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Spatial variability of soil fertility in Ramagarh village in Purna Valley of Vidarbha

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Abstract
An investigation was conducted at Ramagarh village in Daryapur tehsil of Amravati District to quantify the spatial variability of available macronutrients (N, P, K and S) and micronutrients (Fe, Mn, Cu and Zn) through semivariogram analysis and prepare kriged maps through ordinary kriging. In case of available N, P, K and S it was varied from 115.4 to 245.23, 21.06 to 63.17, 470.85 to 870.13 and 8.99 to 16.1 kg ha^{-1} with a mean value of 185.29, 30.44, 656.17 and 11.93 kg ha^{-1}, respectively. Among the three different theoretical model tested, the spherical model was found best fit for all the fertility parameters studied like available N, P, K, S, Fe and Zn whereas Gaussian model was found fit for Mn and Exponential model was fitted for Zn.

Keywords: Spatial variability, semivariogram analysis, kriged maps and spherical model

Introduction
Soil is a medium for plant growth and development that leads to crop production, similarly crop productivity depends on many factors and fertility is profitable amongst all and has direct relation with crop yields, provided other factors are in optimum level. Soil fertility must be periodically estimated as there is continuous removal of macro and micronutrients by crop intensively grown in every crop season. Continuous cropping system for periods without adequate supply of additional amount of nutrients resulted into possibility of deficiencies of essential nutrients in due course of time. The fertility problem cannot be solved merely by supply of plant food elements but there deficient management has also to be given a due thought as fertilizer being one of costliest input required. Hence balanced scheduling of optimum dose is necessary to get the maximum returns. The future planning for an intensive farming should be based on the nutrient status of soil as assessed by soil testing so that the problems related to residual effect of fertilizers, compatibility of fertilizers, appropriate method and time of their application, suitability of fertilizers for various crops, soil types and fertilizer pesticide – herbicide interactions can be done. The soils in Purna valley have been extensively studied during 1990 to 1993 by several workers, Nimkar (1990), Magar (1990), Kadu (1991) and Balpande (1993). The salinity / sodicity problems have been diagnosed in these soils although most of the soils are found to have good production potential.

In view of the increasing temperature and intensified agriculture practices, it becomes imperative to monitor the changes in soil fertility periodically. In this context, it is proposed to conduct a systematic study of soil fertility by collecting samples on a grid basis (on 250×250 m distance) in Ramagarh village. The present investigation was carried out in Ramagarh village of Daryapur tehsil in Amravati District. The fertility of Ramagarh tehsil was assessed during this investigation with the objectives to study the fertility characteristics of soils and also to study the spatial variability of soil fertility.

Among different methods of spatial interpolation of soil properties, ordinary krigging is most commonly used. The correct application of krigging techniques requires an accurate determination of the spatial structure through semivariogram. Webster and Oliver (1992) reported that at least 50-100 samples might be required to obtain a reliable semivariogram that correctly describes spatial structure.

The information on spatial variability of soil properties at village or watershed level, particularly, in soils of basaltic terrain is meager. Therefore, the present study was planned to quantify.

Materials and Methods
The available Nitrogen (N) was determined by using alkaline potassium permanganate ($KMnO_4$) solution and determining the ammonia liberated (Subbiah and Asija, 1956). Available Phosphorus (P) was determined by using sodium bicarbonate $NaHCO_3$ (0.5 M)

(0.5 M) extractant as per Watanabe and Olsen (1965) method. The available Potassium (K) was determined by using neutral ammonium acetate method and the potassium in extract was determined by Flame photometer (Jackson, 1967). Kriged map for each soil property was prepared using geostatistical analyst of Arc GIS 10.0. The interpolation methods that are used to generate surface maps of soil properties gives the best results if the data is normally distributed (a bell-shaped curve). If the data is skewed (lopsided), it needs to be transformed to make it normal. Thus, it is important to understand the distribution of the data sets of different soil properties. Several transformation functions are available and logarithmic transformation functions are commonly applied. In the present study, logarithmic transformations available in Geostatistical Analyst of Arc GIS software were applied wherever the data sets of soil properties found non normal to make it normal.

