Water Area Variation in Poyang Lake based on satellite monitoring from 1977 to 2021

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Abstract

Lake has an important role of Earth's hydrologic cycle. The changing of lake water area shows the ecological health of lakes by instant feedback. Most analyses of long-term monitoring of lake area are not comprehensive enough, This study based on the remote sensing images from 1977 to 2021, combined with the Keyhole satellite data, hydrographic survey, meteorology monitoring and land use change survey, investigated the Poyang lake water area changes. Moreover, examined the response relationship between lake water area and the impact factor, analyzed the influence of river lake interaction on lake water area.The results showed that: (1) From 1977 to 2017, the water area of Poyang Lake in flood season (June to September) and dry season (November to Next February) showed a significant downward trend by years. (2) In flood season, runoff, sediment, precipitation has significant correlation with water area. In dry season, sediment showed a significant correlation with water area. (3) The Three Gorges Dam water impoundment at the upper reaches of the Yangtze River weakened eliminated the blocking or reversing flow from the Yangtze River, caused the water area decreased in advance at the end of flood season after 2005, and decreased rapidly in dry season after 2003. (4) The change of lakebed elevation caused by sedimentation and human activities also accelerated the shrinkage of water area. Result demonstrated that the variation of river lake interaction is the primary cause of Poyang Lake water area dramatic change.

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Lake has an important role of Earth's hydrologic cycle. The changing of lake water area shows the ecological health of lakes by instant feedback. Most analyses of long-term monitoring of lake area are not comprehensive enough, This study based on the remote sensing images from 1977 to 2021, combined with the Keyhole satellite data, hydrographic survey, meteorology monitoring and land use change survey, investigated the Poyang lake water area changes. Moreover, examined the response relationship between lake water area and the impact factor, analyzed the influence of river lake interaction on lake water area.The results showed that: (1) From 1977 to 2017, the water area of Poyang Lake in flood season (June to September) and dry season (November to Next February) showed a significant downward trend by years. (2) In flood season,

runoff, sediment, precipitation has significant correlation with water area. In dry season, sediment showed a significant correlation with water area. (3) The Three Gorges Dam water impoundment at the upper reaches of the Yangtze River weakened eliminated the blocking or reversing flow from the Yangtze River, caused the water area decreased in advance at the end of flood season after 2005, and decreased rapidly in dry season after 2003. (4) The change of lakebed elevation caused by sedimentation and human activities also accelerated the shrinkage of water area. Result demonstrated that the variation of river lake interaction is the primary cause of Poyang Lake water area dramatic change.

Keywords: Poyang Lake remote sensing image, climate change, human influence, river lake interaction

1. INTRODUCTION

Lake is an important role of Earth's hydrologic cycle, which is natural reservoir of water formed by stagnant water in the depressions of the earth, has broad expanse of water and slow current(Qi et al. 2020). Water storage function of lake not only provide water to the surrounding area, but also influence river flow regulation and groundwater levels(Y. Li et al. 2017; Rosenberry et al. 2015). Lake surface evaporation effects microclimate temperature change. The ecosystem formed by the lake also provides the integral living habitat for creature(Vaheddoost and Aksoy 2018). The stable state of the lake are especially necessary for overall ecological balance. In recent years, the average global temperature has climbed sharply, accompanied by the influence of human activities, which made the major of lakes in the world had changed in different degrees. The Changes of lake have led to cascading changes in the surrounding environment. Lakes on the Qinghai-Tibet Plateau (QTP) have notably expanded over the past 20 years. The permafrost occurring beneath the bottom and surrounding the lake could degrade in the process of lake expansion or erosion. Lead to the release of organic carbon into lakes, affecting the water environment, and perhaps be further discharged into the atmosphere, affecting regional climate changes(G. Zhang et al. 2020; Y. Zhang et al. 2022). Some scholars use big data to analyze the characteristics of global lake changes and confirm that the changes of lake area affect the overlying atmosphere and lake-air interactions, and causing the changes of lake temperatures(Huang et al. 2022).

The water area of lake can visually show the changes of the lake, which affected by many factors, such as the river, climate, or topography of the lake basin. Therefore, keeping a good grip on lengthy sequences of data sets in lake change will help us understand the true state of the lake. However, there are still problems with long-term monitoring of large lakes, lake monitoring time series are incoherent or too short, or select a single influencing factor to analysis, that is not comprehensive enough for large lakes, and even lead to radically different conclusions. Some scholars combining multiple remote sensing data retrieves the open surface water area series of Lake Chad, results show that the total inundation area continuously recovered from 1982 to 2020(H. Li et al. 2021). But the observations in 1960s to 1970s show that Lake Chad has shrunk from about 25,000 km^2 to less than 1350 km^2. The continuous long-term monitoring will more accurately describe the changing characteristics of the large lake(Mahmood and Jia 2019).

Lake Poyang is the largest freshwater fluvial lake of China, connected with the middle and lower reaches of the Yangtze River, located in China's most important economic development region-The Middle-lower Yangtze Plain (Fig.1). Meanwhile Poyang Lake has unique rhythmic changes, lake water area appear lake landscape in flood season, and appear river landscape in dry season, the extreme variation of lake area not only play a role in flood storage, but also provide habitat for a variety of wildlife(F. Li et al. 2014). The morphological changes of Poyang Lake water area has great significance for the production and development of the basin. After the 21st century, many scholars have found climate change and frequent human activities have affected the Poyang Lake hydrological rhythm changes, through water level monitoring found the water level of the Yangtze River are also contributing to the change of Poyang Lake(Wu and Zhan 2020; Z. Zhang et al. 2015). Therefore, Using real-time dynamic monitoring, and comprehensive evaluation of the influencing factor on the water area change is very necessary. In this study, using 40 years' historical image to extracted Poyang lake area of flood season and dry season water data, combined with the basin hydrology, meteorology, land use data, and using statistical methods to analyze the relationship between hydrological rhythm changes on climate change and human activities in Poyang Lake. Providing theoretical basis for Poyang Lake water resources regulation.

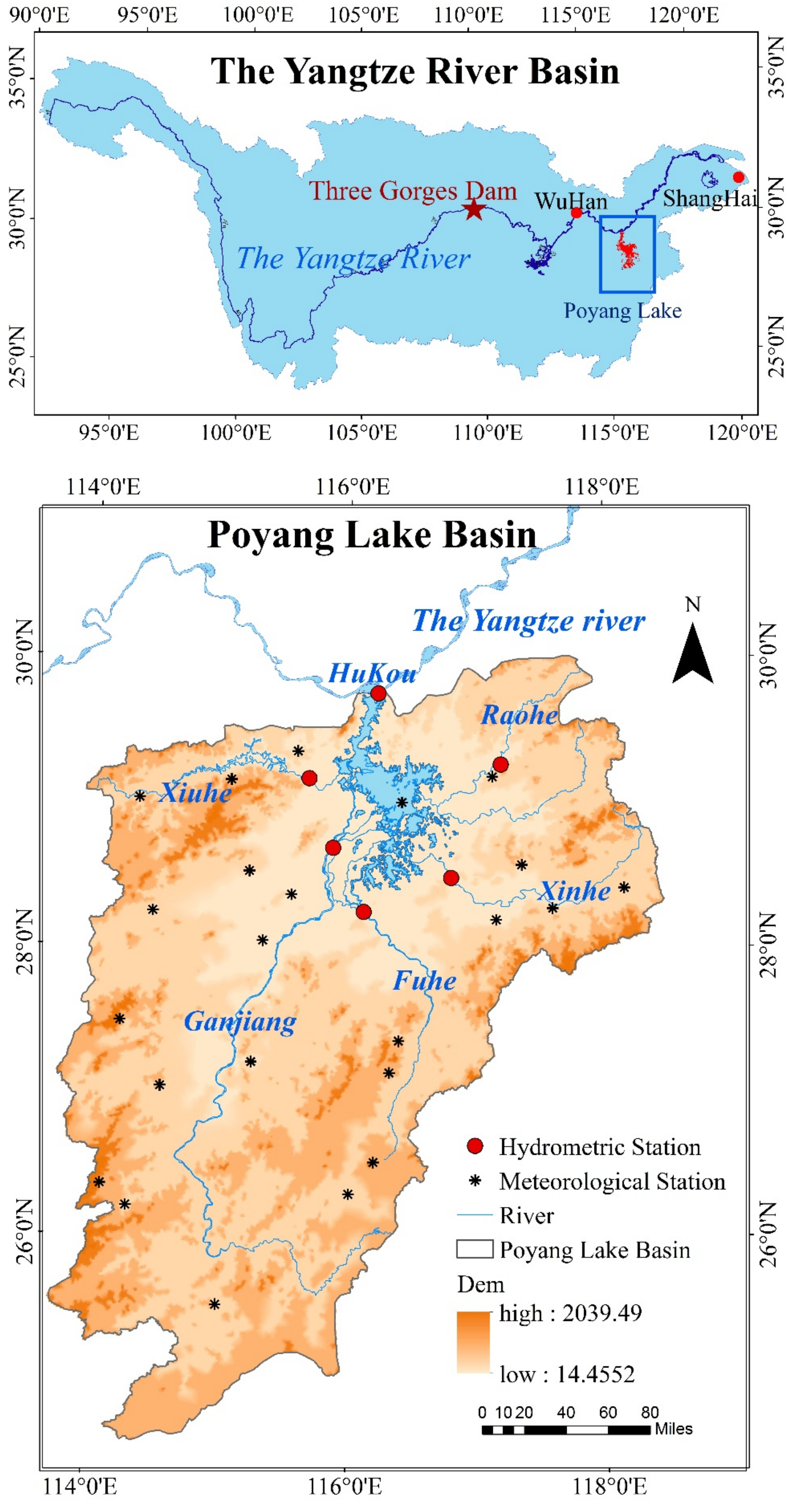

The Yangtze River Basin
Three Gorges Dam
WuHan
ShangHai
The Yangtze River
Poyang Lake
Poyang Lake Basin
The Yangtze river
HuKou
Raohe
Xiuhe
Xinhe
Fuhe
Ganjiang
N
Hydrometric Station
Meteorological Station
River
Poyang Lake Basin
Dem
high : 2039.49
low : 14.4552
0 10 20 40 60 80
Miles

FIG. 1 Poyang Lake Basin

2. STUDY AREA AND DATA

2.1 Study area

The water body we studied is located in Poyang Lake basin ,which belongs to the southern bank of the middle reaches of the Yangtze River, with latitude 28°22 '– 29°45' north and longitude 115°47 '– 116°45' East. The basin covers an area of 162225km^2. The runoff of 'five rivers', which including Ganjiang river, Fuhe River, Xinjiang River, Raohe River and Xiushui River, flows into Poyang Lake and flows out from the outlet of the lake into the Yangtze River(Shankman, Keim, and Song 2006).

