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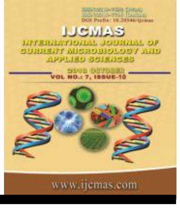

Original Research Article

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Mapping of Spatial Variability in Soil Properties and Soil Fertility for Site-Specific Nutrient Management in Bareli Watershed, Seoni District of Madhya Pradesh Using Geostatistics and GIS

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ABSTRACT

In this paper, spatial variability in soil chemical properties and fertility were investigated in Bareli watershed, Seoni district of Madhya Pradesh. Georefened soil samples with a grid spacing of 325×325 m were collected in the study area and analyzed for soil pH, organic carbon, cation exchange capacity, available macronutrients (N, P and K) and micronutrients (Fe, Mn, Cu and Zn). Spatial variability was quantified through semivariogram analysis using geostatistics and kriged maps were generated in Geographic Information System (GIS). The results indicated that organic carbon was found to be highly variable followed by cation exchange capacity, while pH was found least variable. The soil fertility indicated that available K was found to be highly variable followed by available P, while available N was found to be least variable. All the micronutrients showed moderate variability. The spatial maps indicated that the available N, P and K were low to medium, medium to very high and medium to high, respectively. DTPA-Fe and DTPA-Zn was found deficient in 93.1% and 53.8% of area of the watershed. The reclassified kriged maps of soil fertility parameters generated from the point data clearly delineated different nutrient levels in the soils and very useful for site-specific nutrient management in the watershed.

Keywords

Soil chemical properties, Soil fertility, Spatial variabililty, Kriged maps

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Introduction

The productivity potential of soil varies with its fertility, inherent characteristics and environmental conditions. Understanding the spatial variability in soil properties and its interaction with soil fertility parameters is very important for site-specific nutrient management to improve the productivity. Soil properties change in time and space continuously (Rogerio *et al.,* 2006). Determining soil variability is important for ecological modelling, environmental predictions, precise agriculture and management of natural resources (Hangsheng *et al.*, 2005).

Geostatistical methods are essential for the investigation of spatial variations of soil and crop parameters across agricultural fields, which can lead to the efficient implementation of soil fertility management systems (Najafian *et al.*, 2012). Furthermore, geostatistical methods have been adopted and used in site-specific management applications, soil sampling strategies and assessment of farm management decisions. Semivariogram analysis in geostatistics is done to characterize and model spatial variance of data to assess how data points are related with separation distances, while, kriging uses modelled variance to estimate values between samples (Journel and Huijbregts, 1978).

The problems of declining soil fertility, low crop yield and accelerated soil erosion are associated implications for agricultural development since the bulk of agricultural production takes place under traditional systems, where, soil fertility is a key component. The result is poor farm management practices, low yield and an unnecessary high cost of production. The objective of this study is to assess the spatial variation in soil properties and soil fertility of a continuously cultivated land under rainfed systems using GIS for site-specific nutrient management.

Materials and Methods

The Bareli watershed in basaltic terrain lies between 22^o 29' 39" to 22^o 32' 10" N latitude and 79^o 46' 44" to 79^o 49' 50"E longitude and covers an area of 1795.35 ha in Dhanora block, Seoni district, Madhya Pradesh. Physiographically, Bareli watershed was divided into five major physiographic units *viz.* plateau (P), escarpments (E), hills and ridges (H), isolated mounds (M) and pediments (D). The elevation of the area ranges from 520 to 620 m above mean sea level (MSL). The area is associated with level to nearly level sloping (0-1%) to moderately steep to steeply sloping (15-25%) lands. The climate is mainly dry sub-tropical with mean annual temperature of 28.4^{o}C and mean annual rainfall of 1100 mm. The area qualifies for ustic soil moisture regime and hyperthermic soil temperature regime. The natural vegetation comprises of teak (*Tectona grandis*), babul (*Acacia spp*.), palas (*Butea frandosa*), charoli (*Buchanania lanzan*), ber (*Ziziphus jujuba*) etc. The major crops are paddy (*Oryzasativa*), pigeonpea (*Cajanus cajan*), maize (*Zea mays*) and safflower (*Carthamus tinctorius*) in *kharif* and wheat (*Triticum aestivum*) and gram (*Cicer arietinum*) in *rabi* under irrigation or stored moisture. Mango and Guava are the main fruit crops of the area (Fig. 1 and 2).

