# Chapter 4

# SPATIAL VARIATION OF SOIL FERTILITY IN THE STUDY AREA

## 4.1. Introduction

The soil properties exhibit spatial variation as a result of the dynamic interactions between natural environmental factors such as climate, parent material, vegetation and topography (Jenny, 1941). Soil properties and plant growth are significantly controlled by the variations in landscape attributes including slope, aspect and elevation. Knowledge on of spatial variability in soil fertility is essential for site specific nutrient management practices. The traditional approach in soil fertility management is to treat fields as a homogenous area and to calculate fertilizer recommendations on whole field basis. The spatial variability is used to predict the fertility status of unsampled locations in the field. So the most important way to gather knowledge in this aspect is to prepare spatial distribution maps of soil properties through spatial interpolation technique.

Informations on spatial variability of soil properties is essential for precision agriculture because soil parameters with little or no spatial dependence will not be conducive to site-specific management and, will be managed on the average (Pierce and Nowak, 1999). Geostatistics is an effective tool for detecting, estimating and mapping the spatial structure of soil parameters through semivariogram modeling (Goovaerts, 1997; Isaaks and Srivastava, 1989; Rossi *et al.*, 1992). The semivariogram modeling is an excellent method for exploring the structure of spatial variation in agricultural soils (Cambardella and Karlen, 1999; Geypens *et al*., 1999; Webster and Oliver, 1992).

The soil properties varied spatially and temporarily are influenced by both intrinsic (soil formation factors such as soil parent materials) and extrinsic factors (soil management practices, fertilization and crop rotation) (Son *et al*., 2003). Soil nutrients are important symbols of soil fertility and play an important role in the sustainable utilization of land. Analyzing spatial variability of soil nutrients is also very important for protecting the traditional eco-agricultural model (Jing *et al*., 2014). In recent years, human activities are found to exert great influence on soil fertility (Bouma and Finke, 1993). Hence, in this chapter the spatial variation of soil properties in Thrissur district was carried out quantifiably using semivariogram method, which will be of great significance for the effective use and management of soil nutrients for sustainable agriculture.

## 4.2. Materials and Methods

### 4.2.1. GIS datasets and analysis

The data on various properties of 600 geo-referred soil samples obtained in the previous chapter (chapter – III) were used for this study. Soil samples were representing different agro ecological zones of Thrissur District, and geo referencing was done using a hand held GPS.

The data were imported into ArcGIS10.2.2 (KFRI, Peechi) and interpolated using ordinary kriging technique. This is a technique used to interpolate a surface from various points. At GPS coordinates of each grid point, the correspondent soil nutrient values were interpolated. After that a raster image was derived for each soil property in the district. Finally, the interpolated raster data was then reclassified using the reclassifying module of a spatial analyst tool in ArcGIS10.2.2 to group into three classes, low, medium and high based on the values in the raster data set.

#### *4.2.1.1. Statistical and geostatistical methods*

The main statistical parameters generally accepted as indicators of central tendency and spread of the data were analyzed using SPSS version 17. These were mean, standard deviation, coefficient of variation and extreme maximum and minimum values. To decide the normal frequency distribution, the coefficient of skewness and kurtosis were examined.

Geostatistical software (ArcGIS10.2.2) was used to analyze the spatial structure of the data and to define the semivariograms (Goovaerts, 1997)

#### 4.2.1.2. *Semivariogram analysis*

Semivariogram was defined by the parameters such as nugget, sill, partial sill and range. When the point in which the semivariogram intercept the y axis is called the nugget effect and the distance where the semivariogram model first flattens out is called the range. The value of range in the y axis is the sill of the semivariogram model.

Partial Sill = Sill – Nugget …………………… (2)

Sill = Nugget + Partial sill …………………… (3)

Nugget/ sill ratio define the spatial dependence of the semivariogram, which is also called relative nugget effect (RNE %) as shown in Table 13.

**Table 13. Critical levels of spatial dependence**

| Nugget/Sill *100 Ratio | Spatial dependence | Spatial variation |
|---|---|---|
| < 25% | Strong | Less |
| 25 - 75% | Moderate | Moderate |
| > 75% | Weak | High |

*Source* : Cambardella *et al*., 1994

## 4.3. Results and discussion

### 4.3.1. Spatial variation and distribution of soil properties

The spatial variation of soil properties were assessed quantitatively and the distribution maps drawn using Arc GIS 10.2.2 spatial analyst tool in geostsistics with respect to basic properties, primary nutrients, secondary nutrients and micronutrients. The results obtained are given in the following paragraphs.

### 4.3.2. Basic properties

#### 4.3.2.1. *pH*

Soil pH is an important chemical property governing the availability of soil nutrients in the nutrient pool. In the study area, pH ranged from 2.9 - 7.7 indicating strongly acidic to slightly alkaline with mean value of 5.5 (Table 14). The histogram of soil pH (Fig.16) showed that the data was slightly negatively skewed (-0.3) and mesokurtic (3.0) in distribution. pH had significant positive correlation with N (0.107**), P (0.334**), and K

(0.154**) showed significant negative correlation with EC (-0.154**), S (-0.196**) (Table 15).

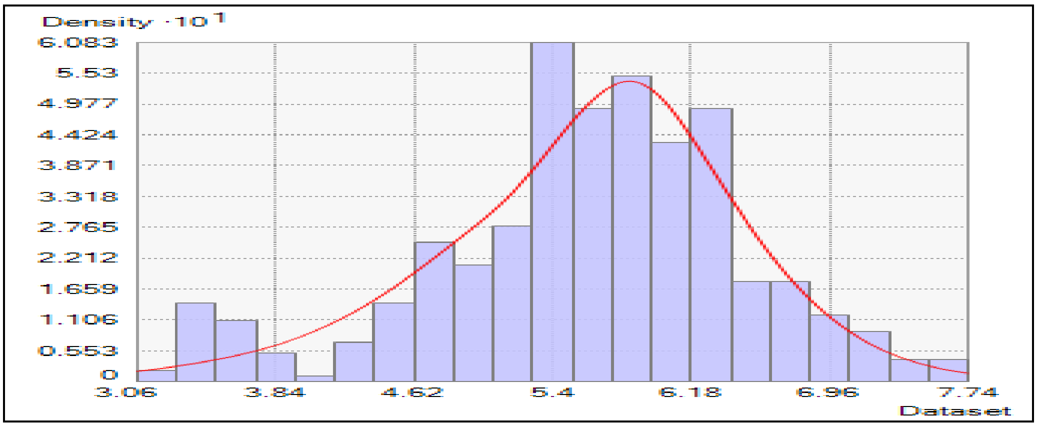

Fig.16. Histogram of soil pH

**Table 14. Basic Soil properties of Thrissur district**

| Soil Properties | Minimum | Maximum | Mean | Std. Deviation | Std. Error | CV (%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| pH | 2.9 | 7.7 | 5.6 | 0.9 | 0.03 | 16.1 | -0.31 | 3 |
| EC (dS/m) | 0.01 | 6.4 | 0.2 | 0.7 | 0.03 | 350 | 5 | 27.6 |
| OC (%) | 0.04 | 6.5 | 1.4 | 0.8 | 0.03 | 57.1 | 1 | 2.4 |

**Table 15. Correlation matrix of soil properties**

|  | pH | EC | OC | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|---|---|---|
| pH | 1 |  |  |  |  |  |  |  |  |
| EC | -0.154$^{**}$ | 1 |  |  |  |  |  |  |  |
| OC | 0.072 | 0.219$^{**}$ | 1 |  |  |  |  |  |  |
| N | 0.107$^{**}$ | 0.156$^{**}$ | 0.973$^{**}$ | 1 |  |  |  |  |  |
| P | 0.334$^{**}$ | 0.008 | 0.199$^{**}$ | 0.126$^{**}$ | 1 |  |  |  |  |
| K | 0.154$^{**}$ | 0.444$^{**}$ | 0.190$^{**}$ | 0.157$^{**}$ | 0.091$^{*}$ | 1 |  |  |  |
| Ca | 0.316$^{**}$ | 0.247$^{**}$ | 0.292$^{**}$ | 0.252$^{**}$ | 0.189$^{**}$ | 0.528$^{**}$ | 1 |  |  |
| Mg | 0.186$^{**}$ | 0.232$^{**}$ | 0.204$^{**}$ | 0.193$^{**}$ | -0.006 | 0.613$^{**}$ | 0.630$^{**}$ | 1 |  |
| S | -0.196$^{**}$ | 0.858$^{**}$ | 0.144$^{**}$ | 0.082$^{*}$ | -0.007 | 0.419$^{**}$ | 0.219$^{**}$ | 0.164$^{**}$ | 1 |

The best fit model for the semivariogram of pH was exponential with determination coefficient 0.46. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil pH in ordinary krigging. The range value of the semivariogram was 3.3 km, in which the points were spatially auto correlated (Table 16). The high range value of pH indicated that the spatial dependence occurred over long distance, which meant the spatial variability was moderate, and the value of range indicating spatial sampling interval of pH also.

The nugget effect of pH was 0.37, which showed over all error caused by the artificial factors as indicated by (Tagore *et al*., 2014).

The value of spatial dependence of pH in the semivariogram was 37 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization as reported by Camberdella *et al*., (1994).

Similar results with moderate spatial dependence of pH was also reported by Jing *et al*. (2014) and Liu *et al*.(2014) in cultivated lands of China (spatial dependence = 33.23, 48.3 respectively). Moderate spatial dependence of pH with spherical model was reported by Wasiullah *et al*. (2010) in Pakistan.

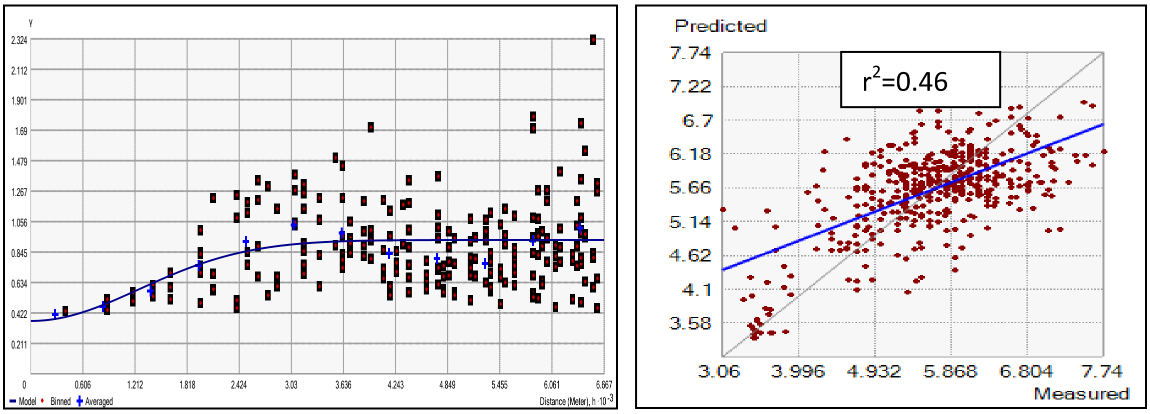

Fig.17. Semivariograms of soil pH (model: exponential)

**Table 16. Characteristics of semivariograms of pH, EC and OC**

| Soil property | Semivariograms characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Range (km) | Nugget (C0) | Partial sill (C) | Sill (C+C0) | RNE % | Spatial dependence | Model | Determination coefficient ($r^2$) |
| pH | 3.3 | 0.366 | 0.56 | 0.9779 | 37 | M | Gaussian | 0.46 |
| EC | 3.2 | 0.2745 | 0.79 | 1.0711 | 26 | M | Stable | 0.58 |
| OC | 0.9 | 0.5986 | 0.42 | 1.0186 | 59 | M | Exponential | 0.45 |

