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The Spatio-Temporal Dynamic Pattern of Rural Residential Land in China in the 1990s Using Landsat TM Images and GIS

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Abstract Through interpreting Landsat TM images, this study analyzes the spatial distribution of rural settlements in China in 2000. It calculates rural residential land percentage for every 1-km^2 cell. The entire country is divided into 33 regions to investigate the spatio-temporal dynamic patterns of rural residential land during the 1990s. According to the remote sensing survey, the rural residential land increased by 7.88×10^5 ha in the 1990s. The increment of rural residential land was 0.55 million ha in 1990–1995 and 0.23 million ha in 1995–2000. In 1990–1995, rural residential land increased dramatically in the eastern regions such as the Yangtze River Delta, Pearl River Delta, and North China Plain, accounting for 80.80% of the national growth; the expansion in the western regions was much more moderate. In 1995–2000, the expansion of rural residential land in eastern regions slowed, accounting for only 58.54% of the increase at the national level, whereas the expansion in the western regions accelerated. Rapid rural residential development resulted from increasing home construction and the limited control on rural land. The great regional disparity reflected the regional economic development and land-use policy change. Our finding shows that nearly 60% of the rural residential area came from cropland.

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Introduction

Although China has witnessed a rapid urbanization process after the late 1970s, 63.78% of the total population still live in rural areas in 2000. Nearly 0.81 billion people are distributed in 0.73 million administrative villages (NSBC 2001). The rural residential land is the built-up area for rural settlements. It includes buildings, roads, huts, vegetable gardens, thickets, livestock enclosures, bare lands associated with villages, and *jizhen* (Petit and others 2001). Human settlements are divided into cities, towns, and villages by the usual classification in China. Rural settlements are under cities and towns. According to their administrative, economic position, and population size, rural settlements include *jizhen* and villages (Li 2000). *Jizhen* is the location of *Xiang* government, which does not meet the town standard. It is usually the rural trade center or small industrial and service center. Villages are divided into central villages and natural villages. The central village usually is the location of the villager committee and has the administrative, economic, and cultural functions, in addition to the production and living base.

Rural home construction and the accompanying new schools, roads, and water and utility lines are associated with rural development of the villages. Farmers improve their houses as economic development occurs, and growth in the number of households has exceded population growth globally (Liu and Samuel 2003). The additional households will build more houses, and the local government will build roads and schools. Hence, the bulk of the construction land was widely scattered in the countryside as a result of rural industrialization and urbanization (Lin and Samuel 2003). However, in the urbanization process, the immigration of a great amount of rural population into cities and towns does not result in the decrease of rural residential land in China. Their houses will be kept or sold and their cropland will be allocated to other people in the same villages.

In China, rural settlements are small, numerous, and dispersed. However, rural residential land is much larger than urban land. By the end of 1999, the built-up area of China was 36 million ha (LRDC 2000). Urban land was 2.94 million ha, whereas rural residential land was 16.5 million ha. Although the growth rate of rural residential development was slower than urban expansion, the increment was larger. For example, the rural residential land and small townships increased 4.71% in 1985~1999. The urban land excluding township land expanded dramatically by 55.02% from 0.98 to 1.52 million ha. The increment of residential land including rural areas and towns was 0.81 million ha, compared with 0.54 million of urban land (excluding township land). In this period, urban population increased dramatically from 251 to 437 million and rural population increased from 0.81 to 0.82 billion (NSBC 2000).

Chinese cultivated land in 1996 per capita was a mere 0.106 ha, which was over 50% less than the world average of 0.236 ha (Li 2000). The cropland loss is of critical importance for assessing Chinese food security. The cropland loss owing to urbanization has threatened China's food security in the near future with the increasing population (Brown 1995). An abundance of literature has addressed the impacts of urban encroachment on high-productive cropland in China (e.g., Li 1998; Lin and Samuel 2003; Ji and others 2001; Seto and others 2002; Tian and others 2005; Yang and Li 2000). Comparatively, the issues related to rural residential land dynamics have long been neglected (Tian and others 2002). As a result of the large volume of rural settlements and limited government control, rural residential development has encroached on much cropland.

Since 1978, the unprecedented combination of economic and population growth has led to a dramatic land transformation across the nation (Houghton and Hackler 2003; Liu and others 2005; Tian and others 2003). Rural residential land development has encroached on forest, grassland, water, and barren land as well. This land transformation increases greenhouse gas emissions such as CO_2, CH_4 , and N_2O (Houghton and Hackler 2003; Tian and others 2003; Verburg and Denier 2001).

Rural landscapes are essential for humans as well as for biodiversity conservation because they provide grains, wildlife habitat and conservation of soil and water quality (Patricia and others 2006). However, rural residential development will have negative impact on these goods and services.

In this study we calculate rural residential land percentage for every 1-km^2 cell. The dataset resolution is high enough to describe the detailed spatial variations of rural settlement distribution. The rural distribution is related to topography, climate, cropland, water resources, and so forth. Regionalization has been employed to study the regional difference. We quantify rural residential land percentage for every region and investigate the relationship between rural settlements and DEM (Digital Elevation Model), annual precipitation, and annual accumulated temperature.

