*Soil Environ. 35(1): 12-21, 2016*
*www.se.org.pk*
*Online ISSN: 2075-1141*
*Print ISSN: 2074-9546*

# Spatial variability of selected physico-chemical properties and macronutrients in the shale and sandstone derived soils

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## Abstract

*Knowledge of soil spatial variability is important for the evaluation of agricultural land management practices in the context of precision agriculture. This research work was carried out to characterize the spatial heterogeneity of selected soil properties in shale and sandstone derived soil at farm level. Representative surface (0-20 cm) soil samples were collected at 50 m x 50 m grid pattern and their precise locations were recorded by GPS receiver to examine the selected physico-chemical properties and macronutrients. Soils of the surveyed area were categorized as alkaline. Soil texture ranged from sandy loam to loam, sandy clay loam and silt clay loam. Soil of the surveyed area was low in organic matter content, plant available nitrogen ($NO_3$-N) and phosphorous content. Soil pH, EC, sand, clay, organic matter, $NO_3$-N and available phosphorus were moderately spatial dependent, while available potassium was strongly spatial dependent. The results recommend that there is a need for a site specific farm management keeping in view the soil heterogeneity.*

***Keywords:*** *Geostatistics, GIS, Kriging, soil heterogeneity*

## Introduction

Sandstone and shale residuum are the parent material which contribute 90 percent of the soil development in the Pothowar region (Mehmood *et al*., 2015). The Pothwar region of the Punjab province is one of the most agriculturally productive rainfed areas of the Pakistan and is of broad agro-ecological significance. Pothwar region faces widespread nutritional deficiencies due to water erosion coupled with nutrient mining and water scarcity (Khalid *et al*., 2012). There are many constraints to sustainable agriculture in the area, nutrient deficiency in the soils being one of the main reasons for low average yield. It is estimated that 90 percent of Pakistani soils are deficient in plant available nitrogen and phosphorous while 50 percent are deficient in potassium content in addition to micronutrient deficiencies (Arin *et al*., 2000).

Uniform fertilizer recommendation on provincial basis leads to over or under fertilization in cultivated areas which in return causes severe yield losses (Ahmed *et al*., 2014). Traditional practices of fertilization lead towards uneven distribution, adsorption, absorption and uptake of plant nutrients with damage of land resources (Jin and Jiang, 2002). Increase in population and hike of fertilizers prices require some scientific and sophisticated techniques to increase fertilizer use efficiency for the natural resources conservation and to avoid economic losses. One of the major factors for low fertilizer use efficiency in Pakistan is the uniform application of fertilizers without considering the spatial heterogeneity of soil physico-chemical properties.

Spatial variability in soil physico-chemical properties and nutrient levels is well documented (Liu *et al*., 2007 : Patil *et al*., 2011: Wang *et al*., 2009 : Ahmed *et al*., 2014). Factors influencing or governing the spatial dependence include climatic conditions (Patil *et al*., 2010) topography (Rezaei and Gilkes, 2005) soil texture (Gami *et al*., 2009), type of vegetation and land use (Wang *et al*., 2009). The advent of geographic information and global positioning system make it easier to demonstrate spatial variability across the field that is otherwise a very laborious method (Burrough and McDonnell, 2011).

Keeping in view the importance of soil spatial variability for site specific agriculture, this research work aimed to characterize the spatial variability using geostatistics and geographical information system. The spatial variability of salient physico-chemical properties were assessed to delineate the whole research farm in to various management zones to serve as an exemplary model for the Pothwar region.

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## Materials and Methods

### Soil sampling, processing and analyses

Study area is located at $73^0$ 0' 47" E and $33^0$ 7' 40" N in the Pothwar region. Study area is spread over 0.94 $km^2$. Soil sampling was carried out before winter crop fertilizing and planting. Two hundred and sixty composite georeferenced samples were collected at 0 to 20 cm depth on a regular grid spacing of 50 m x 50 m. Soil samples were air dried, ground and passed through a 2 mm sieve. The samples were stocked in plastic bags for further analysis. The soil samples were analyzed for Nitrate nitrogen (Vendrell and Zupancic, 1990), available phosphorus (Olsen and Sommers, 1982), available potassium (Rhoades, 1982), particle size distribution (Gee and Bauder, 1986), pH (Mclean, 1982), EC (Rhoades, 1982) and soil organic matter (Nelson and Sommers, 1982).

