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Regional Differences of China′s Urban Expansion from Late 20th to Early 21st Century Based on Remote Sensing Information

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Abstract: This study investigated the regional differences of China′s urban land expansion from the late 1980s to the year of 2008, based on the spatio-temporal analysis of CLCD (China′s land cover/land use database) datasets which were mainly produced from remote sensing imagery data. A newly defined urbanization level index (UI), based on urban land area, is proposed to describe Chinese urban expansion process at 1 kilometer, provincial, regional, and national scales, together with the absolute urban expansion index (UE_a) and the relative urbanization expansion index (UE_r). The results indicate that the percentages of total land area occupied by urban in the late 1980s, 1995, 2000, 2005, and 2008 were approximately 0.25%, 0.32%, 0.33%, 0.43% and 0.52% of China′s total land area, respectively. Between the late 1980s and 2008, the total urban expansion in the mainland of China was 2.645×10^4 km^2, resulting in an annual urban expansion area of about 1322.7 km^2/yr, with the UE_r of 111.9%. This study also finds that there has been an obvious spatial gradient of urbanization ratio running from the east coast to the west inland, and the urbanization gaps among different regions have persisted over the past two decades. The study also reveals obvious temporal variations of the urbanization rates. There was very little urban growth during the period of 1995–2000 due to the governmental policy factors.

Keywords: regional difference; spatial pattern; temporal variation; urbanization; China

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1 Introduction

In many parts of the world, there was a tremendous migration of people from rural regions to urban areas in the past 60 years. This trend has placed about half of the world′s population, and most human wealth, into urban regions (United Nations, 2008). In China, the unprecedented combination process of economy development and population increase has led the country into a quick transition from a largely rural society to a predominantly urban one. In 1947, China had only 69 cities; by 1980 the number of the cities had risen to 223. There are now 670 cities that host 44% of Chinese population (as of 2008), of which 15 are among the world′s 100 fastest-growing cities with populations of a million or more (Normile, 2008).

It has been shown that urban land expansion has significant impacts on atmosphere (Keller *et al*., 1991; Molders, 1999), regional climate (Carlson and Arthur, 2000; Xie *et al*., 2007; Jones *et al*., 2008), soil quality (Islam and Weil, 2000; Cao *et al*., 2007), hydrology (Weber *et al*., 2001; Li *et al*., 2008; Zhang *et al*., 2008), and ecosystem (Diem *et al*., 2006; Xu *et al*., 2007). Therefore, analyzing the characteristics and spatio-temporal differences of urban land expansion has great significances for sustainable urban development. Monitoring urban land dynamics at regional or national scales can provide a linkage to econometrics models to identify the driving forces of urban expansion, and to regional climate models to assess the environmental

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effects of urbanization.

For economic, demographical and geographical researchers, the study on the relationship between urbanization process and urbanized land is one of important topics. Traditionally, urbanization studies are much relied on statistical data, including population and economic statistics. Usually, the national scale census is held every ten years or longer, and it is very difficult to obtain yearly data or up-to-date data using such census method in a country with a large population. Furthermore, in China, researchers have generally agreed that the process of urbanization has lagged behind its economic development due to the strict migration policy, household registry (*Hukou* in Chinese), macro land-use management, and cropland preservation institutions (Lin, 2001; Chen, 2002; Ma, 2002; Zhang and Song, 2003; Shen *et al*., 2006; Normile, 2008). Assessing the level of urbanization using census data, i.e., population data, therefore, has presented obvious problems including overestimating or underestimating the factual urbanization ratio.

Remote sensing (RS) technology, compared to traditional census and investigation, has provided a reliable and relatively inexpensive method to monitor and evaluate the changes of urban land. Many researchers have investigated the magnitude, patterns, and types of changes in urban regions with remote sensing information (Haack *et al*., 1987; Masek *et al*., 2000; Ji *et al*., 2001; Seto *et al*., 2002; Liu *et al*., 2003b; 2005b; Durieux *et al*., 2008). However, the interpretation and analysis of urban land change using RS imagery still present many theoretical challenges and practical difficulties (Tatem and Hay, 2004). Although some global scale land cover datasets are now available through the internet, there are few reliable and precision-enough documentations relating to the national urbanization process. The lack of database supports meant that most previous studies had to be restricted to local or regional scales, such as a single city, a metropolitan region, or a river delta at most. And the topics of previous studies were normally confined to the patterns of urban land distribution, the types of urban land expansion, driving forces of urban changes, and so on (Herold *et al*., 2003; Liu *et al*., 2003c; Seto and Kaufmann, 2003; Weber and Puissant, 2003; Liu *et al*., 2005d; Tian *et al*., 2005; Bao and Wang, 2009). Little attention has been paid to the research in a large spatial scale and a long temporal scale.

In this study, we used urban land information which was derived from remote sensing information by using GIS technique, rather than urban population by using census method, as an alternative indicator to assess Chinese urbanization process. The objective is to evaluate the characteristics and spatio-temporal differences of urban distribution and urban expansion in China from the late 1980s to the year of 2008. Two issues were mainly focused on the urban distribution patterns and its changes during different eras, and the urban expansion patterns and its temporal dynamics. The main research questions posed include: 1) How much urban land was there in each period? 2) How much has urban land expanded since the late 1980s? 3) What is the spatial pattern of urban land distribution in each era? And 4) what are the spatial and temporal characteristics of urban expansion process?

2 Data Sources and Processing

2.1 Remote sensing imagery and China′s land cover/land use database

The primary data source of this study is remote sensing imagery, i.e., Landsat MSS/TM/ETM+ and China-Brazil Earth Resource Satellite 1 (CBERS-1) images which were mainly taken in 1989/1990, 1995/1996, 1999/2000, 2004/2005 and 2007/2008. The spatial resolution of the above imagery is about 30 m. The images were enhanced using the linear contrast stretching and histogram equalization to help identify ground control points, and rectified to a common Albers coordinate system. Senior and experienced researchers were then organized to work on these RS imagery through a series of unified technical standards for image processing, computer-aided visual interpretation, error checking, and field validation. Land maps at scale of 1∶100 000 were classified into 25 categories, which were then grouped into six aggregated classes, i.e., cropland, woodland, grassland, water body, built-up area, and bare land. A detailed technical description can be found in previous papers (Zhuang *et al*., 1999; Liu *et al*., 2003a; 2003b; 2005a).

