Changes of Wetlands in Southwest of China based on Remote Sensing Image and Statistical Data Recognition Technologies: from 1990 to 2016

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Abstract. Wetlands play a significant role in the sustainable development of ecological environment. Nevertheless, the ecosystem of many wetlands has been disturbed and even undermined by recent urbanization and human productive activities. Especially, impact on wetland landscape will affect its ecological function. In this paper, we analyze the changes of wetlands in Southwest China, and have produced the following four results: (1) the area of wetland waters in the study area has been decreasing year by year. From 1990 to 2010 this tendency was particularly prominent; (2) The changes of the international, national and provincial important lake wetlands, which are represented by Lashi Sea, Dianchi Lake and Fuxian Lake, are not obvious in four periods; (3) The sum of the other lake watersheds changed significantly in four periods, slightly higher in 2000 than in 1990, and then decreased rapidly year after year; (4) The changes of the important large reservoirs are more obvious than other lakes; (5) Other reservoir, bottomland and marsh declined sharply by 44.79% from 375.47 km2 in 1990 to 201.07 km2 in 2016;(6) Natural, societal, and economic, as well as human, activities are the major factors of the changes of the wetland landscape in the southwest China. Results suggest that the ecological environment of wetlands should be protected to maximize the function of wetland ecosystems in southwest China.

1. Introduction
Covering 6% of the world’s land surface, wetlands form an important ecological infrastructure and provide varied ecological and social services for the sustainable development of ecological environment[4] [11]. They help to retain water in the landscape [6], play a role in the flood protection system and retain sediments, nutrients and pollutants on their way to the river system [1] [8]. However, these services have changed significantly around the world in recent decades [2]. They are also considered important ecosystems for the conservation of biodiversity as they support a wide variety of flora and fauna [12]. In addition, it reflects the human impacts on environment at various temporal and spatial scales [14]. Recently, it is widely believed that the sustainability of urban development depends on the provision and maintenance of forward-looking municipal and ecological infrastructures. So it is important to investigate the dynamic evolution of the wetland landscape pattern and their driving mechanisms in a larger scale dimension. Understanding the state of wetland ecosystems and their
changes at the national and local levels is critical for wetland conservation, management, decision-making [3].

Landscape ecology emphasizes the interaction between spatial patterns and eco-logical processes, and the causes and consequences of spatial heterogeneity across a range of scales. One approach to achieving better understanding of the changes in wetland landscapes lies [5], therefore, in the analysis of wetland structure, spatial-temporal pattern, ecological process, and driving mechanism using landscape ecological methodologies and theories [13].

So far, most investigators focused on analyses of the changes in landscape structures. Others have studied the ecological planning, design, and management of landscapes by using landscape ecological concepts and metrics. Some research has focused on biodiversity conservation and ecological environment assessment.

In recent years, the dynamics of wetland landscape patterns in China have been investigated using different methods in different locations [7]. Most of studies contribute to the development of wetland science and landscape ecology, and most detailed studies on wetland vulnerability to accelerated sea-level rise have been over small spatial scales and short timescales [9].

However, research on the dynamic changes in the wetland landscape pattern and the driving mechanisms is still limited [15], particularly in a specific region with some unique wetland characteristics [16], such as the plateaus and basins in southwest China. In this study, remote sensing image and statistical data recognition technologies were used to analyze Landsat imagery series data from 1990 to 2016. To understand how wetlands in the study area change. Thus, this paper aims to answer following questions:

1) What was the status and trend of Wetlands in Southwest China from 1990 to 2016?
2) What were the characteristics of the changes?
3) What future wetlands management strategies can be implemented to maintain a sustainable wetlands environment in southwest China?

2. Field area and data sources

2.1. Field area
The field area is mainly situated in Southwest China, covering lakes from Hekou County to Yuanjiang county of Yunnan province in the south, from Longchang County to Xichang county of Sichuan province in the north; and it extends from Bijie city of Guizhou province in the east to Lijiang city of Yunnan in the west (Figure 1).

![Figure 1. Research area in China](image)

The research region includes southern Sichuan Province, most of the central region of Yunnan Province, and the western Guizhou Province. It belongs to the famous Yunnan-Guizhou plateau region, and covers the areas from E 100.05° to 105.34° in longitude and from N 22.54° to 29.36° in latitude.
The middle part is plateau region, while the northern part and southern part are low and flat. The sources of most main Chinese rivers flow across this region. Most of the area has a warm climate and abundant rainfall.