Poyang Lake basin belongs to the subtropical monsoon climate, with strong solar radiation. Due to the obviously difference precipitation in the basin, the seasonal variation of runoff into the lake of the "Five Rivers" is very significant, during April to September, the runoff into the lake accounts for 75% of the whole year. June, the lake area begin increases. July, Heavy rainfall in the basin ended, but the middle and upper reaches of the Yangtze River have flood come to the outlet of Poyang Lake, and produced a roof support or irrigation to the water level, making a high water level of Poyang Lake continued to September. The flood season from June to September every year, and the dry season from November to February the next year. In winter, area of lake shrink, and lake bed is bare(X. Li and Zhang 2015).

2.2 Data collection

The data used in this study include:(1) The weather in flood season and dry season in Poyang Lake basin is mostly cloudless, in order to avoid the interference of cloud cover on sensing images, we chose this period's images to calculate average value of water area and analyzed. The remote sensing images of Poyang Lake Basin are from Landsat series (MSS, TM, ETM+, OLI), the distribution of data is from 1977 to 2021(Fig.2), download from United States Geological Survey (USGS, website at*https://earthexplorer.usgs.gov//*). We selected high-quality images with good extraction effect, and the extraction results passed visual inspection. Finally, 328 images were screened out by excluding missing data in 1980, 1982, 1985, 1994 and 2009. (2) In order to better reflect the comparison of lake changes, we compared historical images of Poyang Lake with earlier periods of less anthropogenic disturbance, the historical images are high-resolution satellite images on December 13, 1967 taken by the USGS (website at*https://earthexplorer.usgs.gov//*), and visual inspection showed that the extraction results were accurate. (3) Runoff and sediment data were obtained from actual measurements of the Poyang Lake Basin and Lake Estuary Hydrological Stations (Fig.1), runoff data distribution period 1977 to 2020, sediment data distribution period 1980 to 2020, which from the Hydrology Data Yearbook published by the Ministry of Water Resources and Power, PRC. (4) Temperature and precipitation data of the Poyang Lake Basin were obtained from 23 measurements of meteorological station (Fig.1), data distribution period 1977 to 2020, which were downloaded from China Meteorological Data Network (*http://data.cma.cn/*). (5) The land use data of Poyang Lake Basin were obtained from China National Land Use Database and has been classified by secondary classification system. We selected land use data in 1980, 1995, 2000, 2005, 2010, 2015 and 2020. All measured data we used in this study were checked and rated as good quality.

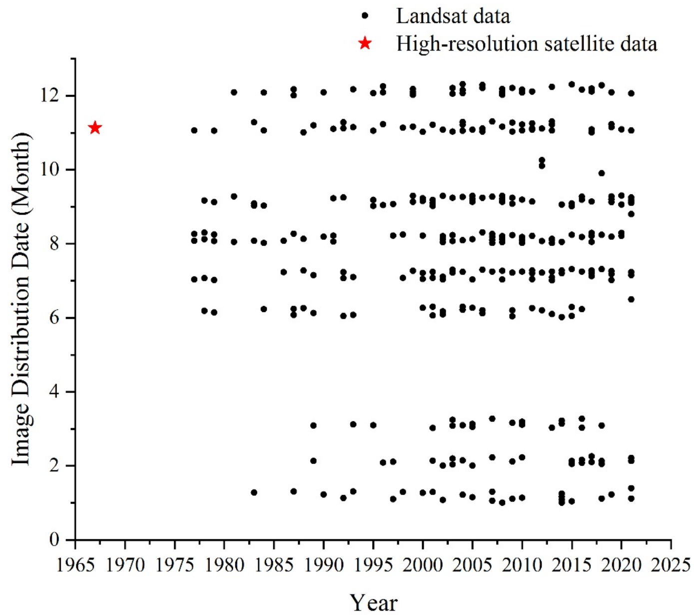


Fig.2 Remote sensing temporal data distribution

3. METHODS

3.1 Extraction Method of Water Area

Using the multi-band pixel value comparison method to extract water information and calculate water area. Using spectral characteristics of water image set thresholds, extracted water and lake information. Landsat7 satellite broke down, so repaired it and the result were consistent with the pixel values of adjacent pixels. After manual visual verification, the extraction of water information is accurate(Vahtmäe and Kutser 2013).

3.2 Statistical Analysis

Using Mann-Kendall mutation test to detect the change-point year of streamflow-sediment flux, using Mann-kendall trend method to detect whether the water area of Poyang Lake had trend change in time series(Mann 1945; Kendall and Gibbons 1990). Using correlation analysis to investigate the relationship between water area and impact factor, which including net runoff outflow of lake, sediment discharge, rainfall, and temperature. At last using the cross-tabulation matrix and change in terms of percent of the landscape to assess the total change of land categories(Pontius, Shusas, and McEachern 2004). Based on the image comparison results, discussed the characteristics and main influencing factors of water area change in Poyang Lake.

4. Results

4.1 Trends and Change Point of Lake Water Area

In terms of Fig.3, water area of 1977 to 2021 in flood season have a significant downward trend (MK trend test Z=-1.67, passing the 95% test), decrease rate being -9.14km2/a. The largest area was 4662.05 km2 in 1998, the smallest area was 2139.37 km2 in 2006. MK mutation test showed that change-point year was in 2005, after 2005 water area declining rate was increased.

In dry season, the lake water area have a significant downward trend, (Mk test Z=-3.09, passing the 99% test) decrease rate being -17.52km2/a. The largest area was 3202.91 km2 in 1997, the smallest area was775.41

km2 in 2019. MK mutation test showed that change-point year was in 2003, after 2003 water area declining rate was increased (Fig 3).

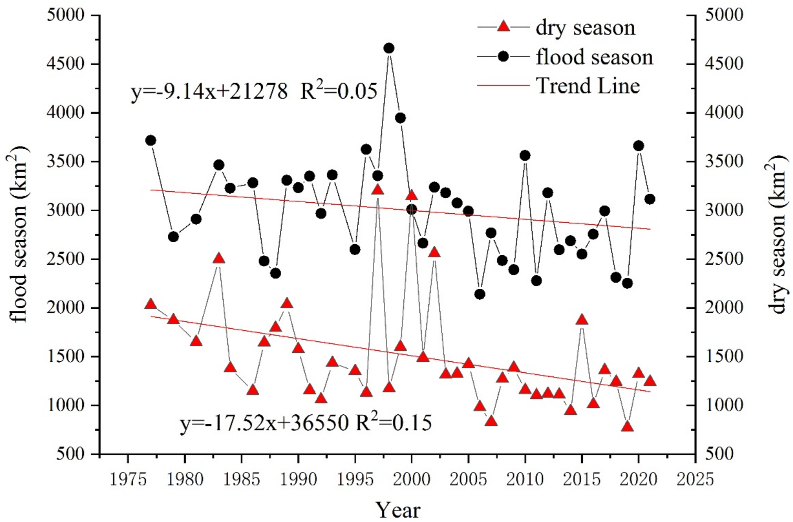


Fig.3Characteristics of water area variation in Poyang Lake during 1977-2021

4.2 Analysis of Lake Water Area Impact Factor

Poyang Lake is a classical river-connected drain lake. In terms of Fig 4, the hydrological relationship of Poyang is complex, in the analysis of influencing factors. This study considered runoff, precipitation, evaporation, lakebed and water utilization. Except that the groundwater exchange relationship is too complicated and difficult to obtain, does not select. In the analysis, the influence of runoff expressed by net runoff, which means the total runoff of five rivers into the lake minus runoff from the estuary of the lake, selected sediment to investigate the variation of lakebed, and land use to investigate the water utilization.

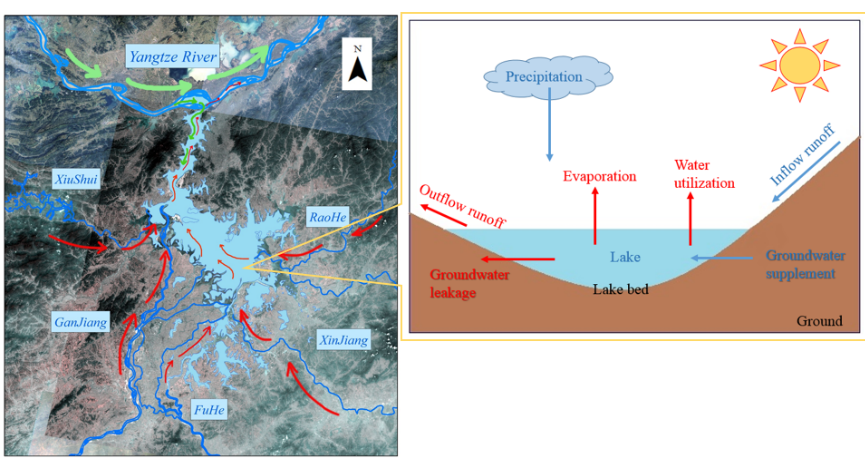


Fig.4 Hydrological relationship diagram of Poyang Lake

4.2.1 Changes of Net Runoff in Lake

Fig 5 shows net annual runoff of lake from 1977 to 2020 have an increasing trend, Mk trend test confirms that the increasing trend is not significant (coefficient 0.54), and Mk mutation test also shows that change point was insignificant. The relationship between lake area and net outflow runoff were tested by Pearson analysis, results showed that in dry season the correlation coefficient between lake area and runoff was 0.09, in flood season correlation coefficient was 0.48, indicating that there was a correlation between lake area and net outflow runoff in flood season, and consequence passed 99% level test.