Semivariogram analysis: The theory of recognized variables (Matheron 1971) was used to investigate the soil spatial variability. Spatial variability is expressed by semivariogram $\hat{\gamma}$(h) which measures the average dissimilarity between data separated by a vector h. (Journel and Huijbregts 1997). It was computed as half of its average squared difference between the components of data pairs.

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

$\hat{\gamma}$(h) = Sample semivariance.

N (h) = Number of data pairs within a given class of distance and direction

Z (x_i) = Value of the variable at the location x_i

Z (x_i+h) = Value of the variable at a lag of h from the location x_i.

The experimental semivariogram value for each soil property was computed using geostatistical analyst of Arc GIS software and plotted with lag distance on abscissa $\hat{\gamma}$(h) on the ordinate. Lag increment was fixed as 400 m of sampling distance. The computed semivariograms values $\hat{\gamma}$(h) for corresponding lag (h) were fitted with the available theoretical semivariogram models using root mean square error (RMSE). Two commonly used semivariogram models namely spherical and Gaussian models were fitted for each soil property. The models are described below.

Spherical model: $\hat{\gamma}(h) = C_0 + C\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right]$,

if 0≤h≤a, = C_0+C, otherwise

C_0 = nugget

C+C0 = sill

A = range

h = lag distance

Gaussian model:

$C_0 + C\left[1 - \exp\left\{\frac{-h^2}{a^2}\right\}\right]$ for h≥0

C_0 = nugget

C+C_0 = sill

A = range

h = lag distance

In the two semivariogram models, the characteristics of the semivariogram such as nugget, sill and range were expressed by C_0, (C+C_0) and 'a', respectively. The semivariogram value at the origin (0 lag) should be zero. If it is significantly different from zero for lags very close to zero, then this semivariogram value is reported to as nugget. The sill is the semivariance value at which the variograms levels off. The range is the lag distance which semivariogram reaches to the sill value.

Ordinary kriging of soil properties

Surface maps of basic soil properties were prepared using semivariogram parameters through ordinary kriging. Ordinary kriging estimates the value of soil attributes at unsampled location, z(u) using weighted linear combination of known soil attributes z(u_a) located within a neighbourhood w(u) around 'u'

$$z^*(u) = \sum_{\alpha=1}^{n(u)} \lambda_\alpha z(u_\alpha)$$

Where, λ_α = Weight assigned to z (u_α) located within a given neighbourhood within a given neighbourhood W(u) centered on u. The n (u) weights are chosen so as to minimize the estimation or error variance which is expressed by

$$\sigma_E^2(u) = \mathrm{Var}\{z^*(u) - z(u)\}$$

Kriged map for each soil property was prepared using geostatistical analyst of Arc GIS software v. 10.0.

Cross validation of kriged thematic maps

Accuracy of soil maps was evaluated through cross validation approach (Santra *et al.* 2008). Two evaluation indices namely root mean square error (RMSE) and coefficients of determination (R2) have been used. The MSE measures the accuracy of prediction whereas; R^2 measures the effectiveness of the prediction.

RMSE measures the magnitude of error at any point and calculated as

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[z(x_i) - \hat{z}(x_i)]^2}$$

Where, $z(x_i)$ = Observed value at location i

$\hat{z}(x_i)$ = Predicted value at location i

R^2 is the measure that how effective a prediction might be, relative to that which could have been derived from using the sample mean and is given by

$$\frac{\sum_{i=1}^{N}[\hat{z}(x_i) - \bar{z}]^2}{\sum_{i=1}^{N}[z(x_i) - \bar{z}]^2}$$