We examined the patterns of rural residential development across China for two periods throughout the 1990s. According to the regionalization, we compared the different characteristics of rural residential land growth in two periods and analyzed the potential driving forces that explained the variation in the spatial pattern of rural home development. In comparison with urban development, the ecological effects of rural residential development are likely to be larger (Theobald and others 2000) because low-density development consumes more land, resulting in more extensive habitat conversion and fragmentation. Rural residential development tends to be distributed in areas with high biodiversity due to biophysical factors and natural amenities (Hansen and others 2005). The attraction of human-adaptive species may significantly modify the community near villages (Garrott and others 1993; Hansen and Rotella 2000). Land-use change and land management practices affect a variety of ecological processes. Land-use impacts on ecological processes include local extirpations, introductions of new species, changes in land-cover extent, changes in juxtaposition of land-cover types, changes to disturbance regimes, changes in vegetation structure and composition, and effects on air, water, light quality, and noise pollution.

The article focuses on proactive rural settlement distribution and dynamic patterns of rural residential development. It identifies key research issues as (1) quantifying rural residential land percentage for every 1-km^2 cell, (2) determining conditions under which rural residential land distributes, (3) comparing rural residential development in 1990–1995 with 1995–2000, and (4) crafting socioeconomically reasonable incentives for stimulating or reducing rural residential development. In order to narrow the increasing income gap between urban and rural populations, the central government has begun to pay more attention to farmers, agriculture, and villages. This study will contribute by analyzing rural residential development and, therefore, has policy implication for land use.

Data Source and Method

Data Source

The processes of agricultural restructuring, rural industrialization, and rapid urbanization since the 1990s have given rise to a new trend of massive farmland loss for the benefits of market-driven farming and nonagricultural developments. The research focus of the International Geosphere-Biosphere Program (IGBP) and International Human Dimension of Global Environment Program (IHDP) is to understand the spatial and temporal variability in land-use and land-cover dynamics, along with their driving forces. National Land Use/Land Cover datasets (NLCD) for the three periods 1990/1991, 1995/1996, 1999/2000 with mapping scales of 1:100,000 were built in order to characterize spatial and temporal patterns of land use and cover change in China (Liu and others 2002, 2005).

In order to build the modern process of Chinese land-cover dynamic change and to predict the land-cover change trend, the Chinese Academy of Sciences organized 8 research institutes including more than 100 scientists to conduct its second nationwide land-use and land-cover classification project in the late 1990s. In 1997, the national land-use datasets at a spatial scale of 1:100,000 were developed from 520 Landsat TM images primarily from 1995/1996 by visual interpretation and digitalization with technical support from Intergraph MGE (Modular GIS environment) software (Liu and others 2002, 2005).

The time at which the images were acquired was considered critical. The selection of TM images was based on cloud-free, vegetation phenology and a near anniversary date. The best time for obtaining suitable images for each region was determined and tabulated according to vegetation phenology (Ji and others 2001). The images were chosen in the exuberant planting season in the northern area and the inactive vegetation growth season was selected in the southern area. The chances of obtaining cloud-free images were rare in the southwestern area. There were as few as two or three useful scenes available in some regions.

The chosen images were radiantly corrected in Remote Sensing Satellite Ground Receiving Station, Chinese Academy of Sciences. They were geo-referenced using 1:100,000 relief maps before the interpretation began. Then they were RGB false-color composed with 4, 3, 2 bands using MGE software. For each scene, at least 20 evenly distributed sites served as ground control points (GCPs). The root mean squared error (RMS error) of geometric rectification was less than 1.5 pixels. Interpreters identified the land-use types on the computer screen, based on the understanding of the object's spectral reflectance, context, shades, and experience knowledge. Then they drew the boundaries of objects and added the attributes (labels) of the polygons to produce the digital map. Finally, they were edited and compiled into the vector maps. To support image interpretation and the validation of land-cover classification, we used a variety of data, including topography, DEM, roads, rivers, soil type, and climate.

The land-use vector datasets were corrected into the uniform coordination system based on the Gaussian–Krüger projection using ArcGIS software. The central longitude is 105°E and the double standard latitude is 25°N and 47°N. The land-cover vector datasets were joined into the provincial datasets. The work scheme can be seen in Figure 1.

A hierarchical classification system of six land-cover classes was applied to the Landsat TM/ETM (Enhanced Thematic Mapper) data (Liu and others 2005). They were croplands, woodlands, grasslands, water bodies, unused land, and built-up land (Table 1). These 6 classes were divided into 25 subclasses. Built-up land included urban land, rural residential land, and other built-up land such as roads or airports. Urban land was land used for an urban build-up area. Rural residential land was land used for settlements in villages or *jizhen*.

Land-use dynamics in 1995–2000 were extracted by comparing remotely sensed data in 1999/2000, including a total 512 scenes of Landsat ETM images along with some images from 17 scenes of the China-Brazil Earth Resources Satellite (CBERS-1) with TM images in 1995/1996 (Liu and others 2002, 2005). The CBERS images have 20 m ground resolution and almost the same spectral bands as Landsat ETM. The most important principle for us to choose the remotely sensed image is that the imaging data (season) should be consistent. Land-use change during 1990–1995 was extracted by comparing Landsat TM images in 1990/1991 and 1995/1996. In the early 1990s, the images of 1990 were used primarily and the images of 1991 were used only in the places where the 1990 scenes were not available. In the mid-1990s, at the sites where the images of 1995 did not meet the quality requirements, the images of 1996 were used.

