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Spatial variability and geostatistical analysis of selected soil

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Abstract

A study was conducted to explore the spatial variability of major soil nutrients of Agricultural fields in South-western region of Bangladesh. From the study area, 40 surface soil samples were collected by a random sampling strategy using GPS. Then soil physico-chemical properties i.e., pH, electrical conductivity (EC), organic matter (OM), total nitrogen (TN) N, soil available nutrients (P, K and S) were measured in laboratory. After data normalization, classical and geo-statistical analyses were used to describe soil properties and spatial correlation of soil characteristics. Spatial variability of soil physico-chemical properties was quantified through semi-variogram analysis and the respective surface maps were prepared through ordinary Kriging. Spherical model fits well with experimental semi-variogram of pH, EC, OM, TN, available P, K and S. Soil pH, available phosphorus (Av P), potassium (Av K) and sulfur (Av S) have the moderate spatial dependence, with nugget/sill ratios of 41.13% to 72.21%. The others have the strong dependence with nugget/sill ratios of less than 25%. The spatial variability of estimating soil properties varies within range of 0.0142 for Av P to 0.0383 for Av S and this model can calculate the un-sampled within neighboring distance of about 12.65 m for Av S to 150.82 m for TN, respectively. Cross validation of kriged map shows that spatial prediction of soil nutrients using semi-variogram parameters is better than assuming mean of observed value for any un-sampled location. Therefore, it is a suitable alternative method for accurate estimation of chemical properties of soil in un-sampled positions as compared to direct measurement which has time and costs concerned.

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Introduction

Soil parameters are important for evaluating soil quality as well as soil fertility. These parameters of soil are related to variability in different land use pattern and their degradation will result in a decrease of levels of soil fertility, nutrients and thus productivity (Gray and Morant, 2003). It is critical for farmers attempting to increase fertilization efficiency and crop productivity from scientific information concerning spatial variability and distribution of soil properties (Mabit *et al.,* 2008; Tesfahunegn *et al.,* 2011); fertilization based on large scale maps with recommendations related to soil fertility may also lead to reduced fertilizer inputs without reducing yield (Jalali, 2007). Therefore, assessing the spatial variability of soil chemical parameters is crucial to efforts designed to introduce sustainable cropping systems, especially for developing countries such as Bangladesh. Moreover, it should keep in mind that changing one component, one may affect the optimums for others. In understanding those interactions and how to manage them the real value of site-specific management should find out. Responding to those interactions, paying attention to details of the system is the key to profitable implementation of site-specific management.

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Soil variability is the outcome of many processes acting and interacting across a continuum of spatial and temporal scales (Parkin 1993; Cambardella *et al.,* 1994). The variability of soil properties within fields is often described by traditional statistical methods, which assume that variation is randomly distributed within mapping units. Geo-statistical methods, based on the theory of regionalized variables, are more useful tools for describing and understanding the spatial variability of measured variables compared with the traditional statistical methods (Bregt *et al.,* 1992). Semivariograms and kriging statistics have been used extensively to explain and characterize the spatial variability of chemical properties of soils under different cropping patterns (West *et al.,* 1989; Cahn *et al.,* 1994; Cambardella and Karlen, 1999; Borges and Mallarino 1997; Kollias *et al.,* 1999). During the last 10 years, data obtained from GPS (global positioning system), GIS (geographic information system), and geo-statistics have played an important role in the study of soil nutrient spatial variability with respect to soil nutrient site-specific management in some developed countries (Vetsch *et al.,* 1995; Jin, 1998). The results from these countries show that soil variability can occur at any scale, ranging from a few millimeters to large fields of several hectares.

For geostatistical analysis including construction of sample variograms and kriging were performed with the aid of geostatistical software, ArcMap10.0. The degree of spatial dependence for each variable was determined with geostatistical methods using semivariogram analysis and kriging (Mcbratney and Pringle, 1999). Semivariogram is a measure of the dissimilarity. It provides a description of how the data are related (correlated) with distance. The average dissimilarity between data separated by a vector h is measured by the experimental semivariogram Ŷ (h), which is computed as half the average squared difference between the components of every data pair (Journel and Huijbregt, 1978).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z_{(i+h)} - Z_i]^2$$

Where (h) is the number of experimental pairs [$Z_{(i+h)}, Z_i$] of data separated by a vector h. A semivariogram consists of three basic parameters which describe the spatial structure as γ (h)= Cr+ C, h≥ r. C_o represents the nugget effect, which is local variation occurring at scales smaller than the sampling interval, such as sampling error; $C_o + C$ is the sill (total variance); and is the range, at which semivariogram levels off (beyond that distance the variables are not spatially correlated).

The nugget/sill ratio indicates what percent of the overall variance is found at a distance smaller than the smallest lag interval, and gives a sense of how much variance you have successfully accounted for in the model.

Kriging is an interpolation technique that generates the best linear unbiased estimate at each location using the spatial variability obtained from the variogram model. Kriging offers a wide and flexible variety of tools that provide estimates for un-sampled locations using weighted average of neighboring field values falling within a certain distance called the range of influence. Kriging requires a variogram model to compute variable values for any possible sampling interval. The variogram functionality in conjunction with kriging allows us to estimate the accuracy with which a value at an un-sampled location can be predicted given the sample values at other locations (Isaaks and Srivastava, 1989).

