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Spatial Assessment of Soil Fertility Status in Shiratti Sub Watershed of Semi-arid Tropics in Southern India

Vasundhara, R., Rajendra Hedge, Dharumarajan, S. and Niranjana K. V

ICAR- National Bureau of Soil Survey and Land Use planning, Regional Centre, Bangalore (560 024), Karnataka

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Corresponding Author

Vasundhara, R.
e-mail: vasundharagowda@gmail.com

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Abstract

Spatial variability of soil fertility assessment is necessary for enhancing crop and soil productivity particular of the area. The study was carried out to evaluate the nutrient status of soils in micro watersheds, of Shiratti taluk in Gadag district, Karnataka with objectives of (i) to assess the spatial variability of Soil nutrients at a regional scale through geostatistical methods and to assess the relationships of nutrient availability with several soil properties. Around 831 surface soil samples (0–15 cm depth) were collected from farmer's fields with total area of 5698 ha, at 250×250 m^2 grid interval during 2014–15, using GPS locations. Semivariograms were calculated for all nutrients and their main parameters (nugget effect, sill and range) were obtained. The CV values of measured soil properties ranged from 13.18 for pH and 149 for EC. Among the soil nutrients highest variation was observed in Zinc 126.84 and lowest was in potassium 55.38. Moderate spatial dependence for soil pH, OC, P_2O_5, K_2O, Fe, Mn and Cu and strong spatial dependence for extractable B and EC were observed. Available Fe and Zn deficiencies were noticed in 48 and 83% of the study area, respectively. Majority of the area recorded low in organic carbon, available P_2O_5, S, and B whereas available K_2O is medium to high in status. Soil pH showed significant and negative correlations with the concentrations of extractable available S, B, Fe and Mn and Fe; whereas the available K_2O, Zn and Cu correlation was significant and positive with soil organic carbon concentration.

Keywords: Spatial distribution, semivariogram, geostatistics, soil nutrients, organic carbon

1. Introduction

In India 41% of the food grains produced from rainfed areas which are having 68 per cent area out of the 143 m ha net cultivated land in the country (Srinivas rao et al., 2006). In rainfed semi-arid and dry sub-humid regions, the yields of important crops range from as low as 0.5 to 2 t ha, with an average of and 1-1.5 t ha in Asia and North Africa (Wani, 2003 and 2011). The major constraints for poor productivity in rainfed agriculture are poor soil fertility, erratic and low a rainfall Ncube et al., 2009). To achieve potential yields in rainfed soils, require appropriate nutrient management strategies for multi nutrient deficient soil (Sahrawat, 2008). There is an increasing concern about the sustainability of Indian agriculture from deteriorated in soil (Pathak, 2010). In this view the watershed scales, the information about spatial distribution characteristics of soil nutrients and relationship between soil nutrients

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and land use can provide some important basis for ecological restoration and rebuilding of degraded soil and ecosystem (Li et al., 2010). Hence, attention has to be paid to diagnose and take corrective measures for deficiencies of secondary and micro nutrients in various crop production systems (Rego et al., 2005; Sahrawat et al., 2007, 2011; Manna et al., 2012). In India several studies have assessed the soil fertility status in a watershed for recommending optimum soil management practices, crops and cropping systems to ensure sustainable yields in the rainfed regions (Prabhavathi et al. (2013). In this view we have taken a study in subwatershed land resource inventory representing SAT regions of northern Karntaka, India. To assess the resources available and potential areas to enhance the soil productivity and health. The objective of this investigation is to assess the Soil nutrient variability status in watershed by developing suitable nutrient management strategies for rainfed agriculture production systems in the SAT regions of India and to assess the relationship of soil nutrients.