2.2. Data sources
The data sources of this research include the Landsat-TM image of Southwest in China for September 1990, 2000, 2010 and 2016, with a resolution of 30 m*30 m. The image was selected from March to May of the four years of 1990, 2000, 2010, and 2016, because there is less precipitation for each year, and wetlands are rarely affected by floods or droughts. The selection of the objects excluded the farmland wetlands. There are two reasons: Different from reservoirs, the farmland wetlands are maintained only through irrigation. On the other hand, the scope of farmland wetlands is difficult to define by the Image analysis.

2.3. The landscape types and definitions of wetland
On the basis of Criteria for Identifying Wetlands of International Importance and Action Plans of China Wetland Protection (2000), the wetland landscape of southwest in China is divide into five wetland types in accordance with the degree of importance:
1) International, national, provincial important lakes wetlands
2) Other lakes wetlands
3) Important Large reservoirs wetlands
4) Main reservoir, bottomland and marsh wetlands
5) Other reservoir, bottomland and marsh wetlands

In this study, all the identifiable other reservoir, bottomland and marsh wetlands have been selected as much as possible, because the quantity of these wetlands is much, and the area of them is small. Sufficient quantities must be selected to reflect the changes in a more comprehensive way. Table.1 describes the types and quantities of wetlands in the study area.

| Serial number | Wetland type                              | number |
|---------------|-------------------------------------------|--------|
| 1             | International, national, provincial important lakes | 13     |
| 2             | Other lakes                               | 12     |
| 3             | Important Large reservoirs                | 5      |
| 4             | Main reservoir, bottomland and marsh      | 5      |
| 5             | Other reservoir, bottomland and marsh     | 100    |
|               | Total                                     | 135    |

3. Methods
In this study, we used a combination of data collection, local field investigation and image processing. The TM image is processed by using the recognition. The image data is obtained with ArcGIS.

Six steps were taken in analyzing the changes of wetlands in research regions:
1) The Landsat-TM images were processed using the ERDAS IMAGE software system;
2) The wetlands spatial database and attribute database of 1990, 2000, 2010 and 2016 were established by using ArcGIS in combination with Landsat-TM imageries;
3) Using the databases mentioned, the statistical and spatial change characteristics of the wetland in southwest China landscape were analyzed using the patch number, patch area, average patch area, patch area variance, and other characteristics;
4) The landscape ecological indices of the wetlands were calculated using common landscape ecology indices;
5) The wetlands’ spatiotemporal change characteristics, evolution processes, and driving forces for the past 26 years were quantitatively analyzed using canonical correlation analysis;

6) Some recommendations were formulated to better develop, recover and reconstruct a positive eco-environment and to promote sustainable development in research regions.

4. Data Analysis

4.1. The status and trend of wetlands
From Figure 2 and Figure 3, it is clearly observed that the area of wetland waters in the study area is decreasing year by year. From 2000 to 2010 this trend is particularly prominent.

Figure 2. The distribution of wetlands in the study area in four periods
By contrast, it can be seen that except important lakes, other types of wetland underwent very noticeable changes.

![Figure 3](image-url)  
**Figure 3.** Dynamic changes of five types of wetlands in the study area in Four Periods

### 4.2. Changes of Different Types of Wetland Watershed during 1990-2016

#### 4.2.1. The areas of important lakes

It can be seen from Figure 4 that the changes of the international, national and provincial important lake wetlands, which are represented by Lashi Sea, Dianchi Lake and Fuxian Lake, are not obvious in four periods. With the smallest area of 1,066.68 km² in 2010, and in 2016, these important lake waters even slightly increased to 1092.16 km².

![Figure 4](image-url)  
**Figure 4.** Dynamics of Important Lakes Waters in Four Periods

#### 4.2.2. Other lakes waters area

As shown in Figure 5, the sum of the other lake watersheds changed significantly in four periods, slightly higher in 2000 than in 1990, and then decreased rapidly year after year.
4.2.3. **Important large reservoirs areas.** Figure 6 shows that the trend of changes of the important large important reservoirs represented by Songhua dam reservoir and Dumu reservoir, is similar to that of lakes above, but the changes of the reservoirs are more obvious.

