

Influence analysis of artificial ecological water transport on the spatiotemporal variations in vegetation in Qingtu Lake

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Abstract. As an ecological barrier between the Badain Jaran Desert and Tengger Desert, Qingtu Lake plays an important role in maintaining the local ecological environment. Since 2010, annual artificial water transport to Qingtu Lake has caused changes in local vegetation communities, which is of great ecological significance for promoting regional vegetation restoration. In this study, Landsat satellite remote sensing images from 2010 to 2017 were used to compare the water surface area, vegetation coverage, and spatial patterns of *Phragmites australis* communities before and after ecological water transport. The results showed that the water surface area increased rapidly until 2016, and the growth rate of the last two years decreased. There was a slight increase in total regional vegetation coverage, which mainly occurred in the water area due to the substantial growth in *P. australis*. Therefore, artificial ecological water transport promoted the growth in vegetation around the lake, especially the aquatic vegetation, such as *P. australis*. However, the original desert vegetation in the study area may have been reduced due to submergence.

1. Introduction

Qingtu Lake, at the end of the Shiyang River, is located between the Tengger Desert and Badain Jaran Desert in Gansu Province. Since the 1950s, due to the increasing amount of agricultural irrigation in the upstream area, the inflow volume and lake area have continuously decreased. By 1959, the lake had completely dried up; most parts of it have been covered by quicksand or reclaimed, and only a few salinas and swampy grasslands, such as Dongping Lake, Yema Lake, Yelvhu Lake, Xixiao Pond, and Dongxiao Pond, remain [1]. Because of its unique geographical location, the original lake area and its surrounding regions contain typical desert vegetation. These plants play an important role in windbreak and sand fixation in arid regions, thereby making Qingtu Lake a significant ecological barrier between the two deserts [2]. To strengthen its ecological role, the local government decided to transfer ecological water to Qingtu Lake annually beginning in September 2010 [3]. The artificial ecological water transport is of great significance to the restoration of the local ecological environment by preventing the degradation of the local vegetation population, delaying the joining of the two deserts, and promoting local environmental management.

Therefore, it is very important to understand the temporal and spatial trends in regional vegetation during the ecological water transport. Chen *et al* [4] analyzed changes in the spatial distribution of two



different kinds of typical vegetation, namely *Phragmites australis* and *Nitraria tangutorum*, before and after the ecological water transport to Qingtu Lake. Their results showed that the water transport promoted the growth in wetland plants and led to the degradation of desert vegetation. Meanwhile, Dong *et al* [5] showed that the ecological water transport played a positive role in promoting the growth in regional vegetation, as the species richness increased from 9 to 14; it also accelerated the change and succession in the vegetation population structure. Moreover, they proposed that the water supply raised the local groundwater level, and that there was a significant difference in species diversity within 500m away from the water.

The aims of our study are presented in two aspects. First, we used remote sensing data from 2010 to 2017 to extract and count the Normalized Difference Vegetation Index (NDVI) of all vegetation in the study area in order to determine the variation in temporal and spatial vegetation patterns during this period. Second, an improved classification method was used to further improve the classification accuracy. Therefore, the annual change in water surface area after the ecological water transport and the variation in spatial distribution of *P. australis* communities were obtained. The results of our study provide strong scientific evidence for a comprehensive and systematic assessment of the impact of the ecological water transport on the local environment.

