Retrieving groundwater depth in the Lower Reaches of Tarim River by NDVI

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ABSTRACT

The changes of the coverage of vegetation and groundwater depth during the period of ecological construction and environmental protection are the most important two indicators of the level of success in ecological water transportation project in lower reaches of Tarim River.In this study, a new way to predict the groundwater depth in the arid regions has been presented. The spatial and temporal change of vegetation states in lower reaches of Tarim River under the ecological water transpiration have been discussed by using NDVI data derived from SPOT VEGETATION (VGT) NDVI S10 time sequence image data for the year 1999, 2003 and 2006. It is found that the groundwater depth played a dominant role in determining vegetation growth status in the lower reaches of the Tarim River. After the ecological water transportation, the vegetation has been restored in both sides of the watercourse stretching to Taitema Lake, which extend to 3 km in Akedun section, but decline along the stream flow as 1km in Kaogan section. However the area, which is 3km to 15km away from watercourse, has not been influenced obviously. And the area far away (excess 15km) has no influence. Statistic analysis shows that the groundwater depth has negative relationship with NDVI. And the groundwater depth in lower reaches of Tarim River has been successfully inversed through the statistic method; the simulation precision is 75%.
Keywords: ecological water transport, the lower reaches of Tarim River, NDVI, groundwater depth

1 INTRODUCTION

Tarim River, located in the center of Tarim Basin is the longest inland rivers in China. The green corridor on the downstream of the Tarim River plays an important role in the development of the local society and economy. Due to excessive human exploitation of natural resources and low efficiency of water use, many environmental problems such as drought of river, decline of the groundwater level and deterioration of ecological environment etc. have been appeared at the lower reaches of the Tarim River. In order to restore the "Green Corridor" and protect the environment in the downstream, the emergency ecological water transport project in the lower reaches of the Tarim River has been carried out since June 12, 2000. The water flowed into Taitema Lake, tail section of the Tarim River, on November 2, 2001.Taitema Lake, which has been extinct nearly 30 years, was restored with water. Some researches concerning the ecological environment and the change of groundwater level have been presented, as in references 1–15. However, all of these studies are using the traditional methods such as groundwater monitoring ,which is a time-consuming and hard job needing a large number of manual labors and a lot of money in a small spatial scale. With the advent of satellite remote sensing, it has become possible to detecting the groundwater variation both in spatial and temporal scale. The NDVI derived from the visible and near-infrared reflectance has widely applied to the diversity of plant-related environmental studies. This technique not only highlights the vegetated areas of an image but also gives an idea about regarding as to how healthy the plants are. The potential annual evaporation greatly exceeds annual precipitation of about 50mm. So the groundwater, in fact, is the only water resource of natural vegetation, which directly influences the nature vegetation condition. In other words, the nature vegetation growth states can reflect the character of the groundwater level in some extent. Concerning this, we tried to quantify the relationship between the groundwater and NDVI. The main object of this study is to analyze the Spatio-temporal change of vegetation and groundwater after Eco-

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logical water transport to lower reaches of Tarim River and assess the feasibility of using NDVI to retrieve groundwater level in the lower reaches of Tarim River.

2 AREA AND DATA

2.1 Area

The study area is in the southeast of Tarim Basin, which is adjacent to Kuruk Desert in the east and the Taklimakan Desert in the west, reaching the Taitema Lake at the end of Tarim River in the south and Daxihaizi Reservoir in the north, (39°30'-40°35'N, 87°33'-88°28'E). It is one of the driest regions in the western part of China and the terrain inclines from Northwest to Southeast with flat relief where elevation is between 800 to 850m. The annual average precipitation is 17.4-42.0mm. On the contrary the annual average potential evaporation reaches to 2500-3000mm. Because of its dry climate with wind and Sandy, most of the soil is infertile and remarkable saline—alkalization. The vegetation cover is low with meager categories, single plant community composition, high dominance and low diversity. The representative vegetations here are Populus euphratica, Tamarix spp., Halimodendron halodendron, Ahagi pseudoalhagi, Glycyrrhiza uralensis, Apocynum venetum etc. Due to the intensive exploitation of water resources in the upper and middle reaches of Tarim River, its downstream, which extends further down from the Daxihaizi Reservoir, has completely drought up ever since 1970s. And the lower reaches of Tarim River have serious ecological environmental problems, such as the ground-water depth in this area has lowered sharply and the ecosystem is damaged seriously. Subsequently, many plant communities gradually diminish or completely die away.

