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Measurement of urbanization process and the paddy soil loss in Yixing city, China between 1949 and 2000

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Abstract

This study used GIS technology, remote sensing images of 1949, 1966, 1981, 1984, 1988, 1992, 1996 and 2000, to analyze the spatial process of urbanization and its impact on the soil resources in Yixing city, southeast China. The results showed that the urban area grew more than three-fold during 51 years and the loss of paddy soil accounted for 82.9% of all soil loss. According to the expansion dynamics and the results of spatial metrics, the urban expansion process in Yixing could be divided into four steps, the initial step (1949–1966), the almost standstill step (1966–1981), the preparation step (1981–1984) and the rapid growing step (after 1984). The study also indicated that the urban expansion was encouraged by the transportation system, however, restricted by the rivers, lakes and hills. The local government's decision also affected the spatial process of urban expansion. The spatial process of Yixing urban expansion might reflect the spatial process of urbanization of southeast China, the region with a rapidly growing economy.

Keywords: Urbanization; Spatial process; Morphological indices; Soil resource; China

1. Introduction

Urban expansion is one of the most prominent components of LUCC (land use/cover change) in China. Urban expansion due to residential, industrial and infrastructural land expansion has brought in great changes to China (Weng, 2002). Of all the changes, the loss of cultivated soil resource attracts the world's greatest attention, especially after Brown (1995) published his idea that China would not be able to feed itself due to the decline of food supply. Research reveals that China's total cultivated land decreased 4.73 million hectares between 1978 and 1996, and most of the loss had occurred in China's coastal and central provinces (Yang and Li, 2000). Since 1978, there has been a massive transfer of agricultural land to various uses in southeast China due to the rapid urban sprawl. In 2001, the shift from agriculture to construction land was 163,700 ha (Yang, 2004), about 20.5% of the whole loss in the year. However, in this part of the country, the decline of the paddy soil would be of great concern, because rice is served as the main food in the area. Unfortunately, there is little official information about the paddy soil loss in China; even though some information could be found in the yearly published statistics books, the data still lacks accuracy and reliability.

Since the paddy soil loss is in relation to urbanization, it is necessary to first know the Chinese urbanization process. According to the flow of rural–urban migration, Chen and Bao (1994) and Liu (1998) pointed out that China had experienced three different steps of urbanization since the foundation of the P.R. China. The period between 1949 and 1960 was regarded as the start of urbanization in China, the period between 1961 and 1978 was a standstill step, and the period after 1979 was the rapidly growing step. However, the attempt to understand the spatial process of Chinese urbanization is still hampered by the lack of official data (Lin, 2002).

Nowadays with the development of remote sensing technology, digital satellite imagery has the potential to map urban area in a more timely, cheaper and more accurate

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manner (Zhang et al., 2002; Weber and Puissant, 2003), and thus is widely used in the research of urbanization in China in recent years (Li and Yeh, 2004; Xiao et al., 2006). It makes it possible to conduct the research on spatial process of Chinese urban expansion, other than the traditional research on the quantity of urbanization measured from population (Liu and Zhou, 2005). Based on remote sensing images from 1980 to 1998, Shi et al. (2000) pointed out that the urban land use increased rapidly at the expense of great amounts of farmland in the Shenzhen city, China. Shi et al. (2002) surveyed urban expansion in Changshu city, eastern China between 1966 and 2000, and found that the city mainly expanded along rivers and transportation systems. Li and Yeh (2004) stated that there was a strong distance decay function affecting the conversion probability from agricultural land use to urban land use. However, how to quantify the urban expansion pattern is still badly needed in China.

Morphological indices have been introduced to the research of spatial process of urbanization in order to characterize the urban expanding pattern (Turner, 1987; Chust et al., 2004; Sudhira et al., 2004). A large number of morphological indices are based on patch metrics that quantify the spatial pattern at three different levels of organization: the patch itself, the land cover and the landscape (McGarigal and Marks, 1995; McGarigal et al., 2002). The metrics can be used to quantify the temporal and spatial properties of urban development, and to forecast urban growth (Herold et al., 2003). Zhang et al. (2004) made it clear that their results in the research of Shanghai, China supported the hypotheses that, with increasing urbanization, patch density increases while patch size and landscape connectivity decrease. Though some more studies have been done on Chinese spatial urbanization, however, restricted by the provision of remote sensing images, most of them focused on the period after 1986.

