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THE RESEARCH AND APPLICATION OF REMOTE SENSING MONITORING METHOD OF ACTUAL IRRIGATED AREA

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The value of actual irrigated area is an important indicator of irrigation water management, but due to wide space range of irrigated district, ground manual monitoring is very difficult to achieve. Remote sensing methods have a wide rapid coverage, high efficiency, real-time, objective and other advantages, which can be used to solve the difficulties in monitoring irrigated area. In this paper, a remote sensing monitoring method of irrigated area based on modified perpendicular drought index (MPDI) is researched and the differential thresholds for distinguishing irrigation are analyzed and proposed. The method was applied to 5 rounds of actual irrigated area monitoring in Hetao irrigated district, inner Monglia, China., using the satellite images of HJ1A/1B CCD, China, and verified by ground tests. The results show that the method is of high precision, and can provide help for enhancing the management level of irrigated districts

INTRODUCTION

Irrigated land is widely thought to provide two-fifths of the world's food from less than one-fifth of the total cropped area all over the world. This sector however competes heavily for the already limited water resources in irrigation regions. However, policy makers and water managers are often constrained in this context of increasing complexity by insufficient knowledge of current agricultural water management practices. In the current context of water scarcity, it becomes even more important to exactly compute the water available for irrigation and to estimate the efficiency of water use by quantifying the actual irrigated areas.

Conventional methods of mapping irrigated areas through surveys are time-consuming and tedious. Remote sensing offers a relatively inexpensive and reliable technology to estimate area under irrigation. A number of studies have been conducted using remote sensing to monitor irrigated area. Alexandridis et al[1] investigated the Indus river basin to identify the irrigated areas and assessed the performance of the irrigation systems using NOAA/AVHRR images. Boken et al. [2] demonstrated the potential of NOAA-AVHRR for estimating irrigated areas of three states of the USA. Thenkabail et al. [3] used MODIS time series to generate an irrigated area mapping exercise for Ganges and Indus River basins in the Indian subcontinent. Kamthonkiat et al.[4]described a technique named peak detector algorithm to discriminate between rain-fed and irrigated rice crops in Thailand. They used a three-year time series of normalized difference vegetation index (NDVI) to identify cropping intensity using SPOT VGT images. Biggs et al. [5]used MODIS time series combined with ground truth data, agricultural census data and Landsat TM(30 m) data to map surface water irrigation, groundwater irrigation and rain-fed ecosystems of the Krishna river basin in the southern Indian peninsula. Thenkabail et al.[6] used time composites of NOAA AVHRR (10 km) along with SPOT VGT(1 km) and other data sets to derive irrigated areas for the whole world. Velppurl et al [7] used a time-series of NOAA AVHRR (10 km), MODIS (500 m) and Landsat TM (30 m) data separately mapped irrigation were irrigated area in the Krishna river basin. This study demonstrated that the higher resolution satellite data had more precise result of irrigated area. Also the results of three kind of resolution showed a good linear correlation. These kind of studies often identified the irrigated area by the change of vegetation index such as NDVI of times series using satellite data of low spatial resolution. But the irrigation management needs more accuracy irrigated area after one specific irrigation behavior to assessment the irrigation efficiency and track the progress of the irrigation scheduling. So far, there is not any study concerning about estimating actual irrigated after a specific irrigation behavior through the world.

Whether a piece of farmland is irrigated can be indicated by the change of soil moisture. Currently, the methods of estimating soil moisture by remote sensing are mainly divided into two categories. The first type is the optical remote sensing of soil moisture monitoring using visible-near infrared- thermal infrared band such as apparent thermal inertia, vegetation index, crop water stress index and drought index. The second is through microwave remote sensing divided into active and passive microwave remote sensing. The latter makes use of the relationship between bright temperature, dielectric properties, surface temperature and soil water content to estimate soil moisture. This method is of good physical mechanism and is not affected by the weather but high expense [8-12]. Since the optical remote sensing data is simple and easy to obtain adequate sources, it is widely used in the practical business.

In this study MPDI (Modified Perpendicular Drought Index) which is simple and effective was selected to indicate the state of soil moisture content. In the accordance with the law governing the change of MPDI before and after a specific irrigation behavior, the model of estimating actual irrigated area using remote sensing was constructed. And it was applied to. applied to monitor the actual irrigation area in Hetao Irrigation District of Inner Mongolia district in China.

MODELING OF ESTIMATING ACTUAL IRRIGATED AREA

Actual irrigation area studied in this paper refers to the area which is irrigated after one irrigation turn. It is different from cultivated land area and effective irrigation area, usually less than the latter two. For irrigation area is broad, it is difficult to obtain objective monitoring data at present.

