A Comparison of Soil Salinity Estimation in Xinjiang With and Without Human Interference: A Postprint

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Abstract

Using measured spectra of soils with and without anthropogenic interference in Xinjiang as the data source, the continuum removal method was employed to extract absorption features and sensitive bands, and various univariate and multivariate linear regression models for soil salinity estimation were established based on the continuum removal method. The results show that: 1. The continuum removal method can significantly enhance the absorption features of soil spectra in the 400~610 nm and 610~800 nm bands; 2. The correlation between soil salinity content and the first-order derivative of continuum removal is relatively good, with sensitive bands in areas without anthropogenic interference concentrated in the visible region (400~800 nm), while in areas with anthropogenic interference they are in the visible-near-infrared region (400~2 400 nm); 3. The prediction accuracy of soil salinity models from high to low in areas with/without anthropogenic interference is basically: continuum removal 6 absorption features model > continuum removal and continuum removal first-order derivative sensitive bands model > continuum removal 3 absorption features model > single absorption feature model. The [WTBX]R 2[WTBZ] values of the best prediction models in areas with/without anthropogenic interference are 0.86 and 0.92, respectively. The residual prediction deviation (RPD) of the optimal model in areas without anthropogenic interference (6 absorption features) reached 3.06, greater than 3, indicating that it can excellently and stably predict soil salinity values in this region.

Full Text

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Estimation and Comparison of Soil Salinity under Different Intensities of Human Disturbance in Xinjiang

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Abstract: Soil spectra under different intensities of human disturbance were used as the data source to extract the absorption characteristics and sensitive bands by the continuum removal method. Linear regressions were established for estimating soil salinity based on the continuum removal method. The results showed that: The continuum removal method could be used to significantly enhance the absorption characteristics of soil spectra in wavelength bands of 400–610 nm and 610–800 nm; The correlation between soil salt content in the manned/unmanned disturbance area and the first derivative of the continuum removal (FDCR) was better than continuum removal (CR), the sensitive bands were concentrated in the Vis area in the unattended area (400–800 nm), and the artificially disturbed area was Vis-NIR (400–2400 nm); Basically, the accuracy of the models for predicting soil salinity in the manned/unmanned disturbance area was in an order of 6 absorption characteristic models of continuum removal > sensitive band model of CR and FDCR > 3 absorption characteristic models of continuum removal > single absorption feature model. The values of R^2 of the best predictive model of the manned/unmanned disturbance regions were 0.86 and 0.92, respectively. The value of the optimal model of relative percent deviation for the unmanned disturbed zone reached 3.06 and higher than 3, which revealed that the model was excellent and stable in predicting soil salinity in this area.

Keywords: human disturbance; spectral continuum removal; soil salinity; hyperspectrum; Xinjiang

1. Materials and Methods

1.2 Study Area and Sample Collection

The study area is located in the northern part of the Xinjiang Uygur Autonomous Region, with sampling sites distributed at elevations of 800–1000 m. The sampling area covered a range of 200–500 m, with GPS positioning used to record the geographic coordinates of each sampling point (Figure 1). A total of 55 sampling plots were established, including 25 plots in unmanned disturbance areas and 30 plots in artificially disturbed areas. At each plot, five subsamples were collected from the surface layer (0–10 cm) and mixed to obtain a composite sample of approximately 1 kg. The soil samples were air-dried, ground, and passed through a 2 mm sieve for subsequent analysis.

Table 1 Statistical characteristics of soil salt content ($g \cdot kg^{-1}$)

Disturbance Type	Mean (n=15)	Standard Deviation (n=10)	Coefficient of Variation (n=25)	Mean (n=15)	Standard Deviation (n=10)	Coefficient of Variation (n=25)
Unmanned	4.20	5.15	4.20	3.50	1.58	1.58
Artificial	30.08	27.13	30.08	41.63	36.42	41.63
Overall	16.33	15.48	15.99	21.20	19.12	20.51
Range	7.54	6.54	7.03	10.83	11.10	10.78
CV (%)	46.17	42.26	43.95	51.09	58.06	52.54

Note: n represents the number of samples.

1.4 Spectral Data Acquisition

An ASD FieldSpec 3 portable spectrometer was used to measure soil reflectance spectra in the 350–2500 nm wavelength range. The measurements were conducted between May 11-24, 2017, from 11:00 to 16:00 (local time) under clear sky conditions. The spectrometer was equipped with a 15 cm diameter contact probe, and measurements were taken at a 25° solar altitude angle. At each sampling plot, five measurement points were selected within a 1 m^2 area, with 10 spectral scans recorded per point, resulting in a total of 50 spectra per plot.

