IMAGE TRANSFORMATIOM AND GEO-STATISTICAL TECHNIQUES TO ENHANCE AND MAP SOIL FEATURES: AN APPLICATION IN ASSESSING SEDIMENTATION PROBLEM IN SOUTHERN NEPAL

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ABSTRACT

A method is proposed to transform the red and near infrared data into a soil index in order to map soil features. The index maximises soil variation and helps improve soil feature mapping while it suppresses spectral response from vegetation cover. Geo-statistical analysis of field data, on the other hand, helps understand spatial dependency pattern and map it, which may not be directly visible by remote sensing techniques. A case study in mapping sedimentation problem in the lowlands of Nepal is described. Yearly deposit of silt brought by irrigation water degrades soil physical condition and lowers fertility status, which results in eventual reduction of crop yield. Image transformation by means of band rotation helps generate soil index, which allows not only mapping areas affected by sedimentation but also separating areas with recent sediment deposition. Spatial variability study helps understand sediment deposition pattern and map the extent of sediment depth.

1. INTRODUCTION

For evaluation of land resources soil data is very important. It is especially crucial for the study of soil degradation. Remote sensing techniques help increase accuracy and efficiency of mapping. Surface reflectance from soil, however, depends on many factors: particle size distribution, surface roughness, crusting, soil colour, etc. In addition, soil features cannot be optimally mapped since soil brightness values fall within a narrow range in any spectral band except for some areas having very contrasting soils. On the other hand, all the properties of soil can not be directly detected and mapped using remote sensing techniques.

Research works related to mapping/evaluating land resources by means of remote sensing have been mainly on vegetation cover (Tucker, 1979; Curran, 1980; Jackson et al., 1983). Because of high absorption of visible light by plants, especially in red (R) portion of spectrum and high reflectance of radiation from near infrared light (IR), vegetation indices have been generated by band ratios (IR/R ratio) or computing their differences (IR–R). The most popular has been the Normalised Difference Vegetation Index (NDVI). Here the difference is normalised by their sum (IR+R) to eliminate intensity variations. A vegetation index can be also generated by using characteristic pixels representing pure vegetation (100% vegetation sample) and pure soil (0% vegetation), and computing their differences (Nieuwenhuis and Shrestha, 1984), which is used as transformation vector. In this case, all the spectral bands are used, instead of only red and infrared bands. However, application of remote sensing techniques for the study of soil has been modest, perhaps because soil is often covered by vegetation. An attempt to remove the spectral effects of the vegetation in the mixture model of soil and vegetation reflectance by estimating the vegetation component is shown by Hamid (1985). Kauth and Thomas (1976) described using the famous "triangular, cap shaped region with a tassel" in red-NIR space using MSS data that the point of the cap (which lies at low red reflectance and high NIR reflectance) represented regions of high vegetation and that the flat side of the cap directly opposite the point represented bare soil. In addition to the problem of surface cover by vegetation, soil features cannot be optimally mapped since soil brightness values fall within a narrow range in any spectral band except for some areas having very contrasting soils. Enhancement of soil features thus becomes very important.

Soil feature enhancement and mapping however are limited to only soil surface. Some features may not be directly detected by remote sensing techniques, such as soil depth, soil compaction, soil pollution, etc.. In such a case soil spatial variability analysis helps in understanding regionalized variation pattern and mapping such features, which may be very useful in applying suitable management practices and finally in alternate land use planning activities.