Based on the above work, China′s land cover/land use database (CLCD) was then built. Supported by the time-series CLCD, a series of national scale, multi-disciplinary and comprehensive projects are able to be conducted successfully at home and abroad (Liu *et al*.,

2005c; 2005d; Tian *et al*., 2005). In this paper, we analyzed the spatial pattern and temporal trends of Chinese urban expansion process over the past nearly 20 years. The urban built-up features (class code = 51) within urban regions were extracted from all 25 land-use categories and defined as urban land in our analysis, while the rural residential areas (code = 52), infrastructure areas surrounding city or among cities (code = 53) and other features were all discarded.

2.2 1 km component grid dataset

It is convenient and efficient to handle raster data compared with vector data for most remote sensing image processing platforms and GIS environments. Most global or continental-scale studies that were focused on land use/cover change (LUCC) patterns and dynamics, mechanisms, and ecological effects have utilized raster data format, such as the 0.5° × 0.5° climate database, the 8 km × 8 km normalized difference vegetation index (NDVI) database, and the 1 km × 1 km land cover database (Kohlmaier *et al*., 1997; Loveland *et al*., 2000; Friedl *et al*., 2002; Masson *et al*., 2003; Bartholome and Belward, 2005). However, traditional raster data (simply produced by a remote sensing image classification function or the polygrid command in ArcGIS platform) have a disadvantage in that area information is destroyed or degraded dramatically. With that simple raster data model, a cell is allowed only one type of land cover, and therefore the processing efficiency comes at the price of losing land cover variability within each cell. To avoid this shortcoming, we have previously developed a technique that converts vector data into a series of grid datasets named as 1 km component grid datasets. The derived 1 km component grid dataset has a spatial resolution of 1 km but preserves detailed classification information within each 1 km cell, i.e., percentage of each land category within a cell is stored respectively, with the total summing to 100%. A detailed description about this technique can be found in previous research (Liu *et al*., 2003a).

2.3 Regionalization system of China

In order to clearly depict the spatial pattern of urban distribution and expansion, a specific economic regionalization system was introduced to this study. The system used here is also widely used by Chinese central government, including the National Development and Reform Commission, and so on. Many political and economic policies have been designed and implemented based on this regionalization system.

According to the regionalization system, China is divided into five parts or regions: East China, Northeast China, Central China, West China, and the Taiwan-Hong Kong-Macao Region (Fig. 1). East China is the most developed region of China, covering three municipalities (Beijing, Tianjin and Shanghai) and seven provinces (Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, and Hainan). Northeast China has been the traditional industrial base since the 1950s, covering three provinces (Liaoning, Jilin, and Heilongjiang). Central China is the transition zone between east and west and includes six provinces (Shanxi, Henan, Anhui, Jiangxi, Hubei and Hunan). West China is typically less developed and owns the largest territory of China, including one municipality (Chongqing), six provinces (Sichuan, Guizhou, Yunnan, Shaanxi, Gansu and Qinghai), and five regions (Inner Mongolia Autonomous Region (Inner Mongolia), Zhuang Autonomous Region of Guangxi (Guangxi), Hui Autonomous Region of Ningxia (Ningxia), Tibet Autonomous Region (Tibet) and Uygur Autonomous Region of Xinjiang (Xinjiang)).

Due to the special political and economic characteristics, Taiwan, Hong Kong, and Macao of China are normally classified as one distinct class. In this study, only the mainland of China was involved in statistics and analysis, although Taiwan, Hong Kong, and Macro of China were still presented in the figures.

3 Measures on Urban Land Distribution and Expansion

Based on remote sensing information, selected indices were calculated to depict the spatio-temporal patterns of urban land distribution and expansion of China. Specifically, the urbanization level index (UI) for each monitoring year, the absolute and relative urban expansion index (UE_a and UE_r) during every time period, were calculated over a 1 km grid at the first, and then summarized to provincial, regional, and national scales.

3.1 Urbanization level index (UI)

The urbanization level is traditionally defined as the ratio of urban population to total population, which is widely applied by demographic and other sociological

Fig. 1 A typical China′s economic regionalization system

researchers. Because the process of urbanization is accompanied by both urban population increase and urban land expansion, it is also reasonable to define urbanization level as the share of urban land in a specific region. Here the urbanization level index (UI), based on urban land area share, is newly defined and expressed as:

$$UI = \frac{UL}{TL} \times 100\% \quad (1)$$

where UI is the urbanization level index (%), UL is the urban area (′urban built-up′) in a specific zone (km^2), and TL is the total area of the specific zone (km^2).

In this study, UI is used at two different scales. First, UI can refer to the 1 km grid dataset and is specifically associated with the absolute built-up area in each cell. A cell with a UI value of zero refers to a non-urban land; a cell with a UI value of 100 refers to an entirely built-up location, such as the central part of a city. Second, UI can also be applied to a larger or specific region such as a province, where the meaning of UI is more abstract. In such situations, UI is related to the regional urbanization phase and the economic development level. A region with a higher UI is more developed, and vice versa.

Generally, an urbanization level index at a 1 km scale is suitable for the determination of spatial statistics, including the calculation of the total urban built-up area. At a provincial scale, the urbanization level index can be used to determine the relevant provincial urbanization phase and economic development level. In this study, we used UI at a 1 km scale to summarize the provincial built-up area; the provincial UI was calculated by using the spatial statistics function supported by the GIS software.

3.2 Urban expansion index

The urban expansion index describes the speed at which urban lands increase during a specific monitoring period. Generally, this index is further divided into an absolute index (UE_a) and relative index (UE_r). UE_a is defined as the annual urban expansion area, and UE_r is defined as the ratio of the urban expansion area to the original urban built-up area. They are expressed as the following:

$$UE_a = \frac{UL_j - UL_i}{T} \quad (2)$$

$$UE_r = \frac{UL_j - UL_i}{UL_i} \times 100\% \quad (3)$$

where UE_a is the absolute urban expansion index (km^2/yr), UE_r is the relative urban expansion index (%), UL_i is the urban area in the ith year (km^2), UL_j is the urban area in the jth year (km^2), and T is the number of

years from the *i*th to the *j*th year (years).

Like the urbanization level index (UI), the urban expansion index (UE, including UE_a and UE_r) can also be presented at both a 1 km scale and a provincial scale. The UE at 1 km scale is suitable to represent the precise location of urban expansion, while UE at provincial scale is appropriate for the determination of regional development history and development potential in the future. In this study, we used UE at a 1 km scale to represent the pattern of urban expansion, and then obtained the provincial UE by means of spatial statistics.