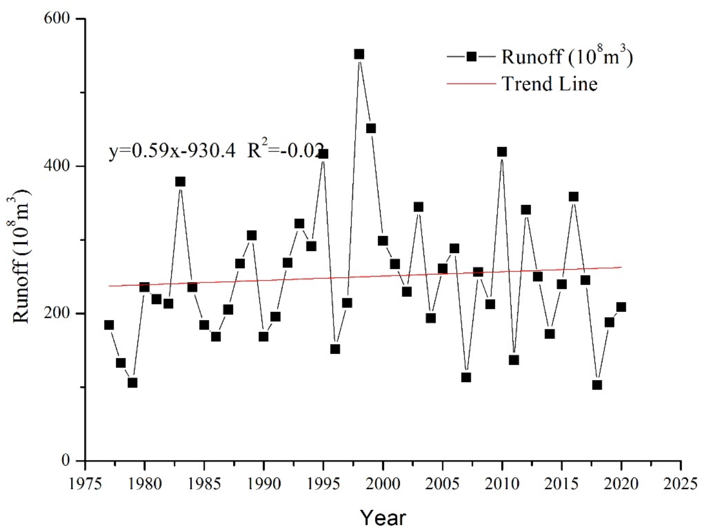


Fig.5 Characteristics of net runoff in Poyang Lake during 1977-2020

4.2.2 Changes of Sediment in Poyang Lake.

In 1980 to 2020, the summation sediment of 'five rivers' has a significant downward trend (Fig 6), the decrease rate being -33.5km2/a (MK trend test Z=-1.67, passing the 95% test), but the change point doesn't significant. Pearson analysis test the correlation between annual sediment and area of two season, result showed that coefficient of flood season area is 0.29, coefficient of dry season area is 0.25, both are at the 95% confidence level. Demonstrating that lake area and sediment have an associative relation.

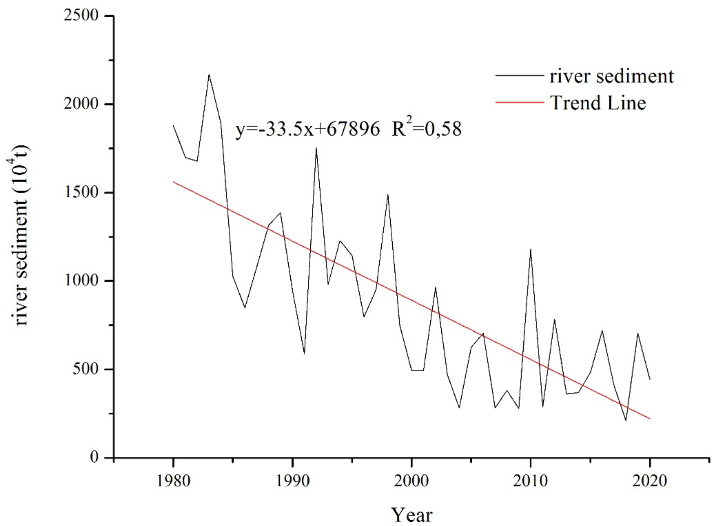


Fig.6 Characteristics of sediment in Poyang Lake estuary during 1980-2020

4.2.3 Changes of Evaporation and Precipitation in Poyang Lake.

In 1977 to 2020, the evaporation of dry season have an insignificant increasing trend (Z=0.56). Evaporation of flood season have a significant downward trend (Z=-2.14), declining rate being4.62 *10-1mm/a, and change point at 1992. Pearson analysis test result shows that: Evaporation and lake area is no significant correlativity. In dry season, the correlation coefficient is 0.11, and in flood season, it is 0.06. (Figure 7)

In terms of Figure 8, during 1977 to 2020, in flood season precipitation have a insignificant downward trend (Z=-0.41), dry season precipitation have a significant increasing trend (Z=2.48). correlation coefficient of flood season precipitation and area is 0.31, at 99% confidence level. In dry season correlation coefficient is insignificant.

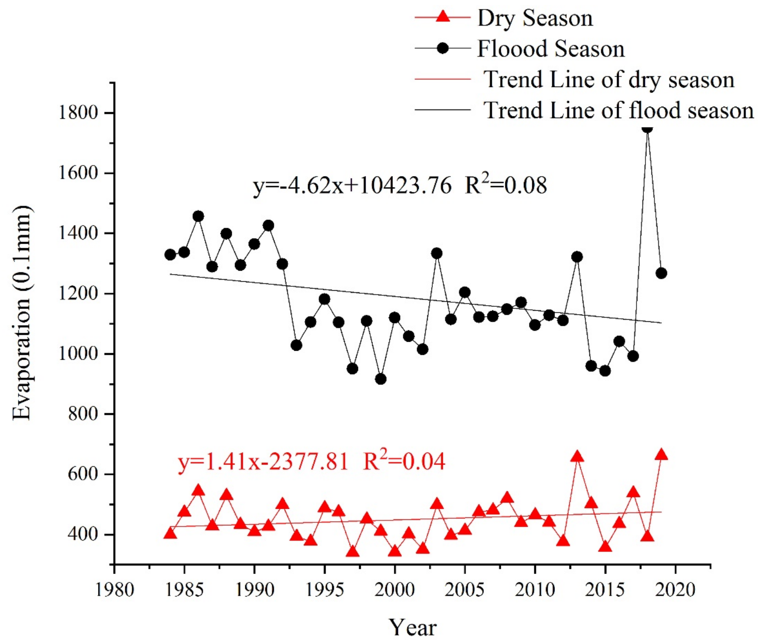


Fig.7 Characteristics of evaporation in Poyang Lake estuary during 1977-2020

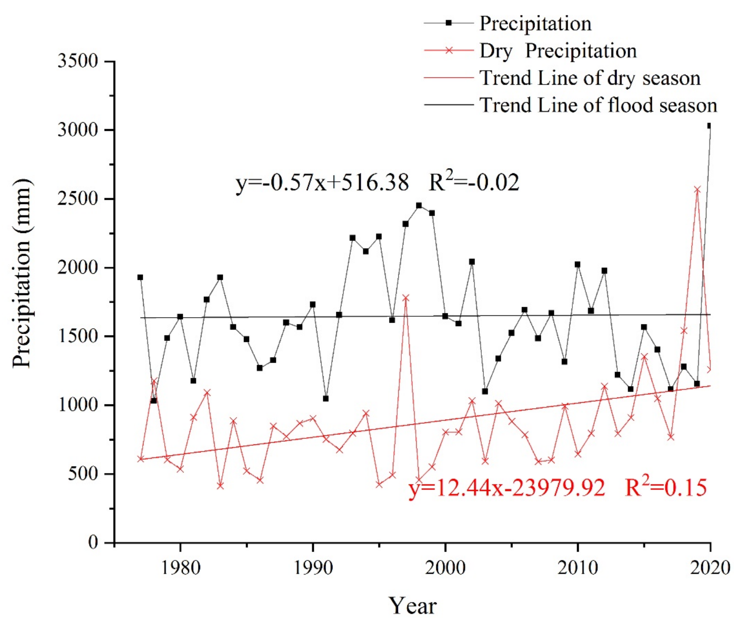


Fig.8 Characteristics of precipitation in Poyang Lake estuary during 1977-2020

4.2.4 Changes of Land Use in Poyang Lake.

Transfer matrix calculated the transfer amount of different land features from 1980 to 2020, which clearly showed the changes in different regions. It is found that during 1980-2020, the changes of land features mainly occurred after 2000, compared with the changes after 2000, the amount of land surface conversion in the early stage was small. After 2000, the most obvious change of the land use in Poyang basin is mainly the swap of ground objects, the most obvious net change of area is Settlement area expanded by 1.53%, the area of Cropland and Water has a slight increase, and the area of Forest and Grassland a small decrease.

The comparison of the image shows that the urban area expanded significantly after 2000. Using the transfer matrix to analyze and verify, and the results show that there was an obvious conversion relationship between Settlement and Cropland. In addition, there is also a conversion relationship between Water and Other, and the conversion relationship is stronger. The most prominent transition is conversion from Other to Water, accounting for 19.81% of the landscape.

Actually, Fig 9 also indicate the prominent conversion from Water to Other, and the obvious expanded of Settlement. Compare with 1980, in 2020 at the Ganjiang river estuary the Other land replace Water area, and mainly Cropland is overrun by Settlement. Also the dramatically increase of Settlement and slightly increase of Cropland in the basin area, all this means water utilization increased in the basin.

Table 2 Land use change information of 1980-2020(%)

		Gain	Loss	Total change	Swap	Absolute value of net change
1980-2000	Cropland	0.40	0.49	0.89	0.81	0.08
	Forest	0.43	0.51	0.94	1.02	-0.08
	Grassland	0.29	0.24	0.53	0.58	-0.04
	Other	0.13	0.10	0.23	0.26	-0.03
	Settlement	0.14	0.00	0.14	0.00	0.14
	Water	0.27	0.32	0.60	0.65	-0.05
2000-2020	Cropland	12.04	12.77	24.81	24.09	0.73
	Forest	11.82	52.94	64.76	65.58	-0.81
	Grassland	3.00	3.47	6.47	6.49	-0.02
	Other	0.14	0.54	0.67	0.42	0.25
	Settlement	2.78	0.76	3.55	2.02	1.53
	Water	2.08	3.06	5.14	4.89	0.25

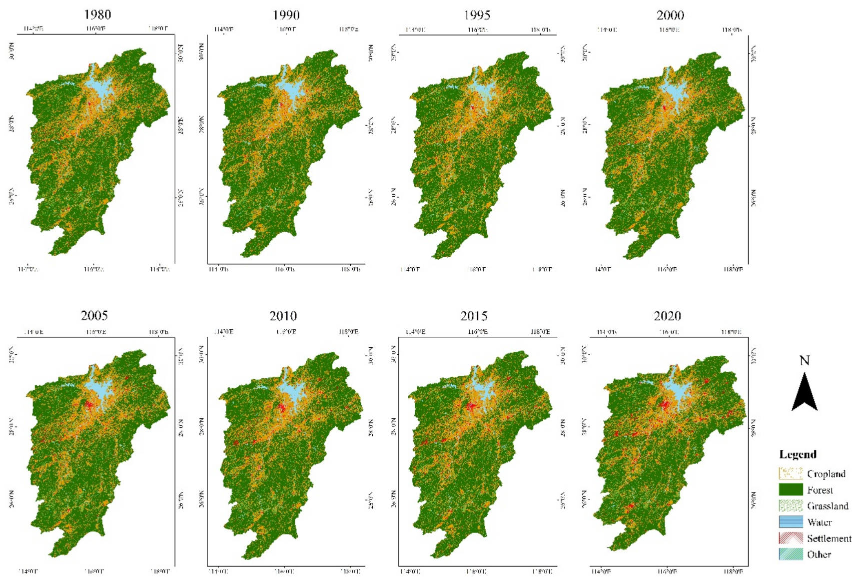


Fig.9 Characteristics of land use in Poyang Lake estuary during 1980-2020

5. Discussion

Poyang lake is a classical river-connected drain lakes. The hydrological relationship of Poyang is complex, Because of its connection with the Yangtze River, the change of the Yangtze River runoff has impact on the water exchange of the lake outlet, resulted a completely different influence mechanism of lake area change in Poyang Lake during flood season and dry season(Wang 2021).

