Remote Sensing and GIS for Urban Growth Analysis in China

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Abstract
The progress of urban remote sensing and GIS in China since the early 1980s is reviewed. The first section introduces the early applications of remote sensing to environmental monitoring and resources investigation, and outlines its achievements. The second section focuses on further analysis of urban expansion from the point of view of spatial distribution patterns and temporal change, taking Beijing, Shanghai, and Dongguan as examples. Urban GIS is discussed in the third section. The regional differences of urban development in China are detailed from south to north. As remote sensing and GIS technologies develop, they will be combined for use in urban planning and management.

Development of Urban Remote Sensing in the 20th Century
A city can be regarded as a hinged center of material flows, energy flows, and information flows within a region. In other words, it is a mixed complex of social and economic development, and regional resources exploitation, continuously promoting productivity levels and the standard of living in the region. We may describe this as similar to the working of the human kidney, which constantly outputs waste products and replaces them with fresh products. Processes of urbanization reflect not only the progress and development of regions, but also mark regional cultures and civilizations of an epoch. Facing rapid change and a complicated urban system, we undoubtedly need to apply 20th century space and aerial techniques for dynamic monitoring. Furthermore, only cities can meet the needs of the high input-and-output talents and funds for GIS and remote sensing applications.

In 1800, the number of urban residents represented only 2 percent of the total population of the world, while the number had reached 10 percent by the beginning of 20th century. Almost two-hundred years later, the urban population has grown to over 3.2 billion, equally half of the global population, and it increases by an average of 1,000,000 people per week. Between 1970 and 1985, the number of people below the poverty line in urban areas increased by 22 percent, so that the problem was more serious for those in urban areas.

In 1993, about 330-million urban residents lived in urban areas of 16,000 km² in China, the numbers of urban residents having doubled from those of the 1970s. Today there are over 660 cities with residential populations of more than 500,000. China is both a country with a huge population and an Asian-Pacific country with a rapidly developing economy. As urbanization processes are being accelerated and more and more mega-cities are appearing, the Chinese population will increase from 1.2 billion to 1.6 billion in the 21st century. Correspondingly, the urban population will reach 29 percent in 2020 and 47 percent in 2050 (Yang, 1996). We will then have to face a series of environmental problems, such as a water resource crisis, increased air pollution, and waste treatment problems. We will have to make a series of decisions, such as construction planning and land management. All of these situations will stimulate the promotion of geographic information systems (GIS) and remote sensing monitoring to deal with present and future urban problems.

Under China’s extended open-door policy and the establishment of special economic regions, development zones, and bonded duty zones throughout the country, regional development in coastal areas has advanced rapidly since the 1980s. Four highly dense urban regions have gradually formed in the Shandong Peninsula, the Liaodong (eastern Liaoning) Peninsula, the Beijing-Tianjin-Tangshan region, the Yangtse River Delta, and the Pearl River Delta. Sixteen mega-cities are distributed along 18,000 kilometers of China’s coastline, including the Special Administrative Region of Hong Kong, along with 102 large-and medium-size cities and 278 small-size towns. Meanwhile, four huge, densely populated urban areas are scattered along the 6,300-kilometer Yangtse River. These include Shanghai, Nanjing, Wuhan, and Chengqing. There are, however, few cities of such size in the wider western and middle inland areas of China, with the exception of Zhengzhou, Xian, and Harbin. The trend of urban distribution mentioned above further enlarges the gap between both sides along the Tang-chong-Ailu population distribution line.

In the early 1980s, aerial and satellite remote sensing techniques were applied to environmental monitoring, land resources investigation, and urban planning and management in China. Tianjin was the first city to conduct an aerial remote sensing experiment. Land-use and land-cover maps were produced, based on false-color infrared images. Meanwhile, environmental quality evaluation was conducted on air, water source and float dust, and content of sulfur dioxide through aerosol sampling and monitoring data of air pollution. The research results were published in the Tianjin Atlas of Environment Quality (Chen, 1986). This achievement had a positive effect on municipal engineering construction projects such as pollution protection of the Haihe River, crossroad planning, planting survival rate, harbor deposit monitoring, and coastal zone development with remote sensing data and maps. It also supplied a scientific basis for the application for a World Bank loan for municipal infrastructure construction. In 1985, NOAA AVHRR and Landsat MSS images were used to evaluate the Ecology and Environment in the Beijing-Tianjin-Tangshan region (Fu and Cao, 1989).

