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Spatial analysis of soil parameters in Domagor-Pahuj watershed using Geostatistical methods of GIS

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ABSTRACT

The water and land management is an important aspect in watershed programme increasing the productivity *vis-a-vis* sustainability of resources. Watersheds are natural hydraulic entity where water flows in a definite path to a common point. For land use planning of any watershed, soil characterization for its area is very essential and important. This would help in knowing the soil fertility status in watershed area. GIS is a tool that can be effectively used for spatial analysis of soil fertility for a desired geographical area. Domagor-Pahuj watershed is situated in Jhansi district of Bundelkhand region and located between 25°28' to 25°31' N latitude and 078°25' to 078°28' E longitude. This watershed has a total geographical area of 1 646 ha out of which 1 373 ha area is treatable and consists of three villages namely Domagor, Dikauli and Naya Khera. A total number of 103 representative soil samples were taken from Domagor-Pahuj watershed during May-June 2010. These samples were analyzed for soil parameters like pH, OC, EC, P, K, Zn, B and S. These sample points were geographically referenced and soil maps were generated using Geostatistical interpolation methods in Arc GIS 10. Ordinary and Universal Krigging methods were applied and compared on the basis of RMSE. Out of the two methods applied, ordinary Kriging was found better for prediction of soil EC, P, B and S, whereas universal Krigging was found better for prediction of soil pH, OC, K and Zn. Thus, spatial maps were generated by Ordinary and Universal Krigging methodsfor these soil parameters and hence may be used for soil fertility status and land use planning of Domagor-Pahuj watershed.

Key words: Geostatistical, GIS, Kriging, Soil, Spatial, Watershed

Soil is a finite natural resource and management and health of soil directly affects sustainability of ecosystem and human health.A prerequisite of ecosystem management decisions is monitoring of spatial distribution of soil characteristics. Variability is one of the intrinsic characteristics of soil quality and within some ecosystem; soil properties may show significant spatial variations (Robinson and Metterninc ht 2006). These variations are mainly arising from factors and process of pedogenesis and land use (Shi *et al*. 2007). Hence, geo-statistical methods can be used for better understanding of spatial variations of the soil characteristics. In recent times, different geo-statistical techniques are widely used for prediction of spatial variations of the soil properties.

Maul and Van Meirvenne (2003) used four techniques including the ordinary Kriging, comprehensive Kriging, simple Kriging and Cokriging methods for estimating of the silt content in Belgium.They also used digital elevation model as a secondary variable and found that comprehensive Kriging method has the lowest estimation error. Erashin (2003) used soil bulk density as an auxiliary variable in Cokriging method to investigate the spatial variation of inflation rate in North–West of Tookat in Turkey. Result illustrated that Cokriging method was a suitable techniques for estimating infiltration rate. Robinson and Metternicht (2006) used three different geo-statistical techniques including Inverse Distance Weightage (IDW), Kriging and Spline methods for predicting of levels of soil salinity, acidity and organic matter in Southwest of Australia.Results showed that the Cokriging and Spline methods were the best techniques for estimating of soil salinity and organic matter content. Also IDW method was suitable for predicting of soil acidity levels. Sokoti *et al*. (2006) used different geo-statistical methods to predict the soil salinity distribution in Urnia plain of Iran. Results indicated that the Kriging method having Gaussian model had the highest accuracy among other geo-statistical techniques for estimating the soil salinity level in areas without having any information

Zare-Mehrjardi *et al*. (2010) evaluated geospatial techniques for mapping spatial distribution of soil pH, salinity and plant cover. They found that Kriging and Cokriging

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methods were better than inverse distance weighting method for prediction of spatial distribution of soil properties. Results also indicated that all the concerned soil and plant parameters were better determined by means of Cokriging method. Kravchenko and Bullock (1999) compared IDW, ordinary Kriging and Lognormal Kriging for soil P and K from 30 experimental fields. They found that if the underlying data set is log normally distributed and contains less than 200 point, lognormal Kriging outperforms both ordinary Kriging and IDW; otherwise, ordinary Kriging is more successful.

In the present study, two types of kriging, viz. ordinary and universal methods were applied for finding the spatial distribution of soil pH, organic carbon (OC), salinity (EC), P, K, Zn, B and S. From these maps, soil fertility status was determined which would help in planning of nutrient management for enhanced and sustainable crop production in Domagor-Pahuj watershed.

