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STUDY OF REGIONAL EVAPOTRANSPIRATION OF HETAO IRRIGATION DISTRICT BASED ON TM-IMAGES

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ABSTRACT Based on the analysis of remote sensing data, the best band combination of TM image is determined. After geometric correction, we use non-supervised classification to classify the image, and finally the land classification and crop planting structure are determined. Using high-resolution IKONOS to assess the accuracy of image classification results, it proves that TM image has high accuracy for the land-use classification of irrigation district scale. The results show that it can effectively overcome the impact of human factors. We can extract crop acreage and its space distribution more accurately. The SEBAL model which is based on the principle of surface energy balance model is used to invert evapotranspiration. The inversion results are close to the measured value. This study provides a new method for the research of water consumption in Hetao irrigation district, China.

Keywords: TM5, Hetao Irrigation District, Evapotranspiration

INTRODUCTION Currently, regional evapotranspiration research has established the theoretical basis and algorithm for the more mature model. However, not all generic algorithm is omnipotent, we must, according to the actual situation of the study area, establish the study area for this specific evapotranspiration model which is the only way to make estimate more accurate and effective. Evapotranspiration calculation of ecological water demand is generally one of the ways. Due to surface factors, hydrological parameters of the variability and spatial heterogeneity, they make a great deal of error from the ecological water demand calculated by the evapotranspiration to the large-scale conversion and at last affect the accuracy of results. Real-time and regional of current remote sensing technology provides a convenient situation to monitor the large-scale land surface energy and water surface. At the same time, with the improvement of the remote sensing spatial resolution, temporal resolution and spectral resolution, it has been estimated as a regional evapotranspiration direction of development by using remote sensing technology to quantitative invert surface

parameters and surface fluxes, based on surface energy balance equation, to calculate land surface evapotranspiration finally.

1 OVERVIEW OF THE STUDY AREA Hetao irrigation district which is located in the west of China is one of the three largest irrigation areas in China. Latitude is 40°19'~41°18' and longitude is 106°20'~109°19'. From east to west is about 270km, north-south width is 40~75 km. Irrigation district is flat terrain. Southwest of the district is high and northeast is low. The elevation is 1007~1050m, slope is 0.125~0.2 ‰. Irrigated area of the total land area is about $1.12 \times 10^6 \text{hm}^2$; the existing irrigation area is about $5.74 \times 10^5 \text{hm}^2$, it is about 51.2% of the total land area.

Annual precipitation is 136.8~213.5mm and evaporation is 1993~2372mm. Average annual temperature is 6~8℃, increasing from east to west. The average relative humidity is 40 ~ 50%. Frozen period last for 5~6 months, the greatest depth of the freezing is 1.0~1.3m. Frozen period is from late November to April of the second year, frost-free period is 135~150d, the annual sunshine hours is 3100 ~ 3300h.

2 DATA SELECTION AND RESEARCH METHODS

2.1 Data selection LandSat5 TM images with high accuracy and a resolution of 30 ~ 120m can meet the Scale applications of irrigation area. However, their shortages are repeating visit to its 16-day cycle, the use of a longer cycle between images by the impact of clouds and the high cost of TM images. In 2005, Hetao irrigation area had only 3 images available for King, and fertility was only one that can not be used to the downstream irrigation area View image owing to cloud cover. Hetao the irrigation area of this study is only carried out on the middle reaches of the terrain.

2.2 Research Methods Based on remote sensing technology, the use of multiple-resolution image data, such as LandSat5 TM and IKONOS extracts the basic characteristics parameters of the irrigation area. The use of Erdas9.1 software extracts planting structure of crops by non-supervised classification and the use of SEBAL model inverts irrigation area evapotranspiration.

3 DATA INTERPRETATION

3.1 Data Preprocessing The basic idea of images correction is to establish the corresponding mathematical model based on images distortion the reasons, then extract the required information by polluted or distortion of the image signal, so that image distortion along the reverse process of the restoration of the original image, their error in accordance with the guidelines provided in advance to maximize access to real images.

The data of this study is 1B product by the radiometric and crude geometric correction. So the refined geometric correction is only one, calibration process is shown in Figure 1.

