MONITORING THE CHANGES OF LAKES IN THE SOURCE REGION OF THREE RIVERS WITH REMOTE SENSING DATA FROM 1976 TO 2009

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ABSTRACT:

As the birthplace of Yangtze River, the Yellow River and Lancang Rive, Source Region of Three Rivers (SRTR) is an important resource for fresh water supplement in China. SRTR also has very obvious ecological function which forms ecological security barrier for China's Qinghai-Tibet plateau. The inland lakes here play an important role for the water cycle in the plateau. The monitoring results were extracted with TM data from 1976 to 2009. The results show that from 1976 to 2009 the lakes' area in SRTR dropped first and then expanded with 2000 as sector. The lakes area was 6778 km2 in 2009, about 1.90% of the whole region, and increased than 1976 by 133.15 km2. Most of the large lakes above 80 km2 have the same change trend. The expanded lakes increased in number gradually, while the changes in the amplitude and time characteristics were different. From 1976 to 2000, the number of new lakes increased while died lakes dropped; and from 2000 to 2009 it is just on the contrary. In the study the index of lake change trend (ILCT) was adopted to contrast lake atrophy condition. With ILCT 24.55 there is an expansion trend for the lakes in SRTR during the last 35 years. The lakes with ILCT's absolute value greater than 1 were those merged with or disconnected from surrounding smaller lakes. Here the precipitation and snow melt are main supplies for the lakes. The change of lakes' area has well correlated with precipitation, and weak correlated with temperature from 1976 to 2009. But from 2000 to 2009, there has a strong correlation with precipitation, temperature. All these show from the side that the precipitation and snow melt are important factors to influence the lakes' change. The lakes have the coordination function for the good ecological environment in the region. The conclusions from the study can provide references in response to climate change research and rational utilization of water resources in SRTR.

1. INTRODUCTION

As the birthplace of the Yangtze River, the Yellow River and Lancang River, SRTR has very obvious ecological function and play an important role.There not only is the ecological barrier for the sustainable development in the downstream region, but also is the treasure house of biodiversity resources, life zone of human culture and common human natural wealth. Qinghai-Tibet railway goes through the region. To protect the SRTR also means to protect the ecological barrier for the sustainable development of human civilization and the environment for human survival. Due to the natural factors like global warming, natural calamities and man-made misfortunes in recent decades, and the irrational exploitation of natural resources, ecological environment in SRTR has been suffering double pressures from natural and social economic. Lake is the most important indicator of ecological system changes in SRTR; so based on lakes to analyze the whole ecosystem change has a guiding value. According to Ecological Environment Monitoring Bulletin in 2006 released by Qinghai Provincial Meteorological Bureau, there was a continuous shrinking trend for most lakes in SRTR which indicates the ecological condition was still degrading here.

At present, domestic and foreign scholars mainly focused on ecological system pattern, grassland degradation, soil erosion, climate, land cover and other aspects [1-8] in SRTR. When it comes to the lakes, more research concentrates in the source region of the Yellow River, and the two largest freshwater Zhaling and Eling lakes are taken as the typical lakes in the studied area [9]. Few studies paid attention to the all lakes in SRTR. Li Hui[10] analyzed the area change and spatial distribution of the largest 24 lakes during the four phases from 1976 to 2005, and the results show the lakes in SRTR experiences contraction before the expansion and the degree of atrophy is greater than that of expansion. With long time series remote sensing data, Li Junli[11] made the map of Lakes distribution and variation in Qinghai-Tibet Plateau and analyzed the characteristic of spatial and temporal changes of Lakes in the closed inland basin in recent thirty years.

With remote sensing technology the study monitored the lakes in SRTR in five phases from 1976 to 2009 years. The spatial distribution characteristics, numbers, areas of lakes with area above 0.03km^2 were analyzed. The ILCT was adopted to express the lakes' change condition quantitatively. And the relationship between the changes of lakes with temperature and precipitation also were discussed simply in the study.

