Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing

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Abstract

This paper presents an integrated study of urbanization trends in Shijiazhuang City, Hebei Province of China, by using Geographical Information Systems (GIS) and remote sensing. The study explores the temporal and spatial characteristics of urban expansion from 1934 to 2001, and land use/cover change from 1987 to 2001. Temporally, urban expansion shows fast and slow growth stages, with the high-speed growth districts shifting to the east or west side of the city. The spatial patterns of urban growth can be categorized into three types: special objectives oriented type, social-political intervention type, and normal urban growth type. The remotely detected land use/cover change from 1987 to 2001 shows that the land use/cover was largely changed. The land use/cover conversion relationship implies that these changes are governed by urban expansion, which produces a force to drive the land use changes in search of a higher return. Lastly, the major factors influencing urban expansion and land use/cover change are also discussed. In general, the population, traffic conditions, industrialization, and policy are the major factors that influenced the urban expansion.

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Keywords: Urban expansion; Land cover change; GIS; Remote sensing; TM; Shijiazhuang

1. Introduction

In recent decades, research on land use/land cover change has become an important aspect of global change, or global warming studies, since land use/land cover change is a major factor for global change...
because of its interactions with climate, ecosystem processes, biogeochemical cycles, biodiversity, and, even more important, human activities (e.g., López et al., 2001; Aguilar et al., 2003). For this reason, Land Use and Land Cover Change (LUCC) was, therefore, treated as one core joint project of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Program on Global Environmental Change (IHDP). In the last 10 years, much more attention has been paid to urban land use/land cover change because ecosystems in urban areas are strongly affected by human activities and have close relations with the life of almost half of the world’s population (Stow and Chen, 2002).

Remote sensing provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency. Dating back to 1960, remote sensing can also provide consistent historical time series data. The importance of remote sensing was emphasized as a “unique view” of the spatial and temporal dynamics of the processes in urban growth and land use change (Herold et al., 2003). Satellite remote sensing techniques have, therefore, been widely used in detecting and monitoring land cover change at various scales with useful results (e.g., Stefanov et al., 2001; Wilson et al., 2003). Recently, remote sensing has been used in combination with Geographical Information Systems (GIS) and Global Positioning Systems to assess land cover change more effectively than by remote sensing data only (Müller and Zeller, 2002; Weng, 2002). It has already proved useful in mapping urban areas, and as data source for the analysis and modeling of urban growth and land use/land cover change (e.g., Grey et al., 2003; Herold et al., 2003; Wilson et al., 2003).

China has experienced rapid development over the last two decades. Together with economic development, the landscape has changed significantly (Liu et al., 2003). In the context of urbanization, large amounts of agricultural lands have been changed with built-up or urban land-use. The impacts of the landscape change on the environment due to urbanization are significant (Carlson and Traci Arthur, 2000; Shen et al., 2003). In China, research has reported on the urbanization and consequential land cover change of some large cities such as Beijing (Gu, 1999; Liu et al., 2000), Guangzhou (Weng, 2002), of the new economic star city of Shenzhen (Shi et al., 2000; Sui and Zeng, 2001), and of the historical city of Lhasa (Zhang et al., 2000). However, less attention has been paid to the big cities in the middle of China which correctly depict the general situation of urbanization and consequential landscape change in China.

Shijiazhuang, as the capital of Hebei Province, is a typical city in the middle of China. Its developmental characteristics and land use change provide good representatives of the middle China cities, since most of them have experienced the same political, economic, and technical revolution events. In this study, we use the spatial analysis function of GIS to specify the urban expansion characteristics of Shijiazhuang City, China, during the past 70 years, and then, use two scenes of Landsat Thematic Mapper (TM) images to detect and evaluate the land use and land cover change that occurred in the last 14 years. The objectives of the present study are:

- to explore the temporal and spatial characteristics of urban expansion in last 70 years;
- to detect and evaluate the land use and land cover change due to urbanization between 1987 and 2001, and output land cover maps; and
- to analyze the main factors governing urbanization and land use and land cover change.

