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A Study of Urban Expansion in the Urban Administrative Districts of Wuhan City, 1987-2005: A Remote Sensing and GIS Perspective

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Abstract: This study estimates the spatiotemporal characteristics of urban expansion in the urban districts of Wuhan city using remote sensing and GIS techniques. Three Landsat TM images for 1987, 1994 and 2005, are interpreted to get vector land use datasets. To conceive urban land dynamics over the period under review, the urban land area dynamics are calculated for each of the 9 urban administrative districts of Wuhan city (Dongxihu, Qiaokou, Wuchang, Hanyang, Hongshan, Qingshan, Jiangan, Jianghan and Caidian). Results indicate that urban development was achieving momentum at the urban fringe, expanding more noticeably during the 1994-2005 period than in the previous 7 years. Large scale new (Greenfield) investments in development zones and in urban infrastructure development, rather than local land users, are the primary drivers of urban land expansion in Wuhan city.

Key words: Urban expansion, urban districts, remote sensing, GIS

INTRODUCTION

Urbanisation is perhaps one of the most widespread environmental changes of the 21st century with enormous impacts at the local, regional and global scales. The conversion of agricultural or natural areas to urban use is now the greatest source of landscape and forest fragmentation on earth (Munroe *et al*., 2005; Alig *et al*., 2004; Seto and Kaufmann, 2003). Although, urbanisation in the form of land-cover (either built-up or impervious surfaces) occupies only about 0.3% of the earth's land surface (Angel *et al*., 2005), there is plentiful evidence that human disturbance due to urbanisation has significantly altered the natural landscape. For example, urbanised areas are responsible for 97% of global anthropogenic CO_2 emissions (Svirejeva-Hopkins *et al*., 2004); carbon dioxide being the gas that generates most of the global warming (Intergovernmental Panel on Climate Change-IPCC, 2007). Transport, industries, the conversion of natural areas to urban land and cement production for the building sector are the major sources of the carbon emissions in the cities. Urbanisation changes the characteristics of the vegetation and soils on the territories of the cities, which in turn leads to the change of parameters of the carbon cycle (Svirejeva-Hopkins *et al*., 2004). Given these impacts, understanding the mechanisms that drive urbanisation is critical to an understanding of global environmental change and sustainable development.

Based upon a case study of Wuhan city, this study examines the spatial temporal characteristics of urban expansion in the nine urban administrative districts, using the 2003 city boundary (the most recent we could obtain). Although, the study primarily focuses on Wuhan city, the findings and discussion will provide insights for other Chinese cities in reviewing their development strategies as most of them are sharing similar urban expansion challenges.

MATERIALS AND METHODS

Study area: Wuhan is located in central China in Hubei Province (Fig. 1 a,b). Its East Longitude extends from 113°41'-115°05' and its North Latitude from 29°58'-31°22'. Wuhan lies east of the Jianghan Plain, at the confluence of the middle reaches of the Yangtze River and Hanshui River. The metropolitan area comprises 3 parts, Wuchang, Hankou and Hanyang, commonly referred to as the Three Towns of Wuhan, hence the name Wuhan, which is a combination of Wu from Wuchang and Han from Hankou and Hanyang. These 3 cities were consolidated in 1927 when Wuhan was established. The 3 towns of Wuhan face each other across the Yangtze and Han rivers and are linked by about 4 bridges at present.

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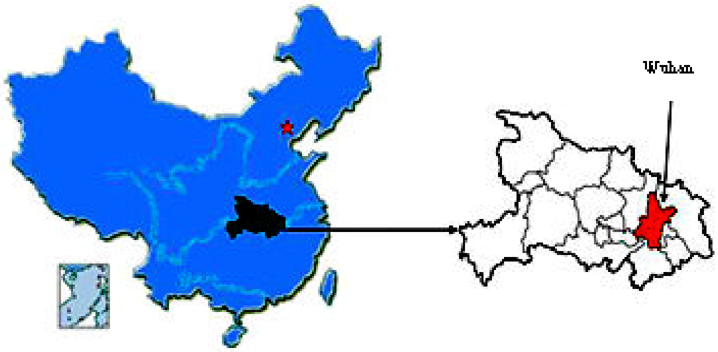

Fig. 1: (a) Location of Hubei province in China (b) Location of Wuhan in Hubei province