Where, R^2 = Coefficient of determination

$\hat{z}(x_i)$ = Predicted value at location i

$z(x_i)$ = Observed value at location i

$\bar{z}$ = Mean of observed values

Results and Discussion

Descriptive statistics of soil fertility

While assessing the fertility, the major nutrients like Nitrogen, Phosphorous and Potassium were studied. Similarly, the micro nutrients like Fe, Mn, Zn and Cu were taken into consideration. The secondary nutrient sulphur was also assessed. Based on the data base presented in (table 1) it was observed that the available nitrogen varied from 115.4 to 245.23 kg ha^{-1}, the available Phosphorous was in the range of 21.6 to 63.17 kg ha^{-1} while potassium has shown its potential availability in the range of 470.85 to 870.13 kg ha^{-1}. The similar variation was also noted in case of available sulphur and micronutrients. The available sulphur varied from 8.99 to

16.1 mg kg^{-1} with mean value of 11.93 mg kg^{-1}. The available micronutrients Fe, Mn, Zn, and Cu varied from 2.54 to 9.81, 2.11 to 7.68, 0.25 to 0.99 and 0.32 to 0.95 mg kg^{-1} with mean values of 5.03, 4.20, 0.56 and 0.66 mg kg^{-1} respectively. Among the macronutrients, available P was found to be moderately variable (CV= 0.27) followed by available N, S and K (CV= 0.20, 0.17, and 0.12 respectively). All the micronutrients were moderately variable with CV ranging from 0.21-0.35. The soil fertility parameters were checked for normality. Among the soil fertility parameters, available P and available Fe found non normal due to higher value of skewness and kurtosis. Logarithmic transformation functions were applied to fit normal distribution.

Table 1: Descriptive statistics of soil fertility parameters.

Soil property	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis
Available N (kg ha^{-1})	115.4	245.23	185.29	36.21	0.20	-0.40	2.13
Available P (kg ha^{-1})	21.06	63.17	30.44	8.26	0.27	2.18	8.35
Available K (kg ha^{-1})	470.85	870.13	656.17	80.88	0.12	0.68	3.77
Available S (mg kg^{-1})	8.99	16.1	11.93	2.05	0.17	0.26	1.73
Available Fe (mg kg^{-1})	2.54	9.81	5.03	1.21	0.24	0.62	4.48
Available Mn (mg kg^{-1})	2.11	7.68	4.20	1.47	0.35	0.71	2.45
Available Zn (mg kg^{-1})	0.25	0.99	0.56	0.17	0.30	0.31	2.56
Available Cu (mg kg^{-1})	0.32	0.95	0.66	0.14	0.21	-0.16	2.55

Semivariogram of soil fertility

Semivariogram parameters for soil fertility properties with the best fitted model were presented in Table 2. Among the three different theoretical model tested, the spherical model was found best fit for all the fertility parameters studied like available N, P, K, S, Fe and Zn whereas Gaussian model was found fit for Mn and Exponential model was fitted for Zn.

Among the macronutrient, highest range was observed for available P and K (2500 m) followed by available N (540 m) and the least range was observed for available S (480 m) indicating that available P and K was spatially correlated for longer distance followed by available N and available S. Reported ranges of Spatial dependence were 53.1 m sampled at 25 by 25 m (Sharmishta-Pal *et al.* 2010) to 8.9 km sampled at 2 by 2 km (Reza *et al.* 2010) for available nitrogen; 25.8 m sampled at 50 m interval (Abu and Malgwi 2010) to 47.7 m sampled at 25 by 25 m for available phosphorous (Sharmishta-Pal *et al.* 2010) and 60 m sample at average interval of 20 m (Geypens *et al.* 1999) to 6.9 km sampled at 2 by 2 km foe available potassium (Reza *et al.* 2010).

The nugget varied among the macronutrient with the values of 38.22, 0.018, 625.38 and 1.7 for available nitrogen, available phosphorous, available potassium and available sulphur, respectively. The partial sill values for available nitrogen, phosphorous, potassium and available sulphur were 798.64, 0.011, 1556 and 2.56, respectively. The values of sill for available nitrogen, phosphorous, potassium and available sulphur were 836.86, 0.029, 2181.38, and 4.26, respectively. Out of the total variance (sill), nugget component for available nitrogen, phosphorous, potassium and available sulphur were 4.56 per cent, 62.6 per cent, 28.66 per cent and 39.9 per cent, respectively. The micro-scale variation was found to be highest for available phosphorous followed by available sulphur, available potassium and available nitrogen. The semivariogram parameter for micronutrients indicated that available Cu had the highest range (2500 m) whereas available Mn and Zn had the lowest range (480 m). Available Fe, Mn, and Zn, was spatially correlated for a short ranges (1919.2, 479.85, and 479.85) and at a distance less than the range, measured soil property of two samples become more alike with decreasing distance between them (Eltaib *et al.* 2002). Spatial dependence of DTPA extractable Zn, Fe, Cu, and Mn were reported by Nayak *et al.* (2006).