2. Description of the study area

The study area is located in North China (Fig. 1) between the range of 114°23'E–114°42'E and 37°58'N–38°60'N, with an area of around 341.63 km², which covers the whole city of Shijiazhuang and its near suburban fringe. Shijiazhuang lies on the alluvial fan of Hutuo river with a slight slope of about 1.5% declining from Northwest to Southeast. The semiarid monsoon climate determines its precipitation, which is only about 500 mm/year with around two-thirds of which occurring in July and August. Hutuo river runs through the North side of Shijiazhuang, and has become a seasonal river mainly due to the mass exploitation and utilization of water resources in the North China plain over the last 40 years. Nowadays, the regional water scarcity in the whole North China plain is becoming the biggest environmental problem and the barrier to sustainable development.
Shijiazhuang is the capital and the largest city in the Hebei Province and is important as the center of administration, culture, economy and transportation. The current population is around 1.6 million. In the early 1900s, it was just a small village with less than 600 inhabitants. The construction of the Jing-Guang railway line (Beijing to Guangzhou) and Shi-Tai line (Shijiazhuang to Taiyuan) provided it a good opportunity for development. During WWII, the city extended fast because of its important position in military operations. After becoming the capital of Hebei Province in 1968, it experienced rapid development with expansion of its urban extent. Especially in the last 20 years of economic reform, urban expansion in Shijiazhuang has been very significant. According to the Economic Annals of 2001, its population and built-up area are 1.6 million and 165.5 km². As a result, the landscape of Shijiazhuang region was largely changed. The impacts on the hydrological environment due to urbanization are very significant in this case (Shen et al., 2003).

3. Materials and methods

3.1. Data

In this study, multi-annual socio-economic statistical data, multi-temporal city maps, and two scenes of satellite multi-spectral image are collected for evaluating the temporal and spatial characteristics of urban expansion from 1934 to 2001 and the land use land cover change between 1987 and 2001. The materials used in this study are listed in Table 1.
Table 1
List of the materials and data used in this research

<table>
<thead>
<tr>
<th>Data types</th>
<th>Year</th>
<th>Producer/provider</th>
<th>Process</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map of Shimen City (1:70,000)</td>
<td>1934</td>
<td>Department of Defense, Republic of China</td>
<td>Digitalization; coordinates integration</td>
<td>Map of urban region in 1934</td>
</tr>
<tr>
<td>Map of Shijiazhuang (1:150,000)</td>
<td>1947</td>
<td>Unknown(^a)</td>
<td>Same as above</td>
<td>Map of urban region in 1947</td>
</tr>
<tr>
<td>Topographical map of</td>
<td>1981</td>
<td>Bureau of Survey and Cartography, Hebei</td>
<td>Same as above</td>
<td>Map of urban region in 1981</td>
</tr>
<tr>
<td>Shijiazhuang (1:100,000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use map of Shijiazhuang</td>
<td>1991</td>
<td>Bureau of Land Resources, Hebei</td>
<td>Same as above; make ground truth dataset.</td>
<td>Map of urban region in 1991; Ground truth dataset.</td>
</tr>
<tr>
<td>Prefecture (1:150,000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map of Shijiazhuang city</td>
<td>2001</td>
<td>Shijiazhuang Bureau of Urban Planning</td>
<td>Same as above</td>
<td>Map of urban region in 2001; ground truth dataset.</td>
</tr>
<tr>
<td>(1:100,000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite images</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 5 TM</td>
<td>1987/06/29</td>
<td>NASA</td>
<td>Geometric correction; Enhancement; Classification</td>
<td>Land use and land cover map in 1987</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>2001/05/10</td>
<td>NASA</td>
<td>Same as above</td>
<td>Land use and land cover map in 2001</td>
</tr>
<tr>
<td>Socio-economic records:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shijiazhuang</td>
<td>1996, 1999</td>
<td>of Land Resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Province</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local chronicles of Shijiazhuang</td>
<td></td>
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</tbody>
</table>

\(^a\) This map is adopted from Shijiazhuang Urban Planning Bureau, 1994.

periods were determined for calculating the extension rate. Fig. 2 shows the urban area of Shijiazhuang city in different historical periods. Use of historical maps to extract the boundaries of the city to investigate patterns of urban expansion is relatively simple and can collect information from the pre-satellite ages. Even though it might have some potential errors in accuracy, because the maps have been drawn up with various degrees of accuracy, the influence of this variability will be minimal due to the relatively coarse time scales used in the present study.

