Using Geographic Information Systems and Remote Sensing Technology to Analyze Land Use Change in Harbin, China from 2005 to 2015

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Abstract

In recent years, the construction of major infrastructure has resulted in the continuous expansion of urban built-up areas in Harbin, China. The continuous expansion of the urban fringes has led to drastic changes in the patterns of land use and caused various problems, such as environmental pollution and shortage of land resources. The purpose of this study is to evaluate the change in land use in Harbin, China over a 10 year period and to provide a basis for decision-making regarding future land use structure adjustment and land management policies in Harbin. With remote sensing and geographic information system (GIS) technology, this project made use of three periods of land use data (2005, 2010, and 2015) revealed characteristics of land use change in Harbin in several respects: land use change area, land use change rate, and land use transfer direction. Additionally, the study provides decision support and a basis for the rational utilization of land and protection of ecological environments in Harbin.

Introduction

The extent of urban built-up areas in Harbin, China has expanded, and land use and land cover are influenced by urbanization (Shi, Chen, and Pan, 2000). According to the State Council's Reply on Harbin Urban Master Plan (2011-2020), Harbin should be guided by the scientific concept of development, the economy, society, population, environment, and resources should be regulated (State Council, 2011). All work in Harbin's urban and rural planning, construction, and management should be done with coordination (State Council, 2011). In the end, Harbin will be built into a modern city with a prosperous economy (State Council, 2011). Therefore, understanding land conversion resulting from the process of rapid urbanization has important practical significance for guiding future land use management and ecological environmental protection in Harbin. Geographic information systems and remote sensing technologies provided technical support for this project.

Study Area

Harbin is the capital of Heilongjiang province and the largest city in the northeastern region of China. Figure 1 represents the study area.

Methodology

Data Acquisition

Landsat TM (2005 and 2010) and Landsat

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8 (2015) remote sensing imagery data was obtained from the United States Geological Survey (USGS) and was used to derive land use classification data. Landsat TM and Landsat 8 imagery were chosen because these data were free and have high spatial resolution (30 meter). These imagery grids were projected into the WGS 1984 UTM Zone 53N coordinate system. The Harbin boundary, Heilongjiang Province boundary, China boundary, and Railways shapefiles were downloaded from China's State Bureau of Surveying and Mapping.

Figure 1. The study area of Harbin.

Supervised Classification

The classification system used for this study was based on the Land Use Database Set released by the Institute of Geographical Sciences and Natural Resources Research of the Chinese Academy of Sciences (n.d.). Changes were made to the classification system for this project. Level II classification was not applied to this study. Class six in the original classification system was unused land, and in this study, class six was referred to as barren land.

With the support of ENVI and ArcGIS software, the classification was preprocessed through radiation calibration, atmospheric correction, geometric correction, and mask cutting. Radiation calibration and atmospheric correction were performed by the Calibration Utilities module and the Flaash module of the ENVI software. Geometric correction was accomplished by using the Georeferencing tool in ArcGIS. Masking was done using the Extract by Mask tool within the ArcGIS ArcToolbox. Then, the land use data for 2005, 2010, and 2015 were extracted based on a supervised classification method combining automatic computer classification and visual interpretation.

The process of supervised classification involved the following steps. Six classes of training sites were created: cultivated land, forest land, grass land, water area, construction land, and barren land. Polygons were drawn in the appropriate areas for each class. For each class, the training sites were distributed across the study area to achieve a representative sample. Then, supervised classification was performed based on the training data using the Maximum Likelihood Classification module of the ENVI software.

Accuracy Assessment

After the completion of the classification, the accuracy of land use classification was determined. The following accuracy assessment methods were from VirginiaView (2013a, 2013b). First, a random point shapefile for the Harbin area was generated using the Create Random Points tool in ArcGIS. The number of points was set to 100. A KML file was generated using the Layer to KML tool in ArcGIS. Then, loading the generated KML file in Google Earth and adjusting the Time Slider in Google Earth to 2005, the land use values of the 100 points were observed and recorded. Next, the observed land use values of the 100 points were added to the point shapefile in ArcGIS. Lastly, a new point layer was generated using the Extract Values to Points tool in ArcGIS; the input point feature class was the random point shapefile, and the input raster was the classified land use raster for 2005. Each point in the resulting point layer had the observations from Google Earth and the value from the classified raster, so the accuracy could be calculated. The accuracy of the classified raster for 2005 was 85%. The same process was conducted for the classified raster for 2010 and 2015, and the accuracy was 85% and 86%, respectively.

