Inversion of Soil Water Content in Jiyang District Based on High Resolution Remote Sensing Image

Wenwen Tang¹ and Fang Dong¹,*

1 School of Water Conservancy and Environment, University of Jinan, Jinan, 25002, China
Email:2008smilefang@163.com

Abstract. The monitoring of soil water content plays an important role in agricultural production. This paper uses high resolution remote sensing image (GF-2 image) and measured soil water content data combined with dual-band, multi-band and PDI index inversion models to invert the soil water content of Xiyan and Wangxingjia Village of Jiyang District, Jinan City, and the effects of soil water content inversion were compared and verified. The results show that the decision coefficients of the multi-band inversion model reach 0.690, respectively, with the highest accuracy. More than 90% of the area in this study area has a soil water content greater than 0.15, which is dominated by suitable and wet soils, mainly distributed in the central part of the study area and near water bodies such as paddy fields, pit ponds and ditches; heavy drought, moderate drought, Light and dry soils account for a very small number, mainly distributed in the southwest direction of the study area, that is, the west side of Wangxingjia Village, distributed in a strip shape. It can be seen that GF-2 images can carry out the inversion of large-scale soil water content and provide a basis for scientific decision-making of agricultural production.

1. Research Background

Soil water content is an important factor in describing ground/gas energy conversion and water cycle. Therefore, studying the soil water content distribution has important practical and scientific value for climate change, water resources distribution, and ecological degradation process and crop yield estimation. Soil water remote sensing inversion technique, which fits the linear nonlinear relationship between pixel brightness values of different bands and soil water, thus inverting soil water content [1]. Traditional soil water monitoring methods are time-consuming and laborious, and it is difficult to reflect large-area soil water information in a timely and dynamic manner [2]. Satellite remote sensing has the advantages of fast, real-time, dynamic and wide coverage. It has made up for the shortcomings of traditional soil water remote sensing monitoring methods to a certain extent, and has become a hot research topic at home and abroad.

2. Overview of the Study Area

Jiyang District is located on the north bank of the lower reaches of the Yellow River and in the southern part of the Lubei Plain. The geographical coordinates are 36°41'-37°15 north latitude and 116°52'-117°27 east longitude. Jiyang District is located in the warm temperate semi-humid monsoon climate zone [3]. Groundwater resources are abundant [4]. This paper selects the area of Xiyan and Wangxingjia Village in Jiyang District as the study area, as shown in figure 1, with a total area of 8513824m².
3. Data Sources

3.1. Source of Image Data
This study adopts high resolution remote sensing image (GF-2 image) independently researched and developed by China. Selects the GF-2 image on April 15, 2019 and downloads it from the data distribution system of Shandong High-resolution Center.

3.2. Source and Treatment of Soil Measured Data
The samples in this paper were collected from Xiyan Village and Wangxingjia Village, Jiyang District, Jinan City on April 15, 2019. And the collection depth was set to 0-5cm. After the removal of abnormal samples, a total of 45 samples were used for modeling inversion of soil water content, 30 samples were used for modeling and 15 samples were tested. The collected 45 soil sample aluminium specimen box with lid was weighed, the quality was recorded as M1, the lid was placed in an oven, and baked at 105 °C for 8 h. After taking out, it was covered and weighed. The quality was recorded as M2, and the drying was repeated twice. Ensure that the water is completely evaporated. Each aluminium specimen box was weighed before being sampled in the field and the quality was recorded as M.