3.3. Annual urban growth rate

In order to evaluate the spatial distribution of urban expansion intensity, we adapted an indicator called annual urban growth rate (AGR) for evaluating the ‘urbanization’ speed of unit area. AGR is defined as follows:

\[
AGR = \frac{U_{A_{n+i}} - U_{A_i}}{nT_{A_{n+i}}} \times 100\%
\]

where \(T_{A_{n+i}}\) is the total land area of the target unit to be calculated at the time point of \(i + n\); \(U_{A_{n+i}}\) and \(U_{A_i}\) the urban area or built-up area in the target unit at time \(i + n\) and \(i\), respectively, and \(n\) is the interval of the calculating period (in years). Generally, the target-calculating unit is set to the administrative district so as to link with administration or economic statistics. In this research, we preferred the geographical gridding unit since the administrative borders have been changed so frequently in this city. The maps were therefore gridded as 1 km \(\times\) 1 km units, and the annual urban growth rates of each unit were then calculated. Lastly,
the grid-based annual urban growth rates were clustered by using natural break method, and mapped to evaluate the spatial features of the ‘expansion’.

3.4. Satellite image pre-processing

Two scenes of Landsat images were collected for analyzing land use land cover change between 1987 and 2001. One was Landsat 5 TM image recorded on June 29, 1987 and the other was Landsat 7 ETM+ image recorded on May 10, 2001. Both images are cloud free. First, the image in 1987 was geometrically corrected to Universal Transverse Mercator map projection system. Then the image in 2001 was also geo-encoded and matched to the TM image with the total RMS error of less than half-pixel. Both images were filtered with a $3 \times 3$ median kernel to exclude noise.

3.5. Land use and land cover classification

Before land cover classification, a 9-class classification system was designed with consideration of the land use properties of the study area as urban/built-up, residential, crop field, vegetable field, forest/trees, orchard, grass, water body, and barren/sandy lands. The widely used supervised classification method, Maximum Likelihood (Murai, 1996), was employed to detect the land cover types. According to the land use map of 1991 and the large scale map of 2001, we created two sets of ground truth samples for each image, one of which used as training data set; the other used as testing data set for accuracy assessment.

4. Results

4.1. Urban expansion over the past 70 years

The urban area of Shijiazhuang city expanded from 6.31 km$^2$ in 1934 to 165.5 km$^2$ in 2001 at an average rate of 2.4 km$^2$/year.

4.1.1. Temporal properties of the urban expansion

Over the past 70 years, the process of urban growth or urban expansion of Shijiazhuang experienced some high- and low-speed stages (Fig. 3). The data extracted from the five historical maps (circles) are consistent
with those from statistical data (cross-line). According to the multi-annual change of urban area (Fig. 3), urban expansion of Shijiazhuang can be divided into four stages as: (1) initial growth stage from 1934 to 1949, (2) short recovery stage from 1950 to 1955, (3) slow growth stage from 1956 to 1980, and (4) fast expansion stage from 1981 to 2001.

During the initial growth stage (1934–1949), urban areas grew very slowly with an annual speed of around 1.15 km²/ year. During this stage, the city was in its initial form with a slow natural growth. According to the Local Chronicles of Shijiazhuang, Shijiazhuang was appointed as a ‘city’ in 1925, and it was later constructed as a military base in WWII by Japanese troops and the National Army due to its important position. The urban growth in 1930s was mainly driven by the military objectives.

The second stage (1950–1955) was during the recovery age with the nation’s reconstruction of ‘new China’ after WWII and the following civil war. Stable social environment brought a quick urban growth at the rate of 3.65 km²/ year. During this stage, the city was in its initial form with a slow natural growth. According to the Local Chronicles of Shijiazhuang, Shijiazhuang was appointed as a ‘city’ in 1925, and it was later constructed as a military base in WWII by Japanese troops and the National Army due to its important position. The urban growth in 1930s was mainly driven by the military objectives.

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From the 1980s, China commenced economic reform. The urban development of Shijiazhuang had a great progression. Thus, the period since 1981 is referred to as ‘fast expansion stage’, which had an annual expansion rate of around 5.6 km²/ year. In the first 10 years, the annual rate of urban expansion reached 3.43 km²/ year due to industrialization. In the second 10 years, expansion was raised to 7.89 km²/ year because of feasible policies, introduction of a market economy, and stable socio-economic environments.