In principle, the actual irrigation area is the identification of available irrigation index for the change of soil water content before and after, under the condition of no precipitation. Without irrigation the farmland soil moisture decreases with the time. Once the farmland is irrigated, the soil moisture surge. According to this law, the model of estimating actual irrigation area of different MPDI index predicting soil water content before and after irrigation is constructed.

Soil moisture and vegetation growth is the most direct and important indexes of drought. Based on the feature of near infrared reflectance (Nir-Red) structure of the spectral feature space can not only reflect the change of vegetation biomass, but also can represent the change of soil moisture content (as shown in figure 1). Nir-Red point in feature space E (R_{Nir}, R_{Red}) to the soil the vertical distance L can be used as a baseline to express the degree of soil drought index [13], the computation formula is showed as Eq.(1).

$$PDI = \frac{1}{\sqrt{M^2 + 1}}\left(R_{Red} + M * R_{Nir}\right) \tag{1}$$

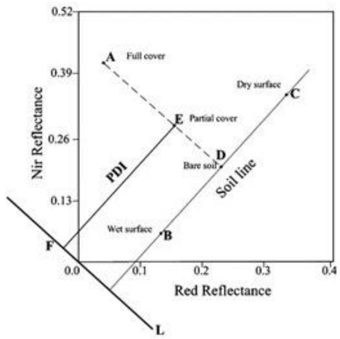


Fig.1 Sketch map of Nir-Red space and PDI

In Eq.(1), *PDI* is for Perpendicular Drought Index soil Drought degree of vertical ; R_{Red} and R_{Nir} stand for the red band and near infrared band reflectance after atmospheric correction; *M* is for the soil line slope.

In optical remote sensing of vegetation, the soil has not been completely covered vegetation canopy spectral characteristics of influence. So when calculating the vegetation characteristics it should rule out the influence of the soil. Accordingly, in the remote sensing monitoring soil physical parameters (such as the surface temperature and soil water content, etc.), vegetation spectral effect should also consider and try to weaken or eliminate the impact of vegetation. Assumption of mixed vegetation information has been removed. Then the correction of vertical vegetation drought index (MPDI) [14] can be expressed as Eq(2):

$$MPDI = \frac{1}{\sqrt{M^2 + 1}} (R_{s,\mathrm{Re}d} + M * R_{s,Nir}) \tag{2}$$

In the Eq.(2), $R_{s,Red}$ and $R_{s,\ Nir}$ respectively vegetation in red band and near infrared band reflectance. Introduction of vegetation coverage (*fv*) aims to eliminate the Nir-Red vegetation spectral information in feature space. Vegetation coverage is one of the important parameters of a characterization of vegetation canopy, it is closely associated with leaf area index. Some studies show that vegetation coverage and vegetation index, the stronger relationship, by vegetation index derive vegetation coverage [15-18]. Baret et al. [16] demonstrated that vegetation index is proposed to obtain such as vegetation index calculation model of air voids as Eq.(3) :

$$\mathrm{P}_o(0) = \left(\frac{VI - VI_\infty}{VI_s - VI_\infty} \right)^{K_p / K_{VI}} \tag{3}$$

In Eq.(3), VI_s and VI_∞ respectively represents the corresponding bare soil (LAI = 0) and complete coverage of vegetation (LAI = 1). *Kp/KVI* depends mainly on canopy structure, leaves, optical performance, sun light direction and the observation direction. The three values is calculated using nonlinear minimization algorithm. Thus to derive the expression of vegetation coverage [17] :

$$f_V = 1 - P_0(0) \tag{4}$$

Guham et al.[14] used the Normalized Difference Vegetation Index (Normalized Difference Vegetation Index, NDVI) to calculate the Vegetation coverage:

$$f_v = 1 - \left(\frac{NDVI_{\max} - NDVI}{NDVI_{\max} - NDVI_{\min}}\right)^{0.6175} \tag{5}$$

The NDVI is defined as:

$$NDVI = \frac{(R_{Nir} - R_{\mathrm{Re}d})}{(R_{Nir} + R_{\mathrm{Re}d})} \tag{6}$$

In Eq. (6) ,*NDVImax*, *NDVImi*n respectively represent the vegetation cover (fv = 1) and completely bare soil (fv = 0) NDVI value. The value of both can be calculated through a single image or a satellite image sequence image completely vegetation of pixel in the picture and bare land of pixel. Also they and can be adjusted according to the geographical characteristics of time and space. The ratio index can minimize atmospheric effect. And the NDVI ratio of the power function model is adopted to reduce the influence of atmospheric turbulence. Jiang Zhangyan [18] used ratio and ratio difference vegetation index NDVI model to estimate vegetation coverage, respectively. And the results show that the two kind of results are similar that the average errors are 6.00% and 5.42%, respectively.

