Spatial-temporal Variations in Lakes in Central Yunnan Province from 1987 to 2017

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Abstract. Lake spatial-temporal variations are sensitive records of climate and environmental changes, directly reflecting global changes. Lakes have great ecological and economic benefits, which play an important role in improving the ecological environment of the river basin, regulating surface and underground runoff, irrigating farmland, breeding aquatic animals and plants, maintaining biodiversity, flood control and disaster reduction, and producing and drinking water. In this paper, we took lakes in central Yunnan province as the research object, based on Landsat TM, ETM+ and OLI remote sensing images data in the period from 1987 to 2017, the vectorized boundary of 5 lakes with areas greater than 30 km\textsuperscript{2} in central Yunnan were obtained by artificial visual interpretation technology and the causes of lake variations were analysed. Several conclusions can be drawn from the present study: (1) From 1987 to 2017, the total lake area in central Yunnan increased from 603.86 km\textsuperscript{2} to 605.71 km\textsuperscript{2}. (2) During the study period, the lake area in central Yunnan increased as a whole, but also showed obvious spatial differences. According to the change of lake area, the study area can be divided into three types: stable, expanding and shrinking. Dianchi lake area is a lake area expanding area. Yangzonghai lake area is a shrinking lake area. (3) Influenced by the complex natural and cultural environment in the study area, the reasons for the change of lake area in different areas are different.

1. Introduction
A lake is a water body with a certain water area and relatively slow water change formed by water accumulation in basins or depressions on land \cite{1}. As an important part of the terrestrial hydrosphere, lakes not only participate in the water cycle in nature, but are also extremely sensitive to climate change, serving as an important information carrier to reveal global climate change and regional response \cite{2-5}.

Yunnan is a province with numerous plateau lakes, among which there are 9 lakes with an area of more than 30 km\textsuperscript{2}: dianchi lake, yangzonghai lake, fuxian lake, xingyun lake, qilu lake, erhai lake, lugu lake, chenghai lake and yilong lake. Jiuhu river basin covers an area of more than 8,000 km\textsuperscript{2},...
accounting for 2% of the province's area. The lake covers an area of more than 1,000 km², with a lake capacity of nearly 30 billion m³. The population of Jiuhu basin accounts for about 11% of the total population of the whole province, which is the most densely populated area with the most frequent human activities and the most developed economy. The annual GDP created by Jiuhu basin accounts for more than 1/3 of the whole province. Jiuhu river basin is also the main producing area of Yunnan grain, bringing together more than 70% of the large and medium-sized enterprises in the whole province. Most of the economic centers and important cities of Yunnan are also located in Jiuhu river basin, which plays a vital role in the national economy and social development of the whole province. With the rapid development of economy, water resource shortage is becoming more and more serious, and the water resource supply and demand in Jiuhu basin conflicts with the lake's low capacity of regulating and storing water. In addition, the lake ecosystem of Yunnan plateau is very fragile. Monitoring the changes of lakes to reveal the influence rules of different factors on the lake area is of great significance for rational utilization, development and protection of lake waters [6-10].

With the advantages of wide coverage, large amount of information and high repetition frequency, satellite remote sensing has become an important information source that cannot be replaced by conventional observation in the study of global change. In recent years, some scholars using RS and GIS technology to the area of the part of the lake changes in different areas of the studies [11-12], the results showed that nearly half a century, along with the global climate warming and under the influence of melting glaciers and permafrost degradation, most areas of lake due to the condition of different respectively showed three kinds of expansion, contraction, stable condition, on the whole is given priority to with expansion trend. In the early scientific research, it is difficult for us to obtain the overall information of the change of the plateau lake population area from these research results, because the researchers, study period, research methods and measurement standards are different, and the study area is mainly concentrated in the single lake with a large area of qiang minority. Therefore, it is of great significance to study regional climate change to master the change characteristics of plateau lakes in central Yunnan in recent decades.

In this paper, on the basis of predecessors' research results, in view of the lack of, taking the central Yunnan province as the research area, using remote sensing and GIS technology in the region of area of more than 30 km² lake area during 1987-2017 to study the changes in the situation, changes and the lake area of analysis, for nearly 30 years in Yunnan plateau lakes in Yunnan area change of overall characteristics have a relatively comprehensive understanding. At the same time, combined with the characteristics of the regional environment, the main reasons for the change of lake area are preliminarily analyzed qualitatively.