2.2 Data

1) Multispectral images

The 10-d NDVI composites at a spatial resolution of 1000m are available from the near real time SPOT-VEGETATION (VGT) data (http://free.vgt.vito.be). VGT data includes two visible channels which are blue(B0 ,0.143μ m～0.147μ m),red band(B2 ,0.161μ m～0.168μ m),near-infrared(B3 ,0.178μ m～0.189μ m)and short wave infrared(MIR ,1.158 μ m～1.175μ m). One is based on a revised maximum value compositing (MVC) method with improved removal of clods and aerosol. Averaged NDVI values acquired from the VGT_MVC data were recoded for each vegetation type over the study 10d. The NDVI values were scale between 0 and 255 like DN value. The pre-processing includes noise reduction, radiometric calibration (sensor calibration, atmospheric correction, solar and topographic correction) and geometric correction.

2) Groundwater depth data

Data on the depth of the groundwater in 39 observational wells in 9 monitoring sections have been collected from Xinjiang Institute of Ecology & Geography of the CAS of the year 1999,2003 and 2006. The depths of the wells rang from 10 m to 20 m for the different distance from the watercourse.

The monitoring data of 250m from watercourse in the 9 monitoring sections were chosen for analyzing same recharge distance from the watercourse, however , lacking of data in 250m for 7,8,9 sections, we used the monitoring data in 200m far away from watercourse in 7th section and 300m in 8th and 9th sections instead.(fig.1).

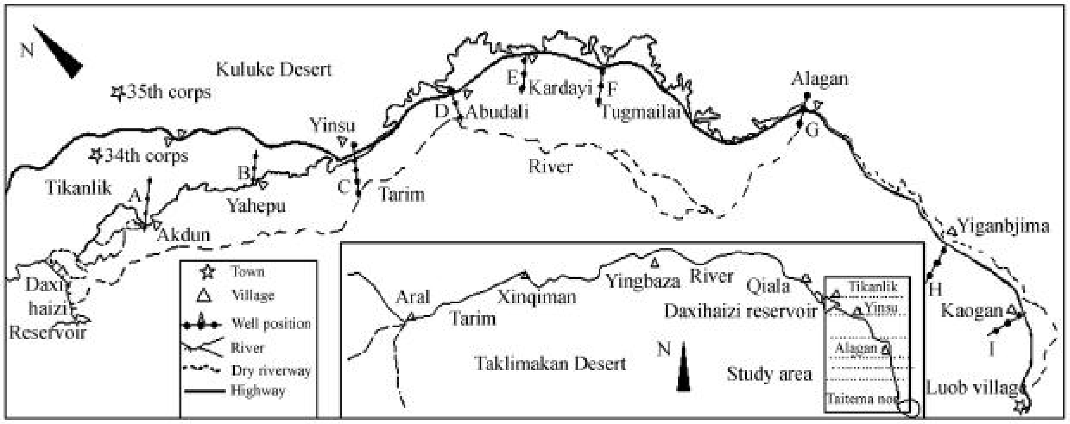

Fig.1 Distribution map of 9 investigation sections in the lower reaches of Tarim River, Xinjiang.

3) Meteorological data

The meteorological data including monthly evaporation as well as average air temperature and precipitation from the weather station named Tekeligan were downloaded from China Meteorological Data Sharing Service System（ http://cdc.cma.gov.cn）.

2.3 Method

Published studies showed that vegetation density responds to the plant water content, and the Normalized Difference Vegetation Index (NDVI) derived from digital satellite data corresponds to the density of green vegetation [16, 17, 18].And vegetation cover of large areas of restoration like that of lower reaches of Tarim river, North-West China will be best estimated using remote sensing technique than point measurements. This study initiated a unique approach to surveying ground water level based on satellite information and monitoring data in extremely arid areas.