Survey of India (SOI) toposheets No. 55 N/14 and 55 N/15 (1:50000 scale) and IRS-P6 LISS-IV data (November, 2013) were geo-referenced using WGS 84 zone 44 N datum, Universal Transverse Mercator (UTM) projection to collect topographic and location information. Georeferenced soil samples (0–15 cm) were collected using the grid method. A grid interval of 325 by 325 m was laid on the georeferenced toposheet and satellite data and used for collection of soil samples. A total of 129 soil samples were collected from the 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 pH, organic carbon, cation exchange capacity and available N, P, K, Fe, Mn, Cu and Zn following the standard procedures (Black 1965; Jackson 1967).

The datasets containing measured soil variables were statistically analyzed using classical statistical method to obtain minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), skewness, kurtosis using SPSS version 11.5 software. The data was normalized before interpolation to generate surface maps of soil properties. In the study, logarithmic transformation functions available in Geostatistical Analyst of ArcGIS software (version 10.1) were applied to normalize the data wherever the data sets of soil properties were found to be non-normal. Surface maps of basic soil properties and soil fertility were prepared using semivariogram parameters through ordinary kriging in geostatistical analyst of ArcGIS software.

Results and Discussion

The descriptive statistics of soil chemical properties (Table 1) indicated that pH varied from 6.1 to 7.8 and organic carbon varied from 0.38 to 1.94 per cent with a mean value of 1.08. Cation exchange capacity (CEC) varied from 24.3 to 57.3 cmol(p^+)kg^{-1} with a mean value of 43.6 cmol(p^+)kg^{-1}. Among the chemical properties studied, organic carbon was found to be highly variable (CV = 0.29) followed by cation exchange capacity (CV = 0.18), while pH was found least variable (CV = 0.05). The descriptive statistics of soil fertility parameters (Table 1) indicated that available N, P and K varied from 125.4 to 464.1, 11.6 to 59.1 and 56 to 986.8 kg ha^{-1} with mean value of 263.4 $kgha^{-1}$, 30.8 $kgha^{-1}$ and 390.7 $kgha^{-1}$, respectively. The DTPA micronutrient cations Fe, Mn, Cu and Zn varied from 0.45 to 27.3, 1.17 to 41.1, 2.24 to 89.7 and 0.14 to 1.62 $mgkg^{-1}$ soil with mean values of 7.94, 19.0, 12.3 and 0.56 $mgkg^{-1}$ soil, respectively. Among the macronutrients, available K was found to be highly variable (CV = 0.48) followed by available P (CV = 0.36). Available N was found to be least variable (CV = 0.23). All the micronutrients were moderately variable with CV ranging from 0.50 to 0.89.

The reclassified maps of soil pH, organic carbon and cation exchange capacity are presented in figure 3, respectively. Spatial variability map of soil pH indicated that it varied from 6.5 to 7.2. The spatial map of soil pH was reclassified into slightly acidic (pH: 6.5-6.8) and neutral (pH 6.8-7.2). Different soil pH classes (Table 2) indicated that majority of area is under slightly acidic (62.7% of TGA) followed by neutral (36.9% of TGA). Spatial variability map of soil organic carbon varied from 0.38 to 1.94 per cent. The spatial variability map of organic carbon was reclassified into medium (0.4-0.6%), moderate (0.6-0.8%), high (0.8-1.0%) and very high (>1.0%). Soil organic carbon classes (Table 2) indicated that majority of area is under high (37.3% of TGA) followed by moderate (27.5% of TGA), very high (22.2%of TGA) and medium (12.4% of TGA). Spatial variability map of cation exchange capacity indicated that it varied from 24.3 to 57.3 cmol(p+)kg^{-1} soil. The spatial variability map of cation exchange capacity was reclassified in to 3 classes viz. 33-41, 41-49 and 49-57 cmol(p+)kg^{-1}.

