



Hyperspectral remote sensing for extraction of soil salinization in the northern region of Ningxia

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Abstract

Soil salinization affects negatively on agricultural productivity in the semiarid region of Ningxia. In this study, the performance of inversion model to determine soil salinization was assessed using some analysis and reflectance of wavelength. About 42 vegetation samples and 42 soil samples were collected for model extraction. Hyper-spectral data processing method was used to analyze spectral characteristics of different levels of salinization area vegetation. Spectral data were transformed in 16 different approaches, including root mean squares, logarithm, inversion logarithm, and first-order differentiation. After the transformation, the obtained soil and vegetation characteristics spectra correlate well with soil salt content, built soil index, and many vegetation indices. Nonlinear regression was employed to establish soil salinization remote sensing monitoring model. By comparing various spectral transformations, the first-order differential of soil spectral was the most sensitive to soil salinization degrees. The model of the current research was based on salinity index (SI) and improved soil-adjusted vegetation index (MSAVI). The correlation between simulated values and measured values was 0.758. Therefore, remote sensing monitoring derived from MSAVI–SI can greatly improve the dynamic and periodical monitoring of soil salinity in the study area.

Keywords Spectral characteristics band · Salt index · Vegetation index · Soil salinization

Introduction

Soil salinization is a major problem to agricultural development, especially in arid and semiarid areas. It causes deterioration of the ecological environment, decline in crop yield, and threat to the ecological environment and the biosphere (Weng and Gong 2006). Soil salinization generally has strong spatial heterogeneity, so remote sensing technology has important application value in monitoring of this problem. Traditional methods require more samples; therefore, the quantity of soil samples affects directly the accuracy of the prediction of soil salinization (Hereher et al. 2010). Remote sensing uses the electromagnetic spectrum of the soil to quickly acquire extensive, multi-band, multi-temporal soil information. It is difficult to achieve accurate data by

relying solely on communication and ground transportation. Modern applications of remote sensing technology, geographic information system (GIS), and new technologies such as numerical simulations and mathematical models provide a new means for the investigation, calculation, simulation, analysis, evaluation, and prevention of disasters (Abd El-Hamid et al. 2019). With the increase in the resolution of remote sensing data, the data source is rich, and different types of data have been successfully applied to the dynamic monitoring of soil salinization. In particular, hyperspectral data can acquire nanoscale continuous spectral information that reflects the indirect trends of the features in the earth surface. In recent years, domestic and foreign scholars have used spectral techniques to quantitatively and semiquantitatively study soil salinization and soil properties (Sandholt et al. 2001; Ding and Zhang 2008; Zhu et al. 2013). Yao Yuan and others used the measured soil spectral data and salt data to establish a salt index and combined with TM image to extract soil salinization information, compared with traditional multispectral image extraction, its inversion accuracy and detection level were significantly improved (Yao et al. 2013a); Zhang Fang et al. used the measured reflectance of

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soil and image reflectance values to predict and compare soil alkalization. The results show that the model constructed with the measured reflectance value is more accurate for pH prediction (Zhang et al. 2011). Giacoli et al. used the vegetation index of vegetation canopy to predict the saline–alkaline information of the soil. The results showed that the canopy vegetation index can accurately predict the degree of alkalinity of the alkaline soil (Jia and Zhang 2012). However, most scholars only consider the bare soil spectral information and less comprehensively consider the indirect effects of vegetation information on the salinized soil spectrum. High saline and alkali can cause dehydration and even death of vegetation crops. Therefore, in salt-affected area, vegetation coverage can be used as an indirect indicator of salinization problem. According to the importance of this problem, this work analyzes the spectral characteristics of vegetation in different salt-affected area-based data of soil salinity using spectroscopy in the field showing red edge features, green peak features, and derivatives (Qiong et al. 2011). To achieve this aim, some points were proposed; the spectral characteristics of vegetation under different salinization degrees were studied by spectroscopy, the characteristic bands of soil salinization were determined according to the correlation coefficient, the indices of soil salinization were established, and the multivariate nonlinear estimation model of salinization was constructed to extract salts. The model is verified by the measured data, which is a more effective method for extracting high-precision salinization information. Hyperspectral remote sensing data sensing technology has achieved breakthroughs in modern technologies such as long-term dynamic monitoring of crop growth, crop species damage, and acquisition the agricultural information accurately (Hong and Abd El-Hamid 2020).

