Agropedology 2017, 27 (02), 117- 124

Assessment of Spatial Variability in Soil Properties of Nagalvadi Micro-watershed Using Geospatial Techniques for Site-Specific Agricultural Input Management in Wardha District of Maharashtra

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Abstract: Soil sampling at many sites is costly and time consuming and hence warrants for predicting the soil properties at unsampled location from sampled site using spatial dependence characteristics of soil properties through interpolation with reasonable accuracy. Soil samples (0 to 20 cm depth) were collected from a regular grid of 200 by 200 m from Nagalvadi micro-watershed of Wardha district, Maharashtra and analyzed for sand, silt, clay, bulk density, pH, organic carbon, cation exchange capacity, soil moisture retention at -33 kPa and -1500 kPa, available N, P, K and micronutrient cations. Soil thematic maps were generated using semivariogram analysis and ordinary kriging. Spatial variability in soil properties indicated that sand, silt, clay, bulk density, organic carbon, cation exchange capacity, moisture retention at -33 kPa, available N, Fe, and Zn have displayed moderate spatial dependence, whereas, soil pH and available Mn showed strong spatial dependence. Soil organic carbon and soil moisture retention at -33 kPa were spatially correlated for a short range. The kriged maps of soil properties and soil fertility generated are useful for better management decisions.

Key words: *Spatial variability, semivariogram analysis, kriging, thematic map*

Introduction

Soil resource information plays a critical role in the management of natural resources. To increase the present level of soil productivity to meet the demand of the future, management of soil resources on scientific principles is very important. Adequate knowledge about the properties of soils is a key issue to support sustainable land management, which, among others, includes erosion control, fertility management, crop choice, and possibilities for irrigation (Van de Wauw *et al.* 2008; Cambardella and Karlen 1999).

Soils are characterized by high degree of spatial variability due to the combined effect of physical, chemical and biological processes that operate with different intensities and at different scales (Jenny 1941; Goovaerts 1999). Spatial variability of soil properties within or among agricultural fields is inherent because of geological and pedologic soil forming factors. The soil properties frequently exhibit spatial dependency and tend to be more similar in samples that are progressively closer to each other (Grewal *et al.* 2001). Detailed soil spatial and attribute information is required for many environmental modelling and land management applications. Various interpolation (kriging) techniques in geostatistics capitalize on the spatial correlation between observations to predict attributes value at unsampled sites using information at sampled sites (Oliver 1987; Goovaerts 1999).

The information on spatial variability in soil properties at large-scale on watershed basis, particularly, in soils of basaltic terrain is meagre. Therefore, the present investigation has been planned to assess and map the spatial variability in soil properties of Nagalvadi micro-watershed in Wardha district of Maharashtra for site-specific agricultural input management using geospatial techniques.

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Materials and Methods

Geographically, Nagalvadi micro-watershed (78°26' to 78°27'E; 21°8' to 21°10'N) with an area of 572.3 ha is located in Karanja tehsil of Wardha district of Maharashtra at an elevation ranging from 460 to 500 m above mean sea level (MSL) (Fig.1). The climate is sub-tropical dry sub-humid with mean annual maximum and minimum temperature of 32.6°C and 19.4°C, respectively. The mean annual rainfall is 1134.40 mm. The area qualifies for ustic soil moisture regime and hyperthermic soil temperature regime. The major crops grown in the area are soybean (*Glycine max*), cotton (*Gossypium spp.*), pigeonpea (*Cajanus cajan*) and sorghum (*Sorghum bicolor*) in *kharif* and wheat (*Triticum aestivum*) and gram (*Cicer arietinum*) in *rabi* under irrigation or stored moisture. Nagpur mandarin (*Citrus reticulata* Blanco) is the main fruit crop of the area.