The NDVI (Normalized Difference Vegetation Index) is a measure of vegetation vigor and density computed from multispectral data. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation [19]. It is calculated based on band rationing between the near-infrared band and the red band.

$$\mathrm{NDVI} = \frac{NIR - VIS}{NIR + VIS} \tag{1}$$

where NIR is the near infrared spectral measurement and VIS is the visible red spectral measurement. Values for NDVI range from 1.0 to -1.0. Vegetated areas generally yield high values for the NDVI because of their relatively high near-infrared reflectance and low visible reflectance.

This study uses NDVI data derived from SPOT VEGETATION (VGT) NDVI S10 time sequence image data for the year 1999-2006 to analyze the spatial and temporal change of vegetation states in lower reaches of Tarim River before and after the ecological water transpiration. Through the changing rate of NDVI, extracted the range of ecological water transpiration influenced on vegetation. Finally, discusses the relationship between NDVI and the groundwater depth through the static method and then establish a simulating model to retrieve groundwater depth by using NDVI (fig.2).

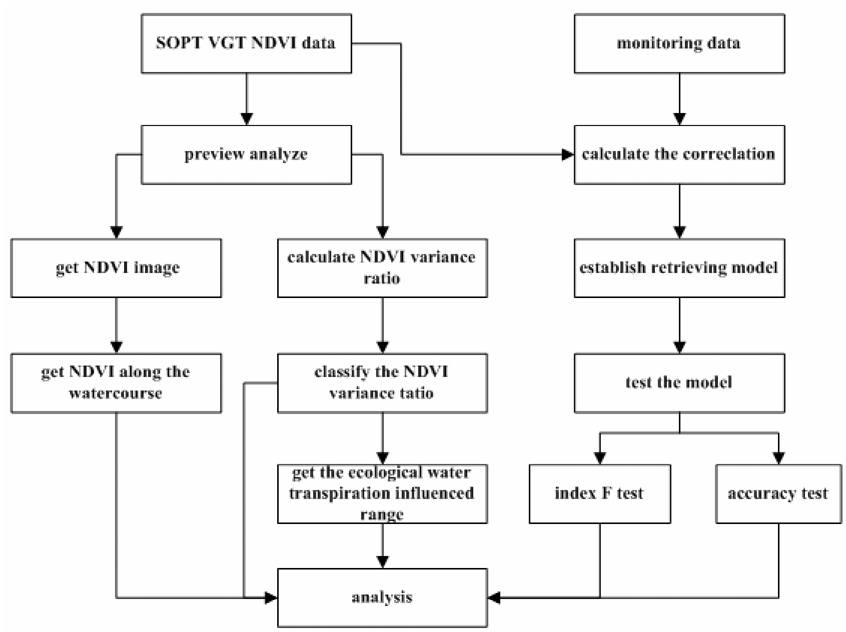

Fig .2 Data disposes flow chart

3 NDVI CHANGE UNDER ECOLOGICAL WATER TRANSPORT

To reduce the influence of NDVI seasonal changes during the study period and reflect more truthfully the influence of the water transport to vegetation states in this area, the average NDVI value and variance ratio were used in this study as the following equations:

$$\overline{NDVI}_i = \frac{1}{N} \cdot \sum_{i=1}^{N} NDVI_{ij} \tag{2}$$

and

$$V_k = \frac{\overline{NDVI}_{i+1} - \overline{NDVI}_i}{NDVI_i} \times 100\% \tag{3}$$

Where $NDVI_i$ is the average NDVI value in the ith year and $NDVI_{ij}$ is the NDVI value in the jth 10-d period of the ith year ;N为12(There are 12 groups of 10-d period from June to September and the period from 1st June to 10th is the first) V_k present the average NDVI Variance Ratio between the year of i and i+1.

We got the NDVI spatial distribution map of year1999, 2003 and 2006 in the vegetation growing density period and extracted the NDVI profile from Akedun section to Kaogan sections along the watercourse.

