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Quantifying spatial variability of available iron and physico-chemical properties in major groundnut growing soils of Cuddalore district, Tamil Nadu

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Abstract
The present study was conducted to determine the spatial distribution and degree of risk of Fe deficiency in major groundnut growing soils of Cuddalore District, Tamil Nadu, India using statistics and geostatistics. By using grid points, three hundred geo-referenced surface soil samples (0-15 cm) from 300 panchayat village of major groundnut blocks (Kurinjipadi, Vridhachalam and Kammapuram) of Cuddalore district, Tamil Nadu were collected and analyzed for pH, EC, OC, free $CaCO_3$ and DTPA-Fe. Analytical data was interpreted and statistical parameters like range, mean, standard deviation and coefficient of variation were calculated. Geostatistical analyses were also carried out, including experimental variogram. Soil fertility maps were prepared for each parameter under GIS environment using ArcGIS v10.2.2. Further, with the ordinary kriging, spatial distribution map showed that the Fe is sufficient for plants in the all the three blocks of Cuddalore Districts the probability map produced based on indicator kriging showed that Fe sufficient was noticed in 100% of crops grown area of the Vridhachalam, Kurinjipadi and Kammapuram block in Cuddalore district. The correlation analysis showed that Fe was significantly and negativily correlated with OC highly in Vridhachalam block and significantly and positively correlated in Kurinjipadi and Kammapuram block.

Keywords: Cuddalore block, spatial variability, thematic maps

1. Introduction

Groundnut (*Arachis hypogaea* L.), is a predominant leguminous oilseed crop cultivated in the tropics and subtropics regions falling in between 40°N and 40°S latitudes, popularly known as peanut, manila, or monkey-nut. Groundnut forms the third main important source of vegetable protein in the world. In India, followed by soyabean, groundnut occupies second position as source for edible oil production contributing to the tune of 27%. Gujarat, Rajasthan and Tamil Nadu respectively are the first three important states contributing in-terms of groundnut area and production. It contributes 4% of Gross National Product (GNP).

Presently, at national level, the total area under groundnut cultivation is 4731 lakh hectares with a total production of 6727 lakh tonnes. Groundnut is cultivated in both season/conditions *viz. Kharif* (Rainfed) and *Rabi* (Irrigated) to the tune of 4132 and 599 lakh hectares respectively (MoAFW, 2020). In Tamil Nadu, groundnut is cultivated in an area of 3.35 lakh hectares with an average annual production of 9.11 lakh tonnes (Dept. of Agri, 2020). As mentioned in the Table-1 earlier, groundnut is generally cultivated in two different soil types *viz*, Red and Black Soil (62% & 12% respectively). The major groundnut growing districts in Tamil Nadu are Tiruvannamalai, Villupuram, Namakkal, Dharmapuri, Tiruchirappalli, Pudukkottai and Cuddalore.

Though iron is the fourth most abundant element in the soil, still its deficiency in plant is most widespread. Iron Deficiency Chlorosis (IDC) occurs as an interveinal to complete chlorosis in young and emerging leaves, in extreme cases, this may result in complete crop failure and decline in yield. The yield loss is noticed to the tune of 16-32% (Singh *et al*., 1995) [10]. This type of chlorosis appears 15 days after emergence (DAE) of seedlings and continues to occur on the young developing leaves throughout the crop growth period, however, its maximum intensity in the field was noticed during 30-70 DAE, the peak vegetative growth period (Singh *et al*., 1995) [10].

In calcareous soils, total Fe is high but occurs in chemical forms not available to plant root. The principal soil factors causing IDC are, the presence of excess lime (15-40% $CaCO_3$), high soil pH (7.5 to 9.0), excess irrigation and high organic matter and P content of the soil (Singh 1994) [9]. Apart from this, the IDC is also associated with soil moisture and low temperature. However, the transformation that occurs in the soils under high pH conditions is known to determine the availability of iron to plants. Scientific reports say that many crops have developed mechanisms through which they can scavenge and make use of the precipitated Fe. It had been estimated that the reduction in the pod yield due to Fe deficiency is to the extent of 13-15 per cent in calcareous soils (Tandan, 1998).