2. METHODS AND TECHNIQUES

2.1 Image transformation technique

In a two-dimensional feature space defined by red and infrared bands, the locations occupied by vegetation, soil and water can be seen occupying 3 pronounced locations forming a triangle (figure 1). The vegetation pixel occupies upper left position indicating high reflectance in near infrared and absorption in red portion of spectrum while soil pixel occupies upper right position indicating high reflectance in near infrared as well as red portion of spectrum. Dark soil surfaces will occupy lower-left positions in the feature space, while water bodies occupy further lower positions. Figure 2 shows clouds of pixels belonging to vegetation types, different soil types and including water bodies. From figure 1, we understand that soil pixels are located from upper right side to lower left side in the feature space. A diagonal line AB (figure 2) can be thus considered the line showing variation in soil differences. A method to transform the red and near infrared data into a soil index or soil line can be by means of band rotation. Anti-clockwise rotation of bands, through 2 degrees, can be performed by applying the following transformation:

$$\begin{pmatrix} X1 \\ X2 \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} Red\_band \\ NIR\_band \end{pmatrix} \quad (1)$$

Using the transformation matrix, new bands (X1 and X2) can be created by the combination of red and infrared data. In order to find the suitable angle of rotations, a linear least square method can be applied. The new band (X1) maximizes soil variation and helps improve soil feature mapping while it suppresses spectral response from vegetation cover. The second band (X2) gives information about vegetation. Since it is perpendicular to X1, it can be considered the perpendicular vegetation index (Richardson and Wiegand, 1977). The perpendicular vegetation index measures the changes from the bare soil reflectance caused by the vegetation. In this way it gives an indication of vegetative cover independent of the effects of the soil.

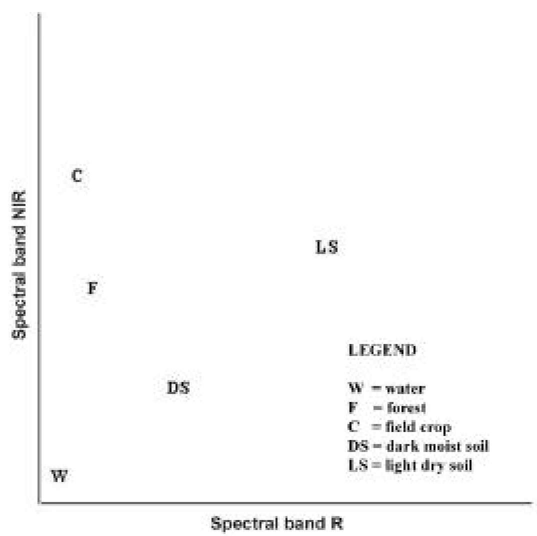

Figure 1: Hypothetical location of vegetation, soil and water bodies

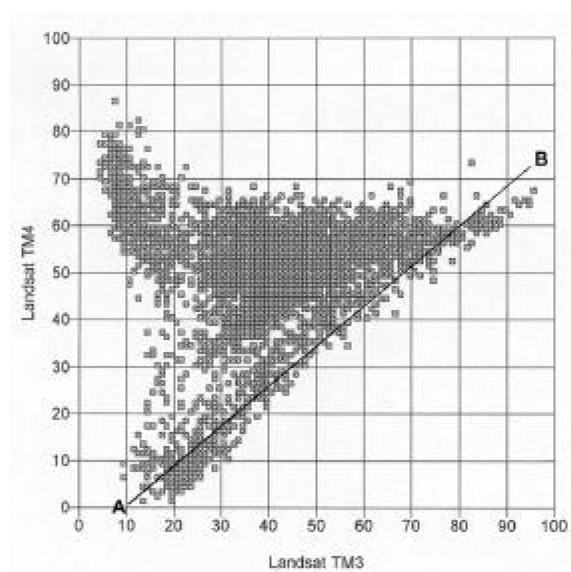

Figure 2: Clouds of pixels belonging to vegetation, soil and water bodies. Diagonal line AB indicates dark soil to light soil.