The objectives of the research work were to (i) evaluate the spatial variability of selected soil chemical properties of agricultural fields and (ii) characterizing and mapping of spatial variability of selected soil chemical properties.

Methods and materials

The study area Batiaghata is located at 22.7417°N 89.5167°E in Khulna district. Batiaghata upazila consists of 7 union parisads. The Jalma union is the largest union of this upazila. The Kajibacha River splits it into eastern and western part. It has 23698 households and total area 248.33 km² (BPC, 2001).The main rivers are Kazibachha, Shoilmari, Salta, Jhopjhopia, Pasur, Sibsa, Rupsa and Nalua. Main canals are Aria, Batiaghata and Halia and beels are Jhalma, Jhalbari, Basurabad, Ginirabad, and Bhatgati. Batiaghata (Town) is situated on the banks of the river Kazibachha, 10 km. south from Khulna city and on the west of Khulna-Chalna road (USDA, 2004).

A total of 40 soil samples (0-25cm) were collected in the field through random sampling from different locations of Batiaghata Upazila under different cropping patterns (rice, pulse, sesame, ladisfinger, lentil, corn, watermelon, pumpkin, chilli, vegetable, orchard and fallow etc). A portable global positioning system (GPS) was used to record each sample site.Soil samples were collected for laboratory analysis. The samples were placed in plastic bags. The collected samples were all air dried, weighed, and sieved to 2 mm to separate the coarse (>2 mm) and fine (<2 mm) fractions. The sieved soils were then preserved in plastic container and labeled properly.These were later used for chemical analyses.

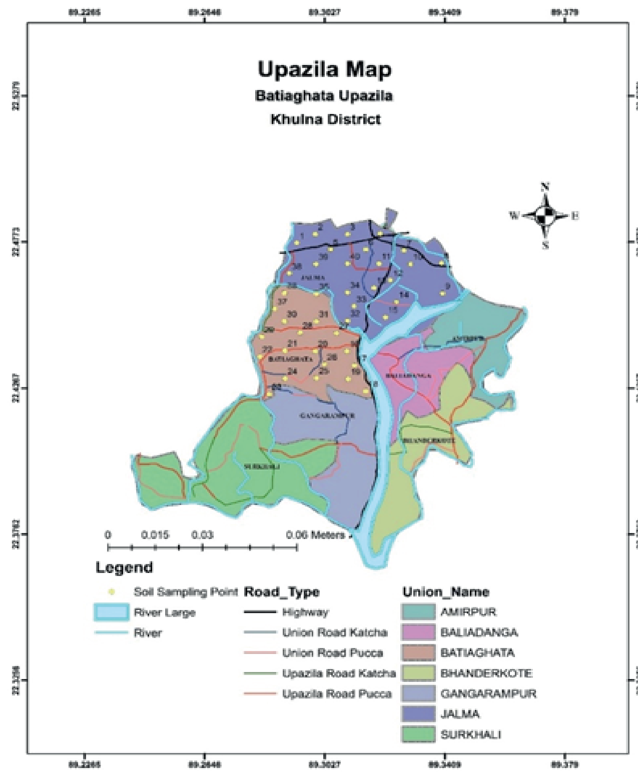


Fig. 1. Batiaghata Upazila Map(LGED, 2010)

The collected soil was sieved through a 2 mm mesh screen to remove plant roots, rocks, and macro fauna. sieved soil samples were analyzed for chemical properties. Soil pH was determined electrochemically using glass electrode pH meter maintaining soil to water ratio 1: 2.5 as suggested by Jackson (1962). The electrical conductivity (EC) to the soil was measured at a soil to water ratio of 1: 5 using EC meter (USDA, 2004). Total nitrogen of the soils was determined by colorimetric method (Bremner and Mulvaney, 1982) following H_2SO_4 acid digestion as suggested by Jackson (1967). Available phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ (Olsen Method) at pH 8.5 and Molybdophosphoric blue colour method of analysis was employed for determination (Murphy and Riley, 1962). The available K was determined from NH_4OAc (pH 7.0) extract as described by Jackson (1967). The extract was analyzed for available K by a flame analyzer at 589 nm (Jackson, 1967). Available sulphur content was determined by turbidimetric method as described by Jackson (1973). It was measured by spectrophotometer at 420 nm. Organic carbon of samples was determined by Walkley and Black's wet oxidation method as outlined by Jackson (1962).

Statistical analysis

Using SPSS classical statistics (mean, median, standard deviation and standard error of mean, skewness and kurtosis) were calculated for all soil parameters. Prior to construction of variograms, the data were tested for normality.For geostatistical analysis including construction of sample variograms and kriging were performed with the aid of geostatistical software, ArcMap10.0. The degree of spatial dependence for each variable was determined with geostatistical methods using semivariogram analysis and kriging (Mcbratney and Pringle, 1999).