The nugget values for available Fe, Mn, Zn and Cu were 0.51, 0.27, 0.003 and 0.004, respectively. The partial sill values for available Fe, Mn, Zn and Cu were 0.42, 1.95, 0.026 and 0.008, respectively. The values of sill for available Fe, Mn, Zinc, and Cu were 0.93, 2.22, 0.029 and 0.012, respectively. Out of the total variance (sill), nugget component for available Fe was highest (54.83) followed by available Cu (33.33%), Mn (12.16%), and Zinc (10.34%). Spatial dependence of available Zn has strong with nugget-sill ratio of 17.01%, whereas, available N, available P, available K, available Fe, available Mn and available Cu has displayed moderate spatial dependence, with nugget-sill ratios ranging from of 31.76% to 49.99% were reported by Hou-Long *et al.* (2010). The semivariograms of available nitrogen, phosphorous, potassium, sulphur, Iron, manganese, Zinc and Copper are depicted in Fig. 1to Fig. 8, respectively.

Table 2: Semivariogram parameters of soil fertility properties

Soil property	Semivariogram model	Range (m)	Nugget (C_0)	Partial sill (C)	Sill (C_0+C)	Nugget/ Sill Ratio (%)
N	Spherical	546	38.22	798.64	836.86	4.6
P	Spherical	2500	0.018	0.011	0.03	62.1
K	Spherical	2500	625.38	1556	2181.38	28.7
S	Spherical	480	1.7	2.56	4.26	39.9
Fe	Spherical	1919	0.51	0.42	0.93	54.8
Mn	Gaussian	480	0.27	1.95	2.22	12.2
Zn	Spherical	480	0.003	0.026	0.03	10.3
Cu	Exponential	2500	0.004	0.008	0.01	33.3

