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Spatial distribution of pH in the soil profiles of representative soil series from rice producing area, district Sheikhupura

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Abstract

Soil pH is one of the chemical properties influencing the nutrient bioavailability. Most of the Pakistani soils are calcareous in nature. Keeping in view the limitations of classical statistics for explaining spatial heterogeneity a survey in the farmer grown rice fields was conducted for mapping of soil pH down the soil profile up to the depth of 100 cm using geo-statistics and GIS as a diagnostic tool. One hundred and seventy five soil samples were collected from the representative soil series of rice producing district Sheikhupura. Sampling was done from five depths of 0-12, 12-24, 24-36, 36-60 and 60-100 cm. Soil profiles were excavated and samples were collected from the five depths to examine the variation of pH down the soil profile. Results indicated that soil pH at different depths was 7.80 ±0.45, 8.09 ± 0.42, 8.29±0.50, 8.39±0.54 and 8.47 ± 0.57 at 0-12, 12-24, 24-36, 36-60 and 60-100 cm depth, respectively. When geo-statistical analyses of the data were performed soil pH at all depths was found moderately to strongly spatial dependent (Nugget sill ratio <35). Maps were prepared to classify the whole district in to different pH management zones for producing regional scale information.

Keywords: GIS, geo-statistics, soil pH, rice

Introduction

Soil pH is considered as a fundamental indicator for nutrient bioavailability. Predominant alkaline pH due to higher calcium carbonate content in the soils of Pakistan is considered as one of the restraining factor for nutrient availability to plants (Rashid *et al.,* 1997; Ahmed *et al.,* 2017). Acidic pH results in the enhanced bioavailability of nutrients like B, Cu, Fe, Mn and Zn. Bioavailability of Mo is higher at alkaline pH (Ahmed *et al.,* 2014). Macronutrients including Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} exist in higher concentration in arid soil and are not soluble in the neutral and alkaline pH range. Similarly bioavailability of P is optimum over a narrow range of pH i.e., 6.5 to 7.5 (Khattak, 2005; Lucas and Knezek, 1972). Therefore pH plays a vital role in the management of the nutrients for growing successful crops. One of the important distinctive characteristics of the soil variables is to show a continual spatial variability. Exploring spatial variability of soil variables serves as scientific basis for the generation of soil management strategies (Ahmed *et al.,* 2017). Quantification of these variables from place to place and from each and every corner of the area is not possible due to laborious soil sampling analysis and usual statistical methods. However, using sophisticated techniques of GIS coupled with geo-statistics serve the purpose (Attar *et al.,* 2012; Ahmed *et al.,* 2014).

Geo-statistics has been considered as a general tool for quantification of spatial variability of soil characteristics leading to predict the values of un-sampled locations on the basis of sampled locations (Jin *et al.,* 2012; Memon *et al.,* 2011). Digital Mapping has been widely used to develop a numerical or statistical model of various environmental variables and soil attributes for the spatial management of soils. Spatial management of soils is associated with application system means assuming that applications are made in amounts and locations where they are needed i.e. targeted application of inputs. Economically variable rate of application allows fertilizer application where response is expected and to be saved where response is unlikely (Bhatti, 2003).

Soil series represent a group of soils with similar profiles developed from similar parent materials under comparable climatic and vegetation conditions. Scientist give a lot of importance to soil series while studying soils as it provides the basis for studying soil characteristics as it includes soils similar in most of the characteristics (Razzaq and Rafique, 2005). Keeping in view the importance of the soil series as a basic unit of soil classification, GIS and geo-statistics tools were used for studying spatial distribution of soil pH of rice producing area.

