International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Prediction of Soil Texture Distributions by using PLSR and Reflectance Spectroscopy

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Abstract**: The texture of soil i.e. Sand, Silt and Clay are the most important physical properties of soil for agricultural management. In the agricultural practices to increase the productivity of soil, moisture-holding capacity, aeration and to support the agronomic decisions the knowledge of soil texture is an essential task. For this purpose, the present research gives better results and fast acquisition of soil information with the use of Visible and Near Infrared (Vis- NIR) Diffuse Reflectance Spectroscopy. A total of 30 soil samples from two different locations from Aurangabad, Maharashtra, India were collected and analyzed for soil texture. To detect the soil texture the Vis-NIR DRS has shown levels of accurate results compared to the traditional laboratory method with less time, cost and effort. To measure the reflectance of soil the ASD FieldSpec4 Spectroradiometer (350-2500nm) was used. By the observation of captured spectra by using Spectroradiometer it showed that on the basis of different textural classes the soil samples could be spectrally separable. For database collection and pre-processing, we have used RS3 and ViewSpec Pro software respectively. The statistical analysis by using the combination of Principal Component Analysis (PCA) and Partial Least Square Regression method gives accurate results. To determine the texture of soil sample thirteen features were calculated. The main goal of this research was to determine the soil texture by using statistical methods and to test the performance of VNIR-SWIR reflectance spectroscopy by using the ASD FieldSpec4 Spectroradiometer for estimation of the texture of the soil. The results showed that R2 = 0.99 gives maximum accuracy for clay content and R2 = 0.988 for silt content and R2 = 0.989 for sand. The Root Mean Square Values (RMSE) for clay, silt, and sand are 0.02392, 0.02399 and 0.02289 respectively. With the use of reflectance spectroscopy and statistical analysis by using regression models we can determine the soil properties accurately in very less time.

Keywords: ASD FieldSpec4 Spectroradiometer, PCA, PLSR, Soil Texture, Vis-NIR Diffuse Reflectance Spectroscopy.

I. INTRODUCTION

The Remote Sensing and Geographical Information System (RS-GIS) growing expeditiously in the technological era and there are the ample number of utilization in the agricultural field and different industries which are reliant on the agricultural area as well. To predict the texture of soil the soil spectroscopy has been affected as a speedy method. Over the past two decades, the utilization of Visible and Near-Infrared Diffuse Reflectance Spectroscopy (VNIR-DRS) increased by interest among researchers in soil science. Relating to physical and chemical properties of soil the main resource support for crop nutrients is soil and some of the most principal features are its characteristics of spectral reflection. By using various analytical techniques, the correlation between the properties of soil and characteristics of spectral reflectance have examined by some researchers [1].

A. Physical Properties of Soil

In agricultural analysis and production, the soil is a key input. The key physical properties of soils such as soil texture, soil structure, color, porosity, depth, density, consistency and characteristics of water can be analyzed through spectral soil analysis.

- *Soil texture:* The relative soil particle contents of different sizes such as Clay (< 0.002mm), Silt (0.002mm to 0.05mm) and Sand (0.05mm to 2.00mm) are indicated by the single most important physical property of soil i.e. "Soil Texture" [2]. The soil texture gives us the information about water flow potential, soil aeration, fertility potential, water holding capacity and suitability for many urban uses like bearing capacity. So, the determination of soil texture is now more important than ever.
- *Soil structure*: The growth of plant root, resistance to erosion and water movement are affected by the soil structure. The classes of structure such as very fine (or very thin), fine (or thin), medium, coarse (or thick) and very coarse (or very thick) represents the average size of individual aggregates.
- *Color:* The color of soil does not influence the use and behavior of soil and is generally determined by the degree of oxidation and the content of organic matter.