Single Land Use Dynamic Degree

The rate of land use change can be measured by a dynamic model of land use types. The dynamic degree of a single land use type indicates the change rate of a land use type within a certain time range within a certain research area (Wang and Bao, 1999). The following model from Wang and Bao (1999) was applied for analysis:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

K is the dynamic degree of a certain type of land use during the study period; U_a and U_b are the quantity of a certain type of land use at the beginning and the end of the study period, respectively; T is the length of the study period. When the period of T is set to year, then K indicates the annual change rate of a certain land use type in the study area (Wang and Bao, 1999).

Comprehensive Land Use Dynamic Degree

Comprehensive land use dynamic degree refers to the rate of land use change within a certain time period in the study area (Wang and Bao, 1999). The following model from Wang and Bao (1999) was used:

$$LC = \left(\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2 \sum_{i=1}^{n} LU_i} \right) \times \frac{1}{T} \times 100\%$$

LC is the comprehensive land use dynamic degree; LU_i is the area of land use type i at the beginning of the study; $\Delta LU_{i\text{-}j}$ is the absolute value of the area of land use type i converted to land use type j at the end of the study; T is the length of the study period. When the period of T is set to year, then LC will indicate the annual rate of land use change in the study area (Wang and Bao, 1999).

Land Use Transfer Matrix

Zhu and Li (2003) wrote, "The significance of a transfer matrix is that it not only reflects the land use type structure at the beginning of the study period and the end of the research period, but also reflects the change of land use types during the study period, which is convenient for understanding the loss of the flow of each type of land use at the beginning of the study period and the source and composition of land use types at the end of the study period." The variables in the transfer matrix can also be percentage values representing the transition probability of regional land use change (Zhu and Li, 2003). The trend of land use change can be inferred from these percentages (Zhu and Li, 2003). The following equation from Zhu and Li (2003) was used:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \cdots & S_{2n} \\ S_{31} & S_{32} & S_{33} & \cdots & S_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & S_{n3} & \cdots & S_{nn} \end{bmatrix}$$

S is the land area; n is the number of land use types; i and j are the land use types at the beginning of the study and the end of the research period, respectively (Zhu and Li, 2003).

Results

Overall Land Use Distribution

Total Area for Each Land Use Type

The land use and land cover maps for 2005, 2010, and 2015 were produced from Landsat TM and Landsat 8 images (Appendix A, Appendix B, and Appendix C, respectively). The total area of each land cover type for the three periods were calculated through Microsoft Excel (Table 1).

Table 1. The total area of each land use for 2005, 2010, and 2015 (in square kilometers).

Class	**2005**	**2010**	**2015**
Cultivated land	29020.29	29431.57	29007.54
Forest	22972.07	22385.59	22601.61
Grass	56.60	54.62	49.64
Water	576.60	690.01	772.13
Constructi-on land	474.21	537.91	668.47
Barren	0.23	0.30	0.63
Total	53100	53100	53100

Histogram

A histogram was generated to compare the area of each land use type for 2005, 2010, and 2015 (Figure 2).

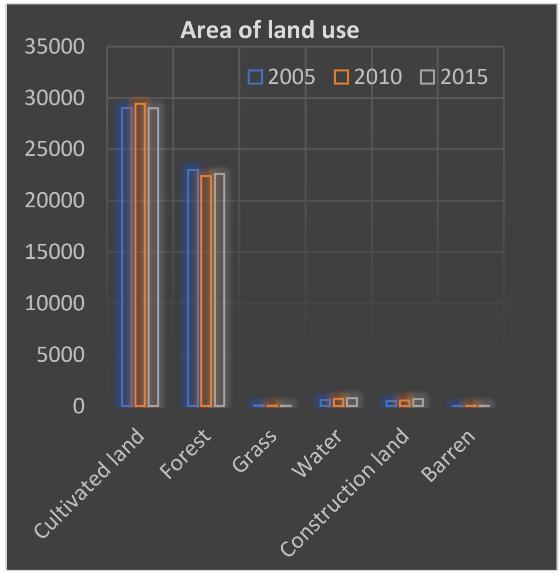

Figure 2. A histogram of each land use for 2005, 2010, and 2015.

