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Spatial variation of soil strength in small hilly watershed of Shivalik-Himalayan region in India

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ABSTRACT : The spatial variation of soil strength at different soil depths in agricultural field and non-arable hilly catchment was studied in *Torrifluventic Haplustepts* soil subgroup at Mandhala watershed in Shivalik-Himalayan region in India. Results showed that ordinary point Kriging interpolation technique was observed to be better as compared to Polynomial Regression and Nearest Neighbour method. Results also revealed that soil compaction values were generally low at field boundary in agricultural fields. High penetration resistance was observed in high elevation at hilly catchment. Variograms revealed that 26 m and 30 m sampling distance would be good enough for interpolating soil strength values all over the field up to 30 and 15 cm soil depth for agricultural field and hilly catchment areas, respectively, in the study area.

Key words : Spatial variation; Soil strength; Kriging; Variogram; Watershed

Soil strength is an important characteristic affecting many aspects of agriculture, such as soil erosion, performance of cultivation implements, root growth, yield and trafficability. The compaction of soils results from cohesive forces between soil particles and their frictional resistance to sliding past over one another. Characterization of soil strength is usually made by measuring the response of a soil to a range of applied force. Soil penetration resistance is an important mechanical property that can be used as an indicator of soil compaction.

Soil physical properties, nutrient levels and water contents vary from field to field and within fields. These spatial variations result from many factors such as land use, previous farming practices, topography of land and nutrient application inaccuracy (Fulton *et al.* 1996). With site specific technology farmers can select specific conservation measures, land use systems, adjust seed rate, depth of sowing, pesticides and fertilizers application for optimizing crop production across the field.

There are reports that soil degradation affects approximately one-third of the world land surface (Lal, 1988), making it necessary to be aware about the spatial variability of soil attributes and crop components (Vieira and Gonzalez, 2003). Soil as a natural resource, has variability inherent to show how the soil formation factors interact within the landscape. However, variability can occur also as a result of cultivation, land use and erosion. Vieira and Gonzalez, (2003) reported spatial variability in soil attributes as a result of land degradation due to erosion. There have been reports of spatial variability of soil properties, mostly affecting crop yield, since the beginning of this century (Harris, 1920), but a comprehensive tool to analyze spatial variability was not available until 1971 (Matheron 1971).

Shivaliks-Himalayan region in India have been identified as one of the eight most degraded agro-ecosystem of India and are included in the priority areas of watershed development programme (Awasthi and Sharma 2000). Because of its fragile geology, erratic rainfall, subsistence farming and biotic pressure high spatial variability of soil physical properties like soil strength, bulk density, hydraulic conductivity, etc. were noticed in watersheds. Assessment of spatial dependence of soil strength requires the application of geostatistical procedure, such as the analysis of scaled semivariogram and analysis of contour maps produced with the interpolated values using Kriging interpolation technique (Vieira and Gonzalez, 2003).

This paper deals with the use of geostatistics in the analysis of spatial variability of soil strength (soil compaction) both in flat agricultural field and hilly catchment of Mandhala watershed in Shivalik-Himalayas of India. The basic objective of the study was to assess the spatial dependence of soil compaction and minimum sampling distance of soil strength

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measurement required for site specific conservation measures and precision farming.

MATERIALAND METHODS

The study was conducted in Mandhala watershed in District, Solan (H.P. State) of lower Shivalik Himalayan region in India. The soils of the study region were classified under *Torrifluventic Haplustepts* soil sub-group with sandy loam to sandy clay loam soil texture. Soil compaction data were recorded in 180 x 160 m agricultural field (maize-wheat cropping sequence) with about 1 per cent slope and 90 m x 40 m hilly catchment *acacia*-grass (silvipasture land use) with about 50 percent slope. In agricultural field 90 sampling points (20 m x 20 m cell) were laid out as more homogeneity of soil structure and moisture contents were observed, while, in hilly catchment 50 sampling points (10 m x 10 m cell) were laid down because of heterogeneity of soil structure and moisture contents in steep sloppy land. The soil strength was measured at each grid node during August, 2005 with the help of Cone Penetrometer (SC900 Model). Soil compaction was measured up to 30 cm and 15 cm (at 2.5 cm interval) depth at agricultural field and hilly catchment, respectively, as presence of stones and gravels (25-35 %) below 15 cm depth at hilly catchment.