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In 1983, aerial remote sensing was successfully applied to tourism, land resources investigation, transportation, and heat islands in Beijing. The results show, for example, that the length of Great Wall sites should be extended from 276 km to 673 km, and the distribution of rubbish heaps and the construction sites between the second and the third ring roads were illustrated. It provided a basis for allocating seven waste treatment facilities and also provided the site selection for the Asian Olympic Game Park.

During 1985 and 1995, a series of investigations were carried out with aerial infrared remote sensing on ecological and environmental issues for Taiyuan, Dalian, Guangzhou, and 90 other large- and medium-size cities in China. In Shanghai, for instance, urban land-use patterns, heat-island effects, and parkland expansion rates were analyzed by means of Landsat TM images. In Luoyang, Yichang, Suzhou, and other medium-size cities, aerial photos and SPOT images were used to produce reference maps for urban planning and infrastructure investment, sponsored by the World Bank.

In order to carry out a sustainable development strategy, utilize land reasonably, and preserve farmland, the State Land Management Bureau organized remote sensing investigations on the propriety of urban land use in large- and middle-size cities throughout the country. The statistics from 66 cities show that cities located in the eastern plains occupy huge amounts of farmland while the proportions are lower in coastal cities or hilly areas along rivers (Plate 1). This investigation will be extended to cover more than 200 large and middle-size cities in China by the year 2000.

The trend in urban GIS is gradually changing from an urban dynamic monitoring system to construction of a long-term urban information system. According to our primary study (Chen et al., 1998), the trend started slowly, but developed rapidly in the southern coastal cities in China. Urban planning and land-management information systems have been developed for these cities. The large cities in the Yangtze River Basin have built their urban information systems into a public benefit supported by provincial governments, with the provision of services for related departments of planning and management. For most large cities in the northern mainland of China, however, urban GIS are still at the research and development stage, or the experimental stage.

The waves of remote sensing and GIS development are generally harmonious with the level of productivity. Their spread is advancing from south to north, in a fashion similar to that of the modern democratic revolution and economic reforms in China. Regional differences remain quite high. In order to continue making progress, we must be able to transmit modern ideas, make reasonable rules, and foster effective outreach policies.

With the development of urbanization and the increasingly wide application of remote sensing and the Global Positioning System (GPS), the technical theories of urban planning and management are gradually being perfected based on GIS. They are moving from the phase of scientific experiments to the industrialization phase, and from governmental actions to enterprise activities and socialization. The National Remote Sensing Center of China carried out research on the criteria for a resource and environmental information system in 1983. The State Standard Bureau and State Mapping and Surveying Bureau jointly established the standard for the urban information system in 1996. A set of monographs and teaching materi-

![Plate 1. Urban expansion in China (original map scale of 1:25,000,000 reduced to 1:40,000,000).](image-url)
als about urban remote sensing and GIS have been available since then (Gong, 1997; Song and Yeh, 1995).

In the 1990s, Chinese urban remote sensing continued to move forward. Remote sensing data were used to trace the course of urbanization and the history of urban evolution, and to explore the pulse of urban development. This provided the scientific basis for establishing an urban development plan. In addition, multiple remote sensing data were used not only as the main information source for updating the database of the urban GIS, but also as the operating system for urban dynamic monitoring.

Spatial and Temporal Analysis of Urban Growth
The development of Chinese cities has a long history, and there are large regional differences. The construction of new urban areas and the reconstruction of old zones continues with unprecedented speed. Many existing environmental problems remain unsolved while more and more new problems have come into being. Therefore, the applications of remote sensing and GIS have become the focus of interest of both urban planning and management departments and experts of RS and GIS, who wish to gain a deeper understanding of problems such as urban-rural changes, landscape structure, and environmental quality.