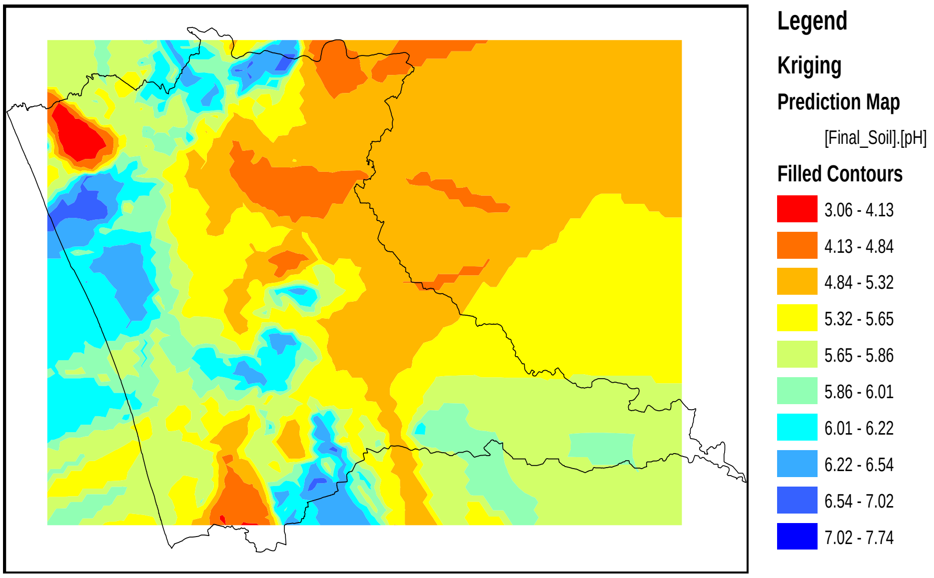

Fig.18. Spatial Distribution of soil pH

### 4.3.2.2. *Electrical conductivity*

EC is the measure of the current carrying capacity of soil solution and it gives a clear idea of soluble salts.

In the study area, EC varied between 0.01-6.4 dS/m indicating normal to saline in nature with mean value 0.29 dS/m. EC showed significant positive correlation with N (0.156**), K (0.444**), Ca (0.247**), Mg (0.238**) and S (0.852**)(Table 15). The histogram of EC (Fig.19) showed that data was positively skewed (5.0) and leptokurtic (27.6) in distribution.

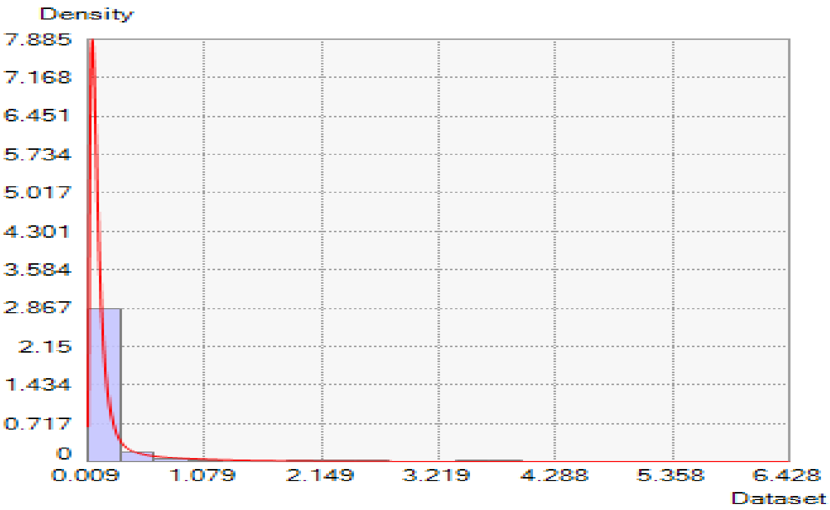

Fig.19. Histogram of EC

The best fit model for the semivariogram of EC was gaussian with determination coefficient 0.58. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil EC in ordinary krigging.

The range value of the semivariogram was 3.2 km, in which the points were spatially auto correlated (Table 16). High range values indicated that the spatial dependence occurred over long distance which meant spatial variability less, and the value of range also indicating spatial sampling interval of EC.

The nugget effect of EC was 0.2745, which showed overall error caused by the artificial factors as indicated by (Tagore *et al*., 2014).

The value of spatial dependence of EC in the semivariogram was 26 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization as reported by Camberdella *et al*., 1994.

Similar results with moderate spatial dependence (54 %) of EC was reported by Cruz-Gardenas *et al*. (2014) in Mexico. On the contrary, the results with strong spatial dependence of EC with high range value of 10.9 km was also reported by Raghupathy and Srinivas (2014) in mango cultivating soils of India.

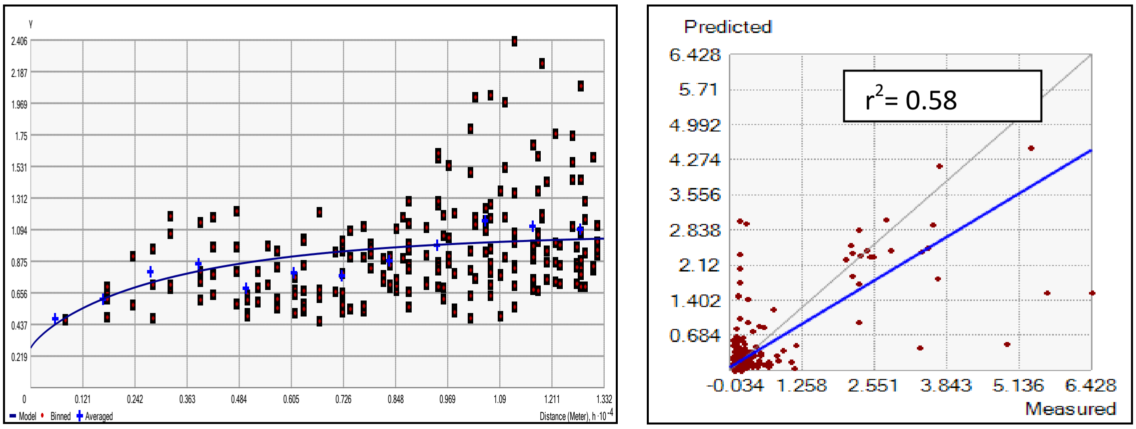

Fig.20.Semivariogram of soil EC (model: stable)

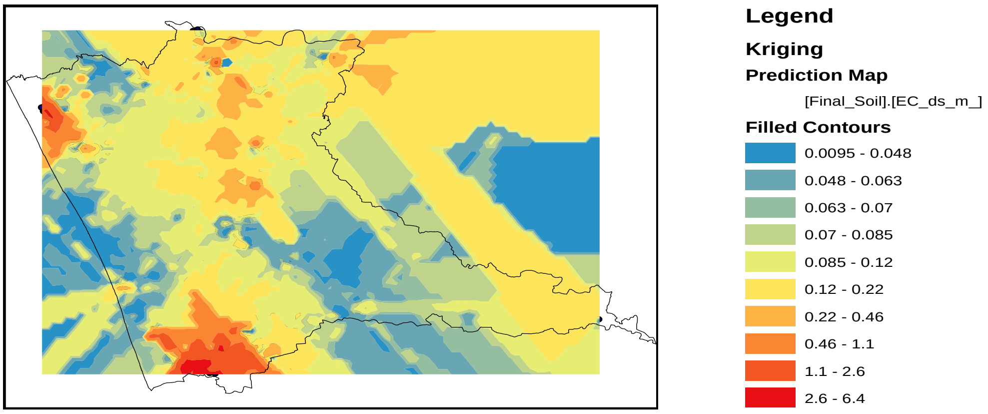

Fig.21. Spatial distribution of EC

### 4.3.2.3. *Organic carbon*

In the study area, OC ranged between 0.04 - 6.5 % indicating low to high content in the soil with mean value of 1.4%. OC showed significant positive correlation with N (0.973**), P (0.199**), K (0.292**), Ca (0.204**), Mg (0.144**) and S (0.226**). The histogram of OC (Fig.22) showed that the soil data were positively skewed (1.0 > 0) and leptokurtic (2.4 < 3) in distribution.

The best fit model for the semivariogram of OC was exponential with determination coefficient 0.45. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil OC in ordinary krigging. The range value of the semivariogram was 0.9 km, in which the points were spatially auto correlated (Table 16). The low range value indicated that the spatial dependence occurred over short distance, which meant that spatial variability was high and the value of range also indicating spatial sampling interval of OC.

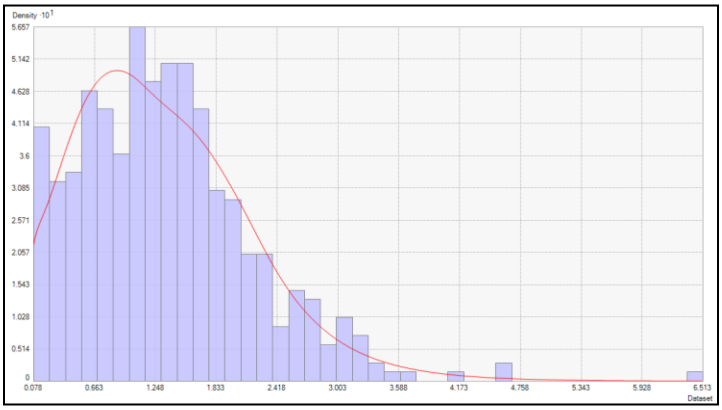

Fig.22. Histogram of OC

The nugget effect of OC was 0.5986, which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of OC in the semivariogram was 59 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization as reported by Camberdella *et al*., (1994).

Similar results with moderate spatial dependence (32 %) of OC with exponential model was reported by Tiwari *et al.* (2015) in Tripura and Cruz – gardenas *et al.* (2014) in Mexico (Spatial dependence – 66%).

On the contrary, another best fit model of hole effect for OC was also reported by Santra *et al*. (2008) in agricultural fields of Delhi and stated that spatial variability was very important for precision farming and environmental modeling.

