Evaluation of impacts of ecological water conveyances on hydrological processes and land cover in Tarim River basin, China using groundwater levels and MODIS vegetation indices

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ABSTRACT

Lower reaches of Tarim River, Western China is a very serious arid and desertification region. During 2000-2006, 2.36 billion cubic meters water has been transported to this area by nine terms to control regional desertification. We apply grey correlation analysis for temporal and spatial variations of groundwater levels from nine monitoring sections and corresponding MODIS vegetation indices (VI) in the third, fourth, and seventh terms of water conveyance to evaluate the impacts of ecological water conveyances on basin hydrological processes and land cover. During the terms of water conveyance, both groundwater level and VI along the canal are rising and a calculated grey incidence degree reaches 0.9. However, the increases of groundwater levels and VI gradually reduce from the source of water input in the direction of the canal and calculated grey incidence degrees were below the level of significance for a single term of water conveyance. At same time, the incidence degrees reduced significantly with increasing distances from the canal. The analysis results shows that spatial variations of changes of hydrological processes and land cover conditions caused by water input were very large, which may reduce the use efficiency of precious water resource in this region.

Key words: Water Conveyance, Groundwater Level, Vegetation index, MODIS, Tarim River

1. INTRODUCTION

The natural vegetation of arid areas, the significant part of the ecosystem, is extremely meaningful in restraining desertification process and protecting biodiversity. As the key environment factor of arid areas, water is not only the basis of the oasis ecosystem component, progress and the stabilization, but also dominating the process of the arid areas oasis and desertification, which are the extremely opposite and conflicting evolvement of zoology process(Chen,2004). Therefore, the growth situation of the plants in arid areas affecting the change of the groundwater levels attracts more and more people’s attention. The study about the lower reaches of Tarim River shows that, the constant drop of the groundwater levels and the severe lost of soil moisture are the dominating factors of the vegetation degeneration(Chen, 2003) . When the groundwater in the best ecology water level, the vegetation grow well; and when the groundwater under the zoology alert level, the life of the vegetation is obviously restricted, most of them decline or die. Thus, further study of the relationship between the plant growing and the groundwater level, is not only the basis in natural ecosystem continuable maintenance, but also offering the scientific basis of recovering the declining ecosystem. Consequently, it will provide decision-making support of carrying out Sustainable development among economy, society and ecosystem in our arid areas.

Nowadays, most researches (Chen, 2006; Chris, 2006; Deng, 2005; Heike,2000; Li, 2001; Wooldridge, 2001; Vicente, 2005) of the relationship between the plant growth situation and the groundwater level in the arid areas focused on observation points, lacking of quantitative analysis in large scale with long timing sequence. In this study, we choose lower reaches of Tarim River as the study target, which based on the groundwater level fluctuation during the third, the fourth and the seventh ecological water conveyances and the corresponding VI data of timing sequence statistics. Using Grey Correlation Analysis method, from different special and temporal aspects, we carry out quantitative analysis on water conveyance effects in lower reaches of Tarim River.

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2. AREA AND DATA

2.1 Study Area

The study area is in the southeast of Tarim basin, located on the alluvial lake plaint of Lower reaches of Tarim River and Qarqan. The exact location is: Taklamakan Desert on the west, Kuloke Desert on the east, Daxihaizi Reservoir No.2 sluice on the north, Taitema Lake of Tarim trail on the south and the geographic coordinate is 39^o 30'～40^o 35'N, 87^o 33'～88^o 28'E (Figure 1). The elevation of the area is 800~850m with the northwest of the land being higher than the southeast in the main, but the fluctuation of the land is not obvious. It is one of the most arid areas in China, and the average annual precipitation is only 17.4～42.0 mm, but annual potential evaporation rate is up to 2500-3000 mm. The weather is dry with so much wind and sand. In the history, the Tarim River was famous for its natural oasis landscape and the important transport position, called "Green Corridor". In the past decades, there were many environmental problems, such as decrease of water amount flow into the lower reaches, decline of groundwater level, canal drying, plain declining, Tugai forests dying, disastrous weather increasing, desertification getting worse, and ecological environment worsening(Gao,2000) . Since 1972, the lower reaches of Tarim River of 300 km length had been under zero flow for about three decades and the Taitema Lake has been already drought up for 30 years. The State Council decided to carry out a general project to deal with the Tarim River ecological problem in the near future. Since April, 2000, there were eight terms imperative transporting water to the lower reaches which was under zero flow condition by the local government in order to recharge shallow ground water beside the canal through infiltration, improve environment of natural plant growth, save the dying vegetation, and promote the ecological protect in the lower reaches (Chen, 2003). Table 1 shows that transfer periods, amounts of and distances of water transferred of ecological water conveyances in lower reaches of Tarim River from 2000 to 2006.