Results and discussion

Explanatory statistical analysis

The summary of descriptive statistics for soil parameters are shown in Tables I. The parameter values strongly varied between fields. Mean and median values of the majority of soil parameters measured at the study area were similar, with median values generally slightly higher than the means (Table 1), indicating dominant measures of central tendency. This similarity was also noted by many other researchers, including Brejda *et al.* (2000), Cambardella and Karlen (1999), Cambardella *et al.* (1994), Emadi *et al.* (2008) and Young *et al.* (1999).

pH of the soil ranged from 5.30 to 8.0 and with a mean (μ) value of 7.35 and standard deviation (σ) of 0.54 of the studied area. pH followed a normal distribution indicated by the Kurtosis and skewness coefficient. This neutral to slightly alkaline soil reaction (pH) is a common feature of Ganges tidal floodplain and Ganges alluvial floodplain soils of Bangladesh (Lake,2000). That value of pH might be a result of application of different types of fertilizers at the surface soil at varying amount. The no tillage soils had a higher soil pH values than plow tillage soils (Chatterjee *et al.,* 2009).

EC of the studied area was found between the ranges 1.5 to 15.8 dSm^{-1}. Mean (μ) and standard deviation (σ) of EC was 7.21 dSm^{-1} and 2.93 respectively (Table I). Maximum areas are saline soil as there is littoral deposition of estuarial intrusion of brackish tidal water from sea through creeks (Lake, 2000; USDA,2016). Most of the areas which are located at the cannel side contain highly saline soil. EC varies with the concentration of dissolved salts (Bohn *et al.,* 1985), and usually pH decreases when the salt concentration increases (Seatz and Peterson, 1965). Moreover, soil EC could be related to other soil properties such as water holding capacity, topsoil depth, soil nutrients levels, salinity, and subsoil characteristics.

Soil organic matter (SOM) ranged from 1.33 to 4.41 %. Mean (μ) and standard deviation (σ) of SOM is 2.53 % and 0.68

respectively (Table I). Vegetable, pulse, and fallow land conserve more SOM than agricultural field (Table I). Soil organic matter was higher at no-tillage soils compared with minimum tillage with chisel plow and conventional tillage with mouldboard plow (Lopez-Fando and Pardo, 2011). Some researchers reported that the highest OM content was found in grasslands compared to agricultural fields (Riezebos and Loerts, 1998; Paz-Gonzalez *et al.,* 2000; Jaiyeoba, 1995). The depletion of organic matter in the cultivated fields can be associated with the intensive tillage and the removal of plant residue.

Total nitrogen of the sample showed comparatively lower values within the range of 0.09 to 10.27 with a mean value of 0.141%. These results might be associated with tiny fertilizer applications in recent decades (Liu *et al.,* 2013). The values showed a positive skewness and leptokurtic in nature.

The values of available phosphorus (Av P) showed leptokurticity. Available phosphorus content of the studied plot was low within the range of 1.35 to 14.55 and with a mean value of 6.33 ppm compared to standard and this might be related to balanced P fertilizer application (Gao *et al.,* 2001). For regions with high soil P (>10 mg kg^{-1}), additional P fertilizer was needed because of its strong after effects and the high soil temperatures increasing P availability during rice growing season (Bruun *et al*., 2006). Lienwber and Schulten (1998) estimated that the amount and type of clay mineralogy in the soil affects P availability.

Available sulfur (Av S) content showed highly variable with a range of 30.2 to 423.6 with a mean value of 2.62 ppm. It showed leptokurtic in nature and a normal distribution, as indicated by the Kurtosis and skewness coefficient. This high range might be due to comparatively low washed out S in the form of sulphates, especially under leaching conditions (Vanek *et al.*, 2008).

The coefficient variation (CV) is the ratio of the standard deviation (SD) to the mean values times 100. Three outof seven soil properties a CV greater than 30%, demonstrating substantial variability within the datasets (Table I). The highest and the least CVs for soil parameters were obtained for Av P (54.19%) and pH (7.35%) respectively, indicating the high variability for Av P relative to other soil parameters (Weindorf and Zhu, 2010). SOM had a relatively high CV of 26.88%, which could be linked to heterogeneity in the land-use pattern, fertilizer application, or erosion. In addition, the higher CV of the EC (40.64%) could be the consequence of agricultural practices such as soil tillage, fertilization, and vertical distribution of finer materials, the removal of nutrients by plants, and the changes of soil water balance.

Results showed there is lower value of skewness and kurtosis among soil parameters (pH, electrical conductivity, and organic matter, extractable elements such as available K, P and S as well as total N)due to intrinsic characteristics of variables, environmental conditions like human activities, sampling methods and number of samples.

Correlations among selected soil parameters

To characterize the relationships between yield and selected soil chemical properties(organic matter, pH, available sulfur,

Table I. Descriptive statistics for selected chemical soil parameters

Properties	Min	Max	Mean	Median	SD	Variance	CV (%)	Skewness	Kurtosis
pH	5.3	8	7.35	7.5	0.54	0.29	7.35	-1.695	4.166
EC (dSm^{-1})	1.5	15.8	7.21	7.2	2.93	8.591	40.64	0.246	0.793
OM (%)	1.33	4.41	2.53	2.21	0.68	0.458	26.88	0.755	0.228
Total N%	0.09	0.27	0.141	0.13	0.04	0.001	28.37	1.225	1.666
Av P (ppm)	1.35	14.55	6.33	5.96	3.43	11.79	54.19	0.498	-0.405
Av K (ppm)	0.41	1.02	0.56	0.51	0.144	0.021	25.71	1.535	2.052
Av S (ppm)	30.2	423.6	2.62	2.83	1.086	1.179	41.45	-0.415	-1.011

$CV (\%) = \frac{\sigma}{\mu} \times 100$

(Where, CV= coefficient of variation, σ = standard deviation, μ = mean) total nitrogen, available phosphorus, available potassium, and electrical conductivity), Pearson's product moment correlation coefficient was calculated for each property (Table II).