2. Materials and Methods

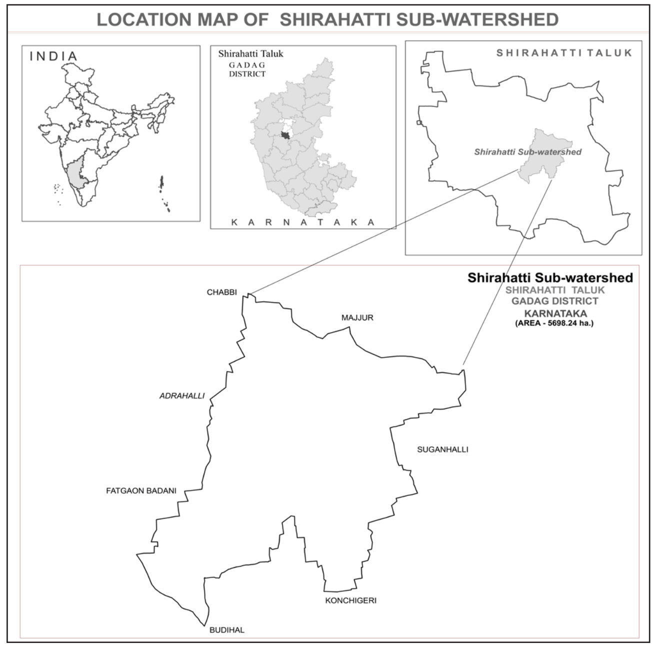
2.1. Study area

The study area is located in the central part of northern Karnataka in Shirahatti Taluk,of Gadag District, Karnataka State (Figure 1). It lies between 75°34'10'' and 75°40' 50'' East longitudes and 15° 3' 20'' and 15° 9'10'' North latitudes and covers an area of 5698 ha. Major rock formations observed in the subwatersheds are Peninsular Gneiss,Gadag Schist, with thick coating of iron oxides and Banded Ferruginous Quartzite The ridges have capping of Banded Ferruginous Quartzite (BFQ), whereas side slopes near the streams are dominated by schist.

The study area falls under semiarid tract of the state and is categorized as drought prone with average annual rainfall of 633mm (Figure 2). The average potential evapotranspiration (PET) is 137 mm. The PET is always higher than precipitation in all the months except in the month of October. Generally, the length of crop growing period (LGP) is 150 days. About 77% area (Figure 2) in the Shirahatti taluk is cultivated at present and about 14% of the area is sown more than once. An area of about 17% is currently barren. Forests occupy a small area of about 1.6% and the tree cover is in a very poor state. Major crops grown in the area are sorghum, maize, cotton, safflower, sunflower, red gram, horse gram, onion, mulberry, sugarcane, bengal gram and groundnut and crops such as onion, sugarcane and chilly are being cultivated with assured irrigation.

2.2. Soil sampling and analysis

Detailed soil survey was taken up using standard procedures as per All India Soil Land Use Survey (Anonymous, 1971). Erosion hazards were judged through existing site conditions and texture by feel method. In the year 2016 nearly 830 surface soil samples (0-15 cm) were collected from the



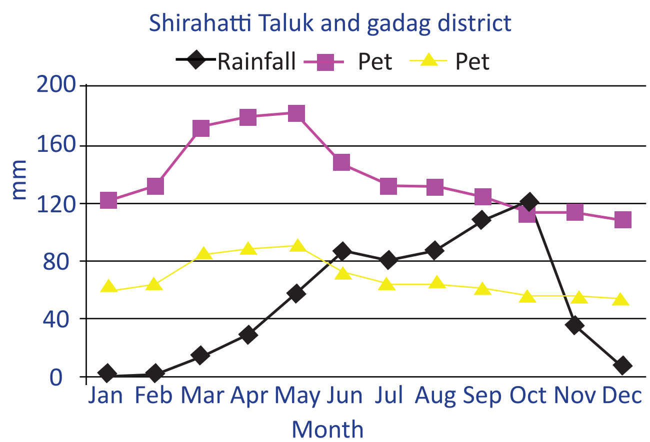


Figure 1 and 2: location map and rainfall distribution study area

different physiographic unit at 250 m grid interval covering 11 micro watersheds excluding water bodies, settlements and forest areas for soil fertility.

Soil samples were analysed for organic carbon (OC), pH, EC, macro and micronutrients. Organic C was analyzed as per procedure laid out by Walkley-Black (Nelson and Sommers, 1975). Available phosphorus was determined by olsen method (olsen et al., 1954) and available potassium was determined by flame photometry after extracted with neutral normal ammonium acetate solution (pH 7.0). Available sulphur was extracted by 0.15% cacl2 solution and concentration of sulphur was determined by the turbidimetric method spectrophotometrically (chesnin and yien, 1951). Hot water soluble Boron estimated by azomethine-h method as outlined Berger and Troug (1983). Available Zn, Fe, Cu and Mn were extracted by diethylene triamine penta acetic acid DTPA solution and analysed using atomic absortion sperophotometer (Lindsay and Norvell, 1978). Soil pH and EC determined as per standard procedure (Jackson 1973).