2. Materials and Methods

2.1. Study area

The central Yunnan (23°20' - 27°02' N, 100°45' - 104°48' E) lies on the southwest China and covers a total area of 1.10×105km² in 2017(Figure 1). This region includes four cities (Kunming, Yuxi, Qujing and Chuxiong).

Given its location on the Yunnan-Guizhou plateau, the vast majority of the land area is mainly mountainous and intermountain basin terrain, with high terrain in the north and low terrain in the south, and gentle ups and downs. Some area's elevation is between 1500 m and 2800m. This area is in the subtropical sub-humid region, a subtropical southwest monsoon climate, wet season clear. The average annual temperature is about 15.1°C, and the average annual precipitation is about 1035mm. The soil types are mainly mountain red soil and there is dry red soil in Jin shajiang area. Vegetation types are diverse, secondary vegetation and artificial vegetation.
2.2. Landsat imagery and preprocessing

The Central Yunnan Province is covered by 8 (128/043, 129/041, 129/042, 129/043, 129/044, 130/042, 130/043 and 130/044) WRS2 path/rows of Landsat images. We collected all available standard Level 1 Terrain-corrected (L1T) products images on the United States Geological Survey (USGS) platform from 1987 to 2017, including 16 Landsat TM images, 8 Landsat ETM+ images and 8 Landsat OLI images. The imaging time of the image is similar, cloudless and of good quality, which meets the needs of image interpretation and this study (Table 1).

Table 1. Satellite data and their sources

| Image/Sensor type | Path/Row | Acquisition date | Source        |
|-------------------|----------|------------------|---------------|
| TM                | 128/043,129/041, 129/042, 129/043, 129/044, 130/042, 130/043 and 130/044 | 1987 | USGS/NASA |
| TM                | 128/043,129/041, 129/042, 129/043, 129/044, 130/042, 130/043 and 130/044 | 1997 | USGS/NASA |
| ETM+              | 128/043,129/041, 129/042, 129/043, 129/044, 130/042, 130/043 and 130/044 | 2007 | USGS/NASA |
| OLI               | 128/043,129/041, 129/042, 129/043, 129/044, 130/042, 130/043 and 130/044 | 2017 | USGS/NASA |
In order to facilitate the experiment, necessary preprocessing was carried out on the original data, mainly including Landsat-7 data band repair, radiation calibration, atmospheric correction and image clipping. Since the fault of Landsat ETM+ sensor produced strip data in May 2003, the data years needed for strip repair in this paper is 2007. Multi-temporal weighted linear regression method with open source code is adopted for strip repair. Radiometric calibration, FLASH atmospheric correction and image clipping are all processed under remote sensing software ENVI5.5.

2.3. Comparison and Selection of Water Extraction Methods
Lake water body information extraction methods include automatic extraction and manual visual interpretation. The former mainly includes single-band threshold method, ratio method, water body index method, spectral classification method, feature transformation method, feature segmentation method, automatic water body discrimination method based on water body spectral knowledge and step by step iterative method. Automatic extraction method is mainly used in the water on the red light, near infrared and short-wave infrared wavelengths strong absorption properties, and through a series of operations to achieve the separation of water and the background features, this kind of method has the advantages of high automation, small workload, but usually higher requirements for the quality of the remote sensing image and threshold is difficult. Artificial visual interpretation method is mainly used to visually distinguish the false color synthesized remote sensing image and obtain the vector boundary of the lake by means of digitalization. Due to the large number and diverse types of lakes in the study area, in order to ensure the accuracy of lake extraction, artificial visual interpretation method was adopted to extract the vector boundary of lakes.