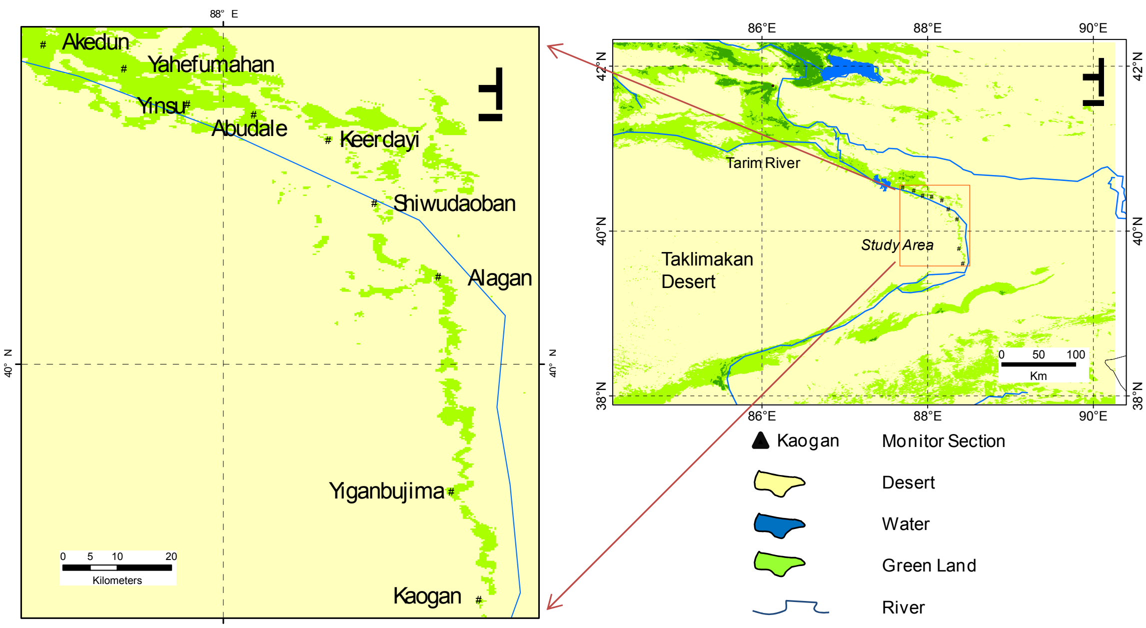

Figure 1. Location of the study areas and monitor points (sections) of groundwater levels. The Green land and desert area were classificated using MODIS NDVI data in 2001.

2.2 Data

The study adopts MODIS daily surface albedo data supplied by LPDAAC, to do some image mosaics, then to reproject, finally get the longitude and latitude unified projective image (GEOGRAPH IC).Then we use equation (1) to calculate the NDVI index as the basic experimental data. Because the limitation of the MODIS data spatial resolution is too little (250m), it isn’t able to satisfy the research of the relationship between the vegetation index beside the canal and the ground water. Therefore, the images in the research area are carried out bi-cubic convolution interpolation, receiving the images with the resolution of 100m and doing further analysis based on them. The surveyed data of the groundwater

Table 1. Transfer periods, amounts of and distances of water transferred of ecological water conveyances in lower reaches of Tarim River from 2000 to 2006