The aim of this study is to elucidate the spatial process of the urban expansion and the loss of paddy soil in Yixing city in the Taihu Lake region, southeastern China in seven different periods between 1949 and 2000. Our particular objectives were: (i) to monitor the urban expansion dynamics and to identify the steps of the urban expansion between 1949 and 2000 in Yixing city; (ii) to quantify the loss of paddy soil due to urbanization; (iii) to characterize the spatial expansion pattern in each period using morphological indices; and (iv) to reveal the geographic factors affecting the spatial process of urban expansion. Since Yixing is located in the fast growing economy region of China, the research on the spatial process of urban expansion might give a new vision on the urbanization process of China.

2. Area description

The study site is an area of about 15 km^2 centered on the Yixing city. The city is situated at the plain of lower reaches of Yangtze River in China. It borders on Taihu Lake and lies to the north of a hill. It is at the geographic center of the triangle, which is defined by Shanghai, Nanjing and Hangzhou, the three biggest and most rapidly growing cities in the Taihu Lake region in China (Fig. 1). The city is squeezed between two lakes, the Tuanjiu Lake to the west and the Dongjiu Lake to the east, which links to the Taihu Lake, and divided by five rivers, Yibei River, Taige River, Daxi River, Nanhong River and Chengnan River (Fig. 3). Because of the well-developed river systems and being abundant with food, Yixing represents the typical characteristics of the Taihu lake region, and is called "a land flowing with milk and honey" from ancient time. Though the river systems had brought bumper crops to the people, however, they restricted growth, so the local government decided to solve the river problems and built up many new bridges after the foundation of P.R. China.

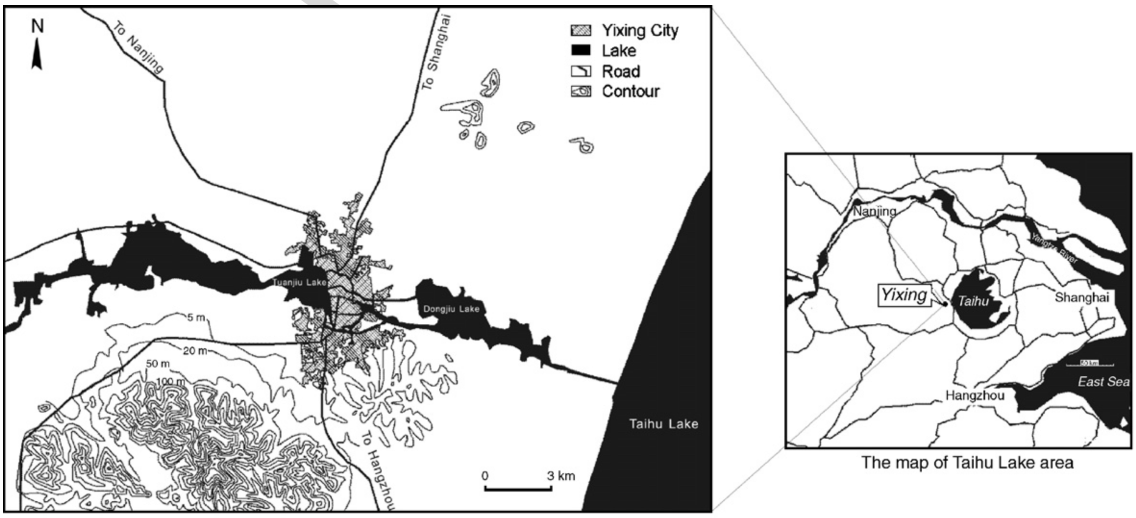

Fig. 1. The location of the Yixing city, China.

Before 1949, Yixing was a small city wrapped in the city walls, only about 90,000 people living in the urban area. However, about 2 years later with the erasing of the city walls, the city started to open to the outside and began to expand; in 2000, the population increased to 373,000 (not including the float population). The city is famous for its pottery products with the history of about 5000 years, and making pottery once occupied a very important position in economic development in Yixing, but nowadays the light industry occupies the most important part of economy.

There are four suborders of soil in the area of Yixing according to the Chinese Soil Taxonomy (Revised proposal), the Stagnic Anthrosols, the Udic Argosols, the Udic Cambosols and the Orthic Anthrosols. The Stagnic Anthrosols is the main soil type in the area and rice is the main crop in the countryside; however, in the recent years, the cropping system is changing, the percent of vegetables is increasing.