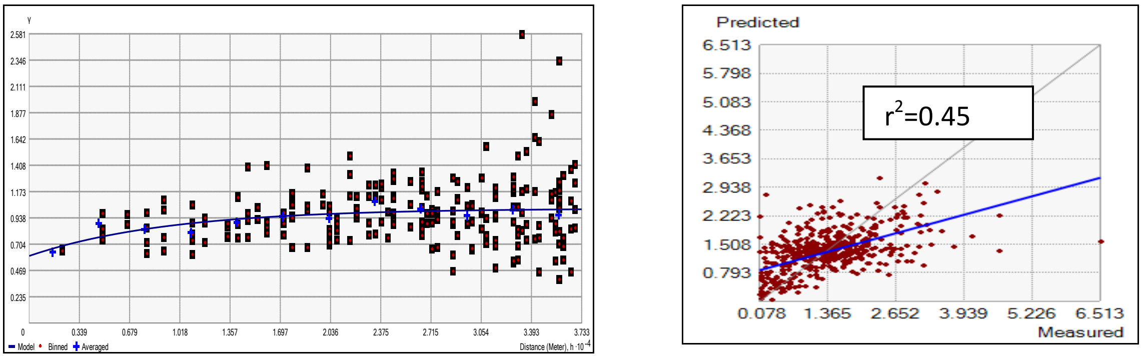

Fig.23.Semivariograms of soil OC (model: exponential)

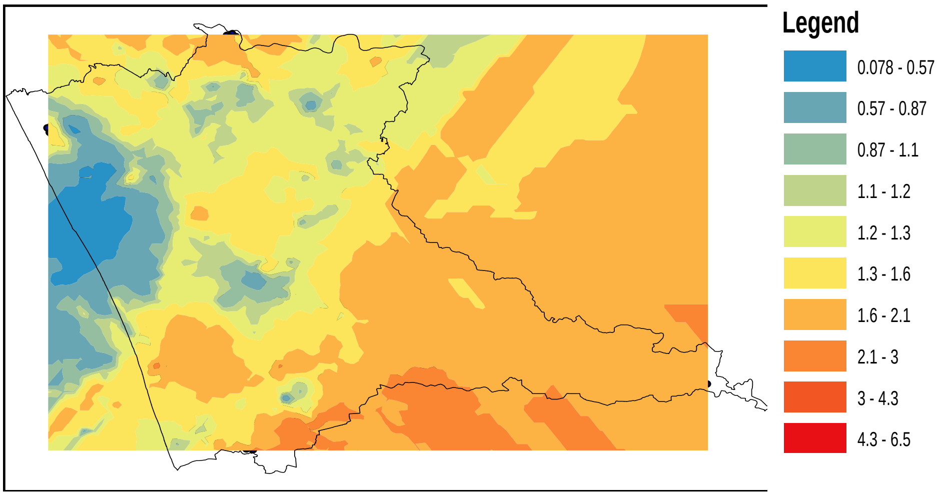

Fig.24. Spatial distribution of OC

### 4.3.3. Primary nutrients

#### 4.3.3.1. *Nitrogen*

In the study area, content of N ranged between 0.001 - 0.1% with mean value of 0.02 %. The histogram of N (Fig.25) showed that the data was positively skewed (1.0 > 0) and leptokurtic (2.4<3.0) in distribution. N showed significant positive correlation with P (0.126**), K (0.157**), Ca (0.252**), Mg (0.193**) and S (0.082*) (Table 17). Positive relation of N with other nutrients is supposed to be due to the indiscriminate and continuous application of chemical fertilizers containing all the nutrients to the soil.

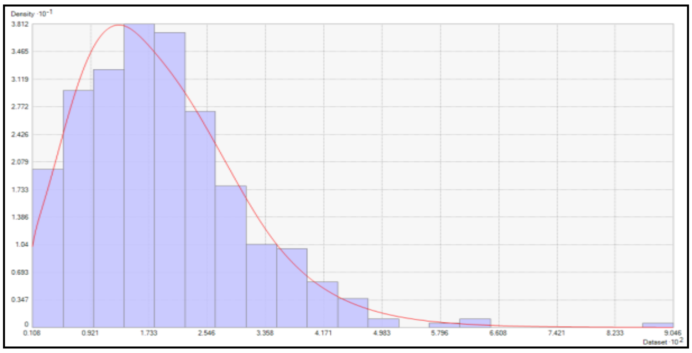

Fig. 25.Histogram of N

The best fit model for the experimental semivariogram of N was spherical with the determination coefficient 0.46. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil N in ordinary krigging.

**Table 17. Primary soil nutrients of Thrissur district**

| Soil Properties | Minimum | Maximum | Mean | Std. Deviation | Std. Error | CV (%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| N (%) | 0.001 | 0.1 | 0.02 | 0.1 | 0.001 | 500 | 1 | 3 |
| P(kg $ha^{-1}$) | 1.0 | 987.4 | 147.7 | 133.5 | 5.7 | 90.4 | 1.6 | 2.7 |
| K(kg $ha^{-1}$) | 1.0 | 3017 | 316.5 | 416.6 | 16.1 | 131.6 | 3.5 | 13.7 |

The range value of the semivariogram was 0.5 km, in which the points were spatially auto correlated (Table 18). The low range value indicated that the spatial dependence occurred over short distance, which meant that spatial variability was high and the value of range  also indicating spatial sampling interval of  N also.

The nugget effect of N was 0.5434, which showed overall error caused by the artificial factors such as environmental and sampling error as indicated by (Tagore *et al*., 2014).

The value of spatial dependence of N in the semivariogram was 58%, showing moderate spatial dependence. This spatial dependence of N might be attributed to the various extrinsic random factors such as soil texture, soil temperature, soil moisture, soil organic matter, plant residues, fertilizer application as indicated by Cambardella *et al*. (1994).

Same results with moderate spatial dependence of N with exponential model was reported by Liu *et al*. (2014) in China. Another study by Jemo *et al.* (2014) also reported the moderate spatial dependence (70 %) of N with rational quadratic model in Nigeria. A contrary result of strong spatial dependence of N was also reported by Jing *et al*. (2014) in China.

**Table 18. Characteristics of semivariograms of primary soil nutrients**

| Soil property | Semivariograms characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Range (km) | Nugget (C0) | Partial sill (C) | Sill (C+C0) | RNE% | Spatial dependence | Model | Determination coefficient |
| N | 0.5 | 0.5434 | 0.39 | 0.93 | 58 | M | Spherical | 0.46 |
| P | 1.4 | 0.6865 | 0.5 | 1.18 | 58 | M | Circular | 0.45 |
| K | 4.9 | 0.0646 | 0.9 | 0.96 | **7** | **S** | Exponential | 0.43 |

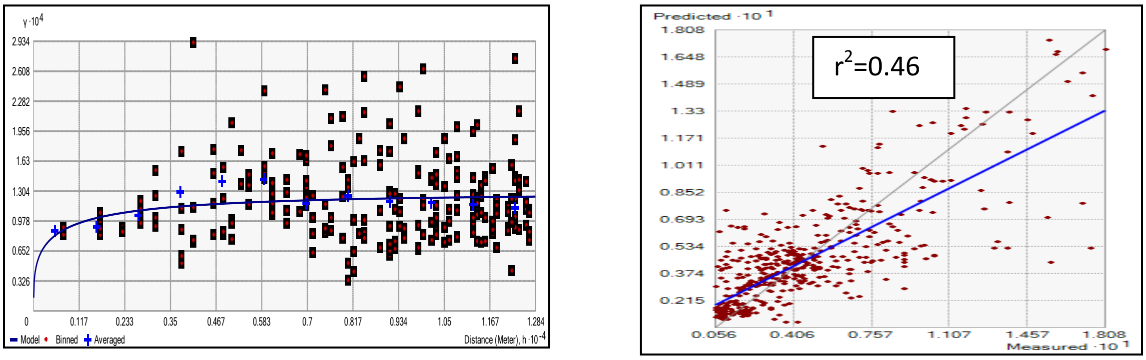

Fig.26. Semivariograms of soil N (model: spherical)

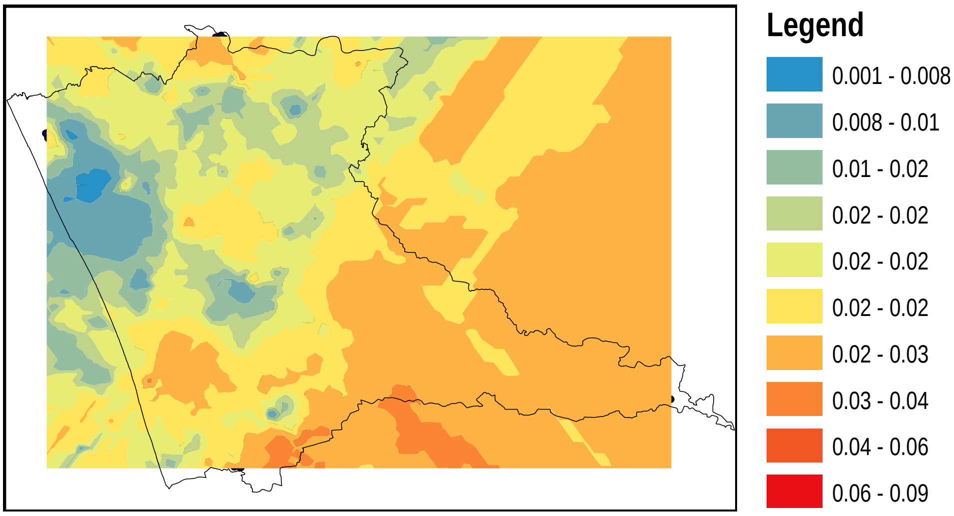

Fig.27.Spatial distribution of N

### 4.3.3.2. *Phosphorus*

In the study area, content of P in the soil samples varied between 1.0 – 987.4 kg ha$^{-1}$ indicating low to extremely high, with mean value of 147.1. The histogram (Fig.28) of P showed that the data was positively skewed (1.6 > 0) and leptokurtic (2.7 < 3.0 in distribution. P had a significant positive correlation with K (0.091*) and Ca (0.189**).

The best fit model for the semivariogram of P was spherical with determination coefficient 0.45. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil P in ordinary krigging. The range value of the semivariogram was 1.4 km, in which the points were spatially auto correlated (Table 18). The low range value of P indicated that the spatial dependence occurred over short distance which means spatial variability was high and the value of range also indicating for the spatial sampling interval of P.

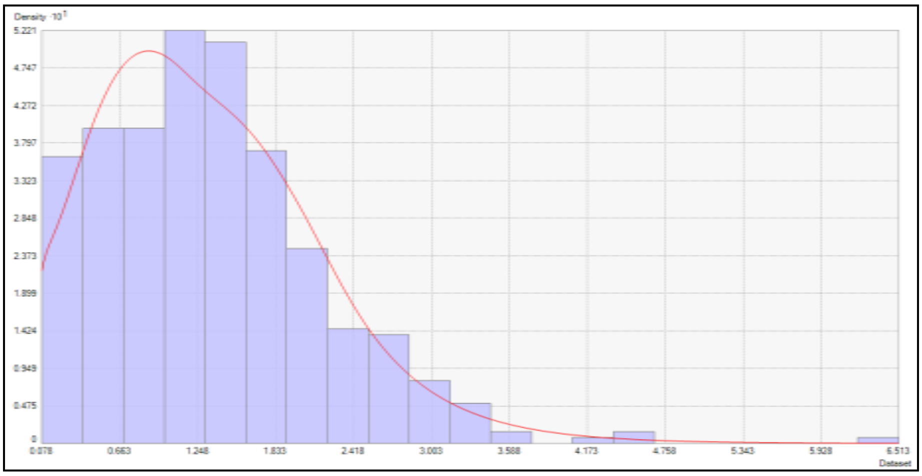

Fig.28. Histogram of P

The nugget effect of P was 0.6865, which was greater than zero, and this indicated overall error caused by the artificial factors as indicated by (Tagore *et al*., 2014).

The spatial dependence of P was shown in terms of nugget/sill ratio (Table.18). The value of dependence of P in the semivariogram was 58 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization, soil erosion, plant residues as reported by Camberdella *et al*. (1994).

Smilar results of moderate spatial dependence of P with spherical model was reported by Liu *et al*. (2014) in China. On the contrary, the result of strong spatial dependence of P in China and weak spatial dependence of P in Nigeria were reported by Jing *et al*. (2014) and Jemo *et al*. (2014) respectively. The continuous fertilization and soil management practices disturbed the spatial structure of P, the excess amount fixed by the Al and Fe in the soil.