2. Study area

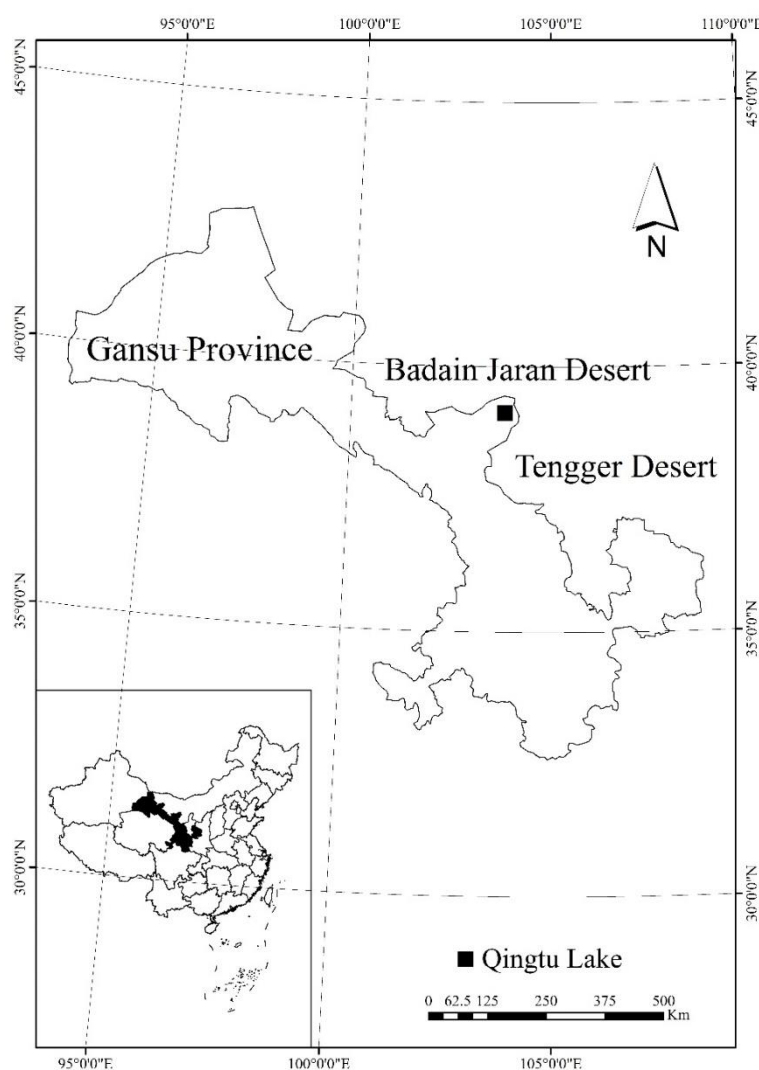


Figure 1. The location of Qingtu Lake.

Qingtu Lake is located in the northwestern edge of the Tengger Desert and in the southeastern edge of the Badain Jaran Desert. Its geographical location is 39°04'-39°10'N and 103°35'-103°38'E, and the regional altitude is approximately 1292-1310 m (figure 1). It is in a region with a temperate continental arid desert climate, where the annual average temperature is 7.8°C. This region has an average of 89.8 mm of precipitation and 2640 mm of evaporation annually and 73% of the precipitation occurs between July and September [6]. The annual frost-free period in this region is 168 days. In this region, the zonal soil is gray-brown desert soil and the intra-zonal soil is meadow-boggy soil and aeolian sandy soil [5]. The regional vegetation types are typical of desert vegetation; *N. tangutorum* communities are continuously distributed over a large area, and *P. australis* is occasionally observed. The associated shrubs are *Lycium ruthenicum*, *Kalidium foliatum*, and *Artemisia desertorum*.

3. Research data and processing methodologies

3.1. Data source and pre-processing

Remote sensing images from different years were used for comparative analysis, namely June 2010, June 2011, June 2012, June 2013, July 2014, August 2015, June 2016, and June 2017. All images were selected from the U.S. Landsat 7 satellite. The orbit of this satellite is synchronized with the sun, and it re-images the Earth every 18 days [7]. With Enhanced Thematic Mapper sensors, we were able to provide panchromatic and multispectral images at 15 m and 30 m resolutions, respectively.