Conveyance Terms	Transfer Period	Amount of water Transferred (10^8 m^3)	Total Distance of Water Transferred (km)
First	May 14 - Jul 12, 2000	1.00	102
Second	Nov 3, 2000 - Feb 5, 2001	2.27	216
Third	Apr 1 - Nov 18, 2001	3.82	360
Fourth	Jul 20 - Nov 10, 2002	3.30	360
Fifth	Mar 2 - Nov 3, 2003	6.23	360
Sixth	Apr - Nov, 2004	2.77	360
Seventh	Apr - Nov, 2005	2.50	150
Eighth	Sep - Nov 21, 2006	2.33	360

were supplied by Xinjiang Institute of Ecology and Geography of the Chinese Academy of Sciences (CAS) with observational wells monitoring data. Nine groundwater level monitoring sections along the lower reaches of Tarim River apeaking the canal were set. Downwards the Daxihaizi Reservoir, there are Akedun, Yahefumahan, Yinsu, Abudale, Keerdayi, Shiwudaoban, Alagan, Yiganbujima and Kaogan (Figure 1). The sections distance of the first six is about 20 km, and that of the later three is 45 km. On each section, with the alternation of 100m or 200m, thirty-nine observational wells were set, and with continuous water con for the lower reaches and the raise of groundwater level, the vegetation effective area is extending.

2.3 Method

2.3.1 Calculation of MODIS-NDVI normalized difference vegetation index

Because images of MODIS band 1 and band 2 have the narrower spectral range, different from the absorption band of water vapor of the near-infrared band of MODIS, the infrared range is more sensitive to the sparse vegetation. Therefore, it is more suitable for surface vegetation correlation analysis in arid area. The calculation of MODIS-NDVI use band 1 (0.620～0.670 μm) and band 2 (0.841～0.876 μm) with a resolution of 250 m (NASA, 1999).

$$NDVI = \frac{B_{nir} - B_{red}}{B_{nir} + B_{red}} \qquad (1)$$

B_{nir} is the reflection value of near-infrared channel, corresponding band 2 of MODIS, B_{red} is the reflection value of infrared channel, corresponding band 1 of MODIS.

2.3.2 The calculation of NDVI Variety Ratio

In order to macroscopically analyze the variety ratio of vegetation growth in the lower reaches of Tarim River after ecological water conveyance, intuitively show the variety trend of vegetation growth situation in the lower reaches of Tarim River after ecological water conveyance, we need to calculate NDVI Variation in each interval between water conveyances.

$$V_k = \frac{\overline{NDVI_{i+1}} - \overline{NDVI_i}}{NDVI_i} \times 100\% \qquad (2)$$

Where, i (value ranges 1 to 3) present the three term of water conveyance (third, fourth and seventh); $\overline{NDVI_i}$ is average value of NDVI.

2.3.3 The analysis of coefficient of variation

The natural phenomena, e.g. vegetation growth trend and distribution of groundwater level, are spatial distribution variables, and their variety degree may be regarded as a definite scale community consisted of structural effect caused by natural factor and random effect caused by its perturb. Variation variogram may describe randomicity and structural attribute of regionalized variables in the same time. It also analyze the regionalized variables exactly in mathematics. Therefore, it is an effective implement in spatial coefficient ratio analysis and spatial structure analysis. Its mathematical expression is shown as following:

$$V(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z(x_i)-Z(x_{i+h})\right]^2 \qquad (3)$$

Where, Z(X) is the value of variable Z in spatial position, N (h) is the total number of sample pairs in the distance of h.

Because the lower reaches of Tarim River locates on the connection of the two big deserts, the main effect factor of the vegetation growth is the water level of the canal. To analyze transversal NDVI of the canal may reflect the effect of the vegetation along the river caused by water conveyance, and we may appraise the effect of the water conveyance.

2.3.4 Grey Correlation Analysis

Grey Correlation Analysis is a popular analysis way in correlation degree at present, which uses the similitude or dissimilitude of the factors progress trend, called "Grey Correlation Degree", to measure factors' correlation degree. Comparing with the traditional multiple factor analysis way, such as correlation and regress, Grey Correlation Analysis may be used while the size of samples is small and its calculation demands less resource. It supplies the quantitative measurement in a system variety trend as well as dynamic course analysis.

(1) Calculation of Reference Sequence and Comparative Sequence

Reference Sequence is calculated using equation (4).

$$X_0^{(0)}=\left\{X_0^{(0)}(t)\middle| t=1,2,\cdots,N\right\} \qquad (4)$$

Where, $X_0(t)$ is reference factor sequence and presents time-series data of groundwater level in this study.

Comparative Sequence is calculated using equation (5).

$$X_i^{(0)}=\left\{X_i^{(0)}(t)\middle| t=1,2,\cdots,N\right\} \quad i=1,2,\cdots M \qquad (5)$$

Where, $X_i(t)$ is reference factor sequence and presents time-series data of NDVI in this study.