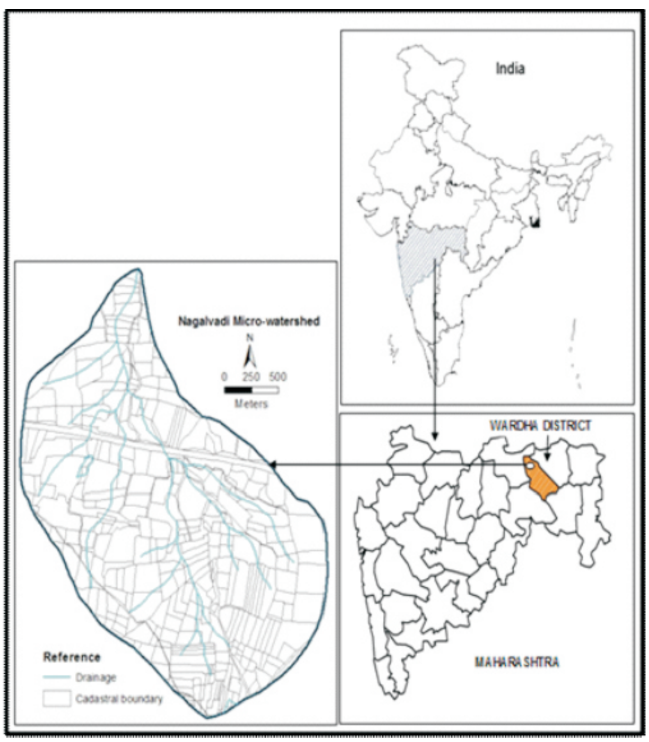

Fig. 1. Location map of study area

Sampling design, sample collection and analysis

A grid size of 200 by 200 m was chosen and established on Survey of India toposheet as well as on cadastral map of the watershed. The soil sample design is presented in Fig. 2 and the flow chart of the methodology is presented in Fig. 3. A total of 146 soil samples were collected at a depth of 0-20 cm in study area. The soil samples collected during the field work were processed, screened through 2 mm sieve, properly labeled and stored in polythene bags for laboratory analysis. Soil samples were analyzed for particle size, bulk density, soil moisture retention at -33 kPa and -1500 kPa, pH, organic carbon, cation exchange capacity and available N, P, K, Fe, Mn, Cu and Zn following the standard procedures (Black 1965; Jackson 1967).

Statistical and geostatistical analysis of soil properties

The measured soil variables in the dataset were analyzed using classical statistical method to obtain minimum, maximum, mean, standard deviation, coefficient of variation (CV) skewness and kurtosis using SPSS (Statistical Package for Social Sciences) version 11.5 software. The interpolation methods that are used to generate surface maps of soil properties give the best results if the data is normally distributed. In the present study, logarithmic transformation functions available in Geostatistical Analyst of Arc GIS software were applied wherever the data sets of soil properties found non-normal to make it normal.

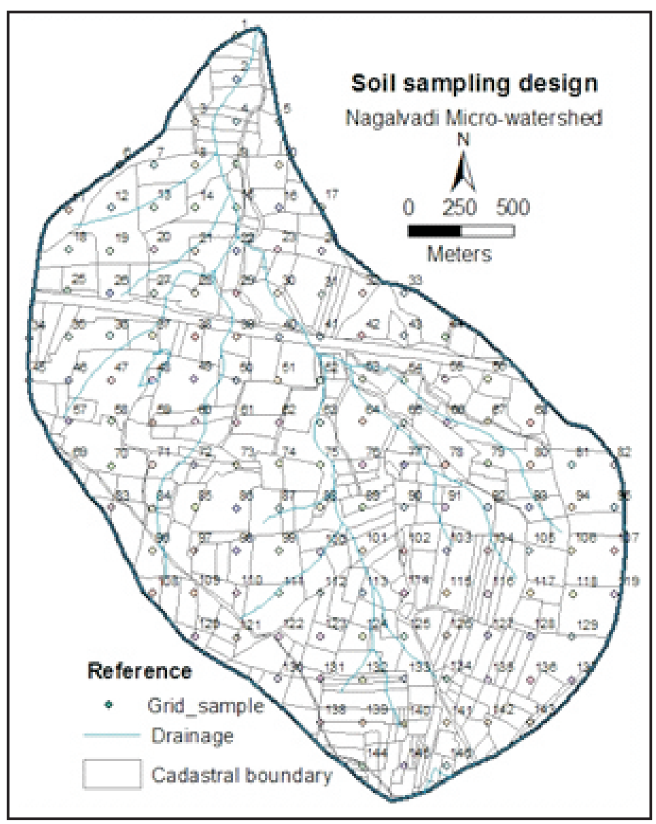

Fig. 2. Soil sampling design of study area

The theory of regionalized variables (Matheron 1971) was used to investigate the soil spatial variability. The theory considers differences between pairs of values of a property at places separated by any distance, expressed by semivariogram which measures the average dissimilarity between data separated by a vector (Journel and Huijbregts 1978). It was computed as half of its average squared difference between the components of data pairs.

