildings vs variables in 1979 ($P < 0.05, n = 120$)

	Road			Rural building		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
Topography						
CV of elevation	−4.03	−3.96	−2.99			
Gully line density				−2.92		
Developed level						
Distance to town	−3.08	−4.28	−3.75	−2.51	−5.67	−3.93
Distance to gully						
Land cover						
% of farmland	2.43	3.52	3.14	3.29	3.42	4.32
% of forest and shrub						
% of grass						

Table 4 *t* Values from regression results for roads and rural buildings vs variables in 1993 ($P < 0.05, n = 120$)

	Road			Rural building		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
Topography						
CV of elevation	−2.39	−3.78	−3.69			
Gully line density				−1.88		
Developed level						
Distance to town	−2.37			−3.01	−4.12	−4.67
Distance to gully						
Land cover						
% of farmland	6.75	6.15	3.86	5.42	3.60	5.24
% of forest and shrub						
% of grass						

Table 5 *t* Values from regression results for roads and rural buildings vs variables in 2005 ($P < 0.05, n = 120$)

	Road			Rural building		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
Topography						
CV of elevation	−3.79	−4.37	−2.90			
Gully line density				−3.02	−1.28	−1.91
Developed level						
Distance to town				−2.88	−4.15	−4.07
Distance to gully				−3.58		
Land cover						
% of farmland	6.86	6.62	5.17	5.56	5.22	5.69
% of forest and shrub						
% of grass						

Table 6 R^2 values from regression results for roads and rural buildings ($n = 120$)

	R^2			P		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
1979	0.72	0.75	0.70	<0.0001	<0.0001	<0.0001
1993	0.70	0.76	0.70	<0.0001	<0.0001	<0.0001
2005	0.66	0.81	0.74	<0.0001	<0.0001	<0.0001

Table 7 R^2 values from regression results for roads and rural buildings when they were combined with environmental variables

Year	Combined with rural buildings			Combined with roads		
	Density	Pattern (50 m)	Pattern (400 m)	Density	Pattern (50 m)	Pattern (400 m)
1979	0.91	0.93	0.89	0.82	0.83	0.83
1993	0.92	0.78	0.71	0.76	0.81	0.80
2005	0.93	0.57	0.95	0.82	0.81	0.79

and 5. The *t* values of regression models validated our expected positive (or negative) influences of environmental variables on roads and rural buildings, except distances to gullies (Tables 1 and 5). Percent of farmland was the most significant variable positively related to both roads and rural buildings. It increasingly explained roads better than rural buildings, especially for density and pattern (50 m) (Tables 3, 4, and 5). The environmental variables significantly influencing roads and rural buildings varied greatly over time. The numbers of variables significantly related to roads decreased from 1979 to 2005, while the numbers to rural buildings increased (Tables 3, 4, and 5). For example, there were three significant variables for roads in 1979, compared with two variables in 2005, where the influence of distances to towns gradually disappeared. In contrast, there were three variables for rural building density in 1979, and the numbers increased to four in 2005. Anyway, farmland significantly and constantly affected the densities and patterns of roads and rural buildings in Dongzhi Yuan, especially in last 10 years. In addition to percent of farmland, CV of elevation also explained roads better than rural buildings. Distance to town, however, explained rural buildings better.

Relationship between roads and rural buildings

There were significant correlations between roads and rural buildings in terms of density and patterns (50 and 400 m) (Table 6). All of the models explained more than 60% of the correlations. For density, R^2 values decreased from 1979 to 2005, while they increased for patterns, especially at the 50-m scale. When rural buildings were combined with environmental variables, regression models explained roads much better, the same with rural buildings, which can also prove the close relationship between roads and rural buildings (Table 7).