Table II. Correlations among selected soil parameters

		pH	EC (dSm^{-1})	OM (%)	Total N (%)	Av P (ppm)	Av K (ppm)	Av S (ppm)
pH	Pearson Correlation	1						
EC (dSm^{-1})	Pearson Correlation	-.427**	1					
OM (%)	Pearson Correlation	-.258	.278	1				
Total N (%)	Pearson Correlation	-.230	.233	.935**	1			
Av P (ppm)	Pearson Correlation	.335*	-.039	-.013	.028	1		
Av K (ppm)	Pearson Correlation	-.493**	.344*	.246	.263	.058	1	
Av S (ppm)	Pearson Correlation	-.330*	.540**	.269	.307	.043	.224	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Correlations were found to be highly significant between some variables as generally reported e.g., organic matter and total nitrogen (r^2= 0.935), electrical conductivity and available sulfur (r^2= 0.540). Significant correlations can also be identified between pH and available phosphorus (r^2=0.335). It is clear that soil pH was strongly negatively correlated with electrical conductivity (r^2= -0.427) and available potassium (r^2= -0.493). Moreover, no significant correlation was observed between organic matter and other properties.

Geostatistical analysis

Semivariogram and spatial dependency

Soil samples from over 40 locations are needed to properly detect anisotropy (Robinson and Metternicht, 2006); hence, it was not feasible to explore directional effects for the data set used in this study. Hence, variogram models were assumed to follow the isotropy and only isotropic variogram models were considered for this study. The accuracy of soil property values can be estimated through kriging (using modeled semivariogram parameters) at unsampled locations was tested using different error estimates.Model parameters for the best fit semivariogram models are presented in Table III. A large range indicates that the observed values of a soil variable are influenced by other values for this variable over greater distances than soil variables, which have smaller ranges (Lopez-Granados *et al.,* 2002).

Several models are used for semivariogram analysis. Spherical model used to calculate the theoretical semivariogram parameter in ArcGIS 10.0. The nugget value represents the random variation usually derived from the in accuracy of measurements or variations of the properties that cannot be detected in the sample range (Trangmar *et al*., 1985). The sill value is the upper limit of the fitted semivariogram model (Webster and Oliver, 2001). The ratio of nugget to sill indicates the spatial dependency of the soil properties. The range of the semivariogram represents the average distance through which the variable semivariance reaches its peak value. A small effective range implies a distribution pattern composed of small patches (Zhou *et al.,* 2010).

Table III. Semivariogram model parameters for soil properties

Soil properties	Model type	Nugget	Sill	% Nugget*	Spatial Class**	Direction (m)	Range
pH	Spherical	0.0017	0.0042	41.13	Moderate	73.1	0.0383
EC (dSm^{-1})	Spherical	0	0.2667	0	Strong	16.2	0.0224
OM (%)	Spherical	0.0073	0.0442	16.50	Strong	64.51	0.0233
Total N (%)	Spherical	0.0136	0.0323	42.29	Moderate	150.82	0.0188
Av P	Spherical	0.1619	0.2932	55.22	Moderate	141.68	0.0142
Av K	Spherical	0.0186	0.0452	41.26	Moderate	56.95	0.0171
Av S	Spherical	0.1957	0.2711	72.21	Moderate	12.65	0.0383

*% Nugget = (nugget semivariance / total semivariance) × 100.
**Strong = % Nugget < 25%; Moderate = % Nugget 25–75%; Random = % Nugget >75% (Cambardella et al., 1994)

The nugget effect can be defined as an indicator of the continuity at close distances. Soil properties with lower nugget effect were generally defined by spherical semivariogram model (Table III). The soil parameters including pH, available sulfur, total nitrogen, available phosphorus and available potassium follow a moderate spatial distribution (except organic matter and electrical conductivity) and clear patchy distribution all over the studied area as the percent nugget value includes 41.13%, 72.21%, 42.29%, 52.22% and 41.26%, respectively (Table III) and (Fig. 1). The spatial variability of estimating soil properties varies within range of 0.0383 for pH, 0.0224 for EC, 0.0233 for OM, 0.0188 for Total N, 0.0142 for Av P, 0.0171 for Av K and 0.0383 for Av S and this model can calculate the unsampled within neighboring distance of about 73.1 m for pH, 16.2 m for EC, 64.51 m for OM, 150.82 m for Total N, 141.68 mfor Av P, 56.95 m for Av K and 12.65 m for Av S,respectively. Their spatial dependence may be controlled by both intrinsic variations of soil properties and extrinsic factors such as human induced activities (Liu *et al.,* 2013; Wu *et al.,* 2010).