3. Materials and methods

3.1. Change detection

The maps and images used in this study are listed in Table 1. The aerial photographs of the city in 1940s and the photographs taken by CORONA satellite in 1966 are from American deciphered historic data and photographs. The other images are obtained from the commercial satellites, such as Landsat and SPOT. In order to measure urban land use at the beginning of 1980s, the topographic map drawn in 1981 is used and the quality is sufficient for the purpose. The Yixing soil map drawn in the early 1980s is also used to analyze the soil loss due to urban expansion.

All the spatial datasets were derived by visual image interpretation with the help of GIS software system to delineate the boundary between the built-up urban area and the surrounding rural land. Weber (2001) showed that it was important to develop a precise and clear definition of urban land use and land cover categories when delineating urban and rural areas. The China's Ministry of Land and Natural Resources published a land use classification system with clear definition of each kind of land use and land cover type in 2002 (http://gtgh.hebgt.gov.cn/public/show.jsp?id=20040223161141). However, there is not a special category for the urban land use, but still several sub categories are related to it, such as the business service land, the public service land, the public building land, the house land, the transportation land, etc. For Yixing city, the visual interpretation was implemented mainly based on the subcategories of the above system and the urban extent then was formed from the combination of these subcategories.

Table 1
List of the remote sensing images and other data

Data type	Time	Features of the data
Aerial photos	1949	Grayscale map, scanned
CORONA satellite photos	1966	Grayscale map, scanned with resolution of 2.7 m
Landsat TM	1984.08	False color, with resolution of 30 m
Landsat TM image	1992.06	False color, with resolution of 30 m
Landsat TM image	1996.12	False color, with resolution of 30 m
Landsat TM image	2000.03	False color, with resolution of 30 m
SPOT image	2000.11	Band Pan, with resolution of 10 m
Topographic map	1981	Scanned indexed color map, with scale of 1:50,000
Yixing soil map	Early 1980s	Scanned grayscale map, with scale of 1:50,000

Visual image interpretations were made by on-screen digitizing; this was done by first georectifying the images and other scanned maps to the same coordinate system in ArcMap, a GIS software package from ESRI (Redlands, CA), and then directly drawing polygons along the city boundaries by mouse and then saving them to different polygons. Herold et al. (2003) explained the details on how to obtain the spatial distribution of urban area using the visual interpretation method.

In the ArcMap GIS system, the first city boundary delineated from the image of 1949 was used as the basic urban boundary map. Then, on the later images, only the expanded areas were identified and delineated as new polygons (patches) with different codes to represent expansion in different periods. Finally, a complete map of urban expansion between 1949 and 2000 in seven periods was completed.

In order to get the area and the location of the paddy soil loss, the scanned Yixing soil map was also vectorized by using the visual image interpretation method. Then, by using the clip or other functions from the GIS system, the expansion patches with the soil type could be obtained for each expansion period.

3.2. Morphological analysis

GIS provides useful tools to implement the morphological approach with powerful functions and convenient modeling environments. FRAGSTATS, developed in the mid-1990s and improved continuously till 2002, is a public domain spatial metrics software. ArcMap also has the tools to do special metrics calculation in its newest version. They calculate varieties of spatial indices to measure the morphological characteristics of the landscape patches (McGarigal et al., 2002). However, how to measure the expansion patterns is still a challenge. We deem that the expansion pattern can be measured from the spatial attributes of the expanded patches, especially the size, the shape and the connection of the patches. So we select MPS, AWMSI, PROX and AWPROX to reveal the different expanding patterns in periods.

The MPS (mean patch size) measures the aggregate properties of the patches for a period. For period i, MPS equals the mean size of the entire expanded patches within the research area.

$$\mathrm{MPS}_i = \frac{\sum_{j=1}^{n} a_{ij}}{n_i} \tag{1}$$

where a_{ij} is the area of each expanded patch j in period i and n_i is the number of all the patches for period i. With smaller MPS, the expansion shows in a more scattered pattern.

AWMSI means area weighted mean shape index, equals the sum, across all patches of the expansion in period i, of each patch perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a circular standard, multiplied by the patch area (m^2) divided by total expansion area.

$$\mathrm{AWMSI}_i = \sum_{j=1}^{n} \left[\left(\frac{P_{ij}}{2\sqrt{\pi a_{ij}}} \right) \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right] \tag{2}$$

where P_{ij} is the perimeter of patch j for period i and a_{ij} is the area of patch j for period i. It measures the overall shape characteristics of the expanded patches. $\mathrm{AWMSI} \geq 1$ and increases when expansion patches are more irregular.