5.1 Influence Mechanism of Lake Water Area Change in Flood Season

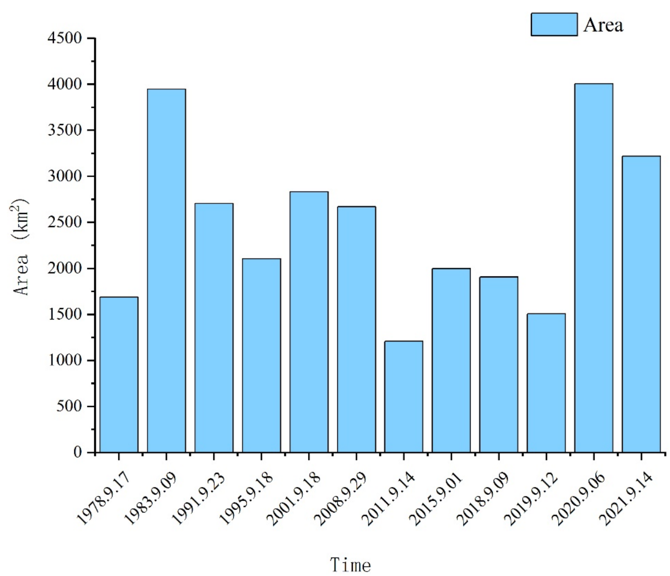
In the prophase analysis, we verified the significant correlation between lake area and runoff in flood season. In addition, we cannot ignore the Yangtze River runoff change effect of net runoff at lake estuary.

Many studies demonstrated that in flood season Poyang lake water area are affected by two runoff, one from the 'five rivers' which belong to the Poyang basin and another from the Yangtze River which perform at lake estuary, both runoff can be exchanged at the estuary of the lake(Hu et al. 2007; Z. Zhang et al. 2015).

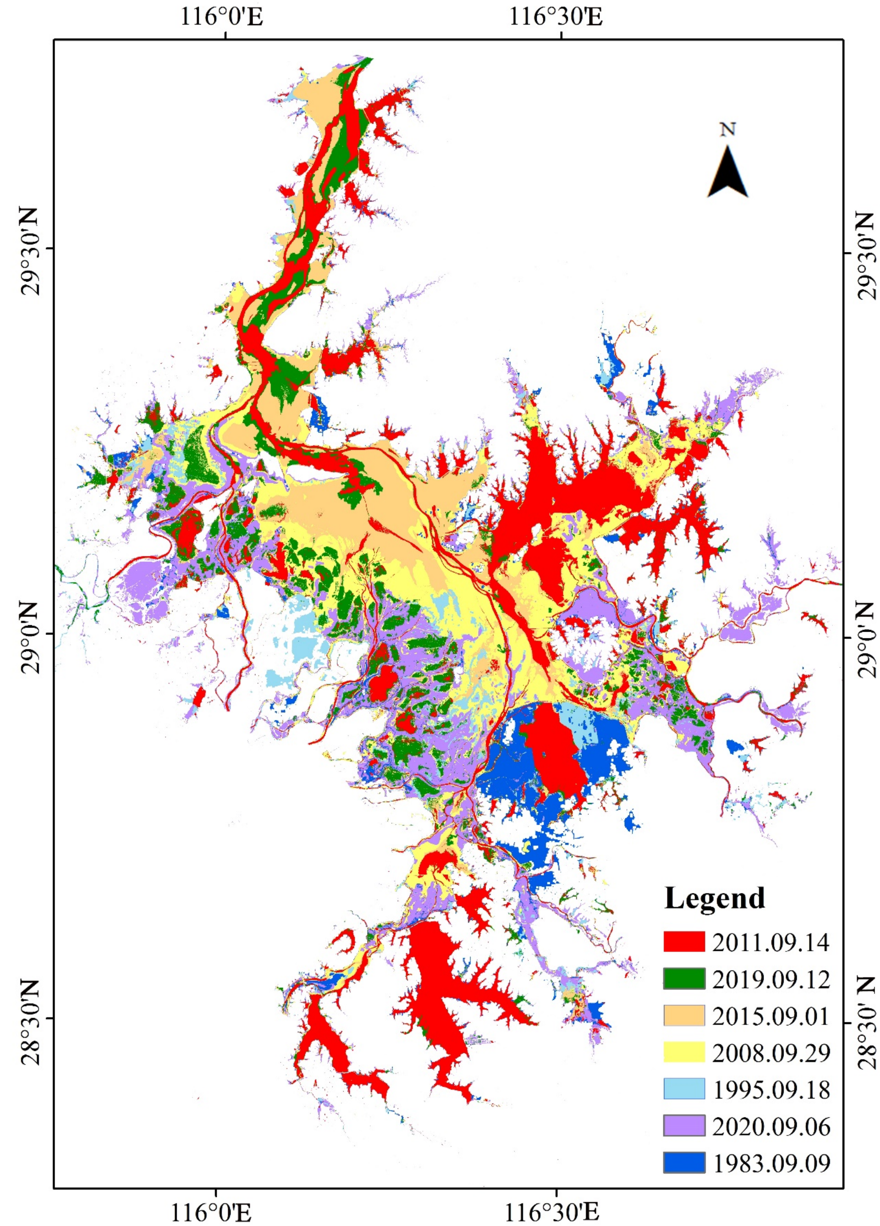
Accordingly, the interaction between The Yangtze River and Poyang Lake can be divided into three stages: 1. December to March of the next year, the Poyang Lake basin runoff dominant period. The runoff of the Yangtze River increases and water level rises, the main stream runoff of the Yangtze River will basin through the estuary flow into the Poyang lake.2. April to August, the river lake interaction period. The high water level of the Yangtze River will have a blocking effect to outflows from Poyang basin, the runoff of Poyang basin can't flow out, generated the flood stagnates in the lake, resulting the lake water area expanded. 3. September to November, the Yangtze River runoff dominant period. The runoff of the Yangtze River increases and water level rises, the main stream runoff of the Yangtze River will basin through the estuary flow into the Poyang lake.

Combined with hydrological records, we compared the images of Poyang Lake in September of each year, if there is a flood event in the Yangtze River basin at the same time, Poyang Lake maintains high water level even at the end of the flood season, in 1983,1991,2020 the main stream of the Yangtze river had flood events in September. Especially 2020 suffered an exceed history record flood in the whole Yangtze River Basin, the water level at Poyang lake broke the historical extreme since the hydrological record. In terms of Figure 10, compared with the lowest net runoff in 2018, the average area of September in 2011 and 2019 was only 1255.40 km^2, It is worth noting that serious drought events occurred simultaneously in Poyang Lake basin and Yangtze River Basin, both drought events lasts long and heaviest. Affected by drought events, in the Poyang Lake basin the flow of 'five river' decreased, and Yangtze River has lowered water level that eliminated the blocking or reversing flow from the Yangtze River to the Poyang Lake, therefore the water area advance reduction.

It should be pointed out that among these changes in the flood season water area is closely related to the changes of the river lake interaction.



(a)

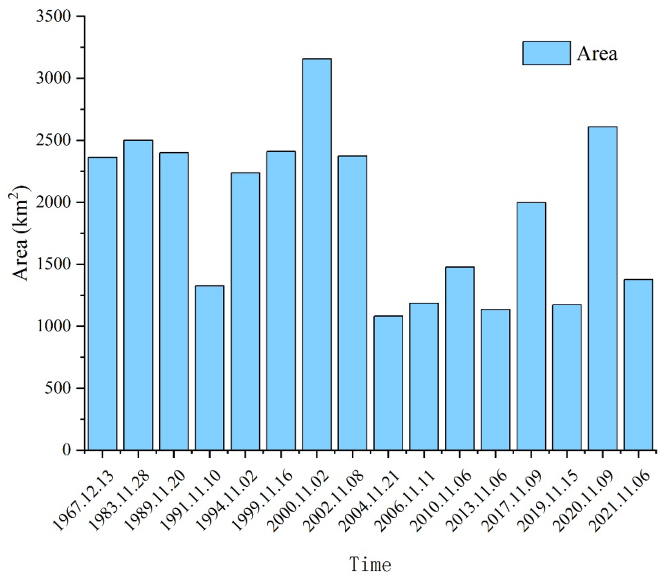


(b)