4 Results and Discussion

4.1 Regional differences of urban distribution

In 2008, totally 5.01×10^4 km^2 of land were urbanized in the mainland of China, or about 0.52% of the whole mainland of China. Urban area coverage in the late 1980s, 1995, 2000, and 2005 was 2.365×10^4 km^2 (0.25%), 3.059×10^4 km^2 (0.32%), 3.177×10^4 km^2 (0.33%), and 4.085×10^4 km^2 (0.43%), respectively. There exist obvious regional differences of urban distribution from the east coast to the west inland (Fig. 2). From the perspective of gross area, most urban lands are distributed in East China or the coast region, followed by Central China, Northeast China, and finally West China. From the perspective of urban land percentage, the urbanization level of East China is always the highest, followed by Central China, Northeast China, and finally West China.

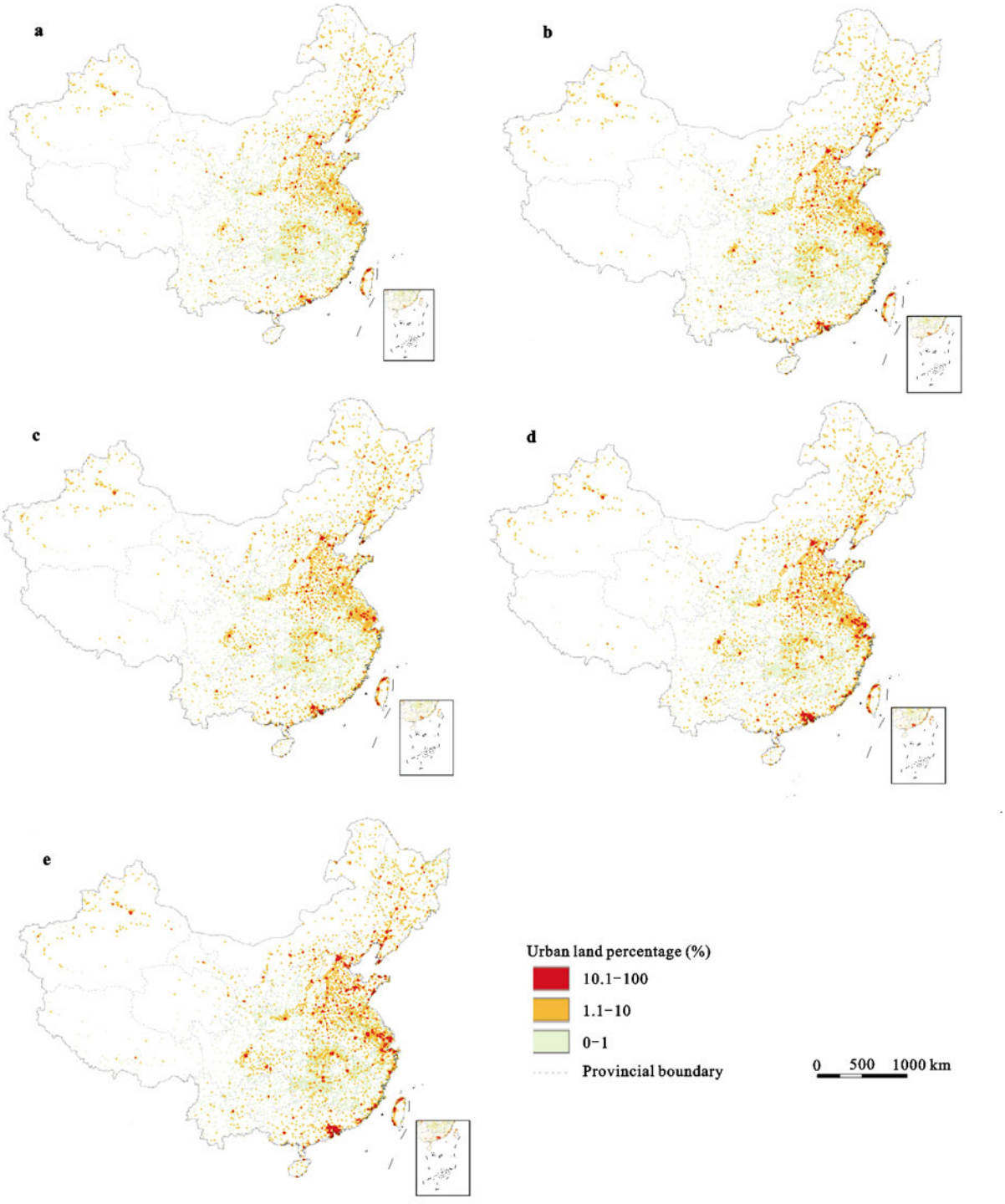
Specifically, in the year of 2008 as an example, the UI was the highest in East China (2.78%) where 2.529×10^4 km^2 of urban land accounted for 50.5% of all urban land of China. The UI in Central China was 1.01% where 1.04×10^4 km^2 of urban land accounted for 20.8% of all urban land of China. The UI in Northeast China was 0.77% where 6.07×10^3 km^2 of urban land accounted for 12.1% of total urban land of China. The lowest UI (0.12%) occurred in West China which, with 8.34×10^3 km^2 of urban area, accounted for 16.6% of the total of the nation. Similarly, the urban land distribution for other years had the same pattern.

The UI of East China for each year was about 4.3–5.4 times the mean value of China as a whole. The UIs of Central China and Northeast China were both approximately 1.2–2.1 times the mean of the whole China, and the UI of West China was 0.23–0.30 of the mean value. The gap of the urbanization level between East China and West China was always conspicuous for the 20-year period study. The UI of East China was about 15.4 times that of West China in the late 1980s, growing to 17.3 times in 1995, 15.9 times in 2000, 21.6 times in 2005, and 23.2 times in 2008. The gap was widened by the high growth rate of East China over the past 20 years, especially from the late 1980s to 1995 and from 2000 to 2008. Factually, since China adopted ′reform and opening up′ policy from the late 1970s, East China have obtained much more domestic and foreign investments than any other regions, while the investments has long been recognized as one of the most important engines of economic growth in China (Chen and Fleisher, 1996; Demurger, 2001; Li and Cheng, 2005; Liu *et al*., 2005d; Cao and Liu, 2010).

The trends of urban development in Central China, as quantified by the UI values, have nearly the same increase, about 0.15%, in late 1980s–1995 and 2000–2005, and slightly increased to 0.19% in 2005–2008. Before 2005, the changes of UI in Northeast China between adjunct monitoring periods were approximately 0.01%–0.04%, while during 2005–2008, this value rose from 0.52% to 0.77%. However, a UI gap between Northeast and Central China occurred and grew to 2005, triggered mainly by the relatively low urban growth rate of Northeast China. The gap in 2005 (0.30) was five times the gap of 0.06 in the late 1980s, while it decreased to 0.24% by 2008 as a result of the strategy of ′Revitalizing the old Northeast industrial base′ which was launched by the central government in 2003 (Fig. 3).