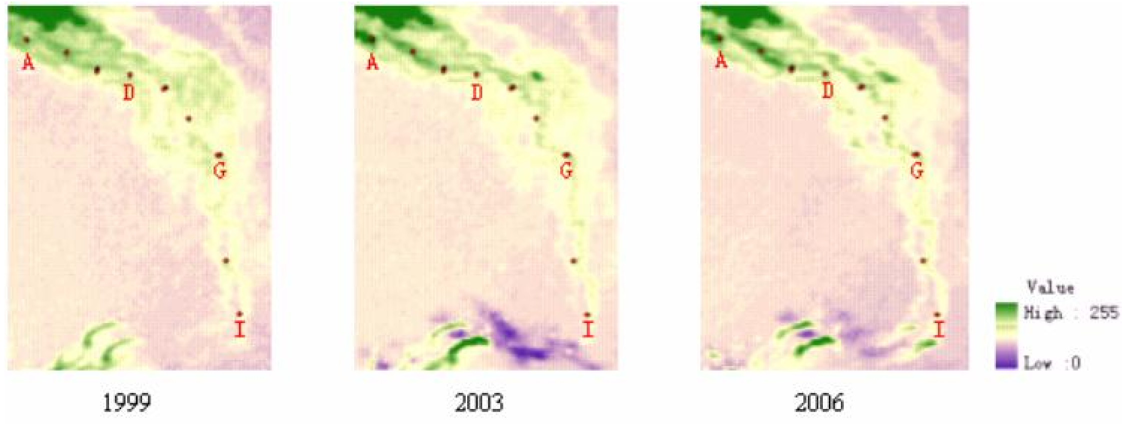

Fig.3 Average NDVI value between 6-9 months of study area

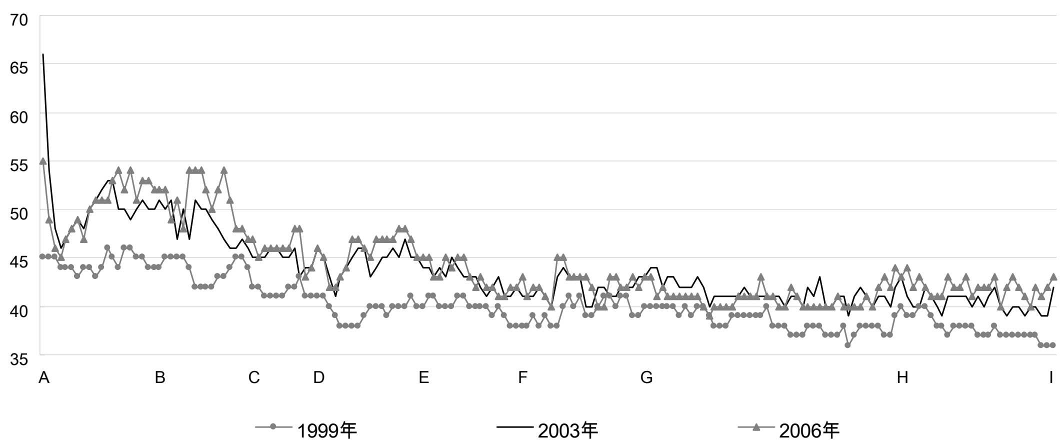

Fig.4 The NDVI profile from Akedun section to Kaogan section along the watercourse

In Fig.3-4,A-I denote the following sections in turn: Akedun, Yahefumahan, Yinsu, Abudale, Keerdayi, Shiwudaoban, Alagan, Yiganbujima and Kaogan

In order to further study the changes in the growth of the vegetation after ecological water transport, we, on the basis of the average value, made the intercomparable variance ratio (Fig.5a) of 2006 and 1999, in accordance with equation(3), and regard the areas with variance ratio over 3 as NDVI positively changing areas, or areas with improving vegetation, while those with under 3 negatively changing areas with deteriorating vegetation, and those between 3 and -3 basically changeless.(Figure 5b)