1.5 Spectral Data Preprocessing

Spectral data were processed using ViewSpecPro and OriginPro 9.1 software. The Savitzky-Golay smoothing algorithm was applied to reduce noise. Wavelength bands of 350–399 nm and 2401–2500 nm were removed due to low signal-to-noise ratios. Additionally, bands around 1400 nm, 1900 nm, and 2200 nm were excluded because of water vapor absorption effects. The continuum removal (CR) method was applied to the spectral data using ENVI 5.1 and OriginPro 9.1 software.

The continuum removal process involves three key steps (Figure 2):

1. **Continuum Removal (CR):** The continuum line is fitted as a convex hull over the spectral curve, and the CR value is calculated as:

$$D = 1 - \frac{\rho}{\rho_{cr}}$$

   where ρ is the original reflectance and ρ_{cr} is the continuum line reflectance.

2. **Absorption Depth (A):** The area under the absorption feature is calculated by integrating the difference between the continuum and actual reflectance.

3. **Absorption Width (W):** The full width at half maximum of the absorption feature.

1.6 Model Development and Validation

The Kennard-Stone algorithm was used to divide the samples into calibration and validation sets. For unmanned disturbance areas, 15 samples were used for calibration and 10 for validation. For artificially disturbed areas, 20 samples were used for calibration and 10 for validation.

Model performance was evaluated using three metrics:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(x_p - \bar{x})^2}{\sum_{i=1}^{n}(x_0 - \bar{x})^2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_0 - x_p)^2}{n}}$$

where n is the number of samples, x_p is the predicted value, x_0 is the observed value, and $\bar{x}$ is the mean observed value.

The ratio of performance to deviation (RPD) was calculated as the ratio of standard deviation to RMSE. Model performance was classified as follows: 1.5 RPD < 2.0 indicates approximate quantification; 2.0 RPD < 2.5 indicates good prediction; 2.5 RPD < 3.0 indicates very good prediction; and RPD 3.0 indicates excellent prediction [18].

2. Results

2.1 Spectral Characteristics of Soil Salt Content

The correlation analysis between soil salt content and spectral reflectance revealed maximum correlation coefficients of 0.937 at 498 nm and 0.912 at 505 nm for unmanned disturbance areas. The continuum removal method significantly enhanced absorption features in the 599–711 nm, 1358 nm, 1817–1992 nm, and 2288–2313 nm bands. Additional characteristic bands were identified at 2354 nm and 2387 nm (Figure 5a).

The first derivative of continuum removal (FDCR) showed strong correlations with soil salt content, particularly in the 677 nm and 2229 nm bands, with R^2 values of 0.62 and 0.69, respectively. The correlation between CR and soil salt content was weaker, with R^2 values of 0.72 for the 400–610 nm band and 0.70 for the 610–800 nm band (Figure 4).

Figure 4. Values of continuum removal in different bands under different intensities of human disturbance

Figure 5. Correlation between soil salt content and continuum removal and its first-order differential under different intensities of human disturbance: (a) CR, (b) FDCR

2.4 Inversion Models for Soil Salt Content

2.4.1 Comparison of CR and FDCR Methods Linear regression models based on CR and FDCR were established for both disturbance types. Statistical significance testing (P = 0.01) indicated that FDCR models performed significantly better than CR models. The unmanned disturbance area showed 6 characteristic absorption bands, while the artificially disturbed area exhibited 6 bands in the 400-610 nm range and additional bands in the 610–800 nm range.

The most sensitive bands for FDCR models were identified at 477 nm, 661 nm, 676 nm, 677 nm, 1549 nm, and 2010 nm. The regression models achieved R^2 values of 0.81, 0.76, 0.80, and 0.81 for different band combinations (Table 3).

Table 3. Inversion models for soil salt content based on spectral absorption index under different intensities of human disturbance

Model Type	Calibration R^2	Validation R^2	RMSE	RPD	Band Range (nm)
CR	0.81	0.76	1.94	2.06	400–610
FDCR	0.80	0.81	1.85	2.11	400–800
CR	0.62	0.67	2.05	1.72	610–800
FDCR	0.68	0.65	1.88	1.85	400–610

2.4.2 Model Performance Evaluation The accuracy of predictive models followed the order: 6-band absorption characteristic models > sensitive band models > 3-band absorption characteristic models > single absorption feature models. The optimal models achieved R^2 values of 0.86 for unmanned disturbance areas and 0.92 for artificially disturbed areas.

The RPD values for the best models were 3.06 for unmanned areas and 2.05 for artificially disturbed areas, indicating excellent predictive capability for the former and good predictive capability for the latter. Models based on the 400-610 nm band consistently outperformed those using other spectral ranges.

2.4.3 Validation Results Cross-validation results demonstrated that FDCR-based models provided more accurate and stable predictions of soil salt content compared to CR-based models. The integration of multiple absorption features significantly improved model performance, particularly for unmanned disturbance areas where soil surface conditions were more homogeneous.

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Note: Figure translations are in progress. See original paper for figures.