First, we pre-processed the images with ENVI 5.3, which included destriped Thematic Mapper data, geometric correction, radiometric calibration, layer stacking, atmospheric correction, image fusion, and cropping. The geometric correction adopted a base map that was corrected from other periods, and the image was corrected by selecting ground control points on the corrected map. Next, we used the Landsat calibration module to read the correlation parameters for radiometric calibration by referring to the MTL information of the header file. Atmospheric correction was conducted using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes atmospheric correction module based on the Moderate Resolution Atmospheric Transmission model, which is equipped with the ENVI software. For the image fusion, an algorithm based on the Gram-Schmidt transformation process was used. Finally, the pre-processed remote sensing image was cropped to obtain a 655×752 pixel image with 15 m resolution, which covered an area of 110.83 km².

3.2. Methodologies

3.2.1. Normalized Difference Vegetation Index. NDVI is used to detect vegetation growth state and vegetation coverage and eliminate partial radiation errors [8]. Although it is not a direct measurement of biomass or primary productivity, because of its strong correlation with biomass, it can better reflect the coverage and yield of vegetation; it has also been widely used in the fields of vegetation estimation and biomass monitoring [9,10]. In addition, as the NDVI data are based on remote sensing technology, the data of each space point have temporal consistency and high comparability. Therefore, analysis of the spatiotemporal change in NDVI can effectively reflect the temporal and spatial variation in terrestrial biomass. In this study, the spatial distribution of vegetation was calculated using the NDVI module in ENVI 5.3, and the Mann-Kendall (MK) test was used to test the change in its trend.

3.2.2. Improved classification method. Although the original supervised classification method [11] can identify the main feature categories and guarantee them with a certain degree of accuracy, it still has some defects. Due to the complexity of object features, numerous phenomena of different spectra with the same object and different objects with the same spectrum exist. It is difficult to select a sufficient number of representative samples to reflect the spectral features of ground objects accurately. Therefore, Liu *et al* [12] presented an improved classification method that combined supervised classification and unsupervised classification methods. This method not only overcomes the

restrictions of the supervised classification method, but also improves the speed and accuracy of classification. Further details on its procedures can be found in the relevant cited literature [12]. However, due to data limitations and the resolution of remote sensing images in this study, the interpretation of the water surface had some deviations, namely, some objects with similar color in the desert area far from the water were classified as water surface. Therefore, we may consider addressing these issues in future research.

3.2.3. Precision evaluation after classification. After the classification, the results were evaluated by establishing a confusion matrix in ENVI 5.3. It can be seen from the results of the precision evaluation that the improved classification method obtained adequate results and ensured the accuracy of the data (table 1).

Table 1. Precision evaluation statistic of the improved classification method.

Year	Overall Accuracy (%)	Kappa coefficient
2010	99.53	0.7977
2011	99.32	0.9859
2012	98.18	0.8960
2013	97.92	0.9409
2014	99.47	0.9901
2015	99.52	0.9898
2016	99.86	0.9955
2017	99.13	0.9862

4. Results and discussion

4.1. Change in water surface area of Qingtu Lake

Schematic diagrams of the interannual variation in the water surface area are presented in figure 2. The ecological water transport started in September 2010, and the water surface area in the first year was 0. According to statistics, the water surface area in 2011 was 0.74 km². Since then, the water surface area has increased rapidly. Compared with 2011, the area increased by 3.14 km² in 2012, 5.46 km² in 2013, 9.44 km² in 2014, 13.91 km² in 2015, 18.35 km² in 2016, and 18.5 km² in 2017. Therefore, after the rapid growth during the first six years, the water surface area growth slowed after 2016. By 2017, the area reached its maximum of, approximately 19.24 km², which was 26 times that of 2011. It could be inferred that the water surface area will be in a relatively stable state of fluctuation in the future.

In addition, the water surface area may be affected not only by water inflow, but also by the local sandy soil and the time of water retention. As the water transport proceeds, soil water content in Qingtu Lake and its surrounding areas will increase significantly; thus, the regional groundwater would be replenished and its level would gradually rise. Moreover, during the infiltration, the spatial movement and distribution of soil water and salt would be disturbed in a short time, which may lead to a short-term shift in plant community composition and structure [13,14]. Therefore, the formation of the water surface would greatly change the local ecological environment.