3. Results and analysis
3.1. Current Situation of Lakes
According to statistics (Table 2), the total area of 5 lakes in central Yunnan in 2017 was 605.71 km². Among them, Dian chi lake area is the largest, 296.35 km², accounting for 48.93% of the total lake area in central Yunnan. Fu xian lake covers an area of 214.17 km², accounting for 35.36% of the total area of lakes in central Yunnan. Qi lu lake covers an area of 31.33 km², accounting for 5.17% of the total area of lakes in central Yunnan. Xing yun lake covers 33.73 km², accounting for 5.57% of the total area of lakes in central Yunnan. Yang zonghai lake area is 30.13 km², accounting for 4.97% of the total lake area in central Yunnan province.

| Lake Names    | Area (km²) | Proportion (%) |
|---------------|------------|----------------|
| Dian chi      | 296.35     | 48.93          |
| Fu xian lake  | 214.17     | 35.36          |
| Qi lu lake    | 31.33      | 5.17           |
| Xing yun lake | 33.73      | 5.57           |
| Yang zonghai lake | 30.13 | 4.97 |
| Total area    | 605.71     | 100.00         |

3.2. Overall Variation Characteristics of Lakes
According to the interpretation results of remote sensing images of lakes in central Yunnan province, the lake area showed an overall increase from 1987 to 2017, with the area increasing from 603.86 km² in 1987 to 605.71 km², with an expansion range of 1.81%. From 1987 to 1997, the lake scale expanded most obviously, with the lake area increasing by 14.74 km². From 1997 to 2007, the lake area decreased by 8.17 km², showing a shrinking trend. From 2007 to 2017, the lake area decreased by 4.71 km², showing a shrinking trend.

According to the analysis of the changes in the area of each lake, from 1987 to 2017, the largest expansion of the lake in central Yunnan was the Dian chi lake, which increased by 8.76 km², accounting for about half of the total change in the lake area at that time. In comparison, many lakes in this period shrank, including Fu xian lake, Xin yun lake, Qi lu lake and Yang zonghai lake.
3.3. Spatial Differentiation Rules of Lake Variation
Although the lakes in this area show an overall trend of expansion, there are still obvious differences within them (Table 3). The Dian chi lake basin showed stable expansion from 1987 to 1997, shrinkage from 1997 to 2007, and slow expansion from 2007 to 2017. The changes of Fu xian lake and Xing yun lake were also accompanied by expansion and contraction. Qi lu lake and Yang zonghai lake continued to shrink from 1997 to 2017 and showed expansion in other years.

According to the score and weight of each index, the eco-environment vulnerability value of the counties in southeast Yunnan was calculated. According to the comprehensive evaluation results and the principle of maximum membership, the eco-environment vulnerability degree of 30 karst counties was graded. According to the division results, there are 4 extremely vulnerable counties, 4 severely vulnerable counties, 8 moderately vulnerable counties, 7 mildly vulnerable counties and 7 generally vulnerable counties in the 30 counties in the region.

3.4. Causes of Lake Variation
The change of lake area is a direct reflection of its water balance. When the income of the lake exceeds the expenditure, the water amount is in positive balance, which means the lake area increases or the water level rises; otherwise, it means the lake shrinks and the water level drops. In the equation of water balance of a lake, the income factors mainly include the precipitation of the lake surface, the condensation of water vapor on the lake surface and the runoff into (below) the lake surface, while the expenditure factors include the evaporation of the lake surface, the infiltration of the lake and the runoff from the lake surface (closed-current lakes are not included). In central Yunnan province, the runoff from the lake not only includes the runoff from precipitation. At the same time, for the high-altitude lakes on the plateau, human activities directly affect the balance of water volume. Therefore, the causes of lake changes in central Yunnan are extremely complicated.

Combined with the preliminary results of this study and the results of previous studies, the main causes affecting the changes of lakes in different regions were discussed. Among them, the change of lake area shows an expanding area, and the main factors affecting the change of lake area are the topography and human activities. In the area of shrinking lake area, the main factors causing the decrease of lake area are precipitation and human activities.

| Lake Names      | 1987 (km²) | 2017 (km²) | Variation (km²) | Variation Type |
|-----------------|------------|------------|----------------|----------------|
| Dian chi        | 287.60     | 296.35     | 8.76           | Expanding      |
| Fu xian lake    | 215.26     | 214.17     | -1.09          | Shrinking      |
| Qi lu lake      | 36.60      | 31.33      | -5.27          | Shrinking      |
| Xing yun lake   | 33.94      | 33.73      | -0.21          | Shrinking      |
| Yang zong hai lake | 30.46    | 30.13      | -0.34          | Shrinking      |

4. Conclusion
In this paper, RS and GIS technologies are mainly used to extract the information of lake area in the plateau area of central Yunnan with a plateau area greater than 30 km² from remote sensing images, we analysed its change characteristics during the period from 1987 to 2017. At the same time, combined with the climate change in the middle Yunnan plateau area in recent 30 years, the main reasons affecting the change of lake area in the middle Yunnan plateau were preliminarily discussed. Through analysis, we come to the following conclusions:

