Mapping of Site-Specific Soil Spatial Variability by Geostatistical Technique for Textural Fractions in a Terrace Soil of Bangladesh

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Abstract

An assessment of field-scale variation of textural fractions was investigated by soil sampling, laboratory analysis and eventually soil mapping by geostatistical techniques and GIS development for a terrace soil of Bangladesh to determine clay distribution throughout the soil in three depth increment (0-30cm, 30-60cm, 60-90cm). The mean particle size distribution of topsoil corresponded to silt loam texture class while subsoil textural distributions were clay loam, silty clay and silty clay loam. The deepsoil clearly corresponded to clay texture class. The topsoil texture fractions showed large variability in comparison to subsoil and deepsoil. The clay content sharply increases with depths. The mean clay contents were 23%, 38% and 43% for the 0-30cm, 30-60cm and 60-90cm depth increments respectively. The subsoil showed distinctly higher clay content than the overlying topsoil causing an abrupt textural change between top and subsoil. The subsoil clay content was nearly twice that of the topsoil, and even more in the deepsoil with a maximum around 50%. This textural difference might be caused by an illuvial accumulation of clay or by pedogenetic formation of clay in the subsoil or destruction of clay in the surface horizon or by a combination of two or more of these processes. The soil maps produced through geostatistical technique (Variograms and Kriging) fairly represents the distribution of textural fractions of the studied site. The maps represent the spatial variation of soil textural properties for clay and sand distribution. Thus, provide useful information on soil texture, moisture, soil fertility and organic matter content. These maps also provide a means of monitoring spatial variation of soil properties that potentially influence crop production in the Terrace soils of Bangladesh.

Key words: Terrace soil, textural fractions, semivariogram, kriging, soil spatial variability and soil mapping

Introduction

The valuable soil resources of Bangladesh are either over-exploited or underutilized because of poor resource management. A land scarce country can hardly afford this. Landuse is determined mainly by the monsoon climate and the seasonal flooding which affects the greater part of the country. The high rainfall and seasonal flooding makes conditions particularly suitable for paddy cultivation, and hence paddy occupies about 80% of the cropped area. Over the past few decades, agriculture and mono-culture of rice has caused degradation of agricultural land and environment due to extensive use of chemical fertilizers and pesticides. Now it is imperative to conduct soil characterization for better understanding and sustainable use of soil resources. The country comprises of three major physiographic units, Holocene floodplain (80%), Tertiary hills (12%) and Pleistocene terraces (8%) with a total land area of 147,570 km^2 (BBS, 2008). The terrace area representing the second largest agriculturally important land type comprises of the Barind Tract (BT), Madhupur Tract and Akhaura Terrace. Within the BT, three major sub-units can be recognized mostly to the north-west of the country: level BT, high BT and north-eastern BT. The soils of the BT classified as deep and shallow grey terrace soil which are poorly drained, and have silty topsoil with mottled grey subsoil overlying a Tertiary clay substratum (Bramer, 2002 and 1996; Saheed, 1992).

The agricultural activities in the level BT mainly depend on seasonal rains. The soil bears poor natural fertility, low water holding capacity, low structural stability of topsoil and low organic matter with deficiency of plant nutrients, and considered as problem soil of Bangladesh (Bramer, 1996). Food security and sustained production of BT areas require sufficient inputs, proper management practices and preferred characterization of soils. Therefore, the study site is selected in BT to characterize the soil which will facilitate implementation of management decisions and optimize input requirements. Moreover, due to the lack of quantitative observations, the descriptions about soil attributes are inadequate in Bangladesh, and the country's typical soil polygon maps consists of boundaries which represent abrupt discontinuity where as soil attributes are heterogeneous and continuous in nature. Thus, an assessment of the field-scale variation of textural fractions was investigated for soil mapping of a terrace soil area of Bangladesh to determine clay distribution over three depths. Moreover, the study was undertaken for the preparation of soil maps governing the within field variability of textural fractions to enable optimum soil management and drainage for crop production in the terrace areas Bangladesh.