Materials and Methods

District Sheikhupura located between the 31.7167° N and 73.9850° E is one of the main rice producing area in Punjab, Pakistan and is famous for the production of quality aroma rice (Figure 1). The most extensively occurring soil

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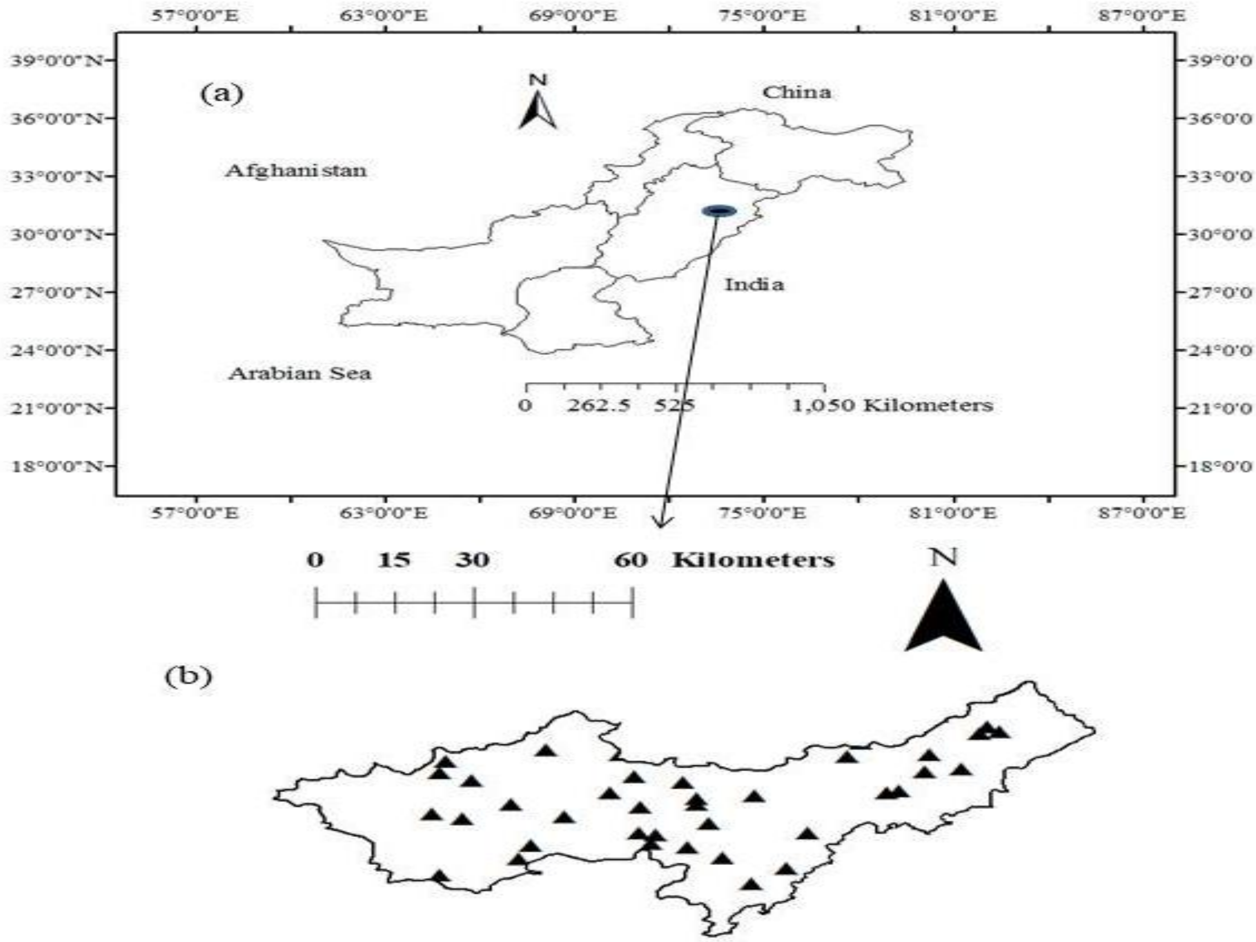

Figure 1: Geographical location of the surveyed area (a) Pakistan and sampling locations in the Sheikhupura district(b)

Table 1: Distribution of sampled sites into soil series, great group and soil orders

