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Comparison of SMMI, PDI and its applications in Shendong mining area

Ying Liu, Hui Yue, Haoren Wang and Wei Zhang

College of Geomatics, Xi’an University of Science and Technology, Xi’an 710054, Shaanxi, China

E-mail: liuying712100@163.com

ABSTRACT. Soil moisture has become the dominant factor in the Shendong mining area for vegetation growth and recovery. Soil moisture monitoring index (SMMI) and the Perpendicular Drought Index (PDI) were widely used to monitor soil moisture, which were all obtained from the NIR-Red spectral space. To validate whether SMMI and PDI were all can be applied to evaluate the soil moisture conditions, SPOT-6 images on October 5, 2015 in Shendong mining area are used to calculate the SMMI and PDI over ground measuring points. The SMMI and PDI are then compared to ground-measured soil moisture data with the satellite overpass. This study concludes that the SMMI and PDI provide quite similar results for soil moisture monitoring and they are quite suitable to assess the soil moisture statue in 0-5-cm-depth. The highest correlation of R²=0.54 for the SMMI and R²=0.52 for the PDI is obtained when compared with relative soil moisture from 0 to 5 cm soil depth. It is evident from the results showing the spatial distribution of drought in Shendong mining area that the SMMI and PDI are highly accordant with landform types and underlying.

1. Introduction

Soil moisture is one of the most direct and important indicators of drought events, moreover, drought is also a complex phenomenon which related to regional climate change and water cycle. Therefore, an understanding of soil spectral behaviour is critical to the drought monitoring and estimation. Ghulam [1] established the Perpendicular Drought Index (PDI) which developed on the basis of spatial characteristics of moisture distribution in NIR–Red space that proved to be effective in large-scale applications over western China using MODIS data. The modified perpendicular drought index (MPDI) is based on the combination of two important indicators of drought soil moisture and fraction of green vegetation. MPDI showed potential advantages for regional surface dryness estimation as reported by Ghulam [2]. Liu [3] according to the distribution characteristics of soil moisture in the spectral space
and using the distance of any point to origin indicating the status of soil moisture, constructed soil moisture monitoring index (SMMI) of TM/ETM+ which was not rely on soil line. To validate the drought indices of PDI and SMMI, SPOT-6 images in Shendong Mining Area with various drought conditions is used to calculate PDI and SMMI over ground measuring points. The PDI and SMMI are then compared to an in-situ drought index obtained from field measurements made synchronously with the satellite overpass, including the bulk soil moisture content at different soil depths.

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. The ecological environment of Shendong mining area is fragile and the climate is characterized by less precipitation, uneven seasonal distribution, strong evaporation, and scarcity in surface water resources. Soil moisture is the leading factor of vegetation growth and recovery in this area.

![Figure 1. Location of Shendong mining area](image)

2.2 Data
Satellite data used in this study is SPOT-6 image with 6m resolution registered on October 5, 2015 over Shendong mining area and its surrounding region in China. 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 SMMI and PDI were obtained by field sample on October 5, 2015. Soil samples from the Shendong site were taken back to the laboratory, and a traditional weighing method was used to obtain relative soil moisture. The number of field sample points was 31.

3. Method

3.1 Perpendicular drought index (PDI)
PDI was defined as line segment that is parallel with the soil line and perpendicular to the normal line of soil line intersecting the coordinate origin in the two-dimensional scatter plot of red against near infrared (NIR) wavelength reflectance. In the NIR-Red space, PDI can be defined as the vertical distance from a random point E (ρ_{NIR}, ρ_{Red}) to line L and it can be expressed as
Where $\rho_{NIR}$ and $\rho_{Red}$ are the atmospherically corrected surface reflectance of Red and Near Infra-Red (NIR) bands of data, $M$ represents the slope of the soil line BC in the NIR–Red space. PDI values vary between 0.0 and 1.0. A pixel which locates closer to the coordinate origin O with a smaller PDI means less water stress or wet surface while it locates further away from the coordinate origin O with a larger PDI value indicates more severe water stress. PDI assumes land cover and soil types are homogeneous over the area of study which is based on the concept of a fixed soil line assumption. Some studies indicated that PDI was an effective index for soil moisture monitoring in bare soil area [4-5].