Based on Table 1 and Figure 2, the area of cultivated land increased first and then decreased. Forest decreased and then increased. Overall, grass showed a slight decreasing trend. Water areas and construction land showed an obvious increasing trend. Barren land area was relatively unchanged because of its small size.

Land Use Dynamic Degree

A table of land use dynamics was calculated (Table 2). Annual change rates are reported in this paragraph. Cultivated land increased (0.28% annually) from 2005 to 2010, but it decreased (-0.29%) between 2010 and 2015. Forest decreased (-0.51%) between 2005 and 2010, and it increased (0.19%) in the second time period. Annual change in grass land was -0.70% from 2005 to 2010 and -1.82% in the second study period; it indicated a decreasing trend in the ten-year period. Construction land increased 2.69% per year from 2005 to 2010 and 4.85% from

2010 to 2015. This reflects that between 2010 and 2015, the expansion of construction land was relatively rapid, and the process of urbanization was accelerating. The comprehensive land use dynamic degree was 0.22% from 2005 to 2010 and 0.16% from 2010 to 2015. This indicates land use change was faster during the first period.

Table 2. Yearly single land use dynamic degree (DD) and yearly comprehensive land use dynamic degree (CLUDD) for 2005-2010 and 2010-2015.

Class	**2005-2010 (DD)**	**2010-2015 (DD)**
Cultivated land	0.28%	-0.29%
Forest	-0.51%	0.19%
Grass	-0.70%	-1.82%
Water	3.93%	2.38%
Construction land	2.69%	4.85%
Barren	5.82%	21.60%
CLUDD	0.22%	0.16%

Land Use Change Direction

The land use transfer matrices are displayed in tables below (Table 3-Table 6). From 2005 to 2010, construction land expanded by 63.71 square kilometers, which mainly came from the conversion of cultivated land and forest land. Between 2010 and 2015, construction land expanded 130.56 by square kilometers, mostly due to the loss of cultivated land and forest land. This showed that the pace of urban development in Harbin was gradually accelerating, but it resulted in the loss of a large area of cultivated land and forest land.

The water area increased 195.53 square kilometers between 2005 and 2015. Water area usually would not change significantly. In this study, this was due to seasonal precipitation. The wetlands near the waters appeared to be arable lands in the dry season and appeared to be water bodies in the rainy season.

Construction Land Expansion

The expansion of construction land in Harbin was a combination of outward expansion and scattered expansion (Figure 3). In the center of the city, there was an outward expansion, and the suburbs were dotted with growth. As the most important

Table 3. The land use transfer matrix between 2005 and 2010 (in square kilometers).

2010 / 2005	**Cultivated land**	**Forest**	**Grass**	**Water**	**Construction land**	**Barren**	**Total**
Cultivated land	27440.89	1279.86	41.76	139.51	118.12	0.16	29020.29
Forest	1830.25	21079.17	3.94	50.06	8.66	0.00	22972.07
Grass	33.03	8.64	4.03	4.63	6.23	0.03	56.60
Water	68.43	7.99	3.71	492.40	4.06	0.01	576.60
Construction land	58.87	9.94	1.16	3.42	400.76	0.06	474.21
Barren	0.10	0.00	0.02	0.00	0.07	0.04	0.23
Total	29431.56	22385.60	54.62	690.01	537.91	0.30	53100.00

Table 4. The land use transfer matrix between 2010 and 2015 (in square kilometers).