S. No	Series	No.of Samples	Great Group	Order	Area (km^2)
1	Eminabad	10	Typic Natrustalfs	Alfisols	70.0
2	Miranpur	40	Ustertic Camborthids	Aridisol	1010.0
3	Bhalwal	35	Fluventic Camborthids	Aridisols	381.0
4	Gujiana	10	Typic Natargids	Alfisols	261.6
5	Satgarah	30	Typic Natargids	Aridisol	1036.0
6	Shahpur	25	Fluventic Camborthids	Aridisol	76.0
7	Miani	10	Fluventic Camborthids	Aridisol	235.7
8	Shahdra	15	Typic Tirrifluvents	Entisols	274.5

series in the surveyed area were identified according to Soil Survey Reports (GOP, 1968). Soil sampling at each selected site was done by digging profiles of identified soil series predominating in most of Sheikhupura district having climatic conditions congenial for rice production. At each site, representative soil samples were drawn at 0-12, 12-24, 24-36, 36-60 and 60-100 cm soil depth. Sampling scheme is summarized in the Table 1. Collected

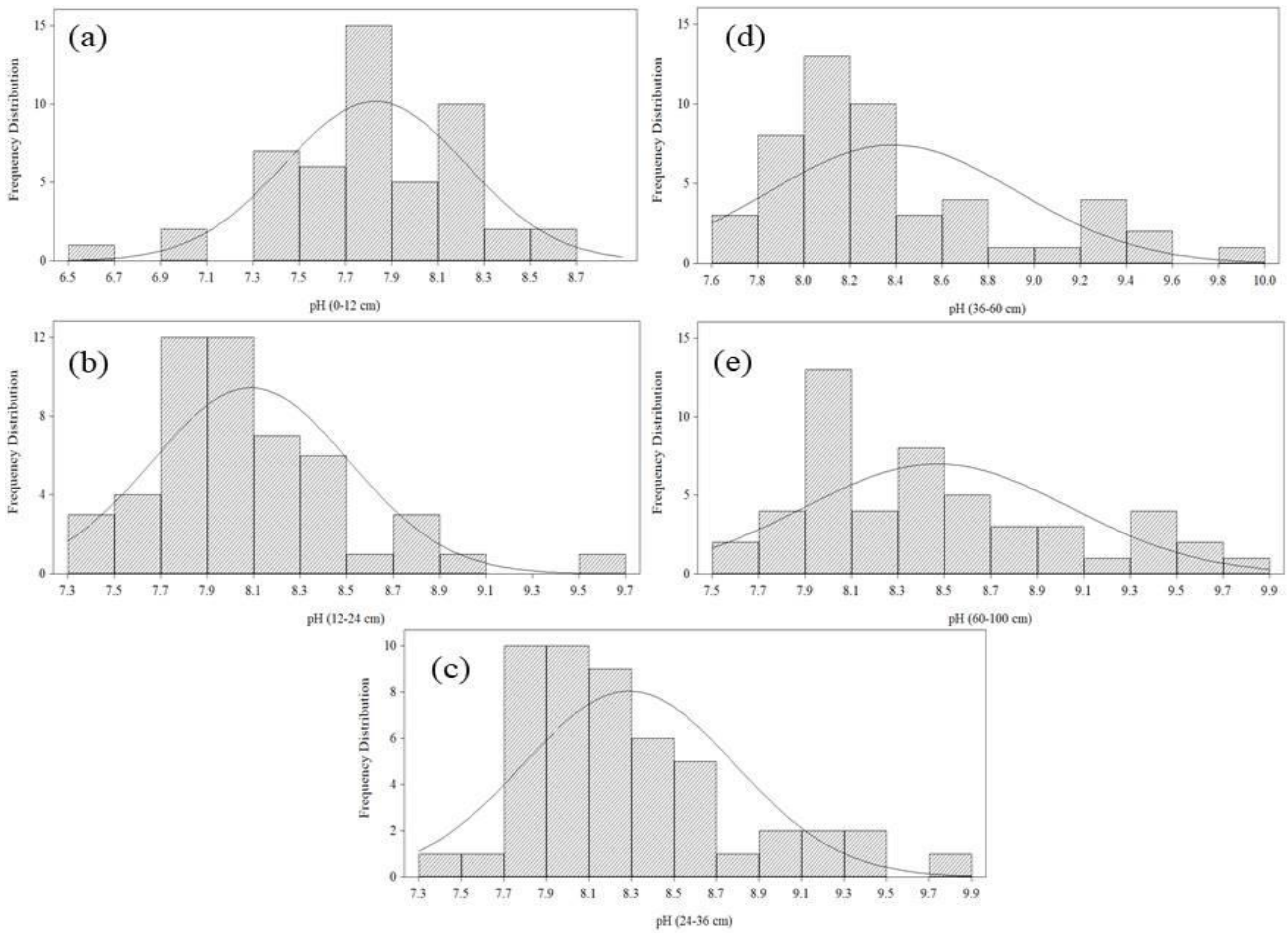

Figure 2: Frequency distribution of pH data set (a) 0-12 (b) 12-24 (c) 24-36 (d) 36-60 and (e) 60-100 cm (Bell shaped curve of frequency distribution charts indicated approximate normal distribution of data sets)

Table 2: Summary of statistical parameters used for use soil pH assessment in the rice area (n = 175)

Depth(cm)	Statistical Parameters						
	Mean	Maximum	Minimum	SD	Skewness	Kurtosis	CV (%)
0-12	7.80	8.70	7.30	0.45	-0.96	1.11	5.76
12-24	8.09	9.67	7.37	0.42	0.35	0.33	5.19
24-36	8.29	9.83	7.47	0.50	0.56	-0.11	6.03
36-60	8.39	9.82	7.71	0.54	0.82	-0.02	6.43
60-100	8.47	9.74	7.65	0.57	0.78	-1.12	6.72

samples were sealed in air tight plastic envelope, labeled and brought to laboratory. They were air dried, ground gently and passed through a 2mm sieve and were stored in plastic containers for further analysis. These samples were analyzed for pH according to Mclean 1982. The pH for each sample was determined in distilled water using soil/water ratio of 1:2 (w/v). The soil/water suspensions were shaken manually every 10 minutes for 