2. STUDY AREA AND DATA

2.1 Study area

SRTR lies in southern Qinghai Province, western China, north latitude 31°39′~36°12 and longitude 89°45′~102°23. As the

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hinterland and main body of Qinghai-Tibet Plateau, SRTR is the source catchment region for the Yangtze River, the Yellow River and Lancang River. Moreover SRTR is the biggest natural protection area in China. The eastern and southeastern regions are adjacent to Gansu and Sichuan Province, and the southern and western adjacent to the Tibet autonomous region. The north is connected with the Zhiduo county and the Hoh Xil Nature Reserve region. The total area is 346500 km^2, about 43% of the total area of Qinghai province. The landform is complex here and mountain landscape is dominated, with average elevation about 4400m. The climate belongs to Tibetan Plateau climate system. Because of the high elevation, thin air in most regions, growth period for growth here is short. The main vegetation types are meadow complying with obvious horizontal distribution and vertical distribution rules. There are many rivers, lakes and marshes, and SRTR is the highest and largest region with the most abundant of wetland types in the world [12].

2.2 Data source and processing

The data sources include TM with resolution 15m in 2009, 2004 and 1990, ETM+ with resolution 15m in 2000, and MSS with resolution 79m in 1976. Artificial interpretation mode was used to extract the lakes information in SRTR. The information extraction process follows the steps in turn: data collection - > image correction - > interpretation rules -- > interpretation sample map - > image interpretation -- > statistics - > change analysis. While interpreting, the scale of view map must be greater than 1:25 000 and the smallest polygon is 4 pixels.

3. THE LAKES IN SRTR IN 2009

The distribution map of lakes in SRTR in 2009 is presented in figure 1. Here the spatial distribution of lakes is uneven. The two largest lakes, Zhaling lake and Eling Lake, lie in the middle slant northeast, and other lakes mainly distribute in the northwest. In 2009, there are 5976 lakes in SRTR, 6777.98 km^2, 1.90% of the whole region. The largest three lakes, Eling Lake, Ulan UL Lake and Zhaling Lake, with area 623.47km^2, 569.62 km^2 and 530.12 km^2 respectively, account for 25.42% of the total area of the lakes. There are 13 lakes with area above 100km^2, 59.56% of the lakes' total area. The number of the lakes above 1km^2 is 216, 6136.45km^2, 90.52% of the lakes' total area. And the lakes with area under 1km^2 is 5760, 641.53 km^2, 9.48% of the lakes' total area. The lakes with area from 0.03 to 0.1 km^2 is 68.88% of the lakes' total number, while the area only accounts for 3.24%.

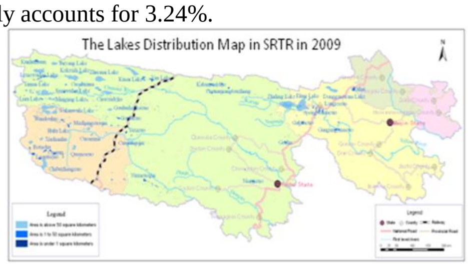


Fig .1 the Distribution Map of Lakes in SRTR in 2009

Tab.1 the Statistics of the Lakes in SRTR in 2009

Area	Number	Number Ratio	Total Area	Area Ratio
>500	3	0.05%	1723.21	25.42%
100-500	10	0.17%	2314.30	34.14%
50-100	10	0.17%	696.86	10.28%
10-50	39	0.65%	936.30	13.81%
5-10	28	0.47%	200.80	2.96%
1-5	126	2.11%	264.99	3.91%
0.2-1	731	12.23%	295.80	4.36%
0.1-0.2	913	15.28%	125.88	1.86%
0.05-0.1	1960	32.8%	135.82	2.00%
0.03-0.05	2156	36.08%	84.03	1.24%

4. CHANGE ANALYSIS

4.1 The change of lakes number and area

From 1976 to 2009, the total area of the lakes above 0.03 km^2 first decreased and then increased in SRTR (as shown in Table 2). And the total area is 6778km^2 in 2009, 1.90% of the whole region, 394.07 km^2 more than that in 2000 and 133.15 km^2 more than 1976. The area of lakes above 10 km^2 accounts for about 60% of the lakes' total area. As shown in Table 3, their numbers changes very little and total areas decreased firstly and then increased from 1976 to 2009. In 2000 their total area is least, but when it comes to 2009 the total area has enlarged to the level in 1976.