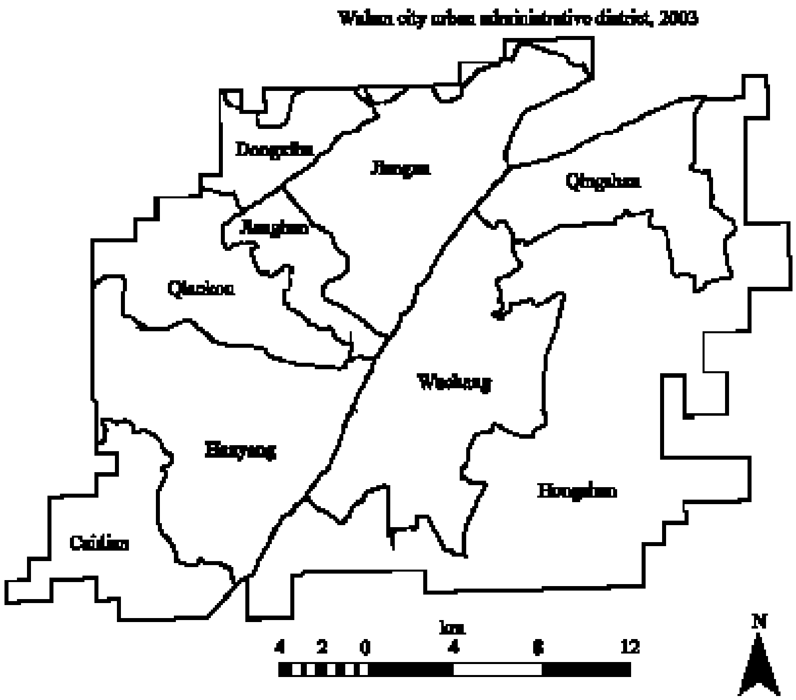

Fig. 2: Urban administrative districts of Wuhan city, 2003 city boundary

Wuhan's geographical structure is simple, mostly low and flat in the middle and hilly in the south, with the Yangtze and Han rivers winding through the city. The city covers an area of 8, 494.41 km^2, most of which is plain and surrounded by hills and a large number of lakes and pools. The city's climate is subtropical monsoon with abundant rainfall and distinctive four seasons. Wuhan is known for its oppressively humid summers when dewpoints can often reach 26°C or more. Spring and autumn are generally mild, while winter is cool with occasional snow. In the past 30 years, the average annual rainfall is 1,269 mm, mainly from June to August; annual temperature is 15.8-17.5°C; annual frost free period lasts from 211-272 days and annual sunlight duration is 1,810-2,100 h. As of August 2007, Wuhan's population was estimated to be 9.7 million of which 6.7 million is urban.

Change detection: The biophysical data of urban expansion in the urban administrative districts of Wuhan city (Fig. 2) were obtained through the change detection analysis of remote sensing imagery. Three Landsat Thematic Mapper (TM) images in (September 26, 1987) (September 29, 1994) and (May 6, 2005) (Fig. 3-5) were interpreted to obtain land use vector datasets. Obtaining images at near anniversary dates is considered important for change detection studies (Jensen, 2007). However, the summer image in 2005 was unavailable. The post-classification image comparison method was adopted in

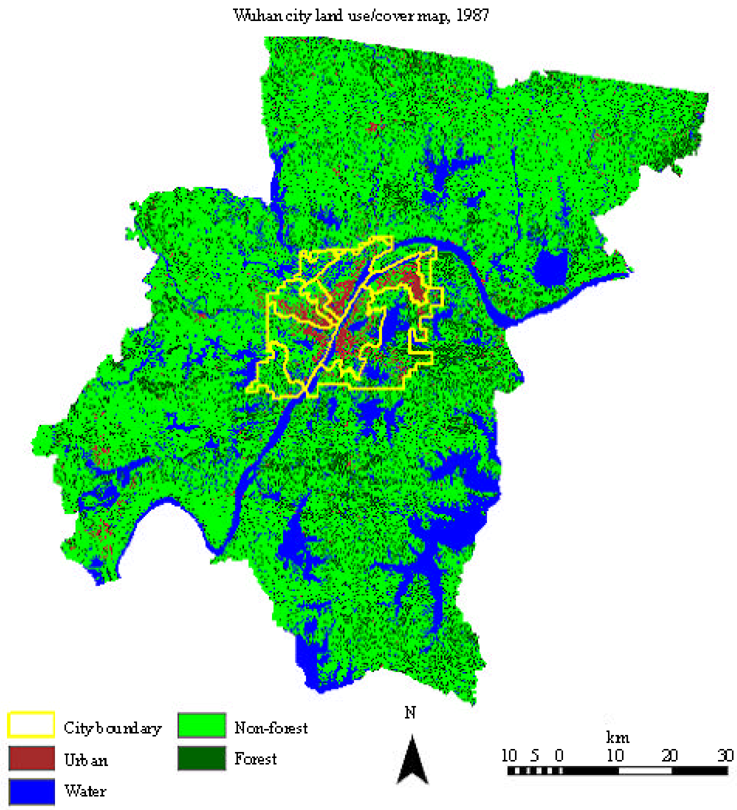

Fig. 3: Wuhan city land use/cover map, 1987

this study to extract the dynamic change vector datasets of land use. The TM image in 1987 was used to interpret the dynamic change vector data by comparing with the vector data derived from interpreting the TM image in 1994. The same method was applied for the period 1994-2005.