2.2 Spatial dependency analysis

Spatial variability study helps to understand the spatial distribution pattern of selected variables. The study uses the theory of regionalized variables (Matheron, 1971) and measures through semi-variance, which is given by:

$$\gamma(h) = 1/2m \, \Sigma \, \{z(x_i) - z(x_i + h)\}^2 \quad (2)$$

where,

$z(x_i)$ = property value at a given location (x_i)

h = lag (both distance and direction)

m = pairs of observation points, separated by h

$\gamma(h)$ = semi-variance at lag h

The theory of regionalized variables is based on two assumptions: (1) The expected value of the variable is constant and does not depend on the position x. When this holds true, the regionalized variable is said to be stationary in the mean with $E[z(x)] = \mu$, (2) The expected square difference between values at locations separated by the lag is finite and depends only on h and not on x. In the present study image transformation technique and spatial variability analysis were applied in a case study in southern Nepal where sedimentation due to irrigation water is yearly problem in the agricultural fields.

3. STUDY AREA

The study area lies in the Chitwan valley, within the Siwalik region of Nepal. The investigated area (Figure 3) lies between the coordinates 27^{o}36'05" and 27^{o}43'23" N and 84^{o}19'27" and 84^{o}27'56" E, covering 19,175 hectares. The elevation ranges from 180 to 220 m asl. This region includes predominantly north dipping, semi-consolidated, interbedded Tertiary conglomerate, sandstone, siltstone and shale units. The region is bordered to the south by the Terai piedmont and to the north by the Main Boundary Fault, which separates the Tertiary sediments of the Siwalik from the older bedrocks of the Middle Mountains.

