Remote sensing based generalized model for estimating soil properties

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Abstract

In recent years, the parallel developments in computing and high-resolution remote sensing sensors have revolutionized the information extraction capabilities. At present, the applications of remote sensing techniques to finer levels of identifying and quantifying the soil characteristics are few. Evaluation of soil characteristics involves decision-making and modeling multiple interwoven criteria. Synergistic use of remote sensing and ancillary data can be made for the development of the database required for estimating the soil characteristics. In this study, an attempt has been made to approximate the soil grain size using reflection data. The system is represented by a Generalized Model (GM). The correlation matrix was developed and decomposed spectrally into components. The developed model was tested in a part of Hardwar District of Uttarakhand state. The model efficiency is found to be about 85%.

Introduction

Estimation of soil grain size is carried out through soil sampling from the field and their subsequent analysis in the laboratory. This makes the entire process a difficult costly, tedious, time consuming and above all it is labor intensive. Hence there is a need to estimate the soil properties using a synergistic approach. Energy-matter interaction is a complex phenomenon. When Electro Magnetic Radiation (EMR) interacts with soil mass, a part of the incoming radiation is reflected back, a part of it is absorbed and another part is transmitted in to the soil mass. The process is dictated by physical and chemical properties of the material. Thus, from study of reflection pattern of EMR it may be possible to estimate the soil properties. In this direction laboratory studies by many investigators (Bowers and Hanks, 1965, Shockley et al., 1962, Orlov, 1966, Dubey 1991) have indicated that the reflectivity of soil mass is influenced by a variety of parameters. Keeping this in view the present study has been carried out in a part of Hardwar district of Uttaranchal State. Investigation program is described below.

Creation of database

In the study area a total of 25 field experimentation sites were selected. At each site an open flat and homogeneous area of about 10m x 10m was selected. In this10m x10m area under study, 5 observation points were selected. From each point about 2 kg Soil was collected for mechanical analysis in the laboratory. A spectra radiometer measures the reflection in much narrower wavelength and hence was preferred and used. The data was collected in the spectral range of 0.4μm to 1.10 pm at a regular interval of 0.05μm. Five sets of readings each, while increasing the wave length were taken. Spectral data from all the five points of an experimental site was used to calculate the average reflectance data. The process was repeated for each sample.

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The collected soil samples were put to mechanical analysis.

Generalized model (gm)

As mentioned above the reflection data is multivariate. The techniques commonly adopted for the analysis of multivariate data are Cluster Analysis, Discriminant Analysis, Multivariate Regression and Multivariate Optimization (Dunteman, 1984).

In the present study data combination (extracting components) that involves the selection of a set of weights to the dependent variables has been adopted for data integration.

The weights have been calculated in such a manner that the combination becomes representative and at the same time it has maximum correlation with the independent parameter. The Generalized Model (G M) involving y as dependent variable and p independent variables, $x_1, x_2, x_3 ... x_p$ can be written as:

$y = b_0 + b1\ x_{11} + b_2\ x_{12} + ... + b_n\ x_{1n} + e$ ...(1)

In matrix notation the above equation can be written as:

$Y = B X + E$, ...(2)

where Y is a column matrix representing the dependent variable, B is a vector representing the weights to the dependent variable, X is a matrix representing the independent variables, and E is a matrix representing the random observational error. It is worth mentioning here that there is no unique weight matrix B that determines the model.

In the present study the problem has been formulated as, the determination of weight vector, $b' = [b_{11}, b_{12} ... b_{ip}]$, such that the variance of: the composite ($b'x = b_{11}x_1 + b_{12}x + ... + b_{ip}x$), which is represented

$$b'b = \sum_{i=1}^{p} b_{li}^2 = 1 \qquad (3)$$

by the matrix b' V b, is maximized. V_{pxp} is a covariance matrix of the observed independent variables. Maximization has been carried out, subject to the constraints described in equation (3).

The objective function has been written in equation. No. 4.

$$y = b'Vb - \lambda\ (b'b - 1) \qquad (4)$$

where y is the function to be maximized, I represent the identity matrix and λ a Lagrange multiplier. The condition, (b'b-1) reflects the condition that b'b-1 = 0. This condition ensures a unique solution. The vector b' has been obtained by maximizing the above-mentioned objective function. Stationary points have been obtained by differentiating equation (4) with respect to b' and equating to zero.

$$\frac{y}{b}, \quad 2\ Vb \quad 2 \quad b \quad 0$$

or ,

$(V- \lambda I)\, b= 0$ (5)

Since b ^{1} 0; the matrix (V-lI) must be singular, that is, (V-lI) = 0; Pre multiplying equation (5) by b' yields.

$$b' (V-\lambda I)b = 0, \text{ or}$$

$$b'Vb = \lambda \qquad ...(6)$$

Equation (6) suggests that b' may be obtained by maximizing b' V b =l, that is the variance of the composite. The vector, b, associated with the largest root and other roots can be evaluated then after. The elements of the vector are the weights to the variable.

Literature shows that it is a common practice to consider the sample correlation matrix instead of the sample covariance matrix while calibrating the model. Keeping this view in the present study, sample correlation matrix has been considered in order to determine the weights. In general the number of the composites may be equal to the number of the dependent variables. In the literature at least three approaches are available for deciding the number of the latent roots and hence the number of composites to be considered in a particular study.

