Analyzing the land use changes in the Poyang lake region

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Abstract. Poyang Lake is the largest freshwater lake in China. It faces a series of ecological and environmental problems, hence it is important and necessary to study the land use change in the Poyang Lake region. In this study, Landsat images in 1976, 1989, 1999 and 2009 were analysed using methods including quantitative changes of land use and land use degree change in the Poyang Lake region. Land use was classified into seven types: cropland, woodland, grassland, water body, construction land, bottomland and unused land. Cropland, bottomland and water body were decreasing while water body decreased relatively slowly. However, construction land, grassland, woodland and unused land increased to a certain extent. The land use degree was above national average. During the period 1976-1989, 1989-1999 and 1999-2009, land use was in adjustment stage, development stage and adjustment stage.

1. Introduction
The term “land use” reflects human control over a piece of land, either for a long time or periodically, using a series of biological and technical activities to achieve social and economic goals, making use of the land’s resources in the process [1]. Changes in how land is used arise from interactions between the natural environment and human society; they also reflect important changes in ecological environments [2]. At present, land use /land cover change (LUCC) has been one of the focuses in the world [3,4].It is planed as IGBP-IHDP core projects [5], and becomes an important part of global changes research [6,7] for its basic and importance in global change, biological diversity and other areas. As an important factor that influences environmental and ecological change, how land use will change in the future is the core scientific problem of the current study [8]. Therefore, analyzing past land use changes is important and necessary for predicting the changes in land use that will occur in the future. This analysis will help promote sustainable development in the social, economic, and ecological realms.

Poyang Lake is now the largest freshwater lake that is linked with the Yangtze River in China. It plays an important role in regional water resource management and biodiversity. The Poyang Lake region is the core economic region of Jiangxi province, as well as the most important production area for agricultural products. Furthermore, it also functions as an ecological protection zone in China. However, in recent years, Poyang Lake faced a series of ecological and environmental problems, such as soil erosion, land desertification, drought and flooding disasters, loss of biodiversity, etc. Studying land use changes in the Poyang Lake region is therefore one of the keys to solving its ecological...
problems.
However, few studies on the impact of land use change in the Poyang Lake region in long-term temporal scale have been reported so far. In this paper, based on the remote sensing images taken in 1976, 1989, 1999, 2009, characteristics of land use change in the Poyang Lake region from 1976-2009 will be analyzed.

2. Methodology

2.1. Study Area

Poyang Lake is located in the north of Jiangxi province on the south bank of the Yangtze River. It is the biggest lake linked with the Yangtze watershed. Because of the dual influence from the Yangtze River and the “five rivers,” consisting of the Ganjiang River, Fuhe River, Xinjiang River, Raohe River, and Xiushui River, Poyang Lake has drastic seasonal changes. It forms a unique geographical landscape in which “high water into a lake, low water like a river” and “floods into a sheet, dry into a line.” The Poyang Lake region refers to the region in which the Poyang water body, lake and continent ground attached to. The study area encompasses the main part of the Poyang region, between 115°47′−116°45′E and 28°22′−29°45′N (Figure 1), covering an area of 23,830.16 square kilometers. The Poyang lake region is a subtropical humid monsoon climate. The average annual precipitation is 1,341-1,940 mm. Its geomorphologic structure distributes in a ring and is centripetal. The order of the geomorphology from the middle of the lake to outer edge is water surface, plain, down land, hills, low middle mountains, middle mountains.

Figure 1. Location of the study area.

Humans have been active in the Poyang Lake region for thousands of years. In the 1960s, inning was prevalent [9]. These inning activities claimed land from the lake region and decreased the size of wetlands, which eliminated or ruined the habitats of many animals, especially of birds, causing a serious threat to biodiversity [10]. However, the Mountain-River-Lake Program of the 1980s had a profound influence on land use and land cover in the center of the Poyang Lake region.

2.2. Data sets and method

In this study, four remote sensing images (Table1) were used to examine land use changes in the Poyang Lake region. The images were geometrically corrected and projected into the Universal Transverse Mercator coordinate system. They were processed to produce color composites images by using these bands: 4(red band), 3(green band) and 2 (blue band). Land regions were classified according to the guidelines given in the National Guide of Survey of Land Use in China [11]. Following those guidelines and considering practical situations, we classified land use into seven types: cropland, woodland, grassland, the water body, construction land, bottomland, and unused land. Land use regions were determined by a combination of supervised classification and visual interpretation of satellite images. A maximum likelihood classification method was used to classify the image data [12]. After classification, land use maps in four periods were obtained. To determine the accuracy of the image
classification, the stratified random sampling method [13] was used to generate 256 reference points for each classified image. The classification accuracy was 84.77% in 1976, 83.2% in 1989, 82.56% in 1999, 80.5% in 2009 and Kappa coefficient [14] were 0.83, 0.79, 0.8, 0.78 accordingly. The above Kappa coefficients were higher than the minimum discrimination accuracy 0.7 and met the requirements for monitoring changes in land use. ArcGIS was used to output the maps (Figure 2).