2.3. Statistical and geostatistical analysis based on GIS

The average and standard error of the soil nutrients were computed; The minimum, maximum, mean, coefficient of variation (CV), skewness and kurtosis values for each analyzed soil property were computed by SPSS13.0 software. The spatial distribution of soil nutrients was simulated by interpolation method, supported by the geo-statistics module of ArcGIS software. To find out the relationship between soil properties and available nutrients, Pearson's correlation coefficients were computed.

The mapping techniques like spatial interpolation and GIS were used to produce spatial distribution and maps for the investigated basic soil properties, and the software used for this study was ArcGIS v.10.1 (ESRI Co, Redlands, USA). In ArcGIS, kriging can express the spatial variation and allow a variety of map outputs, and at the same time minimize the errors of predicted values (Gonzalez et al., 2014). Moreover, it is very flexible and allows users to investigate graphs of spatial autocorrelation. Kriging, as applied within moving data neighborhoods, is a nonstationary algorithm which corresponds to a nonstationary random function model with varying mean but stationary covariance (Deutsch, 1992). In kriging, a semivariogram model was used to define the weights of the function (Webster & Oliver 2001), and the semivarianceis an autocorrelation statistic defined as follows (Mabit and Bernard, 2007):

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

where z (xi) is the value of the variable z at location of xi, h the lag, and N (h) the number of pairs ofsample points separated by h.

During pair calculation for computing the semivariogram, maximum lag distance was taken ashalf of the minimum extent of sampling area. Anisotropic semivariograms did not show anydifferences in spatial dependence based on direction, for which reason isotropic semivariogramswere chosen. Spherical, exponential and Gaussian models were fitted to the empirical semivariograms. Best-fitted model with minimum root mean square error (RMSE) were selected for each soil nutrient:

$$\mathrm{R}MSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[z(xi - \hat{z}(xi)]^2}$$

The exponential,spherical andguassium models were best fitted to all the soil properties. Expression for different semivariogram models used in this study is given below:

Exponential model:

$$r(h) \quad = Co + \mathrm{C1}\left[1 - exp\left\{-\frac{h}{a}\right\}\right] for\ h\ \geq o$$

Spherical model:

$$r(h) \quad = Co + \mathrm{C1}\left[1.5\frac{h}{a} - 0.5(\frac{h}{a})3\right], o \leq \quad h \leq= Co + \mathrm{C1},$$

Guassium model:

$$r(h) \quad = Co + \mathrm{C1}\left[1 - exp\left\{-\frac{\mathrm{h2}}{\mathrm{A2o}}\right\}\right] for\ h\ \geq o$$

Using the semivariogram model, basic spatial parameters such as nugget (C0), sill (C1 + C0), and range (A) was calculated which provide information about the structure as well as the input parameters for the kriging interpolation. Nugget represents variation caused by stochastic factors,such as error in measurement, sill is the lag distance between measurements at which one value for a variable does not influence neighboring values, and range is the distance at which values ofone variable become spatially independent of another (Lopez-Granados et al., 2002).

3. Results and Discussion

3.1. Statistical characterization of data Soil properties (pH, EC & OC) and soil nutrients

Descriptive statistics including mean, maximum, minimum, standard deviation, kurtosis, skewness and CV for, pH, EC & OC Available P, K, S, B and DTPA extractable Zn, Cu, Mn and Fe are given in Table 1. The CV values of measured soil properties ranged from 13.18 for pH and 149 for EC. Among the soil nutrients highest variation was observed in Zinc 126.84 and lowest was in potassium 55.38. The present soil samples collected from different soil types, crop, topography and management practices thus variability in soil properties was expected. The mean micronutrient concentration values followed the order: Mn> Fe>Cu>B>Zn. About 760 soil samples showed below critical levels of Zn content means Nearly 83 percent of the area is suffering from Zn deficient in soil and for iron 515 soils samples having iron content less than <4.5ppm. There is an urgent need to increase the dose of deficient fertilizers for sustainable crop production. The extensive nutrients deficiencies were due to poor organic carbon status of soils (Srinivasarao et al., 2006) and depletion under continuous cropping without application of these plant nutrients (Rego et al., 2007). Low levels of organic carbon in these soils were primarily due to high temperature and low rainfall in these regions (Jenny and Raychaudhuri, 1960) and also due to low organic matter additions (Rego et al., 2003).

