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Development of Soil Spectral Library and Fertility Mapping using Hyperspectral Remote Sensing in Pantnagar Region, Uttarakhand

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***Abstract*:** Hyperspectral remote sensing is an advance technology that facilitates the implementation of field soil data into digital soil mapping. It provides easier and effective way in understanding of soil chemical, physical, mineralogical and biological characteristics. In the present study a soil spectral library and fertility maps were developed based on different soil series for the university farm of GBPUA&T, Pantnagar. Twenty-five soil samples were collected from the farm at regular intervals. The samples were analyzed for soil texture, available nitrogen, available phosphorus and available potassium. Various soil-related indices were calculated from Hyperion imagery, which included Brightness Index, Redness Index, Saturation Index, Coloration Index, Hue Index, Normalized Difference Vegetative Index and Ratio Vegetation Index and Carbon Difference Index. The soil spectra of soil series showed different reflectance intensity due to variability of organic matter, sand, silt and clay. Beni silty clay loam soil showed highest reflectance peak among all the soil series due to maximum silt content whereas Phoolbagh clay loam soil comprises highest organic matter that decreases the reflectance peak. Moreover, the multiple regression equation of available nitrogen and available phosphorus was found significant with R^2 of 0.66 and 0.61 respectively.

***Keywords*:** Hyperion, Hyperspectral remote sensing, Soil Spectral library

Remote sensing technology plays an important role in agriculture and also introduces new opportunities for improving agricultural practices. It consists large varieties of data in both spatial and non-spatial domains over large and inaccessible areas even in areas where little geologic and/or cartographic information available. Thus, the technique is ideally suited for regional studies. Soil is a complex and heterogeneous system; the assessment of soil properties is not so easy by using conventional methods. Soil texture also significantly influences the reflectance pattern. Soil spectral library approach is highly suitable to facilitate the determination of soil characteristic with relatively low cost and effort. The shape of soil spectra holds information about mineral composition, organic matter, water (hydration, hygroscopic and its free pore water), iron form, salinity and particle size (Shepherd and Walsh 2002). Therefore, soil spectral signatures describe the appropriate use of soil in precision agriculture. With increasing demand of spatial and temporal resolution concerning soil properties in various precision agriculture applications, traditional laboratory methods are proving inadequate (Ehsani et al 1999). Hyperspectral remote sensing technology is used to create a spectral signature and fertility mapping associated with different soil properties. Such information is used to improve the prediction accuracy in transforming the hyperspectral signals into meaningful soil attributes. Some spectral libraries also exist in developed countries on the bases of regional soil. Recently, a global spectral library with 3768 soils was developed in which only 104 soils were from the whole of Asia (Brown et al 2006) whereas in India, only a fewer spectral libraries are existing with different soil properties (Srivastava et al 2004, Santra et al 2009, Gulfo et al 2012). Many studies also demonstrated the contribution of RS data in mapping soil properties based on reasonable correlations between soil properties and reflectance spectra (Ray et al 2004, Bajwa and Tian 2005, Ghosh et al 2012, Gautam et al 2016, Bisht and Nain 2016). Due to large variation in soil properties, there is a requirement for developing more extensive spectral libraries and fertility maps representing specific region. Therefore, this study was conducted to develop soil spectral library and fertility maps of Pantnagar region that can further support in the classification and characterization of soils.

MATERIAL AND METHODS

Study area: The study was carried at Agricultural farm of GBPUA&T, Pantnagar, U.S. Nagar (Uttarakhand), India which is located at 29°N latitude, 79.29°E longitude and with an altitude of 243.80m from the mean sea level in the *Tarai* belt (Fig. 1). The study area falls under sub-humid to sub-tropical climate with hot dry summers and cool winters.

Soil characteristic: The soils of Pantnagar belong to Mollisols order and having six soil series viz. Patharchatta sandy loam (Psl), Nagla loam (Nl), Haldi loam (Hl), Phoolbagh clay loam (Phcl), Khamia sandy loam (Khsl) and Benisilty clay loam (Bsicl) (Deshpandey et al 1971). Twenty-five soil samples (surface soil) were collected from the university farm at regular intervals. The field work was undertaken during the month of May on a clear sunny day. The samples were analyzed for soil texture, available N, available P and available K using hydrometer method, Alkaline Permanganate Extractable Method (Subbiah and Asija 1956), Sodium Bicarbonate Extractable Method, (Olsen et al 1954) and Ammonium Acetate Extractable Method, (Muhr et al 1965) respectively. The physical and chemical characteristics of different soil serious examined in the study region was presented in Table 1.