The images were classified using four land use/land cover classes: Urban (built-up), water, non-forest and forest. The built-up class depicts residential areas of single houses and apartment buildings, shopping centers, industrial and commercial facilities, highways and major streets and associated properties and parking lots. The non-forest class includes grasslands, bush land and cropland. Change analysis was performed on each image using ERDAS 9.0. Land use classification was done using the supervised maximum likelihood method. Each Landsat image was enhanced using linear-contrast stretching and histogram equalization to improve the image and help identify ground control points during rectification. The images from the 3 periods were corrected to a common UTM coordinate system, Datum WGS 1984; zone 49 North based on 1:50 000 scale topographic maps. These data were resampled using the nearest neighbor algorithm to keep the original brightness values of pixels unchanged. The resultant Root Mean-Squared (RMS) error was found to be 0.46, 0.5 and 0.44 pixels for the 1987, 1994 and 2005 imagery, respectively.

Before interpreting the images, field trips were conducted to familiarise the researcher with the study area, identify training sites for classification and to collect ground control points using a hand-held Global Positioning System (GPS) which would be used for accuracy assessment after classification. A total of about 120 ground points were collected in several parts of Wuhan city which fall within scene 123-39 (path and row, respectively). A complete coverage of Wuhan city area requires 4 scenes with the following path and row numbers, respectively: 122-38, 122-39, 123-38 and 123-39. Only scene 123-39 (Fig. 2-4) is used for analysis for each of the years under consideration in this study. This is because the other scenes for the years under consideration were not available. Also, scene 123-39 covers the entire urban area of Wuhan city, meaning it was sufficient to meet the objectives of this study.Because the validation through ground truthing was done in April 2008, when the most recent image we have is for 2005, not all ground control points collected during field work could be used for accuracy assessment.

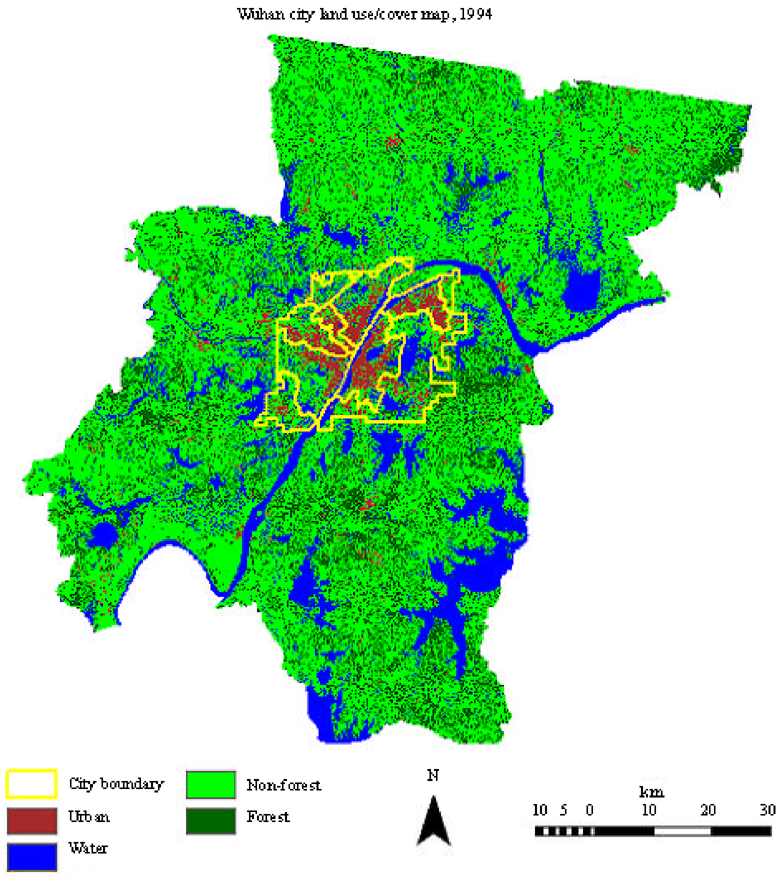

Fig. 4: Wuhan city land use/cover map, 1994

This was because some of the land use types observed during field work were a result of change. Therefore, areas that did not change throughout the study period were identified on the images and used for accuracy assessment. The overall accuracy of land use/cover maps for 1987, 1994 and 2005 were 89.32, 87.17 and 88.29%, respectively. The KAPPA indices were 0.87, 0.85 and 0.86 for 1987, 1994 and 2005, respectively. The highest accuracy rate is found for non-forest and, in descending order, urban, water and forest. The wrong identities of land use patches were all corrected. Field surveys and existing land use maps that have been field-checked and Google Earth (especially the parts of the city that are overlaid with large-scale aerial photos and Quickbird images) were employed as reference data for the assessment of the classification and accuracy.