A detailed analysis on urbanization trends was completed at the provincial level (Fig. 4). In 2008, Shanghai had the highest UI (16.69%), followed by Beijing (10.04%) and Tianjin (7.64%). These three urban areas have much higher UI values because they have been acting as metropolitan regions since the 1950s. Chongqing, the fourth central-governed municipality in West China, set up in 1997 because of the construction of the Three Gorges Dam on the Changjiang (Yangtze) River, was found to have a relatively low UI (0.49% in 2005 and 0.74% in 2008), lower than all of the eastern provinces/municipalities and most of the central provinces. Instead of looking it as a municipality, it is better to view Chongqing as a standard province with a large amount of rural area.

For 2005 and 2008, UI values for eastern provinces



a: late 1980s; b: 1995; c: 2000; d: 2005; e: 2008

Fig. 2 China′s urban land distribution from late 1980s to 2008

were greater than 1% except Hainan. The UIs for the four East China provinces of Jiangsu, Shandong, Guangdong, and Zhejiang have been higher than 1% since 1995, with the 2008 UIs for these four provinces all being higher than 2.5%, specifically, 4.18%, 3.30%, 3.14%, and 2.59%, respectively. The UIs for Hainan stayed around 0.21% prior to 2000, while the value for 2005 increased to 0.36%, and increased dramatically to 0.76% for 2008. All UIs for provinces in West China were lower than 1% over the past 20 years; even the

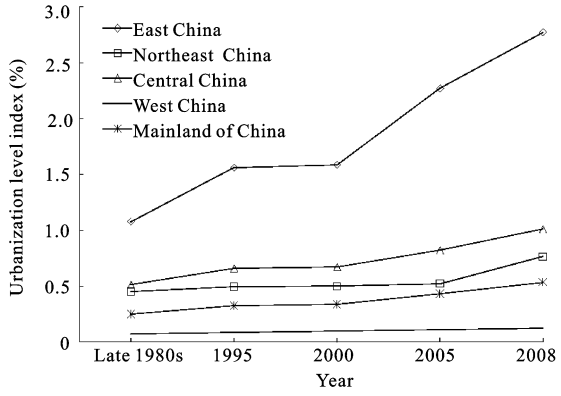


Fig. 3 Urbanization levels index (UI) for different economic regions from late 1980s to 2008

three provinces furthest west (i.e., Tibet, Qinghai, and Xinjiang), yielded lower 2008 UIs than 0.1%, specifically, 0.01%, 0.02%, and 0.08%, respectively. Two of these West China provinces (regions), Tibet and Qinghai, covered urban areas that were less than 200 km^2 in 2008, specifically, 110 km^2 and 160 km^2, respectively. Similar trends in the values of UI and urban area coverage appeared in the other years for which data are available (late 1980s, 1995, 2000, and 2005) (Fig. 4 and Table 1).

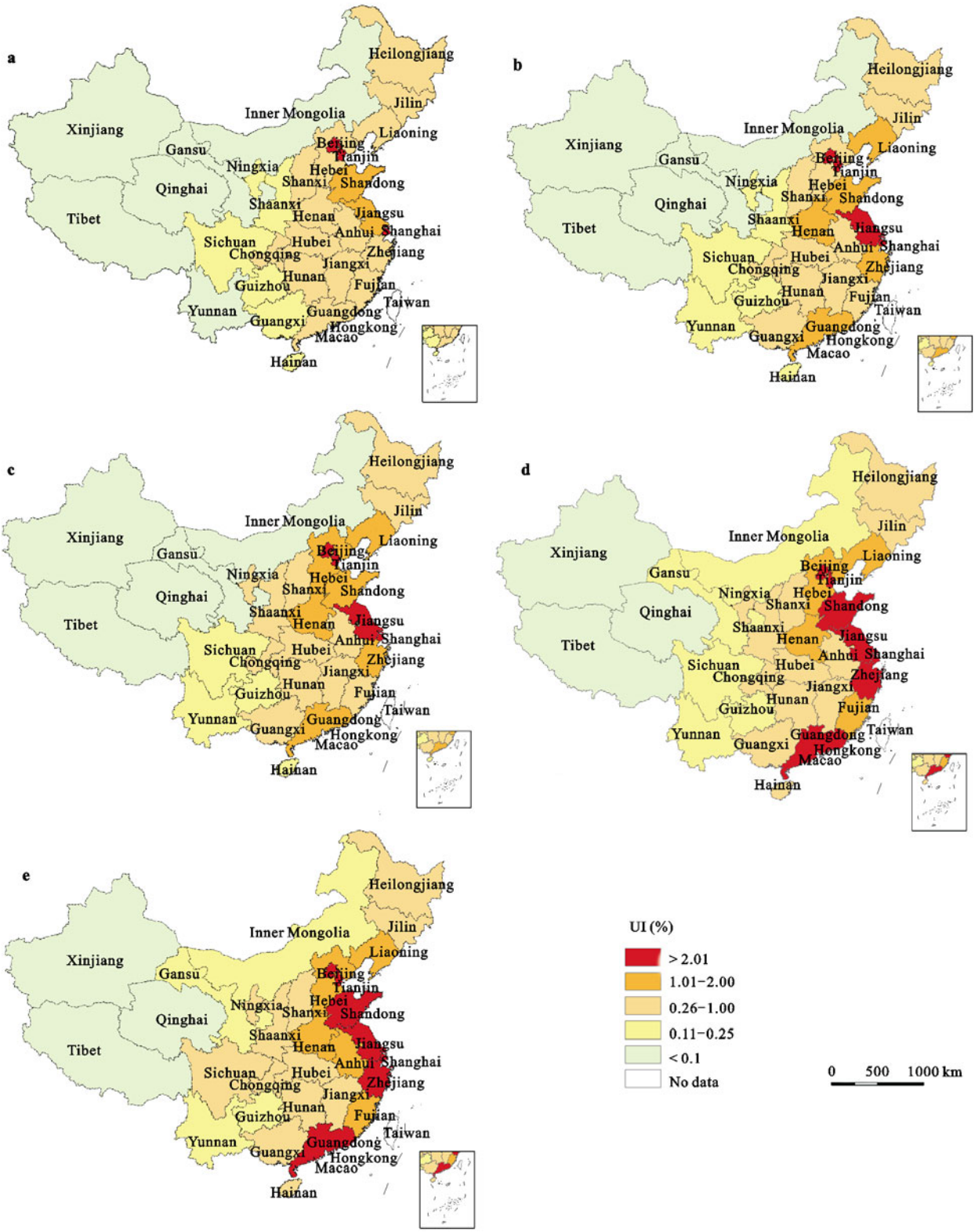
4.2 Regional differences of urban expansion

