

Dynamics Change of Honghu Lake's Water Surface Area and Its Driving Force Analysis Based on Remote Sensing Technique and TOPMODEL model

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Abstract. Honghu Lake is the largest freshwater lake in the Hubei Province of China. This paper introduces a remote sensing approach to monitor the lake's water surface area dynamics over the last 40 years by using multi-temporal remote sensing imagery including Landsat and HJ-1. Meanwhile, the daily precipitation and evaporation data provided by Honghu meteorological station since 1970s were also collected and used to analyze the influence of climate change factors. The typical situation for precipitation was selected as an input into the TOPMODEL model to simulate the hydrological process in Honghu Lake. The simulation result with the water surface area extracted from remote sensing imagery was analyzed. This experiment shows the precipitation and timing of precipitation effects changes in the lake with remote sensing data and it showed the potential of using TOPMODEL model to analyze the combined hydrological process in Honghu Lake.

1. Background

Honghu Lake (29°40'-30°00' N and 113°12'-113°27' E) is one of the large shallow lakes on the Jiangnan Plain, situated in the south of Hubei Province, covering 344.4 square kilometers with an average depth of 2.2 m^[1-2]. Since the mid-20th century, Honghu Lake appear series of hydrological and ecological phenomena such as continental lake shrinkage, wetland degeneration, etc ^[3-4]. Although the reasons for the change of the lake are complex, it could mainly due to the global climate changes and the increasing human activities ^[5]. While which factor influences more on the lake's change is still a considerable controversy ^[6-7].

Remote sensing technique is an effective approach to monitor the lake dynamically ^[8-10]. In this paper, satellite imagery since 1970s were collected to analyze the changes of the water surface area of Honghu Lake, and the influence of each driving force factor in the change of lake's area was quantitatively analyzed by combining meteorological data and watershed model together.

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2. Introduction of Experiment Data and model

The water surface area of Honghu Lake was extracted using the multi-temporal remote sensing imageries including Landsat MSS, TM, ETM and HJ-1 CCD since 1970s (shown in Table 1). The remote sensing imagery mainly concentrated between September and November when Honghu Lake is at its normal level that could represent lake's water surface area each year objectively. Meanwhile, the digital topographic map covered Honghu Lake was also collected for remote sensing imagery geometric correction, the daily precipitation data and evaporation data since 1970s were collected as the climate information to analyze the influence on the change caused by climate change.

Table 1. Remote sensing imagery data list

No	Date	Sensor	Resolution	No	Date	Sensor	Resolution
1	1973-11-02	MSS	80 m	11	1996-10-04	TM	30 m
2	1976-11-14	MSS	80 m	12	2000-10-07	ETM+	30 m
3	1978-10-16	MSS	80 m	13	2001-09-24	ETM+	30 m
4	1979-11-07	MSS	80 m	14	2002-10-13	ETM+	30 m
5	1980-11-02	MSS	80 m	15	2003-10-16	ETM+	30 m
6	1982-11-10	MSS	80 m	16	2006-10-16	ETM+	30 m
7	1984-09-17	TM	30 m	17	2008-10-24	HJ-CCD	30 m
8	1987-09-26	TM	30 m	18	2009-10-01	HJ-CCD	30 m
9	1993-10-12	TM	30 m	19	2010-09-17	ETM+	30 m
10	1994-09-29	TM	30 m	20	2011-10-07	HJ-CCD	30 m

*The Landsat 7 SLC-OFF ETM imagery was recovered by models including multiple image local self-adaptation regression analysis and multiple image fixed window analysis^[11].

TOPMODEL is a popular watershed modelling tool for its deceptive simplicity, clever use of geomorphology, and demonstrated applicability to a wide variety of situations^[12]. TOPMODEL is selected to simulate the different runoff by inputting different rainfall and analyze the response relationship between water surface area and the precipitation.

3. Research Methods

3.1. Remote sensing imagery preprocessing

The remote sensing imagery preprocessing procedure includes steps such as radiometric calibration, geometric correction, etc. Remote sensing imagery including Landsat and HJ-1 were converted from digital numbers to exoatmospheric reflectance.

