# DETECTION OF LANDCOVER CHANGES WITH RAPID URBANIZATION USING REMOTELY SENSED DATA IN AND AROUND CHONGQING, CHINA


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**ABSTRACT:**

Chongqing, as the central city of inland China, has been subject to especially fast economical development. With increasing population and urban development, various impacts on the surrounding environment, such as deforestation, urbanization and pollution, must be taken into consideration. In particular, decrease in vegetated area and disruption of local ecosystems due to urbanization has emerged as a major issue in recent years. This indicates the necessity of urban landscape management and conservation of environments. In this research, Landsat TM and ETM+ data were employed for landcover classification and to analyze changes in landcover over a 8-year period from 1993 to 2001. The landcover classifications were implemented using the supervised method (Maximum Likelihood), based on accurate ground truth data such as field surveys and aerial photographs. The overall results of classification show that the proportion of forest decreased from 24.0% in 1993 to 21.2% in 2001, and urban area increased from 4.3% in 1993 to 6.7% in 2001. In addition, the topography of Chongqing is mountainous, and the landcover is strongly influenced by topography. The research thus also analyzed landcover status and changes according to elevations and slope. In addition, the landcover status and patterns of change were also correlated with distance from the urban core. By clarifying the status of landcover around Chongqing, and by analysing how these landcover patterns are changing, this research hopes to provide baseline data that will be useful to nature conservation and multifunctional landscape planning as the city continues to grow.


## 1. INTRODUCTION

Chongqing City is located in a large catchment basin on the upper reaches of the Yangtze River. The total area of the municipality is 82,300km$^2$, and the population 31 million. The region is surrounded by three mountains; Zhongliang, Tongluo and Jinyun. The slopes of these mountains are covered by evergreen broad-leaved forests. Four nature reserves located in these mountains, Nanshan, Geleshan, Jinyunshan and Tieshanping, preserve especially large tracts of forest habitat, and are vital for conserving regional biodiversity and also for protecting the quality of life. These reserves are called the "Four Lungs of Chongqing" by the local people.

Since 1993, Chongqing has experienced rapid economic growth, due to China's economical development policy for the inland region. Increases in urban population and urban area have come at the expense of rural regions. The city is also well known as a center for heavy industry, including automobile manufacturing and steel and chemical industries. As these industries prosper, they also bring about serious pollution problems.

In response to the environmental problems, various conservation measures have been implemented by the Chongqing government. The "Four Action" plan involves blue sky, green land, clean water and quiet environment. The measures taken under this plan have already begun to show substantial results.

The problems of deforestation and pollution, however, still remain serious due to excessive urban development and the impact of human disturbance. Important work remains to be done in terms of urban environmental management and conservation of vegetated areas. Understanding Chongqing's landcover current status and recent changes will provide basic data for landscape planning and will facilitate decision making when establishing conservation areas. Remote sensing is an effective tool for environmental monitoring over a wide scale, as well as for analyzing landcover changes over time (Turner et al, 2001). The first objective of this study is to utilize Landsat TM & ETM+ data to establish a landcover classification for understanding its current status. The second objective is to quantify patterns of landcover change over the period from 1993 to 2001.

Chongqing is also called the "Mountain City", due to its distinctive mountainous terrain. As most of the city area is distributed at elevations ranging from 200m to 400m, landcover patterns depend mainly on these undulating landforms. This study will thus analyze landcover changes incorporating variables such as elevation and slope. Distance from the urban core area is another variable considered in the analysis.

## 2. STUDY AREA AND METHODS

### 2.1 Study Area


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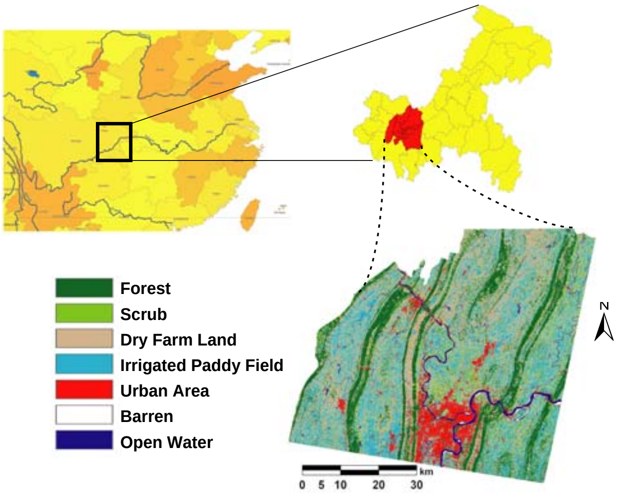