3.2. Analysis of correlations between pH, EC & OC and soil nutrients

For accurate assessment the correlations and regressions were made between pH, EC organic carbon and phosphorus, potassium, sulphur, boron, iron, manganese, copper, zinc (Table 2). Highest significant correlation was the showed in between pH and Mn. The correlations between organic carbon and pH, EC listed in table 2 were not significant. The correlations between organic carbon and K_2O, Zn and Cu is significant and for other nutrient it is non-significant. Less correlation coefficient was due to High variability in data

Table 1: Statistical summary of selected soil properties and nutrients P_2O_5, K_2O, S, B, Zn, Cu, Mn and Fe (n = 831)

Variables	Minimum	Maximum	Mean	Std. Deviation	CV	Kurtosis	Skewness
pH	5.05	10.60	7.79	1.03	13.18	1.11	-0.91
ECe (dS/m)	0.01	2.81	0.16	0.24	149.40	60.82	28.38
OC (%)	0.03	2.54	0.54	0.3	56.06	4.28	2.69
P_2O_5 (Kg ha^{-1})	2.29	80.15	14.2	13.85	97.51	3.49	1.75
K_2O (Kg ha^{-1})	27.43	995.25	266.45	147.56	55.38	2.63	1.27
S (ppm)	0.76	196	13.58	14.35	105.67	76.81	6.97
B (ppm)	0.01	5.2	0.57	0.47	81.05	28.75	21.52
Fe (ppm)	0.52	47.2	5.57	5.72	102.52	14.32	3.36
Mn (ppm)	1.95	41.55	11.69	8.5	72.75	0.91	1.32
Cu (ppm)	0.13	4.56	0.88	0.52	59.85	9.83	5.31
Zn (ppm)	0.02	4.20	0.31	0.39	126.84	46.40	26.60

Table 2: Pearson's correlation coefficients for soil nutrients and selected soil properties

Variables	pH	EC	OC	P_2O_5	K_2O	S	B	Fe	Mn	Cu	Zn
pH	1										
EC	.337**	1									
OC	0.001	-0.024	1								
P_2O_5	-0.024	.100**	0.059	1							
K_2O	.355**	.249**	.140**	.201**	1						
S	.115**	.515**	-0.056	0.022	0.014	1					
B	.210**	.178**	0.001	0.065	0.023	.161**	1				
Fe	-.428**	-.121**	0.015	0.04	-.210**	-0.034	-0.033	1			
Mn	-.482**	-.148**	0.002	-0.003	-.145**	-0.022	-0.062	.226**	1		
Cu	-0.006	0.052	.266**	.072*	.150**	-.075*	-0.034	0.048	.106**	1	
Zn	-.076*	-0.035	.078*	.126**	0.023	-0.04	-0.016	-0.009	0.037	.086*	1

**: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed)

samples, parent material and physiographic units these Results agree with Soil nutrient status was influenced by some factors such as parent material, fertilizer, land use and physiographic units (Zou et al., 2006; Shukla et al., 2016; Weiwen et al., 2016). In another study Relationship between various soil properties and available nutrient status in different soil types varied between significantly negative to significantly positive depending upon soil type, production system and also due to crop management practices being followed particular area (Srinivasarao et al., 2009). Wu et al., (2010) were reported that the total Cu content was positively and significantly correlated with soil organic matter and cation exchange capacity of soil but was negatively and significantly correlated with soil pH. The variability of STN and STP may be related to elements such as land use, topography, soil type, vegetation type, cultivation, and parent material in the terrestrial ecosystem have been reported (Liu et al., 2007). The SOC perform as chelating agents for soil nutrients this results enhanced concentration of nutrient in soil. (White and Zasoski, 1999).