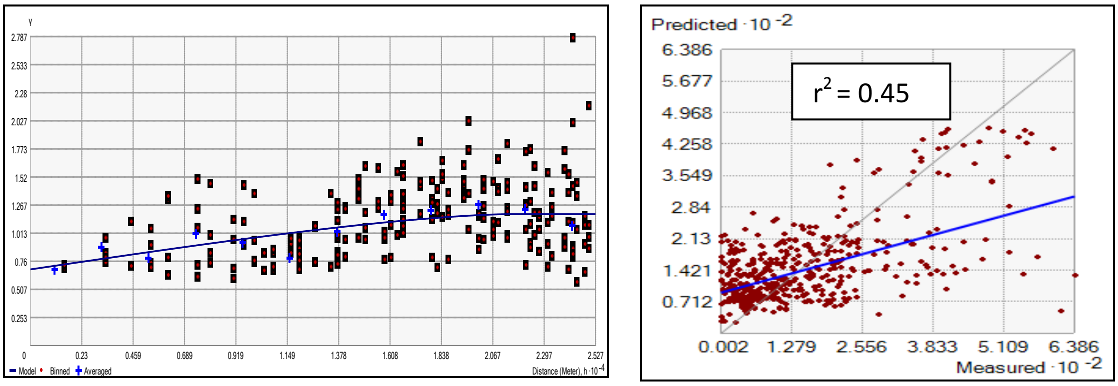

Fig.29. Semivariograms of soil P (model: spherical)

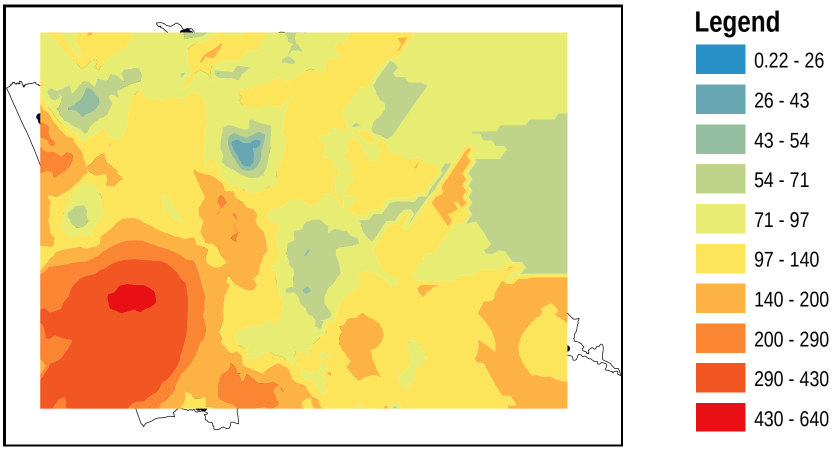

Fig.30.Spatial distribution of P

### 4.3.3.3. *Potassium*

In the study area, content of K ranged between 1.0 - 3017 kg ha$^{-1}$ indicating low to very high with a mean of 316.5 (Table 17). The histogram of K (Fig.31) showed that the data were positively skewed (3.5 > 0) and leptokurtic (13.7 > 3) in distribution. Potassium had significant positive correlation with Ca (0.528**), Mg (0.613**) and S (0.419**) (Table 17). Here also indiscriminate and continuous application of chemical fertilizers containing all the nutrients might have caused the positive relation.

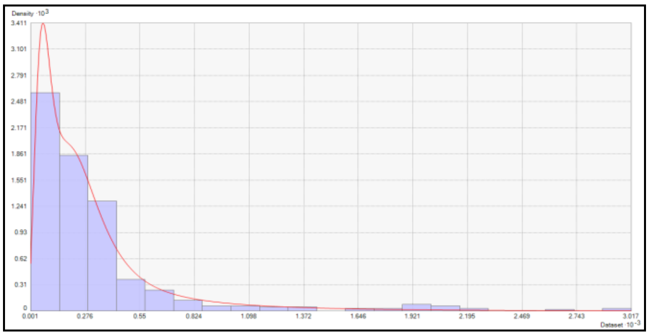

Fig.31.Histogram of K

The best fit model for the semivariogram of K was exponential with determination coefficient 0.43. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil K in ordinary krigging. The range value of the semivariogram of K was 4.9 km, in which the points were spatially auto correlated (Table 18). The high range value was indicating that the spatial dependence occurred over long distance, which meant that spatial variability was less and the value of range also indicating spatial sampling interval of K.

The nugget effect of K was 0.0646, which showed an overall error caused by the artificial factors such as environmental and sampling errors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of K in the semivariogram was 7 %, showing strong spatial dependence. This spatial dependence might be attributed to the intrinsic factors only such as parent material, pedogenic factors, etc. as indicated by Camberdella *et al*. (1999).

Similar results of strong spatial dependence of K (10.96 %) was reported by Jing *et al*., (2014) in China and Lopez-granados *et al*. (2002) in Spain. On the contrary, the results of moderate spatial dependence of K was also reported by Liu *et al*. (2014) in paddy fields of South China. Another studies by Jemo *et al*. (2014) in Nigeria and Cruz - Gardenas *et al*. (2014) in Mexico also revealed the moderate spatial dependence of K (45 %, 57 % respectively) and recommended a strategy for site specific nutrient management for moderate spatial variability. The strong spatial dependence of K in the study area was indicated that the spatial structure of K was not disturbed by the fertilization and other soil management practices. Potassium is not fixed by the kaolinitic clay mineral generally present in the soils of Kerala and hence most of this nutrient in the soils is lost from the system through running water. This creates a strong spatial dependence of K in the study area.

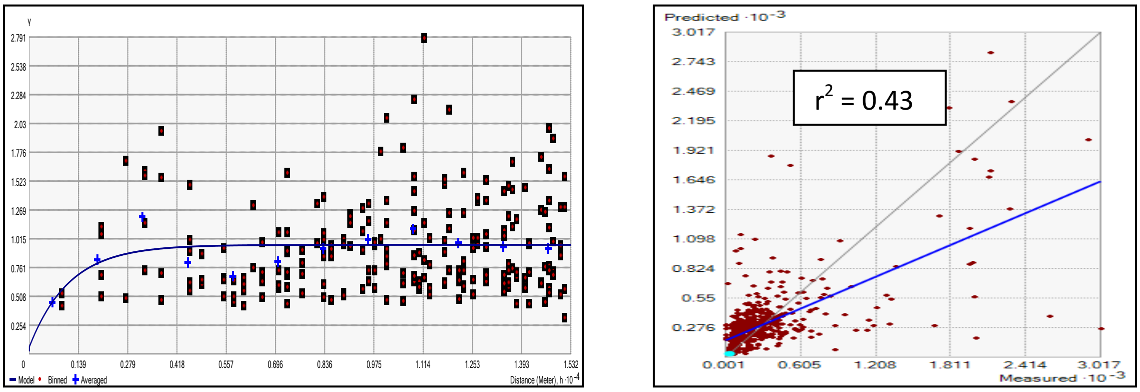

Fig.32. Semivariograms of soil K (model: exponential)

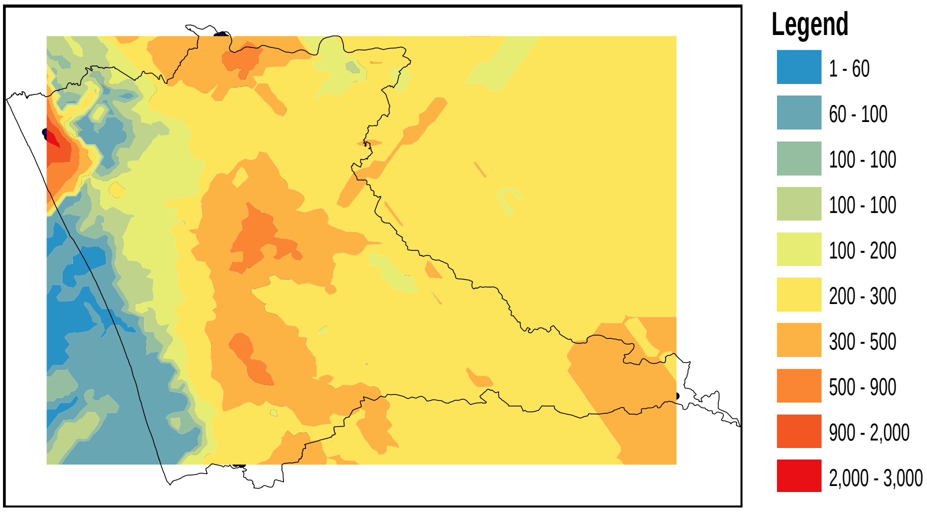

Fig.33.Spatial distribution of K

### 4.3.4. Secondary nutrients

#### 4.3.4.1. *Calcium*

In the study area content of Ca varied between 47.7-1888.5 mg kg$^{-1}$ indicating low to adequate level with mean values 613.8 mg kg$^{-1}$ (Table16). The histogram of Ca (Fig.34) revealed that the data was positively skewed (1.0 > 0) and platy kurtic (0.4 < 3) in distribution. Calcium had a significant positive correlation with Mg (0.630**). Addition of Ca to the soil in the form of lime normally change the pH level that affects the availability of nutrients in soil.

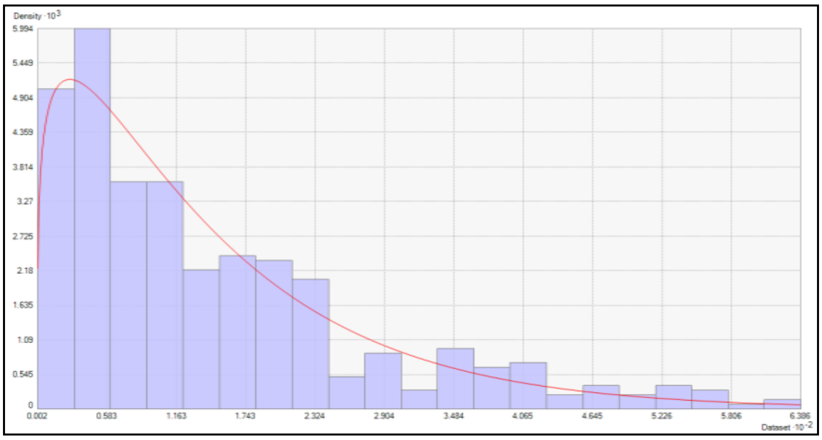

Fig.34.Histogram of Ca

**Table 19. Secondary soil nutrients of Thrissur district**

| Soil Properties | Minimum | Maximum | Mean | Std. Deviation | Std. Error | CV (%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| Ca(mg $kg^{-1}$) | 47.7 | 1888.5 | 613.8 | 393.4 | 14 | 64.1 | 1 | 0.41 |
| Mg(mg $kg^{-1}$) | 5.0 | 501.8 | 96.2 | 66 | 2.5 | 68.6 | 1.8 | 5.5 |
| S(mg $kg^{-1}$) | 0.1 | 373.9 | 17.4 | 35.4 | 1.7 | 203.4 | 4.8 | 26.3 |

The best fit model for the semivariogram of Ca was circular with determination coefficient 0.45. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil Ca in ordinary krigging. The range value of the semivariogram of Ca was 3.4 km, in which the points were spatially auto correlated (Table 20). The high range value indicated that the spatial dependence occur over long distance which means spatial variability was less and the value of range also indicating the spatial sampling interval of Ca.