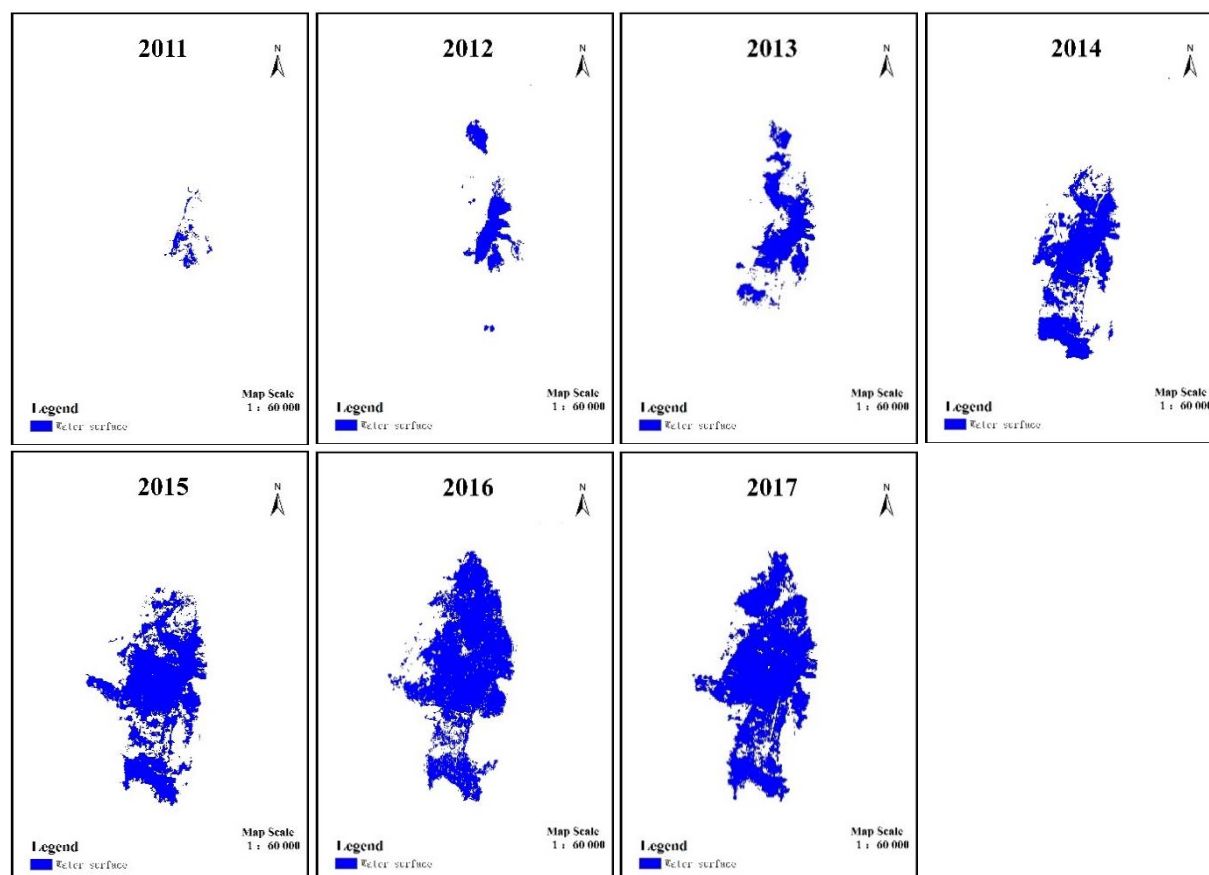


Figure 2. Variation in water surface area of Qingtu Lake from 2011 to 2017. Data were processed through an improved classification method using ENVI 5.3 software. Note that the water surface has increased significantly since the ecological water transport in 2010, especially in the first six years. The area also reached its maximum in 2017, about 19.24 km², which was 26 times that of 2011.