(2) Data Initialization

In order to clear up the differences between dimension and order of magnitude of reference sequence and comparative sequence, and in the same time decrease the errors of the index caused by dimensionless solution, two types of data needs initialization by calculating difference sequence (absolute difference of index) between $X_0^{(0)}$ and $X_i^{(0)}$ using equation (6).

$$\Delta_i(t)=\left|X_0(t)-X_i(t)\right| \qquad (6)$$

Where, the maximum value and the minimum value at $\Delta_i(t)$ are the max-absolute difference and the min-absolute difference (the first class max-difference and the first class min-difference), and are presented using $\max\Delta_i(t)$ and $\min\Delta_i(t)$, t=1,2,...,n.

(3) Calculate the Coefficient of Correlation.

The coefficient of correlation of X_0 and X_i is and $\xi_i(t)$ and is calculated using equation (7)

$$\xi_i(t)=\frac{\min\Delta_i(t)+\rho\max\Delta_i(t)}{\Delta_i(t)+\rho\max\Delta_i(t)} \qquad (7)$$

Where, ρ (resolution ratio) equals to 0.5.

(4) Calculation of Correlation Degree

The correlation degree of $X_0^{(0)}$ and $X_i^{(0)}$ is γ_i and is calculated using equation (8).

$$\gamma_i = \frac{1}{n}\sum_{t=1}^{n}\xi_i(t) \qquad (8)$$

3. RESULT AND DISCUSSION

3.1 The Integral Vegetation Situation Analysis of the Lower Reaches

(1) The NDVI variety ratio analysis

By calculating average value of NDVI of the third, fourth and the seventh water conveyance, and analyzing the variety ratio of each water conveyance, we find the NDVI value' variety trend in different water conveyance processes in the lower reaches of Tarim River.

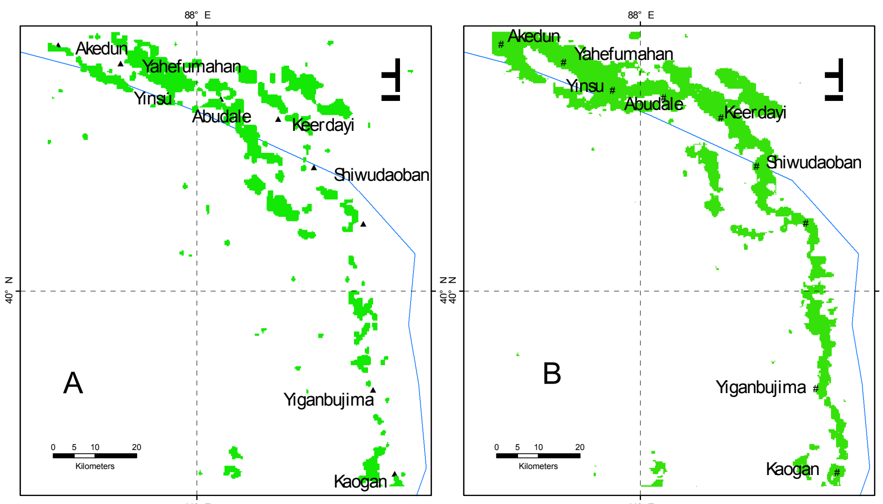

Figure 2. Areas of VI Increase (NDVI Variety Ratio > 0) caused by water conveyances. A: Increase between the third and the fourth conveyance, B: Increase between the third and the Seventh conveyance

The Figure 2 shows the variety ratio result of NDVI value of the third, fourth and the seventh water conveyance. We may see that the sections from Akedun to Kaogan, with the increase terms of the water conveyance, there is more and more effect to the vegetation recovery caused by water conveyance along the middle-line of the canal. And the positive variation range of NDVI gradually decreases in the long and wide directions with the distance increasing along the canal. The effect for the vegetation recovery of third and the fourth water conveyance processes in the lower reaches of Tarim River is more obvious. Along the canal, the NDVI's positive variation shows connective and disconnective spots, and is much lower, much obvious. From the third to the seventh water conveyance processes, the NDVI's variation is more connective, and becomes sheet state.