Materials and Method

Location, geology and soil characteristics of Terrace soil of Bangladesh

The terrace study site lies between latitude 25° 39'29'' N and longitude 88°35'44'' E in Birol Upazila, Dinajpur district, Bangladesh. The terrace soils, commonly known as Barind Tract (BT), are in the Pleistocene physiographic unit which occupies a nearly level to gently undulating landscape. This is mostly made up of older alluvium which differs from the surrounding floodplain. BT is floored by Pleistocene sediments which is compact and sticky known as the Madhupur Clay (MC). Major part of this tract is poorly drained, mottled, silty top soil merged with MC at shallower depth. The BT is fragmented, being made up separate uplifted fault blocks in the north eastern part of the country. It covers a total area of approximately 7,770 km^2 (Brammer, 2002 and 1996).The soil belongs to Amnura soil series and subgroup-Aeric Haplaquept and order-Inceptisols in the USDA *Soil*

Taxonomy. The cultivated layer is puddled and reduced in the monsoon season and under irrigated rice in the dry season. The soil becomes white and powdery when dry. The reaction is medium or strongly acidic when dry but the surface layer becomes neutral in reduced condition. The subsoil has a mixed yellowish brown and grey, red mottled, silty loam or silty clay loam texture which is commonly friable and porous. The soil shows a pronounced increase in mottles and clay content with depth. The substratum is strongly structured and compacted heavy plastic clay. The soil bears low natural fertility and has low moisture holding capacity (Brammer, 2002 and 1996).

Soil sampling design

The field was sampled according to a grid sampling design at 104 locations on a 17 by 10 m grid basis from a representative area of 2.02 ha. Composite soil samples were collected from a radius of 1 m. Soil samples were taken at three depth increments (0-30 cm, 30-60 cm and 60-90 cm) through augering from the marked geo-referenced locations. The samples were analyzed by the Central laboratory, Soil Resource Development Institute (SRDI), Bangladesh.

Soil physical analysis

Texture was determined by Hydrometer method described by Day, 1965. The pH was determined by a glass-electrode pH meter in the soil suspension having a soil:water ratio of 1:2.5, after 30 minutes of shaking.

Statistical and Geostatistical analysis

The data analyses were conducted in three stages: i) Distribution was analyzed by classical statistics. Skewness is considered as the most common form of departure from normality. The exploratory statistical analyses were performed by PASW 18.0 (Predictive Analytics Software) Statistics, ii) to find out the spatial structure of the selected soil properties, variography was used, variograms were calculated and modelled with VARIOWIN 2.2 software (Pannatier, 1996) and iii) the kriged maps of spatial distribution of selected soil properties were constructed using SURFER Version 9.2 software (Golden Software, Inc.). Ordinary kriging was used throughout GIS development for mapping.

Results and Discussion

The results include the exploratory and geostatistical data analysis of the observed physical properties. The objective was to configure the nature and extent of within-field variability of the study site through soil mapping. For this purpose, geo-referenced 312 soil samples from in the terrace soil were collected. The spatial variability of the soil properties were discussed according to topsoil, subsoil and deepsoil characteristics.

Descriptive statistics of soil properties

The soil properties were approximately of symmetrical distribution. This was further confirmed by their respective coefficients of skewness. The mean particle size distribution of the topsoil corresponded to silt loam texture class while subsoil textural distributions were clay loam, silty clay and silty clay loam. The deepsoil clearly corresponded to clay texture class. The coefficient of variation (CV) of textural fractions (9-47%) showed considerable variation which was relatively high for sand fraction. The topsoil texture fractions showed large variability in comparison to subsoil and deepsoil which was reflected by their respective CV`s (Table 1). Figures 1 shows the histograms of topsoil, subsoil and deepsoil clay content and frequency; it is evident that clay content is highest in deepsoil, higher in subsoil compared to topsoil clay content.