From the late 1980s to 2008, about 2.645×10^4 km^2 of urban land were added in the mainland of China, which indicated an annual urban expansion area of about 1322.7 km^2/yr, and an urban expansion intensity of 111.9%. The expansion of urban areas since the late 1980s did not occur evenly through time. The amount of land converted to an urban environment in the late 1980s–1995, 1995–2000, 2000–2005, and 2005–2008 was 6.94×10^3 km^2 (UE_r of 29.4%), 1.18×10^3 km^2 (UE_r of 3.9%), 9.08×10^3 km^2 (UE_r of 28.6%), and 9.25×10^3 km^2 (UE_r of 22.7%), respectively. The period of 1995–2000, therefore, was a time of relatively slow urban growth compared to other periods over the past 20 years.

In addition to major temporal variations, regional differences of urban expansion are apparent. Most urban expansion observed in this study occurred in East and Central China, with much less growth in Northeast and West China (Fig. 5 and Fig. 6). Over the entire study period (late 1980s–2008), for example, 58.3% of all urban expansion in China (1.542×10^4 km^2) occurred in East China, 19.4% in Central China, 2.5% in Northeast China, and 12.8% in West China.

In fact, except the period of 1995–2000, the regional differences of urban expansion within the late 1980s–1995 and 2000–2005 are generally consistent. For example, the percentages of total urban expansion in the late 1980s–1995 and 2000–2005 were respectively 62.2% and 69.0% in East China, 21.3% and 17.1% in Central China, 4.6% and 2.0% in Northeast China, 11.9% and 11.9% in West China. During 2005–2008, this spatial pattern moved to a balance between the Northeast China and the Central China; in this period, the percentages of the total urban expansion for East, Central, Northeast and West were 48.7%, 21.3%, 21.0%, and 9.1%, respectively; while as to the period of 1995–2000, it did not follow the afore-mentioned trend, as illustrated by Fig. 6. The urban expansion process nearly came to a halt during this period. Moreover, urban expansion in West China, though still less than in late 1980s–1995 and 2000–2005, was proportionally the highest from 1995 to 2000 (Fig. 6).

Until the mid-1990s, directly inspired by 'Southern Tour Speech of Mr. Deng Xiaoping' in 1992, economy of China was moving into the fast lane. Rapid economic growth required more urban land and industrial workers than ever, which spurred a relative high urbanization speed during the period from the late 1980s to 1995. After the mid of 1990, noticing the quick urban expansion has consumed so much traditional quality cropland and there might induce practical threat to national food security, the Chinese central government responded to protect basic cropland from urban expansion. Laws such as the Decree on Basic Farmland Protection issued in 1994 obviously produced negative effects on urban expansion (Chen and Fleisher, 1996; Demurger, 2001; Li and Cheng, 2005; Liu *et al*., 2005d; Cao and Liu, 2010). These actions had particular repercussions in the traditional agricultural zones of East, Central, and Northeast China, while little impact was observed in West China. After late 20th century, responded to the Asian financial crisis and the subsequent global economic downturn, the Chinese central government implemented a series of positive policies designed to stimulate the domestic economy and regional sustainable development. And, with local governments at different levels increasingly relied on the 'land finance', from 2000 to 2008, urban expansion of China has maintained a relatively rapid growth (Tan *et al*., 2005; Cao *et al*., 2008; Bao and Wang, 2009; Lin and Yi, 2011).



a: late 1980s; b: 1995; c: 2000; d: 2005; e: 2008

Fig. 4 Urbanization level index (UI) for different provinces

The results of urbanization analysis at the provincial level show that, between 1980s and 2008, Guangdong, Shandong, and Jiangsu in East China had absolute urban expansion values (UE_a) of 201.8 km^2/yr, 141.7

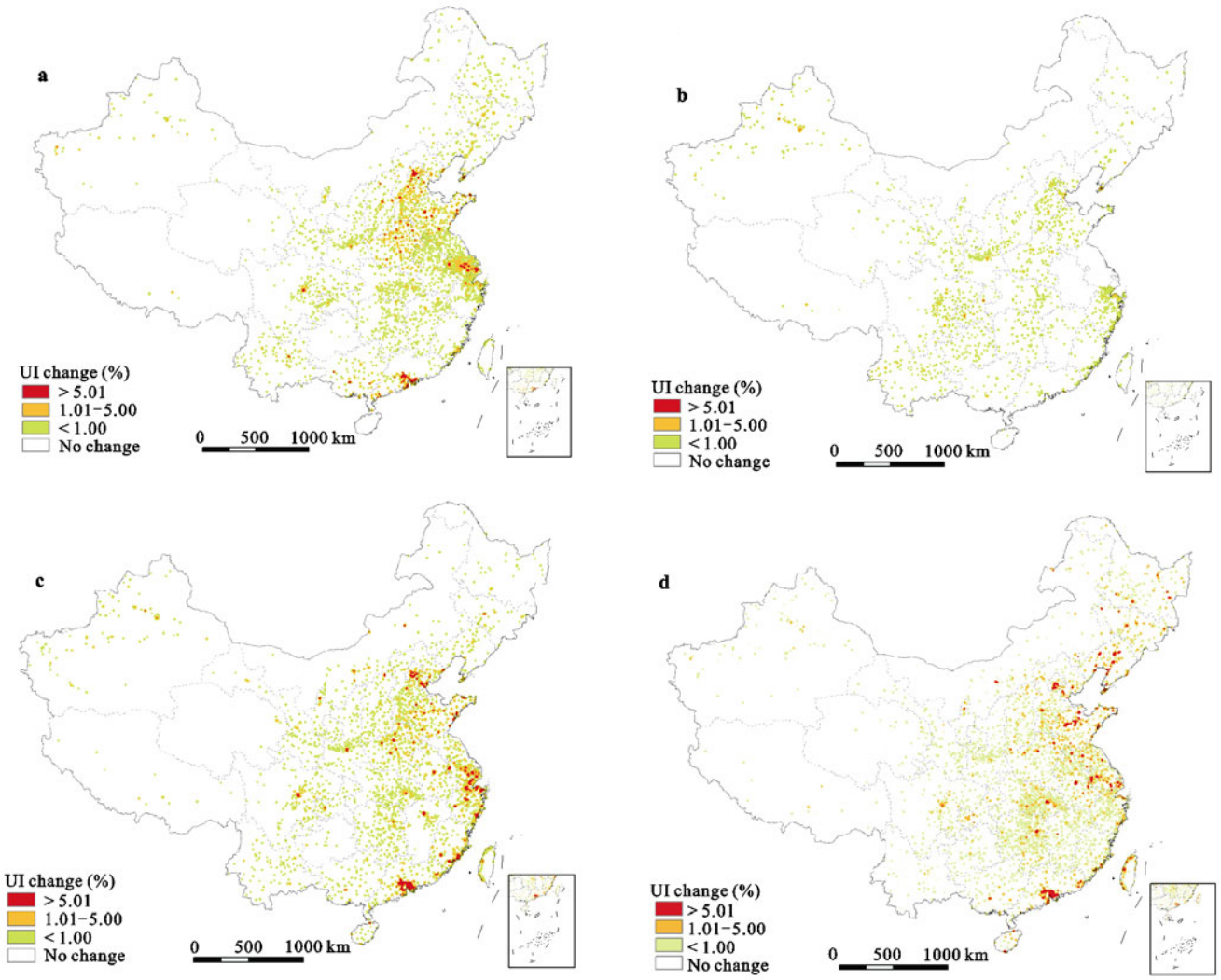
Table 1 Urbanization level index (UI, %) and urban area (km^2) from late 1980s to 2008