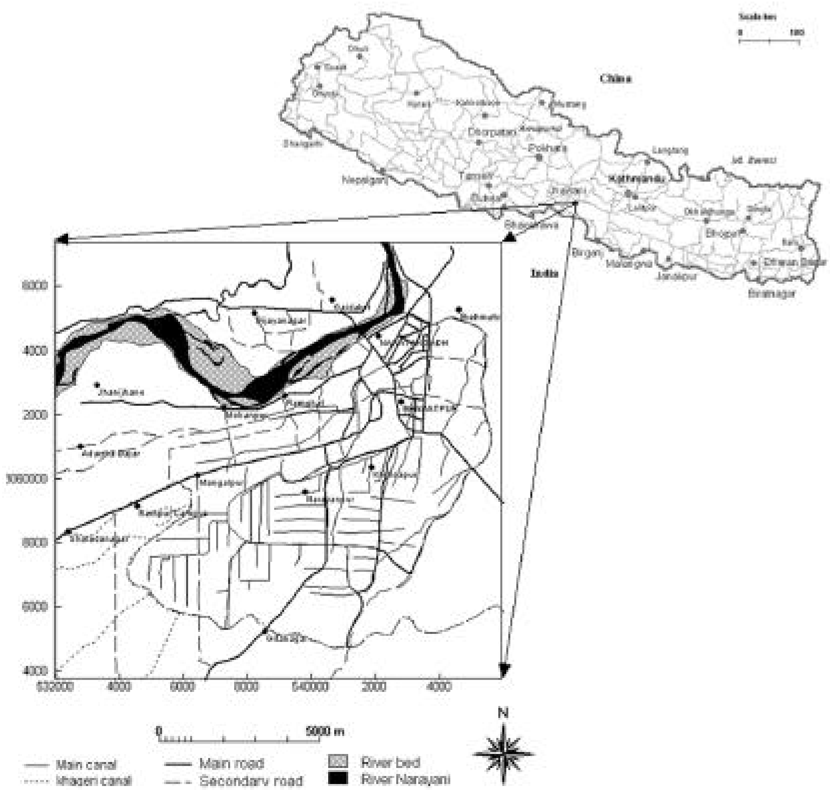

Figure 3: The study area

The area has a subtropical climate, with hot/moist summers and cool/dry winters. The average annual temperature is 24^o C. The mean summer temperature is 29 ^{o} C and the hottest months are May and June, with absolute maximum recorded temperature of 43^o C in June. The mean winter temperature is 16 ^{o} C and the coldest months are December and January, with absolute minimum temperature of 3^o C in January. The annual precipitation varies from 1584 mm to 2287 mm, with an annual average of 1830 mm, calculated from a 10-year period. More than 80% of the rain falls in the rainy season, during the period June - September. The winter months (November - March) are dry and, in some years, these months do not receive any precipitation at all. The calculated annual potential evapo-transpiration is 1954 mm, which exceeds the average annual precipitation of 1830 mm. The moisture deficit during the winter months (October - May) is 679 mm. Main vegetation types in the lowlands are acacia (*Acacia catechu*) and sisal trees (*Dalbergia sp.*), shrubs and coarse grasses. Crops such as rice, wheat, maize and mustard are grown. In the uplands sal trees (*Shorea robusta*) dominate and the crop sequence is maize-mustard/wheat-fallow. With the introduction of irrigation water, rice fields have considerably increased in the area.

Yearly deposit of silt brought by irrigation water however degrades soil physical condition and lowers fertility status. The siltation sediments are fresh materials consisting of unweathered minerals of quartz, feldspar and mica, without organic matter and without particle aggregation (Shrestha, 2000). Porosity is absent which hinders mater movement down the soil profile. The result is poor crop growth and low yields. The effect of sedimentation is at maximum close to the canals and decreases rapidly further away. Sediment depth was measured along a 750 m transect at equal distances of 12.5 m, which shows clearly that the effect is more near the irrigation canals (Figure 4). It is thus very important not only to know the extent of sedimentation problem but also to map the sediment depth.

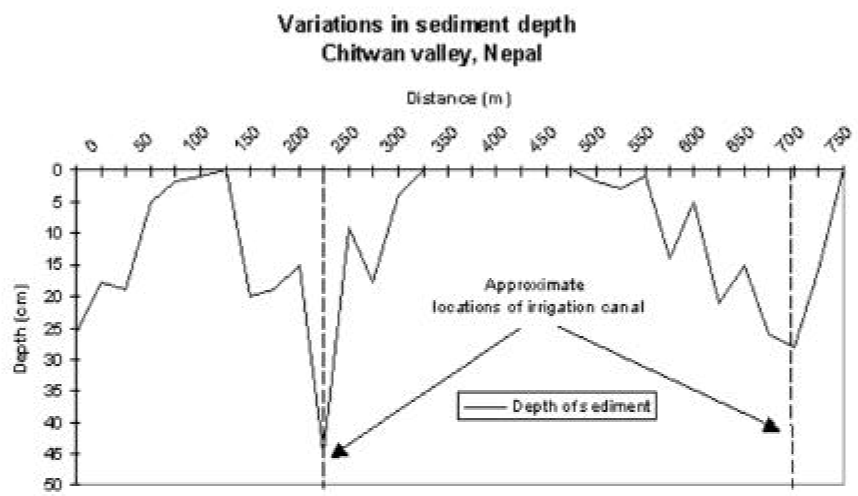

Figure 4: Variations in the depth of sediments laid down by irrigation water along a 750 m transect in the canal B area (Shrestha, 2000).

4. DATA PROCESSING

A Landsat TM quarter scene of 7 May 1992 (path 142, row 41), with spatial resolution of 30 m was acquired. The image was georeferenced using ground control points taken from topographic map sheets (no. 2784 06A, 2784 06B at scale 1:25,000). In order to find the desirable angle of rotation for generating soil line, 299 samples from bare soil surface areas were taken. Their locations in the feature space of Red and Infrared bands display elongated clouds of pixels, regression analysis of which shows high positive correlation ($r^2 = 0.86$). By linear least square method slope of the best fitting line and the offset value were computed as follows:

$$y = 0.84\,x + 13 \tag{3}$$

Where 13 is the constant for line intercept on Y- axis (TM band 4) and 0.84 is the constant for slope of the line which is about 40 degrees (arctan of 0.84 is $40^{o}.03'$). Substituting the cosine and sinus values of 40 degrees in equation 3, the new bands were generated using TM3 (red band) and TM4 (NIR band) as follows:

$$X1 = 0.77\,TM3 + 0.64\,TM4 \tag{4}$$
$$X2 = -\,0.64\,TM3 + 0.77\,TM4$$

In addition, the small bias in NIR (13) discussed in the correlation must be corrected: a shift of data in NIR band by subtracting it from TM4 was desirable. Thus, transformation equation was adapted as follows:

$$X1 = 0.77\,TM3 + 0.64\,(TM4 - 13)$$
$$X2 = -\,0.64\,TM3 + 0.77\,(TM4 - 13) \tag{5}$$