MATERIALS AND METHODS

Domagor-Pahuj Watershed is situated in Jhansi district of Bundelkhand region and located between 25°28’to 25°31’N Latitude 78°25’to78°28’E Longitude (Fig 1) This watershed has a total geographical area of 1646 ha out of which 1373 ha is treatable. Total cultivated area in this watershed is 960 ha and soil is mainly red latrite (90%) and black (10%). This watershed comes under medium rainfall zone (700-1100 mm) and consists of three villages namely Domagor, Dhikauli and Pahuj. Majority of the farmers are small or medium with an average land holding of 2-3 acre. The main crop in *kharif* season is groundnut, however crops like mung, urd, maize and sesame are cultivated in small area. In rabi season, the main crop is wheat and other crops like chickpea, mustard and lentil are also grown in few pockets.

To ascertain the soil fertility status, 103 soil samples from different random locations were collected from watershed area during May-June 2010. These samples were analyzed for soil pH, salinity (EC), organic carbon (OC), K, phosphorus (P), zinc (Zn), B and S at soil lab in ICRISAT, Hyderabad. The analyzed data of soil samples was used for finding spatial distribution using geo-statistical methods.

The presence of spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) is a prerequisite to the application of geostatistics (Goovaerts 1999). Different geostatistical methods such as Inverse Distance Weighting (IDW), Global Polynomial Interpolator, Kriging/Co-Kriging, Spline are widely used for spatial analysis (Johnston *et al*. 2001).But literature cited here has revealed that Kriging/ Co-Kriging method is better than other interpolation methods. Therefore in the present study only Kriging methods: Ordinary and Universal were applied for finding spatial distribution of soil parameters and compared on the basis of prediction errors. Three types of models, viz. Spherical, Exponential and Gaussian were used under both the kriging methods

Kriging depends on mathematical and statistical models. Kriging is an interpolator that can be exact or smoothed depending on the measurement error model. It is very flexible and allows you to investigate graphs of spatial auto-and-cross validation.Kriging assumes that the data come from stationary stochastic process and some assume normally distributed data.Kriging produces an estimate of the underlying (usually assumed to be smooth) surface by a weighted average of the data, with weights declining with distance between the point at which the surface is being estimated and the locations of the data points.

Three methods used for spatial prediction have been compared on the basis of mean error and root mean square error (RMSE).The smallest RMSE indicated the most accurate predictions. The mean error and RMSE are derived using the following formulae:

$$\text{Mean error} = \sum_i^n \frac{(Pi-Oi)}{n}$$

$$\text{RMSE} = \sqrt{\frac{\sum (Pi-Oi)2}{n}}$$

where, Pi – i^{th}, predicted value of soil parameter; Oi – i^{th}, observed value of soil parameter; n, number of observations (samples).

Finally, the spatial distribution maps of soil parameters for Domagor-Pahuj watershed have been generated using the best method and area under standard classes have been estimated.

RESULTS AND DISCUSSION

Summary statistics of soil samples analyzed for various soil parameters are given in Table 1. The soil pH ranged between 6.27 to 8.28 with mean value of 7.49 for these samples. Electronic conductivity (EC) ranged between 0.04 to 0.54 dS/m with mean value of 0.16 dS/m. The range of

Table 1 Summary statistics of different soil parameters under study (n = 103)

Statistics	pH	EC (dS/m)	OC (%)	Ols-P (ppm)	K (ppm)	Zn (ppm)	B (ppm)	S (ppm)
Min.	6.09	0.04	0.22	1.20	25.00	0.22	0.10	1.85
Max.	8.28	0.72	1.10	36.0	335.00	2.50	0.72	37.33
Mean	7.38	0.21	0.50	10.57	81.98	0.77	0.26	10.7
Standard deviation	0.49	0.13	0.18	6.71	54.81	0.36	0.14	8.91
Skewness	–0.43	1.28	1.13	1.28	2.53	1.60	1.28	1.40
SW p-value	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00