Three different interpolation techniques namely, Polynomial Regression, Nearest Neighbour and Kriging were tested to assess the best interpolation techniques for spatial variation of soil strength in that particular set of data. Simple planar surface polynomial regression (Draper and Smith, 1981), Nearest Neighbour and point ordinary Kriging (Cressie, 1991) were used in Golden Software Surfer 8 for interpolation. Twenty five and twenty random point data were collected in agricultural field and hilly catchment, respectively, to validate the interpolation techniques. The interpolated values were plotted against observed values to assess the best interpolated method. Contour maps of soil strength at different soil depths were drawn by best fit interpolation technique.

Data were sampled in such a way so as to allow for the application of geostatistical analysis. Spatial dependence (Vieira *et al.* 1983) can be evaluated by examining the semivariogram. It can be calculated using equation (1).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N} \left[Z(x_i) - Z(x_i + h) \right]^2 \qquad \text{.........(1)}$$

Where, N(h) is the number of pairs of values $Z(x_i)$, $Z(x_i + h)$ separated by a vector h. If the semivariogram increases with distance and stabilizes at the prior variance value, it means the variable under study is spatially correlated and all neighbours within the correlation range can be used to interpolate values where they were not measured. When, semivariograms are calculated using equation (1), the result is a set of discrete values of distances along with the corresponding semivariances for any distance within the measured domain, so there is a need to fit a mathematical model which would describe the variability as a continuous function of distance. The models were fit using least square minimization and judgment of the co-efficient of determination. In this study, variogram used were all fitted to the Rational Quadratic Model (Cressie, 1991), which is

$$\gamma(h) = C\left[\frac{h^2}{1+h^2}\right] + Co \qquad \text{.............(2)}$$

Where, $\gamma(h)$ is semivariogram, C_0 is the nugget value and C is the scale for the structured component of the variogram and h is the anisotrophy.

RESULTS AND DISCUSSION

Soil strength variation at different soil depths

The average values of soil strength showed that compaction was more in hilly slopy land than in agricultural field (Table 1). The average volumetric moisture contents of agricultural field and hilly catchment were determined as 19 and 16 per cent, respectively. Uncultivated land had greater penetration resistance than cultivated soils. Cultivated field had less soil resistance because continued tillage breaks the natural aggregates into weaker units, unlike uncultivated land which had stronger aggregates due to lack of soil disturbance and greater organic matter content (Vangas *et al.*,2004). It was observed that in agricultural field, soil strength increased up to 15 cm then it decreased, which might be due to slow settling of soil particles after plough layer opening during last week of May, 2005 for plantation of maize. In hilly catchment penetration resistance increased up to 12.5 cm depth. Data was collected only up to 15 cm in hilly areas because of predominance of rocks and stone below that depth which

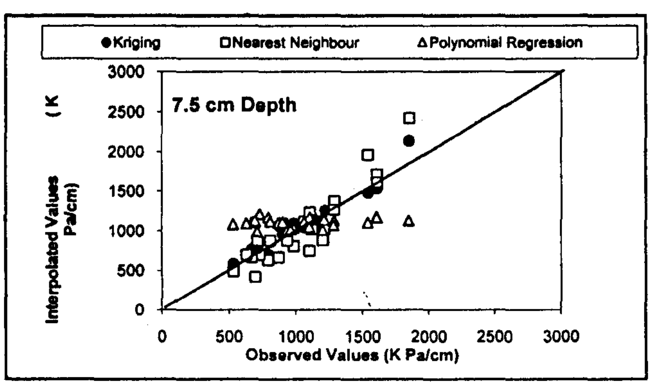
Table 1. *Average soil strength (KPa) at different soil depths in agricultural field and hilly catchment of watershed.*

