Change of Lake Dongting Area and its Relationship with Three Gorges Dam Based on Remote Sensing

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Abstract

In order to understand the annual change trend of the water area of Dongting Lake in recent years, and to explore whether the Three Gorges Project on the upper level of Yangze River is the main factor that affect the change, I use the normalized difference water body index method (NDWI) to analysis the Landsat data and MODIS data from 2005 to 2016. The main waters information of Dongting Lake was extracted and calculated with Google Earth Engine. The results show that the water area of Dongting Lake is generally decreasing. The total area in September and October 2016 was 40.5% lower than that of 2005. Especially after 2011, the lake area fluctuates significantly, and flood diversion capacity is reduced. A preliminary analysis of the possible reasons for its shrinkage is mainly the continuous sedimentation, lake-building, the drastic climate change, and water storage operation of the Three Gorges Project. The results show the variation of lake area could attributed to many causes and the Three Gorges Dam is not the main reason of shrinkage.

Five Keywords: Lake Dongting area Three Gorges Dam Remote sensing Water surface area Impacts

1. Introduction

In China, flood and drought is major climate disasters which is high frequency, long duration and broad affected. Especially in 2011 from April, the Yangtze river– Asia's biggest river – experiencd its worst drought compared with the past 50 years[1]. The drought damages crops, threatens the ecological environment, affects the production and life, and then affects the regional economic development. However, the drought in the middle and lower reaches of the Yangtze river in China did not happen accidentally in 2011.

Dongting Lake is a water lake on the Yangtze River. The water surface area of Dongting Lake varied significantly during last decade. The water system of Dongting Lake area is well developed and its water resources are abundant, but in recent years, it has been plagued by drought and shrinking. According to the observation from National Climate Center of China meteorological administration[2], since 2001, the Dongting Lake area has been basically dry in other years except 2002 and 2010, when there were flooding in Dongting Lake area. The reasons of drought and shrinkage are complicated, including climatic change, human overcultivation, especially infrastructure construction.

The Three Gorges Dam is a hydroelectric gravity dam in Hubei province, China. The dam is intended to produce electricity, increase the Yangtze River's shipping capacity and providing flood storage space[3]. The Three Gorges Dam was successfully constructed in May 2006, and the water storage was officially completed in September 2011.

Previous reason of the shinnkage of Dongting is the sedimentation brought by the Yangtze River and man-made reclamation, which gradually weakened its ability to store floodwater. After the storage of the Three Gorges Dam in 2010, the amount of water diverted into the Dongting Lake during the dry season decreased sharply, which seriously affected the water volume of the Dongting Lake[4].

Based on the strong connection between Dongting Lake and Yangze River, some people hold the view that the shrinkage of Dongting Lake is caused by the construction of the Three Gorges reservoir in the upper reaches of the Yangtze River, and further more caused the drought and flooding disasters in the South China. However, some people hold another view that, Three Gorges Dam adjusted the water area and water volume in the middle and lower reaches of the Yangtze River, and had a positive effect on flood prevention. Therefore, the monitoring of water area change in Dongting Lake area could help government to better understand the complex effects of dam construction and forecast analysis of floods and drought.

This paper tries to figure out how the urban infrastructure, especially damming, will influence water surface range with the support of Google Earth Engine and ArcGIS. A 10 years series of Landsat datasets has been applied to monitoring water area variation from 2005 to 2016. Section 2 explains the conceptual framework of how the shrinkage of the lake was observed. Section 3 presents the methodology of using remote sensing. Section 4 shows the results of the observation and different in means analysis. Section 5 concludes the paper.