### Statistics and geostatistical analysis

Descriptive statistics including mean, standard deviation (SD), kurtosis and skewness were applied to the data set obtained for each macronutrient. Co-efficient of variance was used to examine the variability of macronutrients within the soils. Soil properties and nutrients having co-efficient of variance (CV) values < 15% were grouped as least variable whereas those having CV between 15 to 35% were categorized as moderately variable. Co-efficient of variance value more than 35% indicated high variability. Digital soil maps were prepared using GPS coordinates through Arc GIS 10.1 software, whereas geostatistical analysis was performed by $GS^+$ software.

Semivariogram analysis was applied to examine the degree of spatial dependence of physicochemical variables in the soils (Bhatti *et al*., 1991). Three parameters used to describe the structure of model were nugget variance (Co), sill (Co + C) and range (a). The nugget variance represents experimental error or spatial sources of variation at distances smaller than the sampling interval (Burgess, 1980). The sill represents maximum semivariance that represents the variability. The range is a parameter of a variogram or semivariogram model that represents a distance beyond which the samples behave independently. Spatial class ratios (Nugget/Sill ratio) are used to define different classes of spatial dependence. A variable having Nugget/Sill ratio less than 25 % was considered strongly spatial dependent, moderate spatial dependency if the Nugget/Sill ratio was between 25 to 75 % and weak spatial dependence if the ratio was greater than 75 %(Cambardella, 1994; Attar *et al*., 2012).

Ordinary kriging was used as a spatial interpolation technique because of its higher flexibility. Mean error (ME), mean standard error (MSE), average standard error (ASE), root mean square error (RMSE) and root mean squared standardized error (RMSSE) were used for comparing various models and to check the correctness of simulation (Robinson and Metternicht, 2006). Average standardized error close to RMSE was considered as prerequisite for correct prediction (Hani *et al*., 2010). After the establishment of spatial dependence, isarthimic map for spatial distribution of macronutrients (N, P and K) and physico-chemical characteristics (pH, EC. O.M, sand, silt and clay) were generated. Whole area was classified in to various zones on the basis of N, P and K content.

## Results and Discussion

### Physico-chemical properties of soils in the surveyed area

Data regarding soil physico-chemical properties is summarized in the Table 1. Soil texture affects many physical and chemical properties of soils i.e. aeration, infiltration, retention of water, nutrient absorption, microbial activities, irrigation and tillage practices (Foth, 1990; Gupta, 2004). Dominant textural class observed in the study area was sandy loam and 48% of the total analyzed samples were categorized in this class. Loam texture was prevalent over 45 % of analyzed soil samples. Sandy clay loam and silt clay loam was observed in the 5 and 2 percent of soil samples respectively. Electrical conductivity of soil reflects the concentrations of soluble salts in soil. The electrical conductivity of the soil samples ranged from 0.07 - 0.47 dS $m^{-1}$ with a mean value of 0.23 ± 0.08. The Soil EC was less than 4dS $m^{-1}$; it indicated that all the samples were free from salinity hazards. The measure of soil pH is an important parameter which helps in classification of chemical nature of the soil (Shalini *et al*., 2003), as it measures concentration of hydrogen ions in the soil to signify the acidity or alkalinity. The soil pH values varied from 7.28 to 8.23 with an average value of 7.75 ± 0.19 (Table 1). The pH of soils was alkaline due to the indigenous parent material, calcareousness and low organic matter, this situation is similar in almost all soils (Latif *et al*., 2008; Khalid *et al*., 2012). Soil organic matter is defined as any living or dead plant and animal materials in the soil and it comprises a wide range of organic species such as humic substances, carbohydrates, proteins, and plant residues (Foth and Ellis, 1997). Organic matter content varied from 0.17 to 1.51 % with average value of 0.73 ± 0.28 (Table 3). About 72 % samples of an area had poor SOM contents while 24% were in satisfactory range, and the rest 4% were adequate. The main reason for low organic matter in the area is summer temperature which exceeds to 45 °C due to which rate of decomposition is amplified.