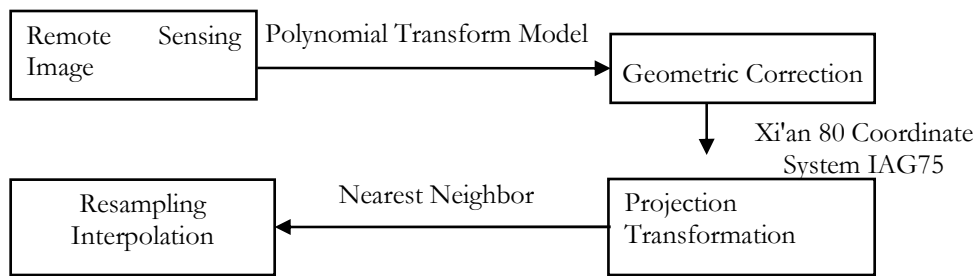


Fig. 1 processing chart of remote sensing image

3.2 Band selection According to the data analysis, principal component analysis and correlation analysis of Images band, we can see that, about seven bands of TM image data, TM5 has the largest amount of information, followed by TM1, TM3, TM4, but the TM1 and TM3 have relevance and the data stack is large, so in this article, we chose band combination of 3\4\5 for the best, as shown in Figure 2.



Fig.2 Bands overlay of band 534

3.3 Classification results

3.3.1 Classification accuracy In ERDAS IMAGINE9.1, we use non-supervised classification method to divide the image into 40 categories, based on experience and the actual data, judge the data one by one and finally merge into seven major categories. Due to lack of measured data, using IKONOS image classification accuracy assessment of the results. IKONOS panchromatic band image accuracy of 1m. It can be a good reflection of the surface coverage and the majority surface coverage can be identified by visual. The results show that other various categories can achieve better classification accuracy except for the woodland and wasteland, the overall accuracy is 0.92. Because of the significant differences in the spectral, water has a higher degree of identification accuracy. We can see that image classification has higher accuracy, and the data is reliable. The results are shown in figure 3(a).

3.3.2 Classified results Every classification name, area and proportion of study area are shown in Table 1 and classify, fruit percentage is shown in Figure 3(b). We can see that the proportion of the crop is 50.8%; it is very close to 51.2%.

Tab1. Land use distribution of research area based on remote sensing

Category name	Water	Wasteland	Buildings and roads	Sand	Saline	Crops	Shrubland	Total area
Area (hm ²)	11493.4	97402	30047.4	9160.2	25941.4	241412	59763.5	475220
Proportion (%)	2.4	20.5	6.3	1.9	5.5	50.8	12.6	100

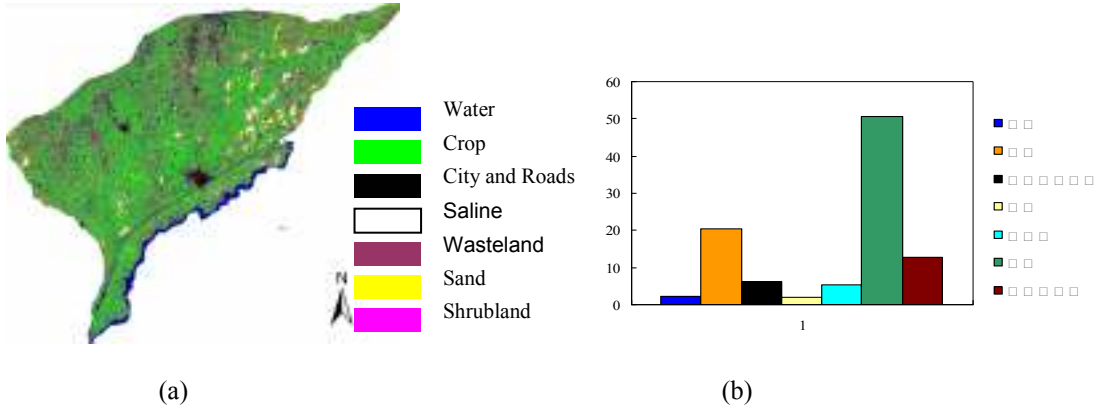


Fig.3 The ratio of the percentage of classification of research area

4 EVAPOTRANSPIRATION INVERSION

4.1 Basic principle Solar radiation is the foundation of earth surface energy exchange. As radiation energy reaches to the earth surface through the atmosphere, the energy is mainly used to heating air, soil and promoting the moisture to evaporate. SEBAL model is based on the earth surface energy balance principle to calculate the evapotranspiration, the formula is as follows:

$$\lambda ET = R_n - G - H - PH \quad (1)$$

Where λET is the latent heat flux; λ is the latent heat of vaporization; ET is the transpiration quantity; R_n is only the radiant flux; G is the soil heat flux; H is the hot flux of the sense; PH is used for the energy of the plant photosynthesis (it can be neglected).