Soil variability is an essential one to assess soil nutrient status and it identify the similar management units for better fertility management (Sawant *et al.*, 2018) [12]. Spatial variability of soil properties is the result of complex interaction between geology, climate, topography, land use and management (Shi *et al*., 2007) [16]. Spatial variability of soil properties can be effectively assessed by geo-statistical methods such as kriging interpolation (Reza *et al.*, 2017) [8]. The kriging interpolation technique predicts the soil properties by spatial auto-correlation and reduces variance of estimation error (Saito *et al.*, 2005) [17]. Ordinary kriging is the most commonly used kriging in practice due to its better performance over other techniques (Hegde *et al.,* 2018) and it provides variability estimates of soil properties using variogram models (Pravat *et al.*, 2016) [14]. The study was carried-out to assess the spatial variability of soil fertility parameters for sustainable nutrient management through geo-statistical methods.

2. Materials and Methods

2.1. Site Description

Cuddalore district is located in the north eastern zone of Tamil Nadu between 15º5′, 11º11′ and 12º35′ North latitudes and 78°38′ and 80º00′ East longitudes with average elevation of 1 m (3 ft) above sea level. The district has an area of 3,703 km². It is bounded on the north by Viluppuram District and Kallakurichi district, on the east by the Bay of Bengal, on the northeast by the union territory Puducherry, on the south by Mayiladuthurai district, on the west by Perambalur District and by a small part with Ariyalur district. The district has 10 taluks, 13 blocks with a total geographical area of 3, 67,781 ha. The mean annual rainfall is 903.8 mm, mostly received from North East monsoon. The mean maximum, minimum and average air temperatures are 33.3, 23.0, 28.1 ^{0}C respectively. The three major groundnut growing blocks were selected for study area *viz*., kurinjipadi (Latitude: 11° 34' 12.00" N Longitude: 79° 35' 60.00" E), Vridhachalam (11° 31' 10.5168" N and 79° 19' 30.5652" E.) and Kammapuram block of cuddalore district

2.2. Soil sampling and analysis

From the entire study area, a total of 300 (Kurinjipadi block n=100, Vridhachalam block n=100 and Kammapuram block n=100) georeferenced soil samples (0-15 cm depth) at an approximate interval of 1 km grid (Fig. 1) were collected with the help of handheld global positioning system (GPS). Soil samples were mixed thoroughly and about a half kilogram of the composite sample was prepared. The soil samples were air-dried, powdered and passed through 2 mm sieve and preserved in polythene bags for further analysis. Soil pH and EC were measured with 1:2 soil water ratio (Jackson, 1973). The soil samples were sieved through 0.2 mm for determination of OC (Walkley and Black 1934). Available Fe in soils was extracted by DTPA (soil to solution ratio 1:2, shaking time 2 h) (Lindsay and Norvell 1978) [2]. Estimation of Fe was done on the clear extract with an atomic absorption spectrophotometer (AAS). Based on the critical limits of Fe in calcareous soil, the soil samples were grouped as low, medium and high. Free calcium carbonate was also estimated by Piper (1966) [18].

2.3. Statistical and geo-statistical analysis

The descriptive statistics of the soil properties *viz*., mean, minimum, and maximum, standard deviation, co-efficient of variation, skewness and kurtosis were analyzed. The relationship between the soil properties was determined using Pearson's correlation matrix in SPSS software. Spatial distribution maps of the soil properties were prepared using interpolation techniques in ArcGIS. The ordinary kriging interpolation technique was used to estimate the spatial variability of the soil properties by fitting semi-variograms which can explain the spatial structure of the soil properties (Nielsen and Wendroth 2003) [19]. The calculation of semi-variograms is expressed as,