Estimating the nature, location and rate of urban expansion: In order to estimate the nature, location and rate of urban expansion, the classified TM images were imported into ArcMap 9.2. First, the images were converted into vector format. There was no need of re-converting the vector datasets into grid raters because they all had the same resolution (cell size) of 25 m. The district boundary vector layer (Fig. 2) was first spatially adjusted using the Spatial Adjustment tool of ArcMap based on the 2005 image. The 2003 district boundary is the most recent we are able to find and the overlay with the TM imagery is shown in Fig. 2-4.Because of the difficulty of finding matching points on the TM image and the boundary layer for spatial adjustment, the boundary layer was first overlaid with a roads layer (with same projection) and then the roads were used to adjust both layers (roads and city boundary) since, roads can be clearly seen on the 2005 TM image. The resultant Root Mean-Squared (RMS) error was found to be 3.59 and was deemed to be satisfactory. Typically an RMS error of less than or equal to half the pixel size of the control layer (12.5 m in this case) is acceptable. The district boundary layer was then overlaid with each of the classified TM image vector layers using the Intersect function of ArcMap. Using the Calculate Area function of ArcMap, land area for each land use type in each district was calculated on the intersect output. All the districts were

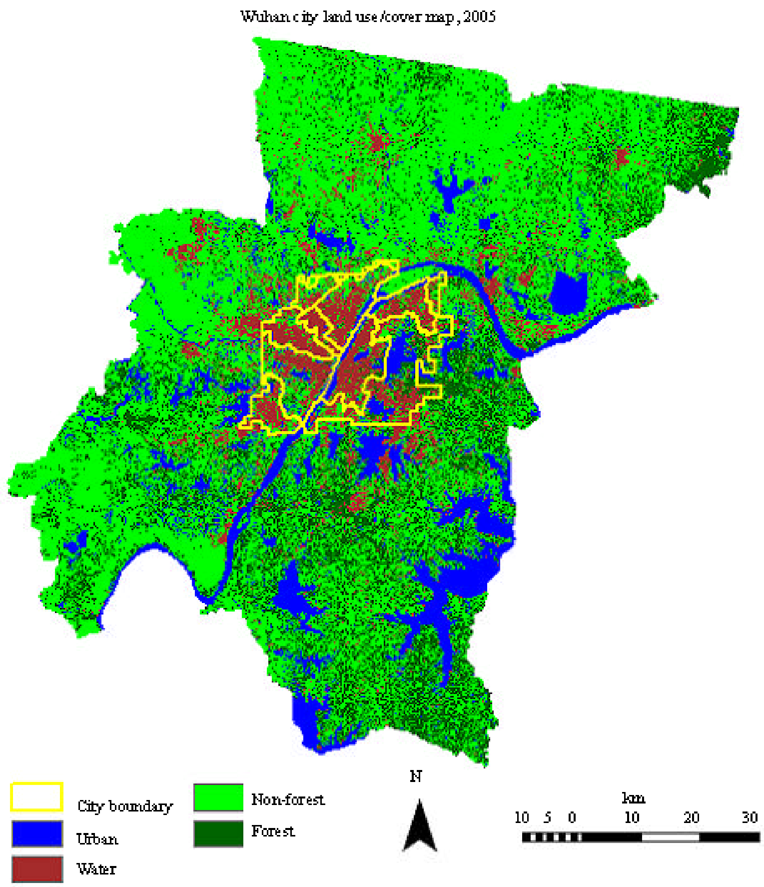

Fig. 5: Wuhan city land use/cover map, 2005

selected by attribute after opening the attribute table of each intersect output. In this way, the area of each district was easily exported into excel for further analyses. Because the TM images were referenced to the UTM system which is in meters, the area obtained was in meters. This had to be divided by 10000 to convert the area from meters to hectares (ha).