PROX equals the sum of patch area (m^2) divided by the nearest edge-to-edge distance squared (m^2) between the patch and the focal patch of all patches of the corresponding period whose edges are within a specified distance (m) of the focal patch. If a patch has no neighbors of the same period within the specified search radius, then the PROX value equals zero. $\mathrm{PROX} \geq 0$, and increases as patches of the same period increasingly occupy the neighborhood and as those patches become closer and less fragmented in distribution.

$$\mathrm{PROX}_{ij} = \sum_{s=1}^{n} \left[\left(\frac{a_{ijs}}{h_{ijs}^2} \right) \right] \tag{3}$$

where a_{ijs} is the area (m^2) of patch ijs within specified neighborhood (m) of patch ij, and h_{ijs} is the distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance, computed from cell center to cell center. In order to indicate the fragmentation of all the expanded patches within a period, AWPROX index is used in the study.

$$\mathrm{AWPROX}_i = \sum_{j=1}^{n} \left[\mathrm{PROX}_{ij} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right] \tag{4}$$

where a_{ij} is the area of patch j for period I and PROX_{ij} is the proximity index of each patch in a period. Since AWPROX gives more weight to larger patches, we think it will represent the whole proximity of the patches.

ArcMap software is used to calculate the MPS and AWMSI by using the urban expansion patches' vector file, while FRAGSTATS is used to calculate AWPROX value by using the Arcinfo grid file, which is rasterized from the vector file with the cell size of 20 m.

3.3. Distance analysis and zonal statistics

In order to show the spatial relationships between the expansion patches and the transportation systems and the urban area, the distance analysis tools in ArcMap were used to calculate the Euclidean distance of the expanded patches to the transportation system and the old urban boundary. The Euclidean distance functions provided in ArcMap describe each cell's relationship to a source or a set of sources. The Euclidean distance gives the distance from each cell in the raster to the closest source, such as the closest town and the transportation systems.

The zonal functions in ArcMap take the distance value raster as input and calculates for each cell some function or statistic using the value for each cell and all cells belonging to the same zone. The zonal statistics tool was used to calculate the average distance value of all expansion patches in each period.

4. Results and analysis

4.1. The expansion dynamics and the steps of urbanization

In this paper, we regard the core part of the Yixing urban area wrapped in city walls in 1949 as the initial urban extent. Fig. 2 presents eight maps showing the spatial extent of Yixing urban area in 1949, 1966, 1981, 1984, 1988, 1992, 1996 and 2000. It is clear that the Yixing city expanded enormously around the initial urban boundary in the last 51 years.

The quantities of the urban area for these 8 years and the expansion of Yixing city in seven periods are shown in Table 2. The expansion of urban area from 147.2 ha in 1949 to 1342.1 ha in 2000 shows that the urban area grew more than three-fold during the period.

The data also reveal different expansion rates at different periods. In the first two periods, the urban area expanded very slowly, only several hectares each year, 3.8 and 2.6 ha/year, respectively. However, after 1981, the average expansion rate increased to 20.0 ha/year and then doubled in the next period, and after that, the expansion rate continued to increase with the average rate of more than 60 ha/year.

Therefore, the whole process of urban expansion in Yixing after 1949 could be divided into four steps: the initial step between 1949 and 1966, the almost standstill step between 1966 and 1981, the preparation step from 1981 to 1984, and the rapid growing step after 1984. The following data on morphological indices will show more details of the four different steps in Yixing urban expansion.