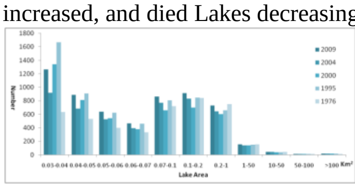
Tab.2 the Statistics of the Lakes above 0.03 km^2 from 1976 to 2009 in SRTR

Time	Number	Total Area	Percentage
1976	4428	6644.83	1.87%
1995	6165	6556.72	1.84%
2000	5231	6383.91	1.79%
2004	4964	6535.90	1.87%
2009	5976	6777.98	1.9%

Tab.3 the Statistics of the SRTR Lakes above 10 km^2 from 1976 to 2009 in SRTR

Time	Number	Total Area	Percentage
1976	64	5620.71	1.57%
1995	61	5502.85	1.54%
2000	60	5453.19	1.53%
2004	62	5572.51	1.56%
2009	62	5670.66	1.59%

During 1976～2009, the change of lakes' number mainly is reflected by the new lakes under 0.2 km^2, especially the number of lakes with area between 0.03 and 0.05km^2 has a large change amplitude in SRTR. From 1976 to 1995, the number of lakes varies obviously, new lakes 3226 and died lakes 1489. From 1995 to 2009, the total number of lakes first dropped and then increased, and died Lakes decreasing, new lakes increasing.



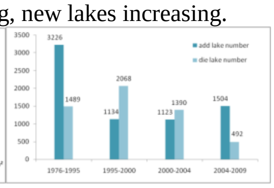


Fig.2 the Statistics of the Lakes in SRTR from 1976 to 2009

Fig.3 the Statistics of the new and died Lakes in SRTR from 1976 to 2009

4.2 The change of typical lakes

There are 16 lakes with area more than 80 km^2 in SRTR, about 85% of lakes' total area. Taking the 16 lakes as typical lakes, we analyzed their change characteristics during 1976～2009 period. In order to describe the area change tendency and the degree of relative changes, the slope of the minimum square linear regression equation is adopted to express the change trend and strength in a continuous period, which can be called the index of lake change trend (ILCT). Specific calculation formula is as follows:

$$\theta_{slope} = \frac{n\times\sum_{i=1}^{n} i\times S_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} S_i}{n\times\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \quad (1)$$

Here θ_{slope} is the slope of the trend line that is ILCT, i corresponds to 5 periods and can be set from 1 to 5, S_i is the lakes' area in period i. The total tendency reflects the change trend in 5 periods from 1976 to 2009. The trend line of each lake's area is the simulation change trend of the lake area from 1976 to 2009. Here the trend line is not a simple connection between last year and the first year, in which $\theta_{slope}>0$ shows the expanding trend, otherwise declining trend.

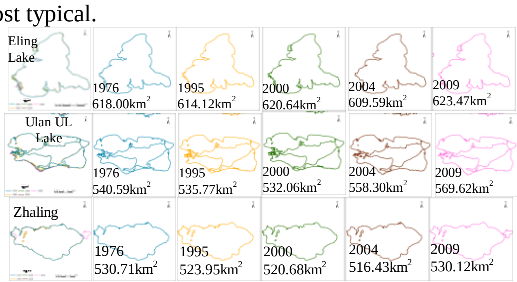
4.2.1 The change of typical lakes

Table 5 is a typical lake area list in SRTR from 1976 to 2009. It can be found from table 5 that the typical lakes' area in SRTR experiences a process decreased first and then increased. And in 2000 for the sector, the total area reduced from1976 to 2000, and enlarged after 2000. But the amplitude is small, 80.90km^2 in 2009 more than that in 1976. There are 7 lakes increased area l: Eling lake, Wulanwula lake, Chibuzhangcuo lake, Lexiewudan lake, Cuorendejia lake, Quemocuo lake, Yinma lake, and the total expand area is 143.77km^2, about 7.26% more than 1976. The other 9 lakes reduced area: Zhaling lake, Jinxiwulan lake, Kekexili lake, Kusai lake, Zhuonai lake, Donggeicuona lake, Taiyang lake, Cuodarima lake, Mingjing lake, and the total atrophy area is 62.87km^2. Here 11 of the 16 typical lakes increased during 2000 to 2004, 9 during 2004 to 2009, 4 during 1976 to 1995, 5 during 1995 to 2000.