The SEBAL model is according to the Landsat 5 image and the meteorological data to calculate ground albedo, the vegetation index, the emissivity and the surface temperature of research area, and calculate the inversion parameter R_b , G and H when the satellite pass by. Then the ET can be calculated.

4.2 Parameter inquire

4.2.1 Atmospheric external spectrum index of reflection r_b Wavelength of Land sat TM band 1-5 and band 7 are between 0.45-2.35 μm . It accepts solar radiation reflected by ground surface objects, so we can calculate the atmospheric external spectrum index of reflection r_b of ground surface objects.

$$r_b = \frac{\pi L_b d^2}{E_b \cos(\theta)} \quad (2)$$

Where L_b is the atmospheric external spectrum radiant luminance of ground object at the spot of band b , $W \cdot m^{-2} \cdot \mu m^{-1} sr^{-1}$; d is the astronomical distance; E_b is average outside atmosphere solar spectrum illumination at the spot of band b , $W \cdot m^{-2} \cdot \mu m^{-1} sr^{-1}$; θ is the solar zenith angle, rad.

To calculate each reflection index of the band, the transformation of the grey level (DN) to radiation value is needed. In the computational process of surface albedo does not need the hot infrared band.

$$L_b = G_{ain} Q_{DN} + B_{ias} \quad (3)$$

$$Gain = (L_{max} - L_{min}) / (QCAL_{max} - QCAL_{min}) \quad (4)$$

$$Bias = L_{min} - (Gain * QCAL_{min}) \quad (5)$$

Where G_{ain} is the gain, $W \cdot m^{-2} \cdot \mu m^{-1} sr^{-1}$; B_{ias} is a setover, $W \cdot m^{-2} \cdot \mu m^{-1} sr^{-1}$; $QCAL$ is emissivity after the calibration and the quantization, it is the zero dimension; L_{min} is the spectrum emissivity when $QCAL=0$ (or 1); L_{max} is spectrum emissivity when it is $QCAL_{max}$; $QCAL_{max}$ is the new emissivity (Rescaled Radiance); regarding all TM value, $QCAL_{max}=255$. L_{min} and L_{max} value can be obtained from the Landsat technical manual.

4.2.2 Ground albedo α To calculate the outside atmosphere albedo α_{toair} is according to the every-band reflection rate.

$$\alpha_{toair} = \sum [w_b r_b] \quad (6)$$

Where w_b is the weight coefficient of the band b ; r_b is the reflection rate of the band b . The albedo makes the simple atmospheric radiation to the atmosphere outside to adjust, obtains the ground albedo α :

$$\alpha = (\alpha_{toair} - \alpha_{path}) / \tau_{sw}^2 \quad (7)$$

Where α_{toair} is the outside atmosphere index of reflection, α_{path} is had considered atmospheric influence's regulation radiation, θ is the solar zenith angle, rad. Through the simple atmosphere correcting to the primitive image, so in this text the influence on calculating of the atmosphere to reflecting rate in the earth surface is neglected, fetch $\alpha_{path} = 0$.

The value of one-way atmospheric transmission rate of the clear sky can generally estimate by the empirical formula (Allen, etc. ,1994):

$$\tau_{sw}^2 = 0.75 + 2 \times 10^{-5} z$$

Where, z is the ground elevation, m.

4.2.3 The difference vegetation of normalization counts NDVI

$$I_{NDV} = \frac{DN_4 - DN_3}{DN_4 + DN_3} \quad (8)$$

Where, DN_3 and DN_4 are the value of grey level of wave band 3 and 4 of formula (8) calculating respectively. The NDVI minimum value is - 0.76, corresponding to the water body; the maximum value is 0.736, corresponding to the high degree of coverage vegetation, and the average value is 0.158. NDVI is mainly between - 0.15~0.5, and the value of the building, the sand and the bare land approaches to 0.

4.2.4 Than emissivity ε The empirical formula to calculate the than emissivity ε in SEBAL:

$$\varepsilon \approx 1.009 - 0.047 \ln I_{NDV} \quad (9)$$

Where, $I_{NDV} > 0$, otherwise supposed ε is 0. In the study district, the earth surface mean value of than emissivity is 0.915, and than emissivity is higher in vegetation fine area, generally above 0.96; Than emissivity of the saline and alkaline land and wasteland are the lowest, basically below 0.90.

