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Spatial variation of soil physical properties in adjacent alluvial and colluvial soils under Ustic moisture regime

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Abstract

Soils vary spatially due to differences in soil management and soil formation factors. The soil spatial variability is an important determinant of efficiency of farm inputs and yield. This study was carried out to identify and compare spatial variation of some soil physical properties by geostatistics in alluvial and adjacent colluvial soils formed under ustic moisture regime at Gökhöyük State Farm (1750 ha), Amasya, Turkey. Seventy four soil samples were collected on a regular grid (500 × 500-m) and additional 224 samples were collected on 28 500-m fine-transects, randomly superimposed between the nodes of grids. Semivariograms and corresponding kriging maps for soil texture, soil organic matter (SOM), bulk density (BD), saturated hydraulic conductivity (K_s), and available water content (AWC) were prepared. Statistical analyses were conducted separately for colluvial and alluvial sites as well as whole area. The soils in alluvial site is rich in clay with high BD and SOM, and low in K_s and AWC; and the soils in colluvial site was designated as low in K_s, SOM, and AWC and high in BD. All variables, except SOM, showed a strong spatial dependency. In general, nugget, sill and range values of most of the studied soil variables decreased from alluvial site to colluvial site. When local (alluvial and colluvial sites separately) and global (alluvial + colluvial) kriged maps for BD, AWC, and soil textural separates, use of global semivariograms (one semivariogram for entire study area) resulted in lost of some details in colluvial sites, suggesting that local semivariograms for alluvial and colluvial soils should be used in kriging predictions at the farm. The results had significant implications for water management as AWC was spatially associated to clay content in alluvial site and to clay and sand contents in colluvial site.

1 Introduction

Soil properties can vary depending on soil forming factors (time, parent material, topography, climate, organisms, and complex interactions among them) and differences in human activities. Heterogeneity is an inherent quality of soil that typifies its distribution in space (Júnior et al., 2006). Therefore, evaluation of soil spatial variability becomes an important issue in agricultural and environmental research.

Geostatistics enables us to describe spatial patterns by semivariograms and to predict the values of soil attributes at unsampled locations by a set of statistical tools (Vieira et al., 1983; Trangmar et al., 1985; Warrick et al., 1986). At present, soil science research largely relies on the use of geostatistics, which, together with classical statistics, constitutes an extraordinarily important tool for agronomy (Júnior et al., 2005).

Soils attributes can show a considerable heterogeneity (Tyler, 1985; Trangmar et al., 1987; Isaaks et al., 1989). Soil variability was widely studied in different contexts such as, soil topography (Miller et al., 1988; Iqbal et al., 2005), evaluation of soil fertility (Yasrebi et al., 2008; Štípek et al., 2002); planning and interpretation of field research (Wilding and Drees, 1986), and the study of the physical and chemical attributes of soil under different management regimes (Mzuku et al., 2005; Wei et al., 2008).

Despite the importance of soil texture and its relative ease of determination using conventional methods, soil maps are produced at large scales to adequately represent their spatial distribution. Quantitative information on soil surface texture would be extremely useful for modeling, planning, and managing the soils (Scull et al., 2005). Duffera et al. (2007) report some soil properties including particle size distribution (soil texture), soil water content, plant available water and cone index shows horizontal spatial structure and captured by soil map units i.e. soil texture maps yet, on the other hand, some properties such as bulk density, total porosity and saturated hydraulic conductivity are not spatially correlated and unrelated to soil map units. They also suggested use of soil map units that delineate boundaries for developing management zones for site-specific crop management

Soil characteristics can highly change by various factors. In this context we mainly work to figure out the effects of the topography on soil. Characterizing spatial variation of soil variables can provide important implications in water and nutrient management and fertilizer applications in agricultural production. The objectives of this study were to characterize spatial variation of soil physical properties in a large state farm covered by alluvial and colluvial soils with known long term management history. The results showed that the source of spatial variation were highly different in alluvial site from that in colluvial site.