Tab.4 the Typical Lakes' Area in SRTR from 1976 to 2009(unit: km^2)

Name	1976	1995	2000	2004	2009	Rate of Total Change	Trend Index
Eling lake	618.00	614.12	620.64	609.59	623.47	5.47	0.641
Wulanwula lake	540.59	535.77	532.06	558.30	569.62	29.03	8.059
Zhaling lake	530.71	523.95	520.68	516.43	530.12	-0.60	-0.87
Jinxiwulan lake	317.08	292.53	287.79	309.07	306.24	-10.85	-0.514
Kekexili lake	312.97	306.30	304.92	314.34	312.86	-0.12	0.782
Chibuzhangcuo lake	282.78	288.93	292.57	282.31	293.42	10.64	1.466
Kusai lake	271.45	261.82	258.01	264.54	264.58	-6.87	-1.102
Zhuonai lake	259.52	258.78	256.93	259.95	257.76	-1.76	-0.235
Donggeicuona lake	248.87	237.35	228.15	231.70	228.97	-19.90	-4.545
Lexiewudan lake	238.67	221.61	225.15	237.39	242.43	3.76	2.33
Cuorendejia lake	137.31	201.68	207.63	199.40	200.84	63.53	12.478
Taiyang lake	101.91	103.69	101.41	101.91	101.30	-0.61	-0.3
Cuodarima	92.36	80.86	76.23	83.98	74.35	-18.01	-3.29
Mingjing lake	92.30	78.32	77.45	87.98	88.15	-4.15	0.136
Quemocuo	84.24	83.53	83.22	83.01	88.26	4.02	0.752
Yinma lake	78.59	100.99	108.27	108.62	105.91	27.32	6.227
Total	4207.37	4190.22	4181.07	4248.52	4288.27	80.90	22.01

The change of lake area not only is reflected by expansion and contraction of the shore line, but also performed by the connection with and partition from the around small lakes. As shown in figure 4, the map of lakes changed most obviously within the 16 typical lakes shows there are around small lakes merged with or isolated from the main lakes which lead to lake's area vary obviously. But the changing of the shore line is not the main reason for the lakes around small lakes. For the change of Lake area lake like Cuorendejia,Cuodarima,Yinmahu, is most typical.



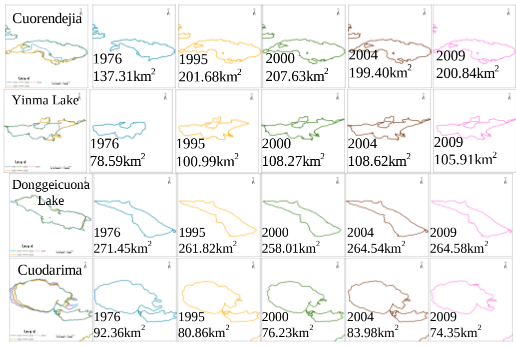


Fig. 4 the Typical Lakes Area Change from 1976 to 2009

4.2.2 The change trend of the typical lakes

The ILCT for the 16 typical lakes in SRTR is 22.01 from 1976 to 2009(as shown in Table 5), which presents an expansion trend. Moreover this expansion is mainly caused by combining with around small lakes. With ILCT 24.55 the lakes in SRTR have the same change trend. From table 5 it can be found that there is a large difference ILCT for different lakes. Combining with figure 4, we find that the lakes with absolute value of ILCT above 1 are the lakes merged with or disconnected from around small lakes. With little area change the third lake, Zhaling Lake, shows a declining trend, even though it merged small lakes around during 2004 to 2009. The ILCT for KeKeXiLi lake and Mirror Lake is greater than 0 though their area decreased in 1976-2009, and it is mainly because their areas increased continually from 1995 to 2009.