There are many methods for detecting land-use changes available in the literature, such as image differencing (Mas 1999; Quarmby and Cushnie 1989), principal component transform (Wang 1993), tasseled cap transform (Fung and Ledrew 1988), Gramm–Schmidt transform (Collins and Woodcock 1994), multidate unsupervised classification (Mas 1999), and image classification (Gordon 1980). The postclassification method is a comparative analysis of spectral classification for times t_1 and t_2 produced independently (Singh 1989). The direct multi-date classification is based on the single analysis of a combined dataset of the two dates in order to identify areas of changes (Singh 1989). Classes where changes occurred are expected to present statistics significantly different from where changes

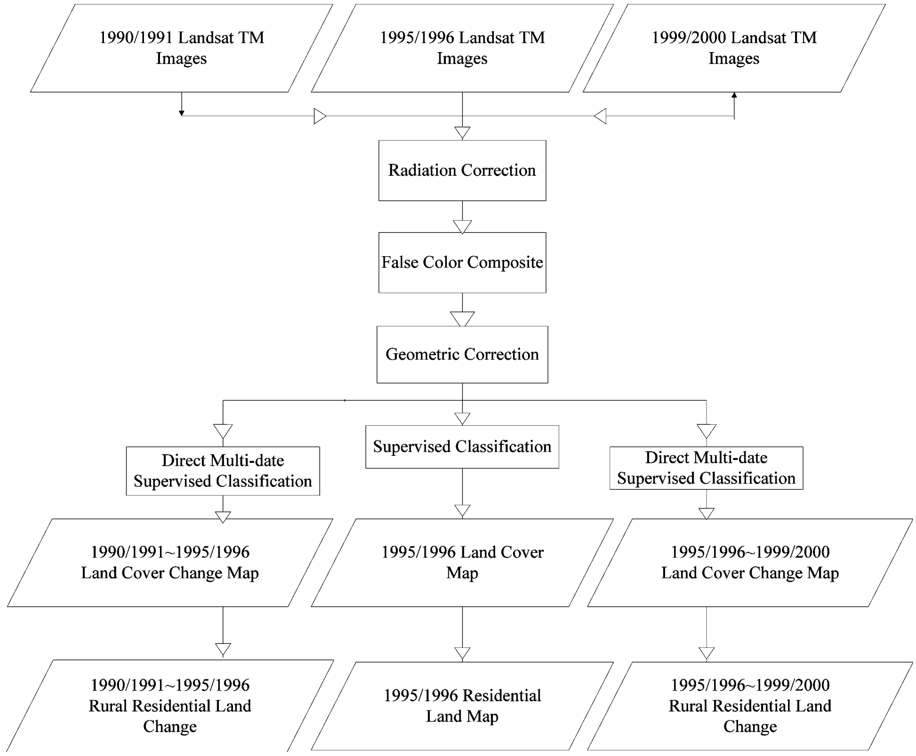


Fig. 1 Working scheme for land-cover change using classification methods

do not take place and so could be identified. They have the advantage of obtaining changes directly with one-step analysis and with a higher accuracy. In the current project, postclassification image comparison and multidate supervised classification were used for extracting changes.

Obtaining images at a near anniversary date is considered important for change detection studies (Pilon and others 1988; Quarmby and Cushnie 1989). Hence, the exogenous influences (such as sun angle, solar radiance, and the difference in vegetation phenological stages) are minimized and do not induce instabilities into the comparison (Ji and others 2001). Prior to image classification, a field trip was made and more attention was paid to the areas that had undergone change, with the aid of hard-copy images of both dates. A higher level of accuracy was achieved because the images were interpreted by the local people of the institute. Training areas were selected from the more confusing classifications especially the grassland and cropland, rural settlements, and bare land by the relief maps. The ground data were collected during the field trip. It was helpful to have this knowledge when identifying dynamic changes in comparison with the different seasons and regions. The quality control group comprised of well-trained researchers checked on the identities and the boundaries of the land-cover patches to decrease the incidences of error.

Using MGE software, the land-use change patches in 1995-2000 were obtained by comparing the TM images (showed as a combination of band 4, 3, 2 RGB) from 1995/

Table 1. The land-use classification system

First-level classes	Second-level classes
Cropland	Paddy land
	Dry land
Woodland	Forest
	Shrub
	Woods
	Others
Grassland	Dense grass
	Moderate grass
	Sparse grass
Water body	Stream and rivers
	Lakes
	Reservoir and ponds
	Permanent ice and snow
	Bottomland
Built-up land	Urban land
	Rural settlements
	Others
Unused land	Sandy land
	Gobi
	Salina
	Swampland
	Bare soil
	Bare rock
	Others

1996 with those from 1999/2000. The land-use maps of 1995/1996 had been used to identify the type of land-use change for each patch. The possible errors from classification by different people who used classified maps to make change detections could be reduced by comparing images directly. The land-use change patches could be considered as real change instead of classification errors and the small location shift. As earlier, the interpreters drew the land-use change patches in 1990–1995 by comparing the TM images from 1990/1991 with those from 1995/1996.

The land use change datasets included 364,379 polygons. All of these were identified at the second level of classification systems. The rural residential land was reselected from the land-use data. The rural residential land dynamics between 1990~1995 and 1995~2000 were reselected from land-use change data in the two periods (Fig. 1).