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

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

Different semivariogram models were evaluated to select the best fit with minimum root mean square error (RMSE). Exponential model was fitted to the empirical semivariograms. The exponential model that fitted to experimental semivariograms is defined below as:

$$\gamma(h) = C_0 + C_1\left[1 - \exp\left(-\frac{h}{a}\right)\right] \qquad (2)$$

Risk of Fe deficiency not exceeding a pre- selected threshold value was assessed by using indicator kriging. Indicator kriging is a nonlinear geostatistics where the conventional linear kriging estimators are applied to the data after a nonlinear transformation. Here the nonlinear transform is to a discrete (binary) indicator variable.

Let us assume that a soil property *z* at location × take value *z*(*x*). In geostatistics, we treat this value as a realization of the random function *Z(x)*. An indicator transformation of *z*(*x*) can be defined by

$$\omega_c(x) = 1 \text{ if } z(x) \leq z_c, \text{ 0 otherwise,} \qquad (3)$$

where,

z_c is a threshold value of the property. In indicator geostatistics, $\omega_c(x)$ is regarded as a realization of the random

$\Omega_c(x)$,

$$\Omega_c(x) = 1 \text{ if } z(x) \leq z_c, \text{ else 0.} \qquad (4)$$

It can be seen that

$$\text{Prob}[Z(x) \leq z_c] = E[\Omega c(x)] = G[Z(x); z_c], \qquad (5)$$

where, Prob[], *E*[] denote, respectively, the probability and the expectation of the terms within the square brackets, and $G[Z(x); z_c]$ is the cumulative distribution function of $Z(x)$ at value z_c. The principal of indicator kriging is to estimate the conditional probability that $z(x)$ is smaller than or equal to a threshold value z_c, conditional on a set of observations of z at neighbouring sites, by kriging $\Omega_c(x)$ from a set of indicator-transformed data.

A set of data on z is transformed to the indicator variable $\omega_c(x)$. The variogram of the underlying random function $\Omega_c(x)$ is then estimated by:

$$\gamma_{\Omega c}(h) = \frac{1}{2M_h} \sum_{i=1}^{M_h} \left[\omega c(x_i) - \omega c(x_i + h)\right]^2 \qquad (6)$$

where, M_h pairs of observations that are separated by the lag interval *h*. A set of estimates of this indicator variogram at different lags may then be modelled by one of the authorized continuous functions used to describe variograms.

An estimate of the indicator random function may then be obtained for a location *x* by kriging from the neighbouring indicator-transformed data. Indicator kriging is equivalent to ordinary kriging of the indicator variables $\omega_c(x)$ using the mean within the kriging neighbourhood as the expectation. Geostatistical analysis consisting of variogram calculation, kriging and mapping was performed using the ArcGIS 10.1 for window.

3. Results and Discussion

3.1. Physico-chemical properties of soil

The pH of the soil in the Vridhachalam block ranged from 6.15 to 7.95. Majority of the soil samples had neutral soil pH (68.0%). There were also slightly acidic (12.0%) and alkaline (20.0%) soils (Table 1). In the Kurinjipadi block, the pH of the soil ranged from 5.40 to 6.94. About 93% of the soil samples had acidic soil pH and 7% of the soil samples were moderately alkaline soils (Table 1). The soil reaction in the Kammapuram block ranged from 6.18 to 8.19. On area basis 56% of the soil samples were neutral, 25% slightly acidic and 19% alkaline in Kammapuram block (Table 1). The variation in soil pH was related to the parent material, and topography. Relatively higher pH value in black soils was due to the accumulation of the high amounts of exchangeable bases in solum as they are poorly drained. The relatively low pH in red soils was mainly due to iron hydroxide species which contributed for higher H^+ concentration (Dasog and Patil, 2011) [5].

