Remote sensing imaging: a useful method for assessing wetland vegetation evolution processes in the Nanjishan Wetland National Nature Reserve, Lake Poyang

Jie Zhang¹,³, Jing Li¹, Xueru Wang¹, Peijun Wu ², Xingchen Liu¹ and Yong Ji¹

¹College of Water Conservancy and Ecological Engineering, Nanchang Institute of Technology, Nanchang 330099, China;
²Office of Poyang Lake Water Control Project Construction of Jiangxi Province, Nanchang 330046, China
³Email: 18502573@qq.com; 841656911@qq.com

Abstract. To obtain authentic details on wetland vegetation distribution and evolution processes, remote sensing images were used to calculate the vegetation area of the Nanjishan Wetland National Nature Reserve (NWNNR) in wet (flooding) and dry seasons. The results showed that the vegetation coverage areas were significantly negatively correlated with the water levels. Moreover, the vegetation coverage areas in the dry season presented an obvious decreasing trend since 2008 when the Three Gorges Dam (TGD) began operations, whereas the vegetation areas in the flooding season significantly increased. A statistical analysis indicated that significant differences occurred in the vegetation areas before and after 2008 in both the flooding and dry seasons. Furthermore, the vegetation distribution regions also changed in the same period over different years. Obvious regional variations were not observed in the flooding season due to the lower vegetation coverage areas. However, the spatial distribution of vegetation in the dry season showed a mix of river, lake and beach regions, which indicated the fertility of the soil for wetland vegetation to grow and develop. From 1995 to 2008, the vegetation distribution area was mainly located in the southwest of the NWNNR. Since 2009, the vegetation distribution in the northeast area has been dominant in the dry season compared with the aggregation in the southwest. The influence of human behavior, extreme climate change and water conservancy project construction had an important influence on the distribution and evolution of wetland vegetation in the NWNNR.

1. Introduction

Similar to forest and ocean ecosystems, wetlands have attracted wide attention because of their high value, which is closely related to human life and economic development [1,2]. Wetlands not only provide freshwater biological resources but also play an important role in flooding control, water purification, regional climate regulation and diverse culture maintenance [3]. However, massive human activities, including large-scale wetland reclamation, water resource overexploitation, and serious environmental pollution combined with insufficient management and protection have led to wetland degradation, biodiversity reduction and ecological function and production and environmental degradation [4,5].

Poyang Lake is the largest freshwater lake in China and is listed as one of the most important wetlands in the world. Due to its special location, Poyang Lake plays a vital role in flood regulation
and biodiversity protection in the Yangtze River Basin of China [6]. Located to the southwest of Poyang Lake, the Nanjishan Wetland National Nature Reserve (NWWNR), which presents a unique wetland natural landscape and rich biodiversity, has been well-preserved because of the limited anthropogenic disturbances, absence of major pollution and small resident population. As one of stations along the East Asian-Australian waterfowl migration route, the NWWNR attracts more than 300,000 migratory birds in the winter season every year. Furthermore, the rich vegetation resources and complex water flow in the estuarine area make the reserve an important place for animal populations as a migration route and refuge.

Its well-protected estuarine wetlands also make the NWWNR a perfect research field for estuary natural geography, hydrology, biodiversity, ecological environment detection, etc. Since the operation of the Three Gorges Dam (TGD) and water conservancy projects in the Poyang Lake Basin in recent years as well as the establishment of an ecological economic zone, the wetland ecology, vegetation type and area in the NWWNR has been gradually and continuously changing [7]. Compared with the past, the dry season in winter has advanced temporally and presents a prolonged duration and lower water levels. Small changes in the vegetation will affect the stability of the whole wetland ecosystem. To effectively manage the wetland ecosystem, the vegetation in the wetland must be analyzed and investigated. In this study, the primitive NWWNR in Poyang Lake was selected as the study area, and Landsat remote sensing image data were used to analyze the distribution and variation characteristics of the vegetation area during the high water level season and low water level season. The results can provide some important information for the management, protection, sustainable development and utilization of wetland ecosystems and are of great significance to maintaining the ecological security of the wetland.

2. Study areas and methods

2.1. Study areas
As shown in Figure 1, the study area is located to the southwest of Poyang Lake. The NWWNR was formed as a front delta by the alluvium from the north, middle and south branches of the Ganjiang River, which converges into the open water area of Poyang Lake. Located at north latitude 28°52'21" to 29°06'46" and east longitude 116°10'24" to 116°23'50", this reserve serves as a land and water transition zone between the estuaries of three tributaries of the Ganjiang River and the great water body of Poyang Lake. Taking two islands as the center, the NWWNR is mainly composed of Nanshan Island, Jishan Island and a large area of lakes and grasslands, and it has a total area of approximately 33,300 hm². In the flooding season, the roads that connect to outside areas are almost completely submerged. Because of the limited population and lack of serious pollution in the surrounding areas, the influence of anthropic activities is low in the NWWNR; thus, this area has been well preserved and presents unique wetland natural landscape and rich biodiversity.