RESULTS AND DISCUSSION

Land use/cover dynamics for all the districts, 1987-2005: The results for land use changes for all the districts over the entire study period of 1987-2005 are shown in Table 1. As expected, urban area increased throughout the study period. It increased by 7,270.92 ha (11.02%) between 1987 and 1994, from 10,174.82 ha (15.42%) to 17,445.74 ha (26.44%), respectively. It increased by 13,764.07 ha (20.86%) between 1994 and 2005, from 17,445.74 ha (26.44%) to 31,209.81 ha (47.31%), respectively. One thing is apparent, that the annual increase rate of urban area during the 1994-2005 period (about 2.0%) over 11 years is somewhat slower compared to that for the 1987-1994 period (1.6%) over 7 years. This can be attributed to the agricultural land protection ordinance which was introduced by the Chinese government in 1994. However, urban expansion was still at the expense of mostly non-forest area most of which is agricultural land. Non-forest area declined by -5,338.03 ha (-8.09%), respectively, from 33,677.91 ha (51.05%) to 28,339.88 ha (42.96%) over the 1987-1994 period. It further declined by a large margin of -11,669.12 ha (-17.69%), respectively, from 28,339.88 ha (42.96%) to 16,670.76 ha (25.27%) during 1994-2005 period. Water saw a relatively large decline of -3,649.71 ha (-5.53%) over 1994-2005 compared to -1,209.49 ha (-1.83%) over the1987-1994 period, respectively. Forest lost -2,523.03 ha (-3.82%) during 1987-1994 period which was almost completely reversed by its increase of 2,454.58 ha (3.72%) during the 1994-2005 period. The increase in forest area reflects the policy of allowing agricultural lands to revert to forest land and reforestation launched by the Chinese government in the early 1990s. In addition, most of the

Table 1: Land use/cover dynamics for all the districts, 1987-2005

	1987		1994		2005		Change in 1987-1994		Change in 1994-2005	
Land use type	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)
Urban	10174.82	15.42	17445.74	26.44	31209.81	47.31	7270.92	11.02	13764.07	20.86
Water	15889.32	24.08	14679.83	22.25	11030.12	16.72	-1209.49	-1.83	-3649.71	-5.53
N/forest	33677.91	51.05	28339.88	42.96	16670.76	25.27	-5338.03	-8.09	-11669.1	-17.69
Forest	7132.01	10.81	4608.98	6.99	7063.56	10.71	-2523.03	-3.82	2454.58	3.72

Table 2: Urban area dynamics by district, 1987-2005

	1987		1994		2005		Change in 1987-1994		Change in 1994-2005	
District	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)
Dongxihu	46.54	1.97	190.60	8.06	824.12	34.86	144.06	6.09	633.52	26.79
Qiaokou	1138.34	23.24	2209.70	45.12	3624.62	74.01	1071.36	21.87	1414.92	28.89
Wuchang	2080.85	22.76	3541.06	38.73	5369.47	58.73	1460.22	15.97	1828.41	20.00
Hanyang	1245.94	13.08	2011.74	21.12	3767.71	39.56	765.79	8.04	1755.97	18.44
Hongshan	1228.88	6.08	2272.67	11.25	6198.80	30.67	1043.79	5.16	3926.14	19.43
Qingshan	1833.23	36.95	2570.32	51.81	2816.09	56.76	737.09	14.86	245.77	4.95
Jiangan	1740.52	21.49	2578.84	31.83	4223.54	52.14	838.32	10.35	1644.70	20.30
Jianghan	860.49	39.27	1578.87	72.06	1932.26	88.19	718.38	32.79	353.39	16.13
Caidian	0.04	0.00	491.95	10.74	2453.19	53.53	491.90	10.73	1961.25	42.80

forest around Wuhan city occurs on hills or protected forest parks both of which cannot be converted into urban use.

Land use/cover dynamics by district-urban area: A closer look at land use/cover dynamics by district reveals a more detailed picture of the dynamics over the study period. For urban land (built-up area) (Table 2), all the districts experienced an increase in urban area during 1987-2005 study period. The influence of the 1994 agricultural land protection ordinance is obvious. For example, the difference in the increase in urban area during 1994-2005 compared to 1987-1994 period is <500 ha for Dongxihu, Qiaokou and Wuchang districts. It is above 500 ha but <1.000 ha for Hanyang and Jiangan, while Qingshan and Jianghan districts actually recorded a reduced increase during 1994-2005 compared to 1987-1994. Only Hongshan (2,882.34 ha) and Caidian (1,469.34 ha) districts registered huge differences in increases during 1994-2005 compared to the 1987-1994 period. Overall and in absolute terms, Hongshan (3,926.14 ha) had the largest increase and was followed by Wuchang (1,828.41 ha) and Hanyang (1,755.97 ha) during the 1994-2005 period. Caidian's (1,961.25 ha) expansion during 1994-2005 cannot be sustained because it was a result of the establishment of Wuhan economic and technological development zone in 1991. Given its small area size (4,582.62 ha) based on the 2003 city boundary, it has no much space for further expansion.