| Table 1. The remote sensing data. |
|-----------------------------------|
| Data source | Time       | Resolution | Project        |
|------------|------------|------------|----------------|
| MSS        | 1976.10.06 | 80 meter   | UTM,zone50     |
| TM         | 1989.07.15 | 30 meter   | UTM,zone50     |
| ETM+       | 1999.12.10 | 30 meter   | UTM,zone50     |
| ETM+       | 2009.12.21 | 30 meter   | UTM,zone50     |

A Geographic Information System (GIS) overlay analysis was applied to further process the land use data. By overlaying data from different time periods, we were able to identify areas where land use changed from 1976–1989, 1989–1999, and 1999–2009. In this paper, land use change and land use degree change were used to quantitatively analyze the land use change pattern in the Poyang Lake region.

2.2.1. Quantitative change of land use
A quantitative analysis of changes in land use was helpful for understanding the pattern of land use change, changes of land use composition, and the degree to which humans used land resources at the time. The quantitative change of land use can be expressed as:

\[ S_1 = (U_b - U_a) \] (1)

\[ S_2 = \frac{(U_b - U_a)}{N} \] (2)

Where \( S_1 \) represents the total change of a certain type of land use during the period; \( S_2 \) represents the per-year rate of change associated with a certain type of land use during the period; \( U_a \) and \( U_b \) represent the areas of a certain type of land at the beginning and the end of the time period, respectively; and \( N \) is the number of years during the time period.

2.2.2. Land use degree change
Land use degree mainly reflects the extent and depth of land use. It not only reflects the natural quality of land itself in land use, but also reflects the composite effect of human factors and natural environment factors. A comprehensive analysis method of land use degree was proposed by [2]. According to the natural balance state of land-nature synthesis under the influence of social factors, the method divided land use degree into several grades and gave grade index accordingly. According to the grade index, the quantitative expressions of land use degree composite index and land use change model were given respectively [15]. In this paper, combined with the actual classification of the study region, the author briefly modified land use degree grades. Then the grading system was obtained (Table 2), in which unused land and bottom land were assigned the factor 1; woodland, grassland and water body, the factor 2; cropland, the factor 3; and construction land, the factor 4.

(1) Composite index of land use degree. Its value reflects the land use degree of a certain region synthetically. The expression is as follows:

\[ L_e = 100 \times \sum_{i=1}^{n} A_i \times C_i \] (3)

Where \( L_e \) is the composite index of land use degree of a certain region; \( A_i \) is the grade of the \( i \)th land use type; \( C_i \) is the percentage of the area of the \( i \)th land use type; and \( n \) is the number of land use grades, with the value between 100 and 400.
Notes: a, b, c, and d correspond to the land use classification map in 1976, 1989, 1999 and 2009.

Figure 2. Land use type of study area.

(2) Land use degree change model. Land use degree change of a certain region is the result of various land use types change in the region. Land use degree and its change or change rate can quantitatively reveal the general proficiency and change trend of land use. The change of land use degree and change rate of land use can be expressed respectively as [16]:

$$\Delta L_{b-a} = L_b - L_a = 100 \times \left( \sum_{i=1}^{n} A_i \times C_{ib} - \sum_{i=1}^{n} A_i \times C_{ia} \right)$$

(4)

$$R = \frac{\sum_{i=1}^{n} A_i \times C_{ia} - \sum_{i=1}^{n} A_i \times C_{ib}}{\sum_{i=1}^{n} A_i \times C_{ib}} \times 100\%$$

(5)

Where $\Delta L_{b-a}$ represents the change of land use degree; $L_a$ and $L_b$ are the composite indices of land use degree at time $a$ and $b$, respectively. $A_i$ is the grade of the $i$th land use degree; $R$ is the change rate of land use degree; $C_{ia}$ and $C_{ib}$ are the area percentage of the $i$th land use degree at time $a$ and $b$. If $\Delta L_{b-a} > 0$, then land use is continuously developed in the region or if $\Delta L_{b-a} < 0$, then the land use degree is reduced.

| Table 2. Classification and evaluation of land use intensity. |
|---------------------------------------------------------------|
| Land use type | Unused land level | Woodland, grassland and water body level | Cropland level | Construction land level |
| Grade index | Unused land, bottomland | Woodland, grassland, water body | cropland | Construction land |
| 1 | 2 | 3 | 4 |

3. Results and discussion

3.1. Analyzing quantitative change of land use
The land use data interpreted from image data are summarized in Table 3. Based on this data, we used formulas (1) and (2) to quantify changes in land use within the Poyang Lake region; the results are summarized in Table 4. As showed in Table 4 and Figure 3, decreases in the areas of cropland, the water body and bottomland occurred, while areas of grassland, woodland, construction land and unused land increased during the period 1976—2009. Cropland was reduced the most, with a decrease in area of 5,151.74 km² and an average annual decrease of 156.11 km². Decreases in the water body area (607.25 km²) and bottomland (978.54 km²) area were the next most pronounced reductions. The average annual decreases of the water body area and bottomland were 18.4 km² and 29.65 km² respectively. However, areas of woodland and construction land increased the most, with an overall increase of 4,047.93 km² and 1,883.23 km² respectively. The average annual increases of woodland and construction land area were 122.66 km² and 57.07 km² respectively. Grassland increased by 446.02 km², with an average annual increase of 13.52 km². Unused land area increased by 430.33 km², with an average annual increased of 13.04 km².