	Late 1980s		1995		2000		2005		2008	
	UI	Area	UI	Area	UI	Area	UI	Area	UI	Area
Beijing*	2.96	0.48	6.20	1.01	6.32	1.03	7.95	1.30	10.04	1.64
Tianjin*	4.18	0.49	4.70	0.55	4.95	0.58	7.21	0.84	7.64	0.89
Hebei	0.62	1.15	0.99	1.85	1.02	1.92	1.26	2.36	1.37	2.57
Shandong	1.46	2.26	1.99	3.07	2.02	3.11	2.63	4.06	3.30	5.09
Shanghai*	8.83	0.56	12.24	0.77	12.24	0.77	14.39	0.91	16.69	1.06
Jiangsu	1.95	1.98	2.79	2.83	2.79	2.83	3.33	3.37	4.18	4.24
Zhejiang	0.80	0.82	1.02	1.04	1.13	1.15	2.34	2.39	2.59	2.65
Fujian	0.46	0.55	0.51	0.62	0.53	0.64	1.01	1.22	1.11	1.34
Guangdong	0.86	1.51	1.35	2.38	1.36	2.41	2.38	4.21	3.14	5.55
Hainan	0.21	0.07	0.21	0.07	0.21	0.07	0.36	0.12	0.76	0.26
East China total	1.08	9.87	1.56	14.19	1.59	14.52	2.28	20.78	2.78	25.29
Liaoning	0.96	1.40	1.04	1.52	1.08	1.57	1.13	1.65	1.84	2.67
Jilin	0.47	0.91	0.53	1.01	0.53	1.02	0.58	1.10	0.72	1.38
Heilongjiang	0.28	1.27	0.30	1.36	0.30	1.37	0.31	1.39	0.44	2.01
Northeast China total	0.45	3.57	0.49	3.89	0.50	3.95	0.52	4.13	0.77	6.07
Shanxi	0.49	0.77	0.62	0.97	0.63	0.99	0.72	1.12	0.83	1.31
Anhui	0.62	0.88	0.74	1.03	0.74	1.03	0.88	1.23	1.26	1.76
Jiangxi	0.28	0.47	0.35	0.58	0.35	0.58	0.51	0.85	0.57	0.96
Henan	0.80	1.32	1.27	2.10	1.31	2.16	1.67	2.77	1.79	2.97
Hubei	0.53	0.99	0.61	1.14	0.62	1.16	0.71	1.32	0.99	1.84
Hunan	0.40	0.84	0.44	0.94	0.45	0.96	0.54	1.14	0.74	1.57
Central China total	0.51	5.27	0.66	6.75	0.67	6.88	0.82	8.43	1.01	10.40
Inner Mongolia	0.10	1.11	0.10	1.14	0.10	1.15	0.11	1.31	0.13	1.46
Guangxi	0.23	0.54	0.34	0.80	0.35	0.82	0.39	0.93	0.43	1.01
Chongqing*	0.26	0.21	0.30	0.24	0.41	0.34	0.49	0.40	0.74	0.61
Sichuan	0.12	0.60	0.16	0.79	0.19	0.92	0.25	1.19	0.27	1.32
Guizhou	0.13	0.22	0.13	0.22	0.15	0.26	0.15	0.27	0.17	0.29
Yunnan	0.08	0.32	0.11	0.44	0.14	0.52	0.16	0.61	0.17	0.65
Tibet	0.00	0.03	0.00	0.04	0.00	0.05	0.01	0.07	0.01	0.11
Shaanxi	0.21	0.42	0.24	0.49	0.27	0.55	0.32	0.66	0.35	0.71
Gansu	0.09	0.37	0.10	0.39	0.10	0.41	0.12	0.49	0.13	0.51
Qinghai	0.02	0.11	0.02	0.11	0.02	0.13	0.02	0.15	0.02	0.16
Ningxia	0.19	0.10	0.23	0.12	0.26	0.13	0.40	0.21	0.50	0.26
Xinjiang	0.05	0.90	0.06	0.98	0.07	1.14	0.07	1.22	0.08	1.25
West China total	0.07	4.94	0.09	5.77	0.10	6.42	0.11	7.50	0.12	8.34
China total **	0.25	23.65	0.32	30.59	0.33	31.77	0.43	40.85	0.52	50.10

Notes: *, central government directly controlled municipality; **, Taiwan, Hong Kong, and Macao of China are not included in the statistics

km^2/yr, and 113.0 km^2/yr, respectively. These were the only three provinces with UE_a exceeding 100 km^2/yr. At the opposite end, UE_a values for Qinghai, Tibet, Guizhou, Hainan, Ningxia, Gansu, and Heilongjiang were less than 10 km^2 /yr. Of these seven provinces (regions) with low UE_a values, five were inland provinces (regions) in West China, one was island province in East China (Hainan), and one was the coldest province in Northeast China (Heilongjiang). UE_a for East China is higher than the sum of all the other three parts over the past 20 years.