2010 \ 2015	Cultivated land	Forest	Grass	Water	Construction land	Barren	Total
Cultivated land	27165.51	1870.37	40.13	141.39	213.75	0.41	29431.56
Forest	1606.12	20688.53	2.33	69.01	19.58	0.02	22385.60
Grass	31.04	1.80	3.22	12.73	5.78	0.05	54.62
Water	118.24	21.95	2.91	540.65	6.23	0.02	690.01
Construction land	86.46	18.95	1.01	8.34	423.03	0.12	537.91
Barren	0.16	0.01	0.03	0.01	0.09	0.01	0.30
Total	29007.54	22601.61	49.64	772.13	668.47	0.63	53100.00

Table 5. The land use transition probability matrix between 2005 and 2010.

2005 \ 2010	Cultivated land	Forest	Grass	Water	Construction land	Barren
Cultivated land	94.56%	4.41%	0.14%	0.48%	0.41%	0.00%
Forest	7.97%	91.76%	0.02%	0.22%	0.04%	0.00%
Grass	58.36%	15.27%	7.12%	8.18%	11.01%	0.05%
Water	11.87%	1.39%	0.64%	85.40%	0.70%	0.00%
Construction land	12.41%	2.10%	0.24%	0.72%	84.51%	0.01%
Barren	43.48%	0.00%	8.70%	0.00%	30.43%	17.39%

Table 6. The land use transition probability matrix between 2010 and 2015.

2010 \ 2015	Cultivated land	Forest	Grass	Water	Construction land	Barren
Cultivated land	92.30%	6.35%	0.14%	0.48%	0.73%	0.00%
Forest	7.17%	92.42%	0.01%	0.31%	0.09%	0.00%
Grass	56.83%	3.30%	5.90%	23.31%	10.58%	0.09%
Water	17.14%	3.18%	0.42%	78.35%	0.90%	0.00%
Construction land	16.07%	3.52%	0.19%	1.55%	78.64%	0.02%
Barren	53.33%	3.33%	10.00%	3.33%	30.00%	3.33%