Table 1. Descriptive statistics of textural fractions of terrace soil samples, n = 104

Variable	Mean	Median	Min	Max	Variance	Std. dev.	Skewness	Kurtosis	CV (%)
Top soil (0-30 cm)									
Clay	23	18	15	29	13.95	3.74	-0.28	-0.98	16
Silt	60	56	49	70	30.29	5.50	0.00	-1.16	9
Sand	17	19	4	35	64.36	8.02	0.15	-1.11	47
Subsoil (30-60cm)									
Clay	38	38	32	45	12.24	3.50	0.13	-1.27	9
Silt	40	30	32	47	11.88	3.45	0.20	-0.63	9
Sand	22	24	9	36	42.44	6.51	-0.27	-0.10	30
Deepsoil (60-90cm)									
Clay	43	44	34	55	21.27	4.61	0.00	-0.64	11
Silt	31	40	22	37	10.86	3.30	-0.23	-0.31	11
Sand	26	27	12	39	42.83	6.54	0.04	-0.96	25

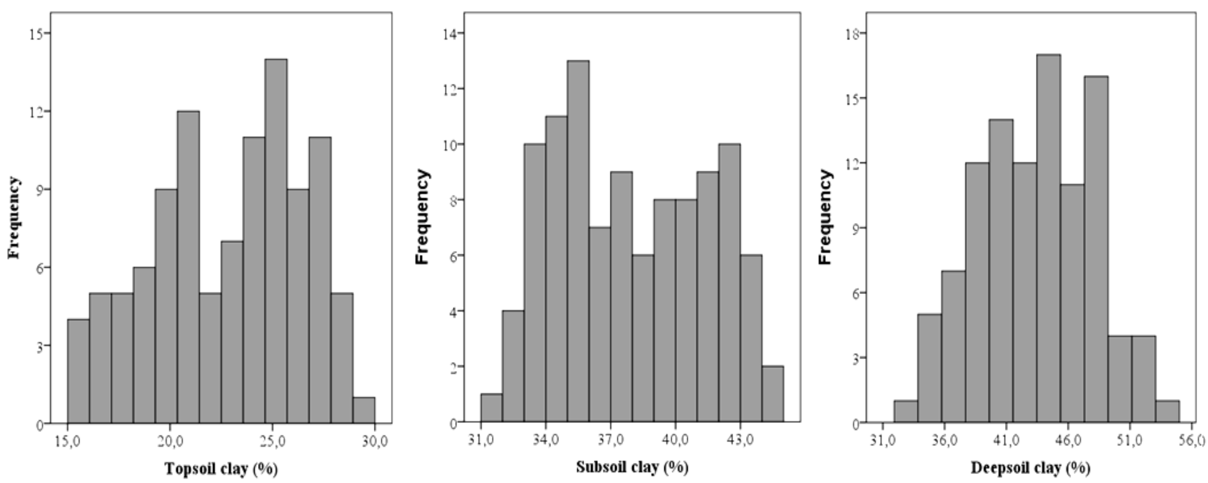


Figure 1. Histograms of a) topsoil clay, b) subsoil clay, and d) deepsoil clay in the terrace site

Mapping of clay and sand content of terrace soil

For mapping of textural fractions variograms were formulated accordingly for three depth increment of soil. The fitted spherical variograms for the clay and sand fractions of the studied site are shown in figure 2 while the model parameters are listed in table 2.

Table 2. Model parameters of omni-directional spherical variograms for textural fractions

Variograms parameters	Topsoil			Subsoil			Deepsoil		
	Clay	Silt	Sand	Clay	Silt	Sand	Cla y	Silt	Sand
C_0, nugget variance $(mS\ m^{-1})^2$	2	13	16.7	5.8	4.5	15	7.3	5	22
C, sill $(mS\ m^{-1})^2$	11.8	29. 4	58.1	11.8	10.9	35.1	20.3	10.5	43
h, range (m)	30	30	35	42	18	30	32	42	42
RNE, relative nugget effect (%)	17	44	29	49	41	43	36	48	51