(2) The variogram of variation analysis

Because of the limitation of the condition and the law, the distribution of the vegetation has not only the spatial distribution law, but also has the part variation, showing the random variety character. In order to do some quantitative research on the range that ecological water conveyance affects the vegetation recovery, we set up the variogram of variation on each water conveyance' average NDVI value along one side of Yinsu, Alagan and Kulgan with the distance of 5km.Aiming at the first five ecological water conveyances, some researches show that the effect range to the vegetation in arid area which caused by local water conveyance is up to 0.8-1 km (Chen, 2004; Deng,2000, Qu, 2005). So it is thought that the variogram of variation curve may reflect the effect in spatial variation caused by the water conveyance to the vegetation in the lower reaches in the range of 0～2 km. The result is shown as the following No.3 image.

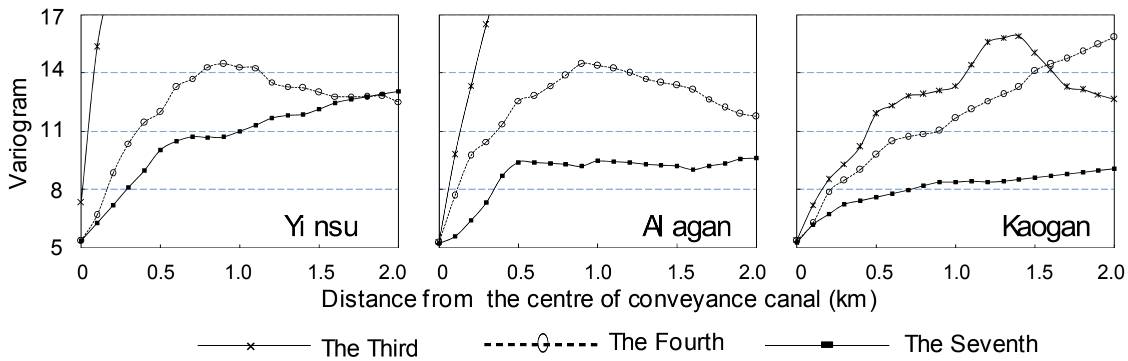

Fig. 3 Variogram graph for third, fourth and seventh water conveyance at three section

We find that most time of the three section's variogram of variation images take on wave phenomenon. This shows that NDVI spatial heterogeneity along the canal is the result of several different scale factor collective actions. From the image, Yinsu's NDVI variogram of variation image has the obvious transition phenomenon in the water conveyance process: there are obvious sill and range. But Alagan and Kulgan has the obvious transition phenomenon after the water conveyance process. It shows that the vegetation in the front part of the lower reaches has a certain scale, but the rest one does not, even there may not take on structure of NDVI in 2km. Calculate NDVI variogram of variation range of Yinsu and Alagan' water conveyance With the spherical model, getting the third, fourth and seventh range of Yinsu which are 0.43, 0.51, 0.75 km, and the fourth and seventh of Alagan are 0.49, 0.68km..Thses show that with the water conveyance project, water conveyance's effect to the front and middle of the lower reaches will be extending in the transversal orientation. We also work out the seventh variogram of variation range of Kulgan, and it is 0.41km. It means that it also affects the last part of the lower reaches, but it is a little.

3.2 The effect of the groundwater variation caused by NDVI

The NDVI variation and variogram of variation analysis tell us that the water conveyances of the lower reaches of Tarim River take the positive effect on the water level raise. The natural vegetation's form, distribution and growth trend have the close relationship with underground moisture. So it is a significant science problem to analyze the relationship between the vegetation of the lower reaches of Tarim River and the groundwater dynamic variation from the quantitative aspect. Therefore we use Grey Correlation Analysis to analyze. During the calculation, because of some related research, the water conveyance condition in the lower reaches and the groundwater level raise have the different lag-phenomena with the vegetation growth situation (Sheng, 2007; Maihemuti Balati, 2005). So in order to get the exact relationship between them, we choose the 16-day later monitoring data of the groundwater.

Table 2. The relation between NDVI and groundwater level in selected sections

Section	YINSU	ALAGAN	KAOGAN
Distance from water source (km)	54	188	310
Grey Incidence Degree			
Third water transport	0.943	0.924	0.874
Fifth water transport	0.955	0.937	0.911
Seventh water transport	0.958	0.942	0.921

The result of Grey Correlation Analysis tells us that along canal in lengthways in each water conveyance process, Grey Correlation Degree all take up decreased trend. To each section, with the increase of the water conveyance terms, groundwater grey correlation degree shows a little increase, but it tend to be stable, especially the Yinsu section which is near to the water conveyance head, and its difference of the third water conveyance process is less and less.