2. Conceptual framework

[1] Jonathan Watts, China crisis over Yangtze river drought forces drastic dam measures, https://www.theguardian.com/environment/2011/may/25/china-drought-crisis-yangtze-dam

[2] National climate center of China meteorological administration, https://cmdp.ncc-cma.net/extreme/dust.php?Year=2011&Month=3&Day=18&search=%CB%A2%D0%C2%CD%BC%D0%CE

[3] Three Gorges Dam, https://en.wikipedia.org/wiki/Three_Gorges_Dam

[4] Dongting Lake, https://zh.wikipedia.org/wiki/%E6%B4%9E%E5%BA%AD%E6%B9%96

The lake area variation reflects the relationship between human behavior and environmental concerns. This huge issue has attracted the attention of many scholars. There are many ways to observe the area of lakes, and the results differentiated by different location of the lake and brings different environmental concerns. Chen and Zong (2013) use the optical dating chronology for a series of paleo-shorelines to measure the surface area of Zhari Namco. They find that lake level has dropped 128 m over the past 8.2 ka[5]. Chunhong Hu and Chunming Fang (2014) use hydrological data to analyze the annual maximum discharge and annual maximum stage development of the middle reach of the Yangtze River and Dongting Lake, and the results shows that the flood situation in the middle reach of the Yangtze River and Dongting Lake will remain stable. Analyzing changes in lake extents and levels across the Tibetan Plateau from Landsat/ICESat data from 1970 to 2010, Li and Liao (2014) conclude that more than 79% of lakes we observed on the central-northern plateau (with continuous permafrost) are rapidly expanding[6], which explains that whether glacier melt is the dominant driver for lake expansions on the Tibetan Plateau.

Remote sensing technology has more advantages in macro and dynamic monitoring of lake water surface area[7]. Many researchers analyze the of shrinking of Dongting Lake using remote sensing. Cheng and Deng (2015) found that the water area of main Dongting Lake is overall decreasing, using Normalized Difference Water Index (MNDWI) explored from the September Landsat data during 1996-2014. Ji and Wu (2015) compared the seasonal difference of Dongting Lake area between 2005 and 2011 using NDWI (Normal Differential Water Index) which extracted from Terra/MODIS (moderate-resolution imaging spectroradiometer) dataset. Their results revealed that there were diversity and complexity of drought causes in Lake Dongting. Ke, Chen and Ji (2017) addresses spatial-temporal variation in water surface area of Lake Dongting and its relationship with water level at Chenglingji of the Yangtze River for the years 2000-2012. Their results show that the lake area decreased from 2000 to 2012, with a strong seasonal variation in terms of rising flooding, retreating and drying periods.

The positive and negative of economic development and human behavior, like damming, on the regional ecological environment will be further discussed in this paper.

3. Methods

3.1 Region of Interest

Dongting lake is the second largest freshwater lake in China, which is mainly composed of three lakes: west Dongting lake, south Dongting lake and east Dongting lake. Study area is the main part of Dongting Lake as Figure.1 showing.

Dongting lake locates in northeastern Hunan province, China. Dongting lake is located in the northeast of Hunan province and the south of Jingzhou, Hubei province, China, and its geographical coordinates are between 28°5′N ~ 29°5′N, 111°75′E ~ 113°25′E.