Materials and methods

Study area

The study area site is located in Xidatan (E 106° 24' 20", N 38° 50' 28"), Pingluo County and Ningxia Hui Autonomous Region (Fig. 1). The average annual rainfall ranges from 150 to 203 mm, and the annual average evaporation is 1709.0 mm. The steaming ratio is about 10. The area is located between the floodplain and Plain of Helan Mountain in Ningxia. Due to low terrain, relatively dry climate, and high groundwater level, soil salinization is a serious problem in the study area, most of which are cracked alkaline soil. The cracked alkaline earth, commonly known as white zombie, has a high alkalinity. It is an alkalized soil formed by salt soil desalination and water erosion under the conditions of desert grassland, and the soil physical and chemical properties are poor.



Fig. 1 Location of the study area and sampling points

Data collection using hyperspectral image

Spectral measurement was carried out on bare soil and vegetation with different salinization degree. The surface of soil with low salinization is mainly covered with vegetation such as rice, alfalfa, and others. The degree of salinization was mostly in the wasteland; it is mainly covered with weeds such as *Artemisia scoparia* and ice grass. In the study area, US UniSpec-SC portable spectrometer with a band of 310–1130 nm was used. The weather was fine, no wind and no cloud, and between 10:00 and 14:00. The spectrometer probe was set at 0.15 m from the ground object. To reduce the field of view of the instrument and reduce the noise impact of the soil spectrum and vegetation spectrum, the instrument is vertically downward, and standard whiteboard correction is performed before each observation. The experiment finally obtained 84 data acquisition units (42 vegetation samples and 42 soil samples). Soil samples were collected from 0 to 20 cm. The conductivity of soil samples and soil pH were measured by conductivity meter, and the linear relationship between soluble total salt content and conductivity was established to calculate soil salinity (Wang et al. 2011).

Laboratory analysis

Conductivity meter ranges between 0 and 20 dS m⁻¹. The EC was measured from a 1:1 dilution extract (soil sample/distilled water). The measurements were performed after 24 h of dilution. The soil salinization grading standards

for this study were determined according to Wang’s observation (Wang et al. 1993) as follows: non-salted soil (<2), lightly saline soil (2–3), moderately salinized soil (3–5), severely saline soil (≥ 10) with unit g/kg.

Correlation analysis and determination of characteristic bands

In order to better analyze the correlation between soil and vegetation spectral data with soil salinity in vegetation cover area and to screen the spectral characteristic bands which are more sensitive to soil salinity reaction, this experiment will log the soil (vegetation) spectral reflectance separately. The root mean square and the first-order differential are transformed and analyzed simultaneously. Soil (vegetation) original reflectance, reflectance first-order differential transformation, logarithmic transformation, logarithmic first-order differential transformation, logarithmic inverse transformation, logarithmic first-order differential transformation using root mean square transformation. The order differential transform is used as a spectral index. Correlation analysis between the spectral index and soil salinity is used to calculate the correlation coefficient *r* between each band on the spectral characteristic curve of soil and vegetation and the measured soil salinity, as shown in formula (1).

$$r_j = \frac{\sum_{i=1}^n (R_{ij} - \bar{R}_j)(SC_i - \bar{SC})}{\sqrt{\sum_{i=1}^n (R_{ij} - \bar{R}_j)^2 \sum_{i=1}^n (SC_i - \bar{SC})^2}} \tag{1}$$

Results and discussion

Spectral data analysis

Original spectrum

In order to ensure the validity of the field measurement, the average value is taken three times at each sampling point as the spectral reflection value of the point. The vegetation has strong absorption in blue and red light, small reflection peaks in the green light band, and high reflection in the near-infrared band, and the spectral curve has obvious peaks and valleys, and the whole salt is different as shown in Fig. 2. The spectral characteristics of vegetation in the degree of vegetation tend to be regular, but as the degree of salinization increases, the vegetation spectrum increases in the visible light band and decreases in the near-infrared band, but do not show regular changes. The spectral reflectance curve of the overlying vegetation canopy on the heavily salinized soil is the most gradual.