Confusion occurred between rural residential features and all other land-cover categories. In southern China, the rural residential houses were separately located in the mountain areas. If the residential land was less than 1 pixel on the TM images, they would not be detected. There were two tasks involved in manual editing. One was to correct the error of omission with respect to rural areas (i.e., those areas of rural residential features that were not identified, especially in South China). The other was to separate the rural residential land class from barren land, as they were often confused with each other. This was achieved with the aid of topographic maps. The field survey was conducted to evaluate the classification accuracy, it was reported that overall accuracy of the land-use classification for the 25 sub-classes was 92.9% (Liu and others 2005). The built-up area such as urban land, rural residential land and other construction land had the highest accuracy of 96.3%. The collected photos and GPS facilities were used to evaluate the accuracy of the land use types, location and boundaries. The land use change patches were evaluated by the experienced specialists and showed overall identification accuracy of 97.2%.

Methodology

A new technique that can convert polygon rural residential land data into 1 km^2 component data was developed. It did not destroy the acreage information and was consistent with the original high resolution vector format data (Liu and others 2002, 2005). We calculated the rural residential development index to analyze and describe rural residential development in 1990–1995 and 1995–2000.

The method included three steps. First, a standard grid frame with vector format was generated using ArcGIS software. Each grid cell had a 1-km width and 1-km length and was identified with a unique ID. Its coordinate met with State Bureau of Surveying and Mapping of China (SBSM) standards Second, we used the frame to intersect with the input vector data to group the input information into each cell. Finally, we calculated the percentage of rural residential land and rural residential development for each cell. Each 1-m^2 cell contained rural residential land area in 2000 and conversion into rural residential land from other land-use types in the 1990s (Liu and others 2005).

The thematic data of rural residential land was calculated by the 1-km vector data. The rural residential land percentage (PR) was employed to study the spatial distribution of rural settlements. The rural residential development index (SI) was applied to study the spatial variance of rural residential development.

Rural Residential Land Percentage (PR)

The vector datasets of rural residential land were reselected from land-use vector datasets of China in 2000. It was intersected with the 1-km vector data. The rural residential land percentage was calculated for every cell, expressed as follows:

$$PR = \frac{RL}{TL} \times 100\% \quad (1)$$

where PR is rural residential land percentage (%) of a cell, RL is rural residential land area of a cell (km^2), and TL is the total land area of the cell (km^2).

PR was divided into five grades: PR < 0.01%, 0.01% $\le$ PR < 1%, 1% $\le$ PR < 5%, 5% $\le$ PR < 10%, and PR > 10%. The larger the rural residential land percentage, the higher the grade.

According to the calculation results of PR in every 1-km^2 cell, the spatial distribution of rural settlements was mapped in Figure 2. It described the spatial distribution of rural settlements explicitly throughout China.

Rural Residential Development Index (SI)

SI was employed to study the spatial variability of rural residential development in 1990~1995 and 1995~2000. The vector datasets of rural residential development in 1990~1995 were reselected from land0use dynamic change datasets. It was intersected with the 1-km vector datasets. Similarly, the vector datasets of rural residential development in 1995~2000 were reselected from land-use dynamic change datasets. Rural residential development was the conversion from cropland, forest, grassland, water, and barren land. Rural land that was encroached on by urban land was excluded.

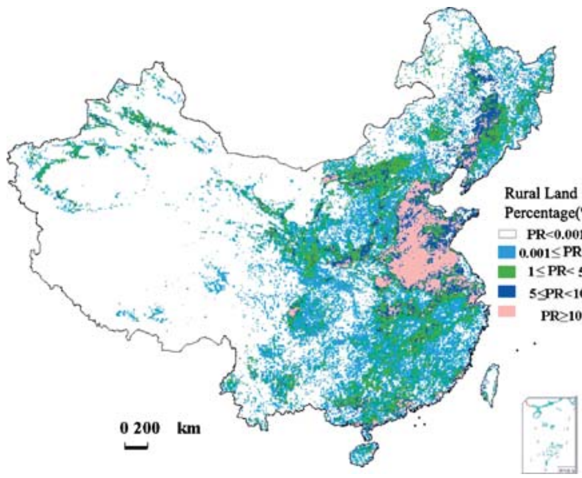


Fig. 2 Spatial distribution of rural land percentage in China in 2000

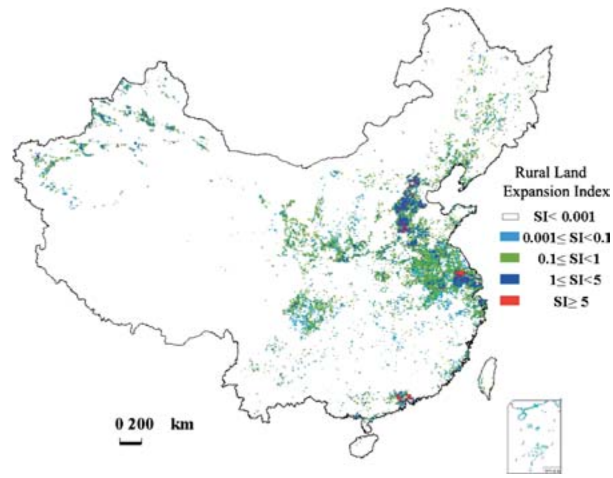


Fig. 3 Rural land dynamic change of China in 1990–1995

SI was calculated for every cell and expressed as follows:

$$SI = \frac{\Delta RLij}{TL} \times 100\% \quad (2)$$

where SI is the rural residential development index of a cell from period i to j and $\Delta RLij$ is the rural residential development from period i to j.