The nugget effect of Ca was 0.2689, which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of Ca in the semivariogram was 33 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization, soil erosion, plant residues as reported by Camberdella *et al*., (1994).

Same results with moderate spatial dependence with pentaspherical model was reported by Cruz – Gardenas *et al*. (2014) in Mexico. On the contrary, strong spatial dependence of Ca (18.25 %) with exponential model was reported by Raghupathy and Srinivas (2014) in mango cultivating lands of India. Another study by Nayanaka *et al*. (2010) reported pure nugget effect of Ca, indicating dominance of random variation in Sri Lanka.

**Table 20. Characteristics of semivariograms of secondary soil nutrients**

| Soil property | Semivariograms characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Range (km) | Nugge (C0) | Partial sill (C) | Sill (C+C0) | RNE % | Spatial dependence | Model | Determination coefficient |
| Ca | 3.4 | 0.2689 | 0.56 | 0.83 | 33 | M | Circular | 0.45 |
| Mg | 3.1 | 0.471 | 0.53 | 1.0 | 47 | M | Gaussian | 0.44 |
| S | 4.0 | 0.29 | 0.767 | 1.057 | 27 | M | Gaussian | 0.40 |

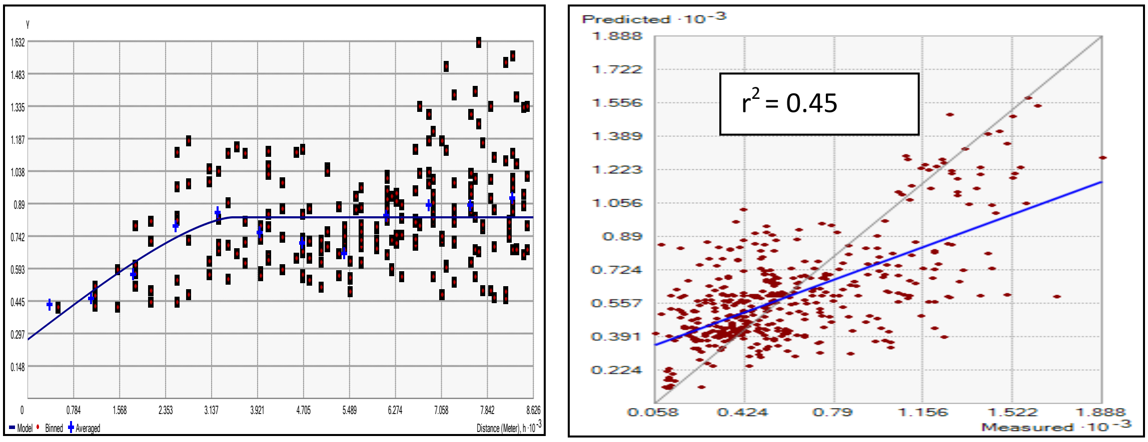

Fig.35. Semivariograms of Ca (model: circular)

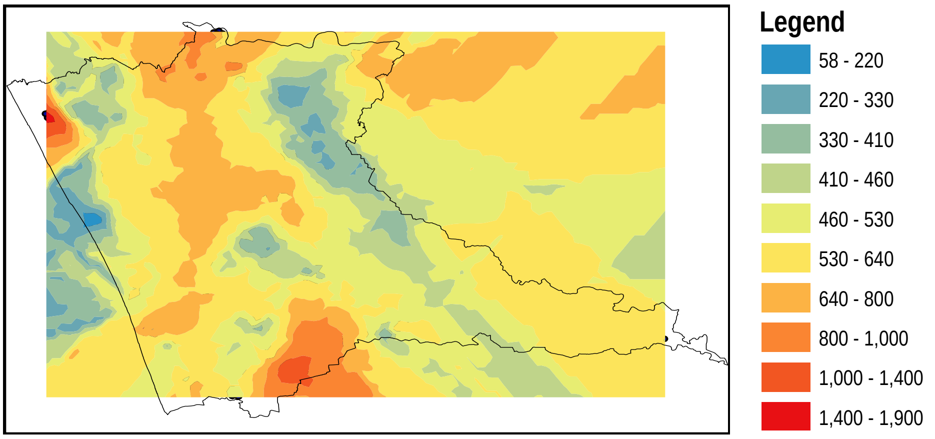

Fig.36.Spatial distribution of Ca

### 4.3.4.2. *Magnesium*

Content of Mg ranged between 4.95 - 501.8 mg kg$^{-1}$ with mean value 96.2 (Table19) in the study area. The histogram of Mg (Fig.37) showed that the data were positively skewed (1.8) and leptokurtic (8.3) in distribution. Mg had significant positive correlation with S (0.164**), Zn (0.179**), Mn (0.402**) (Table 19).

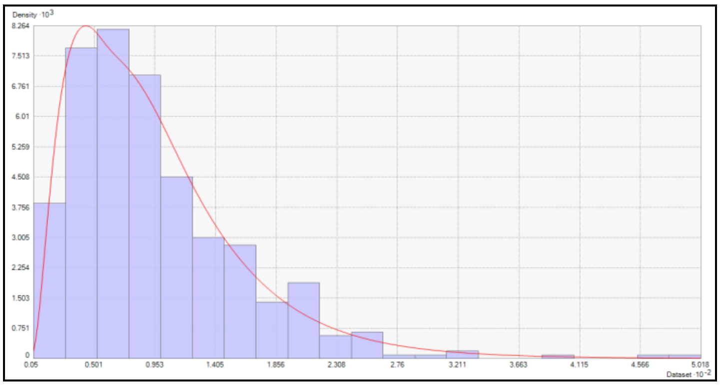

Fig.37. Histogram of Mg

The best fit model for the semivariogram of Mg was Gaussian with determination coefficient 0.44. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil Mg in ordinary krigging. The range value of the semivariogram of Mg was 3.1 km, in which the points were spatially auto correlated (Table 20). The low range value of Mg indicated that the spatial dependence occurred over short distance, which means spatial variability was high and the value of range also indicating spatial sampling interval of Mg.

The nugget effect of Mg was 0.471, which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of Mg in the semivariogram was 47 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization as reported by Camberdella *et al*. (1994).

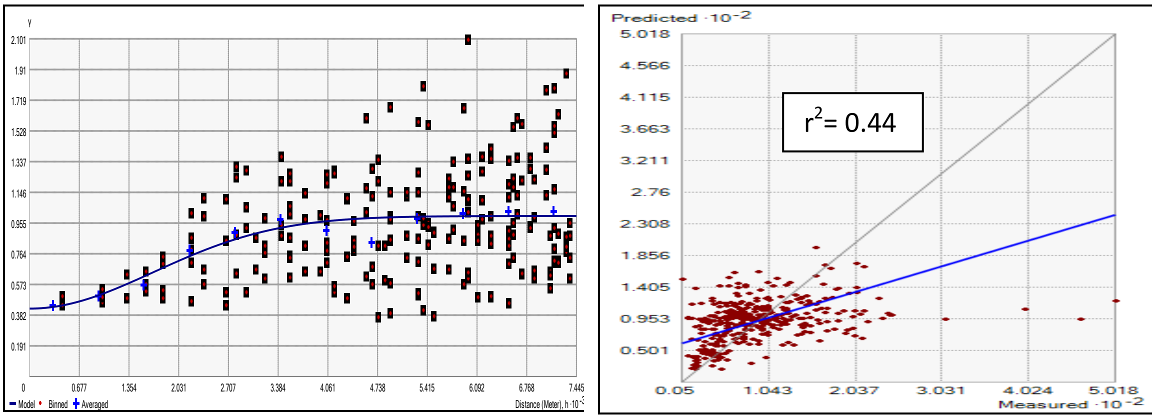

Fig.38. Semivariograms of Mg (model: Gaussian)

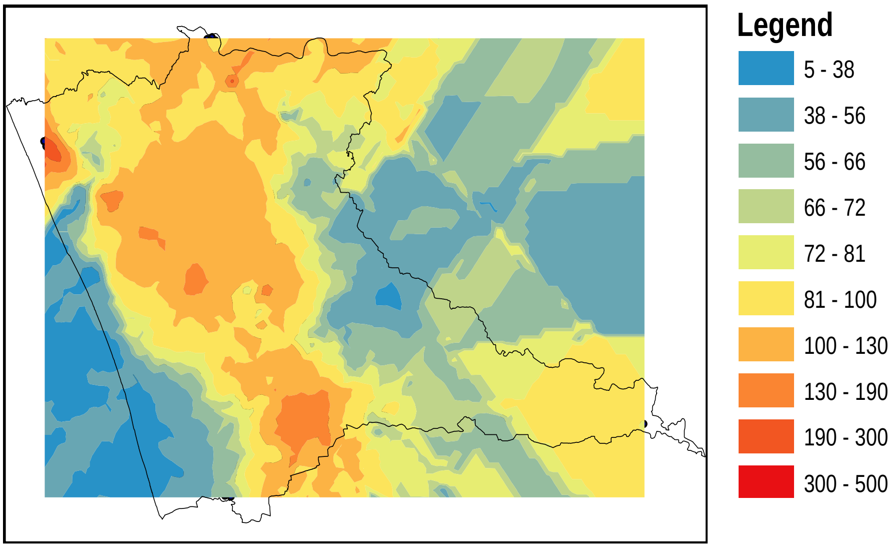

Fig.39.Spatial distribution of Mg

### 4.3.4.3. *Sulphur*

In the study area, content of S ranged between 0.09 - 373.8 mg $kg^{-1}$ with a mean value of 17.4 (Table19). The histogram of S (Fig.40) showed that the data were positively skewed (4.7 > 0) and leptokurtic (27.1 > 3) in distribution. Sulphur had significant positive correlation with Zn (0.122**) and Mn (0.169**).

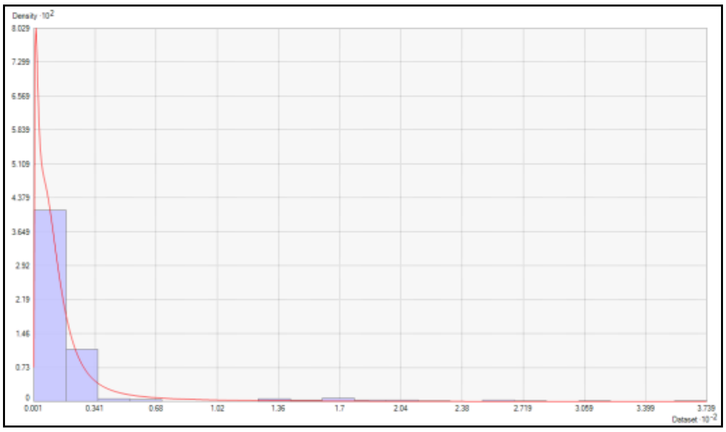

Fig.40. Histogram of S

The best fit model for the semivariogram of S was gaussian with determination coefficient 0.40. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil S in ordinary krigging. The range value of the semivariogram of S was 4.0

km, in which the points were spatially auto correlated (Table 20).The high range value of S was indicating that the spatial dependence occurred over long distance, which meant that the spatial variability was less and the value of range also indicating spatial sampling interval of S.

The nugget effect of S was 0.29, which showed overall error caused by the artificial factors such as environmental and sampling errors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of S in the semivariogram was 27 %, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization and soil erosion as reported by Camberdella *et al*., (1994).