The electrical conductivity of Vridhachalam, Kurinjipadi and Kammapuram soil samples were ranged from 0.02 - 2.41, 0.26 - 0.90 and 0.27-2.61 dS m^{-1} respectively. In Vridhachalam and Kurinjipadi block, the electrical conductivity values were very low, which indicate that the soils were non saline in nature. This may be due to undulating nature of the terrain coupled with fairly good drainage conditions, which favored the removal of released bases by the percolating drainage water (Shivaprasad *et al.*, 1998) [4].

Table 1: Percent distribution of pH, electrical conductivity and DTPA-Fe status of soils in following blocks of Cuddalore District

Name of the blocks	pH			EC (dS m^{-1})			DTPA Fe (mg kg^{-1})	
	Acidic <6.5	Neutral 6.0-7.5	Alkaline >7.5	Safe <1	Critical 1-2	High >2	<3.7 Deficient	> 3.7 Sufficient
Vridhachalam	12	68	20	81	9	0.0	0.0	100
Kurinjipadi	93	7	0	100	0.0	0.0	0.0	100
Kammapuram	25	56	19	62	32	6.0	0.0	100

The Pearson linear correlation analysis results showed that Fe was significantly negatively correlated with pH (r = -0.252) and significantly negatively correlated with OC (r = -0.041) in Vridhachalam block (Table 2). Similar observations were also reported by Reza *et al.* (2021) in the Brahmaputra plains of Assam, India.

Table 2: Pearson correlation coefficient of soil properties of Vridhachalam block

	pH	EC	OC	Free CaCO3	DTPA-Fe
pH	1				
EC	0.059	1			
OC	-0.085	0.087	1		
Free CaCO3	0.174	-0.063	0.043	1	
DTPA-Fe	-0.252	-0.042	-0.041	0.090	1

In Kurinjipadi and Kammapuram block, the linear correlation analysis results showed (Table 3 and 4) that Fe was significantly positively correlated with pH (r= 0.139 & r= 0.214 respectively) and significantly positively correlated with OC (r= 0.062 & r= 0.137 respectively)

Table 3: Pearson correlation coefficient of soil properties of Kurinjipadi block

	pH	EC	OC	Free CaCO3	DTPA-Fe
pH	1				
EC	0.115	1			
OC	-0.143	-0.137	1		
Free CaCO3	-0.245	0.032	0.018	1	
DTPA-Fe	0.139	0.056	0.062	-0.010	1

Table 4: Pearson correlation coefficient of soil properties of Kammapuram

	pH	EC	OC	Free CaCO3	DTPA Fe
pH	1				
EC	-0.107	1			
OC	-0.143	-0.012	1		
Free CaCO3	0.135	-0.176	0.008	1	
DTPA Fe	0.214	-0.040	0.137	0.175	1

3.2. Descriptive Statistics of Soil Properties

Descriptive statistics for pH, EC, OC free $CaCO_3$ and available Fe are shown in table 5. The minimum and maximum concentration of DTPA Fe in Vridhachalam, Kurinjipadi and Kammapuram were 5.29 and 7.98, 4.96 and

7.44, and 4.74 and 7.22 mg kg^{-1}, respectively with mean values of 6.68, 6.12 and 5.92 mg kg^{-1}, respectively. The median values of Fe were lower than the mean in the studied areas, which indicates that the effects of abnormal data on sampling value were not high. The pH values varied from 6.15-7.95, EC ranged from 0.02-2.41 dS m^{-1}, free $CaCO_3$ ranged from 0.05-2.18% and OC ranged from 0.30-2.30 g kg^{-1} in the Vridhachalam block. The EC was found to be highly variable (CV = 77.78%) followed by free CaCO3 (CV = 48.70%) and organic carbon (47.66%), while pH was found least variable (CV = 6.78%) in Vridhachalam block.