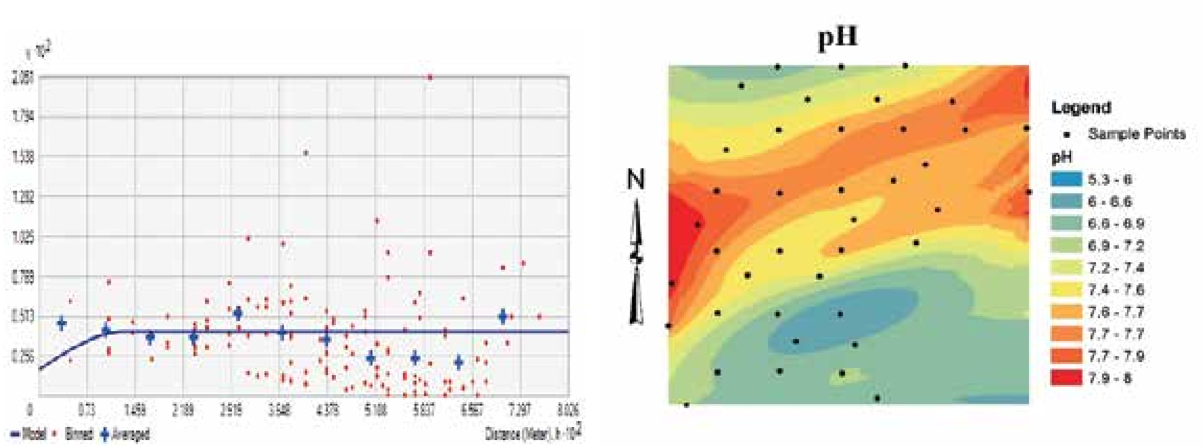
Spatial distribution of soil parameters

Soil parameter maps obtained by ordinary kriging interpolation were displayed in Fig. 2(a) to Fig. 2(g). The results showed that all the soil samples varied considerably all over the studied area. The spatial variation in soil parameters should not be surprising, since the values of the variables are usually the result of an intrinsic variation in soil properties and management practices as previously reported by Mallarino *et al.* (1999).

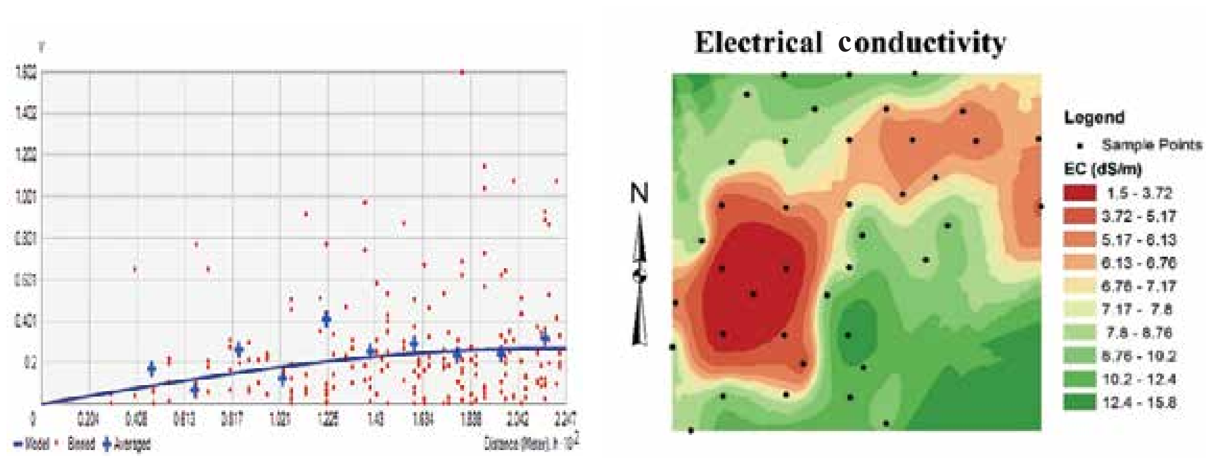
A low ratio (<25%) means that a large part of the variance is introduced spatially, implying a strong spatial dependency of the variable. When the distribution of soil properties is strongly or moderately spatially correlated, the average extent of these patches is given by the range of the semivariogram. Again if the ratio was 100%, or the slope of the semivariogram was close to zero, the soil variable was considered non-spatially correlated (pure nugget). Their spatial dependence might be controlled by both intrinsic variations of soil properties and extrinsic factors such as human induced activities (Liu *et al.,* 2013; Wu *et al.,* 2010). However, unknown spatial dependency of the variable could exist at a lower scale even if a high nugget/sill percentage was obtained (Wu *et al.,* 2008).

The soil parameter pH follows a moderate spatial distribution and clear patchy distribution all over the studied area. pH of the soil was higher in the western part of the study area, while lower pH was found at southern site of the study area. Samples in the Fig. 2(a) were generally characterized by having extensive areas with pH levels 7.6 to 7.7 indicating mildly alkaline pH. Lake (2000) observed that in the relative absence of acidic cations, pH may rise above 7 and pH change with current agricultural practices.

