# Influence of land use and land cover change due to urbanization on hydrological environments: a case study of Shijiazhuang, China

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**Abstract**

This study demonstrates some preliminary results of the analyzing on influence of land use and land cover change due to urbanization on hydrological environment. Two Landsat TM and ETM+ images are used for detection of the land cover changes from 1987 to 2001 through maximum likelihood classifier. Then, an analysis on the change of thermal environment and water balance is conducted to assess the impact of urbanization.

## 1 Introduction

Urbanization is an important aspect of human activities in influencing the climate system. During the process of urbanization, the reflectivity of land surface is violently changed when large amount of natural or agricultural lands are converted to built-up surfaces. These changes strongly affect the atmosphere/land surface energy exchange (Grimmond and Oke, 1995; Quattrochi and Ridd, 1994) and local weather and climate regimes (Changnon, 1992; Oke, 1987; Roth et al., 1989). As for the hydrological cycle, most of the processes between land and atmosphere, surface and subsurface (Grimmond and Oke, 1991; Hammer, 1972) are completely influenced by urbanization.

In recent 2 decades, China experienced a rapid development. Accompanied with the outstanding growth in economy, an evident change in land cover is due to urbanization. In North China Plain, where water shortage is becoming the biggest environmental problem, the change aggregated the vulnerable hydrological environment. Therefore, it is necessary for urban planning and hydrological modelling to study how the urbanization affect environment.

In this case study, the authors attempt to evaluate the influence of urbanization on local hydrological environment through analyzing the main changes in hydrological processes from a perspective of remote sensing.

## 2 Study area and method

### 2.1 Study area

The study area is located in the east part of China between the range of 114°23′-114°42′E and 37°58′-38°60′N with an area of around 341.63 km$^2$, 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 is only about 500 mm/year with around 2/3 of which is occurred in July and August. Hutuo River runs through the north side of Shijiazhuang, and has become a seasonal river today mainly due to the mass utilization of water resources and climate change since the late 1970's.

Shijiazhuang is the largest city of Hebei province as its important position in administration, culture, economy and transportation. The population is around 1.6 million now. In the last 20 years of economic reform, urban sprawl happened in Shijiazhuang is very significant. According to the economic annals, its population and built-up area are 1.6 million and 165.5 km$^2$ in 2001.

The water source of this city is almost from groundwater because the river near it has become dry in 1990s. A little part of the water is introduced from a reservoir to west in the latest years.

### 2.2 Data and processing

The satellite remote sensing data used in this study are two subscenes of Landsat Thematic Mapper images on June 29, 1987 and May 10, 2001, respectively. After geometrically corrected to UTM map projection, the two images were separately classified by using a supervised classifier. And then, the statistical characteristics were calculated for different land classes. The changes in built-up area are detected. And finally, the impacts of the changes on hydrological cycle are evaluated with link to some ground statistic data.

**2.3 Normalized Difference Temperature Index, *NDTI***

A consequent environmental phenomenon occurring with urban expansion is the growth of urban heat island. Even though heat island is a meteorological term related to the increase of air temperature above urban area, the satellite observed land surface temperature usually is used to evaluate heat island. In this study, we use the normalized difference temperature index (*NDTI*) to evaluate the thermal environmental change regarding to urban expansion.

$$NDTI = \frac{T - T_{\min}}{Ts_{\max} - T_{\min}} \tag{1}$$

where $T$ is surface temperature, $T_{min}$ and $T_{max}$ are the minimum and maximum temperature on the image.

**2.4 Impervious surface cover**

An indicator to describe the fractional cover of urban or built-up area is impervious surface cover (ISA) (Ridd, 1995; Carlson and Arthur, 2000). ISA constitutes the fractional cover of a pixel for which the surface can neither evaporate water nor permit rainwater to penetrate. A reasonable definition of ISA can be addressed by satellite is (Carlson and Arthur, 2000),

$$ISA = (1 - f_v)_{dev} \tag{2}$$

where the subscript, dev, indicates that the quantity is defined only for regions classified as developed or built-up; $f_v$ is fractional vegetation cover, calculating by

$$f_v = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \tag{3}$$

where, $NDVI_{max}$ and $NDVI_{min}$ are the vegetation indices for dense vegetation and bare soil, respectively. In this study, we use 0.8 and 0.05 for these parameters.