**Table 1: Physico-chemical properties of soil in studied area**

| Physico-chemical characteristics | Mean | Minimum | Maximum | S.D* | C.V** % | Kurtosis | Skewness |
|---|---|---|---|---|---|---|---|
| pH | 7.75 | 7.28 | 8.23 | 0.18 | 2.40 | -0.49 | -0.16 |
| EC (dS $m^{-1}$) | 0.23 | 0.07 | 0.47 | 0.08 | 35.36 | -0.60 | 0.15 |
| O.M (%) | 0.73 | 0.17 | 1.51 | 0.28 | 39.03 | -0.17 | 0.44 |
| Sand (%) | 51.57 | 18.00 | 78.00 | 7.72 | 14.97 | 3.00 | -0.58 |
| Silt (%) | 36.87 | 10.00 | 53.00 | 8.33 | 22.60 | 0.86 | -0.92 |
| Clay (%) | 11.67 | 2.50 | 32.00 | 6.09 | 52.27 | 0.89 | 1.06 |

*Standard Deviation, **Co-efficient of variance n=260

**Table 2: Assessment of macronutrient contents (mg $kg^{-1}$) in the studied area**

| Nutrient | Mean | Minimum | Maximum | S.D* | C.V** % | Kurtosis | Skewness |
|---|---|---|---|---|---|---|---|
| NO3-N | 7.89 | 1.37 | 18.74 | 3.12 | 39.49 | 0.30 | 0.76 |
| Available P | 7.23 | 1.87 | 27.10 | 3.05 | 42.14 | 6.12 | 1.35 |
| Available K | 144.10 | 65.89 | 293.83 | 46.5 | 32.27 | -0.05 | 0.64 |

## Macronutrient indexation

Nitrate nitrogen (NO3-N) is most commonly measured in standard soil tests for nitrogen, because it is the primary form of nitrogen available to plant and, therefore, an indicator of nitrogen during assessment of soil fertility. Available nitrogen contents ranged from 1.37 to 18.74 mg $kg^{-1}$ with the mean value of 7.89 ± 3.12. According to criteria suggested by Soltanpour, 1985 (Table 4) about 85 % samples were found low and the remaining 15 % were categorized as marginal (Table 3). Sixty five percent of the analyzed samples were poor in phosphorus content while 35 % were in satisfactory range (Table 3). Plant available phosphorous content was deficient in 65 % of the analyzed samples, while 35% was categorized in satisfactory range. Phosphorous content ranged from 1.87 to 27.10 mg $kg^{-1}$ with mean value of 7.23 ± 3.05.

Potassium (K) is the third most required element by the plants, which plays a key role in water balance in plants or regulation of osmosis (Singh and Tripathi, 1993). Plant available K ranged from 65.89 mg $kg^{-1}$ to 293.83 mg $kg^{-1}$ with the mean value of 144.10 ± 46.5. When compared with the critical values 67 % of the total analyzed samples contained satisfactory while 24 % had adequate K contents and the rest 9% were poor potassium content. Low organic matter in soils of surveyed area is the main reason for deficiency of nitrogen. Phosphorous deficiency in alkaline soils developed from sandstone and shale residuum is a common phenomenon as the pH approaches 6, precipitations as calcium compounds begins, at pH 6.5 the formation of insoluble calcium salt is a factor in rendering the phosphorus unavailable. Above pH 7 even more insoluble compounds such as apatite are formed (Malik *et al*., 2014). Alkaline soils with pH ranging from 7 to 8 and above are generally deficient in P content. About 80 to 90% soils of arid and semiarid regions of the world like Pakistan are deficient in plant available phosphorus. In Pakistani soils Mica (K- bearing mineral) is dominantly present in all the three soil fractions sand, silt and clay so most of the soils of Pakistan have sufficient K content. The K content had perpetually been reported as adequate in Punjab soils except eroded or light textured soils (Bajwa, 1990). Rashid *et al*. (2008) also reported similar results and found K in the satisfactory range (80-180 mg $kg^{-1}$) in Chakwal soils which are similar to the studied soils. Potassium was found deficient in the 30 percent of farmer grown groundnut fields (Rashid and Bhatti, 2005) in the same region.