2 Materials and methods

2.1 Site description

The study was carried out in an approximately 1750 ha area at Gökhöyük State Farm (between 722°24′35″–722°24′78″ E and 449°03′30″–449°06′02″ N and with an elevation of 500 m) (Fig. 1), in Amasya province of Turkey. The farm is located in North of Çekerek Creek and consists of three physiographic units; highlands, formed on limestone and sandstone; colluvial soils formed on the sediments from the highlands; and alluvial soils, formed on the deposits of the Çekerek Creek. Only colluvial and alluvial areas were included by the study. Approximately 30% of study areas is alluvial and rest is colluvial soils. The area has terrestrial climate with annual precipitation of 370 mm and average temperature of 13.9 °C. Considerable amount of the precipitation falls in the autumn (September–December) and in the spring (April and May). The slope of the alluvial site changes mainly from 0 to 2% and the slopes are mainly oriented in the southwest. Slope and elevation gradually increases in the north.

2.2 Field history

In general, crops in the alluvial areas are irrigated, while dryland (rainfed) farming is practiced in the colluvial sites. Sunflower, vetch, corn, chickpeas, onions, sugar beets, and alfalfa are the major crops grown in alluvial soils, and wheat is the main crop in colluvial site. The main crop rotation systems consisted of wheat-sunflower,

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wheat-wheat, wheat-chickpeas in alluvial site and wheat-wheat, wheat-bare fallow in the colluvial site.

2.3 Sampling design and laboratory analysis

Study area was initially divided into 500-× 500-m regular square grids, which led to a total of 74 grid points. Then, 28 500-m long fine-transects were randomly superimposed between nodes, in north and south directions. These fine transects were used to better model the semivariogram in short distances. Of these 28 transects, 10 were located in southwest-northeast and 18 were in southeast-northwest directions. Samplings on each fine transect were arranged as 5, 15, 35, 65,105, 215, 295, 395 m (Fig. 1). Soil samples were collected from 0–20 cm soil depth at grid nodes and along the fine transects, resulting in total of 298 samples.

2.4 Exploratory data analysis

The data collected were grouped in two classes, those collected from alluvial area were designated as alluvial soils (AS), and those collected from colluvial area were designated as colluvial soils (CS). Statistical parameters of mean, standard deviation, maximum, minimum, coefficient of variation, skewness, and kurtosis were calculated for each of the variables clay, silt, sand, SOM and, BD in AS and CS.

2.5 Geostatistical methods

We used semivariogram to describe the spatial distribution of soil variables in alluvial and colluvial sites. They were calculated by following equation (Diekmann et al., 2007):

$$\gamma(h) = \frac{1}{2\,|N(h)|} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (1)$$

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where, $\gamma(h)$ is the estimated semivariogram, $z(x_i)$ and $z(x_{i+h})$ are the values of a variable separated by the lag h, and $N(h)$ is the number of data pairs in the corresponding lag. The type of transformation was applied based on the coefficient of skewness as suggested by Webster (2001). No transformation was applied to the data with a coefficient of skewness < 0.5. We also checked the data for anisotropy to calculate the directional semivariograms if needed. The maximum and minimum data pairs in each lag varied. We limited the minimum number of data pairs for a lag with 20 for a safe calculation of semivariance. The maximum value for a lag distance was extended to 1800 m, which is less than the shortest axis of the study area as suggested by Rossi et al. (1992). We applied the least square analysis for goodness of fit for semivariograms. Although the spherical models are generally preferred since they have been found to be a good fit to semivariograms of soil properties (Webster, 1985), we applied exponential and Gaussian models in some cases since they better described our experimental semivarograms. The semivariogram analysis was conducted by GS+ (version 7, Gamma Design Software, Plainwell, MI).

The theoretical development of geostatistical methods is available from a number of publications including Isaaks and Srivastava (1989), Myers (1997), Nielsen and Wendroth (2003). Kriging estimate $z^*(x_0)$ and estimation variance $\sigma_k^2(x_0)$ at any point x_0 were calculated respectively:

$$z^*(x_0) = \sum_{i=1}^{n} \lambda_i \, z(x_i) \tag{2}$$

$$\sigma_k^2(x_0) = \mu + \sum_{i=1}^{n} \lambda_i \, \gamma(x_0, x_i) \tag{3}$$

where, λ_i are the weights; μ is the lagrange multiplier; and $\gamma(x_0, x_i)$ is the variogram value corresponding to the distance between x_0 and x_i (Vauclin et al., 1983). Ordinary point kriging procedure was applied to estimate soil textural separates, BD, and SOM at unsampled locations. To conduct kriging, semivariogram parameters calculated with

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GS+ (Version 5) were used in geostatistics module of ArcView. Each time, the estimates in kriging were controlled by the procedure cross-validation to determine the most proper number of neighboring data points to be used in the estimation (Vieira et al., 1981). A maximum of 15 and a minimum of 10 neighboring data points were used along with semivariograms in kriging estimation. The surface maps of estimates from point kriging and surface maps of error values were examined to assess the quality of the estimations.