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

Where,

$\hat{\gamma}$(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 (ver.10.2.2) software and plotted with lag distance on abscissa and $\hat{\gamma}$(h) on the ordinate. Lag increment was fixed as 200 m of sampling distance.

The computed semivariance values $\hat{\gamma}$(h) for corresponding lag (h) were fitted with the available theoretical semivariogram models using root mean square error (RMSE). Three commonly used semivariogram models namely Spherical, Gaussian and Exponential models were used to best fit for each soil property. The models are described below.

Spherical model

$$\hat{\gamma}(h) = C_0 + C\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right], \text{ if } 0 \le h \le a,$$

$$= C_0 + C, \text{ otherwise}$$

Where,

C_0= nugget, C+C0= sill, a= range

h= lag distance

Gaussian model

$$\hat{\gamma}(h) = C_0 + C\left[1 - \exp\left\{\frac{-h^2}{a^2}\right\}\right] \text{ for } h \ge 0$$

Where,

C_0= nugget, C+C_0= sill, a= range

h= lag distance

Exponential model

$$\hat{\gamma}(h) = C_0 + C1\left[1 - \exp\left\{-\frac{h}{a}\right\}\right] \text{ for } h \ge 0$$

Where,

C_0= nugget, C+C1= sill, a= range

h= lag distance

Where, $\hat{\gamma}$(h) is the semivariance and C_0 is the nugget variance, which is defined as the semivariance at X = 0. The maximum semivariance is defined as the sill (C_0+C), and ais the range of spatial correlation.

Semivariogram parameters namely range, nugget, partial sill and sill have been derived from the best fit model. Surface maps of basic soil properties were prepared using semivariogram parameters through ordinary kriging in geostatistical analyst of ArcGIS software and digital cadastral boundaries were superimposed during map composition. Accuracy of soil maps was evaluated through cross validation approach.

Results and Discussion

Descriptive statistics of soil properties

The descriptive statistics of soil properties are presented in table 1. The mean values for sand, silt and clay content recorded are 17.5, 32.8 and 49.7 per cent with a range of 1.6 to 48.6, 12.4 to 45.6 and 32.9 to 65.8, respectively. Sand had the largest variation (CV = 0.58) followed by silt (CV = 0.21) and clay (CV = 0.14). Average bulk density was recorded as 1.6 Mg m-3 with a range of 1.31 to 1.79 Mg m-3. Bulk density was found to be least variable (CV = 0.08) among the physical properties. Moisture retention at -33 kPa and -1500 kPa ranged from 16.3 to 39.7 and 10.2 to 29.4 per cent with mean value of 29.4 and 19.9 per cent, respectively. The moisture retention at -33 kPa and -1500 kPa were found less variable with CV of 0.18 and 0.21, respectively. The pH ranged from 6.2 to 8.7 and organic carbon ranged from 0.24 to 1.53 per cent with a mean value of 0.7. Cation exchange capacity ranged from 34.7 to 68.7 cmol(p+)kg^{-1} with a mean value of 52.1 cmol(p+)kg^{-1}. The organic carbon was found to be highly variable (CV = 0.33) followed by CEC (CV = 0.13), while pH was found least variable (CV = 0.08). The available N, P and K ranged from 114.9 to 326.1, 0.11 to 25.8 and 123.2 to 817.6 kg ha^{-1} with mean value of 226.5 kg ha^{-1}, 5.7 kg ha^{-1} and 332.5 kg ha^{-1}, respectively. The DTPA Fe, Mn, Cu, and Zn ranged from 5.6 to 46.1, 11.2 to 94.4, 1.3 to 10.2 and 0.2 to 2.2 mg kg^{-1} with mean values of 24.4, 42.7, 5.4, and 0.85 mg kg^{-1}, respectively. Available P was found to be highly variable (CV = 0.98) followed by available K (CV = 0.52) and available N was found to be least variable (CV = 0.13). The micronutrient cations were moderately variable with CV ranging from 0.30 to 0.52.