In this section, the digital topographic map covering Honghu Lake was selected for image geometric correction. Firstly, digital topographic map was rectified by using grid points of kilometers as the control points, then, taking the corrected digital topographic maps as base image, bridges, or other distinctive features of the permanent surface were selected as the control points to adjust geometric correction, and the error is controlled about 1 pixel.

3.2. Water information extraction

After the remote sensing data preprocess, the maximum likelihood classification algorithm was applied to water extraction by selecting training sets using regions of interest including water, vegetation, habitation, etc. The classification result was post-processed with removing isolated pixels using clumping adjacent similar classified areas together using morphological operators to get the water surface area of Honghu Lake. Part of the spatial distribution maps of Honghu Lake's water surface observed by multi-temporal satellite are shown in Figure 1.

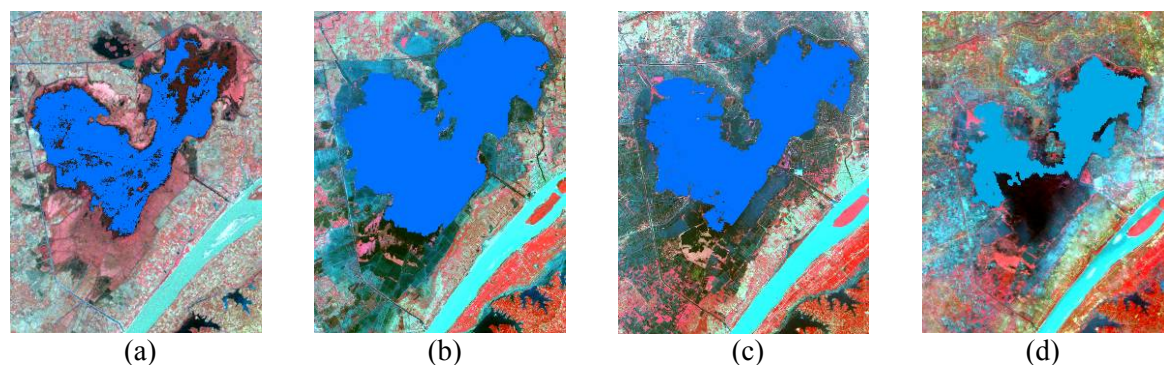


Figure 1. Some of the spatial distribution maps of Honghu Lake's water surface observed by multi-temporal satellite (blue part is the water surface of Honghu Lake). (a) MSS imagery of Oct 16, 1978, (b) TM imagery of Oct 4, 1996, (c) ETM+ imagery of Sep 17, 2010, (d) HJ-CCD imagery of Oct 7, 2011.

3.3. Preprocessing of Meteorological data

From the daily precipitation and evaporation data provided by Honghu meteorological station since 1971, the precipitation, precipitation anomaly, precipitation days, the anomaly of precipitation days, and evaporation for each year were arranged and calculated, and the precipitation anomaly and the anomaly of precipitation days were calculated. The processed water surface area, precipitation, evaporation data of Honghu Lake are shown in Table 2.

Table 2. The water surface area, precipitation, evaporation of Honghu Lake in different years.

Year	Area (kilo hectares)	Precipitation from January to August		Precipitation days from January to August		Evaporation (millimeter)
		Total Precipitation (millimeter)	Anomaly (%)	Total days (day)	Anomaly (%)	
1973	25.13	1301.8	16.2	120	22.7	482.0
1976	20.20	770.1	-31.3	102	4.7	874.6
1978	18.33	867.4	-22.6	80	-17.3	1053.9
1979	20.80	1158.4	3.4	89	-8.3	968.3
1980	21.73	1449.8	29.4	121	23.7	811.4
1982	18.13	967.4	-13.7	114	16.7	880.4
1984	16.87	674.7	-39.8	88	-9.3	907.8
1987	20.13	1242.4	10.8	108	10.7	892.6
1993	22.93	1165.6	4.0	110	12.7	829.2
1994	21.20	927.6	-17.2	108	10.7	883
1996	28.07	1830.3	63.3	109	11.7	832.5
1999	25.40	1443.3	28.8	102	4.7	720.2
2000	18.07	782.1	-30.2	86	-11.3	1001.6
2001	18.40	894.8	-20.2	81	-16.3	1011.5
2002	25.93	1547.9	38.1	111	13.7	877.7
2003	22.27	1137.0	1.4	99	1.7	942.2
2005	18.27	932.7	-16.8	88	-9.3	1043.6