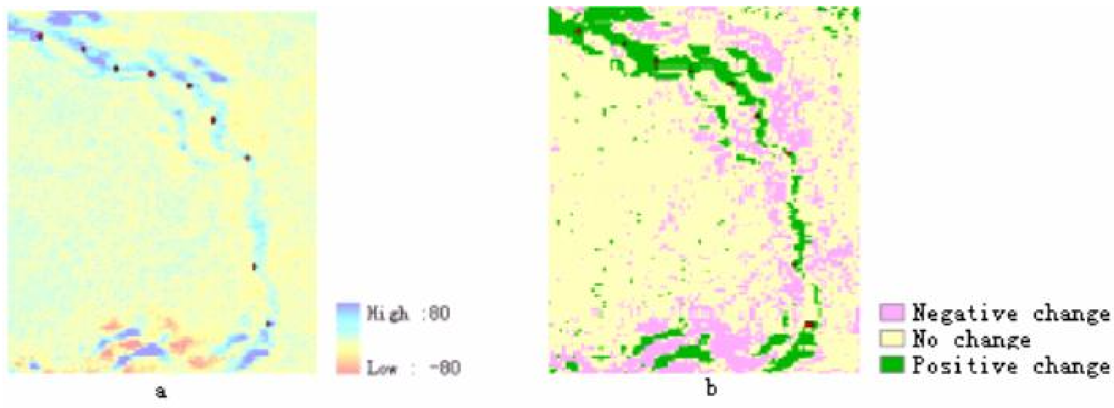

Fig.5 The NDVI Variance Ratio of 2006-1999 and its classification

Analyzing Fig.3-5, the following conclusions can be drawn:
1)Both the average and maximum values of regional NDVI are increasing annually, with the consequent average values of 36.81,37.48 and 38.17, maximum values of 122,142 and 144, indicating that the vegetation along the downstream of Tarim River are recovering yearly.
2)Researching team lead by Xu Hailiang(2003) [2], hold, after ecological water transport, that increase in the elevating speed of groundwater and its band of fluctuation along the watercourse tend to slow down lengthwise and crosswise. This is in conformity with the varying rate of NDVI as demonstrated by Fig.2-4.In addition, we can reasonably conclude, as groundwater supply is exclusively indispensable for the natural vegetation along the downstream of Tarim River and as ,according to studies lead by Gelt(1999) [21], watercourse water plays a significant supplementary role for groundwater , that the varying growth rate of vegetation within the area under research ,in compliance to their distance to the watercourse, is in relation to the ecological groundwater supply.
3)The tendency of ever flourishing vegetation along the watercourse in the 1999-2006 period , is, from a crosswise perspective, presenting itself, which is in conformity with studies by Chen Yaning(2000,2004)[2,14,26] and so forth showing that the influence of ecological water transport for groundwater limits to areas along the river. In analysis of Fig.4, the annual positive varying rate of NDVI in 2006 is higher compared to that in 1999, the areas under the Akedun section are relatively far from the watercourse with more negative changes in particular, in conformity to the rule that vegetation long been short of water supply decline more significantly as the effects of ecological water transport on under water spread and with the passage of time. Areas distant from waterways are deserts with steady NDVI values. According to the classified NDVI varying rate in Fig.4 and the results of Chen Yaning's groups, taking the waterway as the axis, the areas were significantly effected by ecological water transport lying in the 3 km strip alongside the river, where the vegetation have improved to some extent; in the 3-15 km areas, there have not been significant changes in the growth of vegetation as a result of ecological water transport, and the vegetation there keep declining, urging for immediate control; vegetation of desert areas over 15 kilometers from the river remain basically unimproved

4 RETRIEVING GROUNDWATER LEVEL BY USING NDVI

Researches imply that the changing of groundwater is related to the atmospheric conditions (including precipitation, temperature and solar radiation), underlying surface conditions (gradient and length of slopes, soil adoption, water content of vegetation, soil humidity and evaporation) and so on[22,23,24].Research lead by Chen PY(2006) [25] shows that if there is the possibility of proving the tight correlation between NDVI statistics and the groundwater depth, then the potential evapotranspiration, the stream flow and NDVI can be used to simulate groundwater depth, and this was confirmed in Texas.

Calculate the correlation between groundwater depth and NDVI. Under the confidence measure α =0.05, they have better negative relation.

According to the correlation between groundwater depth and NDVI and local conditions of the research area .we select the distance to the water origin, Daxihaizi(D),NDVI, the ratio of the number of the days since the arrival of the river water to the total days(t/T) and the total transfer water amount since the arrival of the river water(Q)(number of transfer water days*daily transfer amount)as independent variable, groundwater depth (W) as dependent variable to establish a regression equation (4).

$$W = 7.279 + 1.723 * (t/T) + 0.012 * D - 0.004 * Q - 0.066 * NDVI \qquad (4)$$

Test the regression equation with the index F, the result is 22.229 far beyond the Critical value under the confidence measure $\alpha = 0.05$.So the equation is significance.