In Kurinjipadi block, pH varied from 5.4-6.94, free $CaCO_3$ ranged from 0.22-2.8% and OC ranged from 0.27-4.80 g kg^{-1} and the OC was found to be highly variable (CV = 41.39%) followed by free CaCO3 (CV = 39.35%) and EC (18.64%), while pH was found least variable (CV = 4.43%)

In Kammapuram block, pH varied from 6.18-8.19, free $CaCO_3$ ranged from 0.35-2.81% and OC ranged from 0.4-4.5 g kg^{-1} and the EC was found to be highly variable (CV = 57.61%) followed by free $CaCO_3$ (CV = 39.47%) and organic carbon (37.26%), while pH was found least variable (CV = 7.74%).

Sun *et al.,* 2003 documented a smaller variation of soil pH compared to other soil properties. This may be attributed to the fact that pH values are log scale of proton concentration in soil solution, there would be much greater variability if soil alkalinity is expressed in terms of proton concentration directly. The variability observed in Fe was largely due to variation in soil parent material, rainfall and soil management.

Table 5: Summary statistics for pH, EC, organic carbon, Free $CaCO_3$ and Available Fe

Parameters	Minimum	Maximum	Mean	Median	SD*	CV (%) **	Skewness	Kurtosis
Vridhachalam Block (n=100)								
pH	6.15	7.95	7.08	6.96	0.48	6.78	0.12	-1.10
EC dS m^{-1}	0.02	2.41	0.63	0.57	0.49	77.78	1.38	2.37
OC (g kg^{-1})	0.30	5.30	2.56	2.55	1.22	47.66	0.09	-0.50
Free $CaCO_3$	0.05	2.18	1.15	1.19	0.56	48.70	-0.24	-1.02
Fe (mg kg^{-1})	5.29	7.98	6.68	6.61	0.61	9.13	0.34	2.80
Kurinjipadi Block (n=100)								
pH	5.40	6.94	6.10	6.07	0.27	4.43	0.40	0.29
EC dS m^{-1}	0.26	0.90	0.59	0.59	0.11	18.64	-0.38	1.26
OC (g kg^{-1})	0.27	4.80	2.44	2.37	1.01	41.39	0.26	-0.61
Free $CaCO_3$	0.22	2.80	1.55	1.54	0.61	39.35	-0.02	-0.71
Fe (mg kg^{-1})	4.96	7.40	6.12	6.11	0.49	8.05	-0.02	3.06
Kammapuram Block (n=100)								
pH	6.18	8.19	6.98	6.82	0.54	7.74	0.52	-0.98
EC dS m^{-1}	0.27	2.61	0.92	0.84	0.53	57.61	1.18	1.07
OC (g kg^{-1})	0.4	4.5	2.63	2.70	0.98	37.26	-0.21	-0.63
Free $CaCO_3$	0.35	2.81	1.52	1.57	0.60	39.47	-0.04	-0.70
Fe (mg kg^{-1})	4.74	7.22	5.92	5.79	0.58	9.80	0.52	2.58

*Standard deviation; **Coefficient of variation

3.3. Spatial Distribution and Available Fe Status Map

Spatial map of Fe prepared through ordinary kriging indicated that sufficient concentration of Fe was mainly observed Vridhachalam, Kurinjipadi and Kammapuram blocks of Cuddalore (Fig. 1-4). Spatial map of DTPA-Fe in vridhachalam, Kurinjipadi and Kammapuram blocks of Cuddalore district showed that DTPA-Fe varied from 5.29 and 7.98, 4.96 and 7.44, and 4.74 and 7.22 mg kg^{-1}, respectively. soil and reclassified in to deficient and sufficient areas against the critical level of 4.5 mg kg^{-1} soil (Lindsey and Norvell, 1978) [2]. The spatial distribution maps clearly indicated that Fe was Sufficient in the all the three blocks of Cuddalore district.

The available iron content was higher in red soil than black soil. This may be due to the granite gneiss parent material which is known to possess higher iron content. The low availability of iron in black soils (Rajkumar, 1994) [12] was attributed to its precipitation by $CaCO_3$ and decreases the availability. The sufficiency in soils might be ascribed to non-calcareousness to slightly calcareous nature of the soils of region and coarse texture of the soils (Katyal and Rattan 2003) [11]. Similar finding was reported by Dinesh *et al.*, 2019 [1].