4.2. Change in vegetation in Qingtu Lake

4.2.1. Spatiotemporal variations in vegetation coverage in Qingtu Lake. The variation in regional NDVI during the period from 2010 to 2017 is shown in figure 3. The trend line indicates that the regional vegetation coverage had an increasing trend during the study period. Additionally, the standardized MK statistic Z was 2.10, which passed the significance test of 95% confidence. The NDVI were between 0.0759-0.1238, with an average of 0.0965. The variation in vegetation coverage in Qingtu Lake had staged characteristics. From 2010-2013, there was a slight downward fluctuation in vegetation coverage, but overall, it was stable with an average value of 0.0775, which was lower than the multi-year mean value. From 2013 to 2015, the vegetation coverage increased sharply. By 2015, the NDVI increased to 0.1199. For the last three years, it had another relatively stable period. The NDVI showed a modest increase and the growth rate decreased. In general, the overall increase in vegetation coverage was modest, and there was moderate interannual fluctuation. Hence, the overall vegetation coverage was steady and increasing. The vegetation coverage across the lake and the surrounding areas (figure 4) has gradually increased since 2013. In addition, as we expected, vegetation was mainly concentrated around the lake. From the observed vegetation patterns and water regimes, it can be inferred that water transport likely promoted the growth in vegetation in the region. However, only the vegetation on the surface increased. As the water surface forms, more aquatic and wetland vegetation may grow in the water and in its surroundings, thereby replacing the existing xerophytic vegetation [5,15].

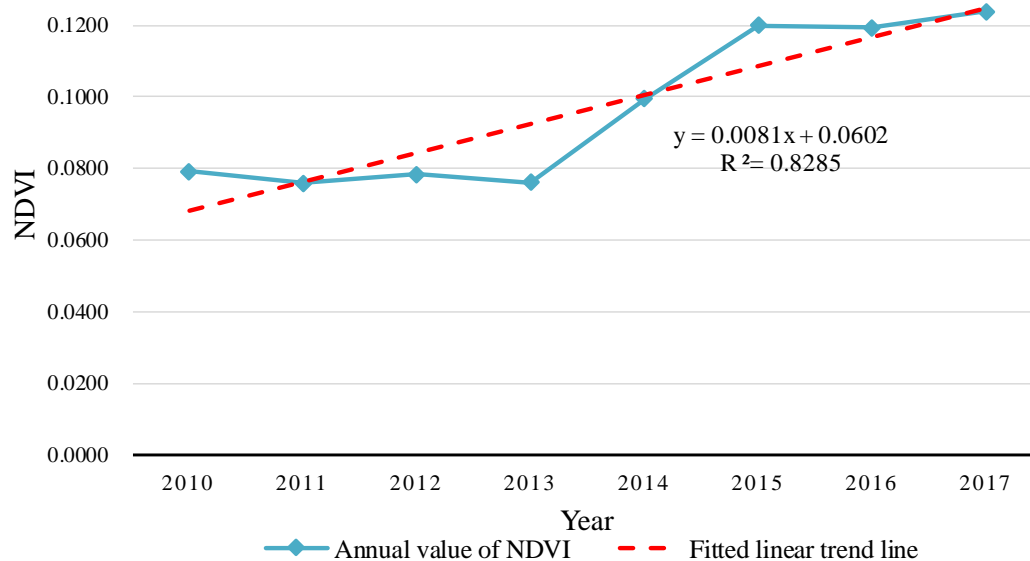


Figure 3. Trend in vegetation coverage change in Qingtu Lake from 2010 to 2017. Note that the regional vegetation coverage increased slightly with a moderate interannual fluctuation during the study period. The general trend is steady and increasing.