5. ANALYSIS THE LAKES' CHANGE INFLUENCED BY CLIMATE FACTORS

The precipitation and surface runoff is the main supply source of lakes in SRTR. In the source region of the Yellow River there is about 48% of spring runoff supplied by melted snow [13, 14]. Actually the melted ice and snow is actually indirect recharge source of the lakes in SRTR. The rainfall condition directly affects the lakes' area, and temperature has indirect effect through the influencing melted ice and snow and permafrost. From 1976 to 2009 the temperature rises in SRTR. After 21 Century, the warming intensifies is very clear in spring and autumn in SRTR which directly impacts on surface runoff. Annual precipitation shows increasing trend in SRTR, and its spatial distribution presents increased in north and decreased in southeastern [15]. As it can be seen from figure 5, the lakes' area and the regional precipitation have the same change trend line in SRTR from 1976 to 2009, with the correlation coefficient 0.666. While the correlation coefficient between the precipitation and the area of lakes above 10 km^2 is 0.762 which proves the correlation between area of great lakes and the precipitation is more closely. There is a weak correlation between lakes' area and temperature in SRTR.

The lakes' area in SRTR shows an obvious expansion trend in 2000-2009. The change trend of lakes' area has a same trend with annual accumulated precipitation and temperature in SRTR; moreover there are strong correlations between these factors. We can come to conclusion that the precipitation and temperature are indeed important factors affected the SRTR lakes expansion in recent ten years.

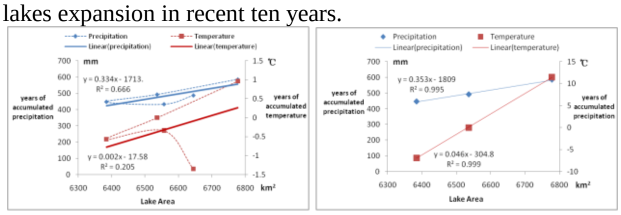


Fig.5 The Relationship between the Lakes' Area and Precipitation and Temperature in SRTR from 1976 to 2009

Fig.6 The Relationship between the Lakes' Area and Precipitation and Temperature in SRTR from 2000 to 2009

6. ANALYSIS AND DISCUSSION

Known as "China water tower" SRTR is not only the origination of Yangtze River, Yellow River and Lancang River but also one of the regions developed most rivers in Eurasia.. With high altitude, steep mountains and harsh environment, the lakes' change here records the changing process of water balance, climatic and environmental sensitively. There are many lakes in SRTR and more than 2000 lakes with area between 0.03 and 0.1 km^2. The lakes here account for 1.9% of the whole region and spatial distribution is relatively concentrated. And the area of lakes above 1 km^2 is about 90.52% of total lakes' area.

From 1976 to 2009, there is an expansion trend for lakes' area in SRTR. During 1976 to 2000, the total lake area was shrinking and then increasing from 2000 to 2009. The areas of lakes above 10 km^2 have the same trend. During the period from 1976 to 2009 the 16 typical lakes' area first dropped and then increased in SRTR. And the number of lakes enlarged gradually increased, but the variation in the amplitude and time characteristics were different. The largest Eling Lake and Wulanwula Lake area have expansion trend, and Zhaling Lake shrinking trend. The lakes with absolute value of ILCT above 1 are the lakes merged with or disconnected from around small lakes. There are obvious changes for the number of lakes under 0.2 km^2 in SRTR from 1976 to 2009, especially lakes between 0.03 and 0.05km^2. During the period from 1976 to 2009 there was a warming and wetting climate trend in SRTR. The increasing precipitation is one of the important factors to the expansion of lakes' area. In addition, temperature change indirect effects of lake area change through the influencing to melted ice, snow and permafrost. From 2000 to 2009, there is a close correlation between lakes' area and precipitation, temperature in SRTR.

On the basic of remote sensing technology the study monitored the lakes' changes in SRTR from 1976 to 2009 years. For the limitation of the data, there is a certain span during dividing the study stages. But the results are consistent with the similar research [10, 16]. Although the image resolution for 1976 was different with other years, our research object is lakes above 0.03 km^2, approximately 7 pixels in the 79 m resolution image. As a result about the change in the overall trend it can be trusted. At the same time, with the limited regional meteorological information site, only the simple correlation between the lakes' area and meteorological information was analyzed. Further studies can be continued by analyzing the change reasons of lakes combined with the meteorological information, actual measured data of hydrological data for the study area.

7. ACKNOWLEDGEMENTS

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