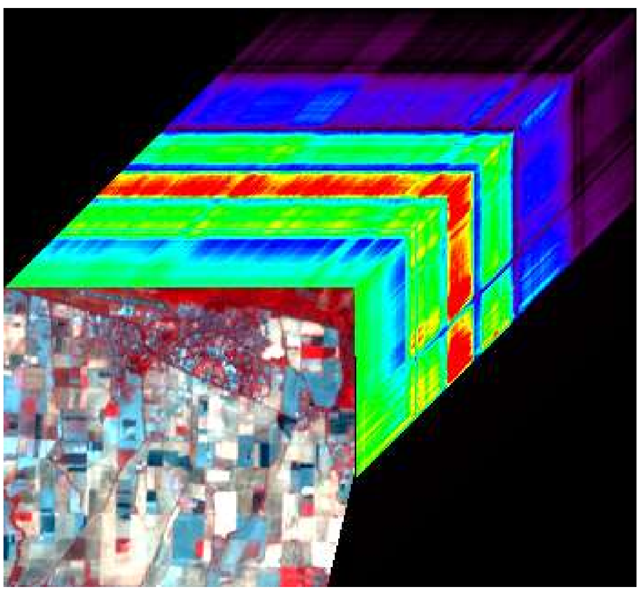

Fig. 1. Hyperion image of 2nd May, 2013 showing agriculture farm of GBPUA&T, Pantnagar

Remote sensing data acquisition: The Cloud free Hyperion imagery of May 2nd, 2013 was acquired from the United States Geological Survey (USGS) archive (http://earthexplorer.usgs.gov/). Hyperion has 242 spectral bands spanning a spectral range from 0.4 to 2.5 µm, with a sampling interval of 10nm

Pre-processing and atmospheric correction of hyperion image: In order to standardize L1GST hyperion image into ENVI format band, the original image was imported using Hyperion Tools 2.0 (White 2013) that contains wavelength, full width half maximum and bad band information. In this study, 147 bands were used finally used which are: bands 9 – 55, 86 – 119, 133 – 164, 183 – 184, 188 – 200, and 202 – 220. The image was atmospherically corrected into the surface reflectance using QUAC (Quick atmospheric correction technique).

Development of spectral library of different soil series: A ground survey of the study area has been made to precisely identify and collect soil samples of different soil series along with geographical coordinates. These geographical coordinates have been plotted on the Hyperion image of the study area and the spectral signature of each soil series have been extracted from the image by ENVI 4.8 software. Thereafter, a spectral library has been developed that comprising the six soil series of the study area.

Computation of spectral indices: Various soil-related spectral indices were computed from Hyperion data, after converting the digital numbers into radiance values. Those indices included soil related indices such as, Brightness Index (BI), Hue Index (HI), Saturation Index (SI), Coloration Index (CI), Redness index (RI) Normalized Difference Vegetative Index (NDVI) and Ratio Vegetation Index (RVI). The statistical models for estimating these indices are presented in Table 1.

Development of multivariate model: In the present study, stepwise multivariate statistical regression was carried out using SPSS package to model the relationship between spectral indices and soil organic carbon. The representative expression of multivariate model has been mentioned below:

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots\dots\dots + b_nX_n$$

Table 1. The physical and chemical characteristics of soils of Pantnagar region

Soil series	Texture	OM (%)	Sand (%)	Silt (%)	Clay (%)
Phoolbagh clay loam (Phcl)	Clay loam	1.89	26.54	44.70	28.76
Benisilty clay loam (Bsicl)	Silty clay loam	1.90	9.61	62.74	27.65
Haldi loam (Hl)	Loam	1.41	34.11	49.06	16.83
Nagla loam (Nl)	Loam	1.37	38.47	39.93	21.6
Khamia sandy loam (Khsl)	Sandy loam	1.27	55.68	27.69	16.63
Patharchatta sandy loam (Psl)	Sandy loam	1.20	52.89	33.98	13.13

Where, Y= dependent variables, b_0= estimated constant, b_n= estimate coefficients, X_n= independent variables

Spectral indices mentioned in Table 1 together with different individual's bands were used as independent variables, while SOC has taken as dependent variable.

