

Original Research Article

Integrating Geostatistics and GIS Technique for Efficient Farm Management and Maintaining Soil Health

Abstract

To understand the spatial dependency of available sulphur and micronutrients in an experimental farm, 83 soil samples (surface and subsurface) were taken from Agricultural College, Killikulam to characterize the spatial variability of available Sulphur and micronutrients. The geostatistics and geographic information system (GIS) techniques were applied. With the help of geostatistical analyst of ArcGIS software kriged map of different soil parameters were prepared. Available S, Fe, Cu and Zn were fitted with a spherical model and that available Mn was fitted with an exponential model. Soil available Cu had strong spatial dependence with a range of 3.62 km. Available Fe, Zn and Mn had moderate spatial dependence with a range of 9.47 km, 5.61 km and 2.70 km, respectively. Available sulphur had weak spatial dependence with a range of 6.86 km. The spatial distribution of the available sulphur and micronutrients were significantly correlated to the soil formation factors. Human activity, such as application of fertilizer and pesticide also had significant effects on the spatial distributions of the available micronutrients.

Key words: spatial variability, soil micronutrients, farm management, soil health

1. Introduction

Soil is an important source of available micronutrients. Either shortage or surplus of available micronutrients in the soil would limit growth of crops. Understanding the spatial variabilities and distribution patterns of soil available micronutrients is essential for management of the soil. There are different techniques for evaluating soil spatial variability, including geostatistics and geographic information systems (GIS). These are very useful for the evaluation of soil variations and can exactly characterize soil properties according to their spatial distribution. Such evaluations and interpretations are also applicable to neighbourhood areas (Chen et al., 2009)^[3]. The evaluated soil properties can be mapped at different distances (Foroughifar et al., 2013; Reza et al., 2017)^[4,11]. Spatial distribution maps help in the correct management of soil nutrients. These maps are required to understand the patterns and processes of soil spatial variability and nutrient distribution at different spatiotemporal scales combined with different anthropogenic activities. Geostatistical tools are useful in the preparation of the maps based on the limited number of samples collected from different agricultural practices in different topography. Kriging interpolation technique predicts the values at unsampled locations by spatial correlation and reduces the variance of estimation error and investigation costs (Rosemary et al., 2017)^[12].

Several authors have shown that the spatial distribution maps generated serve as productive tools for site-specific nutrient management. However, there is minimum information on spatial distributions of soil available micronutrients in experimental farm. The objectives of this study were: (1) to analyse the spatial dependency and explain the variation mechanism of available sulphur and micronutrients in an experimental farm and (2) map the spatial distribution of available sulphur and micronutrients in the soil.

2. Materials and Methods

The spatial variability study was conducted in soils of experimental farm of Agricultural college and Research Institute, Killikulam, Tamil Nadu Agricultural university in Thoothukudi district (Fig. 1). Geographically the study area is located between 8°41' N to 8°43' N Latitude and 77°50' E to 77°53' E Longitudes. The annual rainfall of the region is 736.7 mm. The mean maximum and

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minimum temperatures are 38°C and 21°C, respectively. Thamirabarani is the main river flowing in the district from West to East direction.