As for the relative urban expansion index (UE_r) (Fig. 7 and Table 2) between the late 1980s and 2008, 14 provinces (region) had UE_r values that exceeded 100%, indicating that the amount of urban land has more than



a: late 1980s–1995; b: 1995–2000; c: 2000–2005; d: 2005–2008

Fig. 5 China′s urban expansion distribution from late 1980s to 2008

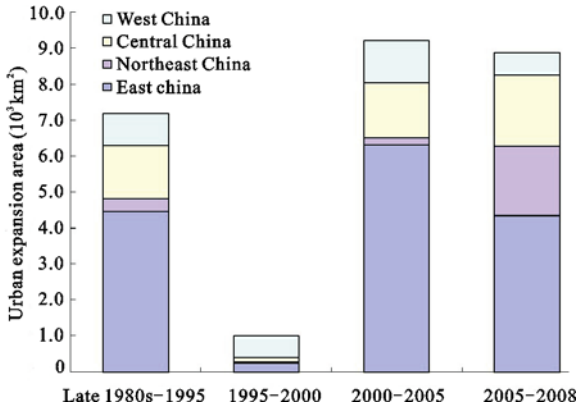
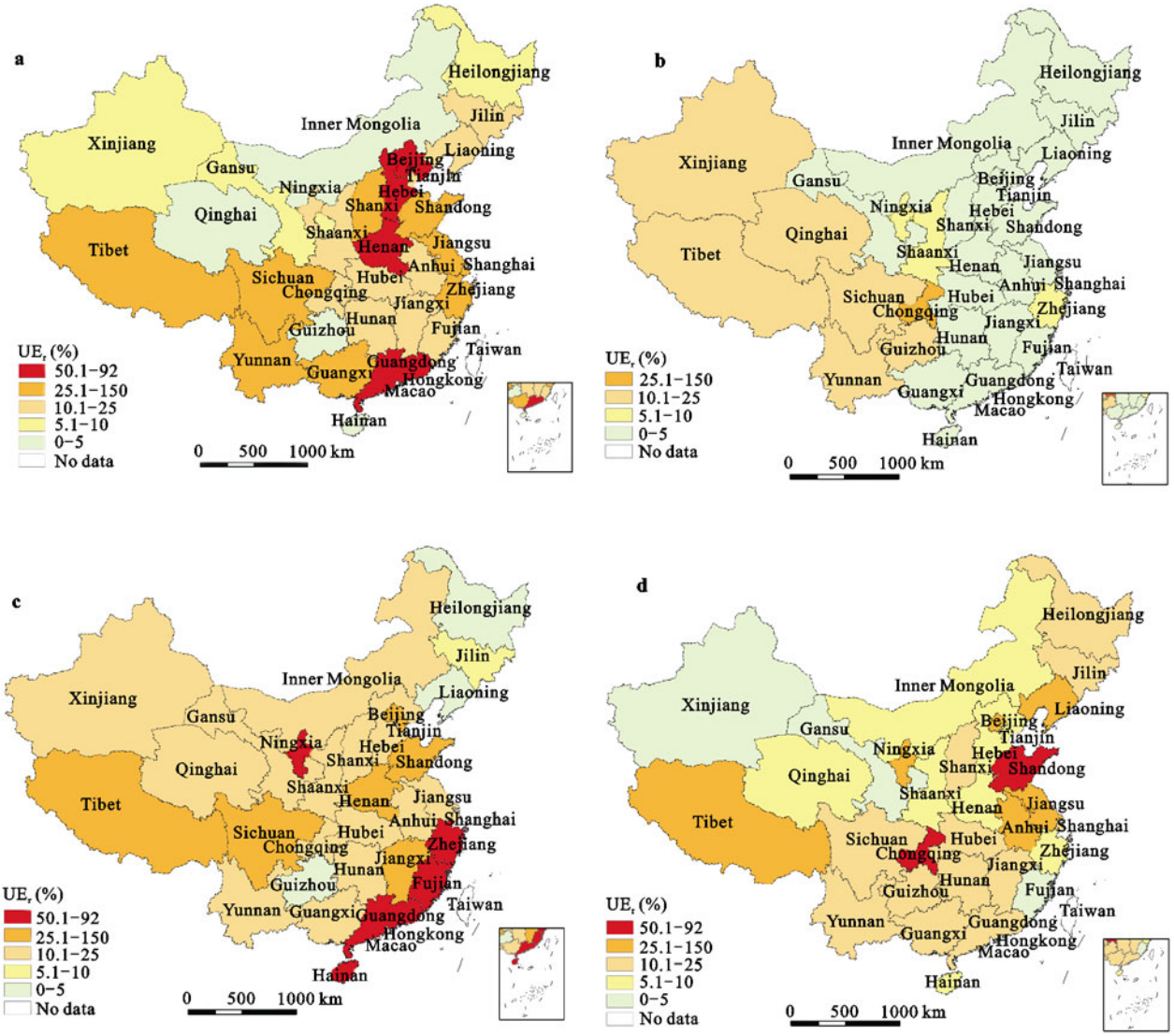


Fig. 6 Urban expansion area for different economic regions from late 1980s to 2008

doubled in size over the past 20 years. Conversely, Inner Mongolia and Guizhou both displayed UE_r values of less than 35%. The provinces that showed either high or low urban expansion intensity were not evenly distributed throughout the country. However, it did not follow the trend of UE_a where East China has the overwhelming dominance. For example, in West China, Tibet, Chongqing, Ningxia, Sichuan and Yunnan had UE_r values higher than 100% owing to their relatively small benchmark area of urban land in the past 20 years.

Using both UE_a and UE_r to examine urban expansion provides a clearer and more realistic picture of conditions in such a heterogeneous and unbalanced space-time dimension, and is more useful in evaluating ongoing changes in the specific provinces and regions, as well as throughout the country than just using historic socio-economic data. The data collected here show that the most significant urban expansion events have oc-



a: late 1980s–1995; b: 1995–2000; c: 2000–2005; d: 2005–2008

Fig. 7 Relative urban expansion index (UE_r) for different provinces (regions)

curred in East China, where UE_r has exceeded 100% in most East provinces (8 among 10) over the past two decades. Generally, large spatial-temporal differences in China′s urban distribution and urban expansion characterize the past 20 years. With the implementation of the national strategies of ′large-scale development of the western region′ in 2000 and ′revitalizing the old Northeast industrial base′ in 2003, West and Northeast China began with an accelerated development speed, thereby reducing the gap between them and central China with respect to urban land expansion area. Nevertheless, there remains a large difference with East China, no matter which index is used: total urban land area (UL) or urbanization level index (UI), absolute urban expansion index (UE_a) or relative urban expansion index (UE_r).