SI was divided into five grades. When SI < 0.001%, it represented the undeveloped area; when 0.001% ≤ SI < 0.1%, it was the low developed area; when 0.1% ≤ SI < 1%, it indicated the rapidly developed area; when 1% ≤ SI < 5%, it was the more rapidly developed area; when SI ≥ 5%, it showed the dramatically developed area. Figures 3 and 4 shows rural residential development in 1990–1995 and in 1995–2000, respectively.

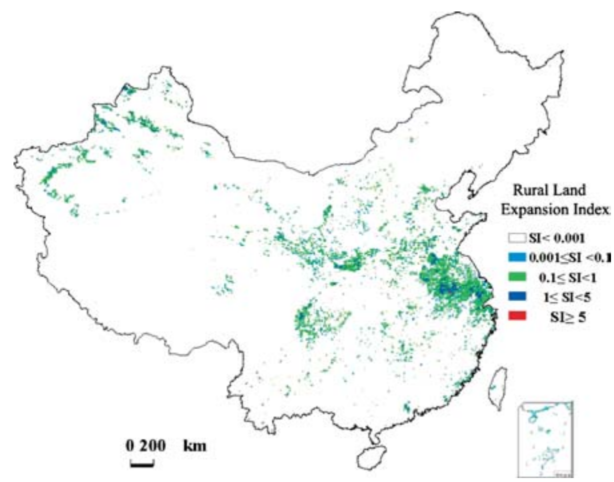


Fig. 4 Rural land dynamic change of China in 1995–2000

Rural Residential Land Regionalization

Regional dynamic process, pattern,m and driving forces are the key research subjects of global land-use and land-cover changes. Regionalization is one of the best ways to compare regional differences and control development (Thorson 1994). With the large area and regional disparity, all kinds of regionalization had been fulfilled in China, such as integrated physical regionalization (Huang 1959; WCPR 1959), geomorphology, soil, climatic, vegetation, hydrology thematic regionalization (NACC 1964), and agricultural and agroclimatic regionalization (Qiu and Lu 1980; Qui 1986). This regionalization is based on a small-scale map (such as 1:15,000,000 or 1:20,000,000).

Rural settlement distribution was affected by topography, climate, cropland, road, and social–economic factors. The vector datasets of rural residential land in the scale of 1:100,000 were intersected with the 1-km vector data. Rural residential land percentage in a 1-km^2 cell was calculated and classified into five grades (Fig. 2). The cells with the same grade value were combined and classified into one region. Because of the complexity of regions, there were some fragments in one region. It was important to keep the reality and completeness of a region in the context of having a commonly recognized rural residential land name. Hence, those fragmented and dispersed cells were rectified and merged into one large region. This practice met common expectations of conducting regional studies. It was effective in producing rural residential land regions. This method had a more detailed boundary because it used the 1- km^2 vector datasets rather than the traditional method using the county or provincial political boundary. The physical regionalization names of other researches were referenced to meet the complex reality (Huang 1959).

Fig. 5 China's rural residential land regions. I North-East Region includesthe following: I_1—Middle of Liaoning-Jilin Plain, I_2—Song-Liao Plain, I_3—Sanjiang Plain, I_4—Changbai Mountains. II Huang-Huaihai Plain includes the following: II_1—North China Plain, II_2—Middle Shandong Hills, II_3—Eastern Shandong Hills. III Middle and Lower Yangtze River Plain includes the following: III_1—Yangtze River Delta, III_2—Dongting Lake and Jianghan Plain, III_3—Poyang Lake Plain, III_4—Dabie Mountains, III_5—Mufu Mountains.; IV South Region includes the following: IV_1—Pearl River Delta, IV_2—Eastern Fujian Plain, IV_3—Guangxi Hill Plain, IV_4—Jiangnan Mountains, IV_5—Hainan Island. V Inner Mongolia Plateau includes the following: V_1—Easterm Inner Mongolia Plateau, V_2—Western Inner Mongolia Plateau, V_3—Hetao Plain. VI Border Among Shanxi, Shaanxi, Gansu, and Ningxia includes the following: VI_1—Guanzhong and Hanzhong Basin, VI_2—Loess Plateau, VI_3—Ningxia Plain, VI_4—Hexi Aisle. VII South-West Region includes the following: VII_1—Sichuan Basin, VII_2—Eastern Sichuan and Chongqing, VII_3—Yunnan-Guizhou Plateau. VIII Tibet Plateau includes the following: $VIII_1$—Western Tibet Plateau, $VIII_2$—Valley of Southern Tibet, $VIII_3$—Eastern Tibet Plateau. IX Xinjiang Region includes the following: IX_1—North-Western Xinjiang, IX_2—Takelamagan Desert, IX_3—North-Eastern Xinjiang

According to the rural residential land percentage and the regionalization method, we divided Chinese land into 33 regions (Grade II) (Figure 5). They were combined into nine larger regions: the North-East Region, the Huang-Huaihai Plain, the Middle and Lower Yangtze River Plain, the South Region, the Inner Mongolia Plateau, the Border Region among Shanxi, Shaaxi, Gansu, and Ningxia, the South-West Region, the Tibet Plateau, and the Xinjiang Region (Grade I). In our study, the nine larger regions were sorted into eastern China and western China. Eastern China included the North-East Region, the Huang-Huaihai Plain, the Middle and Lower Yangtze River Plain, and the South Region. Western China included the Inner Mongolia Plateau, the Border Region among Shanxi, Shaaxi, Gansu, and Ningxia, the South-West Region, the Xinjiang Region, and the Tibet Plateau.