Soil depth (cm)	Agriculture Field		Hilly Catchment	
	Soil strength (KPa)	C.V. (%)	Soil strength (KPa)	C.V. (%)
5.0	917	61	1908	61
7.5	1128	47	2302	46
10.0	1332	40	2039	42
12.5	1393	36	2243	41
15.0	1339	47	1991	41
17.5	1244	57	-	-
20.0	1199	54	-	-
22.5	1183	56	-	-
25.0	1192	59	-	-
27.5	1138	63	-	-
30.0	1150	64	-	-

resisted cone penetration. However, high co-efficient of variations (Table 1) were observed in both the cases which indicated the high spatial variation of soil compaction. A cone index of 2000 KPa was considered as the threshold value of root growth beyond which root growth was affected severely (Fulton *et al.*, 1996). It is also known that some degree of compactness is desirable (Drummond *et al.*, 2000). The average values of soil strength in agricultural field were much below the threshold level (Table 1), but it was more in hilly catchment. However, in small patches in agricultural field, soil strength exceeded 2000 KPa (Fig. 3) which needed to be tilled intensively for good maize-wheat production, as was reported by Philips and Kirkham (1962) who recorded maize yield reduction by 10 to 22 per cent due to compaction.

Geo-statistical interpolation and soil strength contours

Three interpolation techniques namely, Polynomial Regression, Nearest Neighbour and Kriging were tested to identify the most suitable interpolation techniques for observed compaction data set. About 25 and 20 random point data were collected for validation in agricultural field



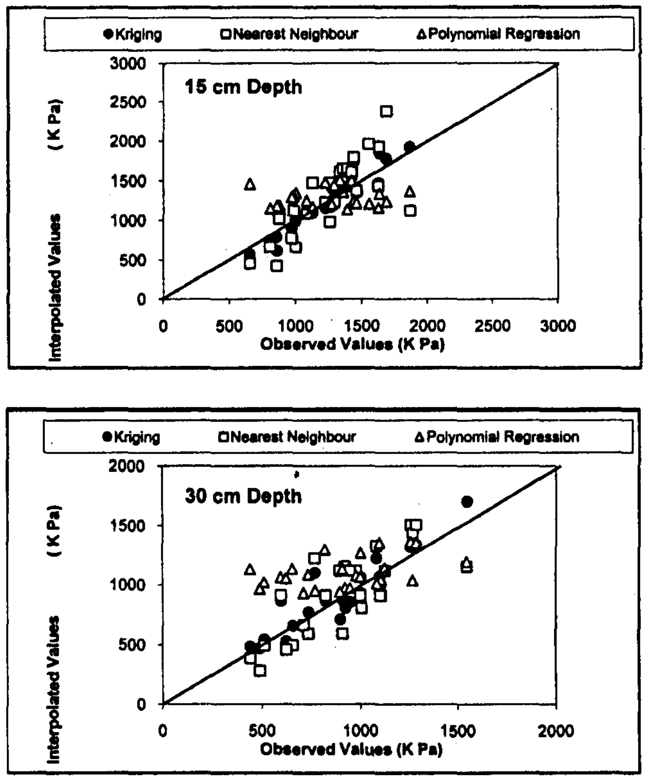


Fig. 1. *Validation of interpolated data of soil strength (KPa) at different depths in agricultural field.*

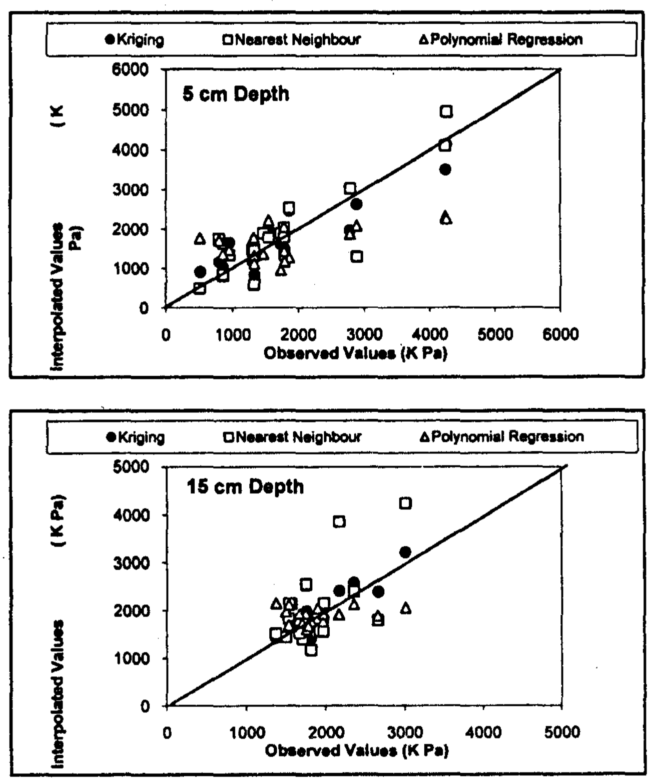


Fig. 2. *Validation of interpolated data of soil strength (KPa) at different depths in hilly catchment.*