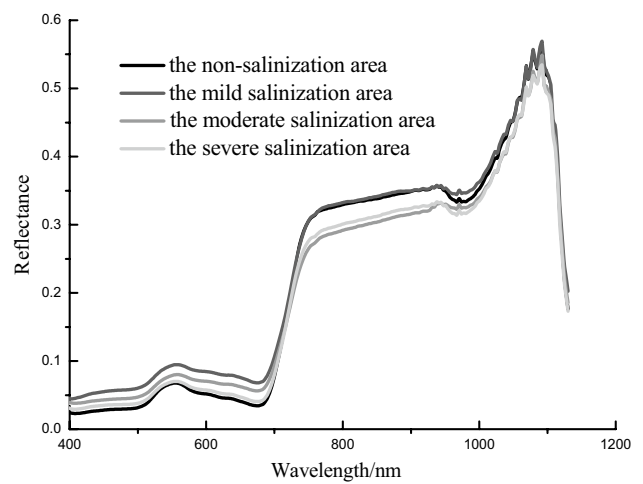


Fig. 2 The reflectance of salinization in different soils

First derivative spectrum

The spectral differentiation technique quickly determines the wavelength of the spectral point and the maximum or minimum reflectivity. It can eliminate the influence of background and illumination factors, especially in the areas with sparse vegetation and mixed spectral components, which is a good way to eliminate background and extract spectral features (Yang et al. 2014). Relative to the spectral curve of the vegetation, the spectral curve of the soil changes gently, the derivative value is small, and the vegetation is completely different. Due to the strong absorption of red light by chlorophyll, it increases sharply around 670 to 800 nm. The state and the derivative value is large, and the soil in this range has a derivative close to zero. This feature can eliminate the influence of the soil background signal on the vegetation spectrum. The first-order differential definition and calculation formula of the spectrum are referred to Qiang et al. (2009). As shown in Fig. 3, the first-order differential transformation reflectivity of the vegetation is obtained in the red edge range in the range from 680 to 780 nm., the first derivative spectrum of vegetation shows a distinct “double peak” phenomenon, the “main peak” is concentrated near 730 nm, the “secondary peak” is concentrated near 760 nm, and the main peak wavelength is smaller than the secondary peak wavelength. With the increase in salinization degree, the canopy coverage of vegetation decreases, the influence of soil background increases, and the double-peak phenomenon becomes less and less obvious. The position of red edge increases with the degree of salinization (i.e., the maximum value of first derivative corresponds to wavelength gradually shifting to the left, showing “blueshift”; the amplitude of the red edge (the maximum value of the first derivative) gradually decreases; the peak area of the red edge (the area

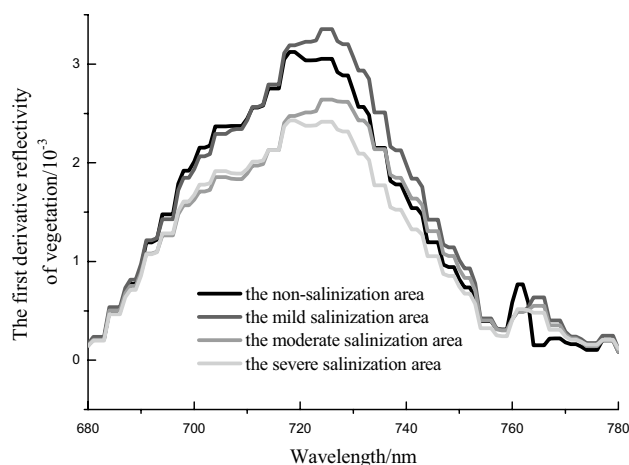


Fig. 3 The first derivative reflectivity of vegetation

surrounded by the first derivative spectrum between 680 and 780 nm) gradually decreases.

The correlation coefficient of the soil salinity and the spectral index measured for the laboratory is the band number, which is the reflectance value of the first band of the first soil sampling unit (and the value of its transformed form), and is a sample of the soil sample. The average value of the unit in the band is the salt content of the first soil sample, which is the average value of the salt content of the soil sample, which is the number of soil samples, which is 30 in this experiment. The relevant results are shown in Fig. 4. The correlation coefficient is calculated based on the sample values between the elements. It varies with the number of samples or the sampling method. Therefore, only by passing the test we can know about its credibility. It can be seen from the analysis in Fig. 4 that the correlation between the spectral reflectance of all types and the soil salinity is significantly improved. The characteristic band is determined according to the principle of maximum correlation, so only the correlation coefficient between the first-order differential spectrum and the soil salt content is considered. The first-order differential reflectance of soil has higher correlation coefficient at 450 nm and 685 nm. The first-order differential reflectance of vegetation has higher correlation coefficient at 960 nm and 1094 nm, and the 0.01 significant level tests are adopted. The above bands are selected as the characteristics of soil salinity.