![Figure 1](image-url)
2.2. Data sources and processing

The water level in the NWNNR is significantly affected by the flow coming from the “Five Rivers” flowing into Poyang Lake Basin and the Yangtze River, and these water sources affect the wetland vegetation area and form a regular seasonal fluctuation of water levels. In general, the water level in the NWNNR is higher from April to September, with the maximum water levels observed in July, while water level is lower from October to March of the following year, with the minimum water levels observed in December or January of the following year. In this study, July and December represented the flooding and drying season, respectively, and the data for these months were processed for the vegetation analysis. Limited by image quality, the Landsat image data downloaded from the "Geospatial Data Cloud" and the "USGS" from 1995 to 2015 were used for the analysis.

In this study, remote sensing data from Zone 50 North (WGS84) was obtained from the "Geospatial Data Cloud" and "USGS" platforms. These data were verified and enhanced by 2% and 5% linear automatic stretching, and then be clipped according to the size of the study area. To separate vegetation from other objects accurately, the classifier was operated by using the true color of the image and the CIR and composite bands represented by the TM2, TM4 and TM6 bands. By calculating the normalized difference vegetation index (NDVI), vegetation and non-vegetation can be well differentiated in the NWNNR, where most lands are covered by water bodies and vegetation.

2.3. Statistical analysis

After classifying the vegetation and non-vegetation areas via ENVI, the data were then transferred into ArcGIS for projection transformation. Meanwhile, the geodetic coordinates, longitude and latitude, scale, north needle and legend were added at this step. Finally, a vegetation distribution map was produced. ENVI5.1 and ArcGIS 10.2 were used to process the TM remote sensing images. A statistical analysis of the processed data was performed using IBM SPSS Statistics 19.1 and Excel. The drawing and optimization of the graphics in this paper were performed using Word, Math Type 6.0, EndNote X7 and Photoshop CS5. Hydrological data were supplied by the Jiangxi Hydrological Bureau, which collects daily hydrological observations and records, performs analyses and publishes the information.

3. Results and discussion

3.1. Vegetation distribution and hydrological progress

The vegetation distribution areas in the flooding and dry seasons are presented in Figure 2 and Figure 3, respectively, excluding the missing data from 1997 and 2001. The results indicate that changes in the wetland vegetation area were significantly related to changes in the water level. Scatter points representing the average monthly values of the hydrological water level at Xingzi Hydrological Station and vegetation areas are presented in Figure 2(A) and (B), and they show that the wetland vegetation in the flood season is significantly negatively related with the change of water level and presents a squared correlation coefficient ($R^2$) of 0.661. However, a significant relationship is not observed between the water level and wetland vegetation in the dry season. The main reason for these findings is because the water level in the flooding season is the primary factor that determines the water depth, which consequently contributes to the area of vegetation that can extend beyond the water surface. However, most of the tidal flats and wetlands in the dry season are exposed to the surface due to the lower water level. In this case, the area of the wetland vegetation is not only determined by the water level, which still covers a certain area of wetland but also related to the succession and reproduction of the wetland plants themselves.

3.2. Distribution characteristics of vegetation areas

Negative NDVI values mean that the land surface is covered with high reflection items, including cloud, water, snow, etc. When the land surface is covered only by rock or bare soil, the NDVI value is usually equal to 0, which indicates that the NIR and R are approximately equal. If the NDVI is
positive, then the land surface is covered by vegetation cover. Pang [8] used NDVI values to investigate vegetation variations in different seasons from 1982 to 2012 on the Tibetan Plateau. The research indicated that the NDVI values in the whole plateau increased as the temperature and precipitation increased from 1982 to 2012 [8]. Zhang [9] performed an analysis of 250-m spatial resolution MODIS NDVI data from 2000 to 2011 to investigate the spatial distribution characteristics and inter annual change trends of forest vegetation in Jinggangshan Basin, Jiangxi Province. The results revealed that the maximum forest vegetation index over the past 10 years occurred in July. The NDVI presented higher values in summer and autumn but lower and unstable values in winter [9].

![Figure 2](image1.png)

**Figure 2.** Scattered points and regression model for water level and wetland vegetation area in flooding season (A) and dry season (B).

![Figure 3](image2.png)

**Figure 3.** Vegetation distribution areas for flooding season (A) and dry season (B) in Nanjishan National Nature Reserve.