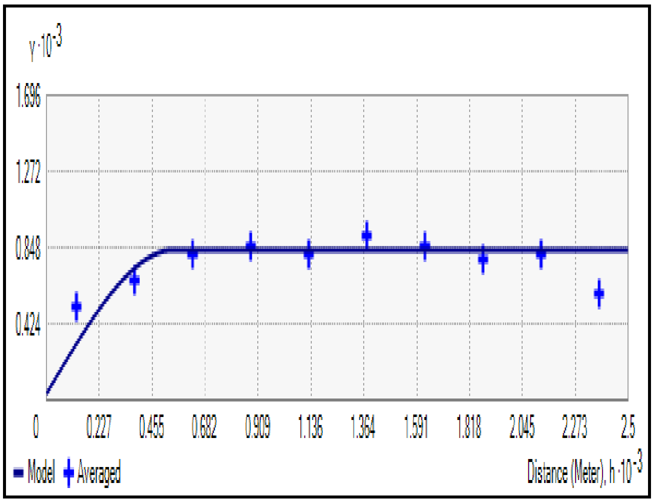

Fig 1: Semivariogram of N

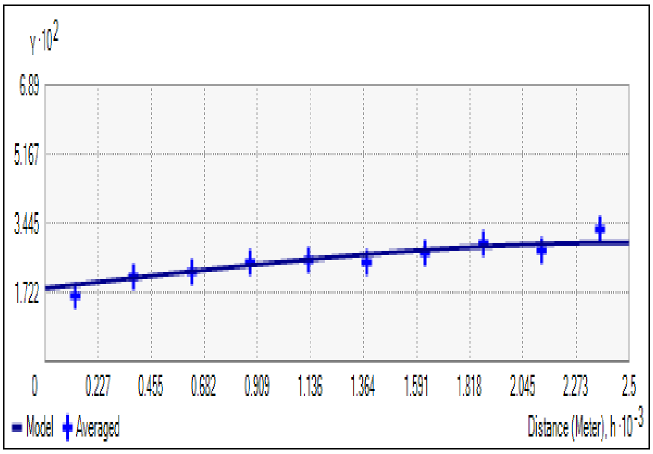

Fig 2: Semivariogram of P

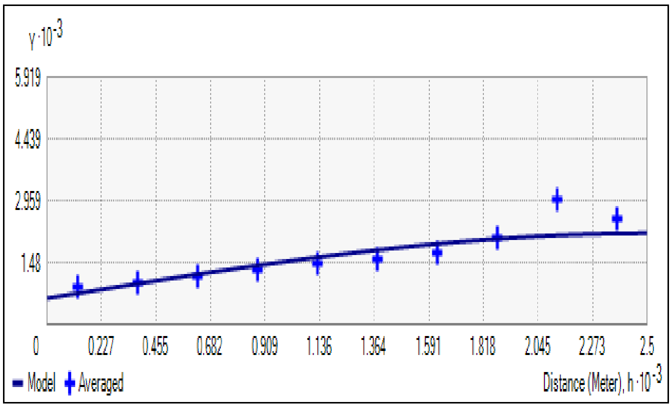

Fig 3: Semivariogram of K

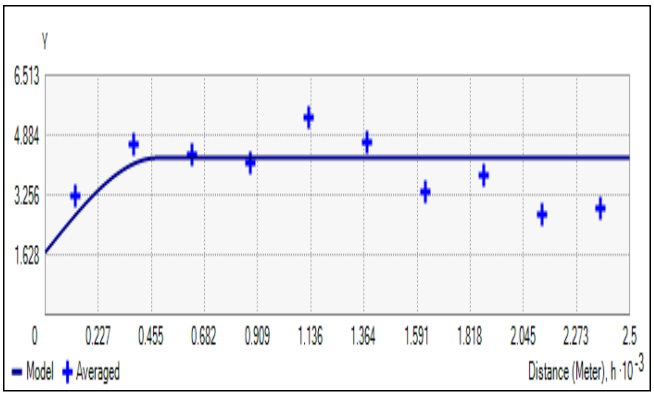

Fig 4: Semivariogram of S

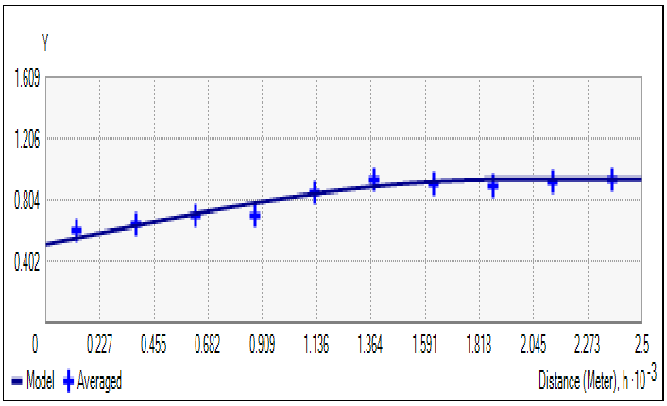

Fig 5: Semivariogram of Fe

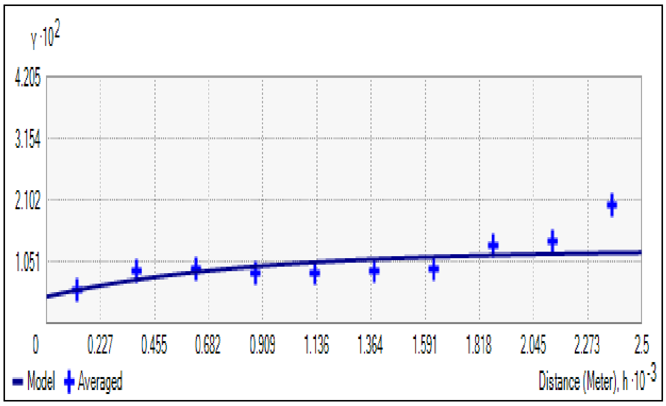

Fig 6: Semivariogram of Mn

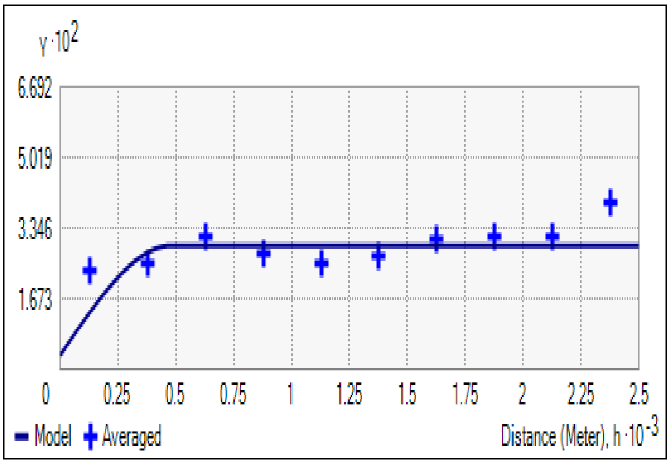

Fig 7: Semivariogram of Zn

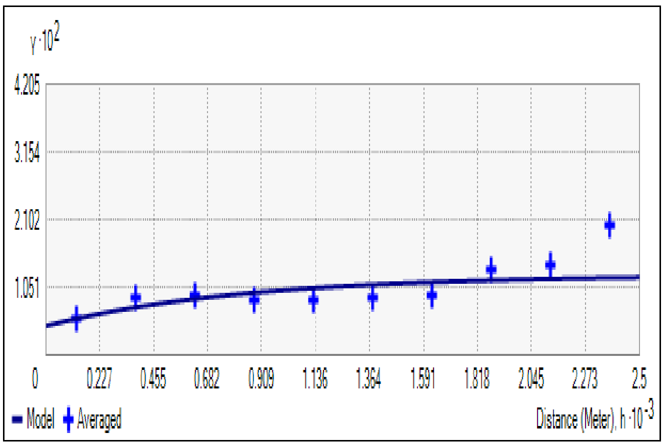

Fig 8: Semivariogram of Cu

Kriged maps of soil fertility

Spatial variability maps of available macronutrient (N, P, K and S) prepared through ordinary kriging is presented in Fig. 9 to 12, respectively. Spatial map of available N shows that it has areas under very low (<140 kg ha^{-1}) in some part of the village and low (141-280 kg ha^{-1}) major part of the village. Spatial map of available P shows that it is moderately high (21-28 kg ha^{-1}) in same patches of the village followed by high (18-35 kg ha^{-1}) and under very high (>35 kg ha^{-1}) most of the area of the village. Spatial map of available K shows that the study area has very high available potassium content (> 300 kg ha^{-1}) and for brevity the area is