In order to obtain an image without vegetation and water, and thus having only soil, it is necessary to apply following conditional expression:

$$X3 = \text{If } X2 < 0 \text{ then } X1 \text{ ELSE } 0 \qquad (6)$$

This generates new band (X3) having only soil surface features; the rest of the area have pixel value zero.

In the field, data on sediment depth was collected along transects. The distance between the transects was kept at 50 and 100 m. Observations were located at fixed intervals of 12.5 m. Some observations were also done at 25 m or 50 m intervals. Altogether 170 locations were studied. Semi-variances were computed at different lags (multiples of the sampling interval of 12.5 m) using equation 2. The semi-variogram is fitted by a spherical model, which is derived from the volume of intersection of two spheres (Webster and Oliver, 1990). The sill variance is 115 and the range is 90 m which shows that beyond this distance there is no spatial dependency. To map the spatial variation of sediment depth point kriging method of interpolation (Krige, 1966) was applied in a 400 by 690 m2 area. The estimation is done by the weighted average of the property values at the surrounding locations.

5. RESULTS

The new band (X1) maximises soil feature variations and helps improve soil mapping since it suppresses spectral response from vegetation cover. The new band can be thus considered the soil index. The second band (X2) suppresses soil information but enhances vegetation features. The colour combination of the bands X2, X1 and the original TM band (e.g. TM5) maximises colour separation referring to soil features as compared to colour combinations of TM bands 4, 5 and 3. The siltation area in the Chitwan valley, obtained by image classification technique (Figure 5), could be further classified into older sediment deposition, moderately old sediment deposition and young sediment deposition by combining classes generated from the new band (X3) (Figure 6). The freshly deposited sediments are lighter in tone as compared to older sediments or sediments mixed with topsoil.

The interpolation map of the sediment depth shows concentration of lines indicating maximum variation over short distances close to the irrigation canal and the water outlet points (Figure 7).

6. CONCLUSION

Image transformation by band rotation using red and NIR bands maximises soil information. The technique can also be applied in other degradation studies, for example the application in soil erosion modelling where mapping of bare soil surfaces is important.

Spatial variability study helps in mapping soil properties not directly visible by remote sensing technique. Combination of both the techniques, image transformation and spatial variability analysis, will be very useful for land use planning activities.

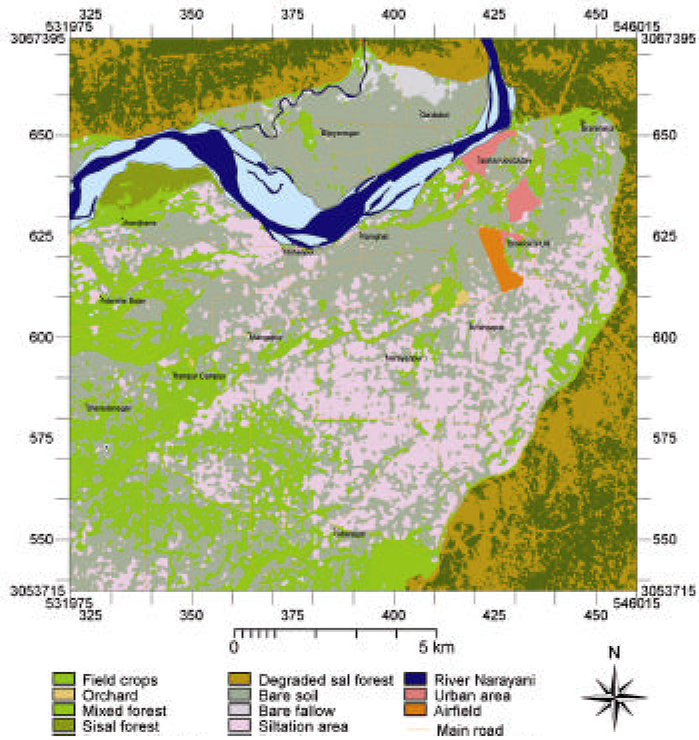

Figure 5: Land cover/land use classification (Shrestha, 2000)