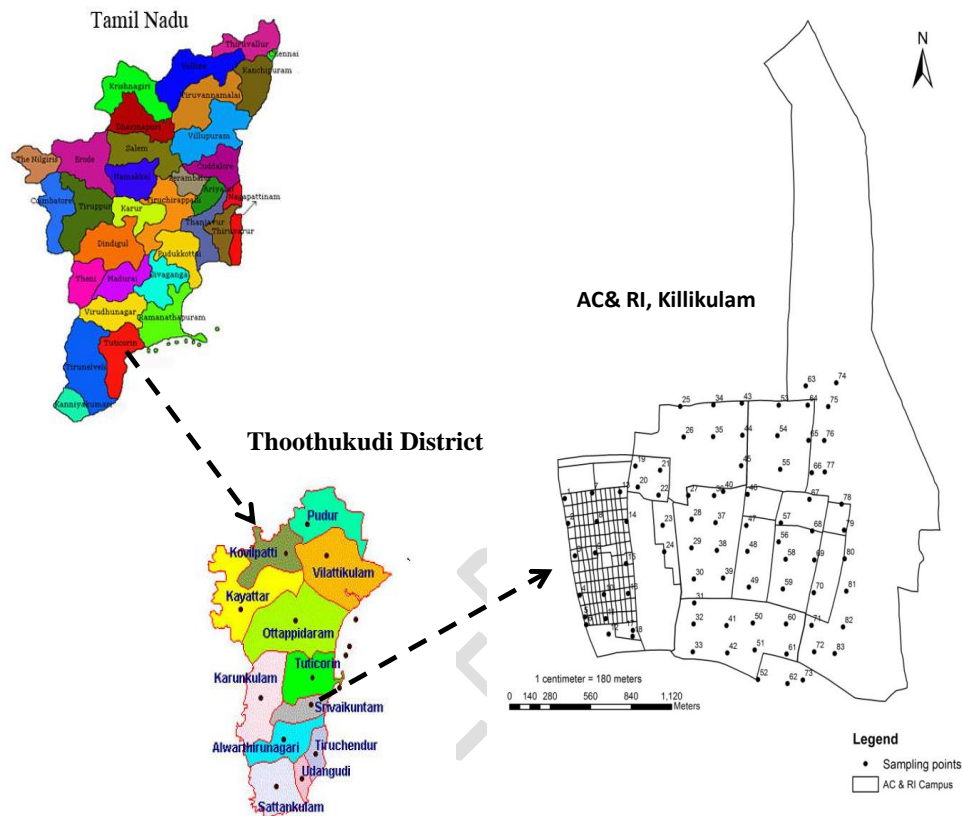


Fig.1. Study area located in AC & RI, Killikulam farm of Thoothukudi District in Southern Tamil Nadu, India and soil-sampling points.

Grid wise (200 x 200 m grids) soil samples were collected from 83 locations. Soil samples were collected from two sampling depth, surface (0-15 cm) and sub surface (15-30 cm) at each grid point. A global positioning system (GPS) device was used to record the coordinates of each sampling point. Samples were air dried in shade and passed through 2 mm sieve and analyzed for available sulphur and micronutrients (Fe, Mn, Cu and Zn). The soil available sulphur was determined by CaCl_2 0.15% extract (Williams and Steinbergs, 1959) ^[16]. The micronutrients (Fe, Mn, Cu and Zn) were extracted by diethylenetriaminepenta acetic acid (Lindsay and Norvell, 1978) ^[7], followed by analysis using atomic absorption spectrophotometer (Varian Spectr AA 55B).

Descriptive Statistics

The descriptive statistics namely minimum, maximum, standard deviation, mean, median, coefficient of variation, skewness, and kurtosis were calculated for each soil variable. The statistical analysis in the present study was done using the Statistical Product and Service Solution (SPSS 16.0) statistical package (Hejase&Hejase, 2013)^[5]. A correlation analysis was conducted to determine the relationship among surface soil properties under study.

Geostatistical Analysis

Geostatistical analysis of soil properties was performed to develop semivariogram model using Geostatistical analyst module of ArcGIS 9.1. The data were checked for skewness. The skewed soil properties were transformed using natural logarithm to a nearly normal distribution and back transformed using back transformation (Tripathi *et al.*, 2015)^[15]. Different variogram models *viz.*, Spherical, Gaussian and exponential were fitted. Using the fitted models, an ordinary kriging were performed to estimate properties at unmeasured points as interpolated values for mapping (Schepers *et al.*, 2004)^[13].