### 4.1.2. Spatial distribution of the urban expansion intensity

The spatial distributions of urban expansion intensity during the different periods are illustrated by the index of annual urban growth rate (Fig. 4). On the base of 1 km × 1 km grid, annual urban growth rate varies significantly.

During 1934–1947 (Fig. 4a), the mean value of annual urban growth rate was 1.9% with a maximum of 7.2%. Most of the high-speed expansion grids are distributed at the western part of the city. This is because of the military usage for barracks and military magazines during the Resistance War against Japan and the following civil war from the late 1930s to 1947. Particularly, the railway surrounding the city was used to transport military materials, and outside of it were defense trenches and walls.

From 1981 to 1991 (Fig. 4c), the mean value of annual urban growth rate was 3% with a maximum of 9.75%. High-speed expansion cells are mainly distributed around the old city territory of 1947 (Fig. 4b). The large area of high-speed expansion cells at the east part of the city was for industrial (textile, pharmaceutical, and steel) and residential use, while the cells at west part were for administrative (Province government) and educational (colleges) use. In 1950s, the military defense works were disposed of and Shijiazhuang was planned as an important textile production base in China due to its good position in the cotton belt of North China so that more than 10 large scale textile enterprises were constructed. Furthermore, the provincial capital of Hebei Province was moved to Shijiazhuang in 1968 for political reasons.
distributed at the southeast of the city and the North side of Shi-Tai line, as used for residential, education, and factories. These expansions can be understood as natural urban growth due to economic development.

In the last period from 1991 to 2001 (Fig. 4d), the mean value of annual urban growth rate suddenly rose to 7.81% with a maximum of 10.1%. Except for the ‘in-filling’ growth at the fringe of old city territory, most of the high-speed growth cells are ‘out-extension’ growth, which mainly lie on the Northwest and Southwest side for residential and associated use. It seems that the change of railways in the southwest side has affected urban growth to some extent in that direction.

The high-speed cells on the east side were used by the so-called new high-tech district, which has been established in most cities throughout China during the 1990s for attracting overseas investment.

4.2. Landscape change in the recent 14 years

In order to evaluate the landscape change due to high speed urbanization in the recent years, especially after the Economic Reform from 1980s, two scenes of TM and ETM+ images were used for land use/land cover classification as described earlier, and the land use and land cover change was then detected and analyzed.

Fig. 5 shows the two land use/land cover classification maps. The classification accuracy is assessed through evaluating the overall classification accuracy and Kappa statistics, which are calculated according to the method of Congalton et al. (1983) by using the two sets of testing datasets. The overall accuracies of the classifications are 84.96% and 87.84% in 1987 and 2001, respectively; these indices can meet
Fig. 5. The land use and land cover map of Shijiazhuang in (a) 1987 and (b) 2001.
2001 was produced (Table 2). Fig. 6 demonstrates the appeared. Through change detection analysis, the land trees and orchard distributed at the North side are dis- have largely decreased; and most part of the windbreak ban region is largely broadened; the agricultural lands demonstrated in Fig. 5, landscape change is significant: the urbanization (Fig. 5). This has been caused by the urban ex- pansion and concentration of housing as the population also increased significantly during the 14 years to 2001. The urban lands converted from crop- and vegetable-lands distributes as circles around the old city terrain in 1987 (Fig. 5). On the other hand, the new increased resi- dential land is mainly as a result of population growth in suburban region (Fig. 5). As mentioned above, the increased vegetable lands were mainly converted from orchard gardens (Fig. 5) in pursuing a higher economic return, and for the same reasons, many crop lands around the village were converted to vegetable cultivation (Fig. 5).