3 Results

In contrast to sand and silt content, clay content in the alluvial area is higher. The particle size gradually changes from coarse to finer toward to the river, from the northwest to the southeast. In the colluvial site where slope changes from 2 to 4%, sand was the dominant particle size. High BD was coincided with high clay, and low sand and silt contents in the alluvial and the colluvial sites. Unexpectedly, organic matter was low in the areas with very high clay content. Clay can stabilize organic matter against degradation, but this low organic matter occurred in clay rich areas was attributed to the unfavorable conditions caused by high clay content that decreased organic matter addition to the soil. On the contrary, the reason for the high soil organic matter in coarse textured areas can be attributed to more available soil water, pore space, and the aeration capacity that resulted in SOM addition in greater amounts.

Descriptive statistics for soil variables in the study area are given in Table 1. Clay contents are generally high. On the other hand, a low mean value for sand content was found especially in the alluvial site. AWC was also low in both sites. High SOM was determined in alluvial soils, whereas, lower values were detected in colluvial soils. Clay, silt, and SOM contents were more varied in alluvial site while BD and K_s were more varied in colluvial site. Table 1 presents the parameters of semivariograms for selected variables for alluvial, collovial, and whole (alluvial + colluvial) area. The range of BD increased from 414 m in colluvial area to 1018 m in alluvial area.

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Figure 2 displays different increases in semivariances and maximum with increasing lag distances. The variograms for clay, SOM and K_s in alluvial area rise abruptly and reach to their highest value in a greater range comparing with those in colluvial area. The variograms show higher values of sill and range in alluvial site (except for the range of AWC) than in colluvial soils. This increase show a greater structured variance and a longer range in the later, which may indicate a continuous depositional event in colluvial site and relatively stable conditions in alluvial site

The kriged contour maps of clay, sand, SOM, BD, K_s, and AWC for the alluvial and colluvial sites are shown in Figs. 3 and 4. Kriged maps indicated soils with high clay and low sand and with high BD were found in the SW and in the center of the alluvial site, respectively. Kriged maps for K_s show that soils with high values located on the North in both sites.

The data from the whole study area (alluvial+colluvial) were analyzed together and results were shown in kriged maps (Fig. 5). From these maps, soils with the high clay were found in the center and the SW edge of the field, high sand in the north and high SOM mainly in the center and southern part of the field.

4 Discussion

The majority of the soil properties were slightly skewed with a coefficient of skewness < 0.5. However, their distribution can be deemed normal. Although similar mean values occurred for clay content in alluvial and colluvial soils, clay was far more variable in the alluvial soils due to the nonuniform deposition of clay by Çekerek Creek. The relatively high standard deviation on alluvial site was also support this conclusion. While soil texture differed between the sites, the mean BD values of the sites were similar. This may be due to compaction of the clay soils in the alluvial site due to the field traffic on the farm and monoculture practiced (alfalfa and wheat). The reason of high K_s in alluvial soil is due to silty soils distributed in the northeast of the field. There is also high standard deviation in K_s in alluvial soils because of the high variation in

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soil texture over the field. Another possible reason of high K_s in alluvial soil would be intensive plant root growth despite to high clay. These plant roots may generate macro pore flow which is very important in vertical transport of water and chemicals in soils. AWC was low in both sites because of the high clay content in some localities and high silt content in others. Comparatively higher SOM in alluvial soils was attributed to irrigation that resulted in plant residue return to the soil in greater amounts than occurred in colluvial site.