Changes of roads and rural buildings in the buffer areas of gullies

Roads and rural buildings sprawled at the buffer areas of gully lines. From 1979 to 1993, the

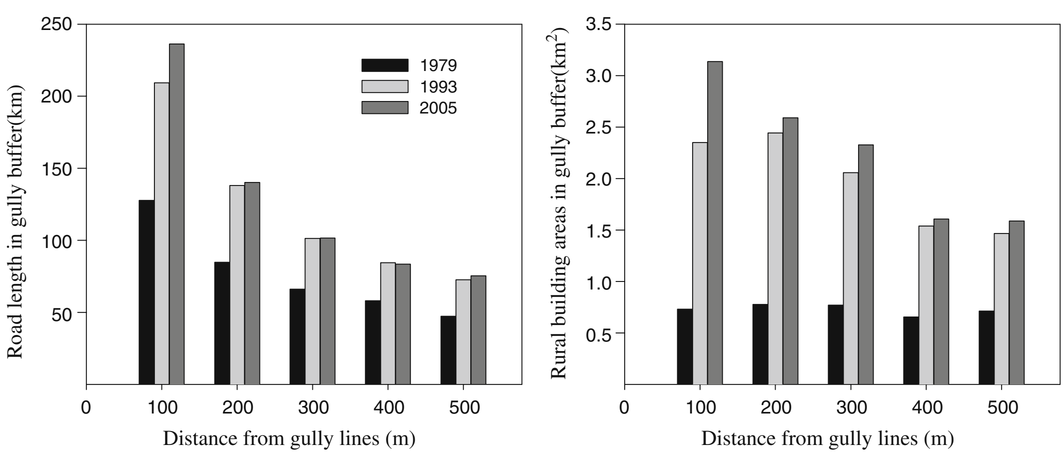

Fig. 4 Roads and rural buildings in the buffer areas of gully line in Dongzhi Yuan

increases occurred mainly in the 100-m buffer areas. From 1993 to 2005, roads still increased mainly in the 100-m buffer area, but rural buildings increased in all buffer areas, which indicated that rural buildings have sprawled more than roads in gully areas (Fig. 4). In 100-m buffer areas, road densities were 1.54, 2.63, and 2.85 km/km^2, and rural building densities were 0.88, 2.83, and 3.78 per square kilometer, respectively, in 1979, 1993, and 2005. Both densities have exceeded the average values of the whole region since 1993.

Discussion

It is very necessary for us to understand the factors that can influence the development of rural areas in explaining the interaction between landscape and culture changes (Schnaiberg et al. 2002; Gonzalez-Abraham et al. 2007a, b). Roads and buildings were chosen as obvious symbols of rural development in Dongzhi Yuan, which has a long agricultural history. The results illustrate that topography, land cover, and development level explained the densities and spatial patterns of roads and rural buildings well, though the explaining power varied over time.

Roads were more easily explained by environmental factors than rural buildings for both densities and patterns. We try to discuss the essential differences between roads and rural buildings by exploring their construction processes and social functions. Roads are designed to connect local resources and people with markets and population centers (Forman and Alexander 1998), so natural factors significantly induce or constrain construction of roads (Saunders et al. 2002; Hawbaker et al. 2006). In addition to percent of farmland, CV of elevation was also significantly related to roads (Tables 3, 4, and 5), which reflected that topographic relief is another important natural factor determining roads in Dongzhi Yuan. The decrease of the numbers of variables related to roads resulted in relatively simple influences on road density and pattern. Contrarily, it was more difficult to explain buildings in rural areas due to more social purposes. Generally, rural buildings in Dongzhi Yuan developed around old villages where the people have long-term planting traditions or around new places with good scenes and appropriate locations (Liang and Zhao 2001). In addition to percent of farmland, distance to town is the second most powerful variable to explain rural buildings. Towns and the places near towns are appropriate to local residents because of higher populations and better society welfare. People prefer to live either near farmlands for their crop planting or near towns for their daily lives. Similarly, topography, such as gully density, can also explain rural buildings (Liang and Zhao 2001). Recently, with the economy development and rural population growth, the variables related to rural buildings increased and their influences became more complex (Tables 3, 4, and 5). In particular, the influences on rural building patterns were larger than rural building density. As a result, they caused more dispersed rural building patterns (Fig. 3), which led to negative ecological consequences, such as landscape fragmentation (Miller et al. 1996; Gonzalez-Abraham et al. 2007b; Sevenant and Antrop 2007). From this point of view, it shows why environmental variables explained roads better than rural buildings.