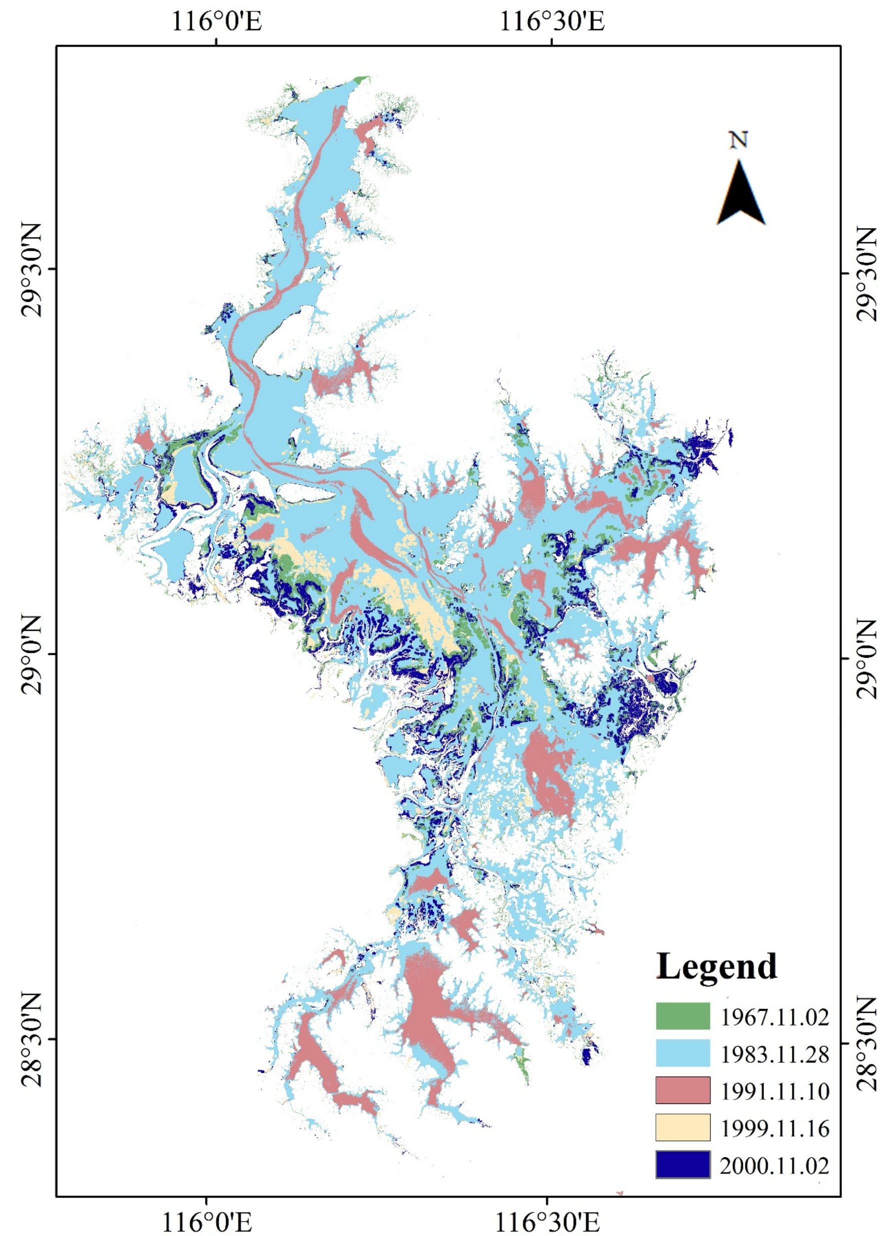
Fig.10 Comparison of lake water area at the end of flood season (a.b)

5.2 Influence Mechanism of Lake Water Area Change in Dry Season

In dry season, temperature and sediment showed a correlation with lake area, compared year-to-year images in the early dry season. Images show that the most obvious changes of water area concentrated at the estuary of Ganjiang River and the estuary of Poyang lake (Figure 11). In 1991, 2004, 2006, 2010, 2013, 2017, 2019 and 2021 the water area at the estuary of the Ganjiang River decreased, especially in 1991, 2006, 2004, 2006, 2010, 2013, 2019 and 2021 at the early dry season the water area at the estuary of Poyang Lake shrank and the lakebed was plainly visible. MK mutation test confirmed that change-point year was in 2003, compared with the average water area of 2300km^2 in the early dry season of 1990s, after 2003 the average water area of Poyang Lake decreased to 1500km^2 in the early dry season. However, the same period sediment and temperature has not changed so dramatically, combined with variation characteristics of water body area in flood season, we consider that due to water area has shrunk in advance at the end of the flood season, caused the water area shrink dramatically in early dry season. Changes of the Yangtze River runoff altered the inter relationship between the river and Poyang Lake, and disturbing the lake basin hydrological processes and water resources(Q. Zhang et al. 2014; Lai, Jiang, et al. 2014; Liu et al. 2020). It has been suggested that after the Three Gorges Dam (TGD) has been in operation water impoundment at 2003, Comparing the water level and runoff of the main stream of the Yangtze River before and after, the water impoundment of the TGD significantly exacerbated the water level and runoff decline from late September to November. Thus the Yangtze River's blocking effect to outflows of Poyang be weakened, the outflows of Poyang lake through the estuary of the lake more quickly.



(a)


116°0'E
116°30'E
N
29°30'N
29°0'N
28°30'N
Legend
1967.11.02
1983.11.28
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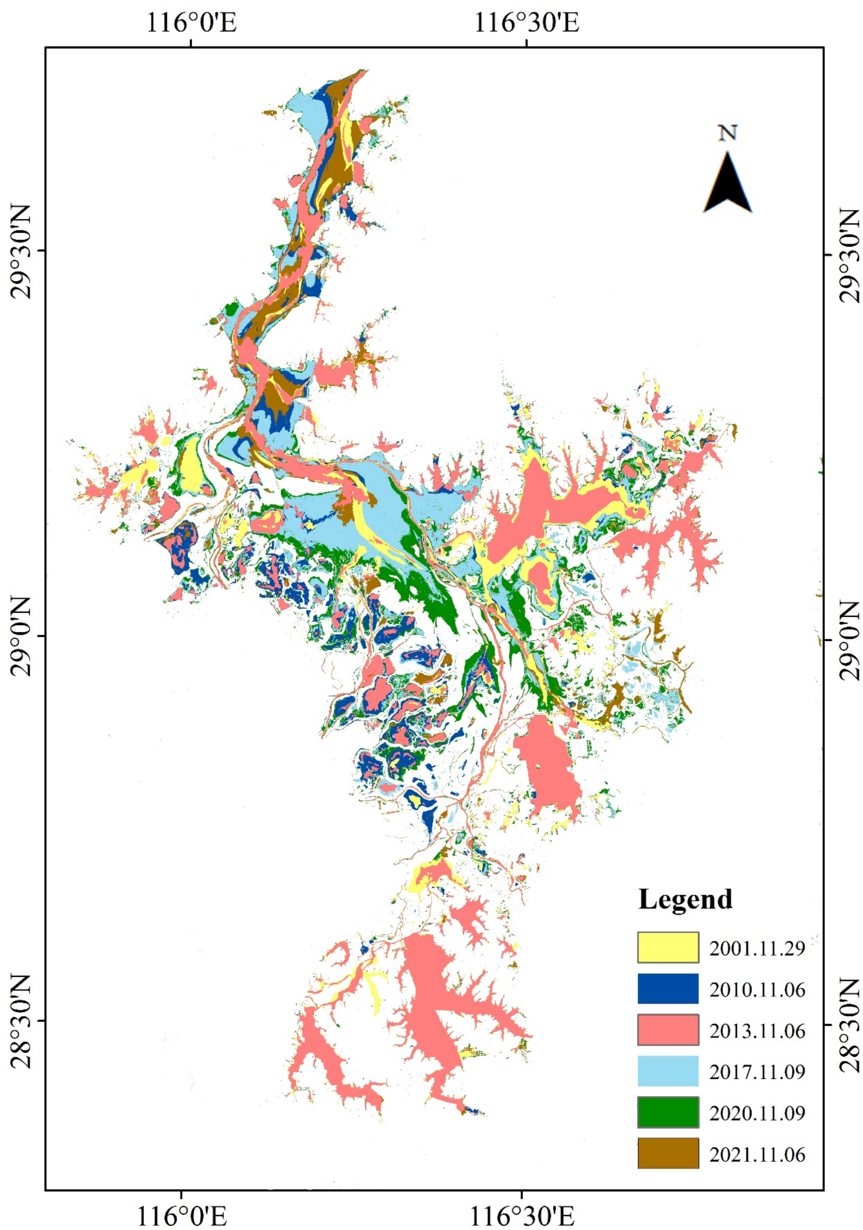
2000.11.02

(b)



(c)

Fig.11 Comparison of lake water area at the early of dry season (a.b.c)

Meanwhile despite the summational sediment of 'five rivers' has a significant downward trend, during 1980-1990, the high sediment of 'five rivers' caused higher sedimentation at Poyang lake, Especially the siltation phenomenon at the Ganjiang river estuary is obvious. Comparing images that lakebed rises significantly at the estuary of Ganjiang River and Xiushui River. From 2000 to 2020, under the influence of human activities such as large-scale afforestation and reservoir construction, the sediment of 'five rivers' was reduced. Some studies have found that the elevation of the lake estuary decreased significantly, which is related to the factors such as continuous sand mining and current scouring(Guiping et al. 2015; Feng et al. 2011; Ye et al. 2018; Lai, Shankman, et al. 2014; Jing et al. 2017). changes in lakebed topography also cause the water flow more rapidly into the Yangtze river.

Given the above discussion, the flood events along the Yangtze River necessarily influence the water area in flood season. there is an obvious linkage between the sediment of 'five rivers' and the change of water area in dry season, Besides, the TGD water impoundment operation affected the river lake interaction, and eventually leading the water of Poyang lake premature to flow into Yangtze River, causes the lake area to decrease earlier at the end of the flood season.

6. Conclusions

Through comparative analysis of satellite images of Poyang Lake in the past 42 years, combined with hydrological, meteorological and land use data, we draw this conclusions:

1. During 1977 to 2021 flood season, lake water area at the rate of -9.14km2/a have a significant downward trend. In dry season, the lake water area showed a significant downward trend with the rate of -17.52km2/a. The change point years of flood season water area are 2005 and dry season water is 2003.

2. The runoff of lake, sediment and precipitation have a significant correlation with flood season water area, and in dry season the sediment have significant correlation with water area.

3. The analysis of satellite imagery confirm that in flood season there is a direct correlation between the change of water area and the change of net runoff of lake, and this correlation is affected by river lake interaction. As classical river-connected drain lakes, the occurrence of flood or drought events in the main stream of the Yangtze River will affect the blocking or reversing effect of Yangtze River to Poyang lake, thus affecting the change of net outflow of lake, bring the changes of water area.

4. In dry season, based on the analysis of image and land use, caused by sediment deposition the elevation of the estuarine entrance lake lakebed is raised, especially at the Ganjiang river estuary, affected the water body shape. Meanwhile after 2000, in the end of flood season, the TGD water impoundment operation on the upper Yangtze river, affecting the runoff of the lower Reaches of the Yangtze River, impair the river lake interaction, which made the area of Poyang Lake shrink in advance, made the water area shrank in advance, and affected the water area in dry season.

Results show that the variation of water area in Poyang Lake is not only affected by the runoff of the Poyang Lake basin, but also by the runoff of the Yangtze River main stream and the sediment inside the Poyang Lake basin. The downside is the effect of groundwater on the lake is not considered enough. Therefore, In Poyang Lake water resources utilization, not only need to consider the changes of lake basin, but also the runoff changes outside the basin should be concerned.