classified into two classes and the spatial map of K shows that most of the area is under 470 to 652 Kg/ha. Spatial map shows that the variability of available sulphur major area under the range of 10.32–11.91 mg kg^{-1} followed by 11.91-13.81 mg kg^{-1} and central area 13.81-16.10 mg ha^{-1} of the village and some northern part of the village under the range of 8.99 -10.32 mg kg^{-1}.

Spatial variability maps of available micronutrient (Fe, Mn, Cu, Zn) prepared through ordinary kriging are presented in Fig. 13, Fig.14, Fig.15, and Fig.16, respectively. Spatial map of available Fe shows that very low to low (<2.50-4.5 mg kg^{-1}) area under north and northern west part of the village and moderately high (4.5-9.0 mg kg^{-1}) available in central and southern part of the village. Spatial map of available Mn shows that the moderate (2.0-4.0 mg kg^{-1}) and moderately high (4.0-8.0 mg kg^{-1}) majority area of the village. Spatial map of available Zn shows that very low to low (<0.30-0.60 mg kg^{-1}) and moderately (0.60 to 1.20 mg kg^{-1}) major parts of the village. Spatial map of available Cu shows that the range moderate to moderately high (0.20-0.80 mg kg^{-1}) and majority area under high ranges (0.80-1.20 mg kg^{-1}) part of the village.