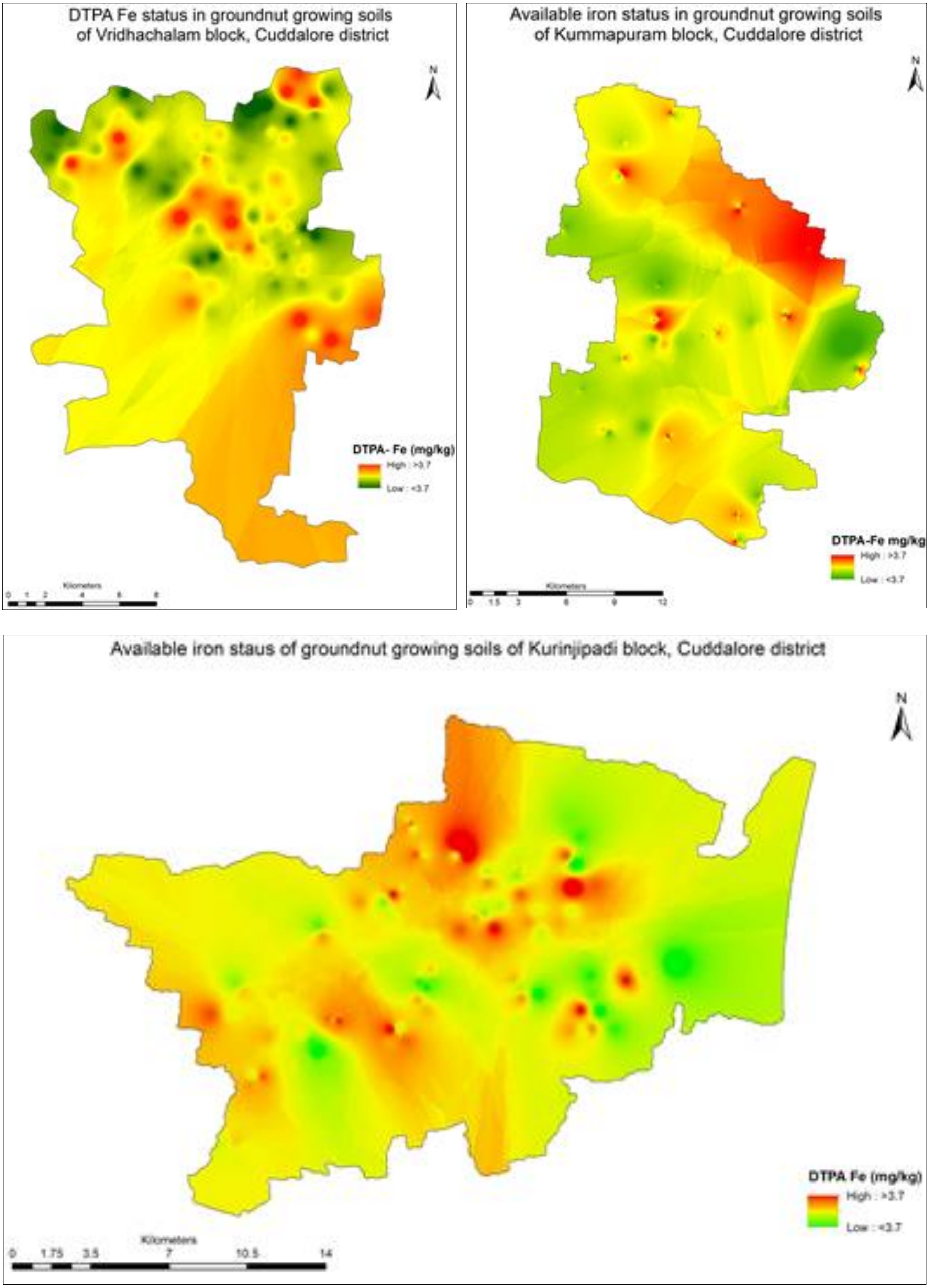

Fig 1: Spatial distribution map of Iron for (a) Vridhachalam Block, (b) Kammapuram block and (c) Kurinjipadi Block of Cuddalore district