**Table 3: Soil fertility index of soils in studied area**

| Available nutrient | Poor | Satisfactory % | Adequate |
|---|---|---|---|
| Organic matter (%) | 71.92 | 23.85 | 4.23 |
| NO3-N (mg $kg^{-1}$) | 84.62 | 15.77 | NIL |
| Available P (mg $kg^{-1}$) | 65.38 | 34.62 | NIL |
| Available K (mg $kg^{-1}$) | 8.85 | 66.92 | 24.23 |

n=260

**Table 4: Guideline values for various nutrients**

| Status | Organic Matter<br>-------- %---------- | Available Phosphorus | Available Potassium | Available Nitrogen* |
|---|---|---|---|---|
| | | ---------------------------------- | %---------------------------------- | |
| Poor | < 0.86 | < 8 | < 90 | < 11 |
| Satisfactory | 0.86 - 1.29 | 8 – 15 | 90 - 180 | 11 – 20 |
| Adequate | > 1.29 | > 15 | > 180 | > 20 |

(*Soltanpour 1985)

## Spatial variability of physico-chemical properties and macronutrients in the soils

The semivariogram models and best-fit model parameters for physico-chemical characteristics (pH, EC, organic matter, sand, silt and clay) and bioavailable macronutrients (N, P and K) are presented in Table 5. All studied physico-chemical properties and plant available macronutrient showed a positive nugget which might be due to sampling error, short-range spatial variablity and can be associated with the random and inherent variability (Wang *et al.*, 2009).

Spatial structure of sand and clay was best described by exponential model and their Nugget/Sill ratios were 50% each which indicated the existence of moderate spatial dependence and the range for sand and clay was 6.33 km. The silt did not show the spatial dependency in studied area. Exponential model was proved best for explaining the spatial structure of soil pH with the range 5.54 km. Soil pH was also found moderately spatial dependent as nugget to sill ratio was 37.81 %. Spatial structure of the EC was best described by the exponential model with range of 3.85 km.

**Table 5: Parameters related to semivariogram models and interpolation of plant available macronutrients**

| Nutrient | Model | Range ($A_0$) | Nugget/Sill (%) | $R^2$ value | RMSSE[a] | ASE[b] | RMSE[c] |
|---|---|---|---|---|---|---|---|
| pH | Exponential | 5.54 km | 37.81 | 0.91 | 0.92 | 0.17 | 0.16 |
| EC | Exponential | 3.85 km | 49.95 | 0.50 | 0.99 | 0.076 | 0.075 |
| O.M | Exponential | 1.92 km | 29.37 | 0.70 | 0.95 | 0.26 | 0.25 |
| K | Exponential | 327 m | 0.043 | 0.90 | 0.93 | 37.23 | 34.48 |
| P | Spherical | 2.11 km | 38.80 | 0.57 | 0.88 | 2.69 | 2.36 |
| N | Exponential | 6.33 km | 49.96 | 0.22 | 0.95 | 3.11 | 2.96 |
| Clay | Exponential | 6.33 km | 50 | 0.34 | 0.98 | 5.91 | 5.79 |
| Silt | NIL | NIL | NIL | NIL | NIL | NIL | NIL |
| Sand | Exponential | 6.33 km | 50 | 0.63 | 0.94 | 6.97 | 6.54 |

[a]Root mean square standardized error; [b]Average standardize error; [c]Root mean square error