Results and Analysis

Spatial Distribution of Rural Settlements in 2000

The spatial distribution of rural settlements on a large scale was impacted by physical factors such as topography, climate, soil moisture and properties, rivers and cropland, economic development, roads, historical culture, and so forth. Figure 2 shows the spatial distribution of Chinese rural settlements. It was clear that most of the grids with a high percentage of rural residential land in China were distributed on the large plains and population-dense regions such as the North China Plain, the Middle Liaoning-Jilin Plain, the Yangtze River Delta,m and the Pearl River Delta. The North China Plain had the densest rural settlements and the highest rural residential land percentage (10.62%) because it was the major grain-producing region. Rural residential land percentages of the Middle Liaoning-Jilin Plain, the Yangtze River Delta, and the Pearl River Delta were 7.37%, 6.8%, and 5.34%, respectively. However, urban land percentages of the Yangtze River Delta and the Pearl River Delta were higher than that of the Middle Liaoning-Jilin Plain (Tian and others 2005). In eastern regions, rural residential land percentages of plain regions, including the Songliao Plain, the Sanjiang Plain, the Dongting and Jianghan Plain, the Poyang Lake Plain, the Eastern Fujian Plain, and the Guangxi Hill Plain were much larger than the mountainous regions such as the Dabie and, Mufu mountains and Jiangnan Hills (Table 2). Although the Eastern and Middle Shandong Hill regions were mountainous, their rural residential land percentages were 6.09% and 5.01%, respectively, because they were in the population-intensive coastal provinces. The rural residential land percentage of Hainan Island was 1.99%.

In the western regions, rural settlements are concentrated in the Sichuan Basin, the Ningxia Plain, the Hetao Plain, the Guanzhong-Hanzhong basin, and the Hexi Aisle. Rural settlements of the plateaus (e.g. Loess Plateau, Yunnan and Guizhou Plateau, Eastern and Western Inner Mongolia Plateau) and mountain regions (e.g., Eastern Sichuan and Chongqing) were sparse. In Xinjiang, rural settlements were distributed along the oasis. The rural settlements of the Tibet Plateau were the sparsest. In general, regional difference of rural settlements had been impacted more by topography in China.

From the DEM, we found that 59.16% of the rural residential land was located on lowland with an elevation of less than 100 m and 83.38% of rural residential land was distributed below 500 m (Fig. 6a). A small amount of rural settlements was distributed in the widespread mountainous region and the plateau.

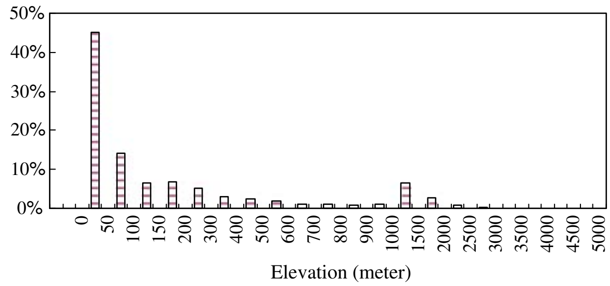
Table 2. Rural residential land percentage and dynaic index in China in the 1990s (%)

Regionalization Grade I	Regionalization Grade II	PR of 2000	SI in 1990–1995	SI in 1995–2000
I North-East Region	I1 Middle of Liaoning-Jilin Plain	7.37	1.80	0.02
	I2 Song-Liao Plain	2.55	0.94	0.03
	I3 Sanjiang Plain	1.34	0.88	0.01
	I4 Changbai Mountain	1.15	1.16	
II Huang-Huaihai Plain	II1 North China Plain	10.62	5.09	1.57
	II2 Middle Shandong Hills	5.01	0.27	0.42
	II3 East Shandong Hills	6.09	2.80	0.31
III Middle and Lower Yangtze River Plain	III1 Yangtz River Delta	6.80	24.31	8.3
	III2 Dongting Lake and Jianghan Plain	3.72	2.16	1.46
	III3 Poyang Lake Plain	1.76	0.66	1.01
	III4 Dabie Mountains	0.59	2.96	1.62
	III5 Mufu Mountains	0.65	0.42	0.32
IV South Region	IV1 Pearl River Delta	5.34	28.11	4.80
	IV2 Eastern Fujian Plain	3.64	2.90	1.86
	IV3 Guangxi Hill Plain	3.45	3.01	0.05
	IV4 Jiangnan Hill	0.79	1.43	1.15
	IV5 Hainan Island	1.99	0.79	0.01
V Inner Mongolia Plateau	V1 Easterm Inner Mongolia Plateau	0.22	1.63	0.42
	V2 Western Inner Mongolia Plateau	0.02	1.95	7.69
	V3 Hetao Plain	2.38	0.79	0.60
VI Border among Shanxi, Shaanxi, Gansu, and Ningxia	VI1 Guanzhong and Hanzhong Basin	5.05	3.36	4.58
	VI2 Loess Plateau	0.43	1.57	2.67
	VI3 Ningxia Plain	3.98	2.55	7.32
	VI4 Hexi Aisle	1.16	4.47	3.25
VII South-West Region	VII1 Sichuan Basin	3.58	9.62	9.84
	VII2 Eastern Sichuan and Chongqing	0.36	5.98	4.08
	VII3 Yunnan and Guizhou Plateau	0.29	2.21	1.85
VIII Tibet Plateau	VIII1 Western Tibet Plateau	0.0002	1.01	2.06
	VIII2 Valley of Southern Tibet	0.03		
	VIII3 Eastern Tibet Plateau	0.05	1.57	3.84
IX Xinjiang Region	IX1 North-Western Xinjiang	0.39	7.93	10.42
	IX2 Takelamagan Desert	0.01	8.22	12.09
	IX3 North-Eastern Xinjiang	0.02	1.81	8.93