Beijing Case
The first false-color infrared aerial photographs were taken over Beijing in 1983. Twenty-seven thematic maps were made from these photographs (Chen, 1986; Fu and Cao, 1989). Prof. Dai Changda (Dai et al., 1996) used TM images dated 26 September 1987, 17 October 1989, 25 October 1992, and 7 September 1994 to detect land-use change in Beijing. It was found that the builtup area in Beijing increased about 39 percent from 1987 to 1994. New greenbelts were established in suburban and rural areas. In 1987, parkland in Beijing and its eight satellite cities occupied 8.5 percent of the total area. This increased to 16.93 percent in 1994. Obviously, this percentage is still very low. The transportation network has rapidly expanded into the suburbs. The third and fourth ring roads were legible on the TM images. In 1967 there were about 20 roads connected with these two main roads. In 1994, however, there were more than 100. Thus, traffic accidents and traffic jams increased significantly. Bei-jing is one of the few major world cities without a river. In the 1980s the area of public water surface was only 5.9 km². This went up to 20 km² in the 1990s, the increase being mainly the result of an increase in the number of fishponds in the area.

Research by Prof. Gu (Gu, 1997) revealed the trends of Beijing dynamic change. The commercial downtown areas declined and needed full reconstruction. For example, 31 supermarkets were constructed in 1995, while 60 supermarkets were reconstructed in the 1996 to 1997 time period. Land-use patterns in the inner city are changing. In 1998, 35 towns and industrial zones were constructed in the outer suburbs, distributed in a ring whose radius extended some 20 to 70 km from the city center. Three-hundred fifty-eight industrial enterprises inside the third ring road, which occupy 40,000 m², are being moved out to the suburbs in rapid succession. A large number of villas and recreational villages are being constructed in the outer suburbs.

Shanghai Case
The first aerial photographs were taken over Shanghai in 1947 at a scale of 1:8,000. Since 1984, aerial infrared photography surveying has been carried out ten times, at scales ranging from 1:10,000 to 1:35,000. All these photographs were widely used in the investigation of city construction; water, air, and waste pollution; urban environment; ecological environment and land use; as well as archaeology and disaster research (Sun and Zhou, 1994). For example, remote sensing photos and images acquired in 1993-1994 were used during extant land investigation and mapping. All the results were used in the modification of master urban planning for Shanghai (Mei, 1992). Through the survey and research, we obtained all the neces-
sary data regarding construction density and dangerous house distribution. At the same time, the research analyzed the geometric scales of urban roads, public parking lots, and the speed, density, and flow of vehicles. A general environmental quality assessment model of the Pudong District was established based on land use, parklands, dumping of solid waste, pollution of surface water, and distribution of feedlots. A three-dimensional simulation of urban parkland growth was conducted. The ecological and economic benefits of existing parklands were assessed. The urban heat island, as well as the type and distribution of land surface, was studied.

At the same time, the progress and regularity of Shanghai's urbanization in the past half century were studied. Using 14,000 aerial photos, ten Landsat MSS images, ten Landsat TM images, and some SPOT images, we discovered that the built-up area in Shanghai had expanded from 91 km² in 1947 to 364 km² in 1996 (Plate 2). The rate of increase was not uniform over the years and the region, as listed in Table 1. The rate was 3.43 km² per year from 1949 to 1964, 1.31 km² per year from 1964 to 1979, and 10.33 km² per year from 1970 to 1996. For example, the Pudong District expanded only 25 km² from 1947 to 1988 before opening, averaging 0.61 km² per year. After opening in 1989, the Pudong District expanded to 78 km² in 1993, 96 km² in 1996, totally 57 km², with an average of 8.14 km² per year.

**Table 1. Urban Growth in Shanghai**

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<tr>
<td>Built-Up Area (km²)</td>
<td>91.6</td>
<td>127.4</td>
<td>150.1</td>
<td>169.6</td>
<td>188.1</td>
<td>215.7</td>
<td>241.2</td>
<td>364.0</td>
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<td>Increased Area</td>
<td>35.8</td>
<td>22.7</td>
<td>19.5</td>
<td>18.5</td>
<td>27.6</td>
<td>27.6</td>
<td>25.5</td>
<td>122.8</td>
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<tr>
<td>Rate of Increase</td>
<td>3.25</td>
<td>3.78</td>
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Urban Remote Sensing in Chongqing City

Chongqing became a provincial-level municipality in 1997 with an area expanding from 23,000 km² to 82,000 km², and covering 80 percent of the Three Gorges reservoir area. Chongqing is facing arduous problems such as rebuilding the old industrial bases, assisting with migration resulting from the Three Gorges Dam project, and protecting the environment. Therefore, remote sensing and GIS technologies are of great value in helping to solve the problems of city reconstruction, farmland misuse, deforestation, and water and soil loss.