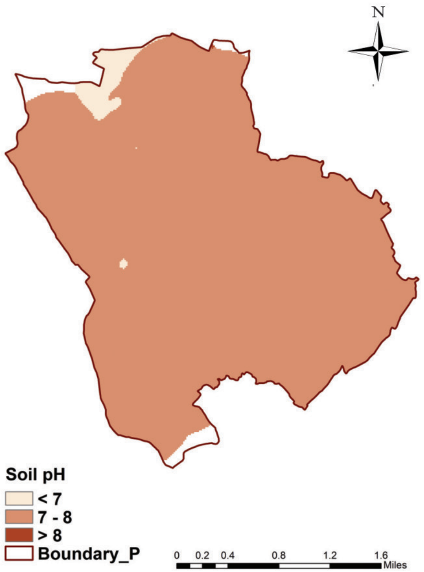

Fig 1(a) Soil pH map of Domagor-Pahuj watershed by ordianry kriging

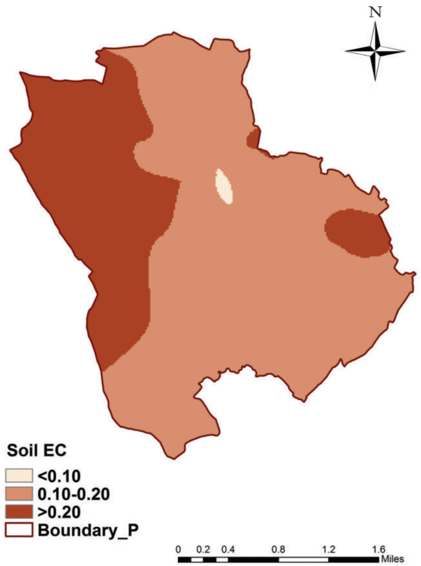

Fig 1(b) Soil EC map of Domagor-Pahuj watershed by ordinary kriging

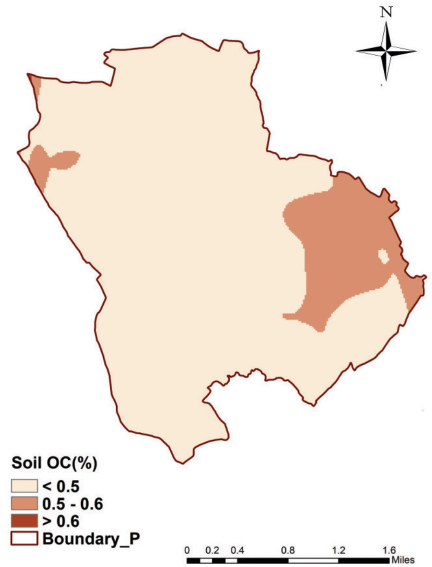

Fig 1(c) Soil OC map of Domagor-Pahuj watershed by ordinary kriging

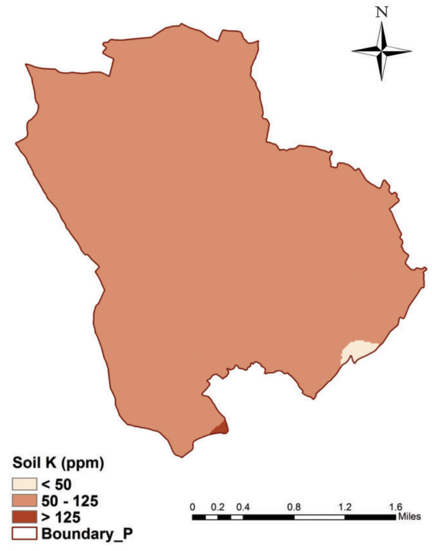

Fig 1(d) Soil K map of Domagor-Pahuj watershed by universal kriging

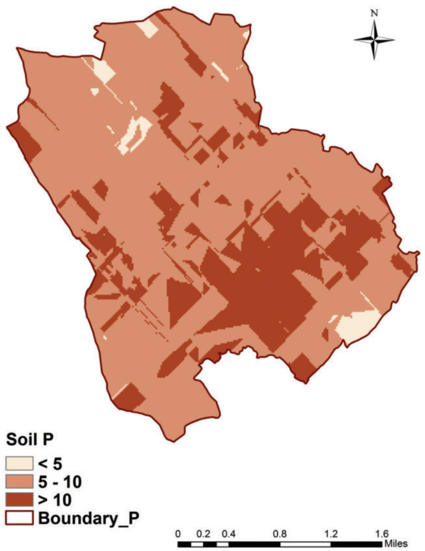

Fig 1(e) Soil P map of Domagor-Pahuj watershed by universal kriging

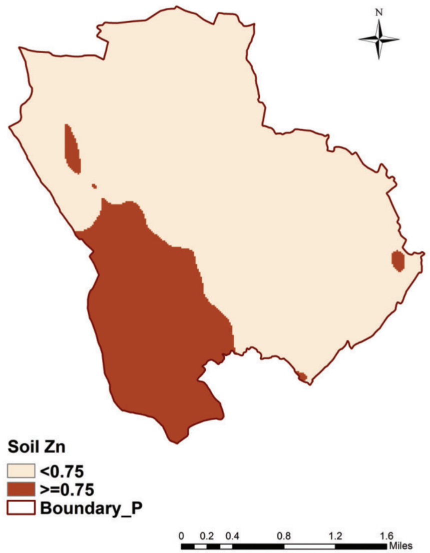

Fig 1(f) Soil Zn map of Domagor-Pahuj watershed by universal kriging

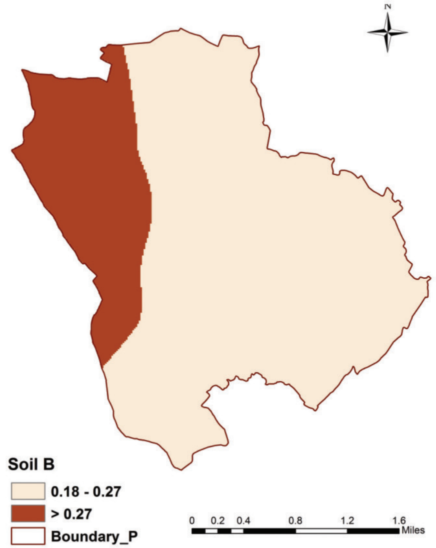

Fig 1(g) Soil B map of Domagor-Pahuj watershed by ordinary kriging

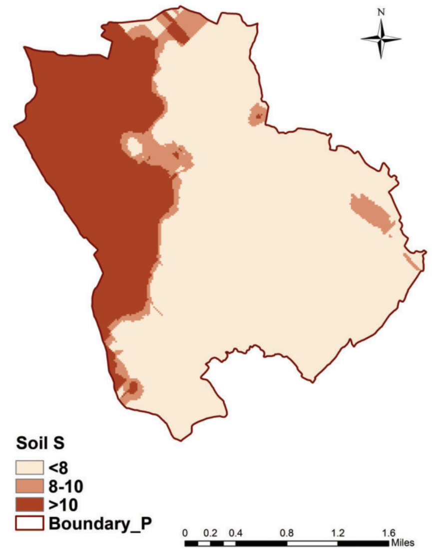

Fig 1(h) Soil S map of Domagor-Pahuj watershed by ordinary kriging

Table 2 Comparison of ordinary and universal kriging methods