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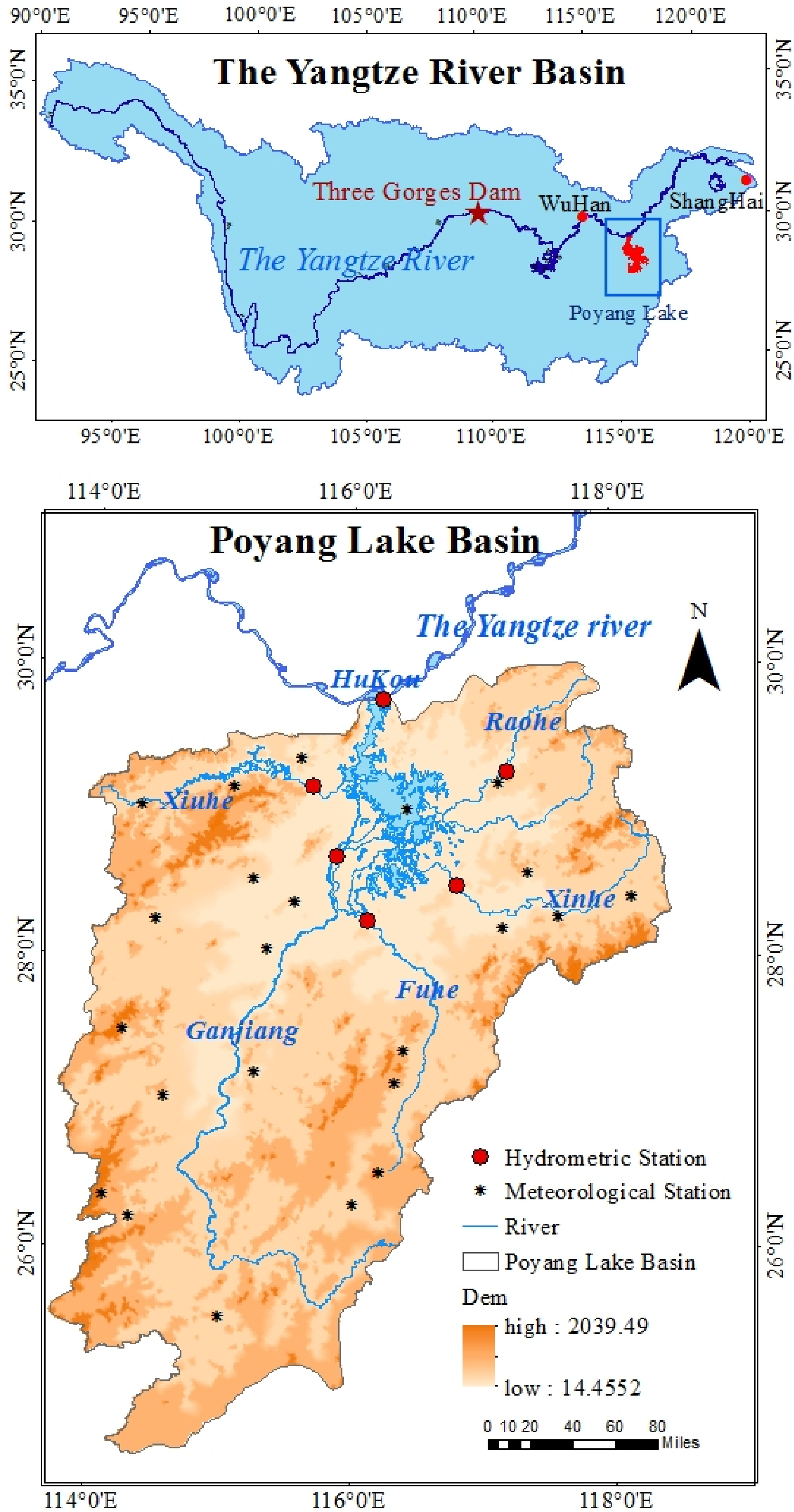
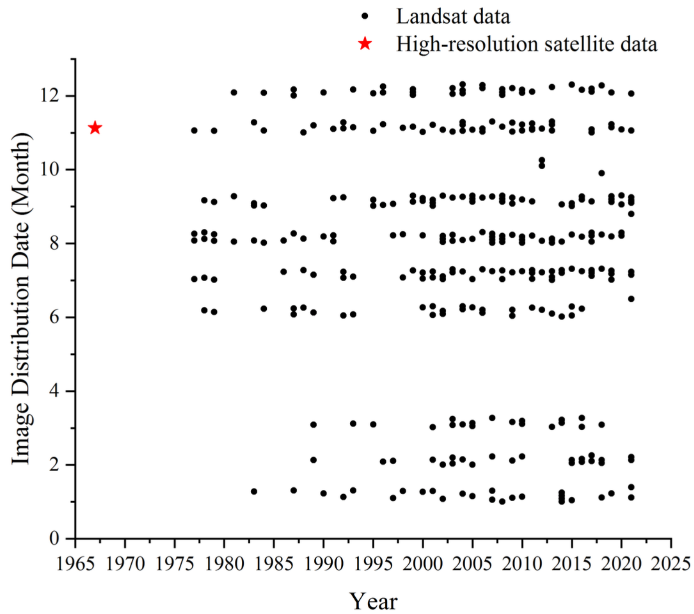
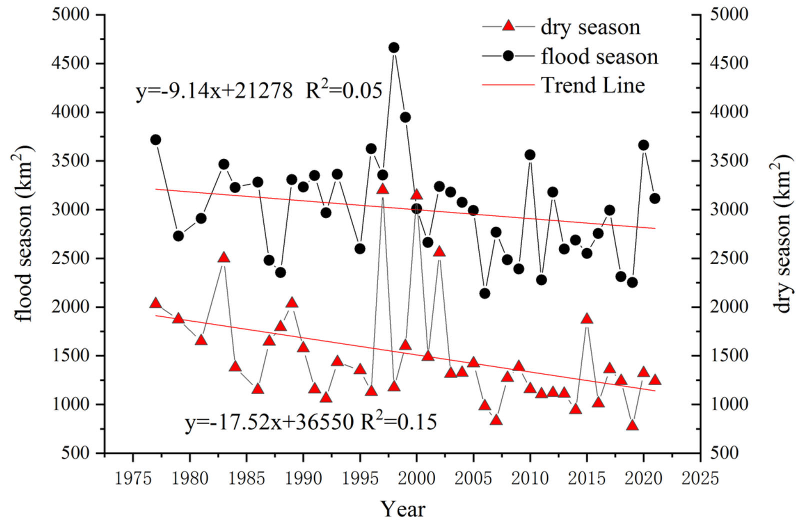
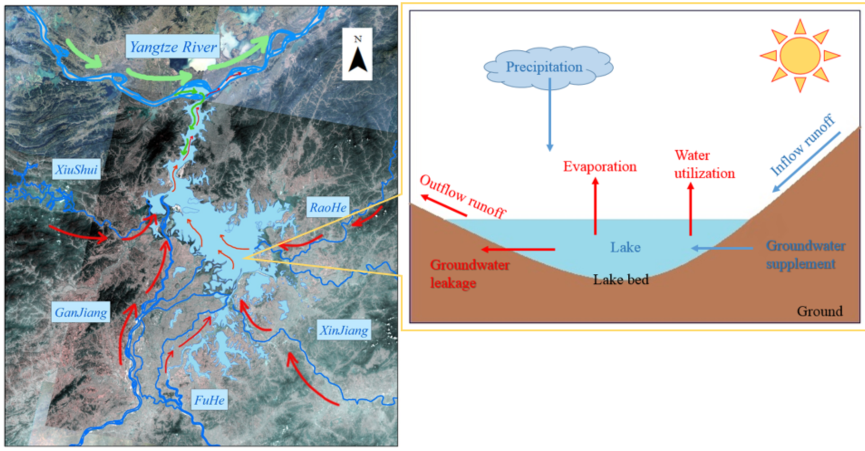
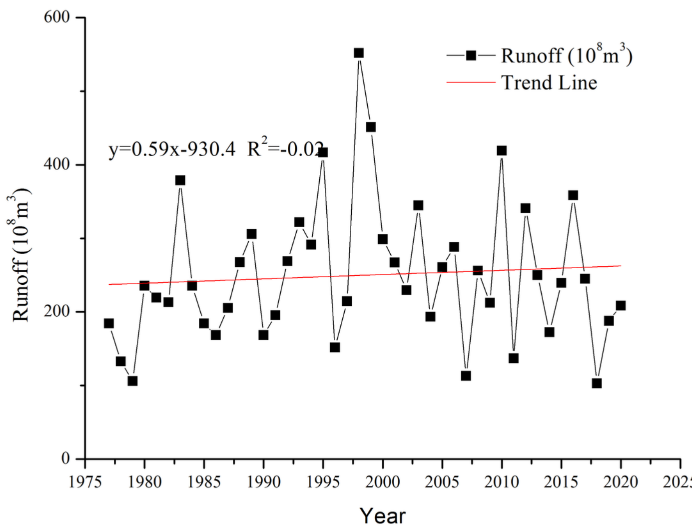
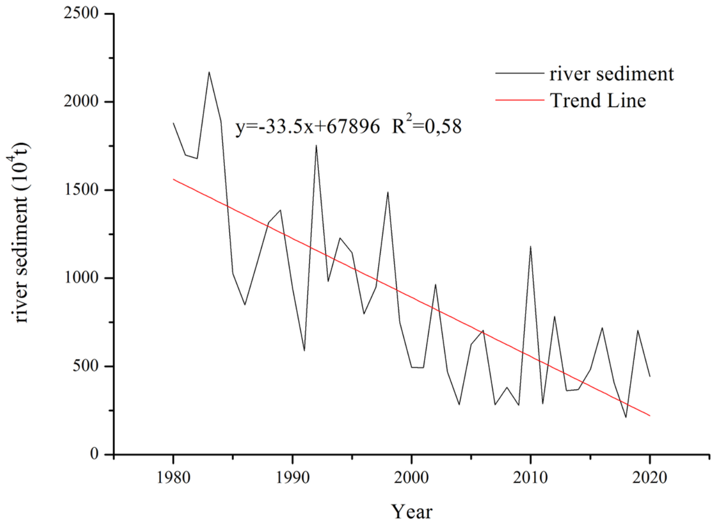