3. Results and Discussion

Table 1 presented statistical results of the available sulphur and micronutrients for 83 soil samples. Available sulphur was low to high in surface and subsurface soils. Available Fe was low to high with average value of 9.77 mg/kg in the surface soil and 8.98 mg/kg in subsurface soil. The mean available Mn for both the depts. were 9.42 mg/kg and 8.33 mg/kg, respectively, The available Mn, Cu and Zn content ranged from low to high in both the surface and subsurface soil depths. The mean values of soil available Fe, Mn, Cu and Zn were higher for the surface soils except soil sulphur having reverse trend of having high sulphur in the subsurface soil. This may be due to the presence of more amount of clay that has resulted in retention of more amount of nutrients.

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Table 1. Descriptive statistics of soil properties in study area

Soil Properties	Min	Max	Mean	SD	CV (%)	Kurtosis	Skewness
Surface soil (0-15cm)							
Available S (mg/kg)	3.17	17.58	10.42	3.61	34.64	-0.98	0.08
Available Fe (mg/kg)	1.10	24.00	9.77	7.02	71.88	-0.97	0.67
Available Mn (mg/kg)	1.12	25.10	9.42	6.55	69.55	-0.47	0.94
Available Cu (mg/kg)	0.38	5.27	2.44	1.12	45.85	-0.31	0.24
Available Zn (mg/kg)	0.05	4.90	1.16	0.99	84.92	2.46	1.45
Subsurface soil (15-30 cm)							
Available S (mg/kg)	2.83	15.89	11.10	3.64	32.76	-0.53	-0.85
Available Fe (mg/kg)	0.26	25.31	8.98	7.20	80.17	-0.11	1.02
Available Mn (mg/kg)	0.26	25.76	8.33	5.95	71.41	1.40	1.36
Available Cu (mg/kg)	0.09	4.79	1.78	1.07	60.32	-0.07	0.65
Available Zn (mg/kg)	0.09	4.19	1.02	0.89	87.47	2.01	1.45

The overall variability in soil properties can be assessed by the coefficient of variation (CVs). The CVs less than 15 indicated the low variation; CV ranging from 15-50% reveals moderate variability and CV > 50% represents high variability for the collected soil parameters. Descriptive statistics showed low to high variation in soil properties. Soil sulphur were found to have moderate variability in all the depths as shown in Table 1. Available Zn exhibited very high variability in the surface and subsurface soils. The available Cu showed moderate variability in surface soils and high variability in subsurface soils. The addition of copper fungicides manures and application of fertilizers might be attributed to the variability in available Cu. The available Fe, Mn and Zn were observed to have high variability in both the depths. This variation in S and micronutrient concentration in the experimental farm is primarily because of nature of parent material, types of crops grown and amount

and type of fertilizers applied. The native supply of S and micronutrients is determined by weathering of the parent material (Anderson, 1988)^[1]. The organic acids released from the decomposition of crop residue as well as by the microbes facilitate the weathering of soil minerals and thus nutrient release. The mean concentrations of available nutrients followed the order: available S > available Fe > available Mn > available Cu > available Zn.

All the soil properties at both sampling depths had positive skewness, except soil available sulphur in the subsurface soils. Available Fe, Mn and Cu had highly skewed distribution due to large variation within the field. Available Zn had a similar value of skewed distribution for both sampling depths.

Correlation between soil properties

Table 2 shows the degree of correlation between soil properties. Almost all of the variables except few were significantly correlated among each other. Available Fe, Cu and Zn were in positive correlation with the pH. The available Mn were, however, in negative correlation with pH. In addition, the soil available Fe, Mn and Cu were in positive correlation with organic matter. Available copper was relatively high which was due to higher contents of organic matter and clay, because soil available Cu was in positive correlation with organic matter (Liu et al. 2004)^[8].