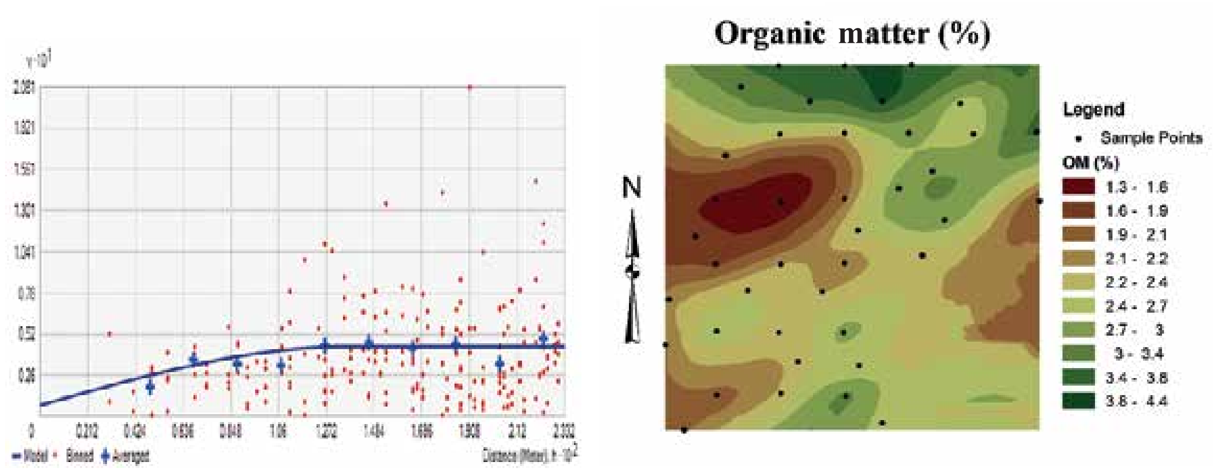
EC of the soil is higher in the south east site as shown in the Fig. 2(b), where there has a scope of large amount of littoral deposition of estuarial intrusion of brackish tidal water from river through creeks and possess slightly saline soil. The important changes occurred in soil properties with cultivation. Soil degradation increased with soil tillage and rapidly deteriorated soil fertility by decreasing OM.



Model: 0.00172*Nugget+0.0025*Spherical (0.0383, 0.0128, 73.1)

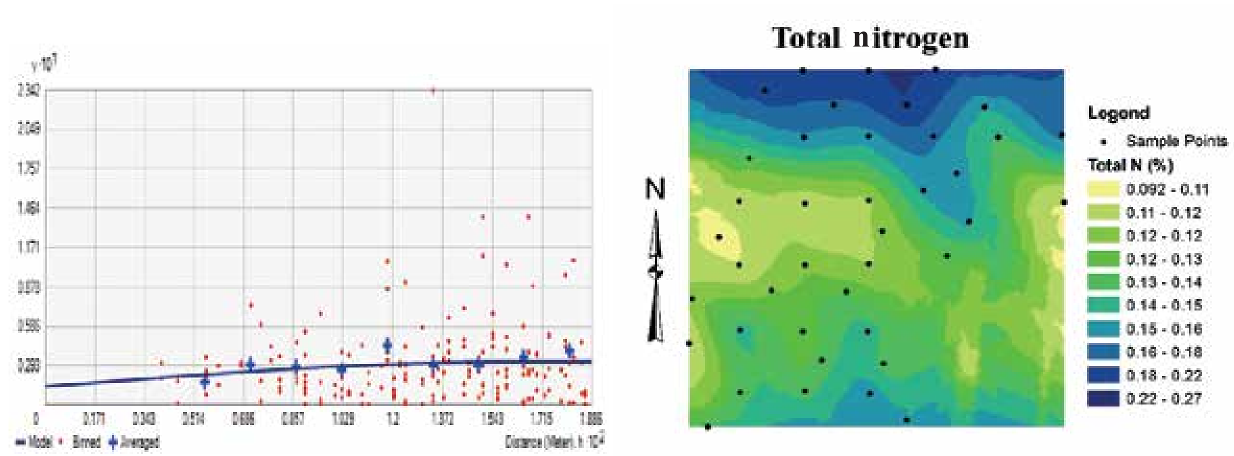


Model: 0*Nugget+0.2667*Spherical (0.0224, 0.0134, 16.2)