1:60,000-scale aerial false-color infrared photography with a swath width of 15 km was taken in the area along the Yangtze River in 1984. Infrared photography at a 1:10,000-scale of city areas and 1:10,000-scale of 772 km² of suburban areas was taken again in 1992 to 1993. MSS images were also used to investigate urban landforms in 1989, and the development of an urban geographic information system began in 1996. The system has been put into operation to provide basic information for regional planning and urban construction.

Town Development for Migration in the Three Gorges Reservoir Area

The world-renowned Three Gorges Dam is now under construction. After completion, the reservoir will cover an area of 1,084 km². Two cities, 11 counties, 111 towns, and 1,599 factories need to be moved out. About 32,000 ha of farmland, forest, and river shoals will be submerged and 1.2 million residents will have to be re-located (Chen and Wei, 1999). In order to manage this unparalleled huge migration, satellite and airborne remote sensing, GPS, and GIS technologies have been used to supervise the status and dynamic change information.

At the beginning of the project evaluation, land resources in the reservoir area were investigated using satellite and airborne remote sensing, and an atlas of the Yangtze River Three Gorges ecological environment was published (Y. Chen, 1999).

Immediately following government approval of the project in May 1993, several teams were organized to devise the plans for the emigrations that were to take place in the Three Gorges reservoir area in Fengjie, Wushan, and Badong counties, based on several time phases such as pre-closure of dam in 1997, and the second phase of emigration in 2003 (Wang, 1998; Wang, 1997).
New Trends in Urban Remote Sensing and Information Systems

Urban Database Updating by Using High Spatial Resolution Satellite Images

The atlas Space View of Hong Kong, published in 1999 (Chen et al., 1999), consists of high-resolution images such as the Russian COSMOS (2 meters), French SPOT-4 (10 meters), Canadian RADARSAT (10 meters) satellite images, and Chinese scientific experience satellite images (3 meters). These images and their corresponding interpretation maps vividly depict the achievement of Hong Kong urban development programs, providing first-hand data for updating the urban database. The four new towns of Quanwan, Shatin, Tunmen, and Dapu have developed into satellite towns. Yuen Long, Fanling, and Sheung Shui are also rapidly developing. The development of these new towns provides a great amount of land, with a well-developed infrastructure for industry and business, and more space for an improved residential environment in Hong Kong. Thematic maps such as vegetation types and vegetation index, land use and land cover, nature reserves, and natural disasters were made from these images.

Aerial Three-Dimensional Remote Sensing for Dynamic Monitoring of Urban Environment and Cadastral Surveying

Towards the end of the 1960s, the Chinese central government drew up a plan for remote sensing technology in China. Since then, research and development of remote sensing sensors have been included in the National Five-Year plans. The new remote sensing technologies have been applied to resource exploration and environmental monitoring. For example, the dynamic three-dimensional aerial remote sensing imager, developed by the academician Xue Yongqi and Professor Li Shukai's team, was used to acquire three-dimensional urban remote sensing images under the integration technologies of GPS, laser telemeter, and imaging spectral cell matching just before the return of Macao to Chinese sovereignty in December 1999 (refer to page 591 of this issue).

The Application of Resource Satellite Remote Sensing Images to Urban Planning and Management

Urban growth is not an isolated phenomenon. Cities and their satellite towns are influenced by and dependent upon each other. For example, the growth of a mega-city may promote or impede the development of adjacent cities. Annexation and amalgamation between cities forms group cities or city cycles. Satellite remote sensing again becomes a higher-level hotspot for regional town planning. Current satellite image data with medium spatial resolution will continue to play an important role.

In the early 1990s, Landsat TM and MSS images were used during town systems research in China. The images were used to calculate the populated areas in the North China plain, the Yangtze and Pearl river deltas, the Liaodong peninsula, and the Sichuan basin. A cell-based population density map was produced. This method is especially applicable to the population census in northwest China where the population is sparse. In October 1999, China and Brazil cooperatively launched the BERS-1 resource satellite. The satellite has two multi-spectral scanners with spatial resolutions of 19.5 meters and 80 meters, respectively. We will use them to acquire data about the latest national town development in order to revise the layout of town systems for the twenty-first century.

Acknowledgment

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References


(Note: The customary western practice of listing author's family names last, except in the list of references where only the first author's name is listed family name first, is followed herein.)

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