That extremely low nugget ratio (0.03%) occurred for sand in collovial site was attributed to its deposition controlled by slope steepnes. Cambardella et al. (1994) interpreted spatial continuity according to degree of nugget ratio for the semivariograms. The variable BD was strongly spatially dependent in both sides. Strong spatial dependency of BD was attributed to strong association between BD and soil textural separates, which also exhibited a strong spatial dependency in the study area. Our calculations showed that, except K_s, all soil variables studied were strongly spatially dependent as their nugget ratio was less than 25%. Lower nugget effect with lower range values for BD found in the colluvial area may indicate the combined influence of soil texture, topography, and the land use on BD. Similar conclusion was made by Cambardella et al. (1994), who stated that strongly spatially dependent properties might be controlled by intrinsic variation in soil characteristics such as texture and mineralogy.

Values for sill and range of all the variables (except the range of AWC) were greater in alluvial site than in colluvial site. This difference showed a greater structural variance and a longer range in the former, which may indicate a more patchy distribution of these variables in colluvail site. Of the soil variables studied, the greatest variation occurred for K_s in both sides. A moderate nugget effect occurred for K_s indicated that considerable amount of this variation comes from processes such as short range variation and variance caused by laboratory procedures. Experiments have shown that K_s varies widely among materials with different particle-size distribution. Indeed, replicates of the same test in the same laboratory often yield highly dissimilar results (Arya et al., 2000; Mbonimpa et al., 2002). Therefore, the high nugget variance for K_s was expected on both sides. Semivariograms for SOM indicated strong spherical structure in both sides. Greater variation in SOM in alluvial area could be due to difference in addition of organic matter to soil due to differences in agricultural practices.

The Çekerek Creek deposited its sediments in the direction normal to its flow path, resulting in a deposition trend in decreasing sand content and increasing clay content away from stream bank. In contrast to colluvial area, some faint local trends occurred for BD in alluvial area (Fig. 3). These trends were attributed to compaction due to very high clay content combined with high trafficking conventional tillage. Kriging predicted surface maps for sand, clay and BD indicated similar spatial patterns in alluvial area. Also, semivariogram with a sill smaller than general variance indicate a strong global trend for these variables in alluvial site (Fig. 3). All these suggest that a strong spatial relation existed between BD, sand, and clay contents in alluvial site. However, no similar trends occurred among these variables in colluvial site (Fig. 4).

Some faint trends occurred for sand content in the alluvial area contrasting to colluvial area. Although sand distribution in the alluvial site was mainly in the direction of SW to NE, due to the deposition of the river sediments in the direction normal to its flow path, such a similar trend was not detected in the colluvial site. Also, no trends were detected for distribution of clay at either site. Kriged maps indicated that soils with high clay content in alluvial site occur in the SW and the center of the field, whereas, clay content in the colluvial site decrease from the river bank to the hillside in the north (Figs. 3 and 4). The kriged maps of clay and sand contents represent a reciprocal distribution in alluvial soils. However, no such distribution was observed for sand and clay content in colluvial site.

Soil organic matter content in alluvial soil is generally higher than in colluvial soils, and this was attributed to poor drainage conditions, high ground water table, and more rigorous plant growth in some localities. While faint local trends were detectable for SOM in alluvial area due to differences in cropping pattern and associated tillage, no trends was detected in colluvial area due to more uniform tillage and cropping pattern.

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Localities with high K_s in alluvial site were found in NE and NW, due to high silt content (between 48 and 60%). As expected, values for K_s in alluvial site were negatively associated with clay content. Yet, the correlation between the sand content and K_s was weak due to soil compaction especially in the low drainage areas around the center of the alluvial site and generally low sand content across to field. Consequently, kriged maps of BD and K_s were negatively associated in areas with the high soil BD in alluvial site due to compaction. However there is a good spatial similarity among the sand content, BD and K_s in colluvial site.

Krigged map of AWC for alluvial site shows lower values especially in the NE where silty soils are dominated. However, relatively greater values were found in the rest of the alluvial area due to relatively greater clay content of top soil. Figure 4 shows that AWC is relatively low in the colluvial site and spatially associated to clay and sand contents.

In the kriged maps of the whole area, some details for BD, K_s and AWC shown in Fig. 5 were absent; however, no such information loss occurred in the alluvial site. Therefore, we concluded that a preliminary analysis should be conducted with local semivariograms (semivariograms for alluvial and colluvial sites), and if necessary, kriging predictions should be made with local semivariograms rather than with a global semivariogram (semivariogram representing alluvial + colluvial site).