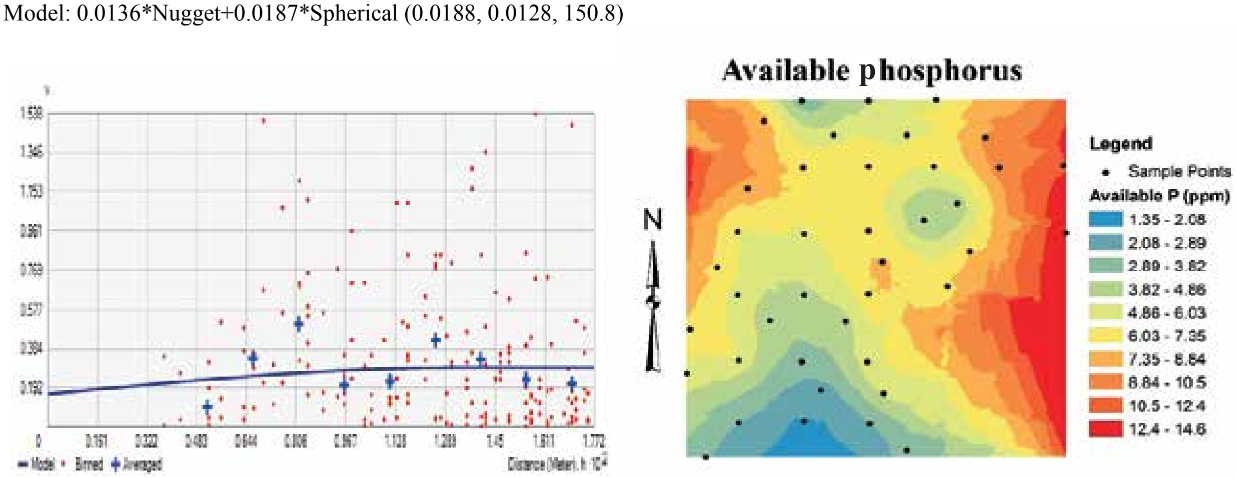


Model: 0.0073*Nugget+0.0369*Spherical (0.0233, 0.0128, 64.5)

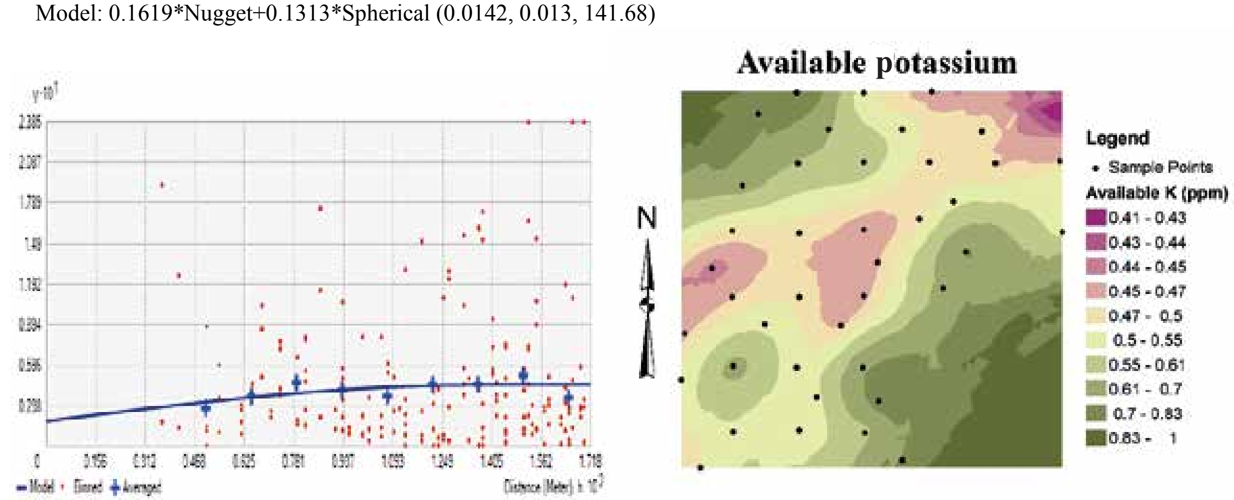
Fig. 2. Semivariograms and kriged maps of soil (a) pH, (b) EC and (c) OM



Model: 0.0136*Nugget+0.0187*Spherical (0.0188, 0.0128, 150.8)



Model: 0.1619*Nugget+0.1313*Spherical (0.0142, 0.013, 141.68)



Model: 0.0186*Nugget+0.0266*Spherical (0.0171, 0.0128, 56.95)

Fig. 2. Semivariograms and kriged maps of soil (d) Total N, (e) Av P and (f) Av K

Therefore, a sustainable soil management system should be applied to decrease soil degradation (Acquaah, 2002).

Higher percentage of OM was observed in the northeast part of the study area, while low percentage of OM was found at middle point of the study area. Samples were generally characterized by having extensive areas with OM concentrations between 2.2 to 2.4%in the Fig. 2(c).The semivariograms and kriged map of OM show similar (strong) spatial distribution trend as EC. The Variability of soil OM might be result of landscape attributes including slope, aspect and elevation, and land use might be the dominant factors of SOM in an area with the same parent material and the same climate (Rezaei and Gilkes, 2005).