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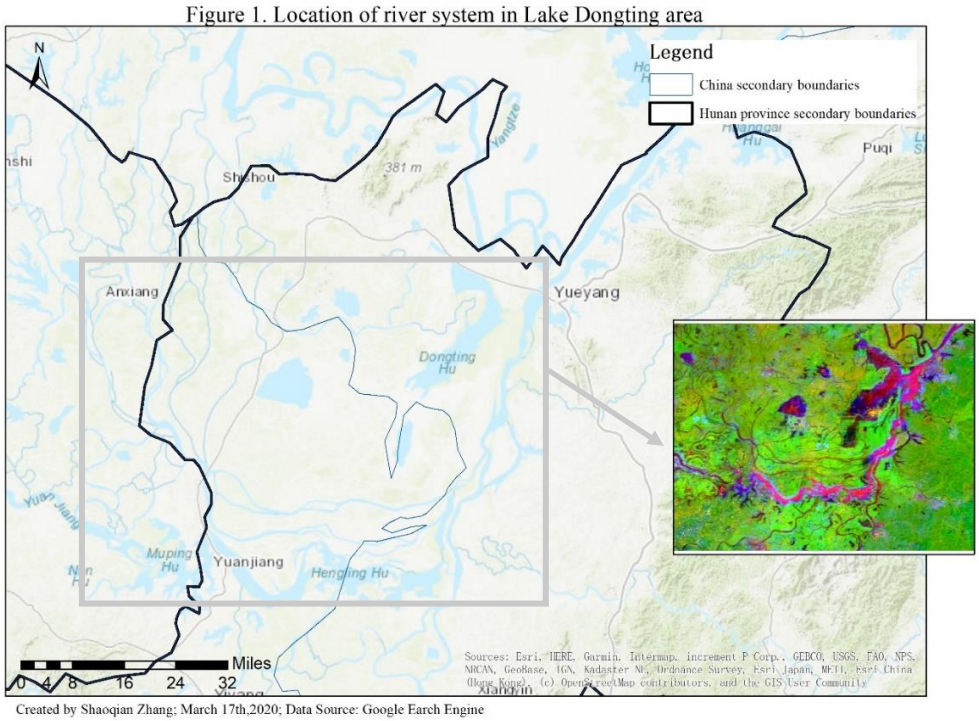
[5] Shrinking lakes in Tibet linked to the weakening Asian monsoon in the past 8.2 ka. Yiwei Chen, Yongqiang Zong, Bo Li, et al. DOI: https://doi.org/10.1016/j.yqres.2013.06.008. Published online by Cambridge University Press: 20 January 2017

[6] Patterns and Potential Drivers of Dramatic Changes in Tibetan Lakes, 1972–2010. Yingkui Li, Jingjuan Liao. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4221193/

[7] Li Jiren, Huang Shifeng (2003). ‘‘3S’’ technology and it’s applications on water sector[M]. China WaterPower Press, Beijing

The four rivers of Xiang, Zi, Yuan and Li Rivers in the south converge, and the north is connected with the Yangtze river, which plays an important role in flood storage in the middle reaches of the Yangtze river. The lake locates in a humid subtropical monsoon climate zone. Annual rainfall is 1100 ~ 1400 mm. The annual rainy season from April to June accounts for more than 50% of the total precipitation, and it is usually heavy rain or rainstorm, forming good hydrological, soil and climatic conditions. The favorable natural environment breeds the rich and diverse wetland vegetation and animal wetland climatic conditions. Dongting lake district is also an important national fishing and commercial grain base.

Figure 1. Location of river system in Lake Dongting area



Notes: The Basemap is self-created using ArcGIS with province and cities boundaries of Hubei and Hunan. The zoomed map is created using Band (2,1,1) of MOD09Q1 with a false-color RGB from 2015-09-01 to 2015-10-30. Water appears red. Source: Google Earth Engine.

3.2 Satellite Data

In order to observe overall water surface variation of Dongting Lake, Landsat 7/8 Data were selected as main data source to create the time series data from 2005 to 2016, including each year's September and October. Considering the date of the acquired images and clearance of the map, I use USGS Landsat 7 Collection 1 Tier 1 and Real-Time data Raw Scenes (LANDSAT/LE07/C01/T1_RT) to create Landsat images from 2005 to 2012, which covers from September 1st to October 30th. Then, I choose USGS Landsat 8 Collection 1 Tier 1 and Real-Time data Raw Scenes (LANDSAT/LC08/C01/T1_RT) to create Landsat images from 2013 to 2016, which covers from September 1st to October 30th. The reason of choosing September to October is because the lake area is stable without the influence of higher precipitation in summer.