5 Conclusions

Spatial variation of some soil properties in alluvial and adjacent colluvial soils, both formed under ustic moisture regime, were compared in Central Anatolia of Turkey. The results had important implications for fertilizer and water use and soil tillage. In alluvial site, a greater spatial variation and global trend in sand content attributed to pattern of alluvium deposited by Creek Cekerek. That a comparable greater coefficient of variation occurred for SOM in the alluvial site (21%) than in the colluvail site (5%) suggested that variable rate fertilizer application program (site-specific management) may be necessary in the former. Overall, lower SOM content occurred in the colluvial site was attributed to lower amount of SOM addition by residue resulted from mostly dryland agriculture practiced in this site. In colluvial site, conservation tillage is necessary to increase SOM content and to manage soil water more efficiently. For a better nutrient and water management, local maps of nutrients (N, P, K) should be used along with maps of plant available water content. The areas with high clay and BD and low K_s should be managed alternatively. Applying deep tillage, adapting suitable plants and crop rotation system may be practiced in these localities. Kriged maps showed that when global semivariogram was used in kriging predictions, some details for K_s, BD, and AWC were absent. This suggested that the physiographic land units should be considered, and if necessary, local semivarograms should be preferred in kriging predictions.

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Table 1. Descriptive statistics and Geostatistics for studied variables in alluvial, colluvial and whole (combined) areas.

		Model	Mean	Std. dev.	CV	Nugget	Sill	Nugget ratio	Spacial class	Range m	R^2
Clay, %	Alluv.	S[1]	49.2	15.25	31.0	3.7	178.9	2.03	Strong	1316	0.97
	Coluv.	G[3]	49.5	5.66	11.0	4.33	22.87	15.92	Strong	990	0.94
	Whole	S[1]	49.3	13.37	178.8	2	182.7	1.08	Strong	1599	0.99
Silt, %	Alluv.	S[1]	35.9	10.12	28.0	4.2	54.31	7.18	Strong	1385	0.97
	Coluv.	G[3]	29.0	4.28	15.0	1.44	23.83	5.70	Strong	1250	0.97
	Whole	S[1]	34.1	9.48	89.9	0.023	0.53	4.16	Strong	1707	0.98
Sand, %	Alluv.	S[1]	14.7	8.16	56.0	4.4	87.55	4.79	Strong	2052	0.99
	Coluv.	E[2]	21.4	5.67	27.0	0.01	30.75	0.03	Strong	1256	0.98
	Whole	S[1]	16.7	8.85	78.3	0.122	1.049	10.42	Strong	1736	0.99
BD, $gr\,cm^{-3}$	Alluv.	S[1]	1.3	0.10	8.0	0.00227	0.1144	1.95	Strong	1018	0.96
	Coluv.	S[1]	1.3	0.10	8.0	0.00081	0.00549	12.86	Strong	414	0.97
	Whole	S[1]	1.3	0.11	0.0	0.00154	0.00988	13.49	Strong	1113	0.95
K_s $cm\,h^{-1}$	Alluv.	E[2]	3.5	7.65	222.1	1.7	3.933	30.18	Moderate	1191	0.89
	Coluv.	E[2]	0.6	1.57	245.0	0.767	1.874	29.04	Moderate	966	0.75
	Whole	E[2]	2.9	7.14	250.0	1.595	3.31	32.52	Moderate	1167	0.92
AWC, %	Alluv.	S[1]	7.0	2.25	32.0	0.852	3.762	18.47	Strong	803	0.98
	Coluv.	S[1]	6.6	2.14	32.5	0.005	0.186	2.62	Strong	873	0.93
	Whole	E[2]	6.8	2.33	34.2	0.525	2.228	19.07	Strong	606	0.98
SOM, %	Alluv.	S[1]	2.3	0.59	26.0	0.0118	0.0451	20.74	Strong	1680	0.98
	Coluv.	G[3]	1.7	0.30	17.0	0.003	0.0626	4.57	Strong	809	0.97
	Whole	S[1]	2.2	0.65	29.55	0.009	0.0472	16.01	Strong	1069	0.95