Establishment and verification of soil salinity model

Calculation of spectral index

The soil salinity index can reflect the distribution of soil salinity, and the use of characteristic bands with the greatest correlation with soil salinity to construct high-spectral soil

salinity index has great advantages in salinization extraction and detection (Ding et al. 2012; Yao et al. 2013b). The correlation coefficient R^2 between the salt index SI and the measured soil salinity is -0.587 , which passes the 0.01 level significance test and can be used to invert the soil salinity as shown in Eq. (2):

$$SI = \sqrt{R_{450}^2 + R_{685}^2} \quad (2)$$

The main harmfulness of salinization is influencing the growth of vegetation, the growth of vegetation is destroyed, and the degree of salinization can be identified by the change of vegetation index. In this experiment, five common vegetation indices are selected, which are simple ratios. Vegetation index (RVI), normalized vegetation index (NDVI), difference vegetation index (DVI), and soil line-based vegetation index: soil-adjusted vegetation index (SAVI), improved soil-adjusted vegetation index (MSAVI), optimized soil-adjusted vegetation index (OSAVI). Five indices were calculated by the selected characteristic band, and the soil salt content was analyzed. The results are shown in Table 1. It can be seen from the table that the correlation coefficient of MSAVI is the largest. Therefore, based on this experiment, the optimal soil salinization index model is established.

Establishment of remote sensing model

It is used to analyze the statistical relationship between things. It can help us to accurately understand the influence degree of variables and other variables, taking soil salinity as the dependent variable and salt index and vegetation index as independent variables, multivariate nonlinear regression (trend surface analysis); the results show that there is a good nonlinear relationship between soil salinity and the two indices, R^2 of the established model is 0.747, and F value is 6.3 at 0.01 level significance tests.

$$y = 15330091.35x_1^2 - 275.215x_2^2 - 33646.03x_1x_2 + 310.54$$

where x_1 is the salt index and x_2 is the vegetation index.

Model verification

The inversion model was tested based on the twelve soil sample units that were not involved in the modeling. The model samples are basically clustered near the diagonal, which is 0.758 as shown in Fig. 5. The consistency between the simulated and measured values is good, so the model established in this paper is effective and passed the test, which can be used to predict the total salt content of the soil.