(1) From 1987 to 2017, the lake area in central Yunnan was ≥ 30.0km², and the total lake area increased from 603.86km² to 605.71km². From 1987 to 1997, the lake scale expanded most obviously, with the lake area increasing by 14.74 km². From 1997 to 2007, the lake area decreased by 8.17km², showing a shrinking trend. From 2007 to 2017, the lake area decreased by 4.71 km², showing a shrinking trend.
(2) During the study period, the lake area in central Yunnan of Yunnan province increased as a whole, but also showed obvious spatial differences. The Dian chi basin showed steady expansion from 1987 to 1997, contraction from 1997 to 2007, and slow expansion from 2007 to 2017. The changes of Fu xian lake and Xing yun lake were also accompanied by expansion and contraction. Qi lu lake and Yang zonghai lake continued to shrink from 1997 to 2017 and showed expansion in other years.

(3) Central Yunnan is a vast area with significant differences in natural and cultural environment, resulting in different causes of lake changes in different regions. In general, the causes of lake changes in central Yunnan are extremely complicated. The main factors affecting the change of lake area are the topography and human activities. In the area of shrinking lake area, the main factors causing the decrease of lake area are precipitation and human activities.

Acknowledgments
This study was supported by China National Natural Science Research Fund Project (No.41261092, NO. 41561083), Yunnan Province Natural Science Research Fund Project (No. 2015FA016) and Talent Introduction Start-up Fund Scientific Research Project of Kunming University of Science and Technology (No. KKSY201556044).

References
[1] Cheng c, Fu w x, Hu z l, et al. Changes of major lakes in Central Asia over the past 30 years revealed by remote sensing technology[J]. Remote Sensing for Lang&Resources,2015,27(1): 146-152.
[2] Xu s, Liu z m, Wang z m, et al. Dynamics of lake area changes and its driving force analysis in Jilin Province from 1986 to 2008[J]. Journal Of Lake Sciences,2010,22(6):901-909.
[3] Yao x j, Liu s y, Li l, et al. Spatial-temporal variations of lake area in Hoh Xil region in the past 40 years[J]. Acta Geo - graphica Sinica,2013,68(7): 886-896.
[4] Zhu g, Gao h j, Zeng g. Lake change research and reasons analysis in Xinjiang arid regions during the past 35 years[J]. Arid Land Geography,2015,38(1): 103-110.
[5] Li l. Spatial-temporal characteristics research of lake variations and ice phenology in Hoh Xil region in recent years[D]. North-west Normal University,2015.
[6] Shao j l, Zheng w, Liu c. Analysis of spatial-temporal variations in the main flood season and their influencing factors of the Dongting Lake based on meteorological satellite data[J]. Resources and Environment in the Yangtze Basin,2015,24(8): 1315-1321.
[7] Li j g, Li j r, Huang s f, et al. The remote sensing monito-ring analysis of Chinese Dongting Lake water area variations in last 10 years using Terra / MODIS data time series[J]. Journal of China Institute of Water Resources and Hydropower Research,2010,08(3) : 201-207.
[8] Zhao y l. Dynamic monitoring on water level of angulinao lake and the causes of its iring up[J]. Journal of Geo-information Science,2009,11(3): 312-318.
[9] Wan w, Xiao p f, Feng x z, et al. Monitoring lake changes of Qinghai-Tibetan Plateau over the past 30 years using satellite remote sensing data[J]. Chinese Science Bulletin,2014,59(10): 1021- 1035.
[10] Ma ronghua, Yang guishan, duan hongtao, jiang jiahu, wang su-min, feng xue-zhi, li ai-nong, kong fan-xiang, xue bin, wu jing-lu, li shi-jie. The number, area and spatial distribution of lakes in China.Science in China: earth science, 2011,41 (3) : 394-401.
[11] Chang xueli, zhao xueyong, wang wei, liu liangxu. Response of lake uplift to climate change in horqin sandy land. Journal of ecology, 2013,33 (21) : 7002-7012.
[12] Sun rui, cui guofa, thunder, zheng yao min. Evaluation method of conservation value of wetland nature reserve. Journal of ecology, 2013,33 (6) : 1952-1963.