Table 1 : Descriptive statistics of soil properties

Soil property	Minimum	Maximum	Mean	Standard deviation	CV	Skewness	Kurtosis
Sand (%)	1.6	48.6	17.5	10.2	0.58	0.74	3.08
Silt (%)	12.4	45.6	32.8	6.8	0.21	-1.00	3.94
Clay (%)	32.9	65.8	49.7	7.0	0.14	-0.04	2.63
BD (Mg m^{-3})	1.31	1.79	1.6	0.12	0.08	-0.38	2.53
Moisture retention (-33 kPa) (%)	16.3	39.7	29.4	5.3	0.18	-0.48	2.73
Moisture retention (-1500 kPa) (%)	10.2	29.4	19.9	4.2	0.21	-0.10	2.67
pH	6.2	8.7	7.7*	0.62	0.08	-0.17	1.88
OC (%)	0.24	1.53	0.7	0.23	0.33	0.52	3.49
CEC (cmolp+kg^{-1})	34.7	68.7	52.1	6.98	0.13	-0.28	2.59
Available N (kg ha^{-1})	114.9	326.1	226.5	30.0	0.13	-0.44	5.99
Available P (kg ha^{-1})	0.11	25.8	5.7	5.6	0.98	1.73	5.69
Available K (kg ha^{-1})	123.2	817.6	332.5	174.2	0.52	1.02	3.25
Available Fe (mg kg^{-1})	5.6	46.1	24.4	10.3	0.42	0.29	2.05
Available Mn (mg kg^{-1})	11.2	94.4	42.7	22.1	0.52	0.81	2.4
Available Cu (mg kg^{-1})	1.3	10.2	5.4	1.61	0.30	0.59	3.40
Available Zn (mg kg^{-1})	0.2	2.2	0.85	0.4	0.47	1.01	3.75

*Median value

Semivariogram of soil properties

Semivariogram parameters (range, nugget, partial sill, sill and nugget/sill ratio) for soil properties with the best fitted model are presented in table 2. Among the three different theoretical models tested, the Exponential model was found best fit for sand, silt and clay, whereas, Gaussian model was found best fit for bulk density with low root mean square error (RMSE). Sand silt, clay and bulk density had a range of 2800 m. The long range for sand, silt, clay and bulk density indicates that these properties were more spatially correlated for a longer distance. Samples separated by distances closer than the range are related spatially and those separated by distances greater than the range are not spatially related. Trangmar *et al.* (1985) reported that semivariogram range depends on the scale of observation and the spatial interaction of soil processes affecting each property. Out of the total variation (sill), nugget component was 25.8, 27.8 and 36.4 per cent for sand, silt and clay, respectively. Nugget component was found to be 44.4 per cent of total variation in bulk density. The sand, silt, clay and bulk density showed moderate spatial dependence with nugget/sill ratio

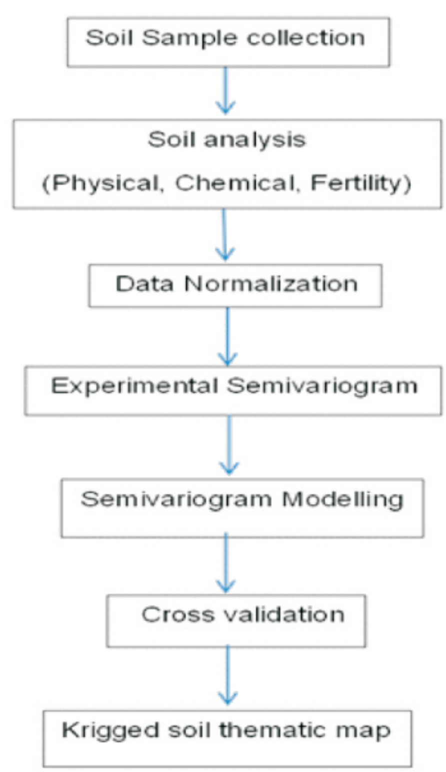

Fig. 3. Flow chart of methodology

ranging between 25 to 75 per cent (Cambardella *et al.*1994).

Spherical model was found best fit for moisture retention at -33 kPa and Gaussian model for moisture retention at -1500 kPa with low root mean square error (RMSE). The range varied from 758 m to 1291 m. Out of the total variation (sill), nugget component for moisture retention at -33 kPa and moisture retention at -1500 kPa were 25.2 per cent and 28.9 per cent, respectively. The soil moisture retention at -33 kPa and -1500 kPa showed moderate spatial dependency. The micro-scale variation was strong for moisture retention at -1500 kPa compared to moisture retention at -33 kPa (Sharma *et al.* 2011).