It can be concluded that the soil with vegetation band reflectance of R_i as linear combination of pure vegetation and soil reflectance. That is:

$$R_i = f_v R_{v,i} + (1 - f_v) R_{s,i} \tag{7}$$

In Eq.(7),the $R_{v,I}$ and the $R_{s,\,i}$ are on behalf of the band reflectance of vegetation and soil part in R_i. Get the soli reflectance $R_{s,i}$ by deformation of Eq(2):

$$R_{s,i} = \frac{R_i - f_v R_{v,i}}{1 - f_v} \tag{8}$$

Combined the Eq. (8) and Eq.(2) and get MPDI formula:

$$MPDI = \frac{R_{\mathrm{Re}d} + MR_{Nir} - f_v(R_{v,\mathrm{Re}d} + MR_{v,Nir})}{(1 - f_v)\sqrt{M^2 + 1}} \tag{9}$$

In Eq. (9), $R_{v,\,Red}$ and $R_{v,\,Nir}$ represent the vegetation in the Red band and near infrared band reflectance respectively.Because of the soil moisture increased after irrigation, irrigation land irrigation MPDI value decreases, and after the land without irrigation MPDI values continue to rise. Based on this principle, the model of monitoring actual irrigation area can be constructed:

$$I = MPDI_{t1} - MPDI_{t2} \tag{10}$$

In Eq.(1), $MPDI_{t1}$ and $MPDI_{t2}$ represent the irrigation soil drought index before and after irrigation respectively. Theoretically, $I > 0$ means the field have been irrigated. On the other hand, it means the field have not irrigated. *I* predicts that how great the soil moisture is affected by irrigation. But due to the different condition of the remote sensing images before and after irrigation, it should be set a threshold I^* which is greater than 0.When *I* equals or is greater than I^*, it means this field is irrigated.

CASE STUDY

Study Area

The study area is the Hetao Irrigatian District(Hetao) in China(Fig. 2). Hetao with a total area of 1.0533 million hectare is one of Asia's largest systems of irrigation area. The major kind of irrigation in Hetao is canal irrigation from the Yellow River. It is located in the temperate continental monsoon climate. The average annual rainfall there is 144.5 mm, which have a semiarid climate. The major cropping season extends from April to September. Land is left fallow in the other days of a year. These characteristics make the Krishna basin an ideal study site to investigate irrigated areas.

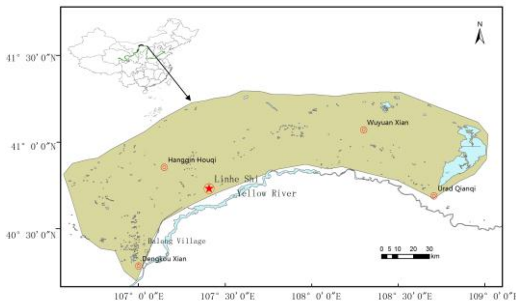


Fig.2 The Location of research area

Data Set for Estimation Irrigated Area

According to the open and close time of canal switch of Baleng , choose the HJ1A/B data before and after one irrigation turn respectively. See Table 1.Fourteen HJ1A/B CCD data used for estimating actual irrigated area were downloaded from China Centre for Resources Satellite Data and Application (http://www.cresda.com/n16/index.html).

There are 20 ground observation points in Baleng Village of County Dengkou. And 10 of them are for calibration and the other are for verification. These data points were spatially well distributed. Whether is irrigated on these points is surveyed artificially.

Table 1. The time of canal open and closed and Satellite transit time

Turn of Irrigation	Time of Open and Close of Canal	Satellite Sensor	Satellite transit time
1	8th,May 8:00-13th,May 2:00	HJ1B-CCD2 HJ1A-CCD1	5th,May 03:26 14th,May 03:36
2	23th,May7:00-24th,May 2:00	HJ1B-CCD2 HJ1B-CCD2	19th,May 03:21 26th,May 03:30
3	17th,June 9:00-19th,June 2:00	HJ1B-CCD1 HJ1A-CCD2	15th,June 03:40 23th,June 03:23
4	14th,July 15:00-18th,July 2:00	HJ1B-CCD2 HJ1A-CCD2	14th,July 03:12 20th,July 03:22
5	26th,August 8:00-29th,August 2:00	HJ1A-CCD1 HJ1B-CCD2	23th,August 03:26 5th,September 03:20