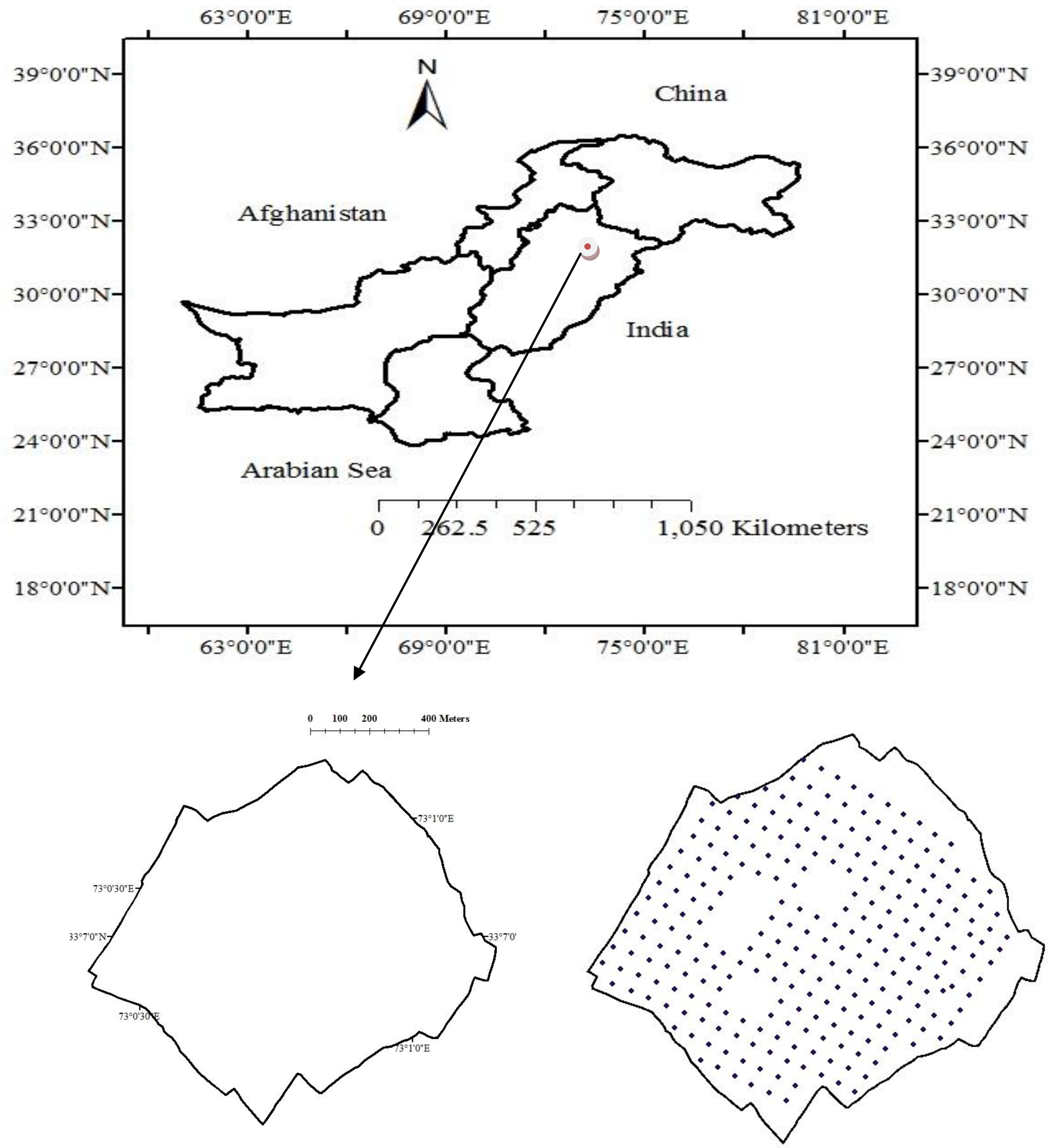


**Figure 1: Geographical location of the surveyed area**

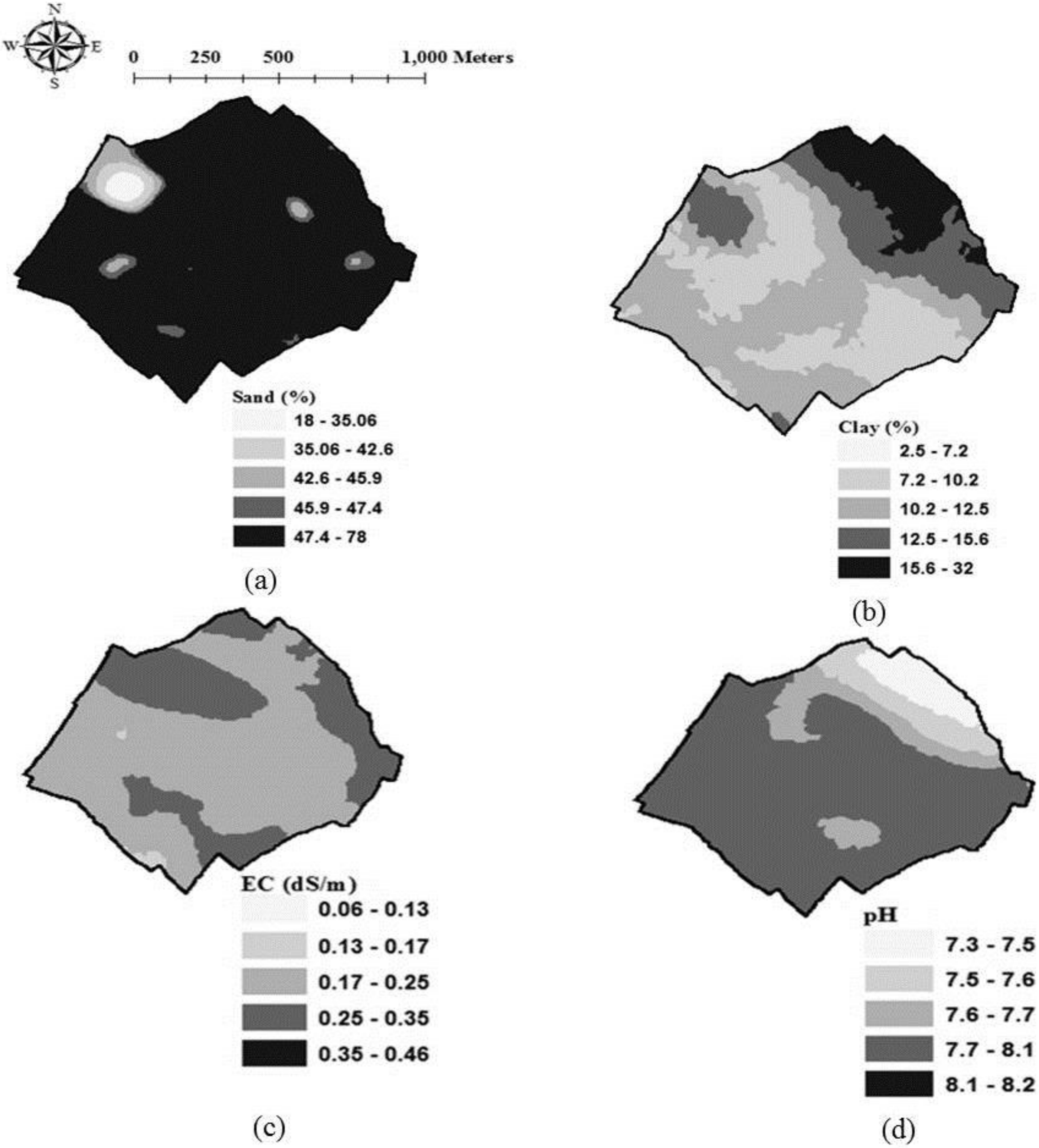