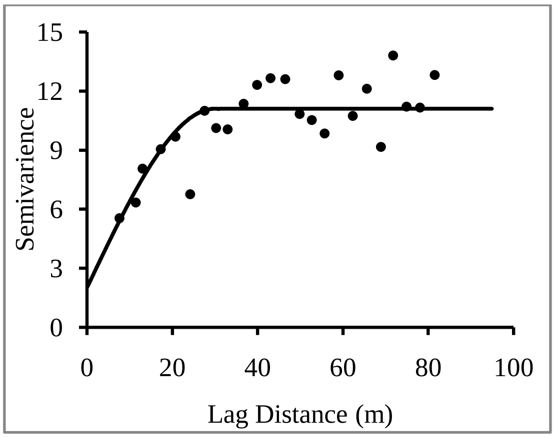
The fitted models suggest that the variability is well structured in space and is isotopic (Table 2 and Figure 2). The presence of nugget variance might be due to short range variability which mainly takes place at distances smaller than the sampling interval. The ratio of nugget variance to the sill variance can be considered as a criterion to specify the spatial dependence of the variables. Cambardella et. al. (1994) suggested that if the ratio of nugget to the sill (RNE) is lower than 25%, spatial correlation is classified as high, 25 to 75% as medium and over 75% as low. The RNE of topsoil clay was 17% which means clay possessed a strong spatial dependence while for sub- and deepsoil clay the spatial dependence is moderate, the RNE value is 49% and 36% respectively. The sand content is moderately spatially dependent which is further explained by the respective RNE`s shown in table 2. On the other hand, the range of spatial dependence can be considered as the distance beyond which observations are not spatially correlated. The spatial dependence for topsoil and deepsoil clay is found at a nearly similar separation distance of 30 and 32 m respectively while the subsoil spatial autocorrelation become much weaker from 42 m apart. In case of sand distribution for each depths increment the approximate distance at which autocorrelation ceases were 35 m, 30 m and 42 m respectively.

The clay content sharply increases with depths in the terrace site (Table 1). The mean clay contents were 23%, 38% and 43% for the 0-30 cm, 30-60 cm and 60-90 cm depth increments respectively. The subsoil showed distinctly higher clay content than the overlying topsoil causing an abrupt textural change between top and subsoil. The subsoil clay content was nearly twice that of the topsoil, and even more in the deepsoil with a maximum around 50%. This textural difference might be caused by an illuvial accumulation of clay or by pedogenetic formation of clay in the subsoil or destruction of clay in the surface horizon or by a combination of two or more of these processes. However, the kriged clay content maps showed that the topsoil and subsoil clay content is relatively higher along the north-eastern side extending to the centre of the field including some area of the western corner of the field shown by dotted lines in figure 3a and dotted arrows in figure 3b. The deepsoil clay content somewhat follows a similar pattern.

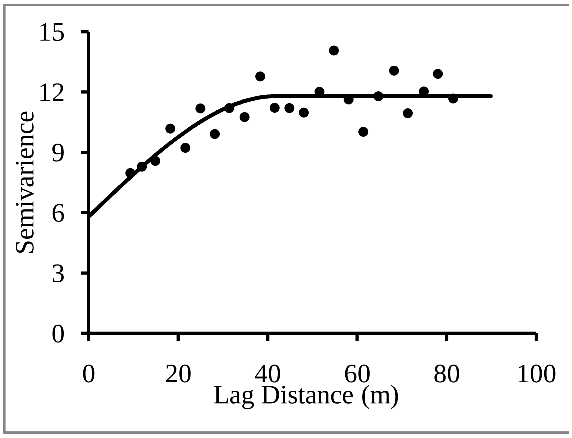
The possible causes of clay distribution differences in the topsoil of the studied area might include:

a) the south-western side of the field is biologically more active as this part of the field get organic matter, and drainage usually follow south-west to north-east which cause the finer material (silt and clay) to be moved in that direction by drainage and also during puddling of the field, and

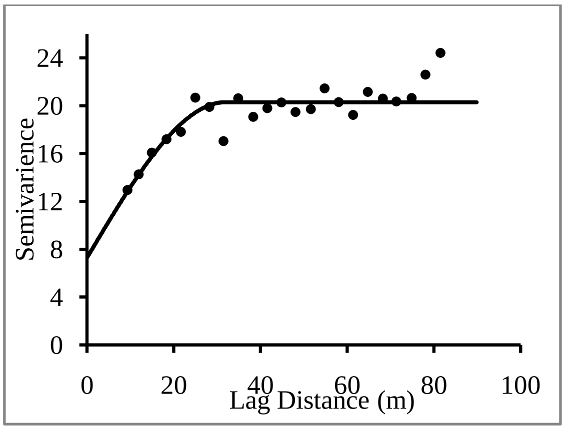
b) unstable silty topsoil along the north-eastern study side is eroded during the monsoon as there flows a stream of narrow tributary which occasionally overflows due to heavy monsoon rain or excess water from its river source.