and hilly catchment, respectively. The interpolated soil compaction values at different soil depths were plotted against observed values (Fig. 1 and 2). For hilly

Table 2. *R^2 values of interpolated soil strength of three geo-statistical interpolation techniques.*

Geo-statisical interpolation techniques	Agricultural field			Hilly catchment	
	Soil depths			Soil depths	
	7.5 cm	15 cm	30 cm	5 cm	15 cm
Polynomial Regression	0.04	0.01	0.19	0.30	0.05
Nearest Neighbour	0.83	0.62	0.62	0.76	0.41
Kriging	0.93	0.88	0.85	0.85	0.80

catchment 5 and 15 cm soil depths were chosen and for agricultural field 7.5, 15 and 30 cm depth were selected for interpolation and contour map development. Ordinary point Kriging interpolation technique was observed to be the best for predicting spatial distribution of soil compaction as it showed higher R^2 values (Table 2) compared to other statistical techniques and was statistically significant.

Variogram

Spatial behaviour of soil strength was evaluated through their variograms along with the 'Rational Quadratic Model' fit to them (Table 3). The range of spatial dependence varied between 22.2 m to 26 m. A high nugget value observed in agricultural field and hilly catchment indicated less spatial continuity between neighbouring points (Vieira and Gonzalez, 2003). The spatial dependence of 22.2 m at 7.5 cm soil depth in agricultural field indicated relatively high spatial variability of soil strength (Table 3), which might be due to unequal tillage operations. The fifth column of table 3 shows the proportion of the nugget values to the sill (scale + nugget effect). This is called correlation ratio, whose closeness to zero indicates continuity in the spatial dependence. The values of correlation ratio were relatively less in agricultural field at lower depth (7.5 cm) and of hilly catchment confirms relatively more continuity in spatial dependence.

Soil penetration resistance was monitored at around 30 m and 26 m interval in hilly slopy land and agricultural field, respectively (Table 3).

Contour maps (Fig. 3 and 4) of soil strength at 5 cm and 15 cm soil depth and 7.5 cm, 15 cm and 30 cm soil depth for agricultural field and hilly catchments, respectively were drawn by Kriging interpolation girding techniques. It is evident from the maps of agricultural field (Fig. 3) that soil compaction (ranged between 800 to 3400 KPa) is generally less in field boundary as compared to certain patches inside the field. High compaction values were observed in some patches at 15 and 30 cm depth. The range of spatial variation was also more in higher depths. However, in hilly catchment the range (800 to 4600 KPa) of spatial variation was much more in 5 cm than 15 cm (Fig. 4) soil depth. In higher elevation high compactness with much variation were observed due to erosion effect (Fulton *et al.*, 1996). Concentric contour rings were observed in higher elevations, indicating higher spatial variation within a short distance. Similar to agricultural field more continuity in spatial variation of soil strength was observed in deeper soil depths (Fig. 3 and 4). Vangas *et al.* (2004) reported clear division of penetration resistance due to different land uses when maps were generated by interpolating the data points with ordinary Kriging to a regular 1 m grid. A majority of the field under cultivation had low penetration resistance than un-cultivated land.