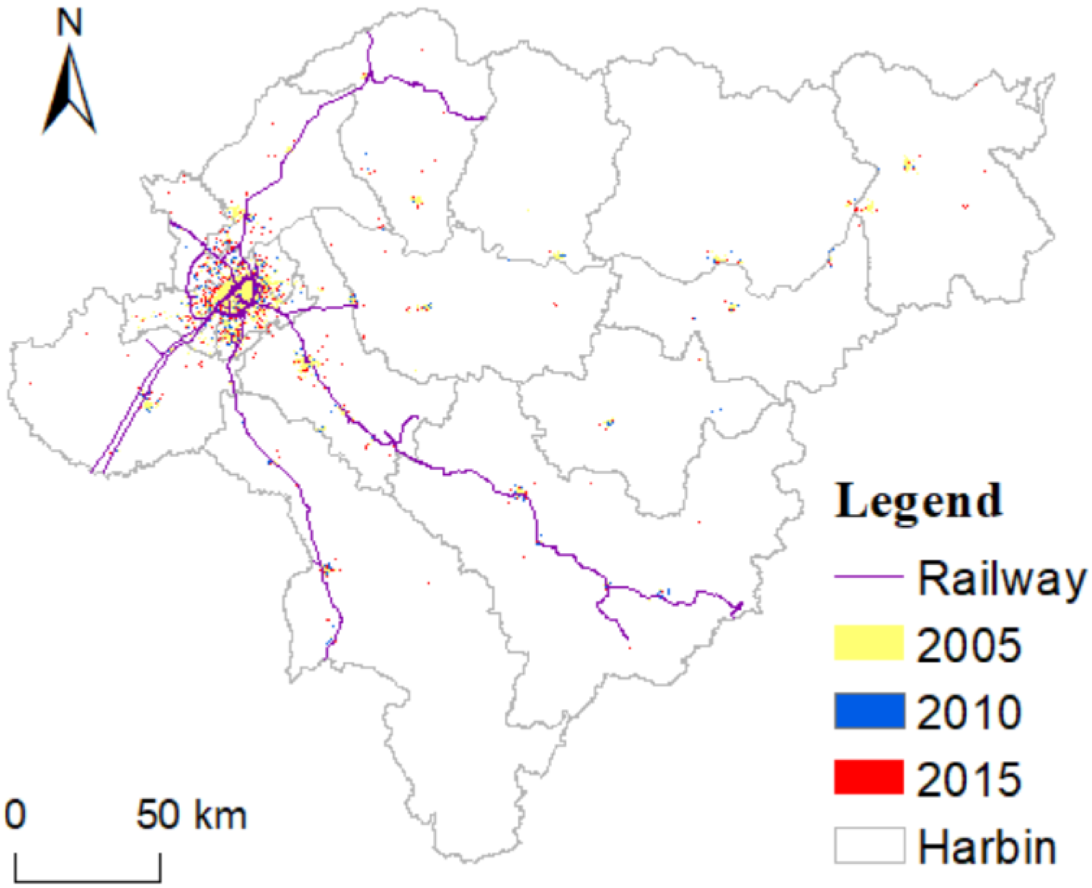

Figure 3. Construction land expansion along the railways.

heavy industry base in northeastern China, development along both sides of the railways was also an important contribution to the Harbin built-up area.

The growth rate of construction land in the districts of Shangzhi, Wuchang, Binxian, Hulan, and Songbei on the south side of the city was relatively large, while the growth rate in the city center was relatively low (Figure 4). The development of the city center was relatively mature, resulting in a relatively small growth area, while the area in the suburbs was vast, which was available for urban growth.

Discussion

The result of Landsat imagery analysis is influenced by the researcher's expertise and judgement. The precision of the Landsat data is 30 meter, which was acceptable for this analysis, but it would be best if higher precision data were used for this research. In addition, this research focused on level I classification, so the more detailed level II classification did not apply to this research. Last, but not least, the seasonal precipitation in the rainy season also inevitably impacted the accuracy of the results.