Table 2. Correlation matrix for soil properties in study area.

	pH	OC	Available S	Available Fe	Available Mn	Available Cu	Available Zn
pH	1						
OC	0.251*	1					
Available S	0.126	0.191	1				
Available Fe	0.338**	0.331**	0.145	1			
Available Mn	-0.170	0.246*	0.283**	-0.038	1		
Available Cu	0.276*	0.331**	0.266*	0.265*	0.038	1	
Available Zn	0.150*	0.154	0.098	0.206	-0.035	0.579**	1

** . Correlation is significant at the 0.01 level * . Correlation is significant at the 0.05 level

Exploratory data analysis

Figure 2 and 3 presented the semivariogram and fitted models for each available S and micronutrient for surface and subsurface soils. The attributes of the semivariograms for each soil available micronutrient are summarised in Table 3. The semivariogram of surface soil properties *viz.*, available S, Fe, Cu and Zn and subsurface soil properties available Fe, Mn, Cu and Zn were well defined by spherical model (Table 3). Surface Soil properties such as available Mn and subsurface soil properties like available S were well fitted by exponential model. A number of researchers reported that spherical models were the most effective for modeling most soil parameters. (Lopez Granados et al., 2002; Jiang et al 2012 and Liu et al., 2014)^[10,6,8].

Table 3. Semivariogram models for soil properties in the study area.

Soil property	Model	Sill	Nugget	Range	Nugget	Spatial
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					(%)	Dependence class
Surface soil (0-15 cm)						
Available S (mg/kg)	Spherical	1.59	11.70	686	88.04	Weak
Available Fe (mg/kg)	Spherical	0.32	0.35	947	52.24	Moderate
Available Mn (mg/kg)	Exponential	0.31	0.15	270	32.24	Moderate
Available Cu (mg/kg)	Spherical	0.97	0.01	363	1.32	Strong
Available Zn (mg/kg)	Spherical	0.35	0.54	561	60.18	Moderate
Sub surface soil (15-30 cm)						
Available S (mg/kg)	Exponential	3.03	10.62	590	77.80	Weak
Available Fe (mg/kg)	Spherical	0.26	0.57	1404	68.60	Moderate
Available Mn (mg/kg)	Spherical	0.57	0.10	270	14.20	Strong
Available Cu (mg/kg)	Spherical	0.35	0.13	284	26.91	Moderate
Available Zn (mg/kg)	Spherical	0.19	0.63	374	76.86	Weak

Nugget variance represents the experimental error and field variation within the minimum sampling spacing. The Nugget/Sill ratio can be regarded as a criterion to classify the spatial dependence of soil properties. If the ratio is less than 25%, the variable has strong spatial dependence; between 25% and 75%, the variable has moderate spatial dependence; and greater than 75%, the variable shows only weak spatial dependence. The spatial variability of soil properties may be affected by intrinsic (soil formation factors, such as soil parent materials) and extrinsic factors (soil management practices, such as fertilization). Usually, strong spatial dependence of soil properties can be attributed to intrinsic factors, and weak spatial dependence can be attributed to extrinsic factors.

The results showed that strong spatial dependency for available Cu in the surface soil and available Mn in the subsurface soil with the nugget to sill ratio of <25 %, their spatial variabilities were mainly controlled by intrinsic factors such as parent material, relief and soil types. Spatial dependence was moderate for available Fe, Mn and Zn in the surface soil (nugget to sill ratio between 25 and 75 %). Spatial dependence was moderate for available Fe in surface and subsurface soil. Weak spatial dependence was exhibited by available Sulphur in both the surface and subsurface soil. Strongly spatially dependent features may be regulated by inherent variation in soil qualities such as texture and mineralogy, which was found by Cambardella et al., (1994)^[2]. The ranges for available Mn and Cu were 2.7 km and 3.6 km, respectively. Available Fe has a range of 9.47 km.