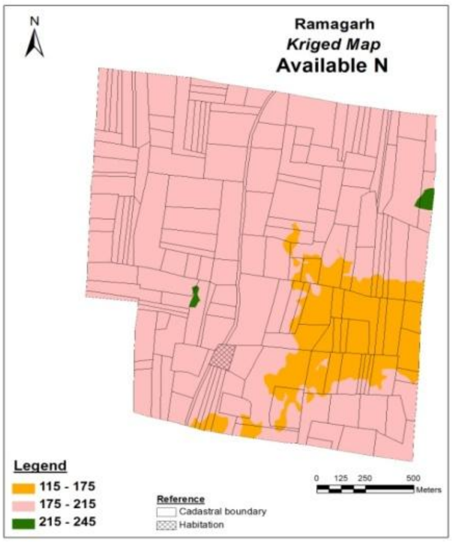

Fig 9: Kriged map of available N

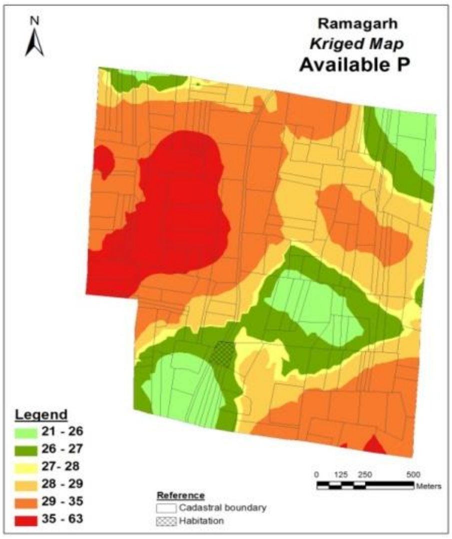

Fig 10: Kriged map of available P

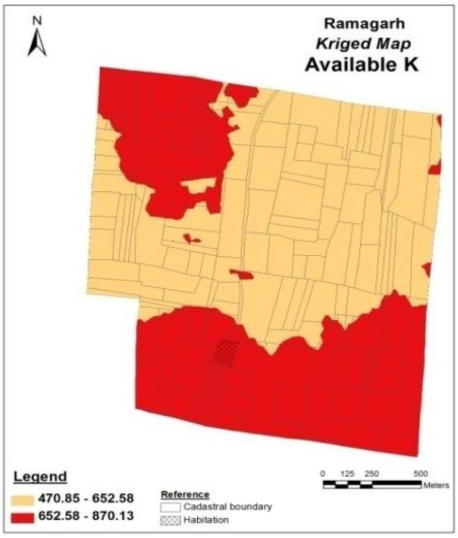

Fig 11: Kriged map of available K

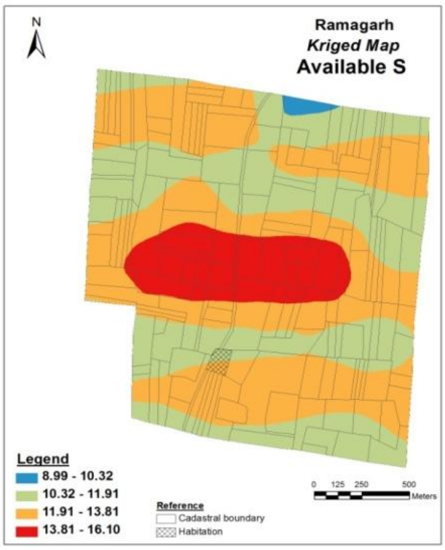

Fig 12: Kriged map of available S

Fig 13: Kriged map of available Fe

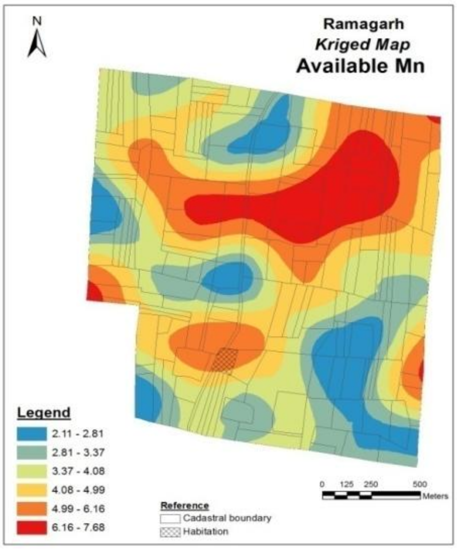

Fig 14: Kriged map of available Mn

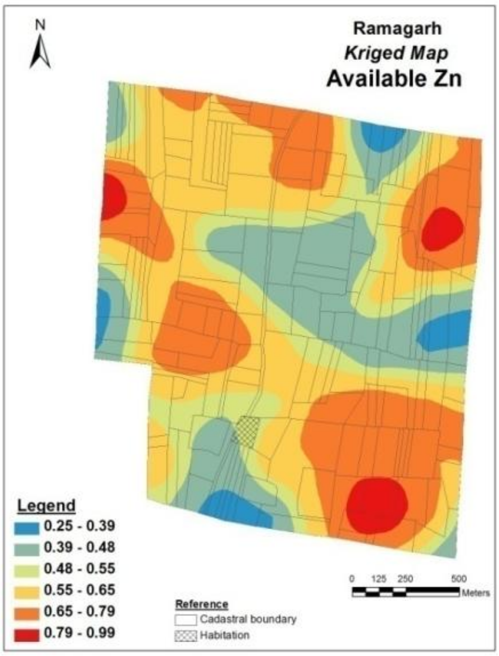

Fig 15: Kriged map of available Zn

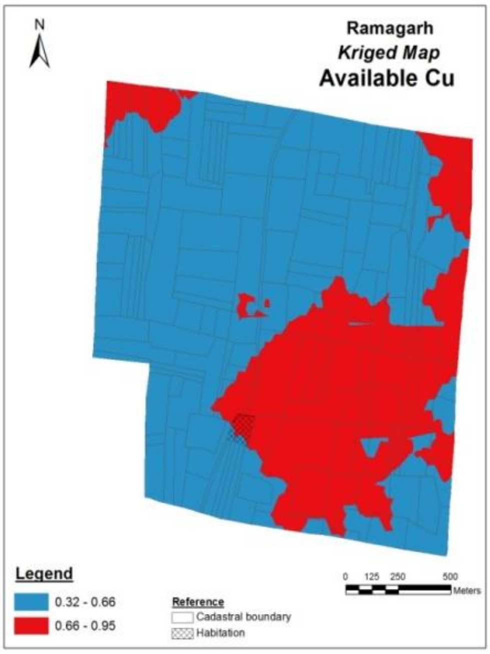

Fig 16: Kriged map of available Cu

Cross validation of soil fertility properties

Among the soil fertility parameters, within the macronutrient, the higher RMSE values were observed for available K (36.15), followed by available N (23.68) and lower RMSE values were observed for available P (4.51), followed by available S (1.9). Higher coefficient of determination (R^2) values was observed for available N (0.31) followed by available K (0.20) on the other hand lowest R^2 was recorded for available P (0.11). Among the micronutrients highest RMSE value was recorded for available Mn (1.08) followed by available Fe (0.81) than available Zn (0.14) and the lowest RMSE value was observed for available Cu (0.09). The highest coefficient of determination (R^2) values was observed for available Mn (0.44) followed by available Zn (0.28) and available Fe (0.19) whereas the lowest R^2 was found in case of available Cu (0.13).

Table 3: Evaluation parameters of kriged map of soil fertility properties

Soil property	RMSE	R^2
N	23.68	0.31
P	4.51	0.11
K	36.15	0.20
S	1.9	0.13
Fe	0.81	0.19
Mn	1.08	0.44
Zn	0.14	0.28
Cu	0.09	0.13

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