30 minutes. Values of pH were recorded after 1 minute of stirring. The determinations were performed at room temperature (20 ± 2^{o} C) using Jenway 3020 pH meter and Philips combined glass/calomel electrode (type CE1), that had previously been calibrated at pH 7.0 and 9.0. The meter was recalibrated, when necessary to ensure accuracy.

Data obtained was tabulated and evaluated based on descriptive statistics (mean, maximum, minimum, standard deviation of means, skewness and kurtosis). Co-efficient of variance was used to examine the variability of pH within the dataset. Variables having CV% values < 15% are grouped as least variable whereas those having CV between 15 to 35% are categorized as moderately variable. Co-efficient of variance value more than 35% indicates high variability (Wilding, 1985). Collected spatial data (coordinates) were used for geo-referencing and digitization of the base maps gained from Survey of Pakistan. Attribute data were used for geostatistical analyses (kriging). Generation of digital maps was accomplished by simulation of geo-statistically analyzed data within the boundaries of digitized maps. The validation and the fitness of the interpolation method were tested via cross validation (Leuangthong *et al.*, 2004). Cross validation estimation is obtained by leaving one sample out and using the remaining data to estimate the value (Ahmed *et al.*, 2017). This test allows evaluating the goodness of fit of the method and the appropriateness of neighborhood, while the interpolation values are compared to the real. The efficacy of applied techniques was evaluated using mean error calculated by the formula (Equation 1) and RMSE calculated by the formula (Equation 2).

$$ME = \frac{1}{n}\sum_{i=0}^{n}[Z^{*}x_i - Zx_i] \qquad \text{Equation 1}$$

$$RMSE = [\sum_{i=0}^{n}(Z^{*}x_i - Zx_i)^2/N]^{\frac{1}{2}} \qquad \text{Equation 2}$$

Where $Z^{*}(x_i)$ and $Z\,(x_i)$ represents the observed and predicted values, respectively.