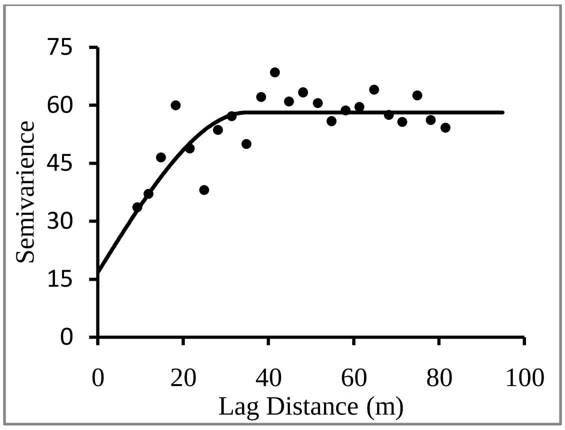
(a) Topsoil clay



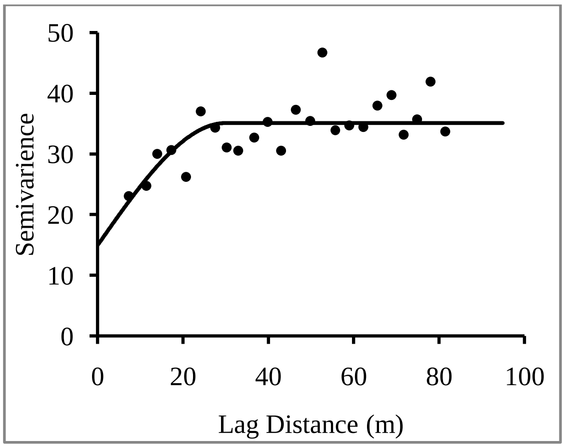
(b) Subsoil clay



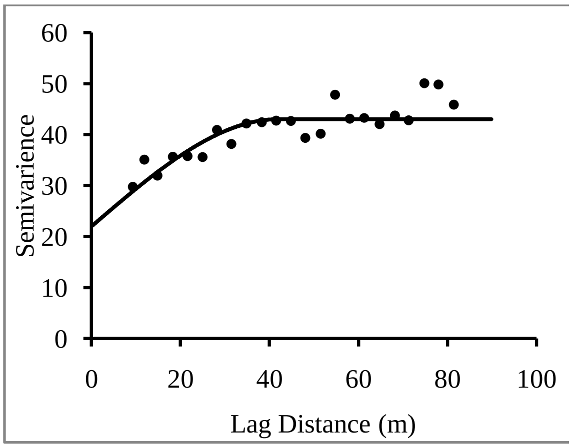
(c) Deepsoil clay



(d) Topsoil sand



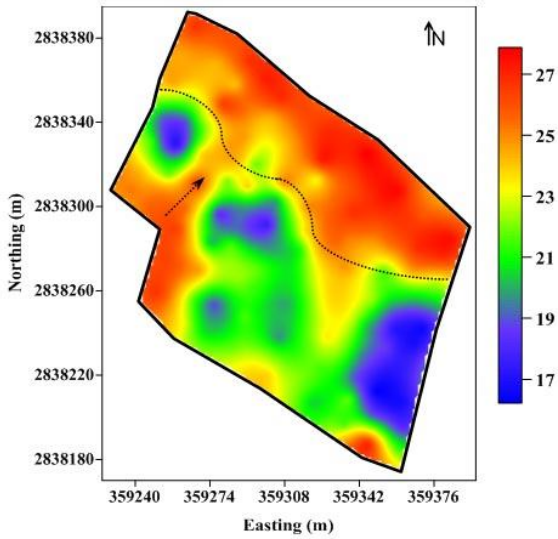
(e) Subsoil sand



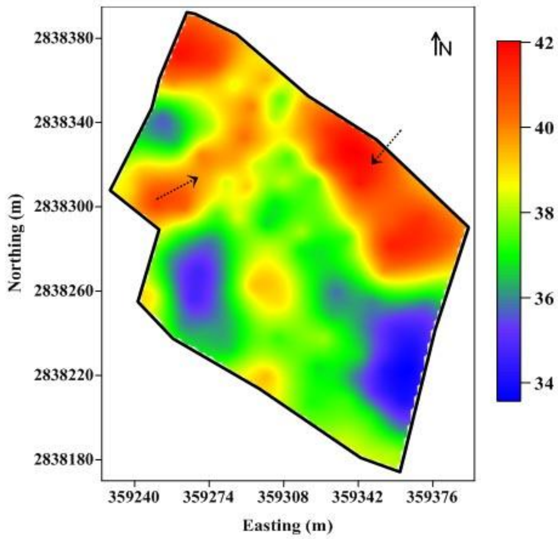
(f) Deepsoil sand

Figure 2. Variograms of clay (a, b and c) and sand fractions (d, e and f) in terrace site