The reclassified maps of available N, P and K are presented in figure 4, respectively. The kriged maps of available N, P and K indicated that available N varied from 125 to 280 kg ha^{-1}, 17 to 51 kg ha^{-1} and 118 to 677 kg ha^{-1}, respectively. The kriged map of available N was reclassified in to very low (<140 kg ha^{-1}), low (141-280 kg ha^{-1}), medium (281-420 kg ha^{-1}), moderately high (421-560 kg ha^{-1}), high (561-700 kg ha^{-1}) and very high (>700 kg ha^{-1}). The data indicated (Table 2) that available N indicated that entire area of watershed was found low to medium in available N. The kriged map of available P was reclassified in to very low (<7.0 kg ha^{-1}), low (7.1-14.0 kg ha^{-1}), medium (14.1-21.0 kg ha^{-1}), moderately high (21.1-28.0 kg ha^{-1}), high (28.1-35.0 kg ha^{-1}) and very high (>35.0 kg ha^{-1}).The data (Table 2) indicated that majority area of the watershed was found to be medium in available P (35.1% of TGA) followed by high (34.8 % of TGA) and very high (29.7 % of TGA) (Table 2).

Table.1 Descriptive statistics of soil chemical properties and soil fertility

Soil property	Minimum	Maximum	Mean	Standard deviation	CV	Skewness	Kurtosis
pH	6.1	7.8	6.7	0.39	0.05	0.48	-0.50
OC (%)	0.38	1.94	1.08	0.32	0.29	0.13	-0.60
CEC (cmolp+kg^{-1})	24.3	57.3	43.6	8.05	0.18	-0.27	-0.76
Available N (kg ha^{-1})	125.4	464.1	263.4	63.1	0.23	0.43	0.19
Available P (kg ha^{-1})	11.6	59.1	30.8	11.3	0.36	0.68	-0.30
Available K (kg ha^{-1})	56	986.8	390.7	189.9	0.48	0.75	0.20
Available Fe (mg kg^{-1})	0.45	27.3	7.94	6.12	0.77	1.11	0.64
Available Mn (mg kg^{-1})	1.17	41.1	19.0	9.51	0.50	0.19	-0.74
Available Cu (mg kg^{-1})	2.24	89.7	12.3	11.0	0.89	4.5	25.7
Available Zn (mg kg^{-1})	0.14	1.62	0.56	0.28	0.50	1.0	1.3

Table.2 Spatial distribution pattern of soil chemical properties and soil fertility

Class	Range	Area (ha)	% of TGA
pH			
Slightly acidic	6.5-6.8	1127.0	62.78
Neutral	6.8-7.2	663.68	36.97
Organic carbon (%)			
Medium	0.4-0.6	223.5	12.4
Moderate	0.6-0.8	498.2	27.5
High	0.8-1.0	669.5	37.3
Very high	>1.0	399.3	22.2
Available N(kg ha^{-1})			
Low	125-280	1595.5	88.8
Medium	280-464	195.1	10.8
Available P(kg ha^{-1})			
Medium	17-25	629.9	35.1
High	25-34	625.9	34.9
Very high	34-51	534.8	29.8
Available K(kg ha^{-1})			
Medium	118-258	345.9	19.3
High	258-677	1444.6	80.4
Available Zn(mg kg-^{1})			
Deficient	<0.6	966.8	53.8
Sufficient	>0.6	823.8	45.8
Available Fe(mg kg^{-1})			
Deficient	<4.5	369.5	20.5
Sufficient	>4.5	1421.1	79.1