Figure 1. Study area of Chongqing, China

Chongqing is located in the southwest part of China（28° 10’-32° 13’N, 105° 11’-110° 11’E）, in the region of the subtropical monsoon climate. Annual mean temperature is 18.9℃, mean temperature is 7.5℃ in January and 28.5℃ in July. The city experiences a long, hot summer, with extreme temperatures reaching as high as 43.5℃. Annual precipitation is 1182.1mm, concentrated in the period between May and October. Annual hours of sunshine is 1112.8-1655.8h, and annual mean relative humidity 80%. Chongqing is also called the “City of Fog”. Annual mean days of fog is 68.3 days, with peak years as high as 205 days.

The topography is montane and hills. The highest point is 1030m in Mt.Jinyun, while the low lying areas along the Yangtze River are below 200m. The core city area of Chongqing is 1534km$^2$, with a population of 3.64 million. Situated where the Jialing River passes through the Sichuan Basin to join into the main branch of the Yangtze, the city enjoys very convenient access to the water transportation network.

The forest coverage surrounding the city is about 20.5%. The four reserves are covered by evergreen broad-leaved forests dominated by trees such as *Catanoposis carlesii var.spinusa*, *Castanopsis fagesii*, *Cinnamonum camphora* and *Machilus pigii*. Other areas are covered conifer forests such as *Pinus massoniana* and *Cunninghamia lanceolata*. Numerous endangered species, such as *Metasequoia glyptostroboides* and *Cycas revoluta Thunb* are preserved in Jinyunshan, which is the only one of the four designated as a national natural reserve. The study area is located in the central part of the city including, 9 districts (Yubei, Jiangbei, Yuzhong, Nanan, Jiulongpo, Dadukou, Shapingba and Beibei) and 1 prefecture (Bishan). The total area covered by the satellite data is 426399.2 ha. Due to the limitations of satellite dataset, part of the study area could not be covered, but this did not effect the research.

### 2.2 Methods

**2.2.1 Reference data collection:** A total of 1,691 photographs, taken in August 2006 and 2007 using a digital camera (Nikon D2000) with GPSMAP 60CS GPS, were utilized to establish ground truth. In addition, 331 of the photographs with location information were utilized as classification reference data and accuracy assessment data. ALOS data (10m, date: May, 2006) obtained from Restec Co., and aerial photographs of Chongqing central city (1:5,000 & 1:10000) purchased from a local bookstore were also utilized as reference data.

**2.2.2 Landcover Classification and Analysis of Landcover Changes:** The research employed Landsat ETM+ (2001/5/22; Path: 128, Row: 39）and Landsat TM（1993/5/24; Path: 128, Row: 39）data downloaded from the Global Land Cover Facility (GLCF) of the University of Maryland. Both data were multispectral and pre-geocorrected, with spatial resolution of 28.5m. The landcover classification was referenced to the location information obtained by GPS, which was mapped onto the satellite images together with ALOS data and aerial photographs using ArcGIS 9.1 (ESRI, Inc). The classification utilized the Maximum Likelihood Method, which is a widely-employed method for classifying landcover. Based on the ground truth, 7 classes of landcover were established: Forest (dominated by natural forest and artificial forest which includes evergreen broadleaved trees and conifer trees), Scrub (dominated by deciduous trees, shrubs with early-stage canopy and young artificial plantation), Dry Farm Land (mostly dry fields distributed on the mountain slopes and planted with crops such as corn and wheat), Irrigated Paddy Field (Mostly distributed on the alluvial flatlands and valley bottoms), Urban Area (the central part of Chongqing city, and arterial roads and other places covered by concrete or asphalt), Barren (sandbars and river gravels, and also construction sites where vegetation has not developed), Open Water (rivers and lakes). Pixel-based classification methods, however, tend to suffer from the so-called ‘salt and pepper’ effect. To counteract this problem, the smallest areas were removed by performing an additional clumping and cell elimination by 3×1 pixel on the initial results of the classification. Analysis was performed using ERDAS IMAGINE 9.1 (Leica Geosystems GIS & Mapping, LLC).

Based on the landcover classification results, landcover changes over the 8-year period from 1993 and 2001 were analyzed. The rate of change for each class was calculated by the following formula :

$$p = \frac{100}{t_2 - t_1} \ln \frac{A_2}{A_1} \qquad \text{(Puyravaud, 2003)}$$

$A_1$ and $A_2$ are the data for the year of $t_1$ and $t_2$ respectively.