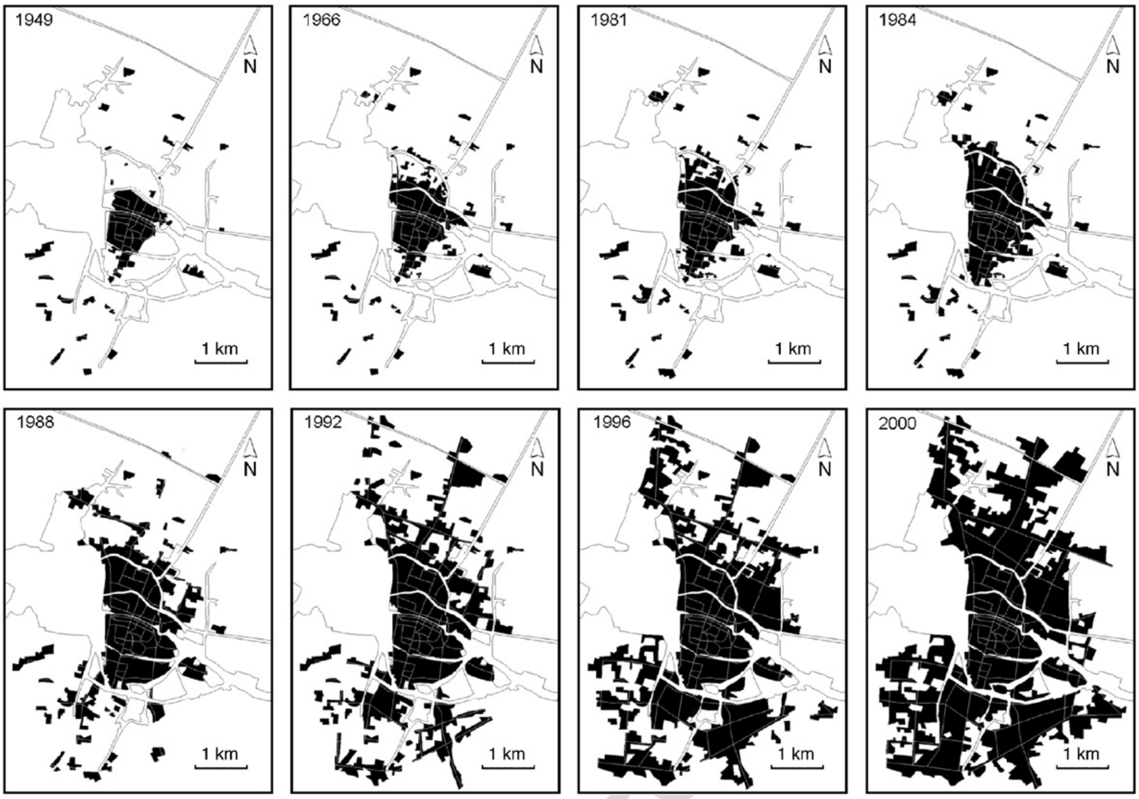

Fig. 2. The spatial distribution and sprawl of urban area in Yixing city between 1949 and 2000.

4.2. The loss of paddy soil

Since the Yixing soil map was developed from the aerial photos taken in early 1980s, we only measure the loss of paddy soil and cultivated soil after 1981. Table 3 shows the quantities of the decline of paddy soil and cultivated soil for each period. The data reveals that the loss of paddy soil and cultivated soil accounted for 82.9% and 91.9% of the total soil loss respectively, and the area of paddy soil totally lost 903 ha, about 47.5 ha/year between 1981 and 2000.

The percent of paddy soil loss is different in each period; it was 92.7% in the period between 1981 and 1984, and then it decreased to 75.5% in the period between 1992 and 1996. The declining process between 1992 and 1996 suggests that the expansion started to occupy other types of soil. We can see from Fig. 3 that the expansion to the south was very close to the hill in this period and the soil type changed to Udic Cambisols. However, in the next period, the percent of paddy soil climbed to more than 85%. This is in relation with the change of expansion direction, because of the restriction of the hill, the expansion mainly happened to the southwest and the north of the city (Fig. 3).

Table 3 also reveals that almost all of the soil occupied by the urban expansion was the cultivated soil in the first two periods. Then, the percent of cultivated soil decreased to the lowest point in the period 1992–1996 and then rose to nearly 90%. The change of the percent of the cultivated soil in the five periods is almost the same as that of the paddy soil for the same reasons.

Table 2
Areas of urban, expansion speed and morphological metrics in different periods

Year	Urbanized (ha)	Periods	Span (years)	Expansion (ha/year)	Morphological indices				Distance	
					Patch number	MPS (ha)	AWMSI	AWPROX	To urban (m)	To road (m)
1949	147.2									
1966	211.5	1949–1966	17	3.8	27	2.39	2.50	35.3	338	53
1981	250.8	1966–1981	15	2.6	27	1.45	1.68	2.8	681	70
1984	310.8	1981–1984	3	20.0	24	2.51	2.02	16.0	463	53
1988	472.9	1984–1988	4	40.5	40	4.05	1.78	14.9	920	80
1992	719.3	1988–1992	4	61.6	53	4.64	2.12	19.6	1500	87
1996	1001.6	1992–1996	4	70.6	53	5.32	1.86	24.8	1448	117
2000	1342.1	1996–2000	4	85.1	60	5.67	1.84	30.3	1631	184