Spherical model was found best fit for soil pH and organic carbon and Gaussian model was best fitted for cation exchange capacity with low root mean square error (RMSE). Highest range was observed for cation exchange capacity (2800 m) and the lowest range was reported for organic carbon (770 m). Out of the total variation (sill), nugget component was 11.7, 50.0 and 44.5 per cent for soil pH, organic carbon and cation exchange capacity, respectively. The soil pH showed strong spatial dependence, whereas, organic carbon and cation exchange capacity showed moderate spatial dependence (Cambardella *et al.* 1994). Organic carbon was spatially correlated for a shorter lag distance (770 m). Similar results were also reported by Santra *et al.* (2008).

Gaussian model was found best fit for available N, K and Fe; Exponential model had best fit for available P, Mn and Cu, whereas, spherical model was best fitted for DTPA -Zn. Higher range was observed for available N and P (2800 m) than available K (2000 m) Out of the total variation (sill), nugget component for available N, P and K were 47.7, 36.4 and 32.0 per cent, respectively. The available N, P and K showed moderate spatial dependence. Out of the total variation (sill), nugget component for DTPA-Cu was highest (44.0 per cent) followed by Fe (32.3 per cent), Zn (28.5 per cent) and Mn (zero per cent). The DTPA-Mn showed strong spatial dependence, whereas, DTPA-Fe, Cu and Zn showed moderate spatial dependence.

Table 2. Semivariogram parameters of soil properties

Soil property	Semivariogram model	Range (m)	Nugget (C_0)	Partial sill (C)	Sill (C_0+C)	Nugget/ Sill Ratio (%)
Sand	Exponential	2800	0.08	0.23	0.31	25.8
Silt	Exponential	2800	4.83	12.57	17.4	27.8
Clay	Exponential	2800	0.004	0.007	0.011	36.4
Bulk density	Gaussian	2800	0.004	0.005	0.009	44.4
Moisture retention (-33 kPa)	Spherical	758	2.43	7.22	9.65	25.2
Moisture retention (-1500 kPa)	Gaussian	1291	1.41	3.47	4.88	28.9
pH	Spherical	1342	0.04	0.34	0.38	11.7
OC	Spherical	770	0.01	0.01	0.02	50.0
CEC	Gaussian	2800	38.7	48.2	86.9	44.5
Available N	Gaussian	2800	161.5	176.9	338.4	47.7
Available P	Exponential	2800	0.20	0.35	0.55	36.4
Available K	Gaussian	2000	0.08	0.17	0.25	32.0
Available Fe	Gaussian	1121	25.8	52.2	80.0	32.3
Available Mn	Exponential	1451	0	0.23	0.23	0
Available Cu	Exponential	2800	0.37	0.47	0.84	44.0
Available Zn	Spherical	1835	0.02	0.05	0.07	28.5