3.4. The features of soil nutrient spatial structure and distribution

The spatial variability in the current data set of samples is due to variability in soil type/ physiographic units and different size of land holdings with varied cropping system/pattern under different management practices in the watershed. The pH values of majority of soils in the watershed varied from neutral to strongly alkaline (6.51 to >9.0). The strongly alkaline soils were found high (24% area) in the watershed in which Hullure-2 micro-watershed has the maximum area (80%) under alkaline soils. The salinity hazard does not exist in the watershed, as the EC range values from 0.013 to 1.92 dSm^{-1}. It was found that organic carbon (OC) status in majority of samples ranged between low to medium (0.03to 0.74%). The soil organic carbon (SOC) content of the watersheds area is low (<0.5%) in 2232 ha (40%) and dominantly occurs in southern part of the study area and High organic carbon content accounts for 818 ha (14 %) of the area can be seen in northern part of study area (Figure 3).

The soil nutrient thematic map revealed that majority of the area (71%) is low in available phosphorus (<23 kg ha^{-1}) and it ranged from 2.29 to 22.9 kg ha^{-1}. About 922 ha (16%) area in the watersheds is medium in available There is an urgent need to increase the dose of phosphorous for all the crops by 25% over the recommended dose to realize better crop performance. Available potassium content is medium in 3560 ha (62%) area (Figure 4), High available potassium content accounts for 1196 ha (21%) and is distributed entire study area. Nearly 3560 ha (62%) and 1603 ha (28%) area is low in

