Response of Vegetation Restoration to Water Resources Transfer Policy in Arid Watersheds, Northwestern China

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Abstract. Minqin Oasis is the irrigation area in the lower reaches of the Shiyang River in the Hexi Corridor. Since the beginning of this century, in order to prevent Minqin Oasis from further degrading due to lack of water, Gansu Province began to construct water transfer projection. In order to study the impact of water resources allocation policy on the ecological restoration of such ecologically fragile areas, this study took Minqin Oasis as the research object, and took Shuangta Irrigation area, which is in the Shule River Basin and similar to Minqin Oasis except for water transfer policy, as the contrast. Based on EOS MODIS NDVI data and runoff data from hydrological station, combined with remote sensing and GIS technology, using spatial analysis and regression analysis and other research methods, this paper analyzed the spatial and temporal characteristics of vegetation changes in the study area from 2000 to 2016, and the response of vegetation changes to water resources changes. The analysis results showed that, the water transfer policy increased the water resource of Minqin Oasis, and the dynamic change of vegetation in Minqin Oasis had a good response to the water transfer policy.

1. Introduction
Since the 1990s, LUCC (land use and land cover change) has become a major cause and an important component of global change, and has become a hot topic of research. Among them, the arid/semi-arid ecologically fragile areas formed due to water shortages have attracted the attention of researchers, and vegetation cover in these areas plays an important role in maintaining ecosystem stability, especially for oasis ecosystems [1].

Monitoring the temporal and spatial variation of vegetation cover and studying the underlying causes are critical for ecosystem management and desertification process assessment in arid environments. A common method of monitoring changes in vegetation cover at a regional scale is to use satellite-derived vegetation indices. The most widely used vegetation index is the Normalized Vegetation Index (NDVI), in addition to other vegetation indices such as Enhanced Vegetation Index (EVI) [2] and Leaf Area Index (LAI) [3-4]. In contrast, EVI is more suitable for areas with dense vegetation and NDVI is more suitable when vegetation is sparse [5]. It is well known that vegetation cover is related to moisture. The amount and intensity of precipitation can affect vegetation coverage by affecting soil moisture, thus affecting the onset and duration of vegetation growth in arid and semi-arid ecosystems, and the response of different types of vegetation to precipitation is different [6-8]. In addition to precipitation, human activities can also have an impact on water resources, such as the Central Valley Project in California [9], and the Tarim River Ecological Water Transfer Project in Northwest China [10].

As a country with extremely uneven water resources distribution, Chinese government has made great efforts in cross-basin water transfer projects. The South-to-North Water Transfer Project, which...
optimizes China's water resources allocation pattern, is still in the research stage to solve the problem of water shortage in the northwest [11]. China's northwest arid regions are characterized by vast deserts and fragile ecology. The Hexi Corridor is an important geographical hub in the northwestern region. There are three inland rivers of Heihe, Shi yang and Shule Rivers. The dozens of oases are the most developed areas of industrial and agricultural economy in Gansu Province and even in the northwest region [12]. Minqin Oasis in the lower reaches of the Shi yang River is one of them. However, since the 1950s, under the dual influence of climate change and human activities, the water resource of the Shi yang River has been decreasing [13-14]. In order to prevent the deterioration of the ecological environment of Minqin Oasis, the Minqin Water Transfer Project began to transfer water to Minqin in 2001.

Previous studies have monitored the ecological status of Minqin Oasis after water transfer. However, artificial oases with similar conditions but not affected by water transfer have not been used as controls. Taking Minqin Oasis as the research object, the cross-basin comparison study was carried out with the Shuangta Irrigation area in the lower reaches of the Shule River as a control. The purpose of this study is to analyze the response of vegetation changes in Minqin Oasis to water transfer policy from 2000 to 2016 through quantitative comparison, and to clarify the ecological effects brought about by the policy of water transfer. This study can be used as a reference for ecological restoration in Northwestern China.