Table 3. The relation between NDVI and groundwater level in selected wells

Section	Yinsu				Alagan			Kaogan		
Monitoring cell	C2	C3	C5	C7	G2	G3	G4	I1	I2	I3
Distance from the canal (m)	50	150	350	750	50	200	500	100	300	500
Grey Incidence Degree										
Third water transport	0.973	0.957	0.941	0.911	0.946	0.925	0.885	0.904	0.873	0.817
Fifth water transport	0.978	0.963	0.954	0.929	0.951	0.937	0.909	0.931	0.917	0.838
Seventh water transport	0.981	0.968	0.951	0.941	0.960	0.944	0.923	0.947	0.935	0.881

To the section of Yinsu, NDVI of each observational wells and the Grey Correlation Degree of every water conveyance are extremely correlative, and all their value are more than 0.9.This means water conveyance has extreme effect on the vegetation of the Yinsu section. From the table we also may see with the distance increasing between the observational wells and the middle of the river, the correlation degree has a little decreasing trend. This means in one water conveyance the ecological water conveyance's effects to the groundwater level is decreasing with the distance of the river center increasing. But with the increasing of the conveyance terms the effect range is extending, and directly taking up on the vegetation.

To the Alagan section, it has the some variety trend with Yinsu, but with the water conveyance terms increasing, its G4 observational wells' result shows us that the ecological water conveyance's effect to the groundwater level is more obvious, and more intensity to the vegetation. It mainly shows on that the variety degree of the water conveyance Grey Correlation Degree is more than the same on the Yinsu section.

To the Kaogan section, its I3 observational wells' Grey Correlation Degree in water conveyance is less than 0.9. It means that ecological water conveyance's effect to the groundwater level outside 500m is faint.

As a whole, through the correlation between NDVI and the groundwater level is intense with the water conveyance terms increasing, the ecological water conveyance's effects to the vegetation is decreasing with the distance of the observational wells to the river center increasing. This means that the ecological water conveyance's effect to the groundwater level of the lower reaches of the Tarim River has a certain range limitation. The ecological recovery in a large range is still a constant research work.

4. CONCLUSIONS

The paper take the lower reaches of Tarim River as a example, based on the time-series of the third and fifth ecological water conveyance, using variogram of variation analysis and Grey Correlation analysis to find out ecological water conveyance's effect range and related character to the groundwater level and the vegetation recovery of the lower reaches of Tarim River. The main results are as followings:

(1) NDVI spatial variety is the result that the ecological water conveyance affects the spatial variation of groundwater level and the vegetation. The analysis shows us that the natural vegetation after ecological water conveyance's effect and the groundwater’s raise have the positive correlation. And with the constantly carrying out the project of the lower reaches of Tarim River and the time went by, the effect range of the vegetation is extending, and the intensity is increasing. It shows as: the correlation between NDVI and the groundwater level is intense with the water conveyance terms increasing, and the range is extending. The ecological water conveyance is significant to the vegetation recovery and ecological protection.

(2)From the variogram of variation and Grey Correlation analysis of ecological water conveyance effect to the vegetation, we may see that: in the transversal direction, the ecological water conveyance effect to the vegetation is decreasing and the correlation between the NDVI and the groundwater level is decreasing with the distance to the canal increasing; in lengthways, from Yinsu section (C), the front of the lower reaches, to Kaogan section, the last part of the lower reaches, the range of the vegetation effect is smaller and smaller, the response delaying.

(3)Analyzing the response of the natural vegetation during the water conveyance, we find that the vegetation response is always linear along the canal. Ending with the seventh water conveyance, the effect range of vegetation of front, middle and last part of the lower reaches of Tarim River are 0.75km, 0.68km and 0.41km. This kind of linear water conveyance along the natural canal has limited in a certain spatial range in affecting the vegetation in lower reaches of Tarim River. It is a long distance to protect the "Green Corridor" and catch the target of carrying out Sustainable development in local ecology progress. This means how to make the advanced use of the ecological water conveyance, carrying out ecology recovery in a large range is a constant research work.

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