![Figure 5. Dynamics of Other Lakes Waters in Four Periods](image)

4.2.4. **Main reservoir, bottomland and marsh wetlands waters area.** From Figure 7, it can be seen that the area of the main reservoir, bottomland and marsh wetlands have a negative correlation with the passage of time. But the study area has less major reservoirs, and the total amount of change is not obvious.

![Figure 6. Dynamics of Important large reservoirs areas in Four Periods](image)
4.2.5. Other reservoir, bottomland and marsh wetlands waters area. Other reservoir, bottomland and marsh wetlands serve significant ecological functions in its wide distribution area. It is clear from Fig.8 that from 1990 to 2016, these small wetlands declined sharply by 44.05% from 375.47 km² in 1990 to 201.07 km² in 2016 (Figure 8).

5. Discussion
From Table 2, the important waters area of the wetlands decreased by 8.78% from 2000 to 2016, while that of other lakes and reservoirs decreased from 44.79% to 64.84%. Among them, the reduction of large reservoirs and other small lakes was most significant.
Table 2. the reduction of water area in different types of wetlands in the study area from 1990 to 2016

| No. | Type                                      | Reduction (km²) | Descending percentage (%) |
|-----|-------------------------------------------|-----------------|---------------------------|
| 1   | International, national, provincial       | 105.124935      | 8.78                      |
|     | important lakes                          |                 |                           |
| 2   | Other lakes                               | 139.765222      | 57.61                     |
| 3   | Important Large reservoirs                | 75.580432       | 64.84                     |
| 4   | Main reservoir, bottomland and marsh      | 16.426968       | 44.79                     |
| 5   | Other reservoir, bottomland and marsh     | 174.401543      | 46.45                     |

The important lakes in the study area have the following characteristic to which great importance had been attached during 1990 to 2016. (1) These waters boast of a large area and a long history with great impacts on the region, such as Diarchy Lake, Fuxin Lake, Silo Lake, Yang Zing Lake, Cao Lake, Era Lake, etc. They play irreplaceable ecological functions, such as in maintaining soil and water, preventing floods or protecting wildlife habitats, such as Lug Lake, Haze black-necked crane habitat, Lash Lake and so on.

Because of the important lakes above characteristics, have received more financial and material investments in the enhancement of its ecological conditions, which is testified by the satellite remote sensing map of the Lash Lake from 1990-2016.

![Figure 9. The satellite image of the Lash Lake in four periods](image)

Located in lining City, Yunnan Province, Lash Lake is the catchment of the Jintao River watershed of northwest Yunnan's plateau.

From the Lash Lake satellite image contrast (Figure 9) it can be seen that in 1990, Lash Lake was occupied for human activities. From 2000 to 2016, the water area of Lash Lake is increasing year by year. And “Management Measures of Provincial Nature Reserves in Lashihai Wetland of lining City, Yunnan Province” was just passed by the Standing Committee of Young County People's Congress in Lining in 1999. At the same year, Lash Lake was funded by the National Science Foundation, United States
Unlike the important international, national and provincial lake wetlands, the research results show that the water area of reservoirs and other lake wetlands has changed significantly in the four periods, especially between 2000 and 2016, for this there are two reasons:

1) Reservoirs and other small lakes, bottomland and marsh wetlands do not have as much social attention as unimportant wetlands.

In the late 1990s, important wetlands in the study area became one of the top concern, but the other wetlands and reservoirs with ecological functions are under inadequate protection.

2) With a relatively smaller area of water, reservoirs and other small lakes, bottomland and marsh wetlands are more susceptible to interference, which may result in its further shrinking and even total disappearance.

6. Conclusion
Since the 1990s, great achievement has been made in the protection of important wetlands. However, the ecological effects of small-scale wetlands and reservoirs are gradually undermined with the shrinking of small-scale lakes and reservoir wetland areas.

In addition to continuing to protect international, national and provincial important wetlands, additional attention and investment to other lakes and man-made wetlands should be increased. Besides relevant departments should increase the social consciousness of the importance and vulnerability of small lakes and constructed wetlands and put them under the key protection. The relevant parts can be included in the scope of the key protection; and publicize it. People and communities from various social fields should be called on to work together towards the protection of wetlands, the essential ecological resources in southwest China.

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