2. Material and Methods

2.1. Study Area

![Minqin Oasis and Shuangta Irrigation area](image)

Figure 1. Location of Study Area in Northwestern China

This study took the Minqin Oasis as the research object, and compared it to the Shuangta Irrigation area; the latter was similar to the Minqin Oasis except for the water transfer policy. Minqin Oasis is
located in the eastern section of the Hexi Corridor (Figure 1), and the Shiyang River is the only surface runoff of it. Minqin Oasis is surrounded by the vast desert, the Gobi and the low mountains, and its central part is low-lying. Shuangta Irrigation area is located in the western section of the Hexi Corridor (Figure 1). Shule River is the surface runoff. Its terrain is relatively flat and slightly inclined from east to southwest. Both Minqin Oasis and Shuangta Irrigation area have a continental climate with drought and little rain, and the evaporation is much larger than the precipitation. The light is sufficient, the frost-free period is long, and it is especially suitable for crop growth. The grain crops are mainly wheat and corn, the economic crops are cotton, oil, melon and vegetables.

2.2. Data
The NDVI data reflecting dynamic changes of vegetation coverage came from MODIS Terra's MOD13Q1 Vegetation Index product with a spatial resolution of 250m and a time resolution of 16d, which was available from the website of NASA LAADS DAAC. MRT (MODIS Reprojection Tool) was used to perform a series of processing such as projection conversion, resampling and data format conversion. ArcGIS 10.2 was also used in processing.

The tiles where Minqin Oasis and Shuangta Irrigation area located are h26v05 and h25v04. The time series of data was 113th–305th day of the year from 2000 to 2016, with a total of 13 issues per year. In Hexi Corridor, the vegetation growth period was from May to October every year.

The monthly runoff data of the two hydrological station was provided by the Gansu Provincial Water Affairs Bureau.

2.3. Methods
2.3.1. Characterizing Vegetation Dynamics with NDVI
The MVC means each pixel value in the image is replaced by the maximum value of the 13-period image in each growth period. This method can effectively reduce the interference of clouds, aerosols, shadows and water vapor, making the research results more accurate.

Both the NDVI maximum and the NDVI average during the growth period could be used to characterize the vegetation coverage. However, the average weakened the degree of vegetation change, while the maximum could be used to characterize the optimal vegetation growth. Therefore, this study chose to use NDVI maximum during the growth period to characterize the vegetation coverage of a certain year rather than NDVI average.

Besides, in order to study the spatial change of vegetation, study area should be classified according to the NDVI. Combine both the existing research and the actual situation of vegetation growth in the study area, the result of classification criteria was shown in Table 1.

| Vegetation coverage area | Non-vegetated vegetation coverage (N1) | Low density vegetation coverage (N2) | Medium density vegetation coverage (N3) | High density vegetation coverage (N4) |
|--------------------------|---------------------------------------|-------------------------------------|----------------------------------------|-------------------------------------|
| NDVI                     | <0.1                                  | 0.1-0.3                             | 0.3-0.6                                | >0.6                                |

2.3.2. Response of Vegetation Changes to Changes in Water Resource
The method to study the response of vegetation change to water resource change is to perform regression analysis. Regression analysis is a statistical method that examines the quantitative relationship between two or more variables. The expression is:

$$Y_i = a + bX_i + \varepsilon$$

(1)

Where a, b are unknown constants; \(\varepsilon\) is a random error; \(X_i\) is an independent variable; \(Y_i\) is a dependent variable.

This study took Eviews 10 software as a tool to perform regression analysis of vegetation changes and water resources changes.
3. Results and Discussions

3.1. Vegetation Dynamics in the Study Area from 2000 to 2016

The NDVI maximum changes during a single growth period were shown in Figure 2(a). It showed that the NDVI maximum of both had a single peak characteristic. In contrast, between the 113th and the 177th days, Minqin Oasis is higher than Shuangta Irrigation area. The changes in the inter-annual time series were shown in Figure 2(b). As can be seen from the figure, the NDVI of these two areas both had upward trends. Besides, Minqin Oasis had a more stable upward trend than Shuangta Irrigation area.