Table 3
The decline of paddy soil and cultivated soil due to urbanization

Periods	Total expansion (ha)	Area of paddy soil loss	Area of cultivated soil loss	Paddy soil loss (% of total)	Cultivated soil loss (% of total)
1981–1984	59.9	55.5	59.9	92.7	100.0
1984–1988	162.1	137.8	161.0	85.0	99.3
1988–1992	246.5	207.2	228.5	84.1	92.7
1992–1996	280.5	211.9	245.6	75.5	87.6
1996–2000	340.5	290.6	305.7	85.3	89.8
1981–2000	1089.4	903.0	1000.7	82.9	91.9

4.3. Spatial patterns of urban expansion in different periods

The change in urban expansion patterns in different periods can be seen in Fig. 3; however, the spatial metrics give more details (Table 2). As we know, the distribution and quantity of expansion in each period is directly related to the duration of expansion period; it is ideal to measure the MPS, AWMSI and AWPROX values based on the same duration. Table 2 shows that the durations of the expansion periods are different; however, the first two periods almost have the same duration (17 and 15 years, respectively), and the later five ones almost have the same duration of 4 years. This suggests that it still be meaningful to compare the morphological indices between the first two periods and among the later five ones.

Though the number of expansion patches is the same, the MPS, AWMSI and AWPROX values are very different in the first two periods, especially the AWPROX value (Table 2). This indicates that the expansion patterns are very different in the first two periods. Furthermore, the morphological indices in the first period are greater than those in the next period, which suggests that the expanded patches be more aggregated and connected in the first period than in the second period. Table 2 also shows that the MPS, AWMSI and AWPROX values in the second period are the lowest in the seven periods, which indicates that the urban expansion almost stopped in the second period.

However, after 1981, since the extent of each period is almost the same, the comparisons of the morphological indices between these periods are more meaningful. Though the AWMSI increases to a peak in the period from 1988 to 1992, it did not change so much after 1981. This means the shape of the expansion remained the same. However, the other indices are different. The MPS value was no more than 2.51 ha before 1984; however, it increased to more than double in each of the later period. The MPS value increases with time, which means that the expansion patches are becoming more and more aggregated after 1984. The AWPROX value also increased with time after 1984, which means that the patches are becoming more and more connected. From the above, we can conclude that after 1984 the urban expanded in a block pattern, with more aggregated and connected patches as compared to the former periods.

Furthermore, in the periods after 1981, the lowest MPS and the number of patches in the period between 1981 and 1984 indicate that the expansion pattern is different from those of the later ones. The higher AWMSI also shows that the expansion is mainly along the road and the city boundary. All these mean that the urban area was about to enter into a fast expanding step. Consequently, the different spatial patterns also support the division of the urban expanding steps.

4.4. The geographic factors that affecting the spatial process

Fig. 3 also shows that the water area strictly restricts urban expansion. The entire shape of Yixing city looks just like a dumbbell expanding to the north and south directions due to the restriction of the two lakes. The rivers also limit the urban expansion. From 1949 to 1984, the urban expanded almost all within the Yibei River and the Chengnan River except very small part beyond the Yibei River in the north (Fig. 3). However, after 1984, the city expanded quickly to the outer space.

The hill to the south also affects the urban expansion in Yixing. Before 1984, the utmost part of the urban area was still more than 1.5 km away from the southern hill; however, in the period between 1992 and 1996, the urban area had already expanded to the foot of the hill. Then, the southern urban area started to expand along the roads of the east and west directions (Fig. 3).

The transportation system is a very important factor affecting urban expansion. The expansion in the earlier years was almost all distributed around the old urban boundary; however, after 1984, the urban area expanded mainly along the transportation system (Fig. 3). The result of distance analysis reveals that the impact from transportation system and from urban boundary is different from each other. The average distance of the patches to the transportation system is shorter than to the old urban boundary (Table 2). This means that the transportation system has bigger weight on the expansion. Table 2 also shows that, with the urban area expanding, the patches go farther and farther from the old urban area, but still close to the transportation system.

In addition, the local government's decisions have a strong influence on the urban expansion. The Yixing Industrial Park for Environment-Protection in southwest