B. Fundamentals of VNIR-SWIR Reflectance Spectroscopy

To analyze some of the essential soil constituents the Visible and Near Infrared-Shortwave Infrared (VNIR-SWIR) Reflectance Spectroscopy is rapid, non-destructive, inexpensive, and more accurate [3]. It can be used as an alternative method to standard laboratory methods [4, 5]. To provide fast spatial data at low cost with high resolution, the Diffuse Reflectance Spectroscopy (DRS) sensors in the Visible (400-700nm) and Near Infrared (700-2500nm) range are more effective. The VNIR Spectroscopy technique gives soil information based on a qualitative and quantitative basis [6].

Manuscript published on 30 September 2019
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In the electromagnetic spectrum as a function of wavelength, the spectral signatures of soils or the characteristics of spectral reflectance are specified by their absorbance or reflectance.

In this research to capture spectral reflectance of soil samples, we have used the Analytical Spectral Device (ASD) FieldSpec4 Standard-Res Spectroradiometer and is perfectly suitable to meet the needs of today's researchers.

C. Study Objectives

The goal of the research reported herein was (1) to test the performance of VNIR-SWIR reflectance spectroscopy using spectral data measured in laboratory by using ASD FieldSpec4 Spectroradiometer (350-2500nm) for prediction of the texture of soil samples, (2) to analyse spectral range of Sand, Silt and Clay with its properties by using computational method and regression model and (3) to develop tool for estimation of soil texture.

The arrangement of the present paper is in five sections. The first section describes the basic introduction of the research, reflectance spectroscopy, and objectives with background study. The second section focuses on the study site, sampling of soil and database collection by reflectance measurement. The third section highlights the experimental section and statistical analysis. Results of the research were explained in the fourth section with detailed discussion. Conclusion and future scope have been given in the fifth section

II. MATERIALS AND METHODOLOGY

A. The Study Site

Thirty (30) soil samples were collected from two locations in Aurangabad, Maharashtra, India with 19.901054 and 75.352478 Latitude and Longitude value respectively. The study site included; Dr. Babasaheb Ambedkar Marathwada University area (location 1) and Beed Bypass road agricultural area (location 2) from Aurangabad city. Each and every sample of collected soil was kept in an airtight plastic bag to maintain the moisture of soil samples, labeled with; collected data, its Latitude and Longitude value, and area. To take measurements, the visible roots were removed and all the 30 soil samples were sieved through 2mm sieve. The graphical location of the study site is as shown in Fig. 1.

B. Soil Sampling

The database of the collected samples of soils from Aurangabad city, Maharashtra, India is created in the RS3 Spectral Acquisition software by using ASD FieldSpec4 Spectroradiometer. The soil sample spectrum was the average of 10 successive scans of 30 samples of soil. The reflectance of each soil sample was displayed in graph data and pre-processed by using the ViewSpec Pro Version 6.2 software.

With a 350-2500nm spectral range of the high-intensity source device, ASD Fieldspec4 Spectroradiometer the soil samples were scanned. For optimization purpose and to avoid errors of reflectance spectra we were taken the white reference of every sample using the standardized white Spectralon panel having 100% reflectance. The height of the optical lens (8-degree FOV) from the sample of soil was 5cm and the light source mounted with 45-degree angle [7]. To better control irradiance conditions in the black room, the measures of soil samples were taken.