Test the accuracy of simulated model. Except for some singular points (error absolute value over 50 percent), simulation accuracy of models exceeds 75 percent, hence the certain predictability of them. (Fig.6)

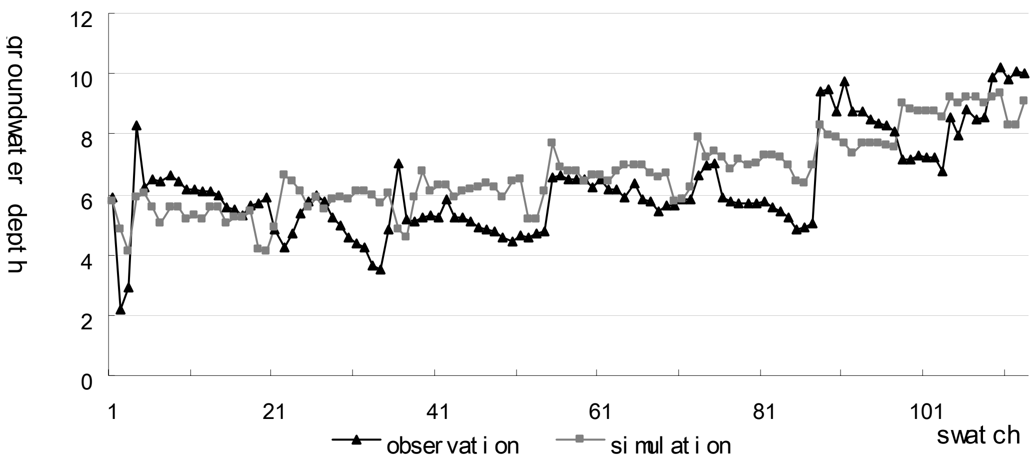

Fig.6 Comparison between observation and simulation of groundwater depth

With the step-by-step conduction of water transportation, factors of groundwater depth and vegetation will on an increasingly complex changing process. Further improvement needs to be accomplished on actual observed statistics in researching area and analysis on relations between all factors. The simulation accuracy is expected to become better through constant modification of the inverse equation.

5 CONCLUSIONS

1) Ecological water transportation in the downstream area of the Tarim River has played a positive role in the ecological recovery. The vegetation alongside the river in this area has been gradually improved since 2000. In the same year, as a result of the lengthened distance from the water origin, groundwater level of monitoring wells descended, with NAVI going down, too. As the water transportation moves on, the gap between ground water level of monitoring wells and NDVI gradually narrowed in this year.

2) Ecological water transportation in the downstream area of the Tarim River has realized the conversion to a better ecological environment. However, the recovery was still limited in a small range. The most influenced area by water transportation ranged from 3 kilometers to less than 1 kilometer along the banks from Akedun section to the Kaogan section; while in the area from 3 Kilometers to 15 kilometers, the influence was not so obvious; beyond 15 kilometers was nearly not influenced.

3) As an efficient and convenient data resource, NDVI extracted from remote sensing images is significant to the monitoring of ecological environment and ground water in arid areas. This paper succeeded in applying NDVI data to

inversion simulation of the data of groundwater depth around the Tarim River. The model shows that groundwater depth is in negative correlation to NDVI, with a stimulation accuracy of 75 percent.

4) Foreseeably the response of vegetation growth to groundwater change will tend to be more complex after the groundwater reaches definite level, using time series remote sensing data to monitor ecological environment has important significance to restoring and rebuilding work after ecological water transport possesses at the lower reaches of Tarim River in future.

5) As the ecological problems in the downstream of the Tarim River are a result of years of time, with its singular vegetation, the impact from distinction of species can by no means be neglected, and the difficulties of recovery increases accordingly. Water transportation is, consequently, still a long-term undertaking. With the step-by-step conduction of the control of the downstream river, this area is expected to be revitalized.

In summary, remote sensing data improves the sparse and insufficient data basis in the study area, and the study result demonstrated the significance of ground-water level to vegetation growth status and ecosystem stability in arid environment and the effectiveness of ecological water transport to ecological construction and environmental protection in the lower reaches of the Tarim River in western China.

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