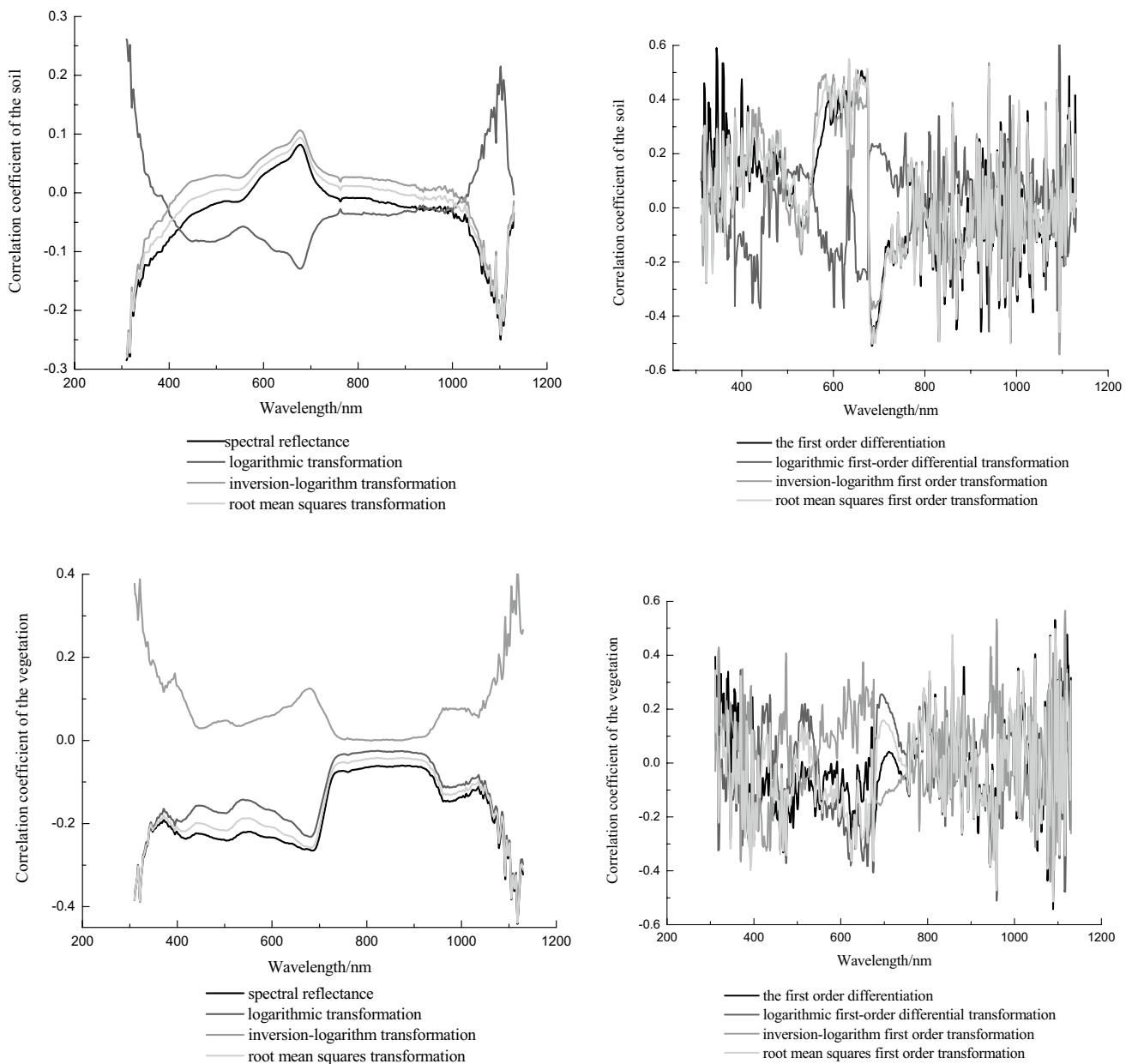


Fig. 4 Correlation coefficients and spectral reflectance of salinity in soil and vegetation

Table 1 The correlation coefficients between spectral vegetation index and soil salt content

Indices	Equation	Reference	R^2
NDVI	$NDVI = (R_{1118} - R_{682}) / (R_{1118} + R_{682})$	Qoian et al. (2013)	-0.56*
SAVI	$SAVI = (1 + 0.5) \times (R_{1118} - R_{682}) / (R_{1118} + R_{682})$	Zhang et al. (2013)	0.57*
RVI	$RVI = R_{1118} / R_{682}$	Zhang et al. (2013)	-0.07
MSAVI	$MSAVI = 0.5 \times [2R_{1118} + 1 - \sqrt{(2R_{1118} + 1)^2 - 8(R_{1118} - R_{682})}]$	Li et al. (2014)	-0.59*
OSAVI	$OSAVI = (1 + 0.16) \times (R_{1118} - R_{682}) / (R_{1118} + R_{682} + 0.16)$	Li et al. (2014)	0.56*
DVI	$DVI = R_{1118} - R_{682}$	Lei et al. (2013)	0.57*

*Significantly correlated at the 0.01 level ($n=30$)

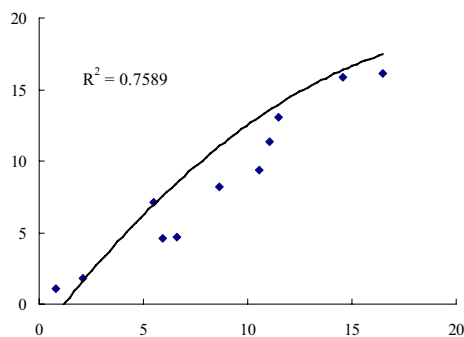


Fig. 5 The correlation coefficient of measured soil salinity and predicted value

Conclusions and recommendations

Conclusion

The spectral characteristics of vegetation in different salinized areas tend to be consistent, but as the degree of salinization increases, the reflectance of vegetation spectrum increases in the visible range and the reflectance decreases in the near-infrared. At 680 to 780 nm (red edge range), the influence of soil properties on vegetation spectrum increases with the increase in salinization degree. The transformed soil and vegetation spectra, in which the spectral reflectance of the first-order differential transformation of the reciprocal logarithm has the best correlation with the measured soil salinity in the laboratory. Selecting the best correlation feature bands 450 nm and 685 nm to construct the salt index model and the 960 nm and 1094 nm building vegetation index models, the results show that the correlation between the two and soil salinity is high, so the soil salinity in the two index construction areas. Remote sensing monitoring model has been verified to have a good simulation effect and can be used to quickly extract soil salinization information in this area, providing a new means for monitoring soil salinization in the future.

Recommendations

This model constructs the vegetation index–salt index characteristic space that characterizes the surface-salinized soil information, and establishes a salinized soil salinization remote sensing model with clear physical meaning. It can avoid the hysteresis problem caused by traditional spectral data and can quantitatively monitor soil salinization at different scales. However, the information contained in the soil spectrum is relatively complex, and there are large differences in the in situ soil samples in the field, which will affect the accuracy of the model. Therefore, the spectral difference between different salinization degrees and coverage levels

will continue to be studied in the next stage, revealing the influence of different canopy spectra on saline soil.

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