Correlation coefficient: The relationship was established between observed and estimated SOC to analyze the accuracy of multivariate model.

$$r = \frac{\sum_{n=1}^{N}(Rn - R')(Cn - C')}{\sqrt{\sum_{n=1}^{N}(Rn - R')^2 * (Cn - C')^2}}$$

Where, *r* is the correlation coefficient, *R* is the selected variables (spectral band values and indices, *N* is the number of soil samples, here N is 25, *Cn* is soil organic carbon content of sample *n* and R' as well as C' are the mean values.

Root mean square error (RMSE): The RMSE has been used as a criterion for model evaluations and has been computed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

Where X_{obs} is observed values and X_{model} is modelled values.

RESULTS AND DISCUSSION

Spectral library of different soils: The spectral signature of the individual soil series has been collected and plotted on the Hyperion image for Pantnagar. The spectral library of soil series namely Patharchatta sandy loam (Blue), Nagla loam (green), Haldi loam (sea green), Phoolbagh clay loam (red), Khamia sandy loam (brown) and Benisilty clay loam (purple) of Pantnagar region has been represented in figure 2 and reflectance value of each soil series corresponding to different hyperion bands was compiled in Table 3. Results showed that the reflectance curves for all six soil series increased continuously in visible bands (426.18nm, 436.99nm, 487.86nm, 538.74nm, 569.26nm, 681.19nm) while corresponding to wavelength 894.87nm, soil reflectance represented less fluctuation as compare to red band (681.19nm). Although spectral curve in SWIR (short-wave infrared) region for different soil series showed almost similar kind of response and maximum reflectance (55.35%) reached at 2052.44 nm. Consequently, the general reflectance of bare soil was increased as wavelength increased (Nagler et al 2000). However, soil series affected the spectral reflectance due to its influence on water holding capacity and the size of soil particles in different soil series. As organic matter content decreases, soil reflectance increases throughout from 0.4 to 2.5µm wavelength. Since the sand content and organic matter content in Khamia sandy loam was 55.68 and 1.27%, respectively and in Patharchatta sandy loam soils are 52.89 and 1.20%, respectively. The reflectance values were high for Khamia sandy loam and Patharchatta sandy loam due to high sand content and relatively low organic matter content. Phoolbagh soil showed lowest reflectance among all six soil series. This soil has high proportion of clay and organic matter *i.e.* 28.76 and 1.89%, respectively that causes a decrease in reflectance. Studies showed that soil organic matter increases the absorbance of the soil(Chen *et al.* 2000). However, silt content of soil is considered as major controlling factor for spectral reflectance. Haldi soil has more silt content (49.06%) than Nagla soil, thus reflectance of Haldi soil is more as compared to Nagla soil whereas Beni soil possesses highest proportion of silt content and showed maximum reflectance peak among all the soil series. Similarly, Saxena *et al.* (2003) also reported the spectral reflectance characteristics of some dominant soils occurring on different altitudinal zones in Uttarakhand Himalayas.

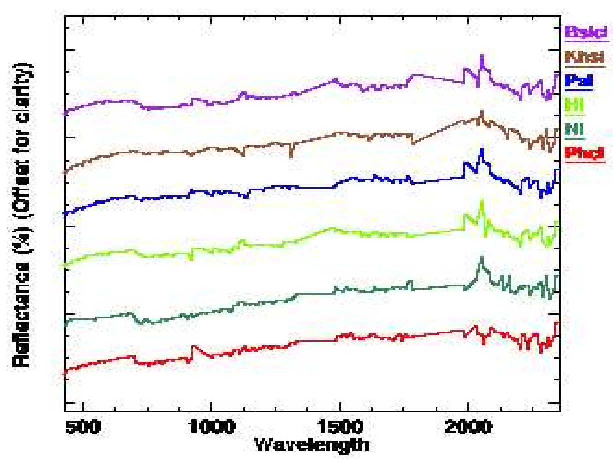

Fig. 2. Comparison of soil spectral library for different soil series of Pantnagar