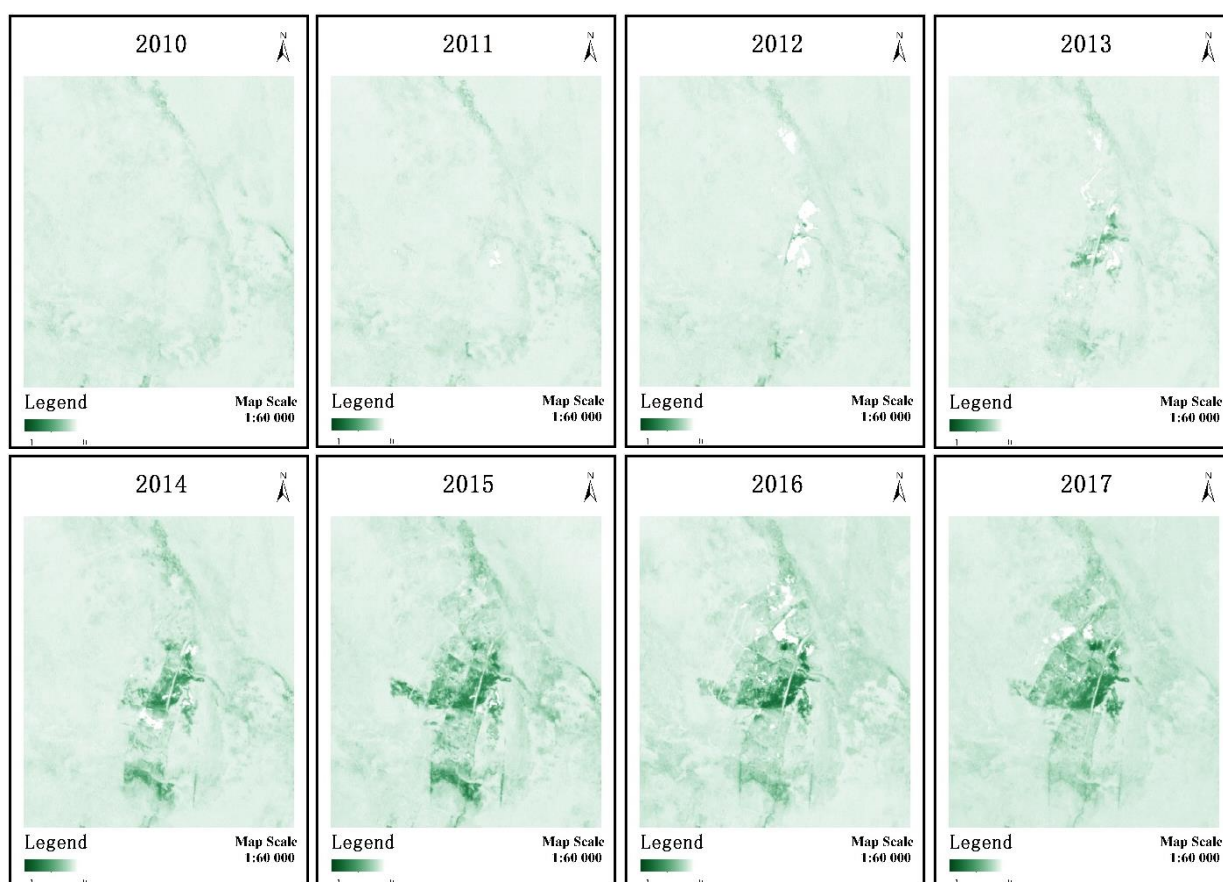


Figure 4. The change in NDVI (scale from 0 to 1) from 2010 to 2017. Note that the vegetation coverage in the study area has increased steadily since 2013. Moreover, vegetation was mainly distributed around the lake.

4.2.2. Spatiotemporal variations in *P. australis* communities in Qingtu Lake. Before the ecological water transport began, most of the *P. australis* communities were distributed sporadically in the study area, except in the south-eastern regions (figure 5). Since the implementation of water transport, there has been a significant change in its biomass and spatial distribution. In 2011, the distribution of *P. australis* communities expanded, and they were partially distributed around the water body. In the following year, they invaded along the south side of the lake. By 2013, with the increase in water surface area, *P. australis* communities were mainly distributed on the shore and surrounding the water area. Their distribution further expanded in the northern area. For the next four years, with the continuous transport of water in each year, *P. australis* communities near the water gradually increased.