Fig.1 Location of study area

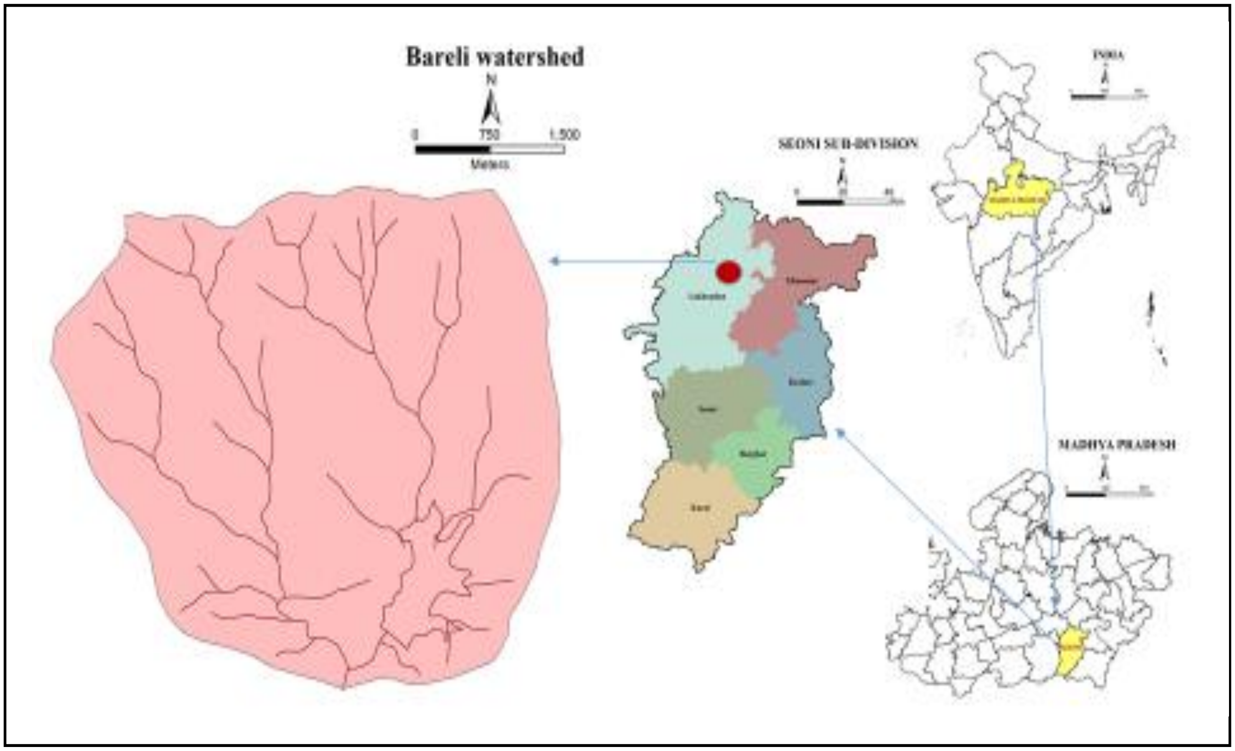
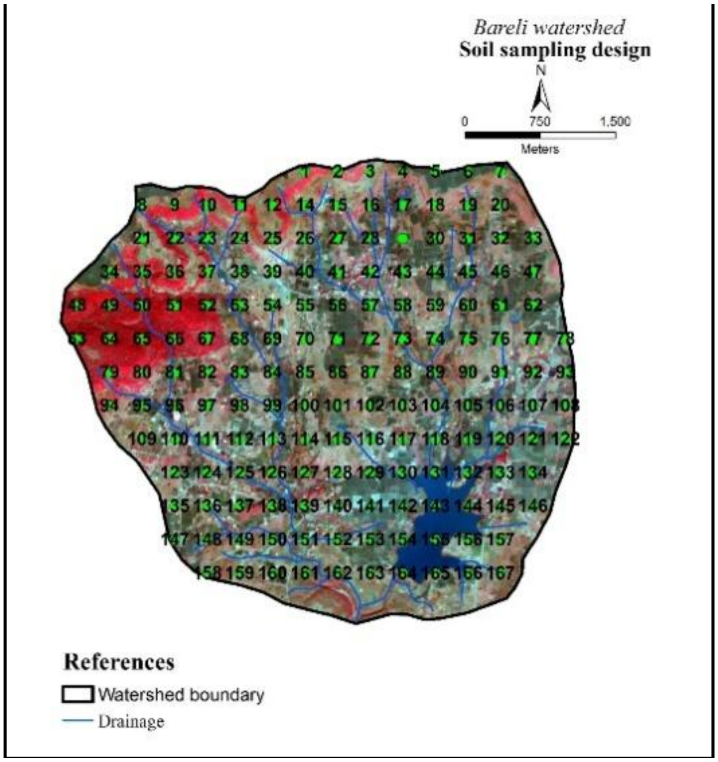