   The calculation formula of soil water content (W) is as follows:

\[
W(\%) = \frac{(M1 - M2)}{(M2 - M)} \times 100\%
\]  

4. Establishment of Inversion Model
In order to select the higher correlation band combination as the inversion factor, the correlation between the soil water content and the corresponding remote sensing images B1, B2, B3, B4 reflectance is analysed (Table 1).
Table 1. Correlation Analysis between Soil Water Content and Single-band Reflectivity

| Band | B1    | B2    | B3    | B4    |
|------|-------|-------|-------|-------|
| Correlation coefficient | 0.6675 | 0.6486 | 0.6442 | 0.8389 |
| \(R^2\) | 0.4456 | 0.4207 | 0.4150 | 0.7037 |

It can be seen that the use of single-band to invert soil water content may lose information on the reaction water content contained in other bands. This paper attempts to use different combinations of different bands and the PDI index is related to the soil water content.

4.1. Establishment of a Dual-band Model

Because B4 has a high correlation with soil water content, B4 is combined with other band components to further screen the soil water content inversion model [5]. For the sake of simple analysis, a combination of bands with high correlations with soil water content is selected for analysis [6]. As shown in table 2 and figures 2, 3, and 4.

![Figure 2](image1.png)

**Figure 2.** Correlation Analysis between B1+B4 Combination and Soil Water Content

![Figure 3](image2.png)

**Figure 3.** Correlation Analysis between B2+B4 Combination and Soil Water Content

![Figure 4](image3.png)

**Figure 4.** Correlation Analysis between B4/B1 Combination and Soil Water Content
Table 2. Correlation Analysis between Band Combination and Soil Water Content

| Band combination form | B1+B4 | B2+B4 | B4/B1 |
|-----------------------|-------|-------|-------|
| R²                    | 0.6153| 0.5995| 0.5722|

It can be seen from table 2 that the linear fit of the B4+B1 band combination is 0.6153. Here, only the factor with the best correlation and the smallest error after regression analysis, that is, the B1+B4 band combination form, is used to establish a dual-band inversion model.

4.2 Establishment of Multi-band Model
In most studies, the dual-band combined inversion factors with high soil water content were selected for linear regression analysis, and linear regression equations were obtained to establish a multi-band inversion model [7-9].

In this paper, a multi-band model of soil water content in Jiyang District was established by using multiple linear regression models of soil water content and dual-band combined inversion factors. Therefore, the combination of the above three groups, namely B1+B4, B2+B4, B4/B1 and the soil water content, is used as the inversion factor to obtain regression equation. The coefficient of determination R² = 0.690. The inversion model (Z) is:

\[ Z = 0.326 + 0.005(B1 + B4) - 0.31(B2 + B4) - 0.000386(B4/B1) \]  

(2)

4.3 Principle and Establishment of PDI Model
The band-based reflectivity is influenced by the soil water content. Zhiming Zhan et al. established the Nir-Red spectral feature space and found the vertical drought index (PDI) [10]. Select the soil line portion of the scatter plot to generate an ASCII file, and perform trend line fitting in Excel, obtain the soil line slope M=1.4837. The PDI of each sampling point was calculated and linearly fitted with the measured values of the 30 soil samples and the corresponding PDI values.

![Figure 5. Correlation Analysis between PDI and Measured Soil Water Content](image)

As can be seen from figure 5, the coefficient of determination R² of the quadratic relationship between the PDI and the measured value of soil water content obtained from the remote sensing image of the GF-2 of the experimental area reached 0.6669, indicating that the PDI is more correlated with the soil water content of the study area.

4.4 Inversion Model Accuracy Verification and Evaluation
The mean absolute error (MAE), mean relative error (MRE), and root mean square error (RMSE) were
used to verify and quantify the accuracy of the three inversion models (Table 3).

Table 3. Test Sample Inversion Accuracy Test Results

| Models    | R2  | MAE | MRE  | RMSE |
|-----------|-----|-----|------|------|
| PDI       | 0.667 | 4.47% | 28.39% | 4.96% |
| dual-band | 0.615 | 4.26% | 27.30% | 4.69% |
| multi-band| 0.690 | 4.08% | 15.04% | 4.56% |

It can be seen from Table 3 that the correlation coefficients between the results of the above three inversion models and the measured values of soil water content are 0.667, 0.615, and 0.690, respectively, indicating that the soil water content inversion in the experimental area using the above model has certain feasibility. The multi-band model has the smallest inversion error and the highest accuracy, so the above data is combined and the optimal inversion model is a multi-band inversion model.