Soil parameter	Kriging (n=103)		Kriging (n=82)	
	Ordinary	Universal	Ordinary	Universal
pH	0.4916 (G)	0.4968 (S)	0.5244 (G)	0.5244 (G)
EC	0.1146 (E)	0.1179 (E)	0.1155 (G)	0.1178 (S)
OC	0.1901 (E)	0.1919 (E)	0.1900 (S)	0.1900 (S)
P	7.0436 (S)	7.0366 (S)	6.5856 (E)	6.3856 (E)
K	49.4251 (E)	49.0682 (E)	49.8661 (S)	49.6878 (E)
B	0.1316 (S)	0.1328 (S)	0.1248 (G)	0.1248 (G)
S	5.1395 (G)	5.9909 (G)	5.6599 (E)	5.5954 (G)
Zn	0.3589 (S)	0.3616 (E)	0.3941 (S)	0.3910 (G)

E, Exponential; G, Gaussian; S, Spherical

soil organic carbon (OC) was 0.22 to 2.50% with mean value of 0.76%. Soil Pand K ranged between 1.20 to 36.0 ppm and 25 to 335 ppm for these samples. There was much variation in soil P, K and S as indicated by values of standard deviation for these parameters. All the parameters are positively skewed except soil pH as indicated by skewness. The normality was investigated on the basis of SW p-value, near zero values showed that all the parameters were normally distributed.