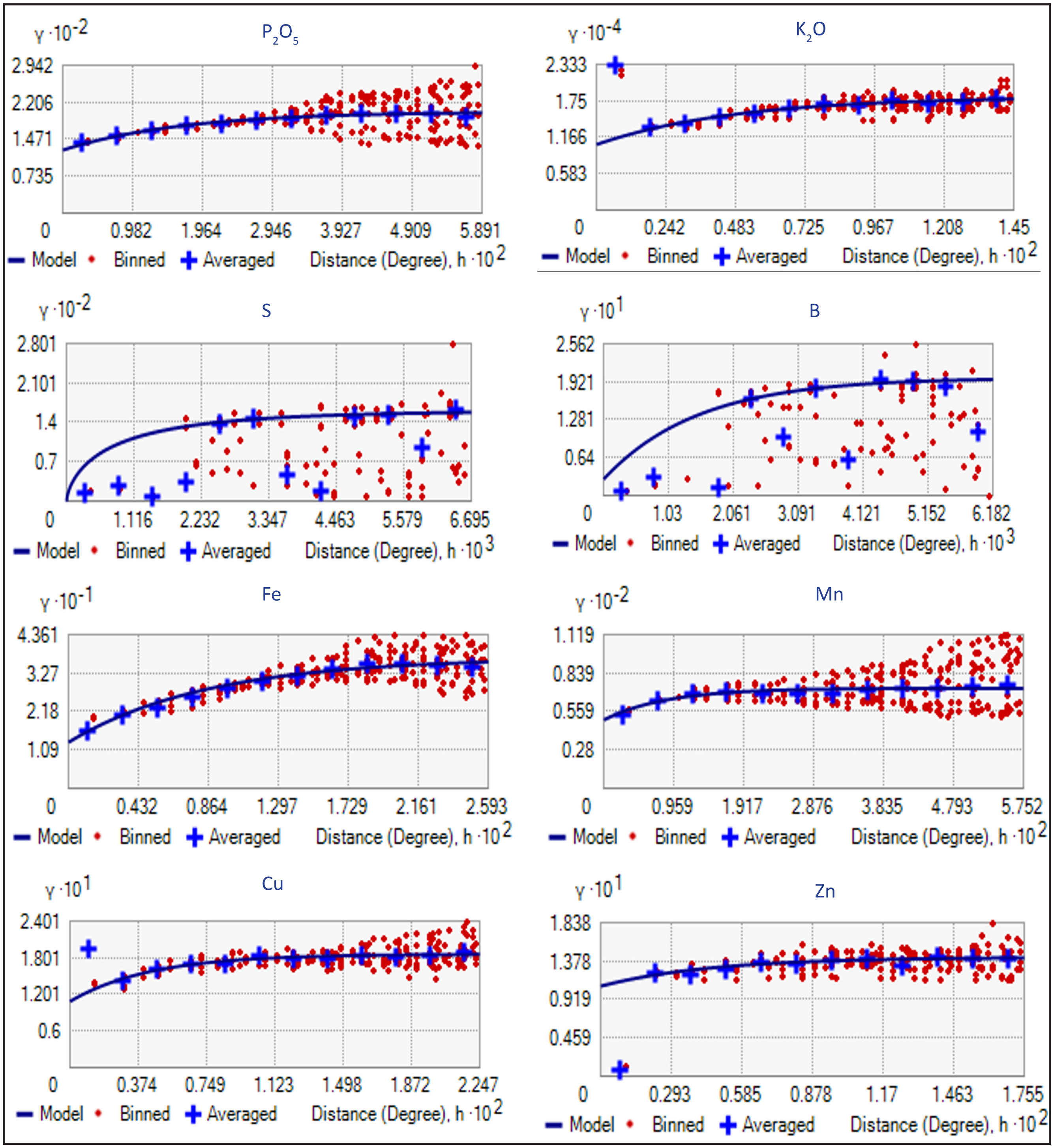


Figure 3: Experimental semivariograms and their fitted models for soil nutrients

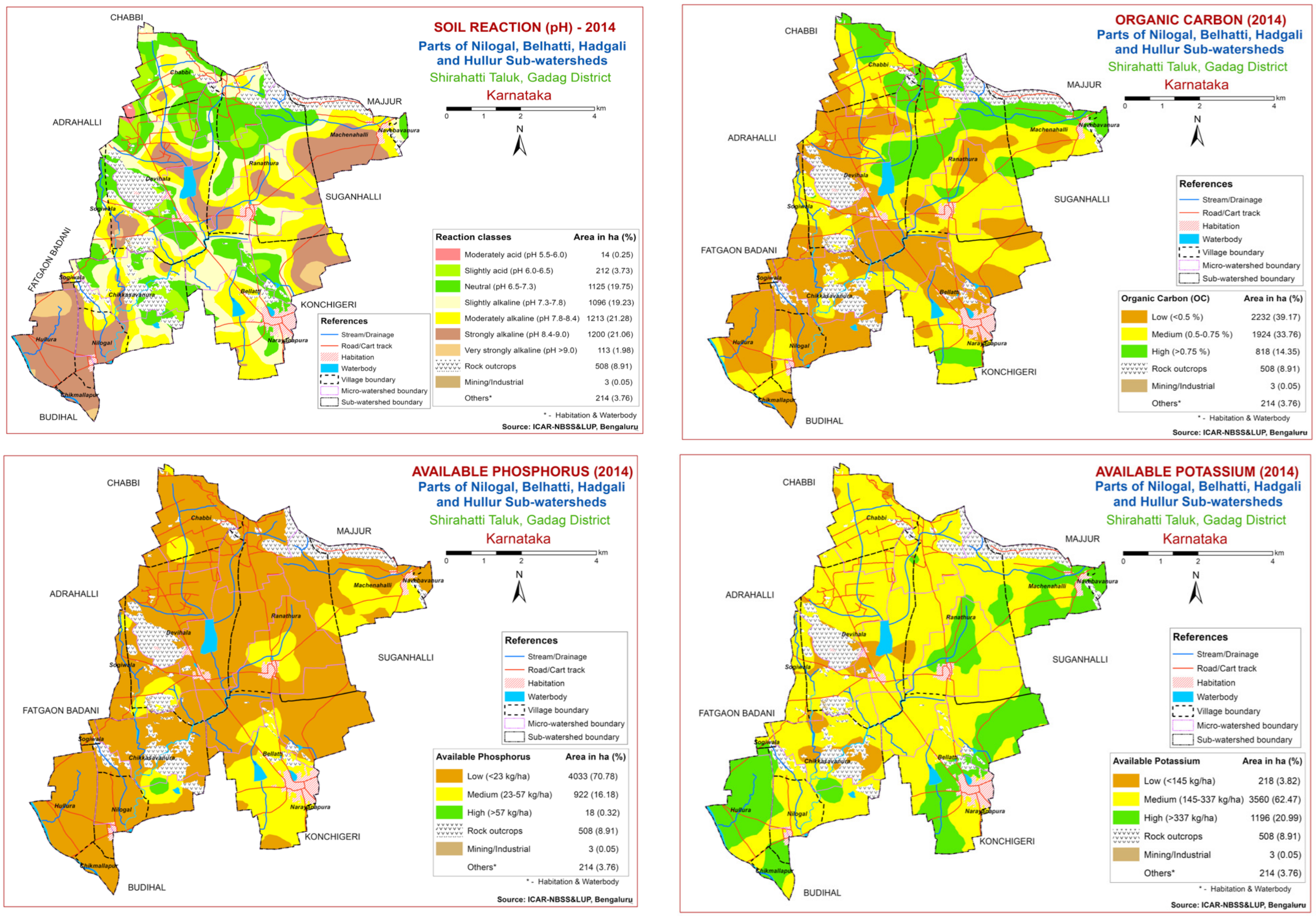
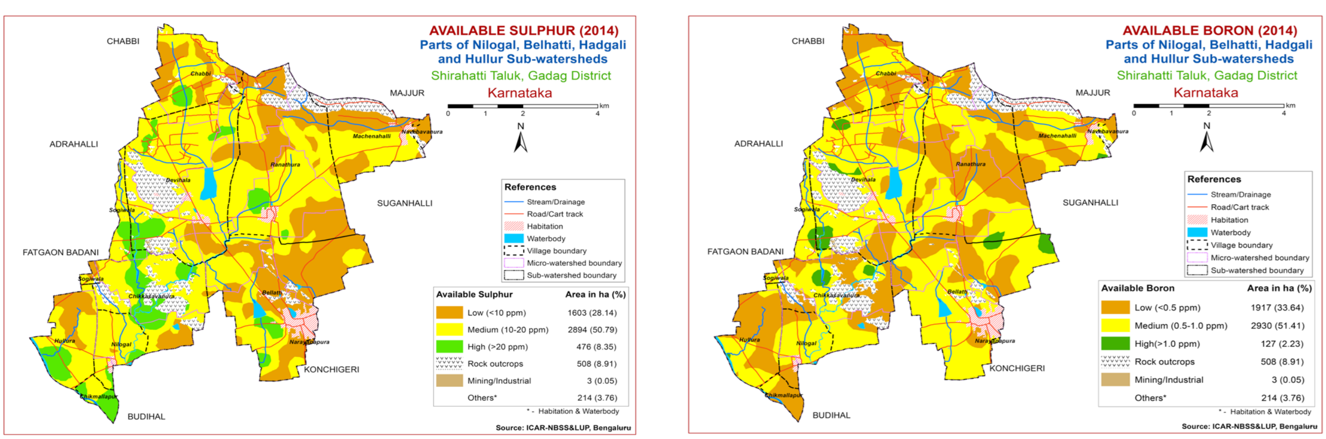