4.5. Results and Analysis of Soil Water Content Inversion in the Study Area

According to the criteria summarized by the experience of the people in the North China on soil water, the soil can be divided into five types. The established standards are shown in Table 4.

Table 4. Soil Water Content Grading Standard

| Degree of drought | Heavy drought | Medium drought | Light drought | Suitable | Wet |
|-------------------|---------------|----------------|--------------|----------|-----|
| Soil water content| 0-0.05        | 0.05-0.12      | 0.12-0.15    | 0.15-0.2 | >0.2|

According to the data, the soil near Xiyan Village is saline-alkaline soil with high water content. The soil of Wangxingjia Village is yellow sand with less water content [11]. Based on the pre-processed high-resolution remote image of Jiyan District, the multi-band inversion was used to obtain the spatial distribution pattern of soil water content in Xiyang Village and Wangxingjia Village of Jiyan District on April 15, 2019 (Figure 6).

Figure 6. Multi-band Model Inversion Study Soil Water Distribution Map
Based on the grading standards established above, the soil water status of the study area was counted. The statistical results are shown in Table 5.

| Soil water content | 0-0.05 | 0.05-0.12 | 0.12-0.15 | 0.15-0.2 | >0.2 | water area² | Percent % |
|--------------------|--------|-----------|-----------|---------|------|-----------|-----------|
|                    | 170.28 | 9194.93   | 240941.22 | 5986921.04 | 1999045.88 | 277550.66 | 0.002     |
| Percent %          | 0.002  | 0.108     | 2.83      | 70.32   | 23.48 | 3.26      |

In terms of quantity, soil water content in more than 90% of the study area is greater than 0.15, and heavy drought, moderate drought, and light drought soil account for a very small proportion, accounting for 2.94% of the study area. It can be seen from Table 5 that most of the soil in the study area has a suitable drought level, and the soil with less water content is distributed in the strip in the southwest of the study area. The wet soil is mainly distributed in the southern and residential areas of the study area. In the previous week of imaging time, Jiyang District was mostly rainy and cloudy, so the soil water content was not excluded due to weather conditions. Based on the above analysis results, it can be concluded that the results of using the multi-band model to invert the soil water content are consistent with the actual situation.

5. Conclusion

(1) The B4 red band has the highest response to the water content of the region, and the band combination including the B4 band information has a higher correlation with the soil water content. Based on the GF-2 image, the determination coefficients of the three-band, multi-band and PDI index and the measured values of soil water content reached 0.615, 0.690 and 0.667, respectively. Compared with the actual situation, the inversion factor in the dual-band combination is less, and the reflection information of soil water content cannot be accurately reflected, resulting in excessive spatial difference of the inversion results; the PDI index is more suitable for bare soil or sparse vegetation area. The soil water content inversion also increases the spatial difference of soil water content for this study area; the multi-band model has the highest inversion accuracy and can better invert the soil water content. It is indicated that the GF-2 image has certain feasibility for soil water content inversion in farmland vegetation area, and has great application prospects in agricultural production.

(2) More than 90% of the study area has a soil water content greater than 0.15, which is dominated by suitable and wet soils, distributed in the central part of the study area, including farmland, village residential areas and the southern part of the study area, close to water bodies such as paddy fields, pit ponds and ditches. The soil; heavy drought, moderate drought, light drought soil accounted for a very small number, mainly distributed in the southwest direction of the study area, that is, the west side of Wang Xingjia Village, distributed in a strip shape. It shows that Jiyang District is close to the Yellow River water source, and the policy of diverting yellow water has effectively alleviated the problem of spring drought in the soil, making the soil conducive to the cultivation of crops.

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