In order to observe the loss of water area clearly. I also use MOD09GA.006 Terra Surface Reflectance Daily L2G Global 1km and 500m (MOD09GA) to create the maps of diminished water areas in the following analysis. MOD09GA dataset were used to build Terra/MODIS Data comparison between 2005 and 2015. MODIS imagery has moderate spatial

resolution, high temporal resolution, and high spectral resolution[8]. MOD09GA is a seven-band surface reflectance daily product computed from the MODIS Level 1B land surface data (sur_refl_b01 is 500m Surface Reflectance Band 1 (620-670 nm), sur_refl_b02 is 500m Surface Reflectance Band 2 (841-876 nm), sur_refl_b03 is 500m Surface Reflectance Band 3 (459-479 nm), sur_refl_b04 is 500m Surface Reflectance Band 4 (545-565 nm), etc.).

Also, I choose MOD09Q1 to visualize the lake area in Figure 1. provides Bands 1 (Red) and 2 (Near Infrared) at 250 m resolution in an 8-day gridded level-3 product. The band is chosen as red, green, blue to represent band 'sur_refl_b02', 'sur_refl_b02', 'sur_refl_b01' in Figure 1.

3.3 Method of water body extraction using NDWI method

First, Landsat 7 and 8 Data are created to simple cloud-free Landsat composites using GEE's default parameters. MODIS data is also created with the absence of clouds or cloud shadow.

There are many ways to extract water body. Frazier use Single-band threshold method to extract information form TM5 image, but it is difficult to distinguish between water and the water transition zone. The multi-band spectral analysis mainly analyzes the spectral curve characteristic relationship between water body and background features, and then extracts water body information by using the logical relation between the bands. Zhou (1999) distinguish water body shadow by using the relation between (TM2 + TM3) > (TM4 + TM5)[9]. Commonly used index model methods is NDWI method of McFeeters et al (1996)[10].

This paper mainly uses the NDWI index (Normalized difference water index) method to extract water information from remote sensing images from September to October from 2005 to 2016. NDWI makes use of the green band to maximize water surface reflectance and minimize the low reflectance of the NIR band by water surfaces[11]. NDVI contains a single band range from -1 to 1. The NDWI is created as following,

$$NDWI = (GREEN-NIR) / (GREEN+NIR)$$

In Landsat 8, GREEN is band 3 and NIR is band 5, so the function is,

$$NDWI = (B3-B5) / (B3+B5)$$

In Landsat 7, GREEN is band 2 and NIR is band 4, so the function is,

$$NDWI = (B2-B4) / (B2+B4)$$

For the MODIS land surface reflectance dataset, Green and NIR correspond to band 4 and 2 respectively.

4. Results

4.1 Water surface variations analysis

To analyze the water areas across time, I apply the function above using the cloud-free Landsat image to calculate the NDWI and adjust the palette to black (lowest value) and blue (highest value). The data for Figure 2 were extracted by Landsat 7 and 8. The visualization

[8] Water surface variations monitoring and flood hazard analysis in Dongting Lake area using long-term Terra/ MODIS data time series.

[9] Zhou, Luo, et al. Remote sensing imaging and analysis. Beijing: Science Press, 1999.

[10] McFeeters, S. K. The use of normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 1996, 17(7): 1425-1432.