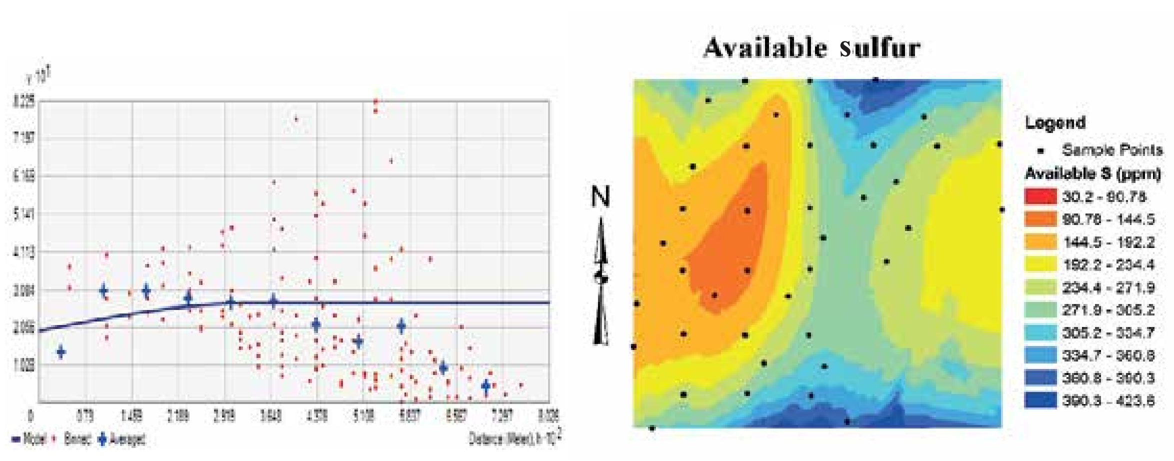
The spatial distribution trend of total nitrogen was totally similar from OM, as indicated in Table 2. From the correlation table it was found that total nitrogen and OM are strongly correlated positively. Soils were generally characterized by having extensive areas with total nitrogen between 0.13% and 0.14% in the Fig. 2(d) found all over the study area. Meanwhile high levels of total nitrogen was found only at north site. The moderate spatial dependency (Table 3) in total nitrogen levels in different land use pattern might be benefitted from the use of NPK fertilizers, while grassland restoration is frequently encouraged by planting N fixing alfalfa (Wang *et al.,* 2009).

areas with available phosphorus concentrations between 6.03 and 7.35 ppm in the Fig. 2(e). This might be related to unbalanced P fertilizer application (Gao *et al.,* 2001) and also because of animal manure application with different amendments (Fu *et al.,* 2010; Rehm *et al.,* 1994; Islam, 2010).

Relatively high available potassium was observed in the southeast part of the study area, while relatively low available potassium was found at northeast site. Samples were generally characterized by having extensive areas with available potassium concentrations between 0.61and0.70 ppm in theFig. 2(f). The distribution of available potassium moderately spatially correlated (Table 3), implies that a large part of the variance is introduced spatially. This spatial variability for soil potassium might be due to regional factors (e.g. topography, climate and soil matrix) (Huang *et al*., 2006). The low application rate of K fertilizer and intensive cropping system were the two major reasons causing the observed severe potassium depletion (Lu *et al*., 2000; Zhang *et al*., 2010).

Model: 0.1957*Nugget+0.0753*Spherical (0.0383, 0.0128, 12.65)

Available sulfur of the soil was higher in the southern part of the study area, while relatively low amounts of available sulfur was found at middle point of the study area. Soils were generally characterized by having extensive areas with



Model: 0.1957*Nugget+0.0753*Spherical (0.0383, 0.0128, 12.65)

Fig. 2. Semivariograms and kriged maps of soil (g) Av S

Available phosphorus of the soil follows a moderate spatial distribution and clear patchy distribution all over the studied area.Available phosphorus of the soil was higher in the eastern part of the study area, while relatively low amounts of available phosphorus was found at southern site of the study area.Soils were generally characterized by having extensive

available sulfur concentrations between 234.4 to 271.9 ppm in the Fig. 2(g).The low amounts of sulfur level might be a result of mostly washed out sulfur in the form of sulphates, especially under leaching conditions (Vanġk *et al.*,2008).

Summary and conclusion

Thus, descriptive statistics indicated the sizeable spatial variability for all soil variables. Further understanding of the spatial structures of soil variables can be helpful for revealing their spatial distribution and achieving the reasonable site specific farming management. The geo-statistical analysis of soil variables suggested that the value nugget-sill ratio ranges from 0% (EC) to 55.22% (Av P), except for available sulfur (72.21%), indicating that internal factors were dominant over external factors. Soil EC and OM had the strong spatial dependence with a nugget-sill ratio of < 25%, because it induced by structural factors. But the spatial variability of other soil variables (pH, TN, Av P, Av K and Av S) had the moderate spatial dependence with a nugget-sill ratio of 25-75%, because the variables were mainly determined by internal and external factors. The spatial correlation distances of all variables varied from 16.2 m (EC) to 150.82 m (TN), indicating that the sampling design is reasonable. Distribution maps, derived by kriging interpolation, illustrated that these studied area were characterized by moderate to high value of electrical conductivity (EC) and available potassium in southeast site. Available phosphorus and soil pH varied all over the studied area, where as total nitrogen and organic matter had high percentage at the northeast corner. The areas with low soil organic matter concentrations (1.3-1.6%) and available sulfur (30.2- 90.78 ppm) were mainly located in middle point of the study area. Notably available phosphorus showed a different trend in spatial distribution from south to north site. These results are reflection of many factors including soil pH, CEC, OC, amount of moisture held by soil particles, fertilizer application, animal manure application with different amendments, intensive cropping system, different land use pattern, topography of the field at different weather condition and texture percentage.

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