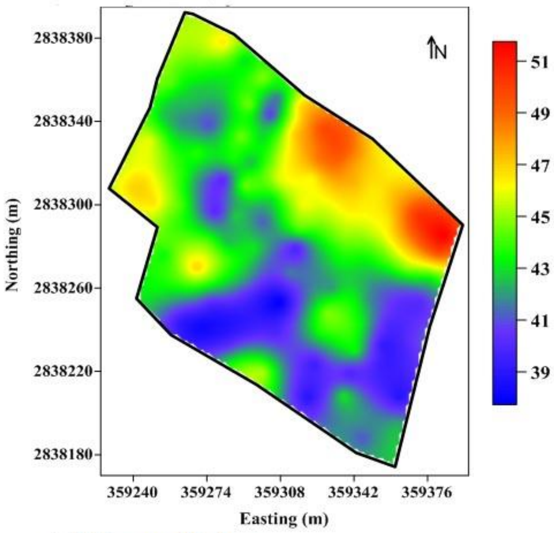
Figure 3. The kriged estimated soil maps that illustrate topsoil clay (a), subsoil clay (b) and deepsoil clay (c) content (%) and associated spatial distribution; and topsoil sand (d), subsoil sand (e) and deepsoil sand (f) content (%) and associated spatial distribution in the terrace soil site of Bangladesh (refer to see the figures in next page)