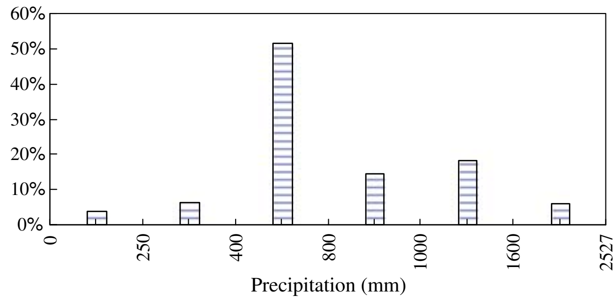
Historically, rural residential land has been occupied by farmers. They cultivated the cropland on the periphery of the villages. Precipitation had significantly impacted the cropland distribution (Liu and others 2005). Nearly 90% of rural residential land was distributed in regions with annual precipitation of more than 400 mm and 51.37% of rural residential land was distributed in regions with annual precipitation between 400 and 800 mm (Figure 6b). Rural residential land was also impacted by temperature. Nearly 18.37% of the rural residential land was distributed within on annual accumulated temperature range of 3000–3900°C and 48.04% of the rural residential land was distributed within annual accumulated temperature range of 4000–5500°C (Fig. 6c). Rural settlements were denser in wet and mild plain regions.

Temporal Disparity of Rural Residential Land in the 1990s

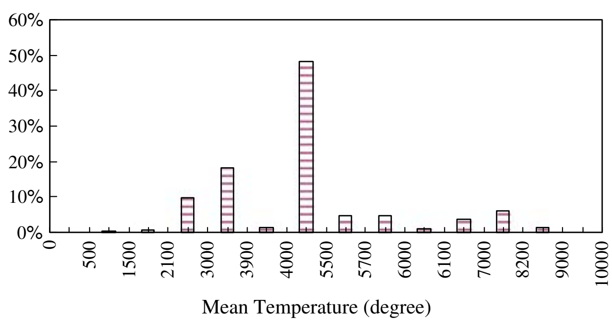
According to the remote sensing survey, the rural residential land increased by 0.79 million ha in China in the 1990s. However, the survey revealed great disparity in the two periods. In 1990–1995, rural residential development was 0.55 million ha, which accounted for 70.3% of the



(a) Along elevation (X axis unit: meter)



(b) Along mean annual precipitation (X axis unit: mm/yr)



(c) Along mean annual temperature (X axis unit: degrees Celsius)

Fig. 6 Rural residential land distribution under different geophysical and climate conditions (*y* axis: percentage). Note: *y* axis represents the percentage of each type of rural residential land located in each zone. **(a)** Rural residential land distribution (*x* axis unit: meter); **(b)** rural residential land distribution along mean annual precipitation (*x* axis unit: mm/year); **(c)** rural residential land along mean annual temperature (*x* axis unit: degrees Celsius)

decade. In 1995–2000, it was 0.23 million ha, which accounted for 29.7% of the decade. This spatial pattern was similar to urban spatial dynamic patterns.

In 1990–2000, rural residential development encroached on a larger amount of cropland, woodlands, grassland, water, and unused land. Nearly 59.82% of the rural residential land came from cropland. Woodlands, grassland, water, unused land, and other land accounted for 9.61%, 13.65%, 6.08%, 0.38%, and 10.46%, respectively.

In this decade, urban land increased by 0.83 million ha (Tian and others 2005). About 0.13 million ha came from rural residential land. In the land-cover conversion matrix, it did not impact the rural residential land development data.

The temporal disparity of rural residential dynamics reflected the different land-use policies and economic growth phases. The Chinese economy was experiencing rapid growth in the 1990s. The Gross National Product (GNP) grew at an average annual rate of 9.4% by the comparable price index. Moreover, the economic development demonstrated two distinct periods. The annual growth rate was 11.56% in 1990–1995 and 8.33% in 1995–2000. The rapid economic growth stimulated rural residential development.