Estimation of Irrigated Areas

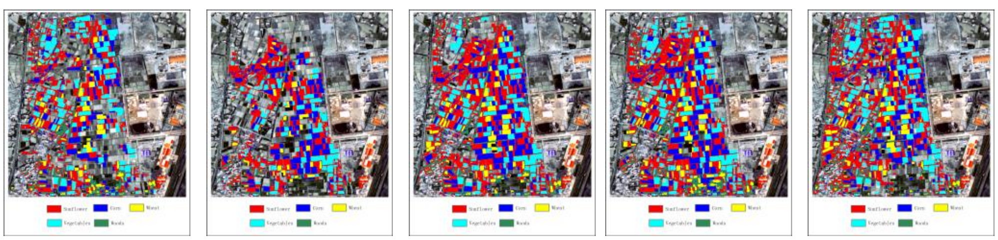
Satellite data were geometrically corrected and the surface reflectance was obtained using a 6S atmospheric correction taking into account near surface radio sound measurements, including atmospheric optical depth and aerosols.

According to Eq(9), the MPDI of 14 issue of the image. And then according to the type (10) are calculated respectively in 2012 five rounds of 10 MPDI phase image difference before and after irrigation.

First of all, set the initial setting MPDI difference threshold and eliminate the farmland area in the study area. According to the MPDI differences of 10 point for calibration for irrigation, adjust the MPDI difference threshold and make the irrigation area of the extraction results consistent with 10 site survey to the maximum. These 10 points are different in land utilization. In case of irrigation during rainfall, rainfall of gardens, wasteland MPDI can be thought of the same, in the irrigation area is extracted by excluding the desert can eliminate the influence of rainfall on the irrigation area extraction.

Take the example, the first round of irrigation in 2012 , MPDI difference threshold analysis process. According to the analysis of 10 infested MPDI difference, there are three point (30 m×30 m) without being irrigated. And the MPDI difference was 1.46, 1.55 and 1.46, respectively. The remaining seven points have been irrigated and their MPDI difference were 1.61, 1.72, 1.68, 1.52, 1.62, 1.80, 1.62.So set the difference threshold as 1.55 to extract the irrigation area. It can make the extraction results and findings of the highest consistency. For I = 1.55, the actual extraction irrigation area of 1410 mu.

As the steps above, analysis remaining four turn of actual irrigation area of irrigation 2012, the value of "I " were 1.64, 1.78, 0.68, 1.64. Then, the irrigation area was 943 mu, 1827 mu, 1778 mu, 1813 mu, respectively. Finally, Combine the results of five turns of estimating actual irrigation area and the classification of crops and the actual irrigated area of different crop types can be obtained as shown in figure 4:



① ② ③ ④ ⑤

Fig.4 The extraction result of five turns irrigation with five crop types

Result and Analysis

Take the 10 gruond truth data for verification to assessment the accuracy of the result including 5 roundsof irrigation in Baleng Villiage in 2012.The result of verification is shown in table 2. Judging from the investigation and remote sensing monitoring extraction, the consistency can reach more than 80%.

CONCLUSIONS

Actual irrigation area of irrigation water use efficiency is one of the important basic indicators of evaluation and management in the irrigation area. It is a combination of irrigation, irrigation facilities, phenology, morphology, water, climate and other natural and artificial factors. The situation is very complicated and there is a lack of objective to obtain the actual irrigated area. With the development of aerospace technology, remote sensing has become one of the important means of information gathering, can provide a wide range, objective of first-hand data. This study aims to solve the problem difficulty to obtain the actual irrigated area. Based

Table 2 The verification of actual irrigation area extraction accuracy("√"measn consistency and "×"means disconsistency)

Point	Round 1	Round 2	Round 3	Round 4	Round 5
1	√	×	×	√	×
2	√	√	√	√	√
3	√	√	√	√	√
4	√	√	√	×	×
5	√	√	√	√	√
6	√	√	×	√	√
7	×	√	√	√	√
8	×	√	√	√	√
9	√	×	√	√	√
10	√	√	√	√	√
Accuracy	80%	80%	80%	90%	80%

on the characteristics of the soil moisture change before and after irrigation, Take use of remote sensing to deduce the change of MPDI. And combined with the a little ground truth data, achieve actual irrigation area. That fills the gap of monitoring the actual irrigation area in our country.Take Baleng village hetao irrigation district in Inner Mongolia for an example. on the basis of the proposed approach in this study, make use of the characteristics of wide coverage, long, short revisit period, rich information of domestic high resolution satellite HJ-1A/ B CCD remote sensing image to extract the actual irrigated area. And combined with the high resolution satellite data of classification of crops, the scored a crop species of actual irrigation area of different types of crops. Compared with the ground survey, the method is simple and the input data is accessible easily. In addition, based the irrigated area of crops, combined with irrigation water-saving irrigation quota of various crops, the use of water for irrigation can be derived, which can support the water-saving irrigation. This method can be used in irrigation schedule, water-saving management and assessment of the effect of irrigation water management and water conservation.

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