Table 2. Spectral indices calculation using hyperion image

Index	Formula Index	References
BI	$\{(B^2+G^2+R^2)/3\}^{1/2}$	(Mathieu and Pouget 1998)
RI	$R^2/(B*G^3)$	(Mathieu and Pouget 1998)
SI	(R-B)/(R+B)	(Mathieu and Pouget 1998)
CI	(R-G)/(R+G)	(Mathieu and Pouget 1998)
HI	(2*R-G-B)/(G-B)	(Mathieu and Pouget 1998)
RVI	NIR/R	(Jordan 1969)
NDVI	(NIR-R)/(NIR+R)	(Rouse et al 1974)

CDI (Carbon difference index) was developed by taking the difference between band 199 and band 184

Where, R, G, B and NIR are red, green, blue and near infrared bands respectively

Where R = 681.19 nm, G = 569.27 nm, B = 487.87 nm, NIR= 894.88 nm

Statistical characteristics of soil parameters: The chemical analysis of 25 soil samples showed high spatial variability in available N, available P, and available K content among the different soil sampling sites. This may be due to natural or by human activity (Olorunlana 2015). The statistical summary of all soil samples of different locations shows the mean, median, standard deviation and coefficient of variation (CV) (Table 4). Mean of available N content for surface soils (0–15 cm) was 90.86 kg/ha, available P was 27.41 kg/ha and available K was 156.8 kg/ha. These values show that overall the soil has low available N, high available P and high available K.

Soil properties showed large variability, with lowest CV being observed for available P (18.67%), whereas available N and available K have moderate CV of 24.69 and 26.95%, respectively. These result revealed that the variability of the soil properties is mainly due to textural characteristics, chemical properties and organic matter.

Pearson correlation between spectral parameters and soil properties: The correlation between soil properties and different spectral indices was performed by using SPSS software package. Table 5 showed the relationship between soil properties (available N, available P and available K) and spectral reflectance. Available N has significant negative correlations with red band (-0.55**), green band (-0.46*), band 97 (-0.44*), band 143 (-0.44*) and HI (-0.41*). All spectral bands and indices except CDI (-0.40) had negative correlation with available nitrogen. The significant correlation of available N was not observed with CI, RI, RVI, NDVI and blue band. However, available P showed negative correlation with spectral bands and indices except NDVI and RVI. It showed highly significant negative correlation with BI (-0.41*) and RI (-0.43*), whereas significant correlation of available K

Table 4. Statistical characteristics of soil samples

Parameters	Mean	Median	SD	CV (%)
Available N (kg/ha)	90.86	87.80	22.44	24.69
Available P (kg/ha)	27.41	27.81	5.12	18.67
Available K (kg/ha)	156.8	184.8	42.26	26.95

Table 3. Reflectance of six soil series of Pantnagar corresponding to different Hyperion bands

Bands		Reflectance (%)					
Bands No.	Wavelength (nm)	(Phcl)	(Bsicl)	(Hl)	(Nl)	(Khsl)	(Psl)
8	426.18	14.04	21.60	17.36	16.20	18.36	18.24
9	436.99	15.28	22.20	20.11	15.87	20.11	17.99
14	487.86	18.75	25.17	20.32	19.64	24.11	21.43
19	538.74	21.29	28.06	23.66	22.56	27.21	23.91
22	569.26	21.49	28.93	25.62	22.66	28.10	26.79
33	681.19	22.96	29.25	27.89	23.45	28.95	28.27
54	894.87	20.48	27.82	25.59	22.25	27.10	28.93
79	932.63	30.59	30.59	28.55	20.40	29.87	30.59
89	1033.49	22.91	27.910	26.91	23.92	27.87	30.90
99	1134.38	30.77	34.19	30.77	27.87	34.19	27.35
110	1245.36	27.84	31.57	30.14	28.70	30.87	30.22
118	1326.05	31.96	34.42	31.96	31.96	33.33	34.42
134	1487.53	33.92	42.40	38.16	38.16	42.20	33.92
137	1517.82	37.33	37.33	37.33	33.84	42.30	37.33
149	1638.80	37.94	37.94	37.94	37.94	36.65	36.15
164	1790.18	35.57	44.17	35.57	35.57	35.57	35.57
184	1991.95	35.76	47.68	47.68	35.76	47.68	47.68
190	2052.44	36.90	55.35	55.35	55.35	55.35	55.35
201	2163.43	35.75	35.75	35.75	44.69	44.69	35.75
205	2203.82	29.41	29.41	29.41	39.22	39.22	29.41
216	2314.81	35.94	35.94	35.94	35.94	35.94	35.94
219	2345.10	43.58	43.58	43.58	43.58	43.58	43.58
220	2355.20	45.12	45.12	45.12	45.12	45.12	45.12