Spatial Dynamic Pattern of Rural Residential Land Between 1990 and 1995

In 1990–1995, rural residential land expanded dramatically and concentrated in the eastern regions, including the Huang-Huaihai Plain, the Middle and Lower Yangtze River Delta Plain, and South China. It expanded dramatically with the rapid economic development. Rural residential land of the Pearl River Delta and the Yangtze River Delta increased by 28.11% and 24.31%, respectively, whereas the North China Plain increased by 5.09%. These regions were highly populated areas. The rural residential development in eastern regions accounted for 80.8% of the national total.

Due to its geographic proximity to Hong Kong and Macao, a great amount of foreign capital was invested in the Pearl River Delta during this period. Many township and rural factories were built along the major roads. New homes were constructed for farmers with their increasing income. The township and rural industries of the Yangtze River Delta developed rapidly. The economic development stimulated rural residential expansion. The physical conditions for agriculture in the North China Plain were advantageous with the long cultivated land reclamation. More than 75% of the region is located less than 100 m above sea level. Because the rural population density was high, the increment of rural residential land was high even though its rural residential land increased by 5.09%, which was much lower than that of the Pearl River Delta and the Yangtze River Delta.

Rural residential land in the Guangxi Hill Plain and the Dongting and Jianghan Plain increased by 3.01% and 2.16%, whereas rural residential land in the Poyang Lake Plain increased by only 0.66%. In the mountain regions, rural residential land of the Dabie, Jiangnan, and Mufu mountains increased by 2.96%, 1.43%, and 0.42%, respectively. Rural residential land of the Eastern Shandong Hills expanded by 2.80%, whereas the Middle Shandong Hills increased by only 0.27%.

The slow expansion of rural residential land of the North-East Region was a result of its slow economic development and its high urbanization level. The demand of rural residential land was low and its rural expansion accounted for only 5.12% of the total at the national level.

Rural residential land in the western region expanded moderately and accounted for 19.2% of the national rural expansion during this period. Only the Sichuan Basin and the Eastern Sichuan and Chongqing increased by 9.62% and 5.98%, respectively. With its high population density, rural settlements of the Sichuan Basin expanded moderately. Rural residential land expansion of the Hexi Aisle, the Yunnan-Guizhou Plateau, the Hetao Plain, and the Inner Mongolia Plateau was very slow. Rural residential land expansion in Xinjiang and the Tibet Plateau was the slowest.

Spatial Dynamic Pattern Between 1995 and 2000

In 1995–2000, rural residential development in the eastern region slowed down and the expansion shifted to the western region. Rural residential development in the eastern region accounted for only 58.54% of the total at the national level compared with 80.8% in 1990–1995. Rural residential land of the Yangtze River Delta, the Pearl River Delta, and the North China Plain expanded by 8.3%, 4.8%, and 1.57%, respectively, which were much lower than those in 1990–1995. Rural residential land in the Dongting Lake and the Jianghan Plain, the Dabie, Jiangnan, and Mufu mountains, and the North-Eastern Region expanded less than in 1990–1995.

In the western region, rural residential land expanded faster in 1995–2000 than that in 1990–1995. The expansion of 58.54% in the west surpassed the eastern region. For example, rural residential land of the Sichuan Basin increased 9.84% compared with 3.58% in the former period. Rural residential development of the Inner Mongolia Plateau, the South-West Region, the Tibet Plateau, and Xinjiang was faster in this period. With the acceleration of economic development of the western region, the rural residential land expanded more rapidly.

Discussion and Conclusion

Our results had shown the spatial distribution of rural settlements of China in an explicit way. The spatial distribution of rural settlements was correlated with physical conditions. The rural settlements were denser in the flat, wet, and mild regions and concentrated in the large plains.

Our findings had demonstrated the temporal disparity during the two periods in the 1990s in response to economic growth and land-use policy. During 1990–1995, rural residential land expanded dramatically in the eastern region where foreign investment, township, and rural industries developed rapidly. The farmers built new houses with their increased income, which accelerated the rural residential expansion. Although the economic development of the western region was relatively slow, so was the rural residential expansion.

The rampant rural residential expansion and resulting loss of cropland in the eastern region had captured the attention of the central government. The Basic Farmland Protection Act was adopted in 1994. The strict cropland protection measures that controlled the land trading and the changes from farmland into other uses in coastal eastern regions effectively slowed down rural residential expansion speed in 1995–2000. Meanwhile, the policy of promoting western development to mitigate the regional imbalance has attracted more capital to the infrastructure and ecological construction. The measures seemed effective and resulted in more rapid rural residential expansion.

It is more difficult to manage rural residential development because rural settlements are small, numerous, and dispersed. The rapid rural residential development is threatening food security and local ecological safety (Xie and others 2005). Many natural and seminatural ecosystems are undergoing dramatic conversions resulting from rapid growth in rural home construction (Patricia and others 2006). With the rapid urbanization process, more rural population will immigrate to the towns and cities. Their rural residential land will be kept in the hands of the farmers in the same villages. Urbanization is the most dramatic form of land transformation that profoundly influences biological and human life (Matthew and Wu 2002). The increasing urbanization process changed the structural complexity of the landscape and increased fragmentation (Jenerette 2001). However, the rates and drivers of rural residential expansion into agricultural land and rural land dynamics and its ecological consequences have not received enough attention. Further investigation on rural land-use dynamics with the social, economic, and physical factors and the ecological impact has important policy implications.

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