2006	13.13	958.1	-14.5	93	-4.3	1040.2
2008	15.80	908.4	-19.0	85	-12.3	940.1
2009	15.07	1108.6	-1.1	84	-13.3	554.5
2010	20.07	1583.8	41.3	105	7.7	532.4
2011	14.07	851.5	-24.0	72	-25.3	missing data

4. Experiments and Analysis

4.1. Analysis of the water surface area change of the Honghu Lake

It could be found in Table 2 that water surface area has significant differences in the different years of Honghu Lake. The maximum area is 28.1 kilo hectares in 1996, while the minimum value is only 13.1 kilo hectares in 2006. The representative value of Honghu Lake's area in the less/more precipitation years in each decade were selected, and the average area of Honghu Lake were also calculated, just shown in Figure 3.

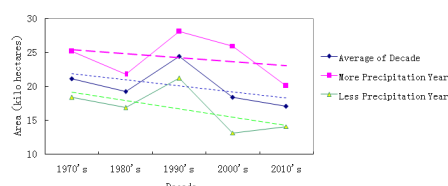


Figure 3. The trend chart of Honghu Lake's water surface area.

4.2. Analysis the influence of precipitation

Precipitation can supplement water quantity in Honghu Lake, and the change of Honghu Lake's water surface area was very similar with that of precipitation, just shown in Figure 4.

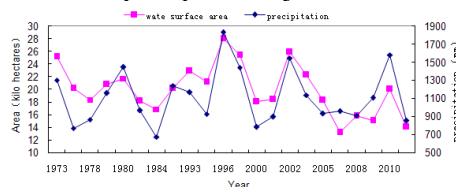


Figure 4. The change of Honghu Lake's area and precipitation.

Besides the direct effect of precipitation, the change of water surface area caused by the time distribution of precipitation should not be ignored. The correlation coefficient between water surface area and the number of precipitation days was 0.6914, as shown in Figure 5.

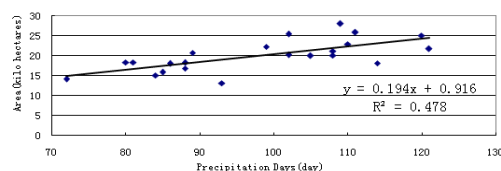


Figure 5. The correlation of Honghu Lake's area and the number of precipitation days.

The results indicate that during 1971 to 2011 the precipitation of Honghu Lake showed a slightly increasing trend, while the precipitation days tend to decrease. Decrease of the number of precipitation days would increase the risk of disaster which would have a certain influence on the area of Honghu Lake. The area of Honghu Lake and precipitation between 1994 and 2010 showed a clear contrast. Precipitation observed by Honghu meteorological station during January to August of 1994 was only 927.6 mm, and the area of Honghu Lake in 1994 reached 21.2 kilo hectares; while the precipitation

observed in 2010 was 1583.8 mm, and the area of Honghu Lake in 2010 was only 20.1 kilo hectares, nearly the same as that of 1994. The similar area maybe in certain degree caused by the similar days of precipitation: 108 days in 1994 while 105 days in 2010.

4.3. Simulate the influence of precipitation with TOPMODEL

In this section, some typical rainfall processes were selected to simulate the rainfall-runoff process with TOPMODEL, with the SRTM data covering Honghu Lake basin. Just in Figure 6, (a) is the heavy rainfall processes in a short period, (b) is the light rainfall processes in a short period, (c) is the heavy rainfall processes in a long period and (d) is the light rainfall processes in a long period, while (e) is the simulate result compared with the output of (a) and (b), (f) is the simulate result compared with the output of (c) and (d). From Figure 6(e) the discharge is determined by the precipitation to a certain degree, the heavier rainfall, the larger discharge, while from figure6 (f), the discharge is also determined by the length of the rainfall period.