was not observed with spectral bands and indices but maximum negative correlation was recorded as -0.37 with band 219 followed by -0.23 with band 214.

Multivariate statistical regression models for soil properties: The Different multivariate models were generated between soil properties viz. available N, available P and available K and spectral parameters using stepwise regression technique (Table 6). The empirical relation between available N and spectral indices was highly significant with R^2 = 0.66 while available P showed significant with R^2 of 0.61. However, available K, though individually had no significant correlation with spectral parameters and also did not form a significant multiple regression equation (R^2=0.51).

A scatter plot (Fig. 3) was prepared between measured and predicted value of available N, available P and available K. Results showed a good agreement between the predicted values and the measured values of available N, available P and available K with R^2=0.64, 0.55 and 0.50 respectively and RMSE has been observed as 16, 12 and 18% respectively. Similar types of studies were conducted by Zheng (2008), Kadupitiya et al (2010) and Ghosh et al (2012).

Variability map generation: The multivariate model of for available N, available P and available K were also applied to the hyperion image data to develop soil fertility variability maps (Fig. 4) over the study area. Available N content varied from 86.4 Kg/ha to 172.9 Kg/ha over agricultural farm of Pantnagar. Available N map was classified into four class average values of 37.5, 75.0, 112.5 and 173 kg/ha, represented from dark to light tones. The results showed that the available N over Pantnagar farm region was relatively low. Available P map was classified into three class values of 13.3, 26.7 and 40 kg/ha, represented from dark to light colors. The yellowish color in this image corresponds to higher amounts of P in surface soil. Most of the regions come under the range of high available P content. It was also observed from Figure 4(c) that most of the study areas come under high available K. Available K map was classified into three class values of 83.3, 166.7 and 250 kg/ha, represented from dark to light colors. The light shade in the figure corresponds to

Table 5. Correlation study of spectral parameters derived from hyperion image and soil properties

Spectral parameters	Soil properties		
	N	P	K
BI	-0.36	-0.41*	0.09
CI	-0.25	-0.01	0.07
HI	-0.41*	-0.05	0.31
RI	-0.32	-0.43*	0.11
SI	-0.38	-0.08	0.19
RVI	-0.10	0.02	0.10
NDVI	-0.12	0.01	0.20
CDI	0.40*	-0.02	0.17
Blue (487.86)	-0.31	-0.31	-0.01
Green (569.27)	-0.46*	-0.36	0.13
Red (681.19)	-0.55**	-0.36	0.13
BAND 97 (1114.2)	-0.44*	-0.18	0.27
BAND 143 (1578.3)	-0.44*	-0.28	0.11
BAND 201 (2163.43)	-0.16	-0.18	-0.13
BAND 215 (2304.7)	-0.16	-0.25	-0.23
BAND 216 (2314.8)	-0.26	0.12	-0.08
BAND 219 (2345.1)	-0.20	-0.22	-0.37