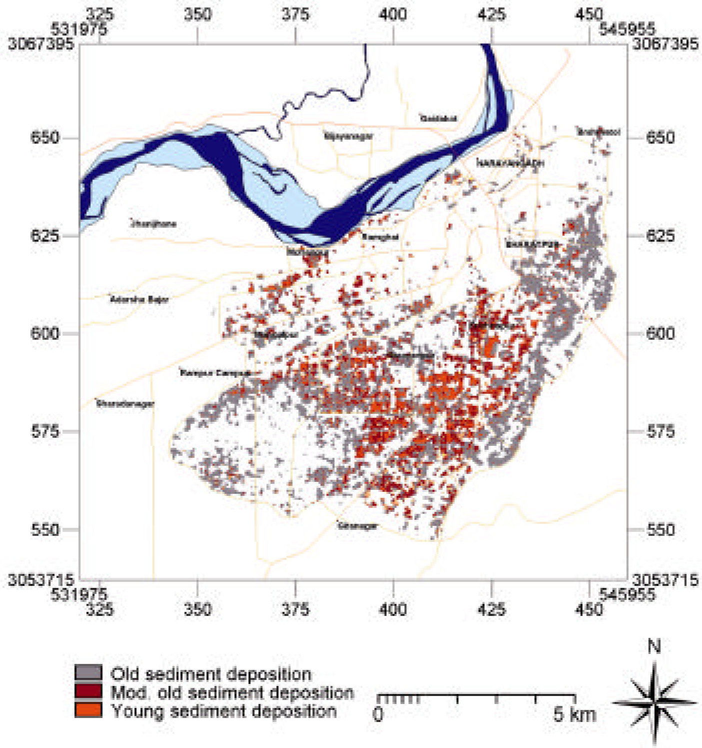

Figure 6: Classification of silt deposit

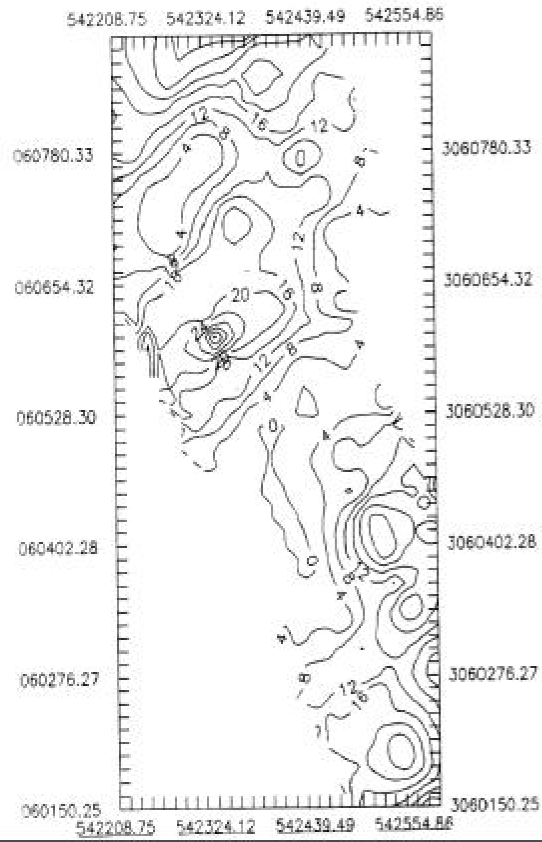

Figure 7: Mapping the effective depths (cm) of siltation

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