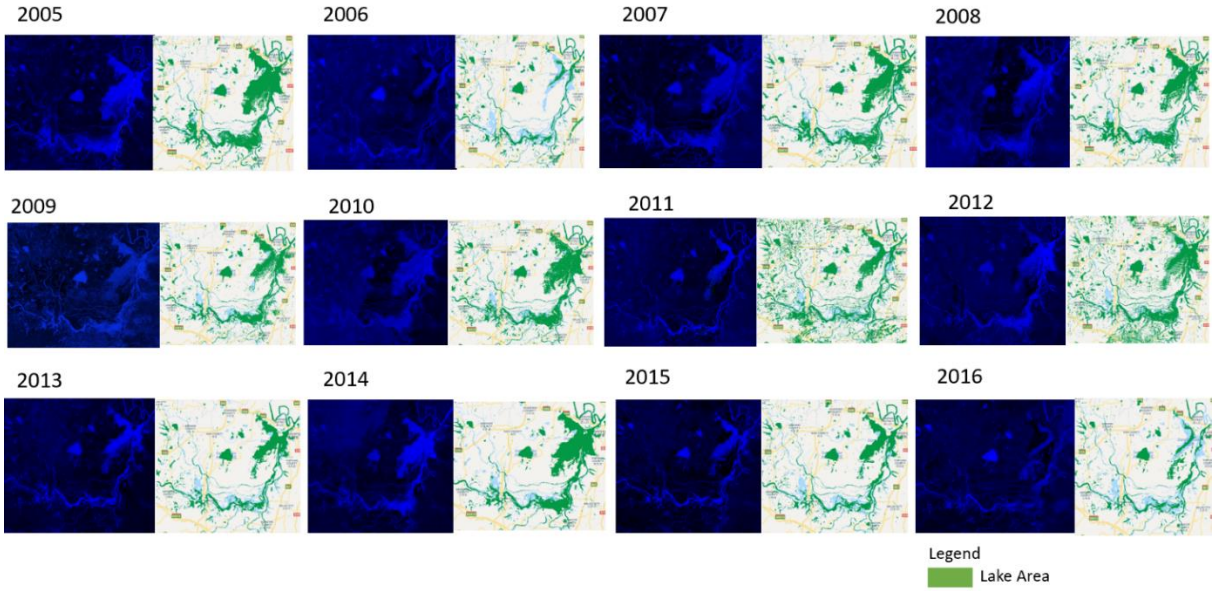
[11] Dorothea Deus.2013. Remote Sensing Analysis of Lake Dynamics in Semi-Arid Regions: Implication for Water Resource Management

shows in Figure 2, left-side picture of each year. Compared to 2005, water surface in 2016 decreased across the whole lake area as the tone of the image became lower.

Furthermore, the lake area suffered obvious shrinkage in 2006 and 2011, which needs further analysis. According to USGS remote Sensing phenology[12], an area with NDWI value from 0.3 to -1 are surfaces without detectable water, while surfaces with detectable water usually has values higher than 0.3. Therefore, I create the right-side picture of Figure 2 by masking itself with a threshold of greater than value 0.3.

To further analysis the change, I compared the water area change between 2005 and 2015 and map the diminished water area in Figure 3, which the data were extracted by MODIS with a threshold of 0. The palette of diminished water area was defined as blue in study area.

Figure 2. Mapping Dongting Lake water area extracted by MNDW method (2005 – 2016)



Note: Own elaboration with Google Earth Engine. The left-side graphs show the images captured by NDWI; the right-side lake area images are filtered by masking itself.
Sources: Google Earth Engine.

The lake area was calculated by, first, mapping the area of interest as a binary variable where 1 represent water area, and 0 represent non-water area, then multiply it with each pixel's area, and reduce the region in the end. The results in Figure 3 show the following characteristics:

The area of Dongting lake fluctuates obviously. The surface of the lake decreases in a parabola. The total area in September and October 2016 was 40.5% lower than that of 2005;