The Yangtze River Basin
90°0'E
95°0'E
100°0'E
105°0'E
110°0'E
115°0'E
120°0'E
35°0'N
30°0'N
25°0'N
Three Gorges Dam
WuHan
ShangHai
The Yangtze River
Poyang Lake
Poyang Lake Basin
114°0'E
116°0'E
118°0'E
30°0'N
28°0'N
26°0'N
The Yangtze river
N
HuKou
Raohe
Xiuhe
Xinhe
Fuhe
Ganjiang
Hydrometric Station
Meteorological Station
River
Poyang Lake Basin
Dem
high : 2039.49
low : 14.4552
0 10 20 40 60 80
Miles

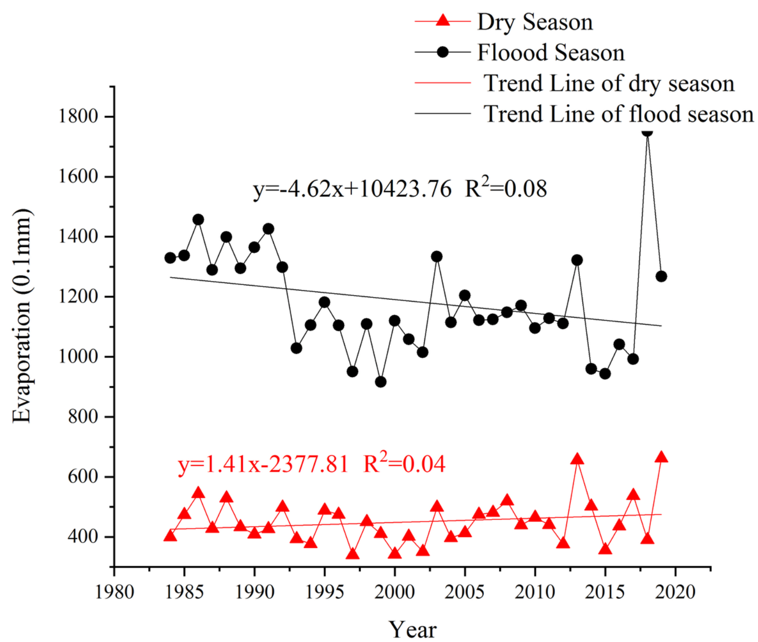

Landsat data
High-resolution satellite data
Image Distribution Date (Month)
Year

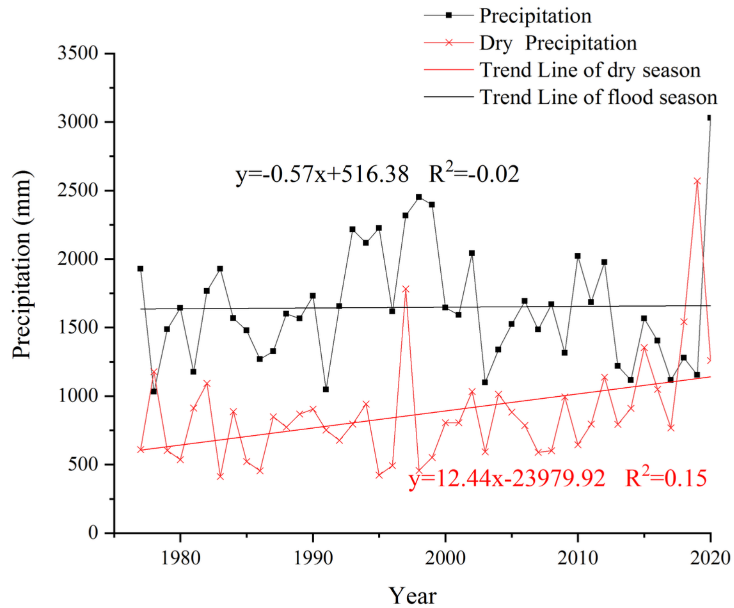

dry season
flood season
Trend Line
y=-9.14x+21278 R2=0.05
y=-17.52x+36550 R2=0.15
flood season (km2)
dry season (km2)
Year

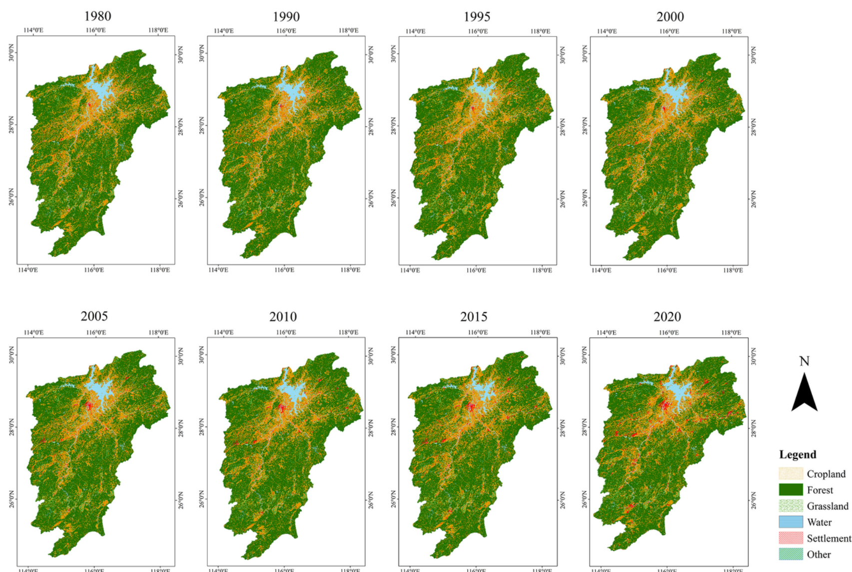

Yangtze River
N
XiuShui
RaoHe
GanJiang
XinJiang
FuHe
Precipitation
Evaporation
Water utilization
Inflow runoff
Outflow runoff
Lake
Groundwater leakage
Groundwater supplement
Lake bed
Ground

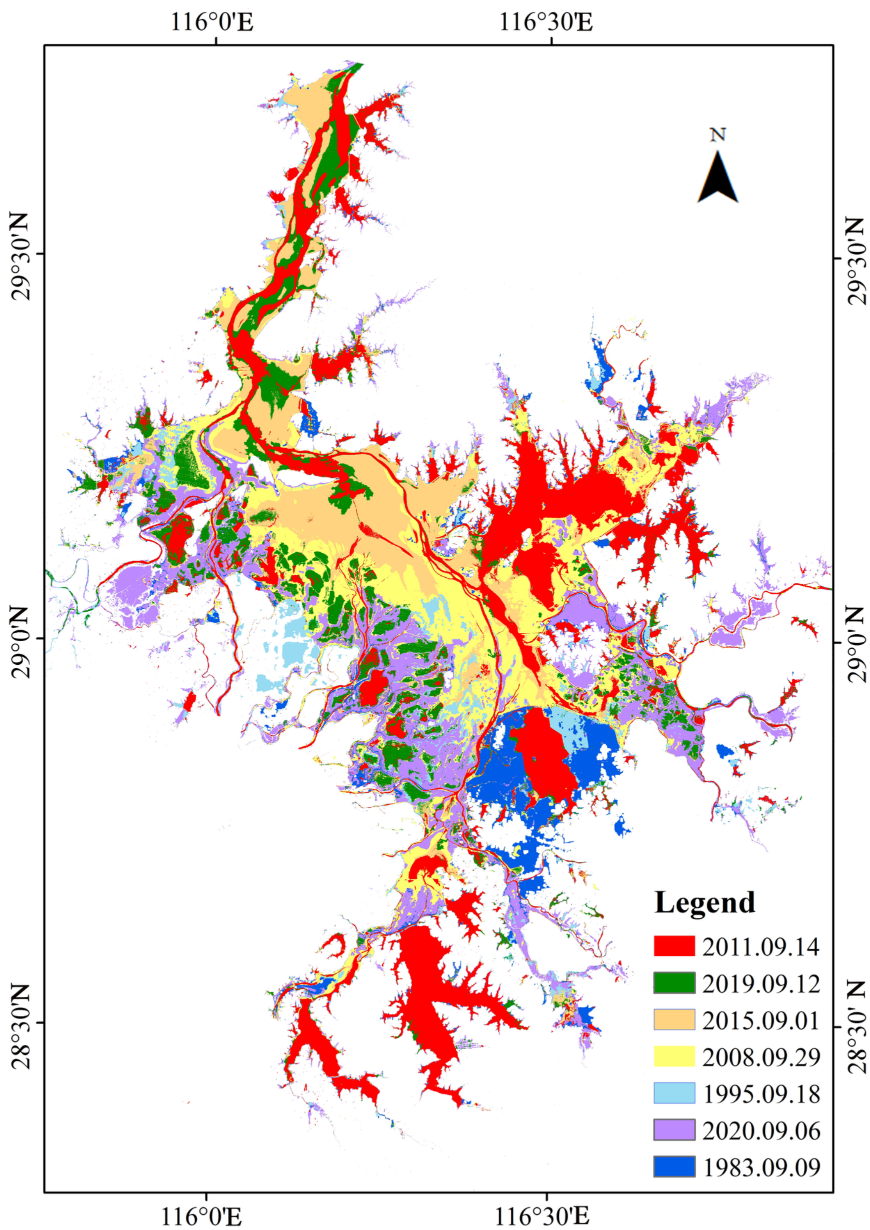

Runoff ($10^8 m^3$)
Trend Line
y=0.59x-930.4 R^2=-0.02
Runoff ($10^8 m^3$)
Year
0
200
400
600
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

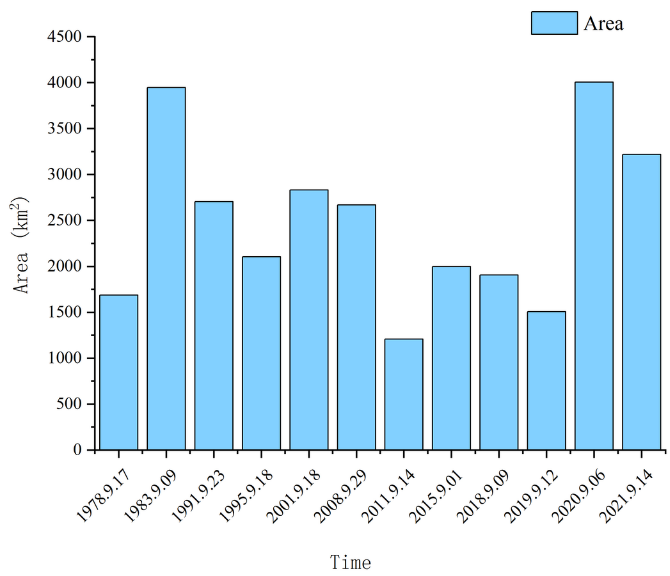

river sediment
Trend Line
y=-33.5x+67896 R²=0,58
river sediment (10⁴t)
Year
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020