5 Conclusions

In this paper, China′s land cover/land-use database (CLCD), which was produced from RS imagery information, was successfully applied to analyzing the regional differences of Chinese urban distribution and urban expansion over the past two decades. This study on Chinese urbanization process is a significant improvement compared to earlier researches at relatively small regions and short periods of time.

The urbanization level index (UI), which is defined on urban land area other than population census data, is

Table 2 Absolute urban expansion index (UE_a, km^2/yr) and relative urbanization expansion index (UE_r, %) from late 1980s to 2008

	Late 1980s–1995		1995–2000		2000–2005		2005–2008		Late 1980s–2008	
	UE_a	UE_r	UE_a	UE_r	UE_a	UE_r	UE_a	UE_r	UE_a	UE_r
Beijing*	88.3	109.3	4.0	2.0	53.4	25.8	114.1	26.3	58.0	239.2
Tianjin*	10.2	12.6	5.6	5.1	52.8	45.8	16.5	5.9	20.1	82.8
Hebei	115.4	60.1	14.5	3.9	89.2	23.3	69.6	8.8	71.0	123.2
Shandong	134.9	35.9	9.2	1.5	189.2	30.4	344.0	25.4	141.7	125.6
Shanghai*	35.9	38.6	0.0	0.0	27.3	17.6	48.5	16.0	24.9	89.0
Jiangsu	141.8	43.0	0.0	0.0	107.7	19.0	290.1	25.8	113.0	114.2
Zhejiang	37.3	27.3	22.2	10.6	247.5	107.3	87.4	11.0	91.7	224.1
Fujian	11.1	12.0	4.2	3.4	116.1	90.6	40.9	10.1	39.5	142.9
Guangdong	145.0	57.6	5.8	1.2	359.1	74.5	447.6	31.9	201.8	267.2
Hainan	0.1	0.6	0.0	0.0	10.1	70.1	45.1	110.2	9.3	259.5
East China total	720.0	43.8	65.5	2.3	1252.5	43.1	1503.7	21.7	771.0	156.2
Liaoning	20.0	8.6	10.4	3.4	15.5	4.9	342.5	62.5	63.9	91.5
Jilin	17.4	11.5	1.6	0.8	16.4	8.0	94.0	25.6	23.8	52.6
Heilongjiang	15.1	7.2	1.4	0.5	4.3	1.6	208.4	45.0	37.2	58.7
Northeast China total	52.5	8.8	13.4	1.7	36.1	4.6	644.9	46.8	124.9	70.0
Shanxi	33.0	25.7	3.3	1.7	27.6	14.0	60.9	16.3	26.8	69.4
Anhui	25.8	17.7	0.0	0.0	40.5	19.6	176.6	43.0	44.4	101.3
Jiangxi	18.0	23.0	1.6	1.4	53.1	45.4	35.2	12.4	24.4	103.8
Henan	128.8	58.4	13.2	3.1	121.7	28.1	67.1	7.3	82.4	124.6
Hubei	24.7	15.0	5.0	2.2	31.4	13.5	174.1	39.6	42.6	86.4
Hunan	16.3	11.7	3.9	2.1	36.1	18.8	142.9	37.7	36.3	86.5
Central China total	246.7	28.1	27.0	2.0	310.4	22.5	656.8	23.4	256.9	97.5
Inner Mongolia	5.3	2.9	1.3	0.6	31.2	13.6	50.2	11.5	17.3	31.1
Guangxi	43.0	47.7	4.4	2.7	21.6	13.2	27.4	8.9	23.5	87.0
Chongqing*	5.5	15.6	18.3	37.7	13.1	19.6	70.0	52.4	20.0	190.0
Sichuan	32.0	32.3	26.4	16.8	54.2	29.5	44.0	11.1	36.4	122.2
Guizhou	0.2	0.5	6.9	15.6	2.3	4.5	7.9	8.8	3.5	32.1
Yunnan	18.9	35.2	16.7	19.2	17.4	16.7	14.5	7.2	16.4	101.7
Tibet	1.7	29.7	1.8	20.9	4.1	38.5	12.6	51.8	3.9	229.4
Shaanxi	11.2	15.8	12.2	12.5	22.6	20.5	15.0	6.8	14.3	67.6
Gansu	2.6	4.2	3.5	4.4	16.5	20.3	6.5	4.0	6.8	36.2
Qinghai	0.1	0.7	3.4	15.1	3.6	13.7	2.6	5.3	2.2	38.8
Ningxia	3.2	19.3	3.0	12.5	14.0	52.0	18.7	27.4	8.0	159.7
Xinjiang	14.0	9.4	32.3	16.5	14.8	6.5	11.2	2.8	17.7	39.4
West China total	137.9	16.7	130.3	11.3	215.4	16.8	280.7	11.2	169.9	68.8
China total**	1157.1	29.4	236.2	3.9	1814.5	28.6	3086.1	22.7	1322.7	111.9

Notes: *, central government directly controlled municipality; **, Taiwan, Hong Kong, and Macao of China are not included in the statistics

more objective and practical in estimating the actual urbanization rate, especially in China where a large number of rural-registered workers have been migrating to the city for a long time. The urban expansion index, which includes the absolute urban expansion index (UE_a) and the relative urban expansion index (UE_r), proved to be a reliable statistic for describing patterns and processes of urban expansion of China at 1 kilometer, provincial, regional, and national scales.

The results indicate that the percentages of total land area in China occupied by urban in the late 1980s, 1995, 2000, 2005, and 2008 were approximately 0.25%, 0.32%, 0.33%, 0.43% and 0.52%, respectively. Between the late 1980s and 2008, the total urban expansion in the mainland of China was 2.645×10^4 km^2, resulting in an absolute urban expansion area of about 1322.7 km^2/yr, with the UE_r of 111.9%.

The study revealed substantial regional differences in

the urban distribution and urban expansion. There was very little urban growth in the period of 1995–2000 due to the central government initiatives designed to halt the loss of agricultural land. A spatial gradient of urbanization level is evident that runs from the east coast to the west inland, and the differences in the urbanization level between different economic regions have persisted over the past two decades. This study also briefly discussed the main driving forces hidden under the spatio-temporal patterns and processes.

The monitoring results, as well as the patterns and processes discovered in this study, provide groundwork for further investigating the concrete mechanisms or detail driving chains that drive urban land use change, and for studying the environmental effects of urbanization by linking the results to regional climate models and ecological models.

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