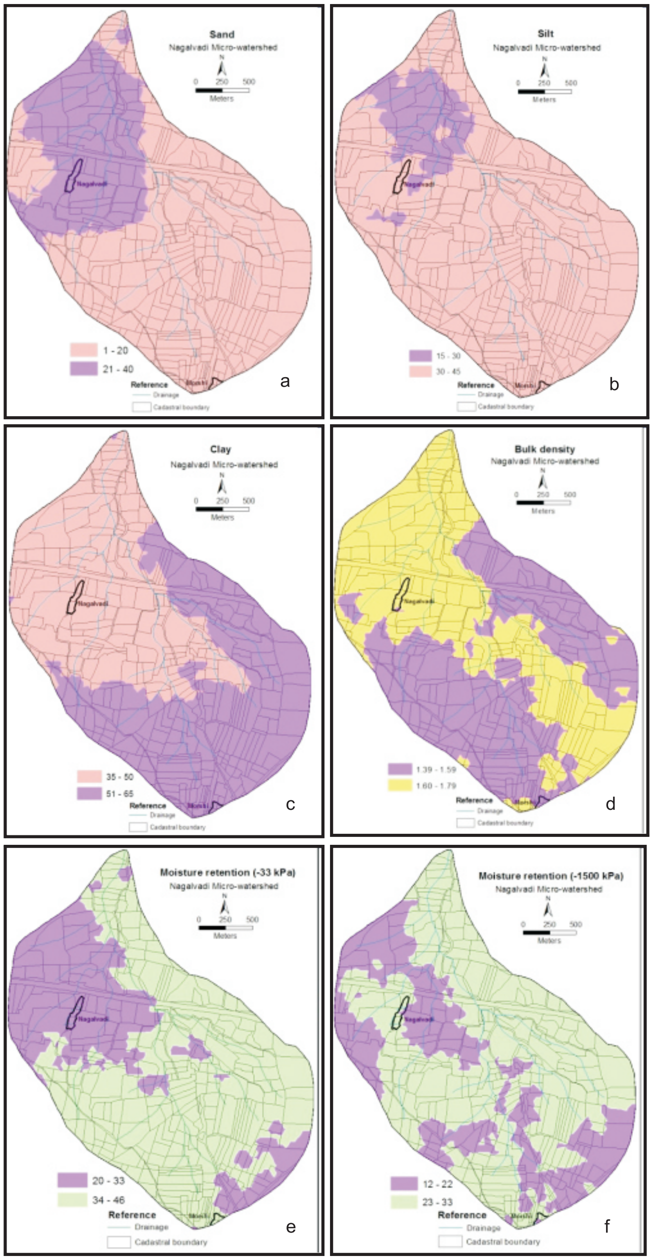

Fig. 4. Kriged maps of a) sand, b) silt, c) clay, d) bulk density, e) moisture retention at -33 kPa and f) moisture retention at -1500 kPa

Kriged maps of soil properties

Kriged maps of soil physical properties are presented in figure 4. Spatial kriged map of sand, silt and clay showed that sand, silt and clay contents varied from 10.3 to 36.4, 28.7 to 40.9 and 43.0 to 56.6 per cent, respectively. The sand and clay contents were spatially correlated. Areas with higher clay content corresponded with lower sand content. Kriged map of bulk density showed that the bulk density varied from 1.51 to 1.65 Mg m-3. Soil moisture retention at -33 kPa and -1500 kPa varied from 23.1 to 36.5 and 25.6 to 35.3 per cent, respectively. There was high spatial correlation between soil moisture retention at -33 kPa and -1500 kPa and clay content. The area with higher moisture retention at -33 kPa and-1500 kPa was associated with higher clay content.

Kriged maps of chemical properties are presented in figure 5. Soil pH indicated that it varied from 6.7 to 8.7 and majority of area is under moderately alkaline (42.4% of TGA) followed by mildly alkaline (33.4% of TGA). Kriged map of soil organic carbon varied from 0.32 to 1.13 per cent and majority of area is under moderate with an area of 297.4 ha (52.0% of TGA) followed by medium with an area of 206.7 ha (36.1% of TGA). Kriged map of cation exchange capacity indicated the spatial variability from 34.8 to 65.2 cmol (p+) kg-1 soil.

Kriged maps of available N, P and K (Fig.6) indicated that available N varied from 191 to 280 kg ha^{-1}, 0.7 to 14.0 kg ha^{-1} and 151 to 300 kg ha^{-1}, respectively. The reclassified kriged map of available N, P and K indicates that entire area of watershed was low in available N, very low to low in available P and medium to very high in available K.

Kriged maps of DTPA-Fe, Mn, Cu and Zn are presented in figure 7. Kriged map of DTPA-Fe spatially varied from 5.6 to 46.1 mg $kg^{-1}$and found to be much higher than the critical level of 4.5 mg kg^{-1} (Lindsey and Norvell 1978) in all the soils. Kriged map of DTPA-Mn showed that available Mn spatially varied from 18.0 to 66.8 mg $kg^{-1}$and found to be much higher than the critical level of 3.0 mg kg^{-1}(Takkar *et al.* 1989). Kriged map of DTPA-Cu showed that available Cu spatially varied from 4.1 to 6.2 mg $kg^{-1}$and was found to be higher than the critical value of 0.2 mg kg^{-1} (Katyal and Randhawa 1983). Kriged map of DTPA-Zn showed that available Zn varied from 0.33 to 1.08 mg kg^{-1} and majority of area was found sufficient in DTPA-Zn covering an area of 495.5 (86.6% of TGA). The yield data collected from the farmers field indicated that the productivity of soybean (12 to 15 q ha^{-1}), cotton (10 to 15q ha^{-1}), wheat (20 to 25q ha^{-1}) and gram (8 to 12q ha^{-1}) is low and needs integrated nutrient management (INM) to improve the productivity of these crops. The average productivity of Nagpur mandarin is low (6 t ha^{-1}) compared to the international average of 30 to 35t ha^{-1} and attributed to inadequate and imbalanced nutrient use and site-specific nutrient management can