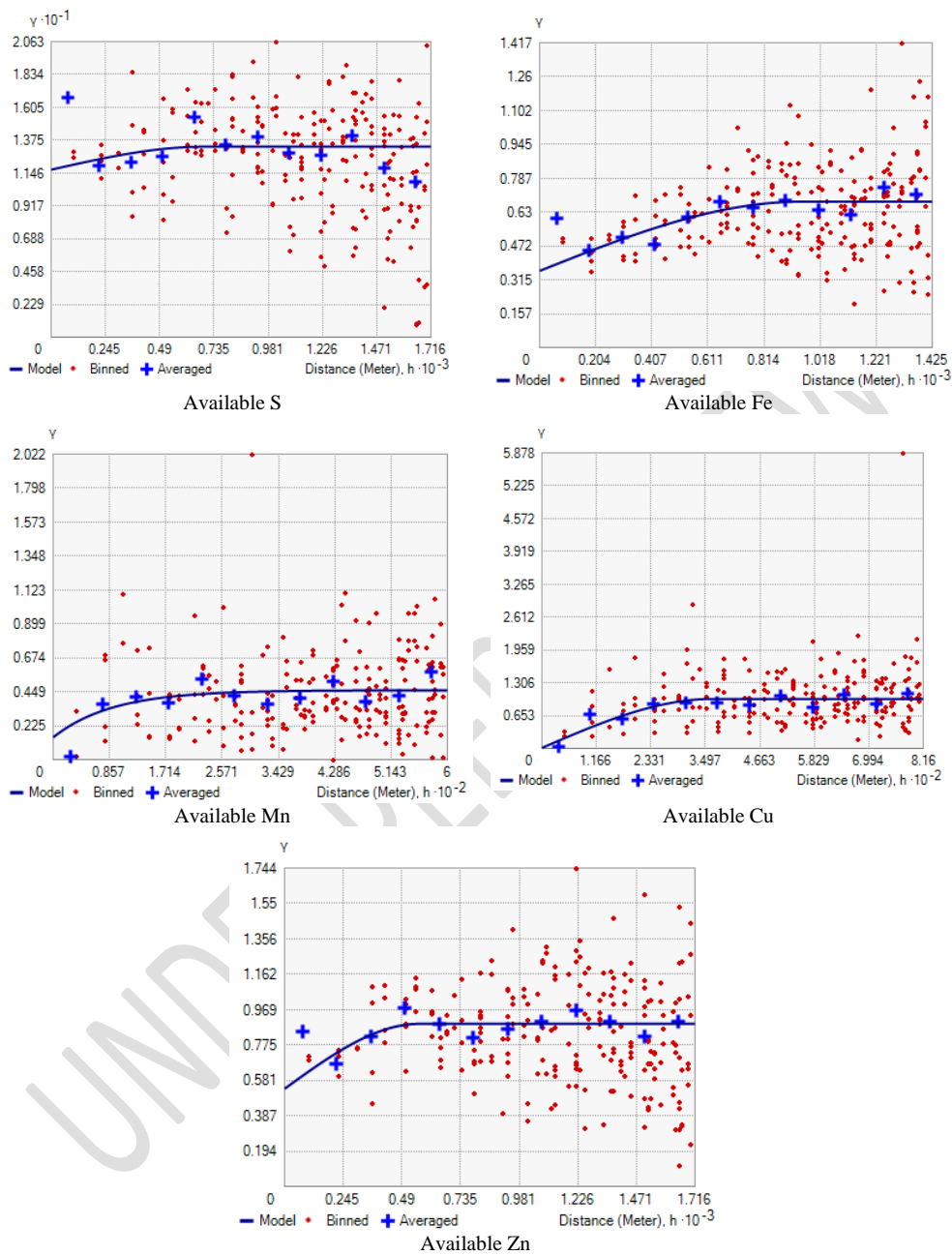


Fig.2. Semi variograms and fitted models of surface soil properties

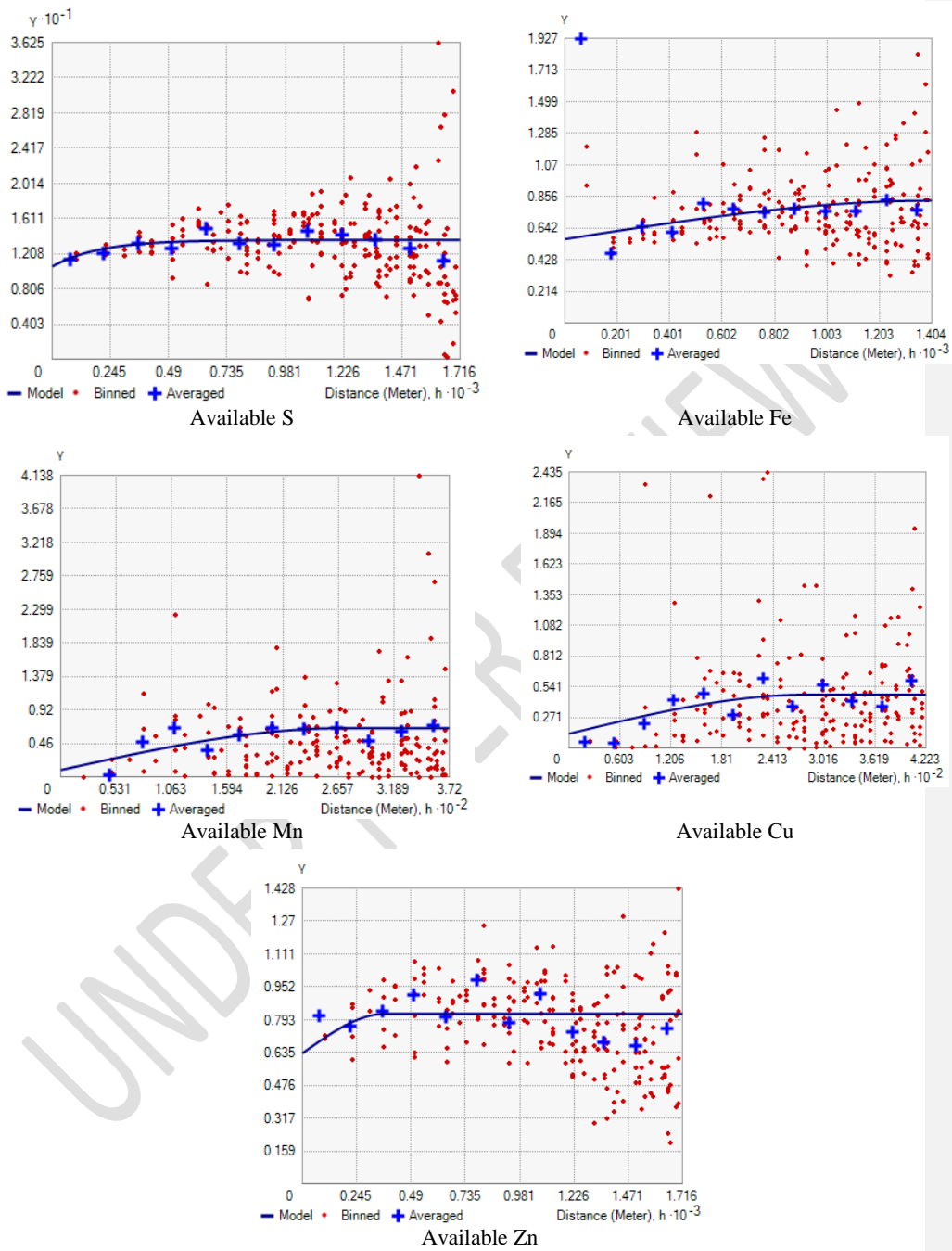


Fig. 3. Semi variograms and fitted models of sub surface soil properties

South east and northeast of the farm were low available Zn zones; the soil available Zn in the zones was less than 1 mg/kg, and lower than the mean available Zn as shown in Figure 4. In contrast, the north west of the farm was a high available Zn zone; the soil available Zn in the zone was high ranging from 1.80 mg/kg to 4.9 mg/kg. The soil pH value in north west of the farm was between 6.0–6.9. High soil pH usually results in low available Zn, as the available micronutrients decrease with increasing pH.