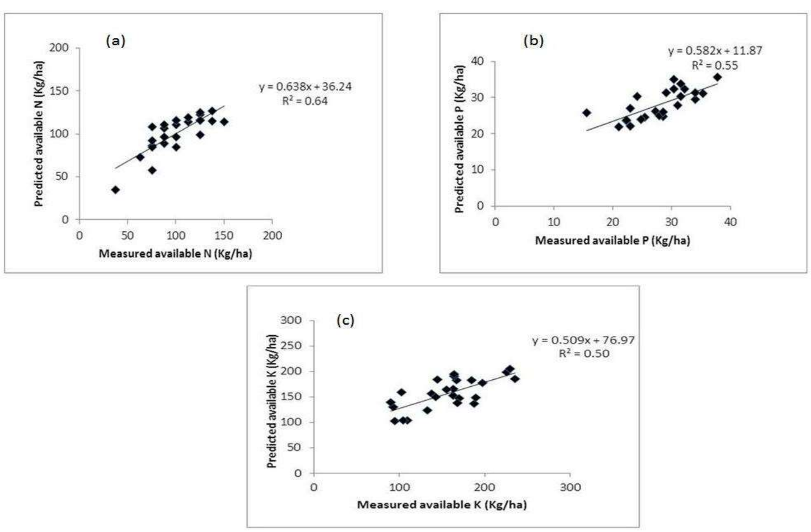

Fig 3. Comparison of measured and predicted (a) Available N, (b) Available P and (c) Available K

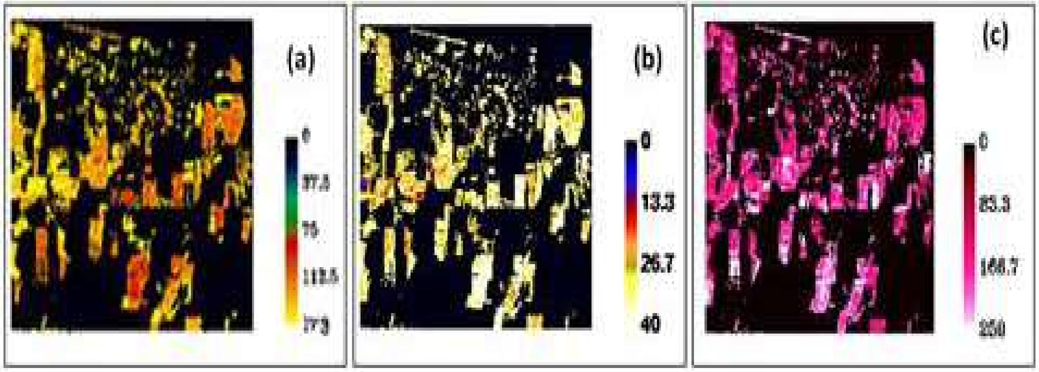

Fig. 4. Spatial distribution of (a) Available N, (b) Available P and (c) Available K

Table 6. Empirical equations between soil properties and spectral parameters derived using stepwise regression technique

Regression model	R^2
Available N (kg/ha)=128.09+253.52*NDVI-47.69*RVI-337.88* RI+309.33*Band 14-286.89*BI+41.03*Band 219	0.66
Available P (kg/ha)= 20.13-1391.35*RI-3.92*CDI-22.66*Band 219+38.06*Band216+161.49*BI-37.87*Band215-47.43*Band14-24.04*Band97	0.61
Available K (kg/ha)= 177.24-226.32* Band 219+765.62*Band 143+26.42* CDI+0.23* HI-676.66*Band97-316.77*Band215+390.49*BI+199.86*CI	0.51

Where, Band 14= 487.9nm, Band 97= 1114.2nm, Band 143= 1578.3nm, Band 215= 2304.7nm, Band 216= 2314.8nmand Band 219= 2345.1nm

higher amounts of K in surface soil. These variability maps can be used for site-specific soil fertility management.

CONCLUSION

The soil spectral library was able to support the characterization of six soil series of Pantnagar region. The soil reflectance intensity was influenced by the proportion sand, clay, silt and organic matter. Organic matter promoted the reduction of reflectance intensity and softening curve of reflectance in Phoolbagh clay loam, Nagla loam and Haldi loam whereas the decrease level of organic matter in Pattarchatta soil series promoted an increase in the reflectance. Benisilty clay loam having high proportion of silt content showed spectral curve with highest reflectance intensity. Therefore, the study showed that hyperspectral remote sensing is feasible, fast and advance technique in soil property assessment.

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