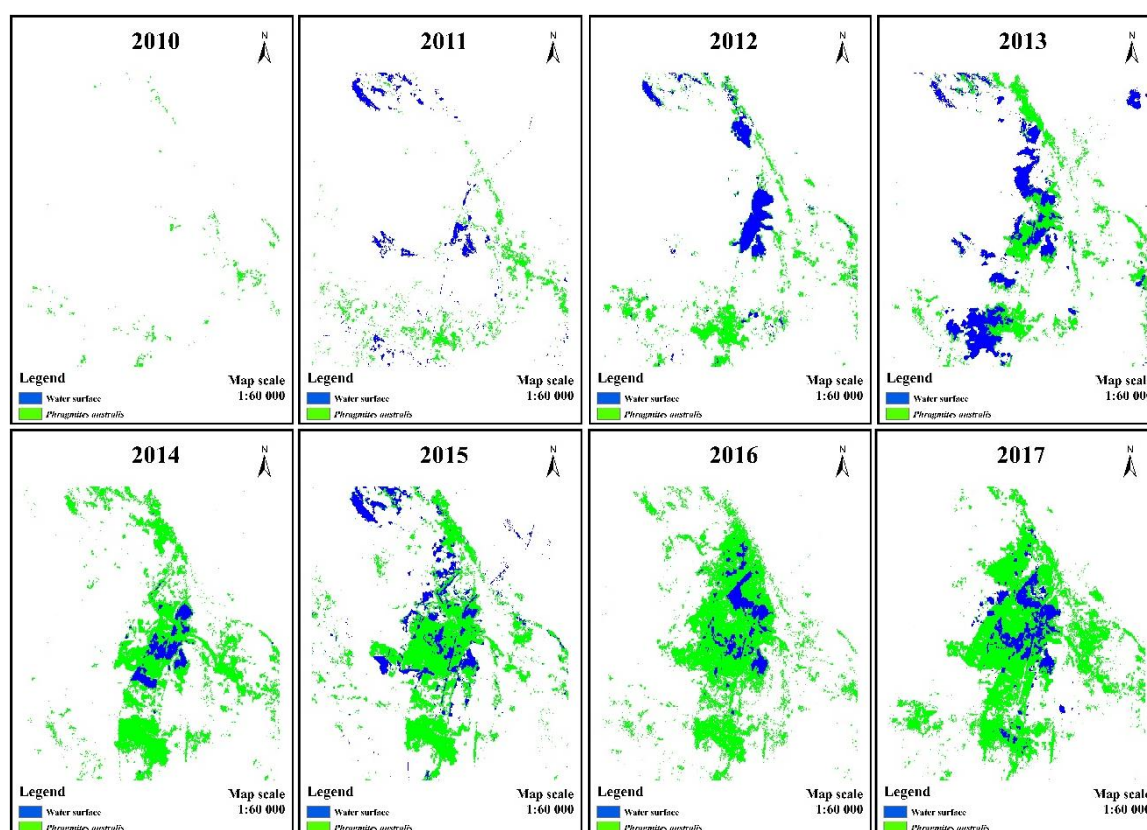


Figure 5. Variation in *Phragmites australis* distribution in Qingtu Lake from 2010 to 2017. The data were processed through an improved classification method using ENVI 5.3 software. There was a significant increase in *P. australis* quantity after the ecological water transport began. In addition, the *P. australis* community expanded along the water surface, and most of them were distributed on the shore and surrounding the water body.

The annual changes in distribution patterns of *P. australis* and ecological water transport showed that variations in *P. australis* distribution were closely related to the changes in the water surface (figure 6). Ecological water transport clearly promoted the *P. australis* communities by increasing the water regime. Compared with the situation before the water transport, the area of *P. australis* increased by four times in 2011. With the expansion of the water surface, the quantity of *P. australis* has increased over the years. By 2017, the area increased to 20.89 km², which was the largest since the water transport began; the area increased by 25 times since 2010.