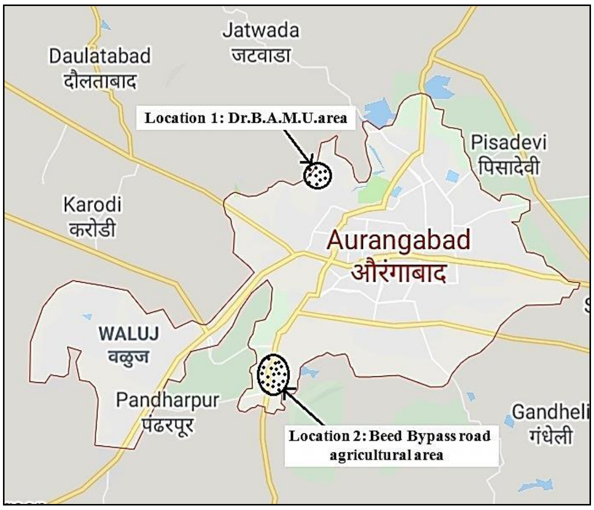

Fig. 1 Geographical location of the study site

C. Reflectance Measurement and Database Collection

The ASD FieldSpec4 Spectroradiometer gives spectrum with 1.4nm (350-1000nm) and 2nm (1000-2500nm) resolution and 2151 bands with 1nm uniform spectral interval [8]. The ViewSpec Pro software used for data analysis to display data in the form of graph and to pre-process the .asd files for statistical analysis. To view the graph data in ViewSpec Pro software the .asd files captured by RS3 software are the input values. The following Fig. 2 shows the statistic mean spectral reflectance of collected 30 soil samples by using the ViewSpec Pro software. From previous studies it is observed that the absorption peak is assumed around 2200nm, 1900nm and 1400nm for clay, silt and sand respectively [9].

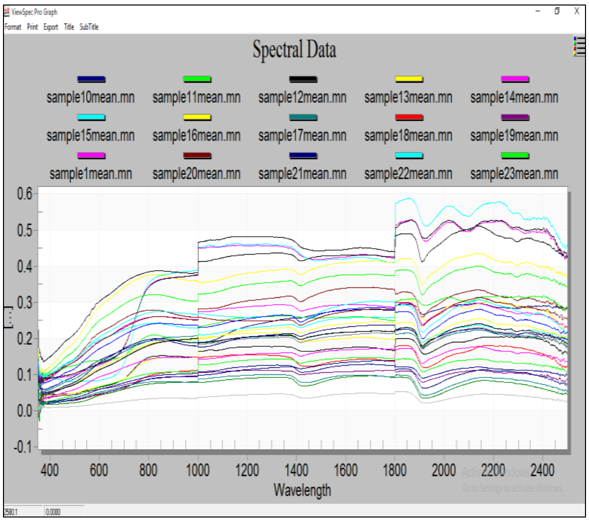

Fig. 2 Statistic mean spectral reflectance of 30 Soil samples.

To pre-process the data viewed in the ViewSpec Pro software, each spectral signature of soil samples were converted to ASCII format.

III. EXPERIMENTAL SECTION

A. *Physical Analysis*

Many researchers concluded that, instead of the use of traditional laboratory method or by using field soil sampling, the proximal Visible and Near-Infrared Diffuse Reflectance Spectroscopy could provide the quick, cheap and better soil prediction [10].

Prior to the texture analysis by using spectral measurement, to determine the predicted data of soil texture i.e. sand, silt and clay by using physical analysis we have used the general feel test, ball squeeze test, and ribbon test. Based on the feeling a moist soil with the fingers soil-texture-by-feel test is generally alternative of an estimation of percentages of the separates. By physical analysis of soil samples using soil-texture-by-feel tests we have observed that, before breaking, the clay (< 0.002mm) forms a ribbon that could rise up to 2 inches, when squeezed between fingers and thumb, the silt (0.002 to 0.05mm) sometimes forms a ribbon, and sand (0.05 to 2mm) forms ribbon that is lesser than 1 inch [11]. So, by the use of this soil texture by feel test we were collected the data of 30 soil samples by physical analysis.

B. *Statistical Analysis*

- *Partial Least Square Regression:*

For analysis of multivariate data, the very successful and has become the most popular regression technique is the Partial Least Square Regression method (PLSR). It is proven that in the soil spectroscopy field the PLSR is a standard tool. To overcome the problem of multicollinearity and high dimensionality we can use the PLSR method.