Over the past twenty years, the vegetation distribution areas have ranged from 1.66 to 76.20 km$^2$ in the flooding season. The wetland plant distribution area changes significantly among different years. As shown in Figure 3(A), wetland plants that breech the water surface are only observed in several highlands and resident communities in Jishan Town, and they covered 1.66 km$^2$ in 1998, when the maximum historical water level was recorded. In contrast, the wetland vegetation distribution areas reached up to 76.20 km$^2$ in 2013 after the operation of the TGD, which was designed to regulate the flooding summit. Wetland plants that grow past the surface water significantly increased throughout the entire nature reserve after water regulation by hydrologic projects. A one way ANOVA (P < 0.01) indicated that the NWNNR vegetation area significantly increased after regulation by the TGD began in 2008. Public documents also revealed a significant difference in the correlation between the wetland vegetation distribution and water levels in Poyang Lake before and after the TGD began operations [10]. Similarly, based on MODIS observations and a phenology-based decision tree approach, Han [7] pointed out that the coverage of different types of vegetation communities has increased over a 15-year period, which could be directly linked to a TGD-induced hydrological regime shift.
The vegetation areas of the NWNNR in the dry season are presented in Figure 3(B). Similar to the flooding season, plants that breeched the surface water also show obvious varieties in different years and the vegetation areas range from 86.25 to 191.65 km$^2$. However, the vegetation areas with positive NDVI values show a decreasing trend, which is different from the change trend observed in the flooding season. The wetland area before 2008 was higher than that after 2008, and a significant difference in the average wetland vegetation areas before and after 2008 is also revealed by the one way ANOVA ($P < 0.01$), which indicates that regulation by hydraulic projects has a significant influence on wetland plants in Lake Poyang Basin.

3.3. Change characteristics of vegetation areas

Using the NDVI, Zhang [11] investigated the relationship between geese habitat and wetland vegetation distribution in East Dongting Lake. The results indicated that wetland plants are significantly correlated with hydrological factors, which profoundly affect the wetland vegetation spatial distribution. A comparison among different years clearly showed that the vegetation distribution area varies significantly and the plant distribution region obviously changes. Figure 4(A) and (B) show that the wetland vegetation coverage is small in the flooding season under higher water levels, and only several highland and resident communities were observed in Jishan Town in 1998. In 2013, after the application of the TGD, the wetland vegetation distribution areas reached up to 35.34 km$^2$. The one way ANOVA ($P < 0.01$) indicated that the NWNNR vegetation area significantly increased after regulation by the TGD after 2008.

Figure 4. Wetland vegetation distribution areas for flooding season in July, 1998 (A) and July, 2011 (B).

However, the landscape of the NWNNR in the dry season is a mix of river, lake and beach due to the lower water level, which produces a large area of fertile beach soil and promotes the development of wetland vegetation. Figures 5(A), (B), (C) and (D) illustrate the dry season in 2004, 2008, 2013 and 2015, respectively, and they show that most areas of the NWNNR are covered by vegetation, which is completely different from the condition observed in the flooding season. The hydrological data of the Xingzi Hydrological Station shows that the lowest water level in the dry season has continuously decreased since 2000, with the lowest water level of 7.11 m recorded in 2004. The hydrological data of the Duchang Hydrologic Station indicated that the lowest water level over the past 60 years at 7.93 m was recorded in 2012. In general, the vegetation distribution area is consistent with the average water level, which indicates a wide vegetation distribution area in the dry season and a small vegetation distribution area in the flooding season.

An analysis of the combination of hydrological data and wetland vegetation areas, the hydrological characteristics and wetland plant distribution in 2008 should be marked as a milestone with special hydrological processes and plant coverage. Due to the rapid decrease of water inflow after the middle of November and the regulation effect of the TGD [12], the water level of Poyang Lake at the end of December 2013 was nearly 1 m lower than the historical average water level, and the water coverage
area was only approximately 220 km$^2$. Since 2008, a large amount of wetland vegetation in the southwest NWNNR has withered prematurely because of dry season advancement and longer exposure times. Concurrently, a greater amount of wetland vegetation has been observed in the middle of the NWNNR because of the longer periods with low water levels. This finding was consistent with that of a published study showing that the vegetation in the center of the NWNNR flourished and the growth of wetland plants in areas not covered by water was stressed in the dry season [10].

By combining Landsat data and classification algorithms, changes in the wetland ecosystems of Poyang Lake over the past four decades have been analyzed [13]. Because of the transition from mud flat to wetland plants, the vegetation area in the dry seasons has increased by 620.8 km$^2$ from 2001 to 2013. Meanwhile, more than 30% of the water areas in the NWNNR have been covered by emerged plants from 2003 to 2014 [14]. With the construction of the TGD as the temporal boundary, two significant regimes in the flooding and dry seasons were observed based on the relationships between the water levels and vegetation coverage. A comparison of the spatial and temporal changes of wetland vegetation from 2000 to 2004 was performed based on a combination of MODIS observations and data analysis, and the results revealed that the impoundment of the TGD has led to a significant decrease in water level and reduction of inundation in Poyang Lake [15]. Meanwhile, the total vegetation coverage and plant communities showed significantly increasing trends, with vegetation expanding towards the lake center.