Our results showed that the overall increase in vegetation coverage was modest, while the area of *P. australis* increased significantly after the water transport began. Therefore, ecological water transport

has promoted growth in local vegetation, especially aquatic vegetation, but it may indirectly lead to the reduction in some desert vegetation in the study area. On the other hand, the growth and decline in some plant populations were not only due to the changes in water surface, but also due to groundwater depth in the region [16,17]. Ecological water transport could replenish the groundwater, and infiltration processes could change the amount of water and salt in the soil. For instance, an increase in water transport could decrease the salinity of the soil, which might have a negative effect on desert vegetation, such as *N. tangutorum* [5]. Thus, it may expedite the succession process in the local environment [15].

Hence, in a future study, we will focus on the effect of water transport on the regional groundwater level, as well as the dynamic relationship between groundwater level and vegetation coverage in this region.

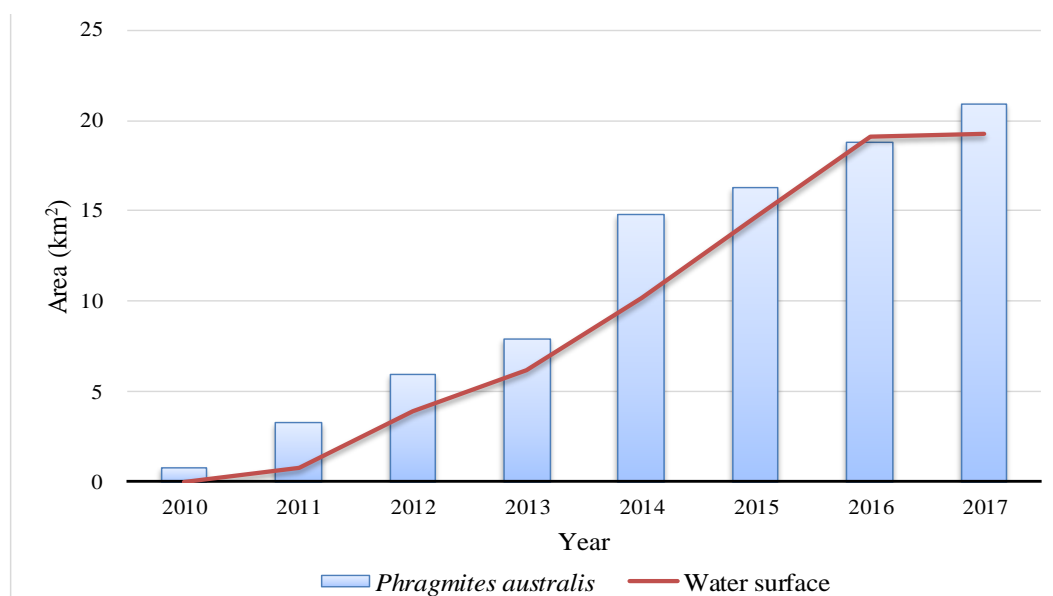


Figure 6. Changes in the area of *Phragmites australis* and the water surface from 2010 to 2017.

5. Conclusion

With the beginning of the annual ecological water transport in September 2010, Qingtu Lake was restored, and its surface area has increased over the years. However, the growth rate has decreased in the last two years. Meanwhile, the vegetation coverage has increased slightly during this period, and vegetation has been distributed more around the lake since 2013. The area of *P. australis* communities increased by 25 times, and its change was closely related to the distribution of the water surface. Overall, it can be concluded that the artificial ecological water transport appears to be beneficial to the restoration of the local ecological environment.

Acknowledgments

This research is supported financially by the National Key R & D Program of China, No. 2017YFC0406100, the National Natural Science Foundation Projects of China, No. 41401011 and No. 41401010, and the Program for Changjiang Scholars and Innovative Research Team in University, No. IRT-17R35.

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