### Table 2
The conversion matrix of land use/cover change from 1987 to 2001 (unit: hectare)

<table>
<thead>
<tr>
<th></th>
<th>1987</th>
<th>2001</th>
<th>Change rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
<td>Residential</td>
<td>Crop lands</td>
</tr>
<tr>
<td>Urban</td>
<td>4077.70</td>
<td>956.72</td>
<td>0.00</td>
</tr>
<tr>
<td>Residential</td>
<td>3196.61</td>
<td>1216.79</td>
<td>358.92</td>
</tr>
<tr>
<td>Crop lands</td>
<td>1216.62</td>
<td>1409.25</td>
<td>4805.12</td>
</tr>
<tr>
<td>Vegetable lands</td>
<td>1072.90</td>
<td>2054.37</td>
<td>396.54</td>
</tr>
<tr>
<td>Trees</td>
<td>120.60</td>
<td>83.52</td>
<td>20.74</td>
</tr>
<tr>
<td>Orchards</td>
<td>202.95</td>
<td>130.77</td>
<td>96.72</td>
</tr>
<tr>
<td>Water</td>
<td>30.96</td>
<td>8.06</td>
<td>2.61</td>
</tr>
<tr>
<td>Sandy/bare soil</td>
<td>25.11</td>
<td>23.94</td>
<td>46.20</td>
</tr>
<tr>
<td>Grass</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>10843.5</td>
<td>6854.9</td>
<td>5726.9</td>
</tr>
<tr>
<td>Change</td>
<td>81.47</td>
<td>−13.44</td>
<td>−51.94</td>
</tr>
</tbody>
</table>
4.3. Driving factors of the urbanization

Urban expansion and subsequent landscape changes are governed by geographical and socio-economic factors, such as population growth, policy, and economic development. In most cases, urban expansion and associated land use/cover changes resulted from a combination of these factors. For example, socio-economic policy can strongly affect urban expansion, and under the changes driven by urban expansion, the land use patterns of the urban outskirts are altered or adjusted in pursuit of high economic returns (orchards or croplands changing to vegetable land).

Even though it is difficult to clarify the influence of these factors in these changes, their influence is examined by analyzing the relationships between developed area (including urban and residential area) and socio-economic factors, such as, population, industrialization, traffic conditions, and infrastructure. Fig. 7 shows the relationships between developed area and these factors during 1978-1998. The data are collected from the Economic Annals of Hebei Province (1978-1998). The population's growth is a major dominant factor driving urbanization (Fig. 7a) during the fast expansion stage. The increase in developed area strongly correlates with the population's growth in a linear form ($r^2 = 0.98$). On the other hand, the improvement of traffic conditions measured by the annual transport weight also plays an important role in promoting the urban development (Fig. 7c). However, the development of gross industrial products and investment in infrastructure show a more complex relationship with urban growth (Fig. 7b and...
d). 1991 appears to be a turning point in the urban development course. Before 1991, or during 1980s, both the growth of gross industrial products and infrastructural investment were slow but the increase in developed area was rapid. On the other hand, the opposite situation was illustrated after 1991, namely, the gross industrial products and infrastructural investment grew rapidly but the increase of developed area was relatively slow. This fact may imply that the urban expansion before 1991 was “extensive sprawl” and a large area of land was just simply urbanized due to new factory establishments. However, the urban expansion after 1991 contains much more intensive components, such as, the improvement of infrastructure and city function, the promotion of industrial technology, and the increase of service industry.

5. Discussions/conclusions

From the above analysis, the spatial patterns of urban expansion in Shijiazhuang can be categorized as three typical types: (1) *special objective oriented type* in the war age (1934–1947), whereby the urban expansion was governed by the establishment of military base and associated use; (2) *socio-political intervention type*, i.e., during the ages of Great Leap Forward and Cultural Revolution. In this period, the urban expansion was strongly affected by the national political situations; and (3) *normal growth type*, i.e., the urban expansion caused by economic development and population growth over the past two decades.

However, as illustrated in the maps of annual urban growth rate and the land use/cover change in recent decades, the urban expansion in Shijiazhuang region differs from some large cities in Asia such as Beijing and Tokyo, whose spreading trends were along radial corridors, such as major traffic lines, from the center of the cities (Liu et al., 2000; Sorensen, 2000), and also differs from the situation in Shenzhen, China, whose urban expansion shows a high correlation with the geomorphologic factor (e.g., slope) and the distance to the Central Business District or major traffic lines (Shi et al., 2000). The urban expansion of Shijiazhuang city shows an areal spreading trend around fringes of the urbanized territory. This is a very common phenomenon in the urban development of most cities in China. One explanation is that the traffic-industrial status determines this kind of urban growth pattern. Owing in part to lack of efficient public commuting systems, especially rail-commuting systems, most of the inhabitants commute by bicycle. As a result, both the working and housing places are close each other. The urban development of most cities in China follows a similar way as shown by Shijiazhuang. In this sense, the pattern of urbanization is determined by technical revolution.
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