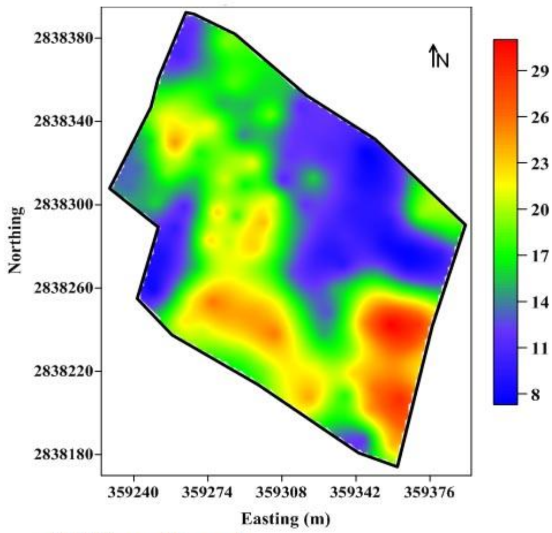
(a) Topsoil clay



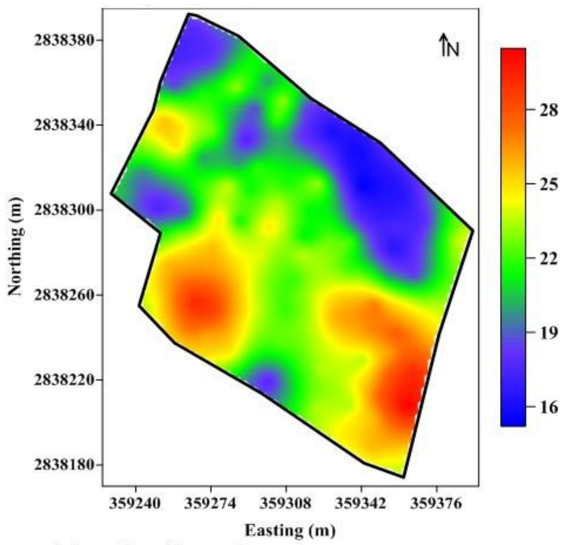
(b) Subsoil clay



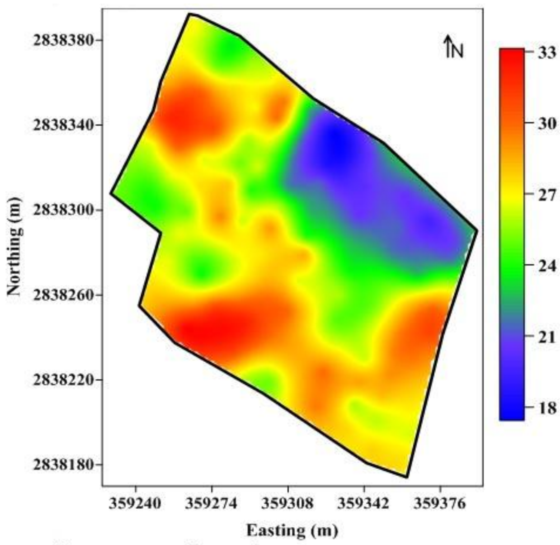
(c) Deepsoil clay



(d) Topsoil sand



(e) Subsoil sand



(f) Deepsoil sand

Conclusion and Remarks

The characteristic feature of the terrace soils of Bangladesh is the clay content below top soil, even more in the deeper soil, which has been characterized and further confirmed by this study. The subsoil clay content (30-60 cm) is almost twice (mean 38%) than the top soil (0-30 cm) clay content (mean 23%) and even more clay content (mean 43%) with stickiness in the deep soil (60-90 cm) as evidenced in this study. The soil texture maps produced through geostatistical technique (Variograms and Kriging) fairly represents the distribution of textural fractions (clay and sand) of the studied site. These soil texture maps represent the spatial variation of soil textural fractions for clay and sand distribution over the field. Thus, these maps can be potential basis to extract useful information on the weight and distribution pattern of sand, silt and clay particles, soil moisture content, soil fertility and organic matter content. These textural maps also provide means of monitoring the spatial variation of soil properties that potentially influence crop production. Furthermore, these maps can also guide soil sampling location, direction and sampling intensity during the soil survey programs, potential basis of soil fertility determination, and the planning and establishment of soil management options for agriculture. While the selection and further specification of site specific management zones could be feasible and integrated from these textural soil maps. However, optimized soil characterization and soil management for a sustainable cropping system could be initiated based on the findings of the study. Additionally, the lateral extent and depth of clayey substratum could be identified for the terrace soils using this geostatistical technique of soil mapping by a more deliberately weighted and adapted frameworks implemented over larger terrace areas of Bangladesh.

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Reference

BBS, 2008. Bangladesh Bureau of Statistics (BBS), Statistical Yearbook-2008. Dhaka-1222, Bangladesh.

Brammer, H. 1996. The Geography of the soils of Bangladesh. The University Press Limited, Dhaka, Bangladesh.

Brammer, H. 2002. Land use and land use planning in Bangladesh. The University Press Limited, Dhaka, Bangladesh.

Cambardella, C. A., Moorman, T. B., Novak, J. M., Parkin, T. B., Karlen, D. L., Turco, R. F. and Konopka, A. K. 1994. Field-scale variability of soil properties in central Iowa soils. Soil Science Society of America Journal 58: 1501-1511.

Day, P. R. 1965. Particle fractionation and particle-size analysis. Methods of soil analysis, p. 545-567, C.A. Black, Ed. Agronomy No. 1. American Society of Agronomy, Madison.

Pannatier Y. 1996. VARIOWIN: Software for Spatial Data Analysis in 2D. Springer-Verlag, New York.

Saheed, S.M. 1992. Soil Survey: perspective and strategies for the 21st century. In: J. A. Zinck, editor, An International Workshop for Heads of National Soil Survey Organizations, ITC publication, No. 21, p. 55-60, The Netherlands.

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