Results and Discussion

Descriptive statistical analysis

Data regarding soil pH of analyzed samples collected at five depths in different soil series is summarized in the Table 1. Our results indicated that soil pH ranged from 7.30 to 8.70 with the mean value of 7.80 ±0.45, 7.37 to 9.67 with the mean value of 8.09 ± 0.42, 7.47 to 9.83 with the mean value of 8.29±0.50, 7.71 to 9.82 with the mean value of 8.39±0.54 and 7.65 to 9.74 with the mean value 8.47 ± 0.57 in 0-12, 12-24, 24-36, 36-60 and 60-100 cm depth, respectively. An increasing trend in the soil pH was observed with the increasing depth in the soil profile of all the sampled soil series which might be due to leaching of salts like $CaCO_3$ down the soil profile in rice producing area as the crop is grown in the flooded water conditions. Calcium carbonate content in the soils ranged from 1.5 to 15.9 percent with the mean value of 8.5 ± 1.5. An increasing trend in $CaCO_3$ content was also observed with increasing depth. Leaching of $CaCO_3$ is a soil forming processes for all calcareous soils in areas where precipitation exceeds evapotranspiration losses of water, however calcium carbonate is not removed from the soil profile but it is redistributed in the soil profile (Arkley, 1963). Soil pH of all the studied profiles was found favorable for growing crops having fibrous root system instead of deep rooted crops. Data set indicated that the soil pH was found least variable at all soil depths as CV% value was found to be less than 15%. Skewness, kurtosis (Table 2) and frequency distribution plot (Figure 2) indicated that data set were approximately normally distributed.

Table 3: Parameters related to semivariogram spherical model and interpolation of soil pH at various depths in soil profile

Depth (cm)	Range (km)	Nugget/Sill (%)	RMSSE	RMSE	ASE	Mean Error
0-12	0.15	7.20	1.43	0.45	0.42	0.010
12-24	0.30	34.04	1.40	0.40	0.36	0.011
24-36	0.14	27.96	1.70	0.56	0.53	0.023
36-60	0.14	31.24	1.11	0.50	0.44	0.019
60-100	0.15	27.05	1.06	0.52	0.46	0.012

Geostatistical analysis and mapping of pH in the studied soil profiles

Semivariogram modelling was done to examine the spatial dependence of soil pH at various soil depths (Figure 3). Parameters related to semivariogram modelling and cross validation are summarized in Table 3. Spatial structure of the soil pH at all the sampled depths from 0-100 cm was best explained by spherical model which is modified quadratic function, (Robertson, 2008) (Figure 4). The equations used for spherical modelling are as under:-

$$\gamma(h) = C0 + C\,[1.5(h / A0) - 0.5(h / A0)3] \quad \text{for } h \leq A0$$

$$\gamma(h) = C0 + C \quad \text{for } h > A0$$

Where $\gamma(h)$ = semivariance for interval distance class h, h = the lag distance interval, C0 = nugget variance ≥ 0, C = structural variance ≥ C0, and A0 = range parameter. In the case of the spherical model, the effective range A = A0. Our results indicated that soil pH was found highly spatial dependent at the surface soils (0-12 cm) while it was found moderately spatial dependent at all lower soil depths. Moderate to strong spatial dependence of the variables is the prerequisite for