CONCLUSIONS

Out of the three interpolation techniques, the ordinary point Kriging interpolation technique was observed to be better interpolator of soil strength values both in agricultural field and high sloppy hilly catchment of watershed. More spatial variability was observed at plough bottom layer (15 cm) in agricultural fields. In agricultural field the average soil compaction values were

Table 3. *Parameters of Variograms models for soil compaction.*

Soil Depth	Nugget Effect/value(Co)	Scale (C)	Spatial dependence (m)	R^2	Correlation ratio (Co/ C)
Agricultural field					
7.5 cm	133000	161000	22.2	0.32	0.45
15 cm	287000	131000	26.5	0.42	0.68
30 cm	308000	281000	26.0	0.44	0.52
Hilly Catchment					
5 cm	748000	800000	30.0	0.60	0.48
15 cm	391000	439000	30.3	0.20	0.47

Note:'Rational Quadratic Model' was used in variogram ; The lag distance plotted in X axis against the nugget value in the variogram, Direction: 0.0 and Tolerance: 90.0

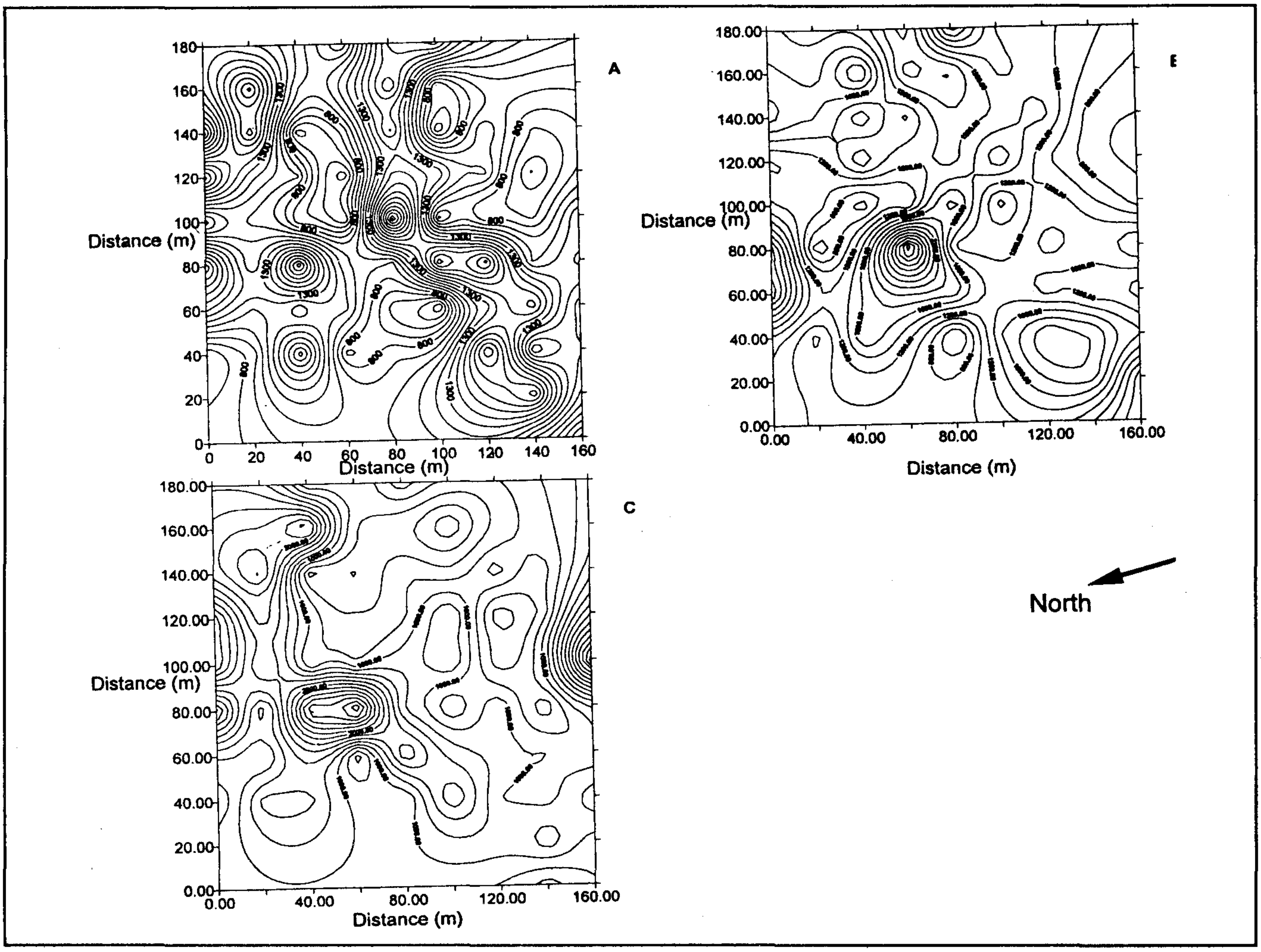


Fig. 3. *Spatial distribution of soil strength (KPa) at 7.5 cm (A), 15 cm (B) and 30 cm (C) soil depth in agricultural field*