Fig.2 Soil sampling design



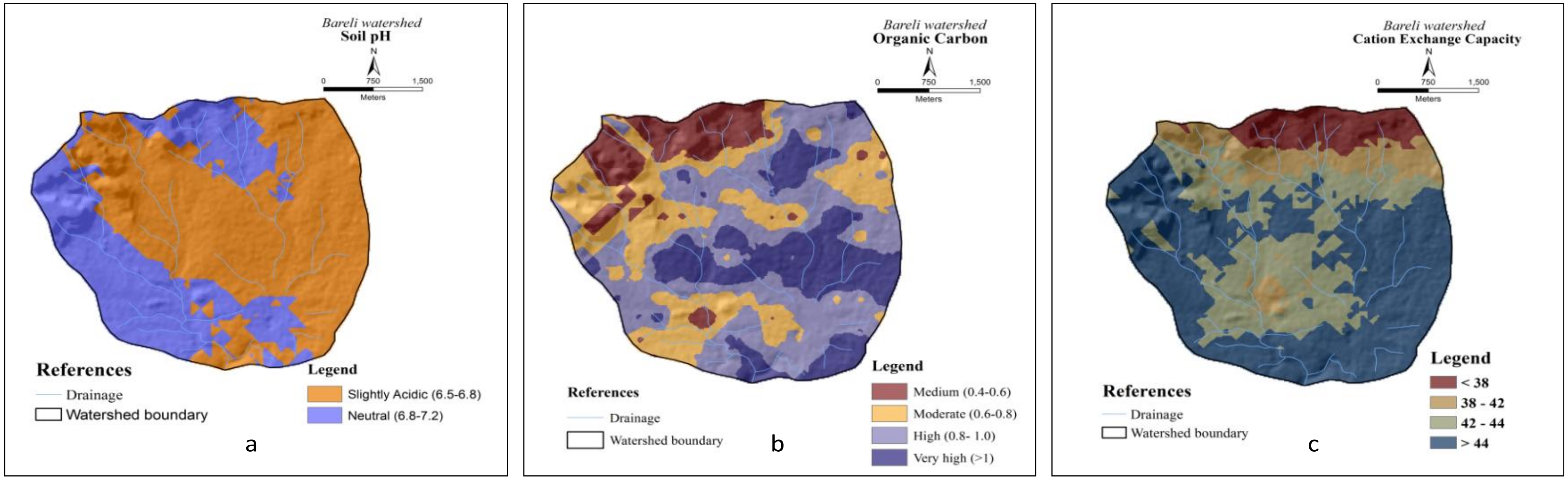


Fig. 3 Kriged maps of a) soil pH, b) organic carbon and c) cation exchange capacity