[1] S = spherical, [2] E = exponential, [3] G = Gaussian

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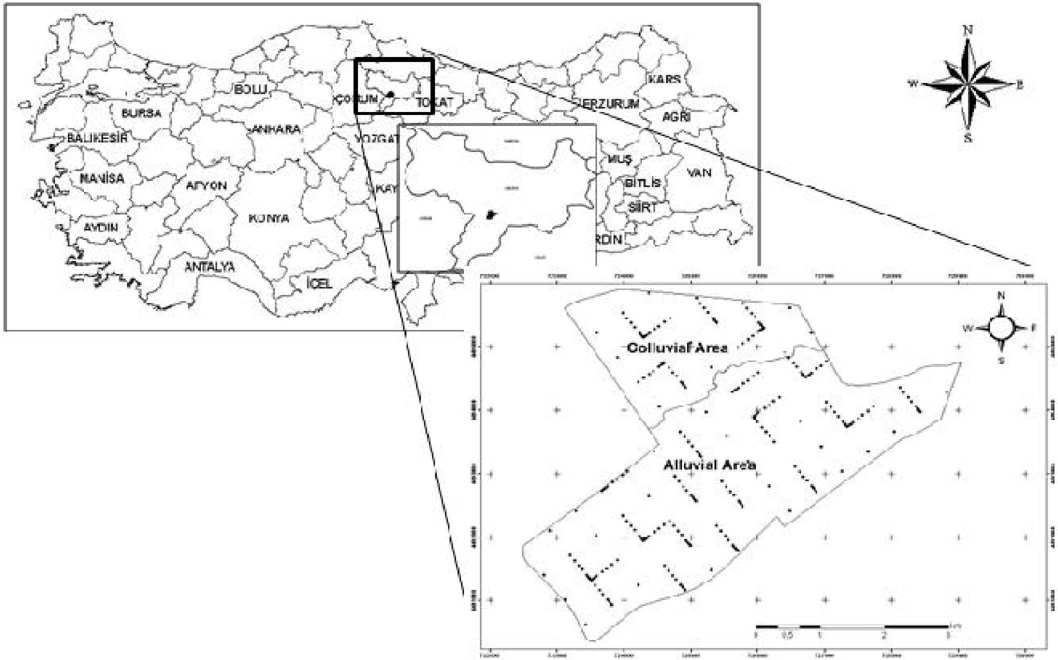

Fig. 1. The map of study area and sampling design.

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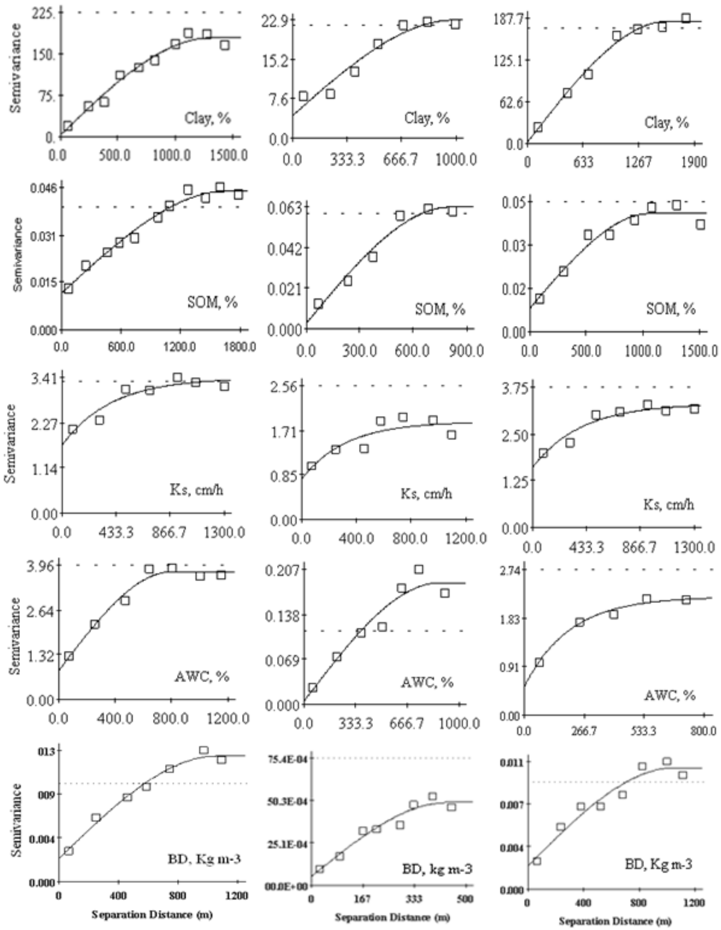

Fig. 2. Semivariogram models showing the spatial dependence of clay, SOM, K_s, AWC and BD for alluvial, collovial and whole area.