**Figure 2: Spatial distribution of Sand (a) Clay (b) EC (c) and pH (d) in studied area**

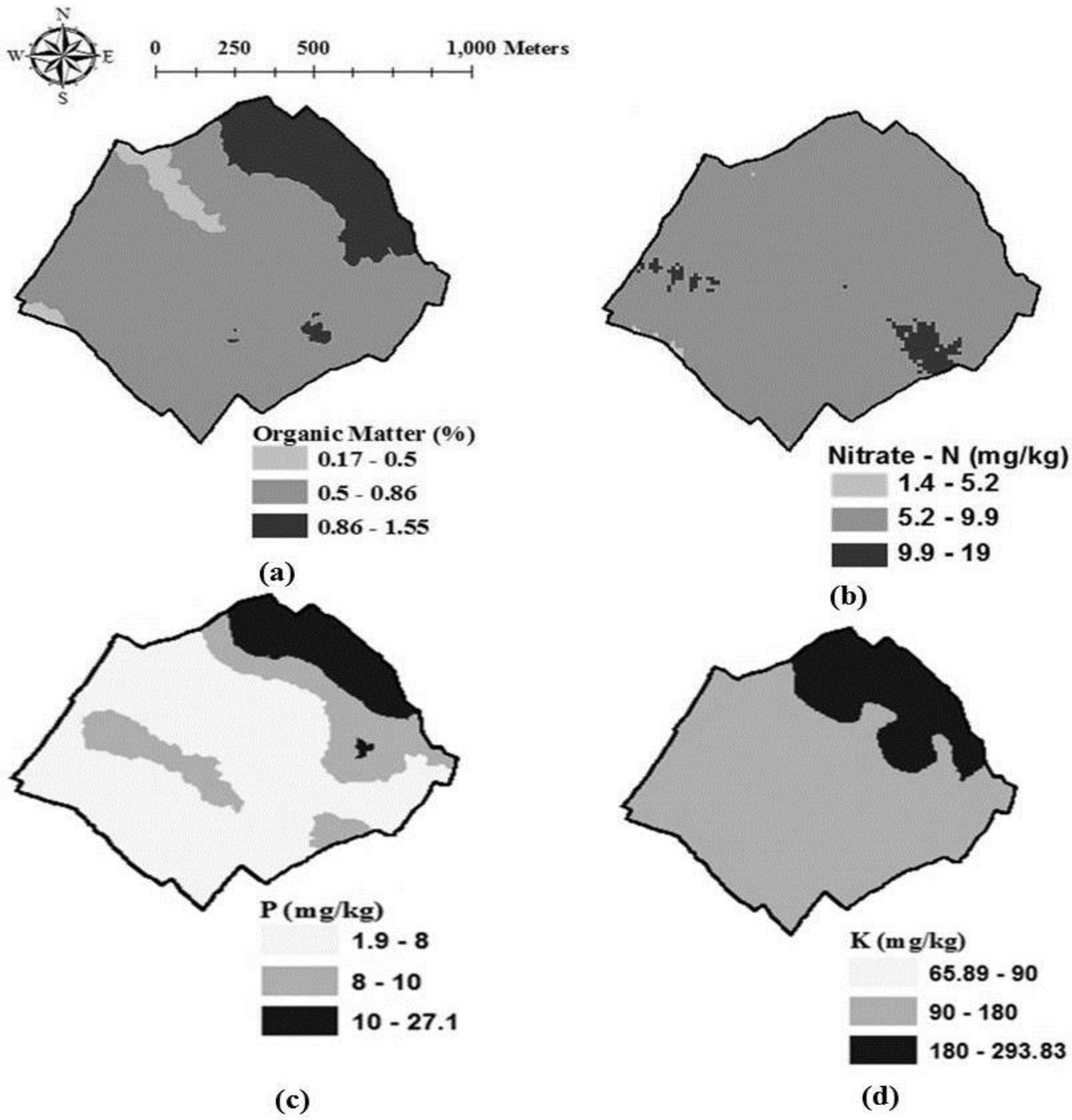


**Figure 3: Spatial distribution of O.M (a), N (b), P (c) and K (d) in studied area**

Soil EC was moderately spatial dependent (nugget/sill =

49.95 %).