**2.5 Water balance evaluation**

In order to evaluate the impact of urbanization on hydrological cycle, we calculate the water balance before and after these changes. Because almost all of the agricultural lands in this region are irrigative, the runoff in the agricultural lands can be considered as nearly zero since the slope of this region is only around 1.5‰.

Because of the deep groundwater in this region, the exchange between soil and groundwater can be ignored. The water balance for a single rainfall event can be expressed as

$$P = Int + E + Inf + R \tag{4}$$

where $P$ is total precipitation of a rainfall event; $Int$ is the interception by vegetation; $E$ is evaporation during the rainfall event; $Inf$ is the infiltration into soil; and $R$ is runoff. On an annual base, the water balance components can be expressed as

$$R = P \cdot ISA \tag{5}$$

$$ET = P \cdot (1 - ISA) \tag{6}$$

**3 Results**

**3.1 Land cover change detection**

Figure 1 illustrates the land cover maps of the study area in 1987 and 2001, respectively. In these two maps, the land cover is classified as 9 classes: urban, residential, trees, orchards, vegetable fields, crop fields, grassland, water surface, and sandy soil (Xiao et al., 2003). The urban and residential areas are treated as built-up area in the analysis of urbanization.

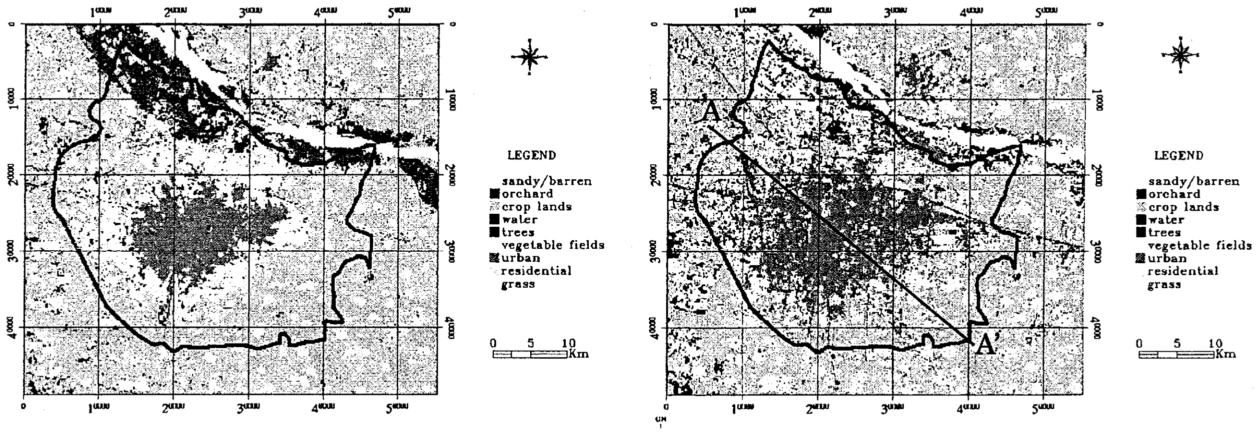


**Figure 1 The land use and land cover maps of Shijiazhuang in 1987 (left) and 2001 (right). (The line AA' is a cross section for analyzing the change in thermal environment )**

An obvious change according to the two class maps is the evident enlargement of built-up area and the decrease of trees (including orchards) and cropland. Table 1 shows the statistics of the changes between the two years.

