Comparison and Application of MPDI and MSMMI for Drought Monitoring in Desert Mining Area

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Abstract. Soil moisture is one of the most important environmental factors and participation as an important parameter in hydrological, meteorological and agricultural production process. Soil moisture monitoring by remote sensing has become the focus of research at home and abroad. This paper takes Shendong mining area as an example and chooses 2015-10-5 SPOT and TM images for remote sensing data source, comparative analysis of MPDI and MSMMI which used for soil moisture monitoring of desertification and their effects. Both MPDI and MSMMI soil moisture monitoring methods were verified by 0-5 cm, 10 cm and 20 cm deep soil moisture (SM) data measured by 2015-10-5.

1. Introduction

Soil moisture is one of the most important environmental variables and participation as an important parameter in land surface hydrology, meteorological and agricultural production process. Soil moisture change on land surface energy budget, runoff and vegetation productivity have a profound impact \cite{1}. With the rapid development of today’s remote sensing technology, soil moisture monitoring by remote sensing has become the focus of research at home and abroad. There are many methods of soil moisture remote sensing monitoring, and the spectral feature space method based on NIR-Red has been further developed and applied because of its simple and easy application \cite{2-3}. Spectral feature space based on NIR-Red was established as soil moisture monitoring index mainly has two kinds: one kind is based on the arbitrary feature space point to a straight line through the origin points of vertical distance to characterization research district soil humidity status (the line perpendicular to the vertical distance from the baseline soil), such as Perpendicular Drought Index (PDI) and Modified Perpendicular Drought Index (MPDI); the other is directly use of any point to the origin of distance in the feature space size, such as shortwave infrared moisture index, Soil Moisture Monitoring Index (SMMI), Modify Soil Moisture Monitoring Index (MSMMI) to indicate the status of soil moisture in study area \cite{4}. Both of these methods are based on spectral characteristics of NIR-Red space, calculation methods are different, both of these methods can be used for soil moisture monitoring and how it works and need further validation.

2. Study area and data

2.1 Study area
Shendong mining area (Figure 1) is located in southeast of the Ordos Plateau, northern edge of the Loess Plateau in northern Shaanxi and the South-East edge of Mu Us Desert (110°18'30"E, 39°11'30"N). This mining area is one of the major coal production bases in China, belonging to the arid and semi-arid desert mine area. Wind erosion area accounted for more than 70% of the total area, the original vegetation was monotonous, and the vegetation coverage was only 3-11%, the average annual rainfall is only 362 mm. Water resources are extremely poor, so it is listed as the key monitoring area of soil and water loss in China.

Figure 1. Location of study area

2.2 Data
Satellite data used in this study was SPOT-6 (Systeme Probatoire d’Observation de la Terre) image with 6m resolution registered on October 5, 2015 over Shendong mining area and its surrounding region in China. Landsat 8 OLI of October 5, 2015 was also used for data validation. After the geometric correction, digital numbers (DNs) values were converted into spectral radiance and FLAASH in the ENVI software was carried out to eliminate the atmospheric perturbation and obtain the reflectance at ground level. Data on relative soil moisture to compare with MPDI and MSMMI were obtained by field sample on October 5, 2015. We measured 5 cm, 10 cm and 20 cm deep soil moisture (SM) data of 31 sample points. Soil samples from the Shendong site were taken back to the laboratory, and a traditional weighing method was used to obtain relative soil moisture.

3. Method

3.1 Modified Perpendicular Drought Index (MPDI)
MPDI is a modified perpendicular drought index (PDI), which was introduced by Ghulam et al (2007). On the basis of the original perpendicular drought index, PDI is only a good monitoring effect of soil drought degree in bare soil area, but the effect of vegetation coverage is not obvious [5-6]. However, the vegetation coverage is the ratio of the vertical projection area to the total area of the vegetation, which is an important factor to describe the canopy reflectance. When the vegetation coverage is less than 100%, the soil has a great influence on the vegetation reflectance spectrum. Therefore, the modified perpendicular drought index (MPDI) with vegetation coverage can eliminate the limitation of PDI to the greatest extent.

\[
MPDI = \frac{(R_{\text{red}} + M \times R_{\text{nir}} - F_v \times (R_{\text{v.red}} + M \times R_{\text{v.nir}}))}{(1 - F_v) \times \sqrt{(M^2 + 1)}}
\]

Where \(R_{\text{nir}}\) and \(R_{\text{red}}\) are the atmospherically corrected surface reflectance of Red and Near Infrared (NIR) bands of data, \(M\) represents the slope of the soil line BC in the NIR–Red space. The greater the vegetation coverage (Fv), the smaller the value of MPDI, the results show that the more humid the surface; the smaller the vegetation coverage, the greater the value of MPDI, the results indicate that the surface is more arid.
3.2 Modified Soil Moisture Monitoring Index (MSMMI)