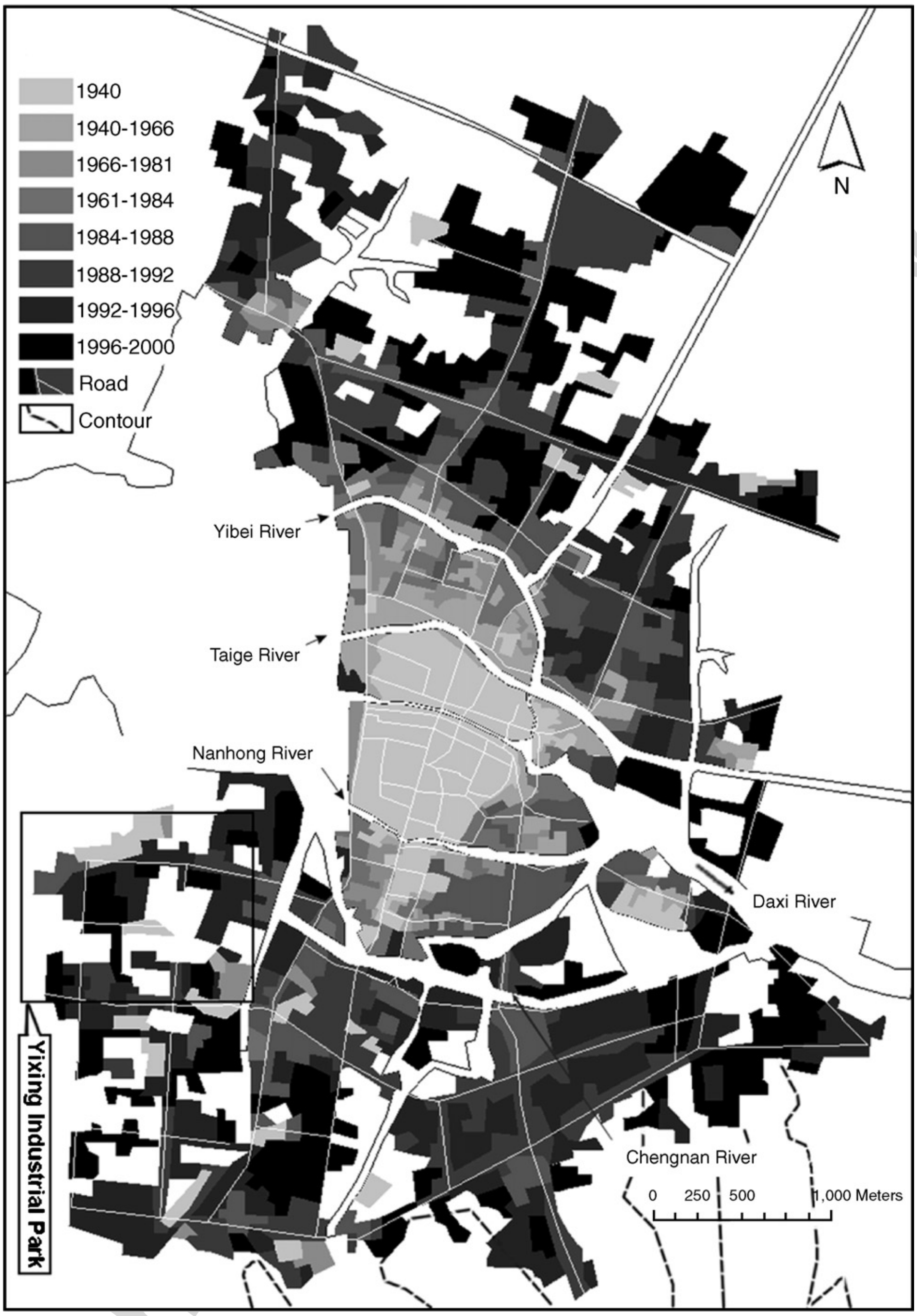

Fig. 3. The urban expansion in Yixing city in different periods.

Yixing was set up in 1992, which stimulated a quick expansion in the southwest. The relocation of the Yixing administration to a new area in the south near the hill also resulted in a new expansion.

Though Yao (1997) stated that the city's expansion is affected by many factors, including those of geographic conditions, the urban public establishment and urban land use; however, from the results of our research, the transportation systems, topographical factors and river systems are the most important factors. The government's decisions are crucial factors as well.

5. Discussion

The integrated application of remote sensing technology, spatial analysis and morphological analysis represented an innovative approach for the study of spatial urbanization process and the affect of urban expansion on the soil resource. The study made use of precious historical photos and Landsat TM images to identify and delineate the Yixing's urban built-up area by using visual image interpretation method. On such basis, the research used morphological indices and spatial analysis method to monitor the loss of soil resource, to reveal the spatial expansion pattern, and to analyze the geographical factors that affecting the urban expansion.