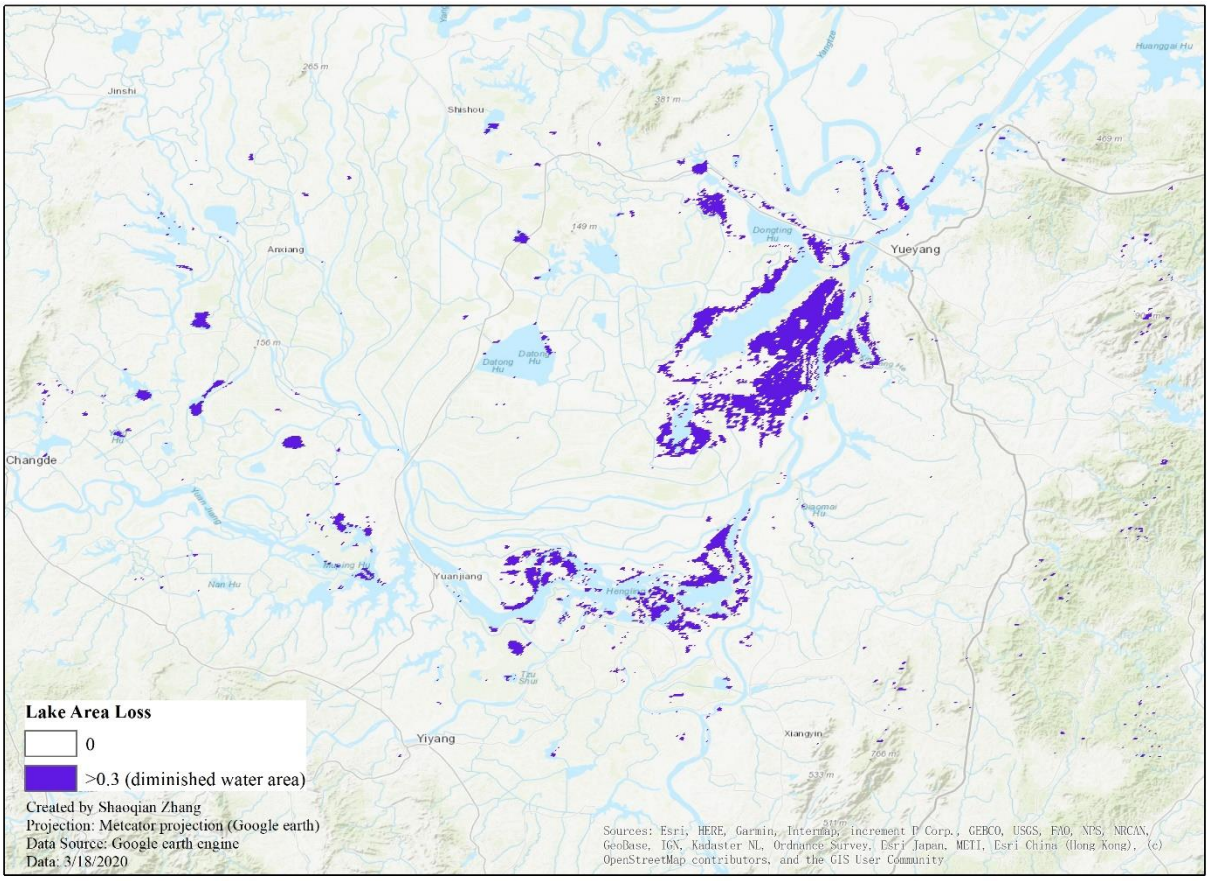
The lake area was the smallest in 2006, 49.6% smaller than the 2,611.33km2 of 2005. In 2006 and 2011, the Dongting lake area experienced severe drought, leading to a significant decrease in water level in 2006. In 2011, in response to a widespread drought in the middle and lower reaches of the Yangtze river, the three gorges dam became watertight and the water area increased significantly;

After the operation of the three gorges project (after 2011), the area of the lake area showed a downward trend. Compared with 2011, the water area in 2016 has shrunk by 54%.

[12] Normalized difference water index. https://en.wikipedia.org/wiki/Normalized_difference_water_index