Land cover was the most important factor determining both roads and rural buildings, and our results were consistent with the work of Liang and Zhao (2001), which was conducted by TM images with 30-m resolution. Since the Tang Dynasty (approximately A.D. 600), agricultural activities have developed greatly in Dongzhi Yuan, and farmland became the main type of land cover. Agriculture economy is dominant in this region, where 72% of household incomes are derived from the sale of farm produce (Nolan et al. 2008). Thus, the quantity and spatial pattern of farmlands has mostly determined the densities and spatial patterns of roads and rural buildings. In 2005, percent of farmland was 84.9%, which has increased by 5.3% from 1979. The explaining power of percent of farmland for both roads and rural buildings increased gradually from 1979 to 2005, which suggested the dominant effect of farmland has an increasing trend in this region (Tables 3, 4, and 5). In particular, rural buildings increasingly exhibited dispersed patterns (Fig. 3), which resulted from long-term impacts of agricultural activities. A case in northern Wisconsin has also indicated the correlation between agricultural areas and dispersed building patterns in rural regions (Gonzalez-Abraham et al. 2007b). In addition, the pattern of agricultural settlements can exist for a long time and will indirectly influence current patterns of roads and buildings by determining the spatial pattern of farmland (Brown 2003; Kirch et al. 2004; Gonzalez-Abraham et al. 2007b). Therefore, when we explain the influence of farmland on the spatial patterns of roads and rural buildings, agricultural settlement history must be considered carefully (Gonzalez-Abraham et al. 2007a, b).

The relationship between roads and rural buildings is very interesting. However, it is difficult to clarify which is reason and which is consequence (Hawbaker et al. 2006). They almost occurred at the same place, so we discussed them together. In Dongzhi Yuan, rural buildings dispersed randomly around the farmlands, and this distribution pattern failed to form larger villages. On the one hand, dispersed settlement patterns and low-density development of rural buildings disproportionately increased road density (Hammer et al. 2004; Gonzalez-Abraham et al. 2007a), and then changed distribution of roads. On the other hand, there was a higher tendency for rural buildings to occur along the primary or main roads. In addition, combined with the environmental variables mentioned above, roads and rural buildings appeared more with significant correlations (Table 7). Therefore, understanding of the interaction between roads, rural buildings, and environmental variables is very necessary to manage landscape and assess environment.

Roads and rural buildings sprawled at the fringe area of Dongzhi Yuan, which have resulted in cultivation increasing or converting native vegetation into arable land on steep slopes (Chen et al. 2007c; Fu et al. 2007; Nolan et al. 2008). Because the vegetation of the gully area was relatively good and the environment was more comfortable for settlement, rural buildings mainly increased in 100-m buffer areas (Fig. 4), which indirectly accelerated gully erosion. Prior research has found that, where the gully line changed greatly, roads and buildings increased more (Wang 2007). The percent of forest and shrub remaining in this region is about 6.9% and percent of grassland is 8.2%. Although there was lower vegetation cover, vegetation restoration and landscape planning after the constructions of roads and rural buildings are still neglected due to the local people's underestimating of the ecological impacts of roads and rural buildings. Consequently, Dongzhi Yuan would become more fragile and susceptible to natural hazards under the influences of roads and rural buildings. In conclusion, environmental factors have greatly shaped roads and rural buildings, which have influenced the environment in turn. Integrated watershed management techniques and state-funded schemes such as the Grain-for-Green project are considered as efficient tools to solve these typical problems (Rao and Kumar 2004; Chen et al. 2007c; Croke et al. 2007), where those factors including farmlands, roads, and rural buildings, as well as local people's demands, are considered (Chen et al. 2007c). Due to the complexity of the problems, there are still great challenges for local people to manage and assess roads and rural buildings in Dongzhi Yuan, and even in the Loess Plateau. Moreover, roads and rural buildings should be characterized not only at a fine grain to capture their local impacts, but also at a broad extent to put the results or the processes into a regional context for ecology management practices in the future.

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