**2.2.3 Change Detection by using characteristical data:** To detect the landcover changes in the distinctive mountainous topography of Chongqing, SRTM-3 data, also obtained from GLCF of the University of Maryland. The original data in raster format was converted to polygon and rectified to a Universal Transverse Mercator projection (WGS 84) using ArcGIS. Elevation data created from SRTM was divided into 4 classes, in 150m intervals starting from an elevation of 300m. Similarly, slope data was divided into 4 classes in 10 degree intervals starting from a slope angle of 10 degrees. For distance from urban core, urban area patches under 10ha from the 1993 classifications results were used to create 2km interval distance vector data up to 32km from the urban core. Lastly, elevation, slope and distance were combined to form

| Landcover Classes | landcover in 1993 | | | Net gain/loss (ha) |
|---|---|---|---|---|
| | Unchanged in 2001 | Loss to other classes in 2001 | Gained from other classes in 2001 | |
| **Forest** | 48895.8 | 33383.2 | 22822.9 | -10560.2 |
| **Scrub** | 3721.4 | 12795.5 | 13145.0 | 349.4 |
| **Dry Farm Land** | 99975.5 | 48045.6 | 65088.8 | 17043.1 |
| **Irrigated Paddy Field** | 50191.3 | 39642.1 | 27154.7 | -12487.4 |
| **Urban Area** | 10429.0 | 4600.8 | 13415.4 | 8814.5 |
| **Barren** | 523.2 | 2004.6 | 1318.6 | -685.9 |
| **Open Water** | 7202.3 | 3961.2 | 1487.6 | -2473.5 |

Tabel.1 Change patterns of each landcover type in between 1993 and 2001

242 polygons that were correlated with the data on changes in landcover. These works were implemented using ArcGIS 9.1.

## 3. RESULTS

### 3.1 Results of Landcover Classification

Forest area in 1993 was 101231.6ha (24.0%) and 90518.8ha (21.2%) in 2001. Most of the forest concentrated on the mountains that surround the city. Urban Area was 18192.7ha (4.3%) in 1993, but increased to 28496.3ha (6.7%) in 2001. The expansion of urban area due to urban development was apparent. Agricultural lands, including Dry Farm Land and Irrigated Paddy Field, covered the largest area. Dry Farm Land and Irrigated Paddy Field accounted for 169639.4ha (40.2%) and 97858.1ha (23.2%) respectively in 1993; and 190122.4ha (44.6%) and 85327.3ha (20.0%) in 2001. Only a slight change in these two landcover classes was seen during the 8 years. The smallest landcover area was Barren, with 3148.7ha (0.7%) in 1993 and 2075.5ha (0.5%) in 2001, followed by Open Water, which changed slightly from 12161.4ha (2.9%) in 1993 to 9363.7ha (2.2%) in 2001.

### 3.2Results of Landcover Change Detection

**3.2.1 Landcover change patterns:** Shown in Table .1 are the results for each landcover type from 1993 to 2001. The Forest and Irrigated Paddy Field classes decreased most significantly, by 10560.2ha and 12487.4ha respectively. Forest gained a total of 22822.9ha from other classes, but lost 33383.2ha, leading to a net loss in area. In contrast, Urban Area and Dry Farm Land showed the greatest increases. Spurred by urban development, the net gain in Urban Area was 8814.5ha, bringing the 2001 total to about double that of 1993. The increase in Dry Farm Land and Irrigated Paddy Field could be due to clearing of Forest and Scrub, but also at least to some extent to classification error. Barren land decreased by 685.9ha, most likely by being converted to Urban Area. Open Water decreased by 2473.5ha.

**3.2.2 Characteristic of the landcover change patterns: A-Elevation:** The results of landcover classification using elevation data (Figure 2.a) show that Forest area decreased at all four elevation classes: below 300m decreased from 24135.0ha (15.2%) to 16513.0ha (10.4%): between 300m to 450m decreased from 32091.2ha (19.4%) to 31286.9 (18.5%): from 450m to 600m decreased from 31735.6ha (43.6%) to 30577.3ha (42.0%): above 600m decreased from 13269.8ha (53.1%) to 12141.6ha (48.5%) in 2001 above 600m.

Urban Area showed the highest rate of increase below 300m, from 12234.8ha (7.7%) to 19092.2ha (12.0%). Urban Area also increased in the 300m to 450m range, from 5118.6ha (3.1%) to 8308.5ha (4.9%).