To identify the noise by filtering and decomposing the data in the system and for extracting the comprehensive variables, it is good to use the PLSR modeling method of multi-dependent variables to multi-independent variables. For soil property in the cross-validation, the Root Mean Square Error (RMSE) was used as a decision standard for calibrating PLSR model. In the calibration set to develop VNIR-DRS soil texture prediction models the Principal Component Analysis (PCA) and Partial Least Square Regression (PLSR) model was applied [12]. The methods were performed in the MATLAB 2018 software.

- *Principal Component Analysis:*

To scale down the dimensionality of data beyond abundant lack of information the Principal Component Analysis (PCA) method was used. It is a statistical procedure to transform a set of consideration of possibly correlated variables into principal components i.e. a set of values of linearly not correlated variables [13]. These represent the linear-independent spatial pattern and uses an orthogonal transformation.

IV. RESULT AND DISCUSSION

From all the thirty (30) soil samples, three (3) main types of soil texture i.e. Clay, Sand and Silt were detected [14]. The 30 samples of soil were separated into 20 soil samples for the calibration set and 10 soil samples for the validation set [15]. For determination of texture of collected samples of soil, it is confirmed that there are three major specific bands around at 1400, 1900 and 2200 nm respectively for sand, silt, and clay. With the use of ASD FieldSpec4 Spectroradiometer, we have captured the reflectance of soil samples. By calculation, the result showed that the PCA values for sand, silt, and clay are 0.060, 0.052 and 0.072 respectively.

The linear fitting plots shown in Fig. 3, 4 and 5 are calculated results of features for clay, sand, and silt respectively. The plot shows the different 13 features calculated for classification by using the regression technique. For detection of soil texture PCA used for feature extraction and PLSR used for classification. The linear fitting plot displays the 13 features with accurate fitting probability on y-axis and data on the x axis. The values correlate to calculated results and demonstrate the linear fitting plot.

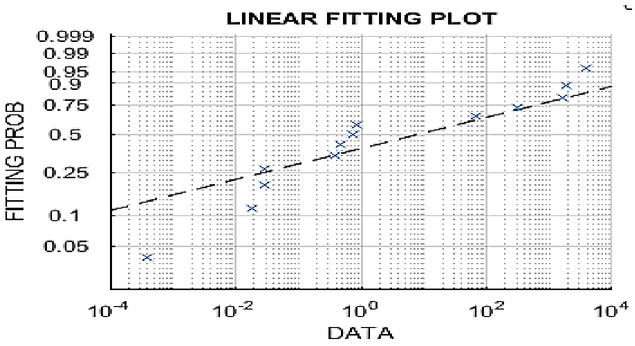

Fig. 3 Linear fitting plot of calculated features for Clay.

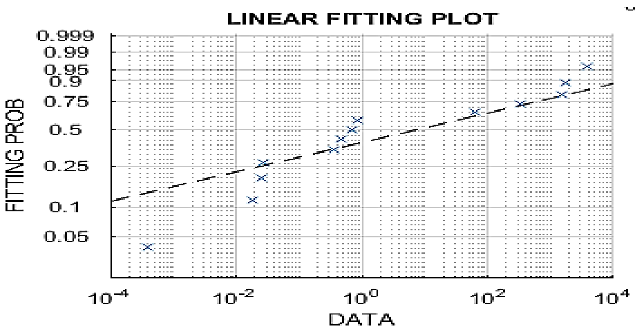

Fig. 4 Linear fitting plot of calculated features for Sand.

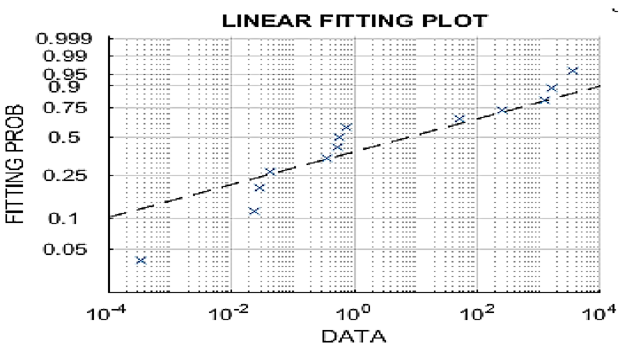

Fig. 5 Linear fitting plot of calculated features for Silt.