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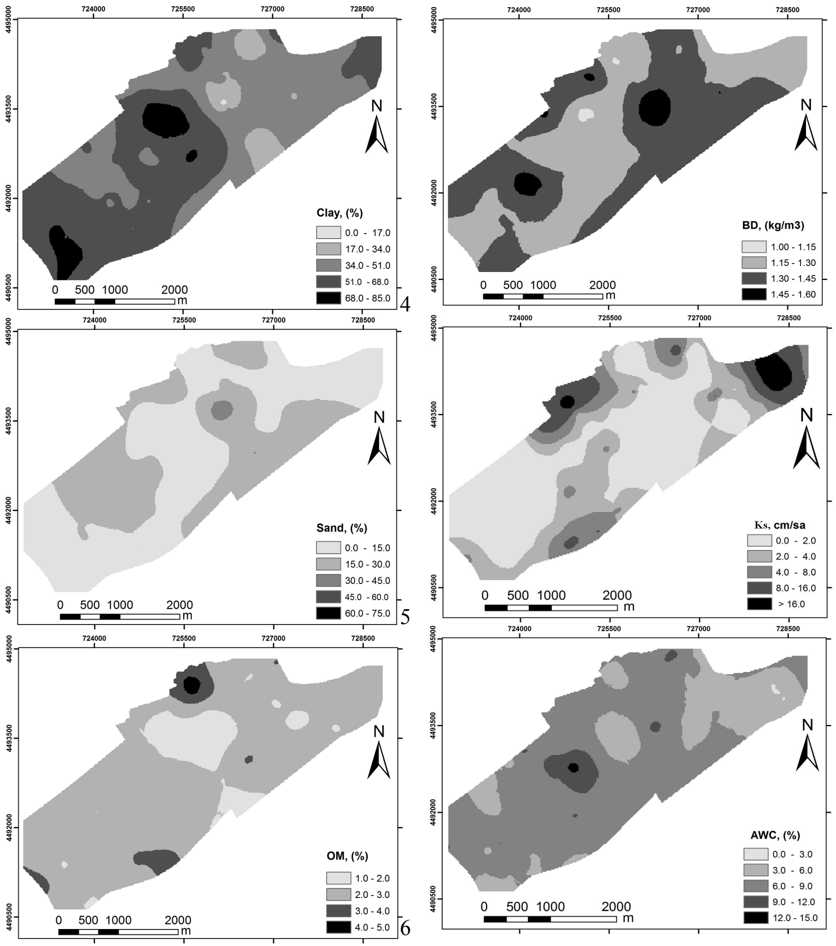

Fig. 3. Kriged maps of clay, sand, soil organic matter, soil bulk density, saturated hydraulic conductivity and available water content for alluvial site.