The two methods, viz. ordinary and universal kriging were applied to soil parameters and compared on the basis of root mean square error (RMSE) in Table 2. It is evident that RMSE was minimum for ordinary kriging in case of soil pH, EC, OC, B, S and Zn,whereas it was minimum in case of universal kriging for parameters soil P and K. In order to determine whether number of samples can be reduced for such analysis, only 80 percent, i.e. 82 samples were taken. Remaining samples were kept for validation purpose; two methods were again applied and compared (Table 2).The values of RMSE were lesser in case of ordinary kriging for soil pH, EC, OC and B. The values of RMSE even reduced for some parameters when 82 samples were analysed. No significant difference was found when 100 and 80% samples were used for analysis, indicating that 82 soil samples suffice the purpose.

The spatial distribution maps of soil parameters were generated for Domagor-Pahuj watershed (Fig 1 (a) to 1 (h)) and area under standard classes were estimated (Table 3). In this way, about 86.5 per cent area was having soil pH between 6.6-7.5 in and only 13.5 per cent area was having more than 7.5 soil pH indicating that soils is mostly saline. In case of electronic conductivity (EC), about 64.6 per cent area has EC between 0.10-0.20 dS/m and remaining 35.4 per cent area was having EC more than 0.20 dS/m. About 58.8 per cent watershed area was found to have OC less than 0.5 % which is on lower side and 41.2 per cent area has OC between 0.5-0.75 percent. There is no deficiency of soil K in watershed as about 95.3 percent area was having K between 50-125 ppm and only 2.8 per cent area was having K less than 50 ppm. Similarly soil P is also sufficient in watershed as about 47.6 per cent area was having P between 5-10 ppm and 52.4 per cent area was having soil P more than 10 ppm.

Table 3 Soil fertility status and distribution in Domagor-Pahuj watershed

Soil parameter	Estimated area		
	Class	ha	%
pH	< 6.5	0.12	0
	6.6-7.5	1406.82	86.5
	> 7.5	219.13	13.5
EC (dSm^{-1})	< 0.10	0.04	0
	0.10 – 0.20	1050.28	64.6
	> 0.20	575.75	35.4
OC (%)	< 0.5	956.61	58.8
	0.5 – 0.75	669.46	41.2
	> 0.75	0	0
K (ppm)	< 50	45.12	2.8
	50 – 125	1549.72	95.3
	> 125	31.26	1.9
P (ppm)	< 5	0.6	0.04
	5 – 10	773.47	47.6
	> 10	851.99	52.4
Zn (ppm)	< 0.75	702.13	43.2
	>= 0.75	923.94	56.8
B (ppm)	< 0.18	6.4	0.4
	0.18 – 0.27	1107.04	68.1
	> 0.27	512.63	31.5
S (ppm)	< 8	1004.03	61.8
	8 – 10	112.87	6.9
	> 10	509.17	31.3

According to the spatial analysis, soils in watershed area were found to be deficient in S and micronutrients like Zn, and B. As far as soil Zn is concerned, it was deficient in about 43.2% area (< 0.75 ppm). In case of soil B, it was also found deficient in about 68.5% area (< 0.27 ppm) and soil S was found deficient in about 68.7% area (< 10 ppm). This indicated that crops yield would be produced less than the potential because of observed spatial deficiency of S andmicronutrients in soil. So farmers have to apply S and micronutrients in soil for taking higher and sustained crops yield (Table 3).

Among two types of kriging applied, ordinary kriging was found best for predicting spatial distribution of soil pH, EC, OC, and B; whereas universal kriging was found best for soil P, K, S and Zn using. Further, 82 samples were sufficient for spatial analysis instead of 103 samples for this watershed. Simple kriging method was not found suitable for predicting any soil parameters used in this study. Wei *et al*. (2006) found that Kriging method could predict organic matter distribution with a high accuracy in north east of China. In contrast, Gotway *et al*. (1996) observed better result than Kriging for soil organic matter and N when using IDW. They also found that accuracy of the IDW method increased as the exponent value increased.

Geostatistical techniques like IDW, Kriging and Spline are useful interpolation techniques for finding spatial distribution of soil parameters for an area like watershed. However, kriging method gave more accurate predictions for spatial distribution of soil parameters than other methods. Thus soil prediction maps generated under this study using kriging methods may help in determining soil fertility status, which would further facilitate nutrient management at field level. Hence, suitable planning for enhanced crop production can be done with the help of soil fertility maps in Domagor-Pahuj watershed.

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