![NDVI in a year](image1)

(a) NDVI in a year

![NDVI in 2000-2016](image2)

(b) NDVI in 2000-2016

Figure 2. Spatial Change of Vegetation in Shuangta Irrigation Area and Minqin Oasis

Dynamic changes in vegetation included not only changes in time series, but also spatial changes. The vegetation coverage of the study area in 2000-2016 was shown in Figure 3.

The ratio of the various vegetation coverage areas in Shuangta Irrigation area and Minqin Oasis were shown in Figure 4. The figure showed that the area ratio of N1 and N2 in Shuangta Irrigation area decreased steadily from 2000 to 2016, and the area ratio of N3 and N4 increased overall; While in Minqin Oasis, the area ratio of N1 and N3 decreased, N2 and N4 showed an upward trend.
Figure 3. Spatial changes of vegetation in Shuangta Irrigation Area and Minqin Oasis in 2000-2016

Figure 4. Area Ratio of each Vegetation Coverage Area in Shuangta Irrigation Area and Minqin Oasis in 2000-2016
3.2. Changes in Water Resources in the Study Area from 2000 to 2016
This study used the hydrological station runoff data to characterize the water resource in study area. These two hydrological stations were the Caiqi Hydrological Station of Minqin Oasis and the Shuangtaipu Hydrological Station of the Shuangta Irrigation area. Both of them were located upstream of the corresponding regional rivers, so they could reflect their respective water resources. The average runoff during the growth period and annual average runoff from 2000 to 2016 were shown in Figure 5. As we could see, although the water resources in the Shuangta Irrigation area were more abundant than Minqin Oasis, the increase of water resources in Minqin Oasis was more obvious and more stable. Besides, in Minqin Oasis, the gap between the average runoff during the growth period and the annual average runoff began to increase significantly in 2009. It was the direct impact of the water transfer policy in Minqin.

![Figure 5. Runoff Data from the two Hydrological Stations in 2000-2016, including Average Runoff during Growth Period and Annual Average Runoff](image)

3.3. Relationship between Dynamic Vegetation Changes and Water Resources Changes
The vegetation changes and the water resource changes were shown in Figure 6.

![Figure 6. Runoff Data and NDVI of Shuangta Irrigation Area and Minqin Oasis in 2000-2016](image)

The NDVI was taken as the dependent variable, and the runoff data from hydrological stations were independent variables for regression analysis. A two-year lag analysis was added to make the analysis more reasonable. The results were shown in Table 2. Shuangta Irrigation area were almost
inconsistent, while Minqin Oasis showed a good consistency, and the consistency of Lag 0 was the best, which meant the vegetation change in the Shuangta Irrigation area had no response to the change of runoff, while the vegetation change of Minqin Oasis had a good response to the change of runoff.

**Table 2. Regression Analysis Results of NDVI Maximum and River Runoff of Study Area**

| Independent variables | Lag 0                      | Lag 1                      | Lag 2                      |
|-----------------------|---------------------------|---------------------------|---------------------------|
|                       | Y=2.09E-05X+0.82   29 | Y=-0.0009X+0.83  75 | Y=0.0005X+0.81  8168 |
| Shuangta Irrigation area | R²=0.0000  P=0.9899 | R²=0.0155  P=0.6464 | R²=0.0067  P=0.7716 |
| Average runoff during growth period |                       |                           |                           |
| Annual average runoff | Y=0.0012X+0.8  095 | Y=-0.0002X+0.82  64 | Y=0.0020X+0.81  8029 |
|                       | R²=0.0108  P=0.6909 | R²=0.0003  P=0.9465 | R²=0.0257  P=0.5680 |
| Minqin Oasis | Y=0.0045X+0.7  824 | Y=0.0037X+0.795  2 | Y=0.0030X+0.8064 |
| Average runoff during growth period |                       |                           |                           |
| Annual average runoff | Y=0.0083X+0.7  678 | Y=0.0068X+0.783  0 | Y=0.0055X+0.7973 |
|                       | R²=0.5286  P=0.0009 | R²=0.3885  P=0.0099 | R²=0.4290  P=0.0080 |
|                       | Y=0.0040X+0.7  540 | R²=0.3927  P=0.0094 | R²=0.4057  P=0.0107 |