The soil available Fe had distinct geographical distribution, was high in Central experimental farm including the north and west area, and the lowest in southeast of the farm, which was comparable with pH and organic matter. The soil available sulphur was high in the central part of experimental farm and low in the south west of the experimental farm. From the maps shown in Figure 4 and Figure 5 of soil available sulphur and micronutrients, information about their spatial distribution over long distances could be clearly achieved.

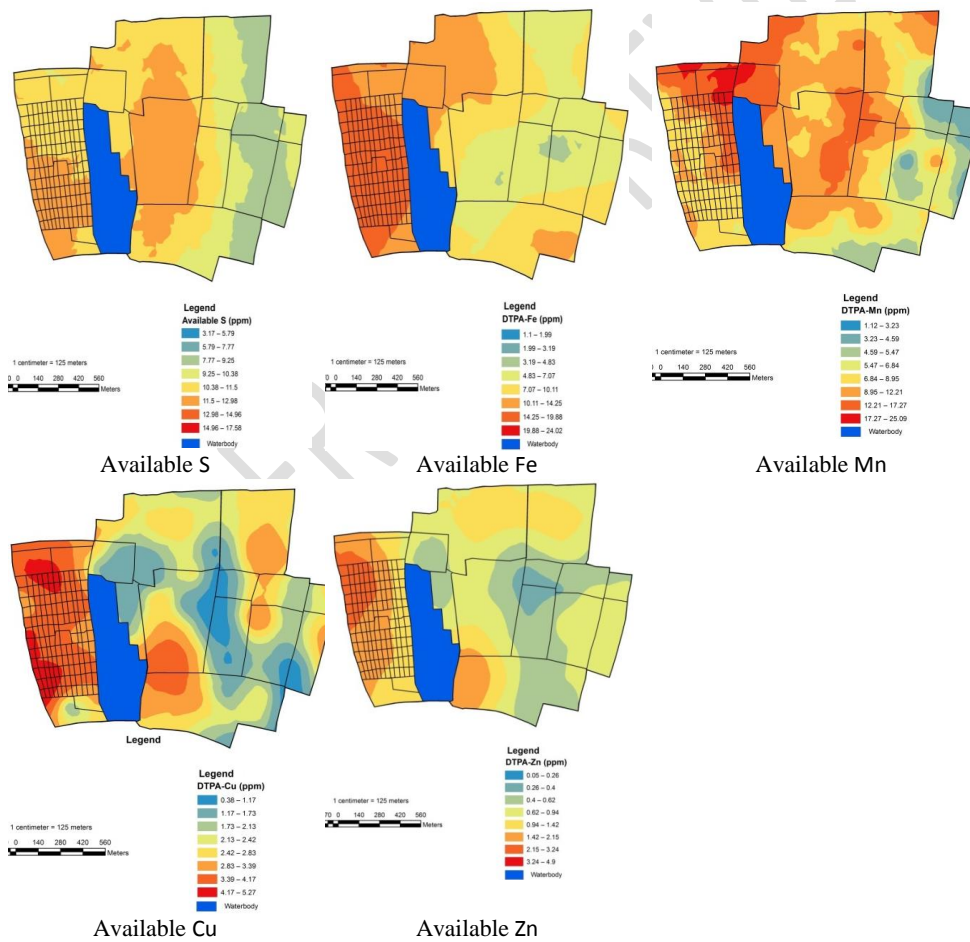


Fig. 4. Map of spatial distribution for surface soil properties in the study area.