The total area of agricultural lands (Irrigated Paddy Field and Dry Farm Land combined) in the 450m to 600m range increased from 34649.2ha (47.6%) to 37722.4ha (51.8%); and above 600m from 9477.8ha (37.9%) to 11005.1ha (44.0%).

Annual rates of change for each elevation class are shown in Figure 2.b. Forest decrease over all elevations, but the rate of decrease (-2.06) was greatest at below 300m. Urban Area increased at a rate of 2.42 below 300m, and at a rate of 2.63 in the 300m to 450m range. Scrub increased at a rate of 3.30 below 300m, but decreased at higher elevations.

**B-Slope:** The results of analysis using slope (Figure 2.c) show that Forest below 10 degrees decreased from 41461.2ha (14.4%) to 32084.4ha (11.2%); and in the 10 to 20 degree range decreased from 40219.1ha (38.8%) to 38957.8ha (36.1%). Urban area below 10 degrees increased from 15290.7 ha (5.3%) to 24345.7ha (8.5%) below 10 degrees; and from 2532.6ha (2.4%) to 3654.4ha (3.4%) in the 11-20 degree range. The total agricultural land (Irrigated Paddy Field and Dry Farm Land) are increased at all slope classes, with the greatest increase coming in Dry Farm Land below 10 degrees.

The annual rates of change for each slope class are shown in Figure 2.d. Forest decreased in all classes except the 31-40 degree class. The rate of decrease, -1.39, was greatest for below 10 degrees. Scrub below 10 degree increased at a rate of 0.48 annually. Urban Area increased in all slope classes, but especially at below 10 degrees (2.53) and from 11-20 degrees (1.99). Barren land decreased at all slopes.

**C-Distance:** The results of analysis using distance from urban area are shown in Figure 2.e. Most of the Urban Area is concentrated in the 0-14km distance, which showed an increase from 16469.0ha (9.2%) to 25655.2ha (14.4%). Distribution of Forest, in contrast, is concentrated at greater distances from the urban core. Forest in the range of 0-4km decreased from 38863.0ha (21.8%) to 34507.0 ha (19.4%), and in the 4-8km range from 32687.1 (23.9%) to 28513.8ha (20.9%). Areas beyond 4km from the urban center are part of the rural landscape, with increases showing in the combined area of Irrigated Paddy Field and Dry Farm Land.

The annual rate of change for each distance class is shown in Figure 2.f. Forest area decreased at all distances; while Urban Area increased from 0 to 20 km. Barren land decreased from 0-16km.

## 4. DISCUSSION AND CONCLUSION

The results of the landcover classification show that the combined area of Dry Farm Land and Irrigated Paddy Field accounted for the largest landcover type at all classes of elevation, slope and distance from urban center. This