4.2.5 Temperature of earth surface T_s Landsat TM/ETM spectrum range of wave band 6 which accepts the long wave radiation of earth surface mainly is 10.4-12.5 μm , and it can be used to calculating the temperature of earth's surface. Stefan-Boltzman law reflects the relation between object temperature and radiation, and the spectrum range of the single wave band 6 is too narrow, so Plank formula is utilized to calculate the luminance temperature of ground object T_s :

$$T_s = \frac{K_2}{\ln\left(\frac{K_1}{L_6}\right) + 1} \quad (10)$$

Where, L_6 is atmosphere external spectrum radiant luminance of the ground object in the wave band 6, K_1 and K_2 is the often coefficient of computation.

4.3 Determination of the model parameter

4.3.1. Net radiation of the earth surface R_n Subtracting the projection energy by all incident energy to calculate:

$$R_n = (1 - \alpha)S_{in} + (L_{in} - L_{out}) - (1 - \varepsilon)L_{in} \quad (11)$$

Where, S_{in} is the incidence shortwave length radiation; L_{in} is the incidence long-wave radiation; L_{out} is the projection long-wave radiation; $(1 - \varepsilon)L_{in}$ is the incidence long-wave radiation item through the surface reflection; α is the reflecting rate in the earth's surface.

Net radiation amount values of study district concentrate on 500~600W/m², which occupies above 90% in the study region area, and mean value is 581.4W/m².

4.3.2. Heat flux of soil G The soil heat flux depends on factors such as the characteristic of the earth surface and soil moisture content, etc. In this paper, by comparison with many kinds of empirical formula of computation soil heat flux, we adopt the empirical formula which Bastiaanssen (2000) proposed to estimate the surface (covers area and bare land including vegetation) G :

$$G = (T_s - 273.16)(0.0038 + 0.0074\alpha)(1 - 0.98NDVI^4)R_n \quad (12)$$

Where, T_s is surface temperature, K. Soil heat flux (G) of the study district concentrates between 40~80W/m², which occupies the study region area above 90%. Its distribution is roughly similar with surface temperature, and contrary to reflecting rate in the earth surface, that is to say, the higher the reflecting rate in the earth surface is, the weaker the corresponding soil ability of absorbing heat is.

4.3.3. Heat flux of the sense H The calculation of the heat flux of the sense assumes that T_1 , T_2 and T_s are linear relations in the study district, through choosing " the cold point " and " the cold point " on the distribution map of surface temperature, adopting Monin-Obukor iteration method; finally asking out steady H value through numerous circulation in rubbing wind speed aa and aerodynamics resistance bb , calculate formulae as follows:

$$H = \frac{\rho_{air} C_{pair} (aT_s + b)}{r_{ah}} \quad (13)$$

$$H = dT \cdot \rho_{air} \cdot C_{pair} / r_{ah} \quad (14)$$

Where, H is the heat flux of the sense (Wm⁻²); ρ_{air} is air density; C_{pair} = 1004 (J/kg/k); r_{ah} is aerodynamics resistance, s/m..

$$\rho_{air} = \frac{1000 \times P}{1.01 \times T_s \times 287} \quad (15)$$

Where, P is atmospheric pressure. H , $a+bT_s$ and r_{ah} are all unknown quantities, and relevant directly each other. We will use the heat flux H of the sense again to calculate Monin-Obukov length, therefore we can only carry on the iteration to solve, and then determines sense heat flux H .

We can Obtain $a=0.499$, $b=-143.66$, $r_{ah}=21.15$ s/m through the computation. Calculate and we receive the hest flux of the sense through the computation that is distributed in 0~599.8 W/m², and mean value is 282.81 W/m² low value is distributed mainly in the water areas, and high value is mainly distributed on the sand ground, it is mainly distributed between 200~300W/m² that the vegetation

condition is good, which accounts for about 50% of the regional area.

4.3.4. Latent heat flux The latent heat flux which is the steam flux of exchanges between the atmosphere and a lower cushion is important component of circulation of moisture and the energy balance, and the latent heat flux and the manifested heat flux are just

opposite. The latent heat flux of studying area is between 0.022~704.77W/m², and mean value is 212.12 W/m². Its distribution rule is contrary to heat flux of the sense.

4.3.5. Period transpiration amount ET According to every result of energy balance equation above, we can calculate the latent heat flux λET . But this is only instantaneous evapotranspiration value of the satellite photography, we can, according to constant characteristic of evaporation compared in one day, extends instantaneous evapotranspiration value ET to entire day evapotranspiration value ET_{24} through the computation evaporation ratio Λ . The formula is as follows:

$$ET_{inst} = 3600 \cdot \lambda ET \cdot \cos(s) / \lambda \quad (16)$$

$$\lambda = 2.501 - 0.00236 \times (T_s - 273.16) \times 10^6 \quad (17)$$

$$\Lambda = \lambda ET / (R_n - G_n) \quad (18)$$

$$ET_{24} = 86400 \Lambda (R_{n24} - G_{024}) / \lambda \quad (19)$$

Where, $\cos(s)$ is the slope cosine of the surface; λ is the latent heat of vaporization; Λ is evaporation ratio; G_{024} is the entire day soil heat flux; R_{n24} is the net radiation of the sun of a whole day, other symbol meanings are the same.