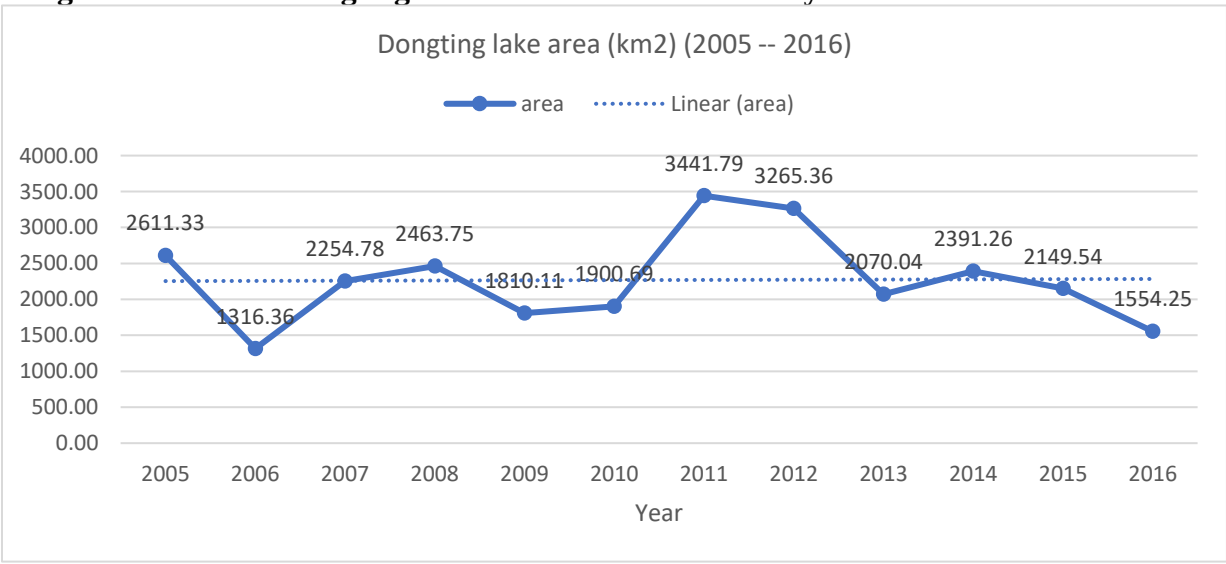
Figure 3. Change in water surface area between 2005 and 2015, Dongting Lake (NDWI)

Figure 3: Change in Water surface area between 2005 and 2015, Dongting Lake (NDWI)



Note: Own elaboration with ArcGIS. Data source: Google Earth Engine.

Figure 4. Chart of Dongting Lake water area extracted by NDWI method in 2005-2016



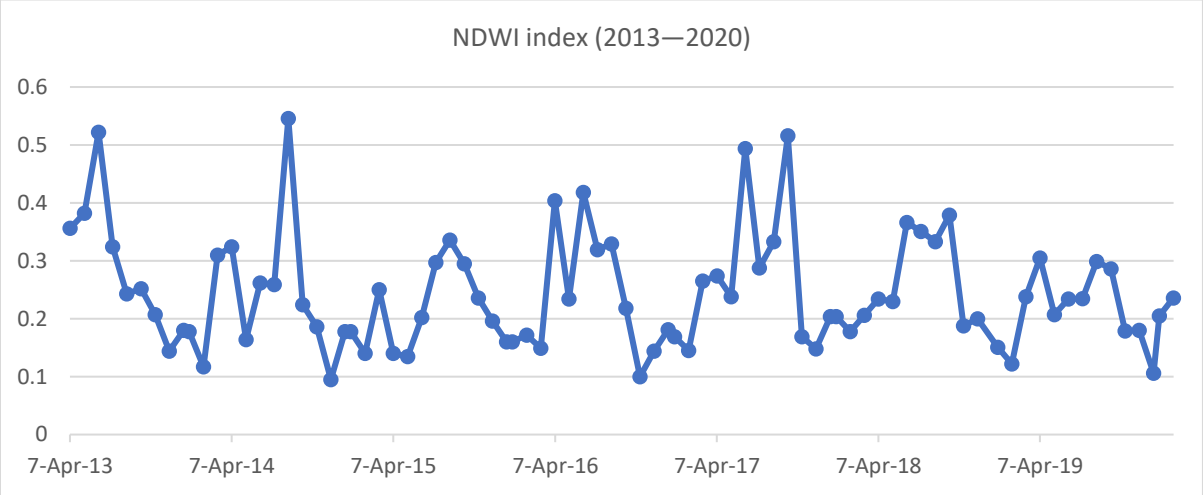
Note: Own elaboration with Microsoft Excel. Data source: Google Earth Engine.