Conclusion

From 2005 to 2015, cultivated land and

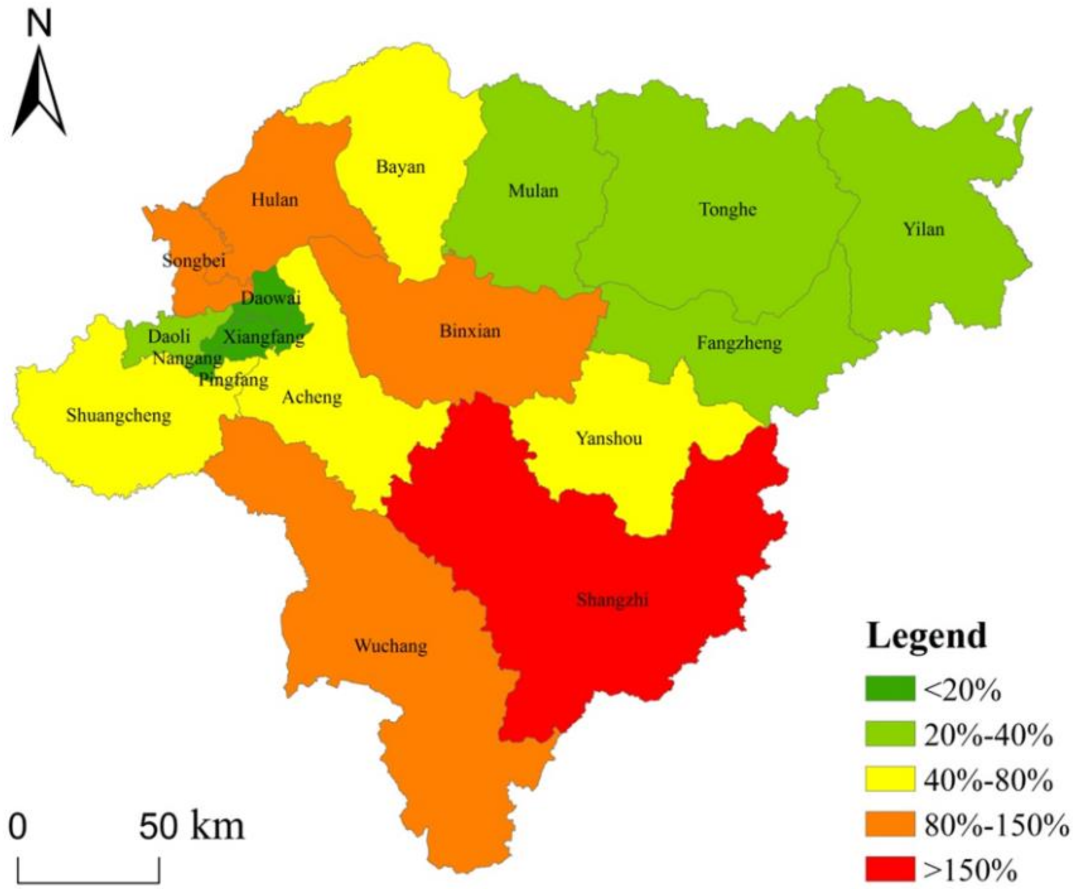

Figure 4. Growth rate of construction land by district from 2005 to 2015.

forest land have always been the main land use in Harbin. The construction land expanded by 194.25 square kilometers due to the loss of cultivated land and forest land and the expansion rate was faster between 2010 and 2015 than between 2005 and 2010. As a developing country, the expansion of the built-up area is an unavoidable part of the process of urbanization. However, in the process of rapid expansion of urbanization, the protection of cultivated land, forest land and other land use should be taken into consideration. In the long run, it is crucial to protect the ecological environment and achieve sustainable development.