Then explore the relationship between the area ratio of various vegetation coverage areas and runoff data (Fig 7). The area ratio of vegetation coverage area in the study area was taken as the dependent variable, and the runoff data was taken as the independent variable for regression analysis. The results were shown in Table 3. It could be seen from the table that in Minqin Oasis, the area ratio of N1 and N3 were negatively correlated with runoff data, and the area ratio of N2 and N4 were positively correlated with runoff data. In contrast, the area ratio of various vegetation cover areas in Shuangta Irrigation area was nearly inconsistent with the change of runoff data.
Table 3. Regression Analysis Results of Ratio of each Vegetation Coverage Area and Runoff Data

|                | N1                  | N2                  | N3                  | N4                  |
|----------------|---------------------|---------------------|---------------------|---------------------|
| Shuangta       |                     |                     |                     |                     |
| Irrigation area| Average runoff      | Y=-0.0055X+0.4752   | Y=-0.0006X+0.2372   | Y=0.0036X+0.125    | Y=0.0025X+0.1751   |
|                | R²=0.1181           | R²=0.0190           | R²=0.1718           | R²=0.01760          |
|                | P=0.1768            | P=0.5979            | P=0.0981            | P=0.6117            |
|                | Annual average runoff| Y=-0.0141X+0.5458   | Y=-0.0020X+0.254     | Y=0.0077X+0.0834    | Y=0.0084X+0.1204   |
|                | R²=0.2295           | R²=0.0678           | R²=0.2349           | R²=0.0589           |
|                | P=0.0517            | P=0.3126            | P=0.0486            | P=0.3478            |
| Minqin         | Average runoff      | Y=-0.0073X+0.194    | Y=0.0080X+0.0469    | Y=-0.0053X+0.3395   | Y=0.0046X+0.1143   |
| Oasis          | R²=0.4018           | R²=0.5832           | R²=0.5324           | R²=0.2189           |
|                | P=0.0063            | P=0.0004            | P=0.0009            | P=0.0583            |
|                | Annual average runoff| Y=-0.0133X+0.2211   | Y=0.0144X+0.237     | Y=-0.0096X+0.356    | Y=0.0086X+0.0986   |
|                | R²=0.3975           | R²=0.5617           | R²=0.5352           | R²=0.2309           |
|                | P=0.0067            | P=0.0005            | P=0.0008            | P=0.0509            |

(a) Shuangta Irrigation area (b) Minqin Oasis

Figure 7. Runoff Data and Area Ratio of each Vegetation Cover Area of Shuangta Irrigation Area and Minqin Oasis in 2000-2016

4. Conclusions
The regression analysis results showed that the change of NDVI maximum in Minqin Oasis had a good response to the water transfer policy. First of all, on account to the water transfer policy, the water resources of Minqin Oasis had increased significantly. As a comparison, the water resource of Shuangta Irrigation area was relatively stable, fluctuating around a certain value. Amount of studies had shown that water was one of the most important factors for vegetation growth in arid environments, especially for natural vegetation. However, most of these studies were self-comparisons
of the study areas, few studies had conducted cross-regional comparisons. Cross-regional comparisons can rule out the interference of many external factors due to the similarity of conditions, which is the innovation of this paper.

There are still some places in this study that are worth refining and in-depth research. Since the MODIS data starts from 2000, if the relevant images before 2000 can be obtained, the results will be more persuasive. Besides, although the vegetation in Minqin Oasis and Shuangta Irrigation area are mainly crops, there are still natural vegetation. The growth law of natural vegetation is different from that of crops. It will make the results of this study more accurate if we can distinguish them in the further study.

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