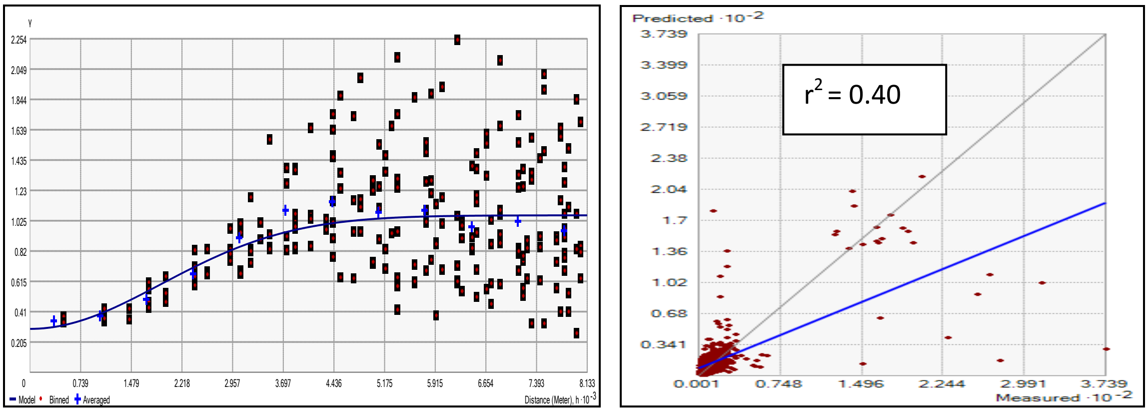

Fig.41. Semivariograms of S (model : gaussian)

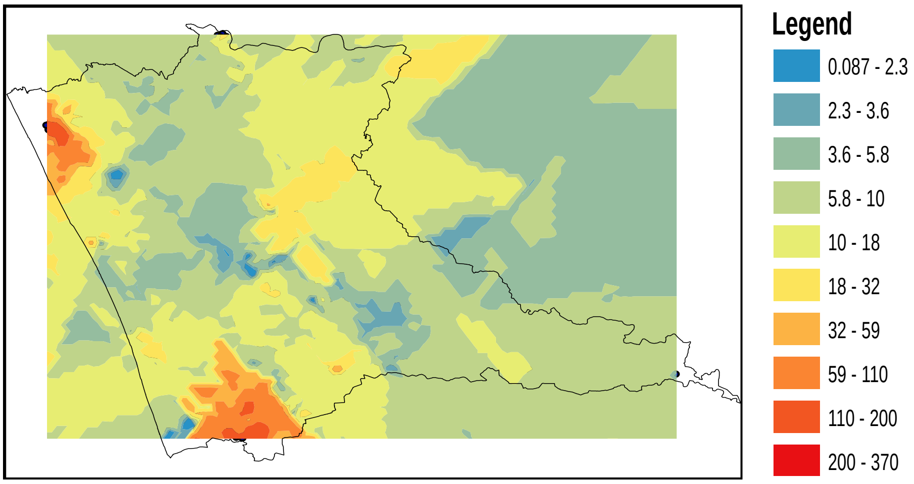

Fig.42. Spatial distribution map of S

### 4.3.5. Micronutrients

#### 4.3.5.1. *Iron*

In the study area the content of Fe varied between 0.2 - 531.5 mg kg$^{-1}$ indicating low to very high with mean value of 69.9 mg kg$^{-1}$(Table21). The histogram of Fe (Fig.43) showed that the data was positively skewed (2.8) and leptokurtic in distribution (14.3). Fe had a significant negative correlation with Mn (-0.195**) (Table 22).

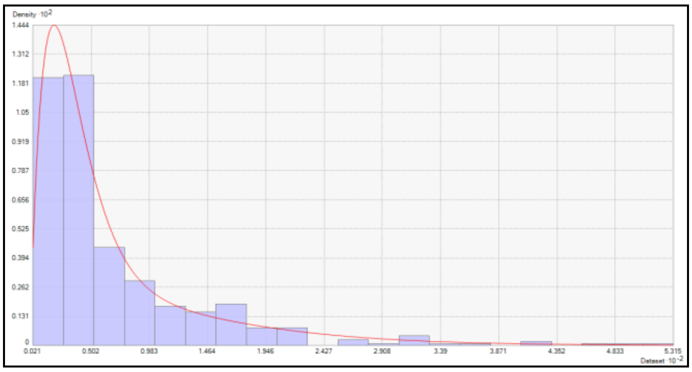

Fig.43. Histogram of Fe

**Table 21. Soil micronutrients of Thrissur district**

| Properties | Minimum | Maximum | Mean | Std. Deviation | Std. Error | CV | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| Fe(mg kg$^{-1}$) | 0.2 | 531.5 | 69.9 | 76.5 | 2.6 | 109.4 | 2.8 | 11.4 |
| Cu(mg kg$^{-1}$) | 0.04 | 35.9 | 5.7 | 27.1 | 0.2 | 475.4 | 2.9 | 9.5 |
| Zn(mg kg$^{-1}$) | 0.02 | 39.8 | 3.7 | 5.5 | 0.2 | 148.6 | 3.8 | 22 |
| Mn(mg kg$^{-1}$) | 0.001 | 343.6 | 33.6 | 52.8 | 1.9 | 157.1 | 2.1 | 5.0 |
| B(mg kg$^{-1}$) | 0.001 | 1.2 | 0.05 | 0.04 | 0.01 | 80.0 | 9.8 | 145.5 |

**Table 22. Correlation matrix of soil micronutrients**

| | pH | EC | OC | Zn | B | Fe | Cu | Mn |
|---|---|---|---|---|---|---|---|---|
| Fe | -.084$^{*}$ | -.067 | .085$^{*}$ | .211$^{**}$ | -.103$^{**}$ | 1 | | |
| Cu | .030 | -.010 | -.001 | .013 | .008 | -.007 | 1 | |
| Zn | .185$^{**}$ | .123$^{**}$ | .226$^{**}$ | 1 | | | | |
| Mn | .133$^{**}$ | .189$^{**}$ | .232$^{**}$ | .451$^{**}$ | -.192$^{**}$ | .195$^{**}$ | .067 | 1 |
| B | .037 | .041 | -.012 | -.092$^{*}$ | 1 | | | |

The best fit model for the semivariogram of Fe was exponential with determination coefficient 0.42. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil Fe in ordinary krigging. The range value of the semivariogram was 8.5 km, in which the points were spatially auto correlated (Table 23). The high range value of Fe indicated that the spatial dependence occurred over long distance which meant spatial variability was less and the value of range also indicating spatial sampling interval of Fe.

The nugget effect of Fe was 0.306 which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of Fe in the semivariogram was 31%, showing moderate spatial dependence. This spatial dependence might be attributed to the extrinsic factors such as soil management practices, fertilization, soil erosion as reported by Camberdella *et al*. (1994).

Similar results with moderate spatial dependence of Fe (37 %) were also reported by Shukla *et al*. (2016) in India. The spatial distribution map of Fe revealed deficiency in south east and north west regions of India as reported by Sen *et al*. (2007).

**Table 23. Characteristics of calculated Semivariograms using ordinary Krigging**

| Soil property | Semivariograms characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Range (Km) | Nugget (C0) | Partial sill (C) | Sill (C+C0) | RNE % | Spatial dependence | Model | Determination coefficient |
| Fe | 8.5 | 0.306 | 0.697 | 1.004 | 31 | Moderate | Exponential | 0.42 |
| Cu | 9.5 | 0.3292 | 0.589 | 0.9188 | 36 | Moderate | Circular | 0.37 |
| Zn | 2.8 | 0.71 | 0.1986 | 0.909 | 78 | Weak | Gaussian | 0.47 |
| Mn | 15.4 | 0.3188 | 0.498 | 0.8168 | 39 | Moderate | Gaussian | 0.36 |
| B | 6.9 | 0.313 | 0.776 | 1.09 | 24 | Strong | Gaussian | 0.40 |

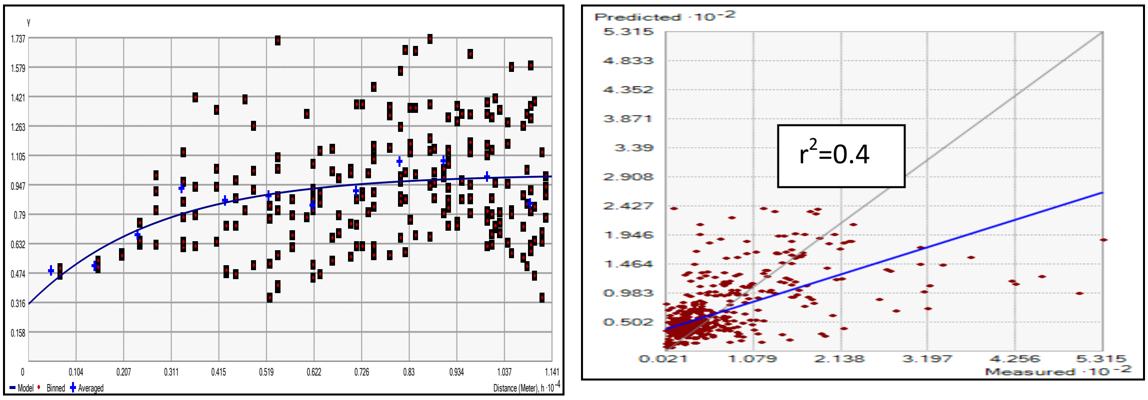

Fig.44.Semivariograms of iron (model: exponential)

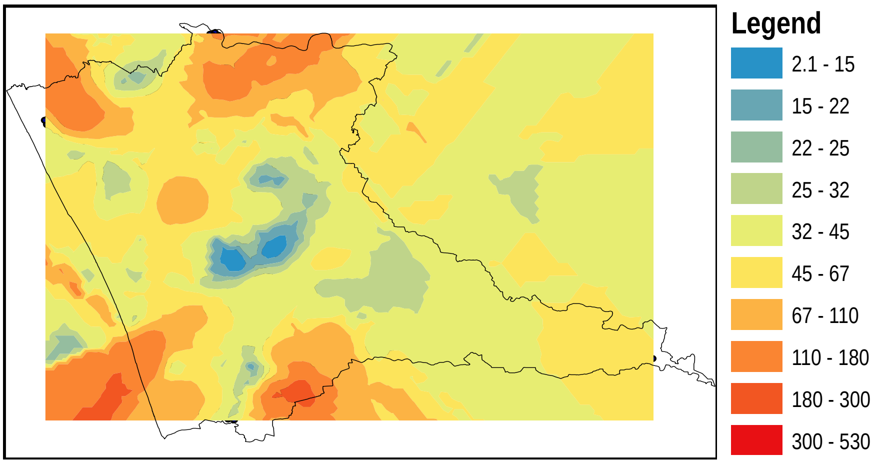

Fig.45. Spatial distribution of Fe

### 4.3.5.2. *Copper*

In the study area the content of Cu ranged between 0.04-35.9 mg kg-1 with mean value of 5.7 indicating low to high. The histogram of Cu (Fig.46) showed the data was positively skewed (2.9) and leptokurtic in distribution (9.5).