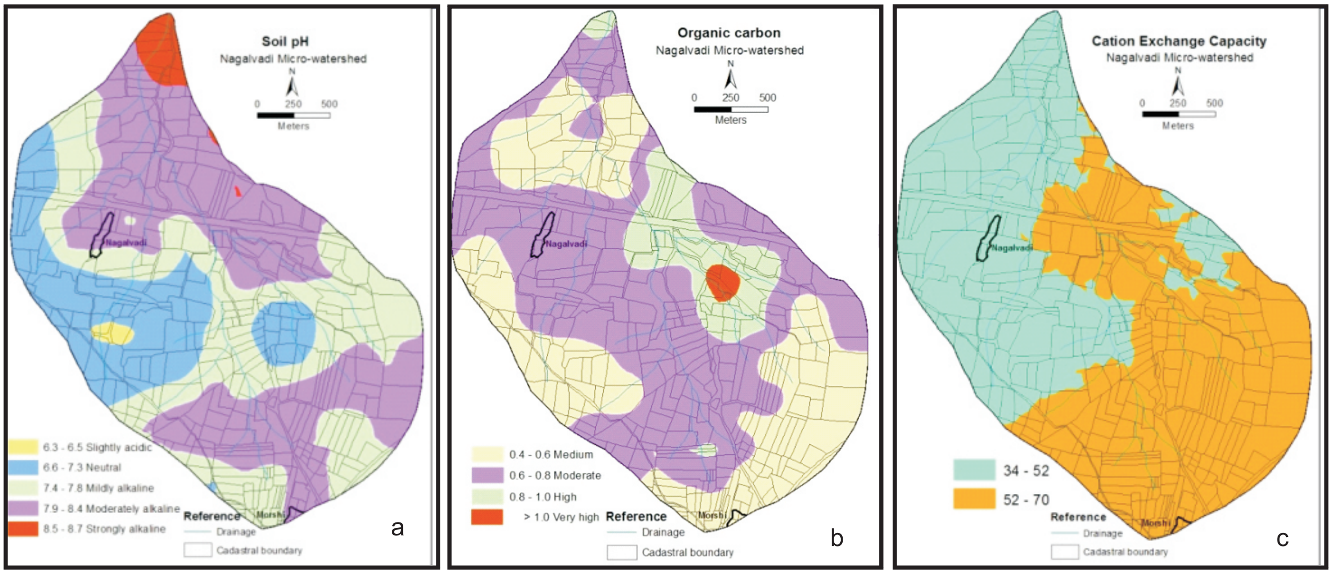

Fig. 5. Kriged maps of a) pH, b) organic carbon and c) cation exchange capacity

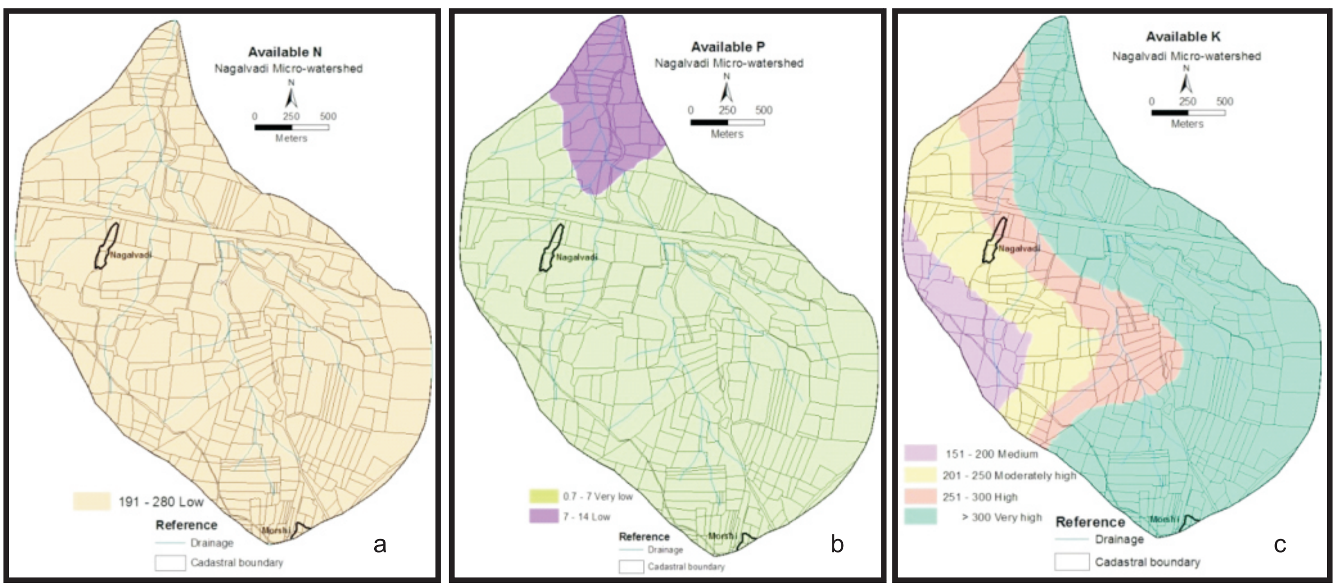

Fig. 6. Kriged maps of a) available N, b) availabel P and c) available K

help tailor fertilizer applications (Sawant *et al.* 2018). Thus, the kriged maps may help in site-specific nutrient and crop management by accounting for the spatial variability in soil characteristics.

Conclusions

Exponential model was found best fit for sand, silt and clay, available P, Mn and Cu; spherical model for soil pH, organic carbon, moisture retention at -33 kPa and available Zn, whereas, Gaussian model was found to be best fit for bulk density, cation exchange capacity, moisture retention at -1500 kPa, available N, K and Fe. Soil pH and available Mn showed strong spatial dependence and other soil properties showed moderate spatial dependence. Bulk density and moisture retention at -33 kPa were spatially correlated for as shorter range compared to other soil properties. The spatial variability maps