The hot spots for urban expansion, in order of magnitude, are therefore Hongshan, Wuchang, Hanyang and Jiangan, based on absolute increases in urban area during the 1994-2005 period (Table 2) and construction activities that can be observed in those districts. For example, the first phase of the Grand Ocean shopping area, which will supposedly have the world's longest Pedestrian Street, has been completed in Hongshan district, opposite Huazhong University of Science and Technology. This is an on-going development which is earmarked to cover a large expanse of land on its eastern side along the *Luo Yu* road. A similar situation is obtaining in Wuchang, Hanyang and Jiangan districts not to mention the numerous infrastructure developments (roads and bridges) and housing re-development projects in all the districts which typically involve knocking down old housing apartments and replacing them with new, usually middle and upper end apartments. There are cross-roads (interchanges) currently being constructed at the junctions of Xu Dong and Zhong Bei roads and Zhuo Dao Quan and Luo Yu roads both of which are in Hongshan district. The main reason why Hongshan, Hanyang, Wuchang and Jiangan will be the focus of future urban expansion is because these four are the largest districts in terms of total area (20,209.12; 9,524.44; 9,142.60 and 8,100.91 ha, respectively). Thus, by default, they have large space on which urban expansion can take place, particularly agricultural land which can easily be converted to urban use. This is truer for Hongshan district which includes a large rural portion in its jurisdiction. The other 5 districts, Dongxihu, Qiaokou, Qingshan, Jianghan and Caidian are relatively small with total areas of less than 5,000 ha each. This is not to suggest that the smaller districts cannot expand on account of the size of the current boundaries. City boundaries in China frequently change to facilitate expansion of urban areas.

The main driving force for urban expansion in Wuhan city, like it is the case in other Chinese cities, is the

Table 3: Water area dynamics by district, 1987-2005

	1987		1994		2005		Change in 1987-1994		Change in 1994-2005	
District	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)
Dongxihu	765.38	32.37	564.61	23.88	74.33	3.14	-200.78	-8.49	-490.28	-20.74
Qiaokou	453.97	9.27	322.43	6.58	125.03	2.55	-131.53	-2.69	-197.40	-4.03
Wuchang	2644.08	28.92	2530.34	27.68	1849.04	20.22	-113.74	-1.24	-681.30	-7.45
Hanyang	2236.05	23.48	2384.05	25.03	1765.06	18.53	148.00	1.55	-618.99	-6.50
Hongshan	5238.80	25.92	4928.04	24.39	4492.84	22.23	-310.77	-1.54	-435.20	-2.15
Qingshan	935.28	18.85	951.02	19.17	862.32	17.38	15.74	0.32	-88.70	-1.79
Jiangan	2703.88	33.38	2123.99	26.22	1199.17	14.80	-579.89	-7.16	-924.82	-11.42
Jianghan	197.26	9.00	122.17	5.58	88.15	4.02	-75.09	-3.43	-34.01	-1.55
Caidian	714.63	15.59	753.19	16.44	574.19	12.53	38.56	0.84	-179.01	-3.91

Table 4: Non-forest area dynamics by district, 1987-2005

	1987		1994		2005		Change in 1987-1994		Change in 1994-2005	
District	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)
Dongxihu	1425.08	60.27	1409.68	59.62	1295.04	54.77	-15.40	-0.65	-114.64	-4.85
Qiaokou	3148.54	64.29	2119.02	43.27	986.40	20.14	-1029.52	-21.02	-1132.62	-23.13
Wuchang	3521.15	38.51	2674.98	29.26	1159.99	12.69	-846.17	-9.26	-1514.99	-16.57
Hanyang	5334.03	56.00	4583.04	48.12	3282.80	34.47	-750.99	-7.88	-1300.24	-13.65
Hongshan	10753.11	53.21	9853.30	48.76	5344.05	26.44	-899.81	-4.45	-4509.25	-22.31
Qingshan	1818.06	36.64	1338.04	26.97	810.84	16.34	-480.02	-9.67	-527.20	-10.63
Jiangan	3324.26	41.04	3028.10	37.38	2347.29	28.98	-296.16	-3.66	-680.81	-8.40
Jianghan	1087.18	49.62	459.82	20.99	148.66	6.78	-627.36	-28.63	-311.16	-14.20
Caidian	3266.50	71.28	2873.90	62.71	1295.69	28.27	-392.60	-8.57	-1578.21	-34.44