3.2. Analyzing land use degree change

The composite index of land use degree in 1976, 1989, 1999, 2009, changes of land use degree and change rates of land use degree in the study region in three periods were calculated by using equation (4) and equation (5) (Table 5).

| Name          | 1976     | 1989     | 1999     | 2009     |
|---------------|----------|----------|----------|----------|
| Cropland      | 15,158.79| 10,186.37| 12,853.94| 10,007.05|
| Grassland     | 656.14   | 1,850.12 | 1,832.31 | 1,102.16 |
| Water body    | 2,159.87 | 3,936.24 | 1,679.77 | 1,552.62 |
| Woodland      | 2,744.41 | 3,177.42 | 4,198.63 | 6,792.34 |
| Construction land | 650.65 | 1,977.26 | 1,579.97 | 2,533.88 |
| Bottomland    | 2,337.54 | 2,611.78 | 704.60  | 1,359.00 |
| Unused land   | 50.32    | 18.50    | 980.93  | 480.65   |

Table 4. The area of each land during periods of 1976-2009 (Km²).

| Land use type | 1976-1989 | 1989-1999 | 1999-2009 | 1976-2009 |
|---------------|-----------|-----------|-----------|-----------|
| cropland      | -4,972.42 | -382.49   | -2,119.08 | -5,151.74 |
| grassland     | 1,193.98  | 91.84     | 1,020.94  | 4,047.93  |
| Water body    | 1,776.37  | -17.81    | -127.15   | -607.25   |
| woodland      | 433.01    | 102.09    | 259.37    | 1,883.23  |
| Construction land | 1,326.61 | -397.29   | 404.79    | 1,883.23  |
| Bottomland    | 274.24    | -1,907.18 | 654.40    | -978.54   |
| Unused land   | -31.82    | -2.45     | -500.28   | 430.33    |

Notes: “–” means decrease, the same below.

Table 5. Land use intensity change indices.

| Composite index | Changes of land use intensity | Change rate (%) |
|-----------------|-------------------------------|-----------------|
| 1976            | 248.45                        | 259.23          |
| 1989            | 260.13                        | 248.45          |
| 1999            | 255.55                        | 10.87           |
| 2009            | 11.68                         | -4.58           |
| 1976-1989       | -4.19                         | -4.19           |
| 1989-1999       | -1.76                         | -4.19           |
| 1999-2009       | -1.76                         | -4.19           |

Land use degree of the study region was above the national average (231.94) [17] in recent 33 years, being a status above average. From the viewpoint of changes in different periods, during the period 1976-1989, land use degree of the study region showed as follows: cropland of grade index 3 had an obviously decrease, unused land of grade index 1 decreased. While woodland, grassland, water body of grade index 2, bottomland of grade index 1 and construction land of grade index 4 had increases in different intensities. But increased area is briefly less than the decreased area which caused the value of land use degree change in this period was negative (-10.87). The value indicated
that land use of the study region is in adjustment phase. Agricultural industry structure adjustment as well as the implementation of Mountain-River-Lake program may be the reason. During the period 1989-1999, land use of the study region showed as: cropland increased quickly. Grassland, water body of index 2, bottomland of grade index 1 and construction land of grade index 4 decreased in different intensities. However, Woodland of index 2 and unused land of grade index 1 increased. This caused the value of land use degree change in the study region during the period was positive (11.68). The value indicated that land use efficiency had improved through the preliminary land use adjustment and land use of the region is in development stage during the period. During the period 1999-2009, the decreased land use types were cropland, grassland, water body and unused land, the increased land use types were woodland, construction land and bottomland. The value of land use degree change during the period was negative (-4.58), indicating that land use of the study region is again in adjustment phase (figure 3).

![Figure 3. Area change of each land use type during 1976-2009.](image)

4. Conclusions
In this study, based on the four interpreted remote sensing images taken in 1976, 1989, 1999, and 2009, we conducted a quantitative analysis on how land use changed over 33 years in the Poyang lake region. We drew the following conclusions:

(1) Land use structure of the study region had great changes. Among all types of land use, cropland area changed the most. Areas of grassland, construction land and unused land had increased in different degrees while area of the water body and bottomland both decreased to some extent. Overall, the water body decreased slowly, with an average annual decrease of 18.4 km$^2$.

(2) Water body was the most stable land type, while unused land, construction land and woodland changed relatively intensively. Moreover, the land use degree is above national average. During the period 1976-1989, land use was in adjustment stage. And during 1989-1999, land use was in development stage. During the period 1999-2009, land use was in adjustment stage again.

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