The comprehensive method used in the research is useful to other relevant research. China is now at the time of fast urbanization and the decline of cultivated soil is becoming a serious problem to the country's food security. However, the monitoring of the urban expansion and the soil loss is still lacking. The research provides a method not only to monitor the urbanization process and its impact to soil resource, but also to analyze the expansion pattern effectively. The method in the research is also applicable to the plain area in the southeast China, where river system and lakes developed very well and where the economy grows very fast in the last two decades. Since urban expansion is the most prominent part of land use change in this area, the research on the spatial process of urbanization in the Yixing city would be a very good help to know the whole urbanization process of the fast growing area after the foundation of P.R. China.

According to the results, the expansion mainly occupied paddy soil in an accelerating trend. As we know, the soil near the city and the transportation system usually is more suitable for urban expansion, while it is more fertile and productive, so the loss of the soil resource near the city would result in more possible decline of food production. The China government knew the situation at the beginning of the fast growing period, and adopted the "basic farmland protection areas regulation" policy to protect some of the soil from being developed as industrial land and urban land. However, the insufficient utilization of land resource wasted a large amount of cultivated soil. The Yixing Industrial Park for Environment-Protection located in southwest Yixing was set up in 1992; however, there were still some place remained bare in 2000 (Fig. 3). Therefore, how to use soil resource sufficiently and effectively is still a question to the country.

The research of spatial process of urban expansion in Yixing city gives a new vision on Chinese urbanization process between the foundations of P.R. China in 1949 and 2000. The expansion quantities and the morphological indices show that the expansion in the period from 1949 to 1966 is at an initial step, in which the urban area expanded slowly along the old urban boundary, and in the period from 1966 to 1981 is at a standstill step, expansions were minimal and more scattered. Then, followed by a preparation step from 1981 to 1984, the urban area entered into a rapidly growing step after 1984. Once in the rapid step, the urban expanded in a block pattern, formed more and more aggregated and connected patches, and reached farer and farer region from the old urban boundary.

The division of the urbanization step from the spatial process is different from that of the urbanization process measured by the rural–urban migration. According to the flow of rural–urban migration, three different steps of urbanization since the foundation of the P.R. China were recognized (Chen and Bao, 1994; Liu, 1998). The first two steps from the spatial expansion and from the migration of rural–urban are almost the same; however, the rapid urban expansion step did not start from 1978 in Yixing. We believe that it is more reasonable that a Chinese city started to expand spatially several years later after China began its economic reform in 1978. As studied before (Shi et al., 2002), the urban expansion is very much affected by GDP and the development of industry; however, the urban area in 1978 is still at the beginning of economic development. Only after 5 or 6 years of economic preparation did the city accumulate enough capital to support rapid urban expansion. Therefore, the preparation period is clearly and reasonably added to the urbanization period measured by the migration of rural population to urban.

The changes of morphological indices support the above mentioned step division of the urban expansion in Yixing in the last 51 years. The urban expansion started in a more aggregated pattern; however, this is the result for the 17 years in the first period. If the expansion patches were measured in each year, the expansion might be more scattered. During the second period, the morphological indices reveal that this is a more scattered and less connected expansion step, because the expansion was very limited, and some of the patches were far from the old boundary. The distance analysis in the period from 1981 to 1984 suggests that the expansion happened still close to the old urban boundary and were nearer to the roads (Table 2); therefore, the patches are slimmer and connected. Then, after 1984, the expansion patches distributed mainly along the transportation system and formed more aggregated and connected patches. These results might be different from the common sense that, with urban expansion, the landscape would change to a more fragmentized state (Zhang et al., 2004); however, when considering the expansion itself, the patches tend to be more aggregated and connected.

The urbanization process is affected by the urban boundary, the transportation system, the water and the topographical conditions. The expansion is encouraged by the transportation system, however, restricted by the water and the hill nearside. Before the rapid expansion step, the urban expansion was always along the old urban boundary and the road. Once in the rapid step, the expansions distributed mainly along the transportation system in block pattern at first, and then fill in the blocks between the urbanized areas.

Though some historical aerial photos are used in the research and this greatly make up some insufficient of the earlier research on Chinese urbanization, the research is still needed to be improved. With more historic images and photos, the spatial metrics could be more accurate and the urban expansion dynamic could be more precise.

6. Conclusion

The integrated method by using remote sensing technology, GIS spatial analysis and morphological analysis is helpful to reveal the spatial process of urbanization, and to analyze the loss of soil resource in China. During the urbanization, the loss of paddy soil accounts for the main part of all the decline of soil resource; this is the most prominent change of land use in the area of southeast China. The measurement of spatial process of urbanization in Yixing gives a new vision on Chinese urbanization; the division of four steps of urbanization is more reasonable than the traditional division of Chinese urbanization from the measurement of rural–urban migration.

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