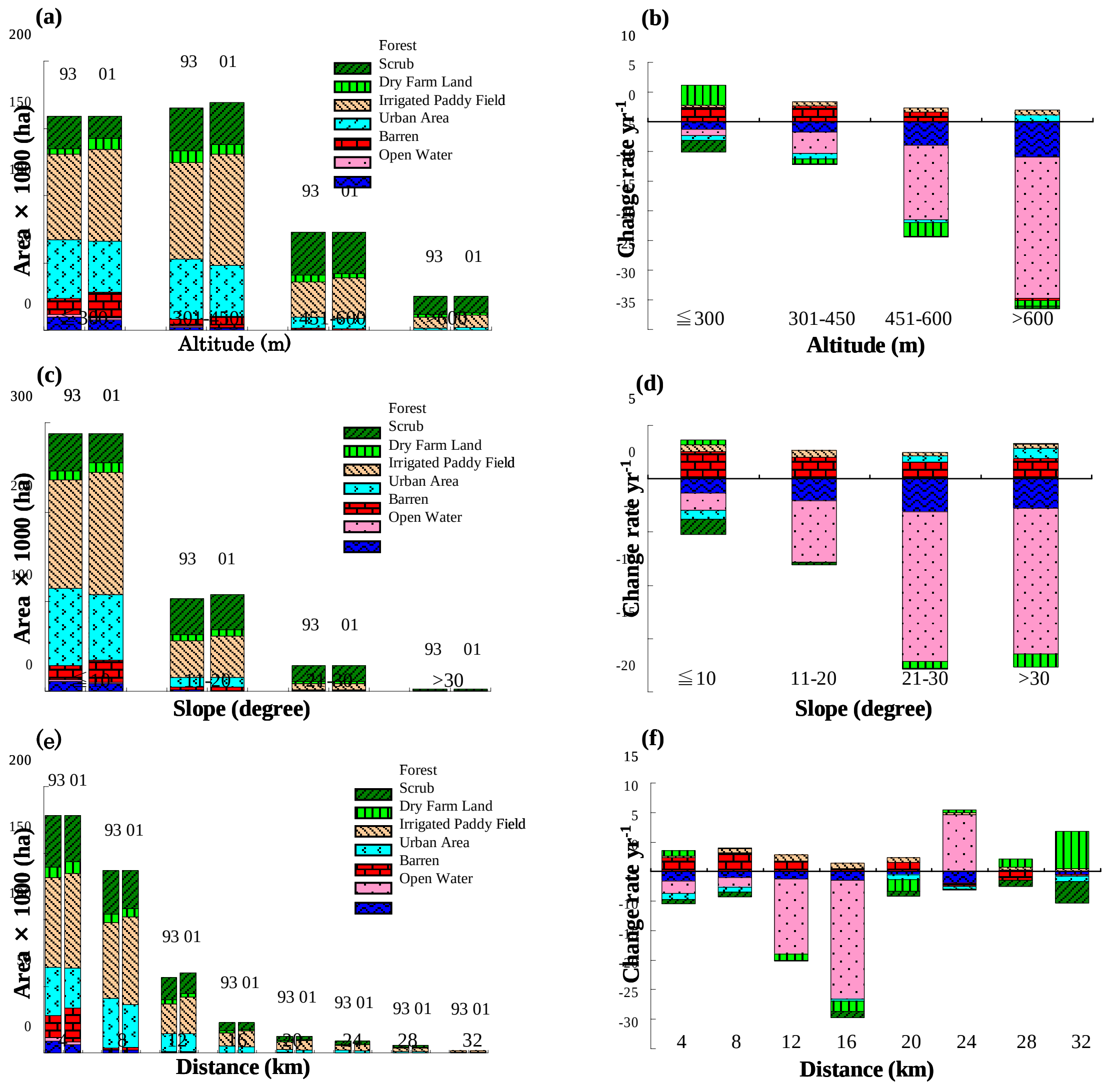


Figure 2. Results of change detection by using characteristical datasets: **(a)** landcover distribution between 1993 and 2001 by altitude and landcover type; **(b)** landcover changes by altitude; **(c)** landcover distribution between 1993 and 2001 by slope and landcover type; **(d)** landcover changes by altitude; **(e)** landcover distribution between 1993 and 2001 by distance and landcover type; **(f)** landcover changes by distance

indicates that the land resources of Chongqing are heavily used for agriculture. Although the city is situated in mountainous terrain, the field surveys and slope data show that there are substantial flat areas to be found among the mountains, which are utilized as Dry Farm Land and Irrigated Rice Paddy. On the other hand, with the recent economic development these spots are also being developed for leisure facilities and residential land, with resulting environmental impacts, such as garbage and deforestation, on the surrounding environment. The results also show that Dry Farm Land is increasing on steeper slopes, most likely in the wake of logging or land reclamation.

Forest is the second largest landcover class. Since 1950, due to forest reserves and logging prohibited areas established by the Chinese government, many of the forests in the Chongqing have been well conserved. In particular, extensive high-quality evergreen broad-leaved forests remain in natural reserves such as Jinyunshan, Tieshanping, Nanshan and Geleshan. Stretches of forest above the elevation of 300m form a continuous habitat corridor, which can be expected to play an important role in conserving biodiversity in the study area. In contrast, forest more closely surrounding the urban area is decreased. The results show that in general the forest area close to the urban center and on gentle slopes is decreasing. Also, some gaps and fragmented patches were found in the forest reserves, which result from increasing demand for timber accompanying urban development. An increase in fragmentation may indicate a loss in habitat quality for plants and animals dependent upon the forest (Harrison and Fahrig 1995, Turner 2001). Conservation of both core areas and connectivity in these extensive mountain forests is thus important.

Urban Area increased even on steep slopes and at higher elevations. This shows that urbanization is now expanding outwards, pushing the suburbs into rural areas. This brings up concerns of the impact urban development is having on local ecosystems that depend upon the rural landscape.

In the future, Chongqing will continue to develop as a major urban center. At the same time, careful landscape planning can allow conservation of a multifunctional landscape, including forest, scrub and agricultural land, in the surrounding regions. This landscape will not only protect regional biodiversity and ecosystems, but will ensure the quality of life for Chongqing citizens for generations to come. This research is designed to serve as a useful base for this sort of landscape planning.

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