**4. Conclusions**

Remote sensing imagery can be used to distinguish wetland vegetation areas from nonvegetation areas, and it represents an effective method for identifying and assessing vegetation area. The wetland vegetation in the NWNNR in the flooding season has decreased due to the high water level. However, the vegetation coverage has increased around the center of the wetland, and a different vegetation pattern has been observed in the dry season. The regulation by the TGD in the flooding season and dry
season had significant effects on the vegetation distribution characteristics in the NWNNR, and it has increased the vegetation area in both periods by regulating the high water level and changing the distribution area and characteristics of the wetland vegetation in the dry season.

Acknowledgments
This study was supported by Jiangxi Provincial Water Resources Department (KT201638); Jiangxi Provincial Technology Department (20142BAB213024; 20171ACB21050; 20182BCB22013) and National Natural Science Foundation of China (51579127; 51769015).

Reference
[1] Mcinnes R J, Everard M 2017 Rapid Assessment of Wetland Ecosystem Services (RAWES): an example from Colombo, Sri Lanka *Ecosystem Services* **25** 89-105
[2] Wondie A 2018 Ecological conditions and ecosystem services of wetlands in the Lake Tana Area, Ethiopia *Ecohydrology & Hydrobiology* **18**(2) 231-244
[3] Highfield W E, Brody S D, Shepard C 2018 The effects of estuarine wetlands on flood losses associated with storm surge *Ocean & Coastal Management* **157** 50-55
[4] Gao C Y, Zhang S Q, Liu H X, Cong J X, Li Y H, Wang G P 2018 The impacts of land reclamation on the accumulation of key elements in wetland ecosystems in the Sanjiang Plain, Northeast China *Environmental Pollution* **237** 487-498
[5] Orimoloye I R, Kalumba A M, Mazinyo S P, Nel W 2018 Geospatial analysis of wetland dynamics: wetland depletion and biodiversity conservation of Isimangaliso Wetland, South Africa *Journal of King Saud University – Science*
[6] Yao J, Zhang Q, Ye X C, Zhang D, Bai P 2018 Quantifying the impact of bathymetric changes on the hydrological regimes in a large floodplain lake: Poyang Lake *Journal of Hydrology* **561** 711-723
[7] Han X X, Feng L, Hu C M, Chen X L 2018 Wetland changes of China's largest freshwater lake and their linkage with the Three Gorges Dam *Remote Sensing of Environment* **204** 799-811
[8] Pang G J, Wang X J, Yang M X 2016 Using the NDVI to identify variations in, and responses of, vegetation to climate change on the Tibetan Plateau from 1982 to 2012 *Quaternary International* **444** 87-96
[9] Zhang J P, Zhang L B, Xu C, Liu W L, Qi Y, Wo X 2014 Vegetation variation of mid-subtropical forest based on MODIS NDVI data - a case study of Jinggangshan City, Jiangxi Province *Acta Ecologica Sinica* **34**(1) 7-12
[10] Feng L, Han X X, Hu C M, Chen X L 2016 Four decades of wetland changes of the largest freshwater lake in China: possible linkage to the Three Gorges Dam? *Remote Sensing of Environment* **176** 43-55
[11] Zhang P Y, Zou Y, Xie Y H, Zhang H, Liu X K, Gao D L, Yi F Y 2018 Shifts in distribution of herbivorous geese relative to hydrological variation in East Dongting Lake wetland, China *Science of the Total Environment* **636** 30-38
[12] Feng L, Hu C.M, Chen X L, Zhao X 2013 Dramatic inundation changes of China's two largest freshwater lakes linked to the Three Gorges Dam *Environmental Science & Technology* **47**(17) 9628-9634
[13] Yao J, Zhang Q, Ye X C, Zhang D, Bai P 2018 Quantifying the impact of bathymetric changes on the hydrological regimes in a large floodplain lake: Poyang Lake *Journal of Hydrology* **561** 711-723
[14] An Y, Gao Y, Tong S Z 2018 Emergence and growth performance of bolboschoenus planiculmis, varied in response to water level and soil planting depth: implications for wetland restoration using tuber transplantation *Aquatic Botany* **148** 10-14
[15] Pang G J, Wang X J, Yang M X 2016 Using the NDVI to identify variations in, and responses of, vegetation to climate change on the Tibetan Plateau from 1982 to 2012 *Quaternary International* **444** 87-96