phenomenon of development zones that are created to host foreign direst investment. The major development zones in Wuhan city include Wuhan Economic and Technological Development Zone, Wuhan East Lake High-Tech Park, Wujiashan Taiwan Businessmen Investment Zone, Guandong and Guannan Industrial Parks and Nanhu and Changhong Industrial Parks. There are many others in each district of Wuhan city. Most development zones are discontinuous from the built-up area and are located on the urban fringe, where farmland has to be expropriated from peasants and local government needs to invest in basic infrastructure, including roads, water, drainage system and power. Comprising industrial, commercial and residential land uses and occupying large amount of farmland (sometimes over 80%) (Deng and Huang, 2004), development zones are often like a huge expansion of the old city in one direction and around a new center. The result of such development is an urban structure with twin-cities or dual-centers, one old and one new (Deng and Huang, 2004). Caidian district in which the Wuhan Economic and Technological Development Zone is located is a typical example of this type (dual-centers) of development. From zero urban area in 1987, it increased to 491.95 ha in 1994 and to 1,961.25 ha in 2005 (Table 2), essentially creating a new mini city where none existed before. This implies that large scale new (Greenfield) investments in development zones and in urban infrastructure development, rather than local land users, are the primary drivers of urban land expansion in Wuhan city.

Land use/cover dynamics by district-water area: Theoretically, water bodies should be completely excluded from urban land cover change detection analysis. However, the case of Wuhan city is special in the sense that 7.69% land cover change in the period 1987-2005 came from water bodies, which include ponds and lakes. These are mostly small-scale water body or the fringe of a large lake. In the period 1991-2002, the area of the water bodies in Wuhan city was reduced to be less then of one fourth of the total land area. Only about 27 lakes remain, which was in sharp contrast with the 300 large lakes in the early 20th century (Han and Wu, 2004). Therefore, water is included in this analysis (Table 3). The largest losses in water were recorded in Jiangan, Wuchang, Hanyang and Dongxihu with losses varying from -114.24 to -924.82 ha. Jiangan saw the largest declines of -579.89 and -924.82 ha during 1987-1994 and 1994-2005 periods, respectively (Table 3). Most of the water bodies, especially small lakes and ponds, should have been taken up by urban development.

Land use/cover dynamics by district, non-forest area: With regards to non-forest area dynamics (Table 4), the largest declines and in order of magnitude were noted in Hongshan, Qiaokou, Wuchang and Hanyang. Hongshan experienced the largest loss with -899.81 and -4,509.25 ha during 1987-1994 and 1994-2005 periods, respectively. Qingshan, Jiangan, Jianghan and Caidian districts recorded declines of between -296.16 to -680.81 ha over the 1987-2005 study period, but Caidian had a rather huge decline of -1,578.21 ha (Table 4) during the 1994-2005

Table 5: Forest area dynamics by district, 1987-2005

	1987		1994		2005		Change in 1987-1994		Change in 1994-2005	
District	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)	Area ha^{-1}	(%)
Dongxihu	127.33	5.39	199.45	8.44	170.84	7.23	72.12	3.05	-28.61	-1.21
Qiaokou	156.86	3.20	246.55	5.03	161.65	3.30	89.69	1.83	-84.90	-1.73
Wuchang	896.53	9.81	396.22	4.33	764.10	8.36	-500.31	-5.47	367.88	4.02
Hanyang	708.42	7.44	545.62	5.73	708.87	7.44	-162.80	-1.71	163.25	1.71
Hongshan	3888.13	19.24	2255.30	11.16	4173.43	20.65	-1632.83	-8.08	1918.13	9.49
Qingshan	374.93	7.56	102.12	2.06	472.26	9.52	-272.81	-5.50	370.13	7.46
Jiangan	332.26	4.10	369.98	4.57	330.92	4.08	37.72	0.47	-39.06	-0.48
Jianghan	46.11	2.10	30.17	1.38	21.95	1.00	-15.94	-0.73	-8.22	-0.37
Caidian	601.44	13.12	463.58	10.12	259.55	5.66	-137.87	-3.01	-204.03	-4.45

period due to obvious reasons already alluded to elsewhere in this study. Dongxihu district had the lowest declines in non-forest area, -15.40 ha and -114.64 ha during 1987-1994 and 1994-2005 periods, respectively (Table 4). Since, Dongxihu recorded large declines in water area (Table 3), it is highly likely that most of the urban expansion that took place in that district occurred on water bodies. Large declines in non-forest area, most of which is agricultural land, could signal the need to further enhance, the protection of agricultural land.