Spatial structure of soil organic matter was also best described by exponential model. Soil organic matter content exhibited moderate spatial dependency, as Nugget/Sill ratio was 29.37 % with the range of 1.97 km (Table 5). The spatial correlation for $NO_3$-N in the soil was characterized by a semivariogram. The best fit model for bioavailable nitrogen was exponential. Nugget/ Sill ratio was 49.96 %, which indicated moderate spatial dependence in the soil. The range for bioavailable nitrogen was 6.33 km (Table 5). Spatial correlation of bioavailable phosphorus was best described by the exponential model. Nugget/Sill ratio (38.80 %) showed that available P in the soil could be classified into moderate spatial dependence within the lag distance of about 2.11 km. The best fit model for bioavailable K in the soil was exponential. Bioavailable K content was strongly spatial dependent, as the Nugget/Sill ratio was 0.4 % and the range was 327 m.

The exponential model is similar to the spherical in that it approaches the sill gradually, but different from the spherical in the rate at which the sill is approached and in the fact that the model and the sill never actually converge (Robertson, 2008). Moderate to strong spatial dependence of studied physico-chemical properties can be ascribed to intrinsic factor including soil forming factors i.e., parent material plays a key role in maintaining the spatial variability (Cambardella *et al*., 1994). According to the results of the study getostatistics based maps for the physico-chemical properties and plant available macronutrients can be generated for site specific nutrient management. After the establishment of spatial dependence, isarthimic map for spatial distribution of macronutrients (N, P and K) and physico-chemical characteristics (pH, EC. O.M, sand, silt and clay) were generated. Maps prepared for the macronutrients using ordinary kriging also indicated the spatial dependence. Similar techniques were successfully used by the researchers to categorize the area in to low, medium and high nutrient content for site specific nutrient management (Eltaib *et al*., 2002).

Map of pH of the shale and sandstone derived soils (Figure 2 d) showed that there was no significant variation in the pH values of various regions of surveyed area. However, the pH was alkaline (≥ 7.5), while the whole area found to be normal EC < 4 dS $m^{-1}$ (Figure 2c). Map of sand content of the soils (Figure 2 a) showed that the whole area is high in sand content while soils of the northern parts of the surveyed area have lower sand content (< 40%). Silt indicated no or weak spatial dependency which prohibited creation of isarthmic map. Clay content of the surface soils (Figure 2 b) showed that it was higher in the north eastern part (≥ 15%). Maps indicated an acute nitrate nitrogen deficiency in the whole surveyed area. The southern side of the surveyed area was extremely deficient in $NO_3$-N (Figure 3B).This result revealed that the $NO_3$-N of the study area can be generally classed as low, although there are some small areas in the field that could be classified as moderate. The phosphorus contents ranged from (1.9 - 8.0 mg $kg^{-1}$) in the most of area which indicated that a very pronounced phosphorus deficiency in the area.

## Conclusion

Soil fertility status at farm level is generally assessed through point sampling at selected locations. This approach does not present holistic picture of the fertility status and present certain bias. Digital soil mapping through geographical information system presents better scenario as employed in the current study for farm level soil fertility assessment. Soil texture of surveyed area ranged from sandy loam to loam. Sand content in the east and clay was found low throughout the surveyed soil. All the soils were alkaline in reaction, while no salinity problem was observed. Deficiency of $NO_3$-N, organic matter content and available phosphorus was observed in the surveyed area, while available potassium found satisfactory in most of the area. Maps of various soil properties showed variation in different areas and can be managed accordingly. Based on the results, the whole area can be divided into different categories on the basis of each plant available nutrient as shown in the maps. Variable rate fertilizer management strategy can be developed using the information generated through such techniques for different zones, which will increase the efficiency of fertilizers. The farm level data generated through GIS mapping techniques can help avoiding over or under-fertilization and will be economical, and environmentally safe.

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