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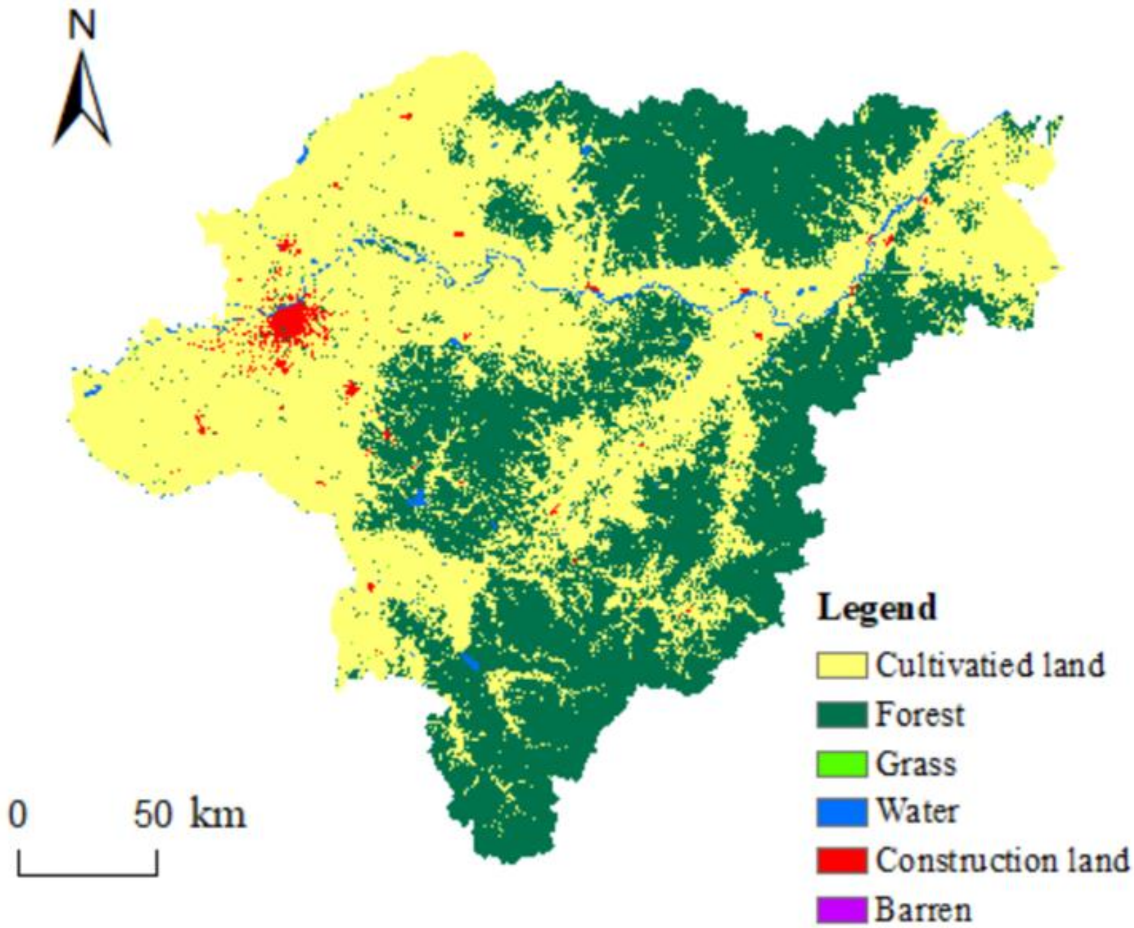
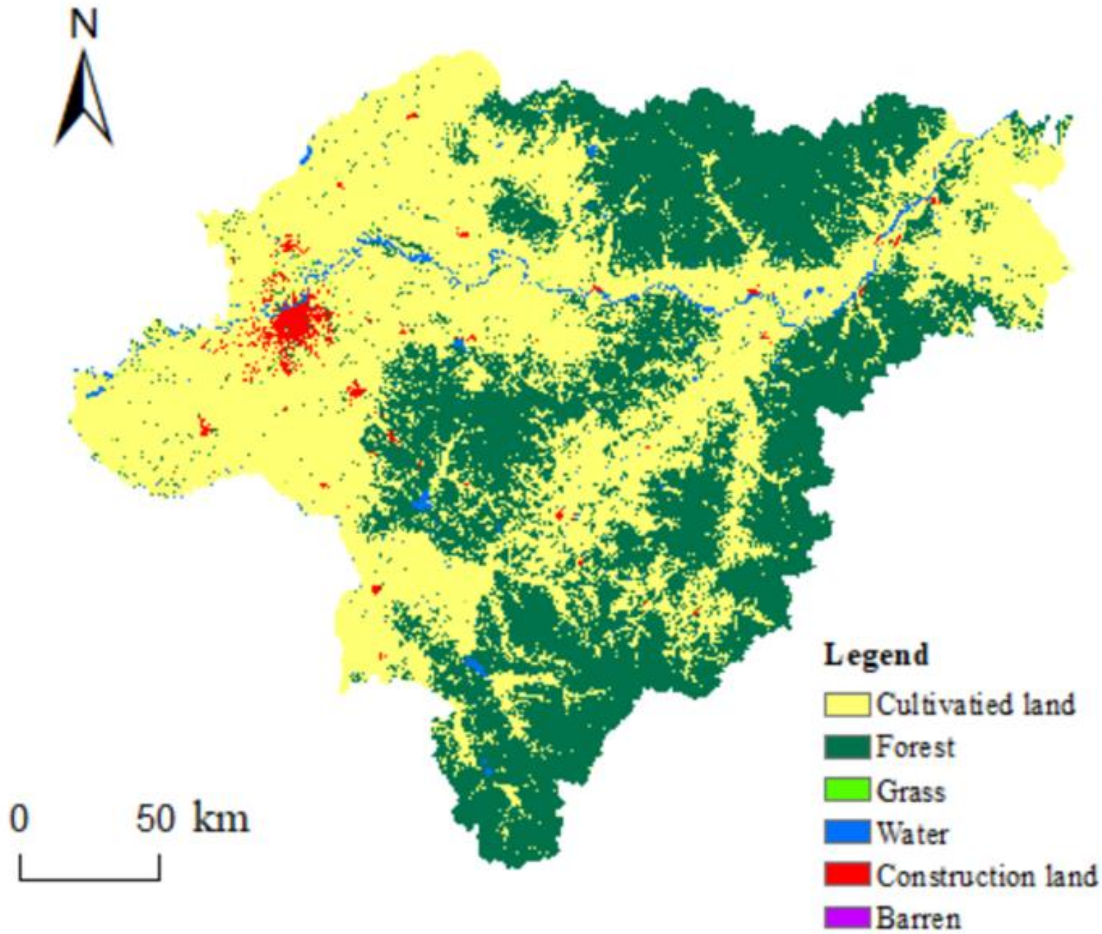
Appendix A. Land use classification in 2005.



Appendix B. Land use classification in 2010.



Appendix C. Land use classification in 2015.