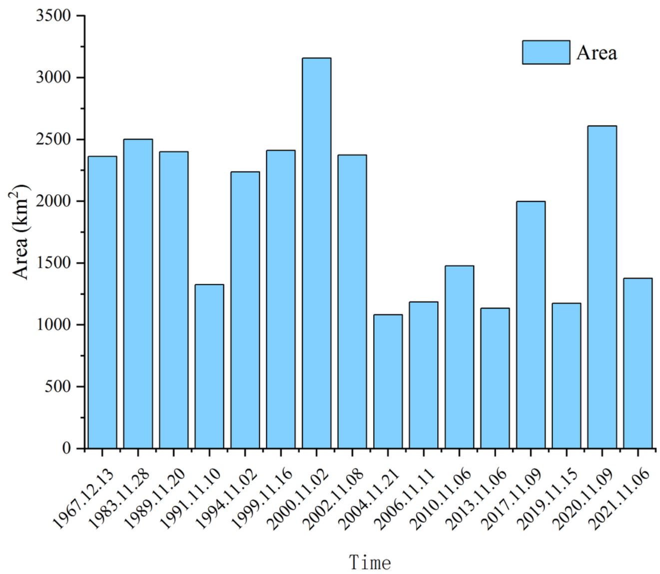

Dry Season
Floood Season
Trend Line of dry season
Trend Line of flood season
y=-4.62x+10423.76 R²=0.08
y=1.41x-2377.81 R²=0.04
Evaporation (0.1mm)
Year
1800
1600
1400
1200
1000
800
600
400
1980
1985
1990
1995
2000
2005
2010
2015
2020

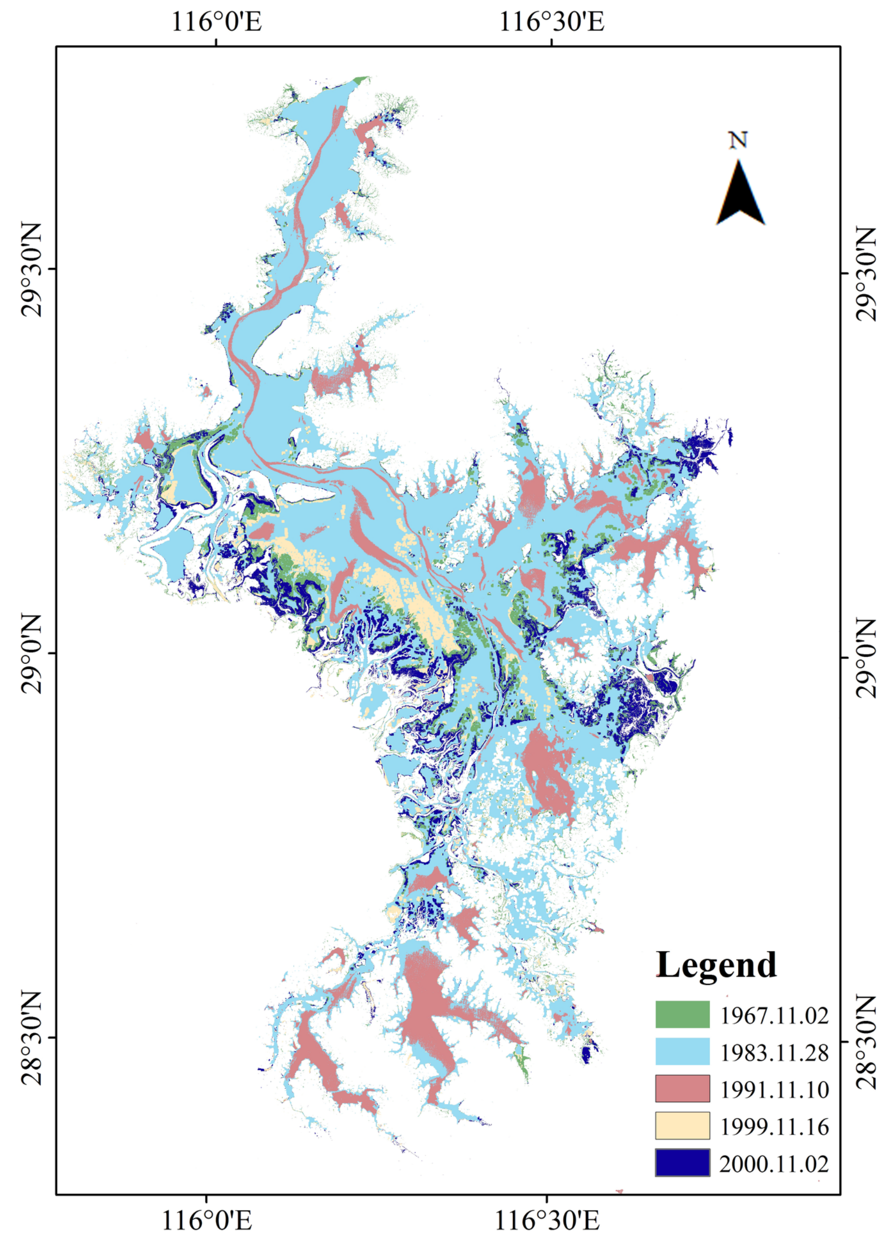

Precipitation
Dry Precipitation
Trend Line of dry season
Trend Line of flood season
y=-0.57x+516.38 R^2=-0.02
y=12.44x-23979.92 R^2=0.15
Precipitation (mm)
Year
0
500
1000
1500
2000
2500
3000
3500
1980
1990
2000
2010
2020

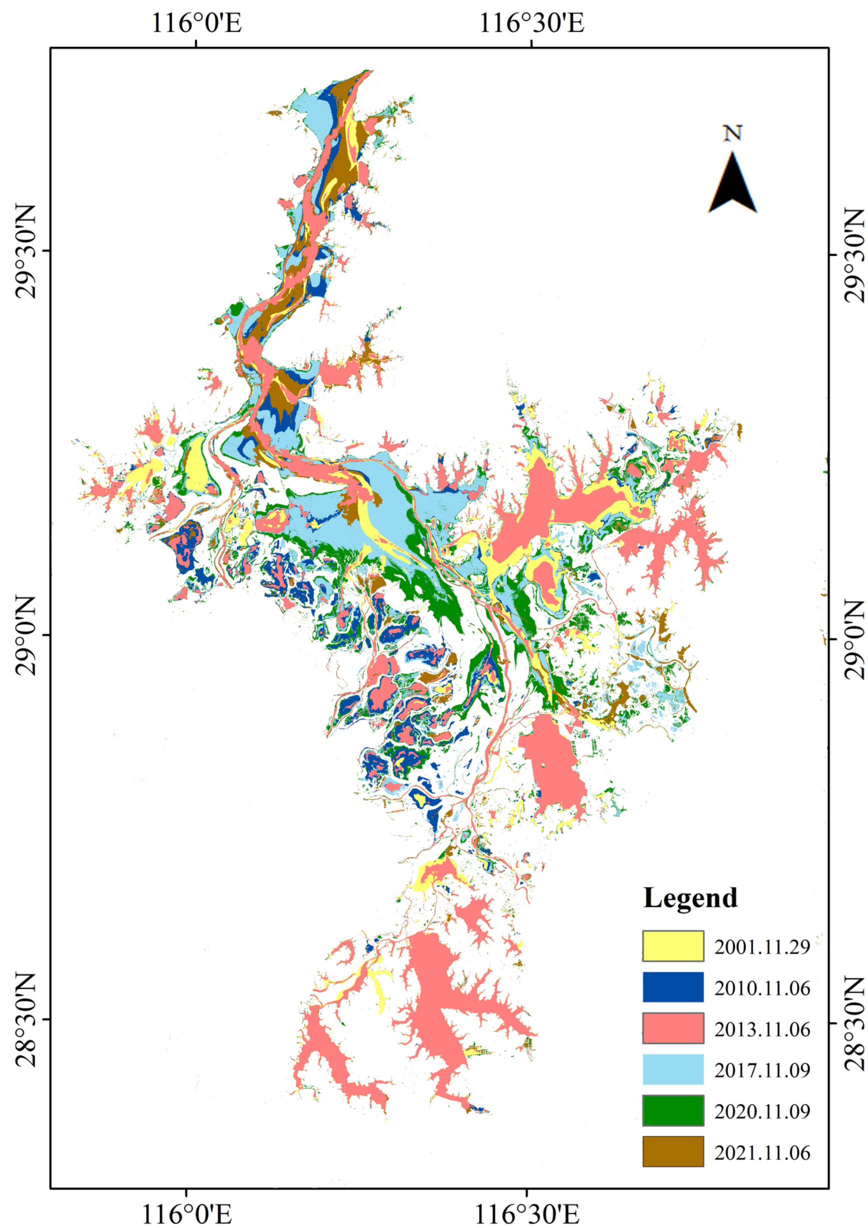

1980
1990
1995
2000
2005
2010
2015
2020
N
Legend
Cropland
Forest
Grassland
Water
Settlement
Other


116°0'E
116°30'E
N
29°30'N
29°0'N
28°30'N
29°30'N
29°0'N
28°30' N
Legend
2011.09.14
2019.09.12
2015.09.01
2008.09.29
1995.09.18
2020.09.06
1983.09.09
116°0'E
116°30'E


Area
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Area (km^2)
1978.9.17
1983.9.09
1991.9.23
1995.9.18
2001.9.18
2008.9.29
2011.9.14
2015.9.01
2018.9.09
2019.9.12
2020.9.06
2021.9.14
Time


Area
3500
3000
2500
2000
1500
1000
500
0
Area (km^2)
1967.12.13
1983.11.28
1989.11.20
1991.11.10
1994.11.02
1999.11.16
2000.11.02
2002.11.08
2004.11.21
2006.11.11
2010.11.06
2013.11.06
2017.11.09
2019.11.15
2020.11.09
2021.11.06
Time


116°0'E
116°30'E
29°30'N
29°0'N
28°30'N
N
Legend
1967.11.02
1983.11.28
1991.11.10
1999.11.16
2000.11.02


116°0'E
116°30'E
29°30'N
29°0'N
28°30'N
N
Legend
2001.11.29
2010.11.06
2013.11.06
2017.11.09
2020.11.09
2021.11.06