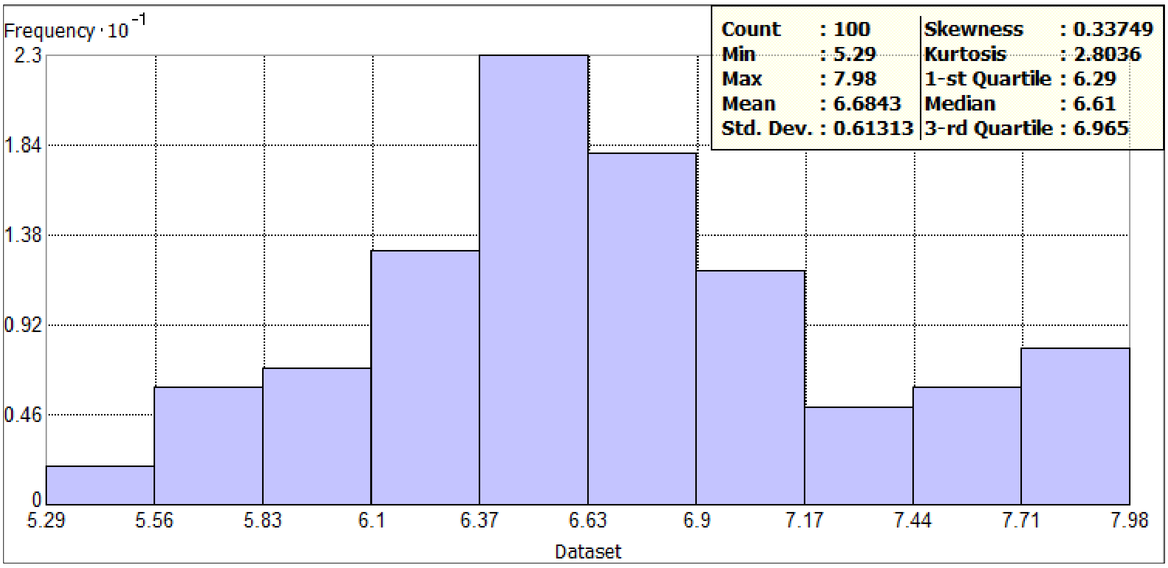

Fig 2: Histograms of available Fe status of Vridhachalam block

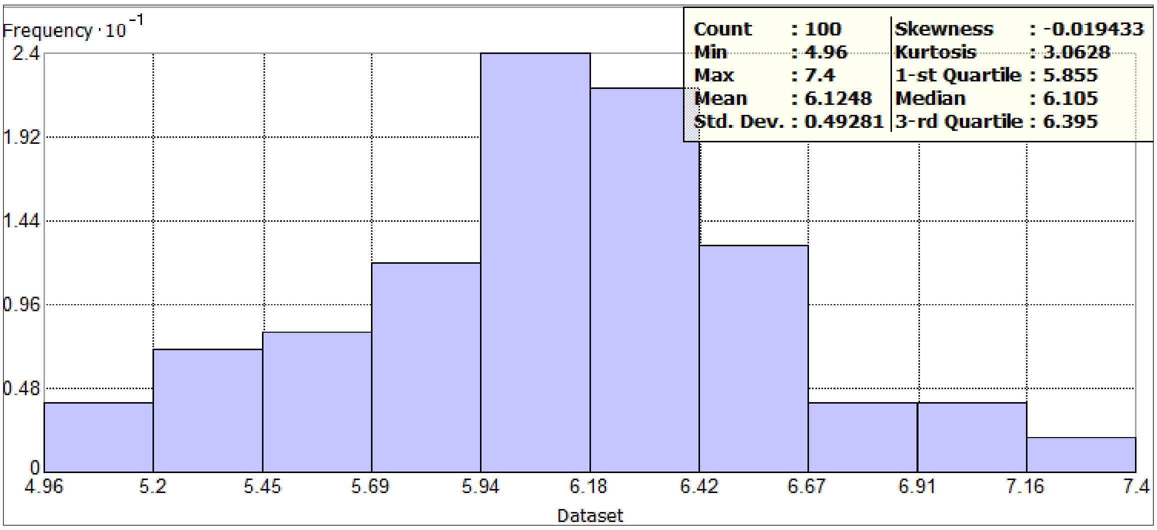

Fig 3: Histograms of available Fe status of Kurinjipadi block

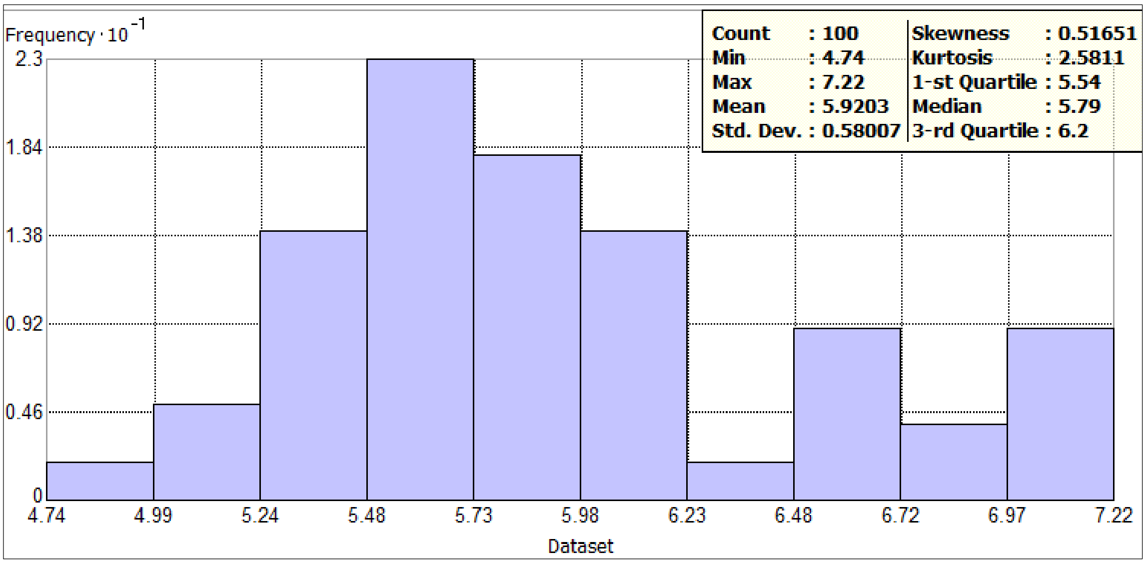

Fig 4: Histograms of available Fe status of Kammapuram block

4. Conclusions

The spatial variability and distribution of Fe in groundnut growing soils of Vridhachalam, Kurinjipadi and Kammapuram blocks of Cuddalore district were evaluated and mapped using geostatistical techniques. The raw data sets of Fe were normally distributed. Exponential model was best fitted with strongly spatially dependent. A good variogram structure of Fe was observed, revealing that there were clear spatial patterns of Fe on the distribution map and also that the current sampling density was adequate to reveal such spatial patterns. The spatial distribution maps indicated that Fe was sufficient in the all the three blocks of Cuddalore district. The probability map produced based on indicator kriging provides information for identification of Fe deficient and sufficient areas, which could be used as a valuable inputs in site specific nutrient management practices and other spatial decision support systems. The study clearly demonstrates that spatial distribution and probability maps of Fe cloud be the primary guide for site specific Fe management and designing future soil sampling strategies in the Vridhachalam, Kurinjipadi and Kammapuram blocks of Cuddalore district.

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