4.4 Region evapotranspiration quantity inversion Using invariable characteristic of the evaporation ratio, we can calculate the daily evapotranspiration quantity. The result of evapotranspiration quantity is shown in Fig. 4 and Fig. 5, and average value of the daily evapotranspiration quantity is 4.71mm/d. The surveying value of micro weather station of field is 5.09mm/d in experiment station; the inversion value is 4.81 mm/d, the relative error is 5.8%; therefore it is reasonable. Due to the influence input by the laminar flow of external heat, it will destroy the self- steady state, and make energy composition change, thus it will have a certain error through using flash vaporization compared to compute daily evapotranspiration quantity. Regarding the longer evapotranspiration quantity computation, we need the long sequence the remote sensing phantom, in view of the fact that the remote sensing data price is expensive as well as phantom lacking, so it leaves out of consideration for the present in this article.

5 CONCLUSIONS Through the analysis of remote sensing data, the best band combination of TM image is determined. After the geometry correction and the non-supervised classification, the classification is carried out. Finally, we obtain land classification and the crops planter structure of the irrigation area. Using high-resolution IKONOS to assess the accuracy of image classification results, it proves that TM image has high accuracy for the land-use classification in irrigation district scale.

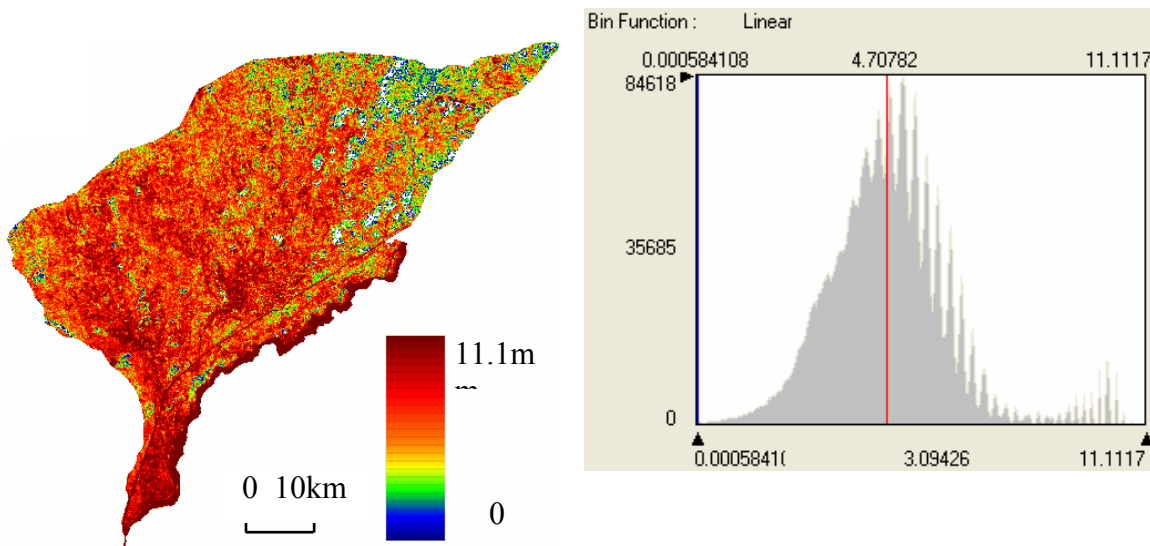


Fig.3 The ratio of the percentage of classification of research area

The SEBAL model is based on the Landsat 5 image and the meteorological data, we can compute ground albedo of research area, the vegetation index, radiate rate and the surface temperature material, and based on the inversion parameter we can calculate R_n , G and H value gradually while the satellites transit. Then we extract the instantaneous ET value. Finally, through the computation evaporation score's method we inquire into the ET quantity of the time interval. After the inversion, we obtain that the daily evapotranspiration is 4.81 mm/d in Shahao experimental station; the surveying value of experiment station is 5.09mm/d; the relative error is 5.8%. The result is reasonable. The error value between inversion results and surveying is allowed. It provides a new method for the region water consumption in the Hetao irrigation district.

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