Land use changes by district-forest area: Forest area presents some interesting findings (Table 5). Whereas there was zero increase in non-forest area and only a negligible increase in water area (Hanyang, 1.55% and Qingshan, 0.32% during 1987-1994 period) (Table 3) over the entire study period 1987-2005, there was quite some noticeable increase in forest area especially during 1994-2005. Hongshan, Qingshan, Hanyang, Dongxihu and Qiaokou districts all recorded net gains in forest area over the 1987-2005 period, their losses in forest area were completely offset by their increases (Table 5). For example Hongshan's loss of -1,632.83 ha during 1987-1994 was completely reversed by its gain of 1,918.13 ha during the 1994-2005 period (Table 5). Wuchang and Jiangan had net losses even though they had some gains during one of the 2 periods. Caidian and Jianghan had net losses during the entire study period, 1987-2005. The reasons for the losses and gains in forest area during the study period have already been intimated elsewhere in this study.

Urban expansion obviously comes with unintended negative impacts that have policy implications, particularly for urban planning. Pollution, including air, water and solid wastes, presents one of the major challenges of rapid urban expansion in Wuhan city. For example, a recent study by Liu *et al.* (2008) has revealed that heavy metal pollution in urban lakes of Wuhan city has increased following rapid urbanisation and industrialisation over the last 2 decades. Their analyses of sediment samples obtained from Moshui Lake in Hanyang district established that the total concentration of heavy metals (e.g., chromium, copper, nickel, lead, zinc) in the sediment was higher than the Severe Effect Level (SEL) at all sampling sites, except those in the riparian zone. The maximum concentrations for chromium and copper were, respectively, approximately 16 and 11 times beyond the SEL values and they appeared as deep as 32 cm in one sample (Liu *et al.*, 2008). Similar pollution concerns were revealed in a study of the Wuhan section of the Yangtze River by Wang *et al.* (2008).

A study by Zhang *et al.* (2007) examined surface water in two contrasting peri-urban areas, a Factory-Based (FB) area and a Vegetable-Based (VB) area, in the Yangtze River Delta region to determine the distribution of heavy metals, nitrogen and phosphorus as well as the speciation of nitrogen and phosphorus. They established that the concentrations of heavy metals (including zinc, copper, chromium and lead) in the surface water in the FB area were higher than those in the VB area. This suggested contamination of surface water from discharge of factory effluent in the FB area but not the VB area (Zhang *et al.*, 2007). Recently, The World Wide Fund for Nature (WWF) has listed the Yangtze among the world's most threatened rivers, its major threat being pollution (Wong *et al.*, 2007). In 2003, the East Lake had 27 discharging points to it and received about 300,000 tons of wastewater daily. Only about half of the wastewater received was treated (Han and Wu, 2004).

Wuhan's commercial and industrial zones have relatively high concentrations of trace metals in atmospheric particulates. For example, a study of PM10 at one urban (Hankou) and one industrial (Changqian) site in Wuhan city found relatively high levels of arsenic, cadmium, manganese, lead and zinc compared with other Asian cities (Hong Kong, Taiwan, Tokyo) (Weiwei *et al.*, 2006). The major sources of the trace metals at Changqian included smelting, coal combustion, traffic, secondary aerosols and steel manufacture. At Hankou, pollution from Changqian, secondary aerosols and traffic were the main sources (Weiwei *et al.*, 2006). These are some of the immediate challenges that urban planners have to deal with as Wuhan city keeps expanding.

CONCLUSION

Land use/cover change detection analysis derived from remote sensing technique has provided an accurate account of urban land expansion dynamics in the urban districts of Wuhan city during the period 1987-2005. The analysis of the associations between the interpreted TM imagery and the actual changes that took place in each district was made visual and intuitive with GIS mapping techniques. Thus, the combined use of remote sensing and GIS in urban change detection analyses need not be overemphasised. We have established that relatively fast urban expansion has occurred in the urban districts of Wuhan city during the period 1987-2005. The largest expansion took place in Hongshan, Wuchang, Hanyang and Jiangan districts, which at the same time are the likely focal centers for future urban expansion. New investments in development zones that are usually established at the urban fringe and are backed by large foreign direct investments, rather than the local land users, are the main forces driving urban expansion in Wuhan city. Non-forest land, most of which could be agricultural land, is experiencing the largest losses to urban development. It could be a signal to further enhance agricultural land protection. Unintended negative impacts that accompany urban growth such as water and air pollution are not insurmountable. Given the resoluteness of the Chinese government in dealing with air and water pollution problems in terms of allocation of funds, technology and highly qualified expertise, the challenges of urban growth will be resolved.

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