A computer program was developed in order to implement the above algorithm. The adopted algorithm for carrying out the G M is summarized as under:

- From the observed data the correlation matrix R has been evaluated. Successive powers, of the matrix R starting with R, R^2, R^4 and so on has been computed, until it is noticed that the elements of $a'R^i$ and $a'R^{2i}$ are proportional to each other. The vector a' can be any arbitrary vector. At this stage the solution is converged and $a'R^i$ is proportional to the largest latent root vector b.
- Latent vector (b) is evaluated corresponding to each of the latent root. This latent vector is also known as weighting vector.
- From the original correlation matrix the residual correlation matrix is computed using spectral decomposition theorem. Operations that are mentioned in steps 1 and 2 above are carried out on the residual matrix in order to obtain the next largest latent root and corresponding weighing vector. This process continues till the correlation matrix is completely exhausted.

Data Analysis & Results

Mechanical analysis of soil sample was carried out to determine the grain size distribution of soil sample. Sample grain size distribution curve is shown in Fig. 1.

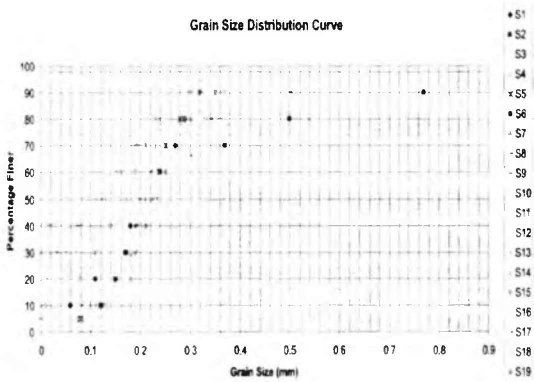

Fig. 1

The graphical relation between soil reflection observed by radiometer and observed d50 of the soil is shown in Fig. 2

Analysis of this figure indicates a definite and strong relation between d50 and soil reflectance. The problem of approximating the soil grain size from observed reflectance has been formulated as under.

$$d_x = A_x\,(\sum W_1\, R_1) + B_x$$

where; dx is the diameter of grain size finer than x percent, W_1 is the weight corresponding to the ith band (4, 5, 6, and 7) reflectance, R_1 is the reflectance in the i^{th} band, both A_x , B_x are constants. Both the constants A_x, B_x, have been evaluated in least square sense. Whereas the W_1 vector has been evaluated using the mentioned GAM. The general model for the approximation of the grain size is:

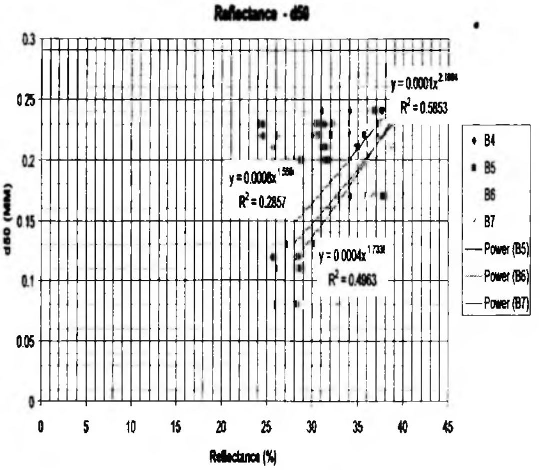

Fig. 2

$d_x = A_x (-0.95 R_4 - 0.15 R_5 + 0.30 R_6 + 0.20 R_7) + B_x$

The coefficients Ax and Bx are given in Table 1.

Table 1 Variation of Ax & Bx

Dia (d_x)	A_x	B_x	R^2
D10	0.15	0.25	0.89
D20	0.40	0.30	0.85
D30	0.55	0.30	0.88
D40	0.80	0.45	0.90
D50	0.95	0.809	0.90
D60	1.05	1.30	0.85
D70	1.05	2.30	0.90
D80	0.45	4.15	0.88
D90	0.25	6.35	0.88

After calibrating the model testing was carried out to predict the grain size using the observed reflection data. The observed and predicted grain sizes were graphically compared in Fig. 3.

A perusal of this figure indicates that the observed and predicted grain sizes from GAM are comparable. Further the prediction efficiency is about 85%.

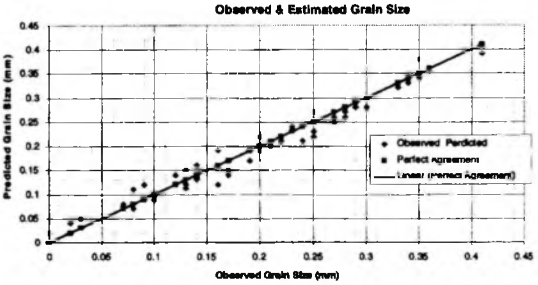

Fig. 3

Conclusions

Above study has demonstrated that the soil properties are reflected in their reflectance pattern. From soil reflectance pattern it is possible to determine the soil grain size distribution. GAM can be used to model the reflection pattern to approximate the soil grain sizes. The laboratory test results are encouraging. For adopting the model to other areas, will require further detailed investigations.

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