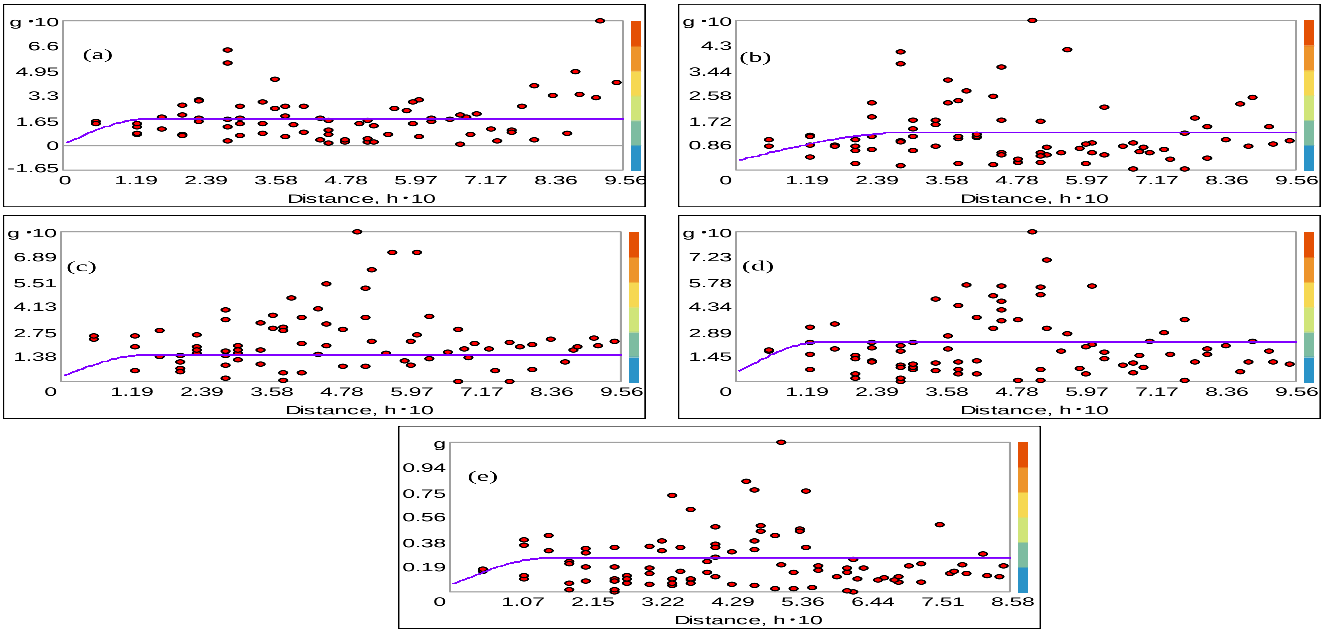

Figure 3: Semivariograms of pH data set (a) 0-12 (b) 12-24 (c) 24-36 (d) 36-60 (e) 60-100 cm