Figure 4: Spatial distribution of soil pH, Organic carbon, available phosphorus and potassium contents in watershed the Northern region of Ghana

available sulphur and Boron respectively (Figure 5). Available iron and zinc content is deficient in 2731 ha (48%) and 4759 ha (84%) area in the watershed respectively. Available copper and manganese content is sufficient in the entire watersheds area. The variability observed in the available micronutrient concentrations was largely due to variation in soil parent material, rainfall and soil management (Li et al., 2008). Sahrawat et al (2007) were reported the wide spread deficiencies of S, B and Zn in the semi arid regions of India.

Semivariogram parameters (nugget, sill, and range) for each soil properties with best- fitted modal were identified based on minimum RMSE. The exponential model fits the experimental semivariogram for all soil nutrients (Figure 3) with low MSE values (Table 3). The nugget (an indication of micro-variability) was highest for K20. Shukla et al (2016) reported the exponential model is best-fitted for all the micronutrients



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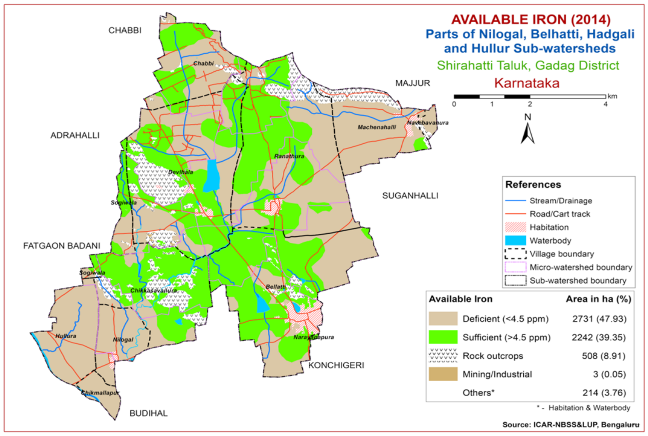