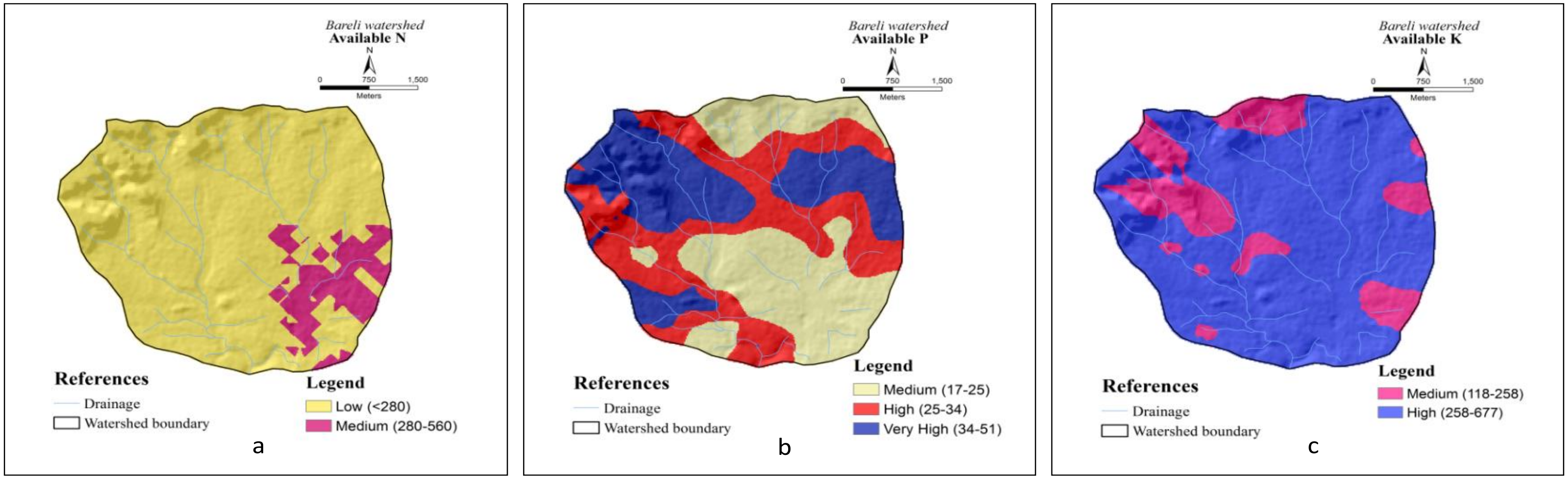


Fig. 4 Kriged maps of a) available N, b) available P and c) available K

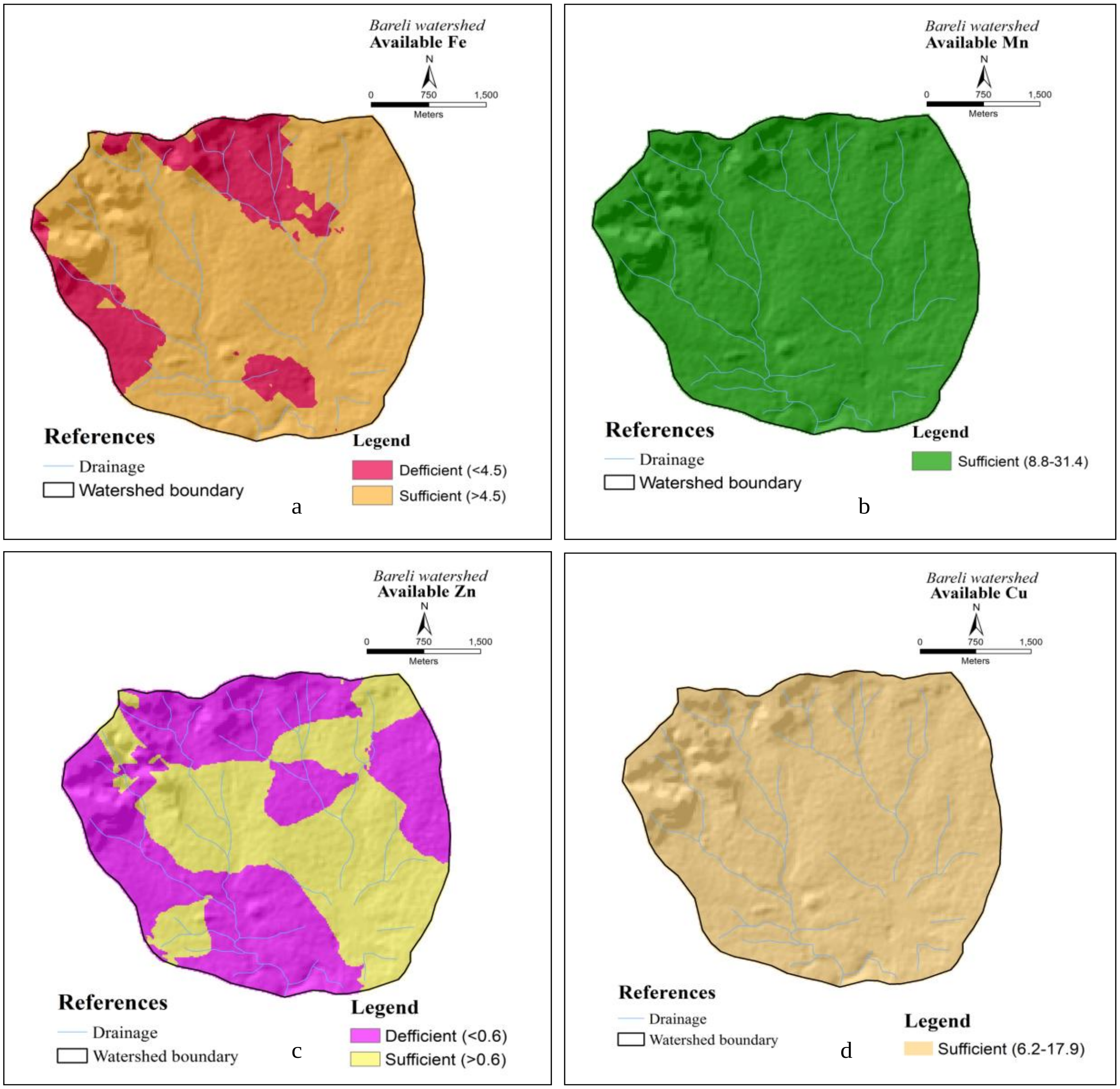


Fig. 5Kriged maps of a) DTPA-Fe, b) DTPA-Mn, c) DTPA-Cu and d) DTPA-Zn

The kriged map of available K was reclassified in to very low (<100 kg ha^{-1}), low (100-150 kg ha^{-1}), medium (151-200 kg ha^{-1}), moderately high (201-250 kg ha^{-1}), high (251-300 kg ha^{-1}) and very high (>300 kg ha^{-1}). The data (Table 2) indicated that majority of area is under high (80.4% of TGA) followed by medium (19.3% of TGA).

The reclassified spatial kriged maps of available micronutrients are presented in figure 5. Spatial map of DTPA-Fe showed that DTPA-Fe varied from 0.45 to 27.3 mg kg^{-1} soil and reclassified in to deficient and sufficient areas against the critical level of 4.5 mg kg^{-1} soil (Lindsey and Norvell, 1978) and 20.5% of TGA was found deficient in DTPA-Fe (Table 2). Spatial map of DTPA-Mn showed that DTPA-Mn varied from 3.15 to 41.1 mg kg^{-1} soil and found to be much higher than the critical level of 3.0 mg kg^{-1} soil (Takkar *et al.*, 1989). Spatial map of DTPA-Cu showed that DTPA-Cu spatially varied from 1.34 to 19.0 mg kg^{-}1 soil and was found higher than the critical value of 0.2 mg kg^{-1} soil (Katyal and Randhawa, 1983). Spatial map of DTPA-Zn showed that DTPA-Zn varied from 0.14 to 1.62 mg kg^{-1} soil and reclassified in to deficient and sufficient areas against the critical level of 0.6 mg kg^{-1}soil (Katyal and Randhawa, 1983; Sharma *et al.*, 1996) and the data (Table 2) indicated that majority of area was found deficient in DTPA-Zn (53.8% of TGA).

The spatial variability in soil properties and fertility was quantified through semivariogram analysis and the respective surface maps were prepared through ordinary kriging in Bareli watershed. The study helped to identify and delineate critical nutrient sufficiency and deficiency areas. The spatial maps indicated that the available N, P and K were low to medium, medium to very high and medium to high, respectively. DTPA-Fe and DTPA-Zn was found deficient in 93.1% and 53.8% of area of the watershed. The generated maps can serve as an effective tool for site-specific nutrient management. This is a prerequisite in order to optimize the cost of cultivation as well as to address nutrient deficiency.

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