4.2 NDWI trends analysis

NDWI index from 2013 to 2020 were extracted from Landsat 8 Collection 1 Tier 1 32-Day NDWI Composite (LANDSAT/LC08/C01/T1_32DAY_NDWI). As Figure 4 shows, the overall trend of water area is decreasing.

Besides, the seasonal variation of NDWI has weakened and has less fluctuation within the year 2019 to 2020 compared with before. The reason underneath is complicated. For example, as the sediment injected into the Dongting Lake from the Yangtze River is continuously decreasing, the sedimentation speed is accelerating, and the amount of water entering the lake is reduced, which further leads to the advance of the dry season of Dongting Lake, which accelerates the reduction of the water area.

Figure 5. Chart of NDWI index (2013—2020) NDWI annually trend (2013--2020)



Source: Own elaboration with Google Earth Engine.

4.3 Analysis of the relationship with Three Gorges

Table 1 show the area of the lake and how I define the influence of damming. The results in Figure 5 shows the different in means analysis before and after the water storage of Three Gorges. Group 1 represent years with influence of dam, and group 0 without. According to the results, $p = 0.2679 > 0.05$, so the null hypothesis could not be rejected. There is no statistically different between the mean of group 0 and group 1. Therefore, the influence of Three Gorges Dam could not be contributed to the main reason of the shrinkage of the lake.

Table 1: the area of lake extracted from Landsat 7/8 from 2005 to 2016 (NDWI)

(1) Year	(2) Area of lake(km^2)	(3) With dam or not
2005	2611.334	0
2006	1316.364	0
2007	2254.778	0
2008	2463.749	0
2009	1810.112	0
2010	1900.688	0
2011	3441.794	1
2012	3265.355	1
2013	2070.04	1

2014	2391.263	1
2015	2149.543	1
2016	1554.253	1

Source: Own elaboration with Google Earth Engine.
Note: In column (3), the year with Three Gorges Dam construction is '1', without is '0'.

Figure 6. Different in means results using STATA

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
0	6	2059.504	195.4259	478.6937	1557.146	2561.863
1	6	2478.708	299.1081	732.6623	1709.826	3247.59
combined	12	2269.106	181.6779	629.3506	1869.236	2668.976
diff		-419.2037	357.2911		-1215.298	376.8905

diff = mean(0) - mean(1) t = -1.1733
Ho: diff = 0 degrees of freedom = 10

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.1339 Pr(|T| > |t|) = 0.2679 Pr(T > t) = 0.8661

Source: Own elaboration with STATA.

5. Conclusions

According to the analysis with NDWI, Dongting Lake is shrinking with not doubt, but I cannot conclude that Three Gorges construction is the main reason.

The lake area is mainly regulated by rainfall, evaporation and other climatic factors, as well as human activities, such as water intake for production and living, flood control and drainage, and returning farmland to the lake. On the one hand, the return of farmland to lakes and the retention of rain-torrents increased the surface area of the lakes during the period of water abundance, but on the other hand, climate change and the development and utilization of water resources lead the decrease of the surface area during the dry season. Therefore, it is necessary to strengthen the research and protection of Dongting lake area, appropriately return the farmland to the lake to improve the lake rate, implement the river and lake system connection project, and alleviate the seasonal water resource shortage in Dongting lake area.

Assessment of water recourses becomes more and more important as human construction increase. This paper could be further implemented into observe the lake area changed in other area also. MODIS dataset provide a much clearer observation of water surface compared with Landsat 7 and 8, since the cloud influence cannot be ruled out totally in the later dataset. Furthermore, MNDWI replaces the near-infrared band in NDWI with the middle red band, which enhances the contrast between water and buildings and reduces the confusion between them, thus improving the accuracy of water information extraction. Therefore, the NDWI index could be replaced by MNDWI or NDVI, which are not analyzed in this paper.

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