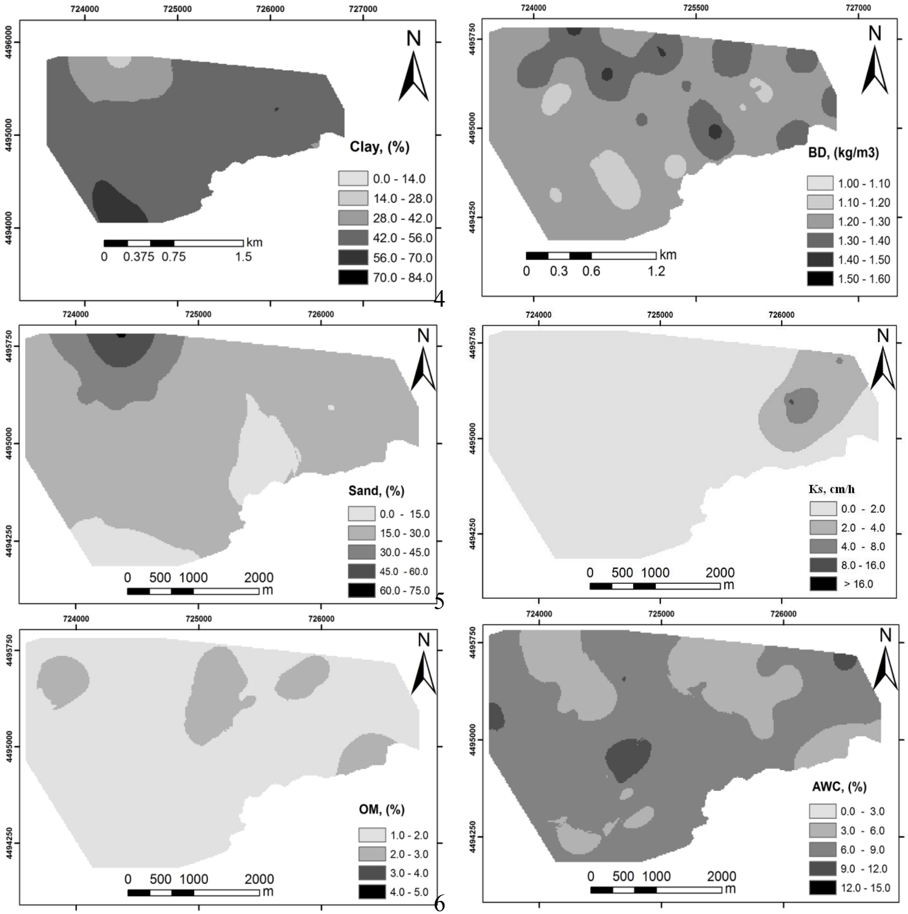

Fig. 4. Kriged maps of clay, sand, soil organic matter, soil bulk density, saturated hydraulic conductivity and available water content for Colluvial site.

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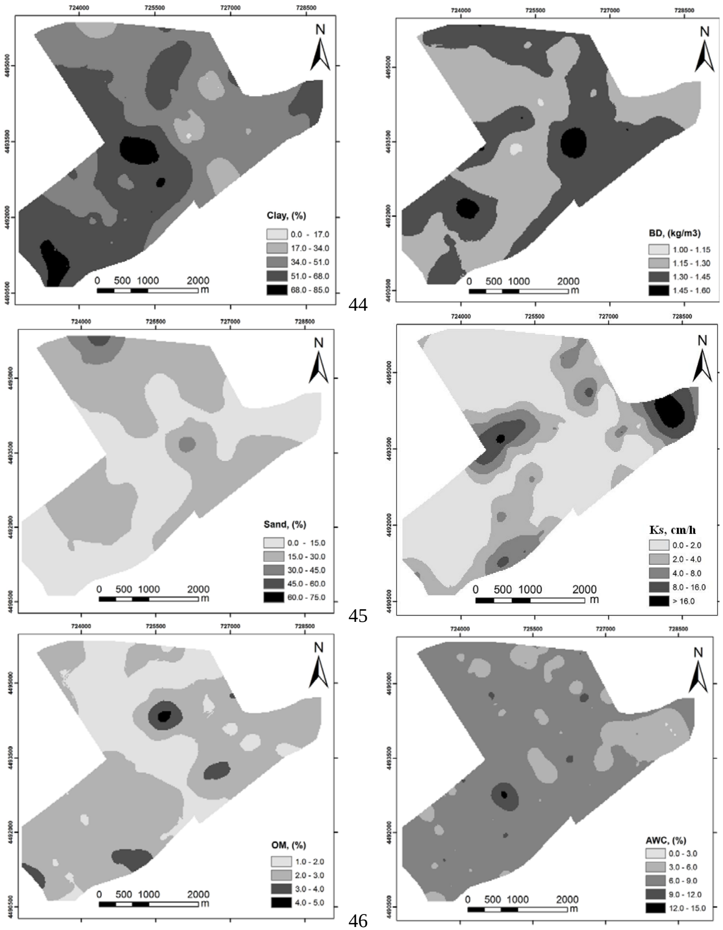

Fig. 5. Kriged maps of clay, sand, soil organic matter, soil bulk density, saturated hydraulic conductivity and available water content for whole site.

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