3.2 Soil Moisture Monitoring Index (SMMI)

Soil moisture monitoring index (SMMI) is defined as the distance of random point E ($\rho_{NIR}$,$\rho_{Red}$) to coordinate origin O in the two-dimensional scatter plot of red against near infrared (NIR) wavelength reflectance, which was not rely on soil line. Generally speaking, the distance of a black body is almost equals zero which is located at the origin O. Any other objects with some reflectance, it will be closer to the origin O due to the higher soil water content it possesses. Meanwhile, the farther the distance, the less the soil moisture or vice versa. The SMMI can be expressed as following.

$$SMMI = \frac{|OE|}{\sqrt{2}} = \frac{\sqrt{\rho_{Red}^2 + \rho_{NIR}^2}}{\sqrt{2}}$$

Where $\rho_{NIR}$ and $\rho_{Red}$ are the surface reflectance of the NIR and red bands, respectively. Values of SMMI vary between 0 and 1; lower SMMI means less water stress and higher PDI represents more severe water stress. Figure 2 shows that in $\angle OEF$, the right-angled side of EF was used to represent the PDI and the hypotenuse OE means the SMMI.
4. Results and Discussion

4.1 Relationship between soil moisture and the SMMI and the PDI

Available soil moisture can directly be linked to the drought conditions. To further understand the performance of SMMI and PDI in monitoring the soil moisture status, they are compared with in-situ measurements of 0-5-cm-depth, 10-cm-depth and 20-cm-depth relative soil moisture data (SM). Taking SM as the abscissa and SMMI and PDI as ordinates, respectively, SM-SMMI and SM-PDI scatter plots (Figures 3) were constructed. Figures 3 shows that higher soil moisture values correspond to lower SMMI and PDI values. There are significant negative linear correlations (reliable at 1% significance level) between the SMMI and PDI and different depths average soil moisture.

![Figure 3](image)

**Figure 3.** Relationship between soil moisture at different depths and SMMI and PDI in the Shendong mining area

The coefficients of determination between SMMI, PDI and 0-5-cm-depth relative soil moisture are the highest, with $R^2=0.54$ and 0.52, respectively. The coefficients of determination between SMMI, PDI and 10-cm-depth relative soil moisture is higher than the 20-cm-depth relative soil moisture, with $R^2>0.33$ and 0.20, respectively. 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. However, SMMI is slightly better than the PDI for monitoring 0-5-cm-depth soil moisture conditions, while the latter are slightly better than the former in reflecting 10-cm-depth and 20-cm-depth soil moisture status.

4.2 Surface drought assessment with the SMMI and PDI in Shendong mining area

The SMMI and PDI are all constructed on the basis of spectral behaviour of soil moisture in NIR–Red space. They can indicate soil moisture status which directly links to the drought, therefore, we can be used the two indexes assess the drought conditions of the study area (Figure 4). Figure 4 shows that the drought condition is quite similar between SMMI and PDI and it is consistent with landform types and underlying in mining area. In the surrounding of Wulanmulun mine and the northern and eastern parts of Shigetai mine, the value of SMMI and PDI is higher than the other parts of the two mines and the drought conditions is more severe. The SMMI and PDI values are lower than other parts of the study area.
area and the soil water content is higher on the two sides of the River Kuye. Compared to the underlying of the mining area (Figure 4(a)), the drought status is normal in most area of the mining area where with better vegetation cover. However, the surface is bare, open pit mining or cover by sand (like samples A, B, C, D), the drought is more severe with the higher SMMI and PDI values. Samples E and F is water with lower value of SMMI and PDI (Figure 4). It is obvious from the results that both the SMMI and PDI are effective methods for monitoring drought events in study area.

![Comparison of SMMI and PDI over spatial distribution of drought in Shendong mining area](image)

**Figure 4.** Comparison of SMMI and PDI over spatial distribution of drought in Shendong mining area

5. Conclusion
This paper has explored the performance of SMMI and PDI in soil moisture assessing. It was revealed from the results that SMMI and PDI derived from NIR-Red space all demonstrated a strong negative linear correlation with different depths field measured soil moisture. The correlation between SMMI, PDI and soil moisture where is highest with $R^2=0.54$ and 0.52, respectively, which passed the 0.01 significant test. The drought conditions are quite similar which derived from SMMI and PDI. The paper concluded that SMMI and PDI are simple and effective methods for monitoring soil moisture status and drought events.

However, PDI is based on a fixed soil line assumption. However, the shape of the soil line changes with the variation of soil type and soil fertilization conditions and, therefore, affect the PDI by changing the slope parameter M. SMMI was only inferred to Red and NIR reflectance which was not rely on a
fixed soil line. Both SMMI and PDI were not consider the effects of vegetation greenness on the index, yet further work needs to be done to discriminate the effects of vegetation greenness on the index.

6. References
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