Fig. 6 Analysis of Sand, Silt and Clay respectively by using Bar charts of 13 features: (a) Integrated value (IEMG) , (b) Modified Mean Absolute Value (MAV1), (c) Modified Mean Absolute Value type2 (MAV2), (d) Simple Square Integral (SSI), (e) Waveform Length (WA), (f) Difference Absolute Standard Deviation Value (DASTDV), (g) Mean Absolute Value (MAV), (h) Variance of Soil (VSOIL), (i) Root Mean Square (RMS), (j) Autoregressive, (k) Hjorth Activity (HA), (l) Hjorth Mobility(HM),(m)HjorthComplexity(HC).

The Table-I shows the calculated parameters for soil texture. It indicates the final simulation of the present research with PCA, R^2 and RMSE values.

Table-I: Parameters for textural fractions.

Soil class	PCA	R^2	RMSE
Clay (< 0.002mm)	0.060	0.990	0.02392
Silt (0.002- 0.05mm)	0.052	0.988	0.02399
Sand (0.05 - 2mm)	0.072	0.989	0.02289

Fig. 6 shows the analysis of 13 features calculated in this study of sand, silt, and clay respectively by using Bar charts. The charts indicated the Integrated value i.e. IEMG, Modified Mean Absolute Value (MAV1), Modified Mean Absolute Value type2 (MAV2), Simple Square Integral (SSI), Waveform length (WA), Difference Absolute Standard Deviation Value (DASTDV), Mean Absolute Value (MAV), Variance of Soil (VSOIL), Root Mean Square (RMS), Autoregressive, Hjorth Activity (HA), Hjorth Mobility (HM) and Hjorth Complexity (HC) respectively. By using the analysis with the help of bar charts we can observe easily the difference between calculated values of sand, silt, and clay for the determination purpose easily.

Based on the above results it is clear that both the PCA and PLSR techniques give more accurate results than other techniques. So, the accuracy of the present study is:

Table-II: Confusion Matrix.

Actual		Predicted		
		Sand	**Clay**	**Silt**
	Sand	7	1	-
	Clay	-	11	-
	Silt	1	-	10

Therefore,

Accuracy = Number of samples predicted correctly /Total number of samples.

Here,

Number of samples predicted correctly =28

Total number of samples =30

So,

Accuracy = 28 /30

= 0.933

% Accuracy = 93 %.

Therefore, the proposed method gives 93% accuracy with the best results.

V. CONCLUSION AND FUTURE SCOPE

To improve performance and accuracy the proposed research represents a prediction of soil texture by using regression technique. In this study we have also done the analysis by applying two methods, one is the PCA analysis for feature extraction and the second one is the PLS regression algorithm for classification. The output of the regression decides to predict soil texture. This research concluded that to determine the texture of soil the VNIR-SWIR reflectance spectroscopy method is vital, speedy and gives fast results with more accuracy than the conventional laboratory approaches. The results gives R2 = 0.99, R2 = 0.988 and R2 = 0.989 for clay, silt and sand respectively. For precision farming practices and decision making in agricultural management, this research gives superior outcomes.

In the future scope, for developing more effective predictive models and more other classes of soil texture, the large area for study along with more samples of soil will be considered. By using satellite imagery or USDA soil texture triangle the discovered soil texture classes will be quantitatively mapped.

ACKNOWLEDGMENT

The Department of Computer Science and Information Technology supports the present work under the funds for Infrastructure under Science and Technology (DST-FIST) with sanction no. SR/FST/ETI – 340/2013 to Department of Computer Science and Information Technology, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad (MS), India. The writers would like to thank the department and university authorities for providing the infrastructure, laboratory equipment and needed support.

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