The physical meaning of MSMMI is that in the characteristic space of near infrared red band reflectance, the MSMMI monitoring index line and the soil line form a right angle triangle. The moisture content of soil in the direction perpendicular to the soil line is similar to that of MPDI, and with the increase of the number of vegetation, the reflectance of the near infrared band will increase [7]. The greater the vegetation coverage, the smaller the value of MSMMI, the more moist the soil, and vice versa.

\[
MSMMI = \frac{1}{\sqrt{2} \times (1 - F_v) \times \sqrt{(R_{nir} - F_v \times R_{v, nir})^2 + (R_{red} - F_v \times R_{v, red})^2}}
\]  

(2)

Where \(R_{nir}\) and \(R_{red}\) are the surface reflectance of the NIR and red bands, respectively. \(F_v\) represents vegetation coverage. \(R_{v, nir}\) and \(R_{v, red}\) refer to the vegetation in the red and near infrared reflectance, approximate value of 0.05 and 0.5.

4. Results

The validity of MPDI and MSMMI soil moisture monitoring methods was verified by 0-5 cm, 10 cm and 20 cm deep soil moisture (SM) data measured by 2015-10-5. The soil moisture (SM) as the ordinate, MPDI and MSMMI as the abscissa respectively, the construction of SM-MPDI and SM-MSMMI scatter plot (Figure 2) and calculate the coefficient of determination.

![Figure 2. Relationship between soil moisture (5 CM) and MPDI/MSMMI of Landsat 8 OLI in 2015-10-5](image)

From the decisional monitoring results of different depth of soil drought remote sensing drought monitoring, the simulation results of soil depth soil layer for mining area of the 0-5 cm is relatively good, and the simulation results on the 10 cm and 20 cm depth of soil drought monitoring are relatively poor. This phenomenon indicates that the closer to the surface layer, the better the effect of monitoring soil drought of both indexes.

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MPDI and MSMMI as the abscissa respectively, the construction of SM-MPDI and SM-MSMMI scatter plot (Figure 3) and calculate the coefficient of determination.

![Figure 3. Relationship between soil moisture (20 CM) and MPDI/MSMMI of SPOT 6 in 2015-10-5](image)

From the decisive monitoring results of different depth of soil, the simulation results of soil depth soil layer for mining area of the 0~5cm and 10cm are relatively good, and the simulation results on the drought monitoring 20cm soil depth is relatively poor. This phenomenon indicates that the closer to the surface layer, the better the effect of monitoring soil drought.

The coefficients of determination between MSMMI, MPDI and 0-5-cm-depth of Landsat 8 relative soil moisture are the highest, with $R^2=0.364$ and 0.375, respectively. The coefficients of determination between MSMMI, MPDI and 10-cm-depth of Landsat 8 relative soil moisture is higher than the 20-cm-depth relative soil moisture. The results showed that SMMI and PDI all can reflect the surface soil moisture and they are more suitable for assessing 0-5-cm-depth soil moisture conditions.

The coefficients of determination between MSMMI, MPDI and 0-5-cm-depth of SPOT 6 relative soil moisture are the highest, with $R^2=0.494$ and 0.502, respectively. The coefficients of determination between MSMMI, MPDI and 10-cm-depth of Landsat 8 relative soil moisture is higher than the 20-cm-depth relative soil moisture, with $R^2=0.417$ and 0.426. The results showed that SMMI can reflect the surface soil moisture and they are more suitable for assessing 0-5-cm-depth and 10-cm-depth soil moisture conditions. However, MPDI is slightly better than MSMMI for monitoring 0-5-cm-depth soil moisture conditions.

5. Conclusion
This paper taking Shendong mining area as an example, using SPOT and Landsat 8 OLI image data validating two different drought monitoring index of mining area, comparison and analysis of two different monitoring models for the same region of the monitoring results of the main conclusions are as follows: (1) From the different depth of soil drought monitoring by remote sensing ($R^2$) decisive
results, the simulation results of 0–5cm drought monitoring soil depth is relatively good, and the simulation results on the drought monitoring 10cm and 20 cm soil depth is relatively poor. This phenomenon indicates that the closer to the surface soil layer, the better the effect of monitoring soil drought index.

(2) Compared with MSMMI and PDI, including the improvement of soil type and land cover, the spatial resolution is improved, and the soil type and surface coverage of MPDI are higher. Generally speaking, MPDI is based on the vertical distance of the soil line from any point in the feature space to the coordinate origin to represent the soil moisture, MSMMI uses the distance from any point in the feature space to the origin to represent the soil moisture condition. We should make full use of them to achieve the best results in the monitoring service of the drought in the mining area. When comparing the monitoring degree of each kind of monitoring index to the drought, we can increase the quantity of the mining area, and improve the comparison result from the different soil moisture.

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