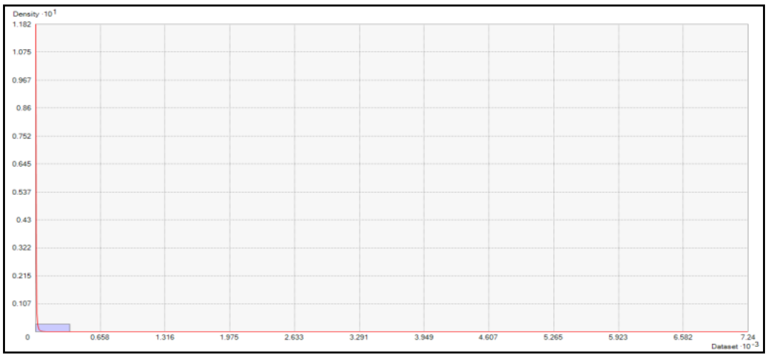

Fig.46.Histogram of Cu

The best fit model for the semivariogram of Cu was circular with determination coefficient 0.37. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil Cu in ordinary krigging. The range value of the semivariogram of Cu was 9.5 km, in which the points were spatially auto correlated (Table 23). The high range value of Cu was indicating that the spatial dependence occurred over long distance which meant spatial variability was moderate and the value of range also indicating spatial sampling interval of Cu.

The nugget effect of Cu was 0.3292, which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of Cu in the semivariogram was 36 %, showing moderate spatial dependence. This moderate spatial structure might be attributed to the extrinsic factors (fertilization and soil management practices) as reported by Camberdella *et al*., 1994. The moderate spatial variation of Cu might be due to frequent use of copper containing fungicides as reported by Sen *et al*. (2007) in India.

Same results with moderate spatial dependence of Cu (34 %) was reported by Shukla *et al*. (2016) in India and another study by Bulta *et al*. (2016) reported moderate spatial dependence (56 %) with exponential model in Southern Ethopia. On the contrary, strong spatial dependence of Cu (0.03%) with exponential model was also reported by Ragupathy and Srinivas (2014) in mango orchards of India.

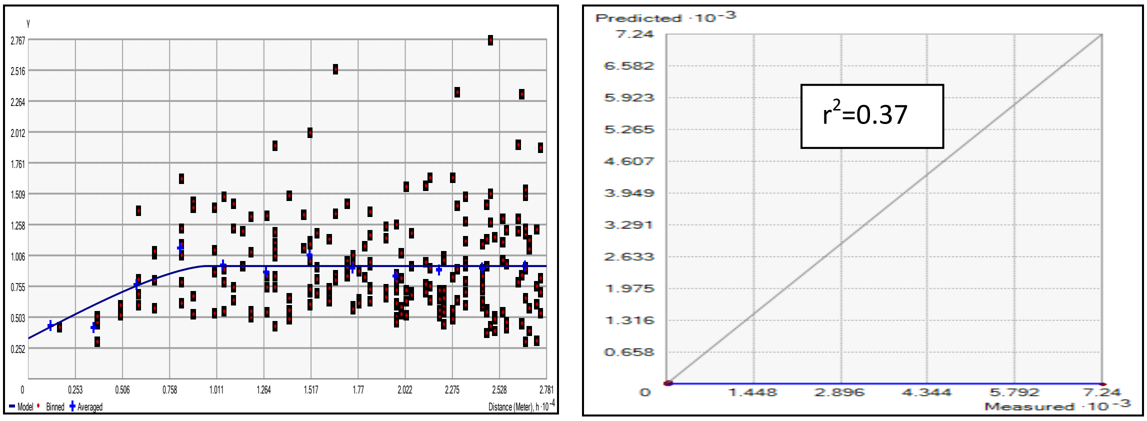

Fig.47. Semivariograms of copper (model: circular)

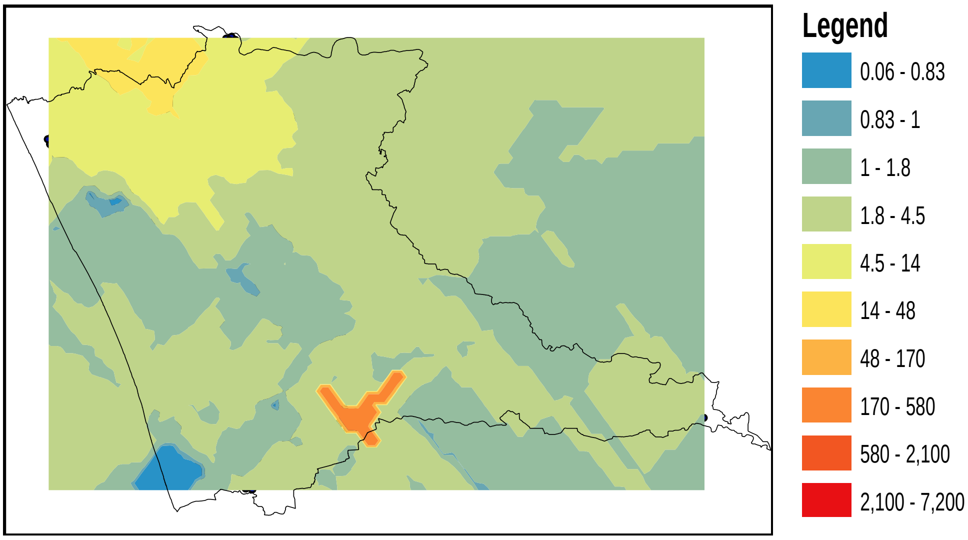

Fig.48. Spatial distribution of Cu

### 4.3.5.3. *Zinc*

In the study area content of Zn ranged between 0.018 - 39.8 mg $kg^{-1}$ with mean value 3.6 indicating low to high status. The histogram of Zn (Fig.49) showed that the data were positively skewed (3.8 > 0) and leptokurtic in distribution (22.0 > 3). Zn had positive significant correlation with pH (0.185**), EC (0.123**), OC (0.226**), Fe (0.085**) and Mn (0.451**) and negative significant correlation with B (-0.092*) (Table 22).

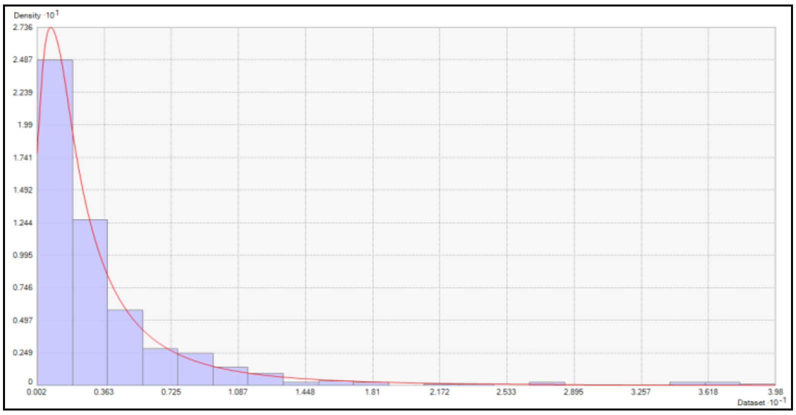

Fig.49. Histogram of zinc

The best fit model for the semivariogram of Zn was gaussian with determination coefficient 0.47. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil Zn in ordinary kriging.

The range value of the semivariogram of Zn was 2.8 km, in which the points were spatially auto correlated (Table 23). The low range value indicated that the spatial dependence occurred over short distance which meant that spatial variability was high and the value of range also indicating spatial sampling interval of Zn.

The nugget effect of Zn was 0.71, which revealed overall error caused by the artificial factors such as environmental and sampling errors as indicated by Tagore *et al*. (2014). The spatial dependence of Zn is shown in Table 23 in terms of nugget/sill ratio. The value of spatial dependence of Zn in the semivariogram was 78 %, showing weak spatial dependence.

Similar results of weak spatial dependence of Zn was also reported by Tagore *et al*. (2014) in Indore district in M.P and Ragupathy and Srinivas (2014) in Mango orchards of India. Weak spatial dependence of Zn was indicating that the soils of the study area was highly affected by extrinsic factors such as soil management practices, fertilization, irrigation and soil erosion (Camberdella *et al*., 1994) and this closely demonstrates the need for site specific nutrient management practices.

The content of Zn in the soil samples of India was highly influenced by the various environmental factors as reported by Behera *et al*. (2011). On the contrary moderate spatial dependence of Zn (60 %) was also reported by Shukla *et al*. (2016) in Gangetic Plains of India and Liu *et al*. (2014) in the paddy field of China with spatial dependence 50%.

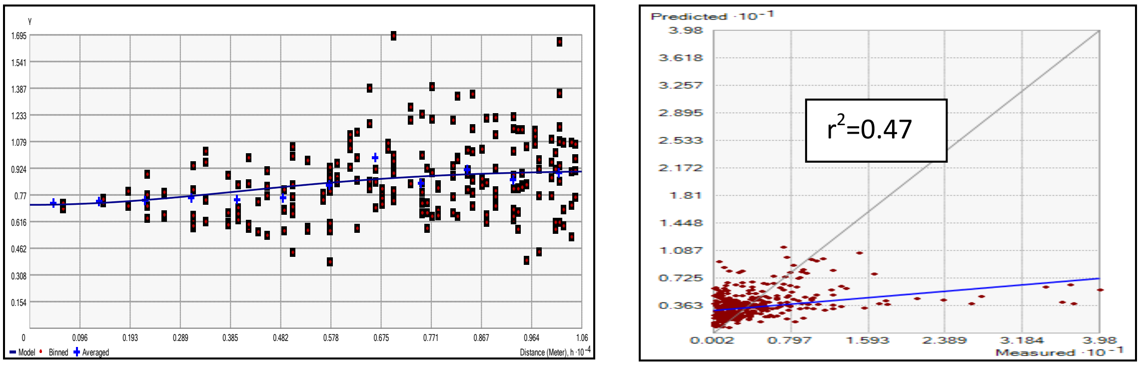

Fig.50. Semivariograms of Zn (model: Gaussian)

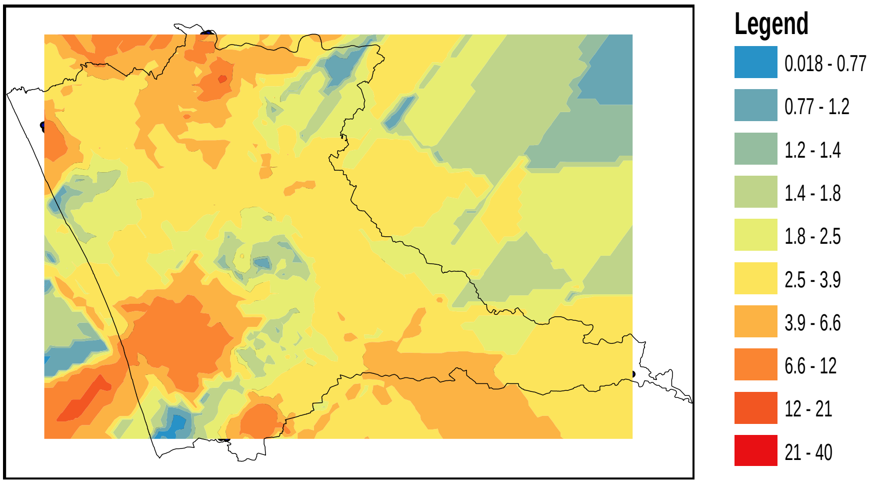

Fig.51. Spatial distribution of Zn

### 4.3.5.4. *Manganese*

In the study area, content of Mn ranged between 0.001-343.6 mg kg$^{-1}$ indicating low to high with mean value of 33.6 (Table21). The histogram of Mn (Fig.52) showed that the data was positively skewed (2.1) and leptokurtic (5.0) in distribution.