generated using ordinary kriging method showed variation in physical, chemical properties and soil fertility. The areas with higher clay content corresponded to higher moisture retention and cation exchange capacity and lower sand content. Soils are neutral to strongly alkaline and govern the nutrient solubility and availability to the plants. The spatial maps of moisture retention may be used for cadastral-level

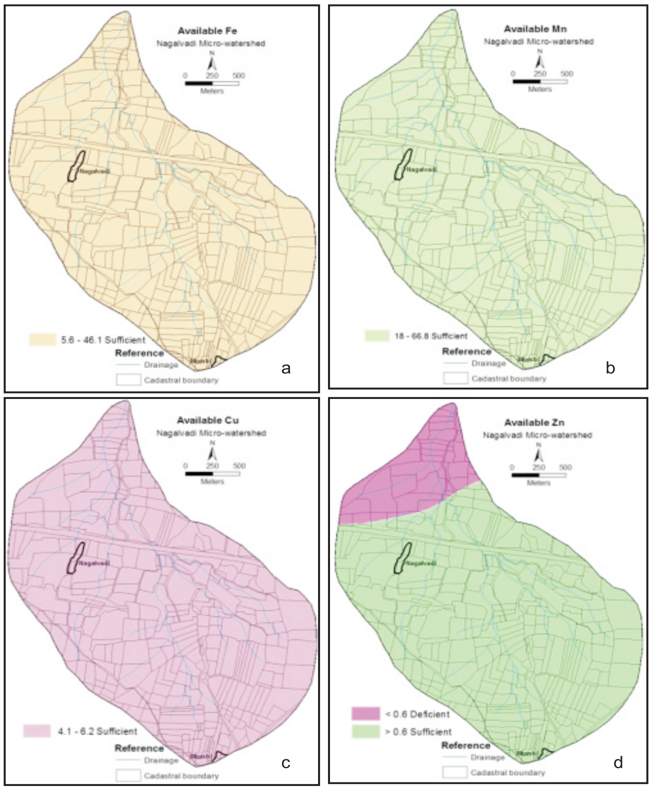

Fig. 7. Kriged maps of a) available Fe, b) available Mn, c) available Cu and d) available Zn

planning of crop selection and water management. Spatial maps of macro and micronutrients depicted the areas with different classes of nutrient availability. Therefore, the kriged maps combined with cadastral maps helps in site-specific nutrient and crop management by accounting for the spatial variation in soil characteristics and soil nutrient availability to improve the nutrient use efficiency of applied nutrients

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Received : April 2017 Accepted : July 2017