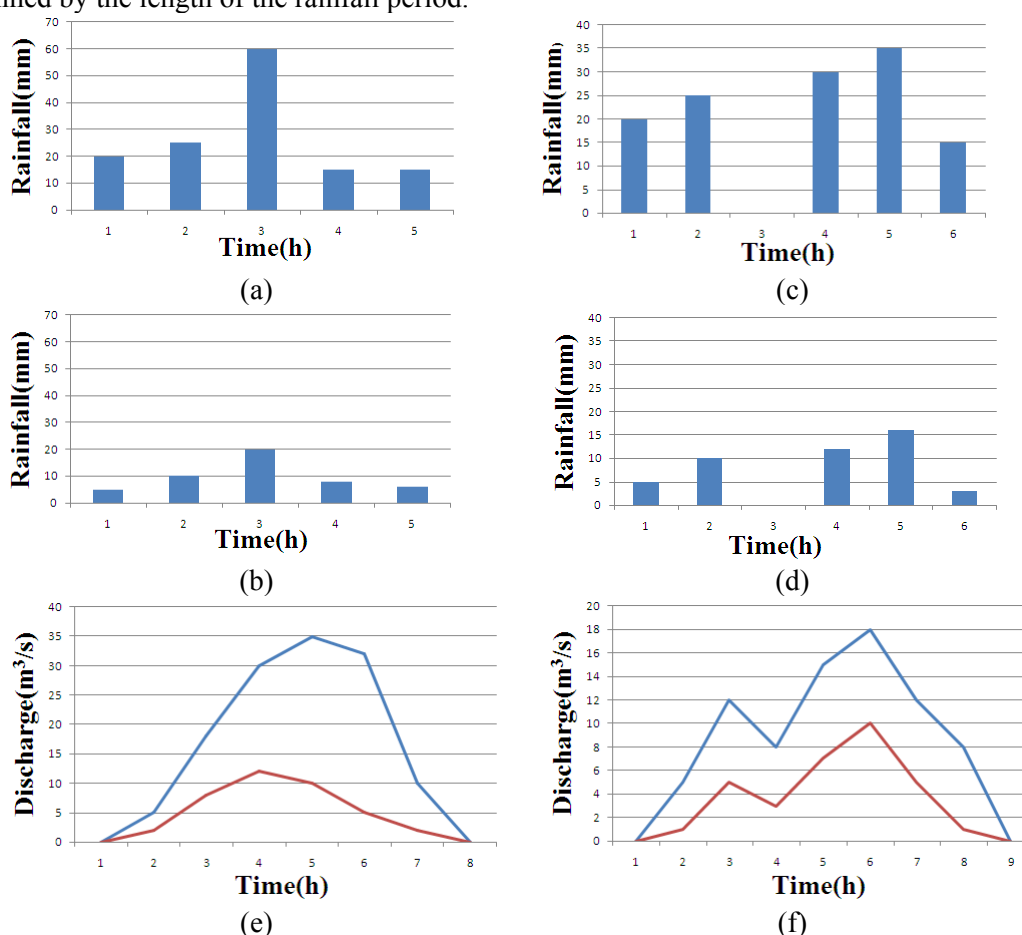


Figure 6. The simulation the influence of precipitation with TOPMODEL for Honghu Lake basin

5. Conclusions and discussion

In this paper, the multi-temporal remote sensing imagery including Landsat and HJ-1, and meteorological data were collected to analyze quantitative change of Honghu Lake's water surface area during the recent 40 years with the support of TOPMODEL. From the analysis of experimental results, the following conclusions are achieved:

- 1) There are relatively significant differences in the water surface area of Honghu Lake between different years. Regardless of the comparison between the more, less or normal precipitation years the water surface area of Honghu Lake were decreased.

- 2) The water surface area of Honghu Lake and precipitation observed from Honghu meteorological station are significantly correlated. Besides the effect of precipitation, the time distribution of precipitation is another important influencing factor should not be ignored, the similar conclusion has been verified with TOPMODEL preliminary.

More comprehensive data, such as the fishery data and model should be applied to establish more complicated model to further explore the impact of various factors on the change of Honghu Lake's water surface area in detail.

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