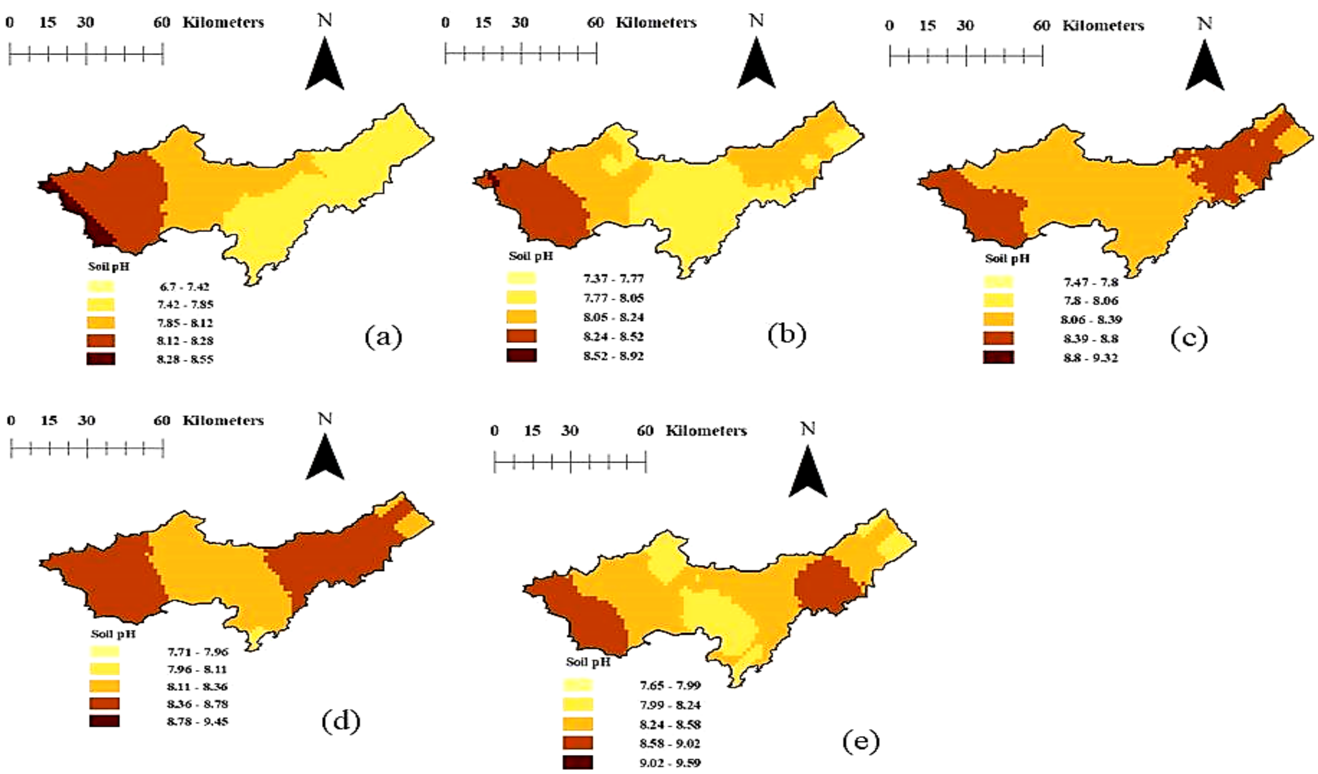

Figure 4: Spatial distribution of soil pH in the soil profile (a) 0-12 (b) 12-24 (c) 24-36 (d) 36-60 (e) 60-100 cm

preparing digital maps otherwise specific protocols are needed to be followed for maps generation. Therefore, moderate to strong spatial dependence provided us an opportunity to prepare digitals maps for estimating soil pH vertically up to the depth of 100 cm in a soil profile. Spatial dependence of soil pH was found to be maintained by anthropogenic activities like cultivation, addition of chemical fertilizers and organic manure at surface soils while in the lower soil depths intrinsic soil factors governing soil pH like parent materials might be responsible for maintaining moderate to strong spatial dependence in the soils (Liu *et al.*, 2004; Spiker *et al.*, 2005; Chunfa *et al.*, 2010; Banerjee *et al.*, 2011).

Moreover, RMSE and ASE (Table 3) values indicated the authenticity of prepared digital maps at all soil depths up to 100 cm (Ahmed *et al.*, 2014). Prepared maps indicated a great variation of soil pH in the studied area and pH varied from neutral to slightly alkaline and strongly alkaline in the whole soil profile. Prepared maps also indicated an increase of pH with the increasing depth in the soil profile. Prepared maps indicated that soil pH was neutral to slightly alkaline in the north eastern areas of surveyed region. Non calcareous sandy clay loam or clay loams occur in the basins and channel fills of river terraces might be responsible for this soil pH (GOP, 1968). These soils are deeply developed and humified. There natural fertility is relatively high and are subject to flooding by runoff water from the adjoining higher land. Therefore, they are mainly used for rice production. Slightly acidic pH predicted in the soils might be due to existence of Miranpur soil series covering about 1010 km^2, which is well drained and has moderately developed soil structure. Presence of canker zone down the soil profile is one of the major causes for alkaline pH in the soil profile. Other soil series sampled during the survey were found to be alkaline in nature due to presence of calcium carbonate. Soil series Satgrah and Eminabad are saline, alkali and pH generally above 9, with the dense sub soils (GOP, 1968).

Conclusion

Surface soils of the surveyed area were found neutral to alkaline in nature having pH value of 6.80 to 7.77 in the upper surface soils (0-24 cm). Semivariogram modeling indicated a strong spatial dependence on the surface soils while moderate spatial dependence in the lower soil depths was observed. Digital maps indicated that the surface soils up to the depth of 0-24 cm were found favorable for growing crops having fibrous root system.

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