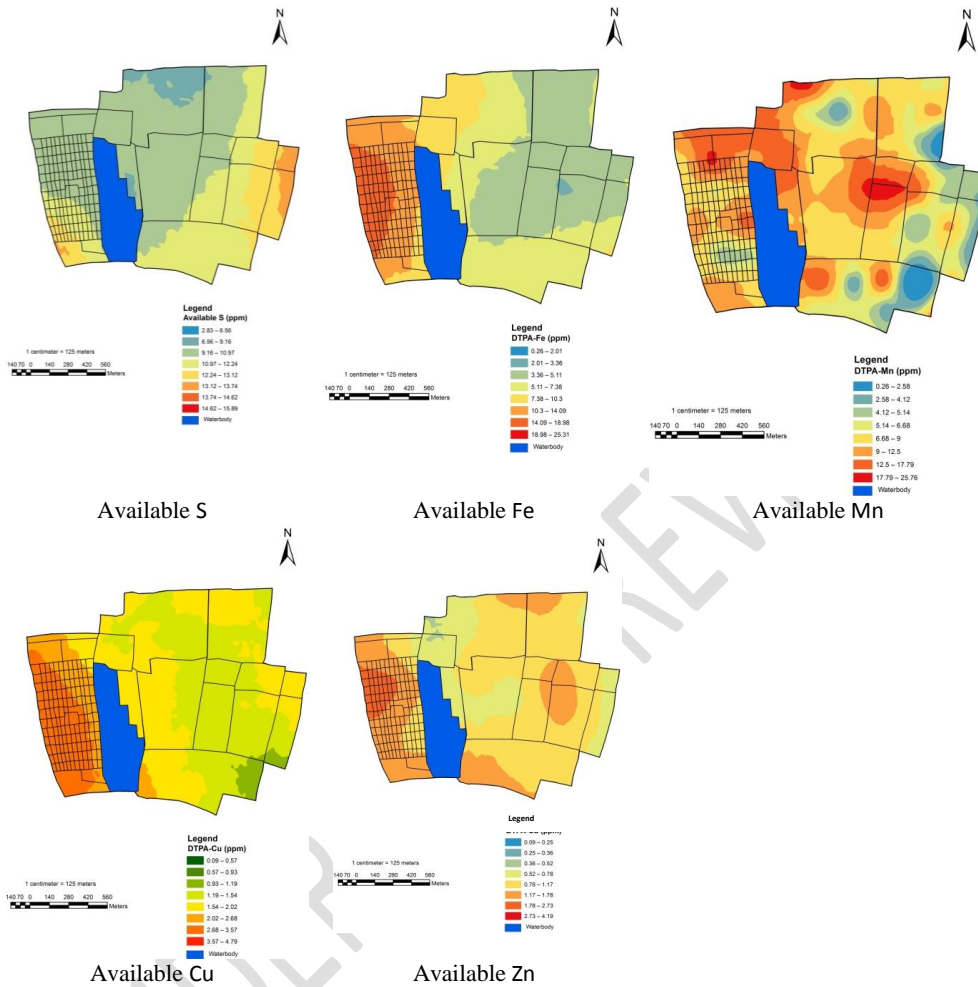


Fig. 5. Map of spatial distribution for sub surface soil properties in the study area.

4. Conclusions

The CV values for the available sulphur and micronutrients decreased in the order of available Zn > Fe > Mn > Cu > S. Geostatistical analysis indicated that the semivariograms for available S, Fe, Cu and Zn were fitted with an aspherical model and that available Mn was fitted with an exponential model. The available sulphur and micronutrients had different degrees of variability; soil available Cu had strong spatial dependence with a range of 3.62 km. Available Fe, Mn and Zn had moderate spatial

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dependence with range of 9.47 km, 2.70 km and 5.61 km, respectively. Available sulphur had weak spatial dependence with a range of 6.86 km. Integrating geostatistics and GIS to study spatial variability and map soil available sulphur and micronutrients provides an opportunity to assess variability in the distribution of native micronutrients. These results provide a basis of information for managing experimental farm in a rationally site-specific and precise way in alleviating the micronutrient deficiency.

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