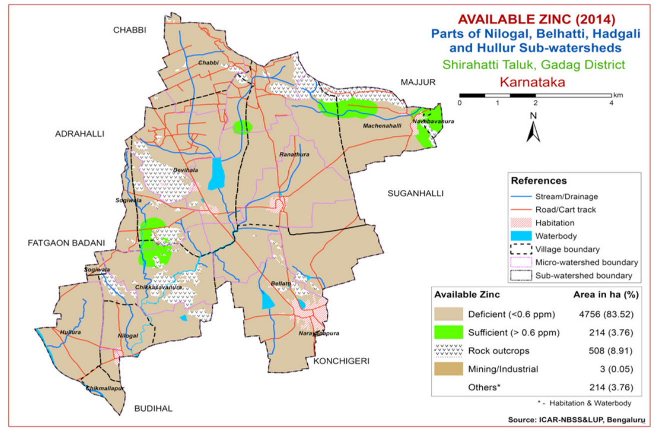

Figure 5: Spatial distribution of available Sulphur Boron Iron and Zinc contents in shiratti watershed

Table 3: Geostatistical parameters of the fitted semivariogram models for soil properties

Soil	Model	Nagget	Partial Sil	Sill	Range	Nagget/Sill	Spatial dependence	MSE
pH	Exponential	0.401	0.670	1.070	0.020	0.370	Moderate	0.950
EC	Exponential	0.000	0.040	0.040	0.004	0.000	Strong	0.990
OC	Exponential	0.038	0.039	0.077	0.014	0.493	Moderate	0.990
P_2O_5	Exponential	125.730	76.550	202.280	0.050	0.621	Moderate	1.005
K_2O	Exponential	10521.240	7639.560	18160.807	0.014	0.579	Moderate	1.009
S	Exponential	60.960	97.360	158.320	0.004	0.385	Moderate	0.990
B	Exponential	0.027	0.170	0.197	0.004	0.137	Strong	1.000
Fe	Exponential	13.123	23.940	37.063	0.025	0.354	Moderate	1.066
Mn	Exponential	49.900	23.030	72.930	0.025	0.684	Moderate	0.960
Cu	Exponential	0.108	0.078	0.186	0.013	0.580	Moderate	1.020
Zn	Exponential	0.107	0.034	0.141	0.013	0.758	Moderate	0.990

in trans-gangetic pains of India. The nugget/sill ratio values was ranging from 0.00 to 0.758, EC and Zn, respectively indicating strong spatial dependence for EC, B and moderate spatial dependence for other properties. This is attributed to inherent soil properties (such as soil mineralogy/physiographic units) as well as management factors including fertilization and cropping sequences practiced. The semivariogram range values of soil properties rage well described with exponential model low for EC, S,B (0.040) and it is high in P2O5(0.050).

Exponential model was the best-fitted model for all the nutrients (Figure 2) with low MSE values (Table 3). Best spatial dependence observed for B, Cu, Zn, pH, EC and OC. The nugget was highest for K_2O which is displays the fact that the collected sampling distance could not capture the spatial dependence well. The nugget/sill ratio values were ranging from 0.35 (Fe) to 0.62 (P_2O_5) for all parameters except B (0.137), indicating moderate spatial dependence and strong spatial dependence for B. This is due to intrinsic nature of soil properties (such as soil pH, EC, SOC and soil mineralogy) with land management practicese including fertilization and cropping pattern followed.

4. Conclusion

Spatial variability of soil nutrients shows strong spatial dependence for EC, B and moderate spatial dependence for other soil properties. The CV values of measured soil properties ranged from 13.18 for pH and 149 for EC. Among the soil nutrients highest variation was observed in Zinc 126.84 and lowest was in potassium 55.38. Majority of the study area is low in available phosphorus, iron and zinc indicates the 25% increase the dose fertilization for better crop performance.

5. Acknowledgement

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