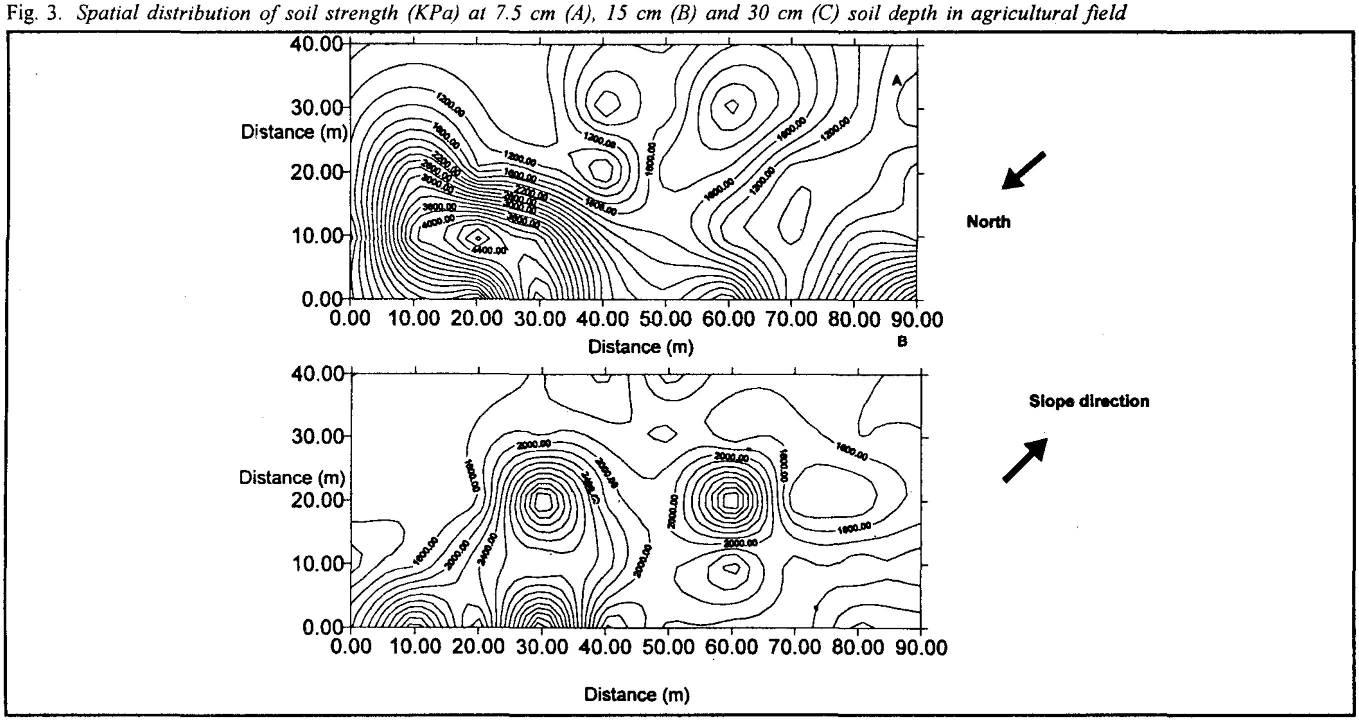


Fig. 4. *Spatial distribution of soil strength (KPa) at 5 cm (A) and 15 cm (B) and 30 cm (C) soil depth in Hilly catchment*

below 2000 K Pa in most of the areas except in small patches. In general, uncultivated hilly catchment had higher soil compaction than cultivated agricultural field. Variograms revealed that 26 and 30 m sampling distance would be good enough for interpolating soil strength values all over the field up to 30 and 15 cm soil depth for agricultural field and hilly catchment areas, respectively in the watershed. Sampling distance of 30 m by using Kriging interpolation technique for measuring spatial variation of soil compaction might be considered for precision farming in Shivalik-Himalayan region in India.

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