Table 1 The conversion matrix of land use types during 1987 to 2001 (unit: hectare)

| 2001 / 1987 | Built-up | Fields | Trees | Others | Total |
|---|---|---|---|---|---|
| Built-up | 12 327.91 | 13 16.66 | 46.79 | 203.52 | 13 894.88 |
| Fields | 4 744.57 | 10 927.57 | 588.15 | 321.17 | 16 581.46 |
| Trees | 537.84 | 1 826.24 | 811.55 | 199.93 | 3 375.56 |
| Others | 88.07 | 163.48 | 41.17 | 18.18 | 310.90 |
| Total | 17 698.39 | 14 233.95 | 1 487.66 | 742.80 | 34 162.80 |
| Change rate (%) | 27.37 | -14.16 | -55.93 | 138.92 | ---- |

$$* \ \textit{Change} \quad \textit{rate}\,(\%) = \frac{\sum A_{2001} - \sum A_{1987}}{\sum A_{1987}} \times 100$$

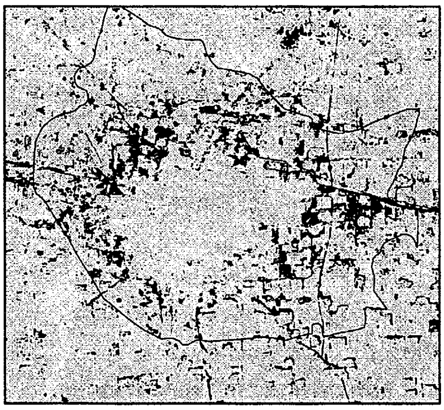

**Figure 2 The distribution of sprawled built-up area during 1987~2001.**

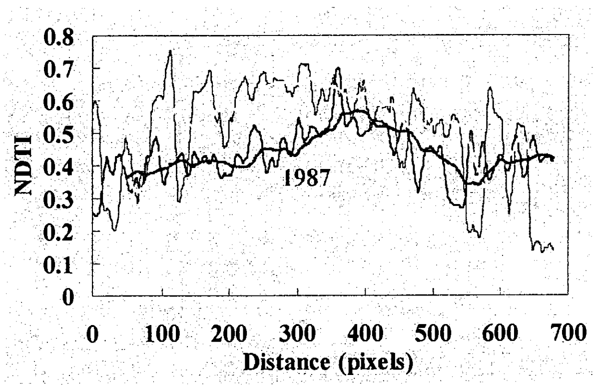


**Figure 3 Enlargement of urban heat island due to urbanization**

Figure 2 shows the sprawled built-up area during the 14 years. Totally, the increased area is around 3800 ha, and the increasing rate is 27.4%.

### 3.2 The influence of urbanization on thermal environment

An obvious effect of urbanization on environment is the thermal environment will be significantly changed because the urbanized surface prevent water being vaporized into atmosphere, therein, the net radiation in such surface will only be converted into ground and sensible heat according to the surface heat balance law. This is the most reason to the phenomenon of so-called urban heat island enlargement. Here, we use the indictor of NDTI to analyze the change thermal environment. The NDTI profiles along the cross section of AA' shows an evident increase in 2001 than in 1987 (Figure 3).

### 3.3 The influence of urbanization on water balance

Another important impact of urbanization on environment is the process of urbanization strongly affects the surface water balance and then affects other hydrological and meteorological factors.

Here, we use the Equation 5 and Equation 6 to evaluate the water balance of the study area in the 2 years. Table 2 shows the water balance in 1987 and 2001. Even though the annual precipitation of 2001 is slightly less than that of 1987, the runoff of 2001 is increased around 18% than 1987 because of the urbanization. This implies that the urbanization make the risk of urban flood increasing in extreme rainfall event.

**Table 2 Change in water balance due to urbanization**

| | P (mm) | R (mm) | ET (mm) |
|---|---|---|---|
| 1987 | 312.9 | 127.3 | 185.6 |
| 2001 | 289.8 | 150.1 | 139.7 |
| Change (%) | -7.4 | 17.9 | -24.7 |

## 4 Discussions

In this study, we evaluate the influence of urbanization on hydrological environment. Actually, assessing the influence is a very complicated work. Here, we only give the preliminary results on the analysis of thermal environment and water balance. Large amount of meteorological data is in processing now. On the other hand, in this present paper we only treated the physical aspects of the impacts and not give any assessment of the impacts on chemical aspect of the environment, i.e. pollution, which is one of the most important aspects as well.

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