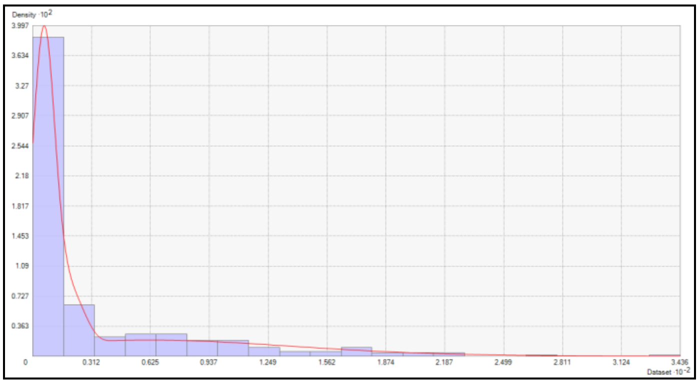

Fig.52. Histogram of Mn

The best fit model for the semivariogram of Mn was gaussian with determination coefficient 0.36. The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil pH in ordinary krigging. The range value of the semivariogram of Mn was 15.4 km, in which the points were spatially auto correlated (Table 23). High range value of the semivariogram of Mn indicated that the spatial dependence occurred over long distance, which meant spatial variability was moderate and the value of range also indicating spatial sampling interval of pH.

The nugget effect of Mn was 0.3188, which showed overall error caused by the artificial factors as indicated by Tagore *et al*., 2014.

The value of spatial dependence of Mn in the semivariogram was 39 %, showing moderate spatial dependence. The soils of Kerala in general contain high levels of Mn, and this can be the reason for the moderate spatial dependence observed in the study. On the contrary weak spatial dependence of Mn was reported by Odoi *et al*. (2011) in Ghana and strong spatial dependence of Mn was reported by Shukla *et al*. (2016) in Indo Ganagetic plains of India.

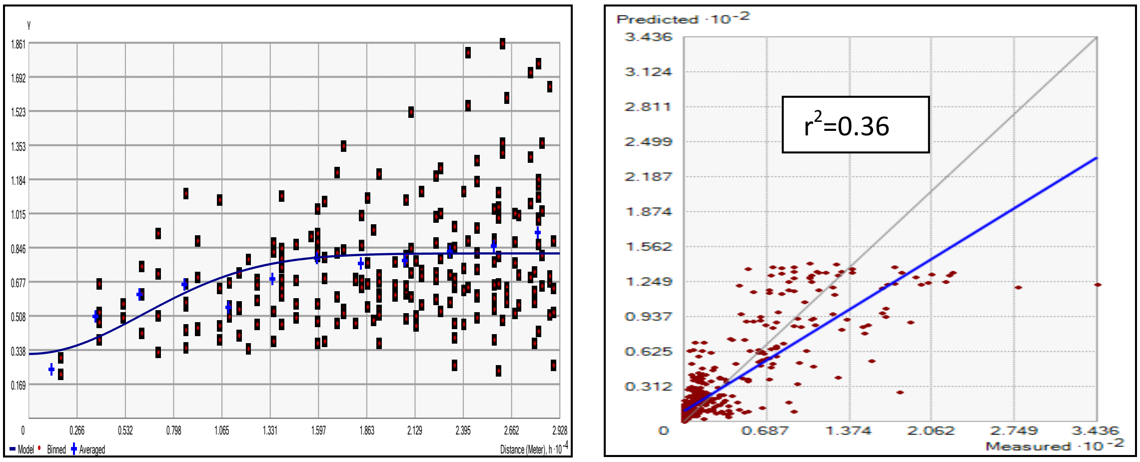

Fig.53.Semivariograms of Mn (model: gaussian)

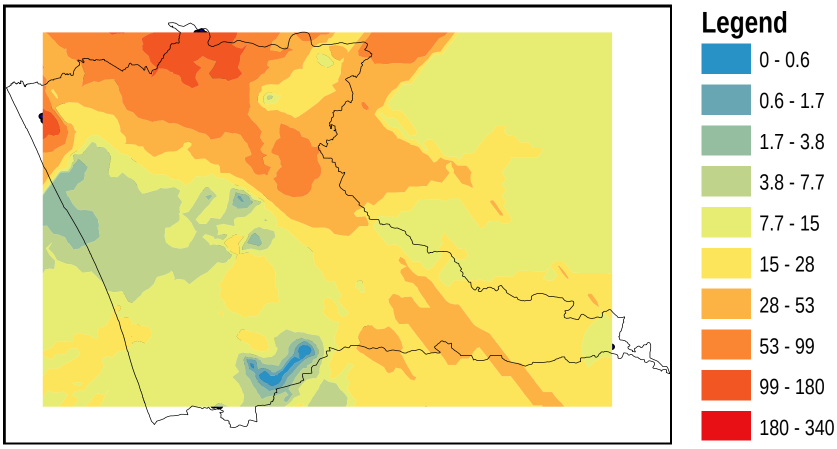

Fig.54. Spatial distribution of Mn

### 4.3.5.5. *Boron*

In the study area content of B varied between 0.001 - 1.2 mg kg$^{-1}$ indicating very low to high status with mean value 0.05. The histogram of B (Fig.55) showed the data was positively skewed (3.8) and leptokurtic (145.5) in distribution. B had a significant negative correlation with Fe (-0.103**) and Mn (-0.192**) (Table 22).

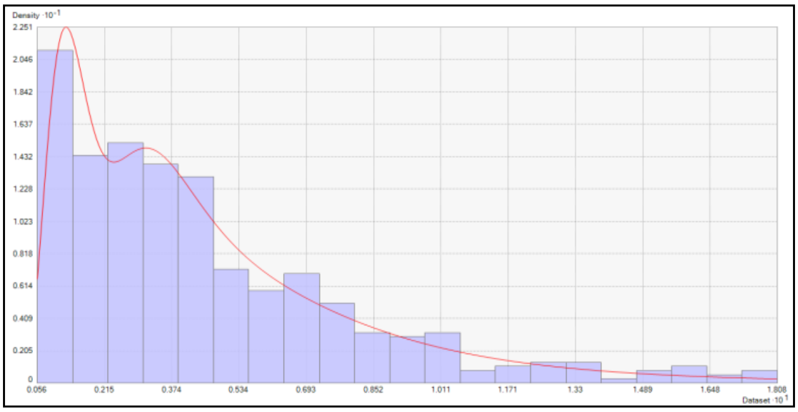

Fig.55.Histogram of B

The best fit model for the semivariogram of B was gaussian with determination coefficient 0.40 (Table 23). The best fit model was selected according to the highest value of the determination coefficient, indicating the correlation between the measured and predicted values of soil B in ordinary krigging. The range value of the semivariogram of B was 6.9 km, in which the points were spatially auto correlated (Table 23). The high range value of B indicated that the spatial dependence occurred over long distance which meant that spatial variability was less and the value of range also indicating the spatial sampling interval for B. The observations greater than the range (6.9 km) were independent as reported by Goovaerts (1997).

The nugget effect of B was 0.313, which showed overall error caused by the artificial factors as indicated by (Tagore *et al.*, 2014).

The value of spatial dependence of B in the semivariogram was 24 %, showing strong spatial dependence. This spatial dependence might be attributed to the intrinsic factors only such as parent material, soil formation processing etc. as reported by Camberdella *et al*. (1994). The semivariogram of B (Fig.48) was indicating considerable variability across the study area. It showed the degree of dissimilarity between observations as a function of distance. The observations at each point were likely to be similar to each other as reported by Karl and Mourer (2010). The management practices of B were readily conducive because of strong spatial dependency of observations (Pierce and Nowak, 1999). B deficiency was most common in soils of acidic pH, light textured and high content of Ca and Fe content as reported by Sahrawat *et al*. (2012).

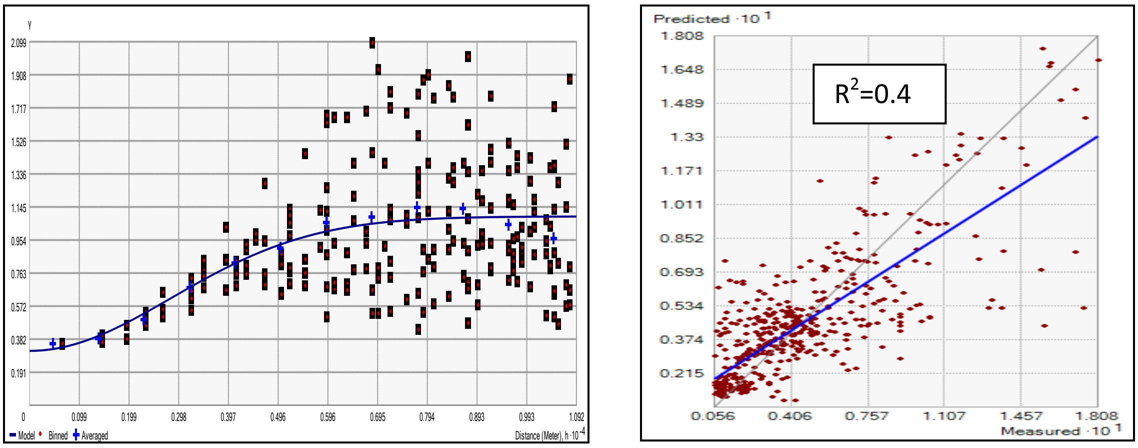

Fig.56.Semivariograms of B (model: gaussian)

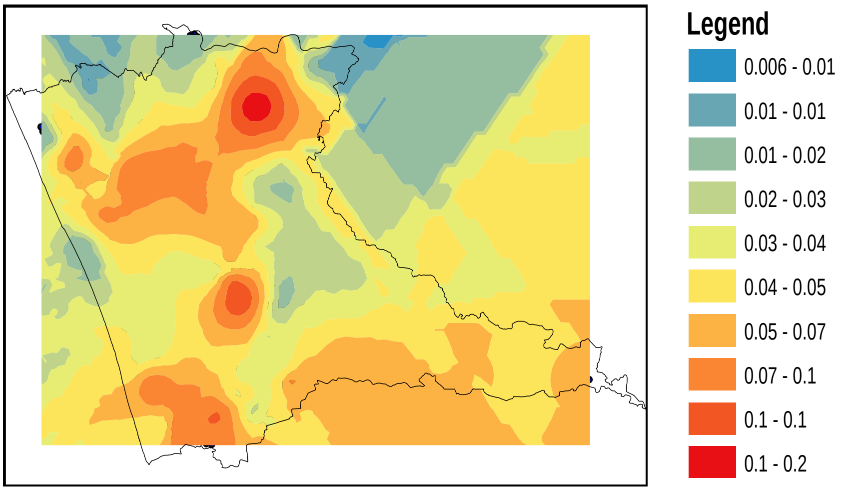

Fig.57.Spatial distribution of B

Weak spatial dependence of Cu, Fe and Mn were reported by Odoi *et al*. (2011) in an industrial area in Ghana and he revealed that the spatial structure of all the micronutrients were highly affected by the extrinsic factors (Anthropogenic, sewage and industrial effluents) and suggested the need to develop proper site specific management strategies.

In this study the geostatistical analysis revealed the strong spatial dependence of K, weak spatial dependence of Zn and others showed moderate spatial dependence in the study area. The results from the present study call to develop a strategy for site - specific application for the parameters showing moderate spatial dependence, taking into account the various random factors such as land erosion, proper fertilization and improved management practices. Zn application could be done using uniform application at the regional level. There is no need to develop a strategy for management of K in the study area because it was greatly affected by the structural factors only such as climate, topography and parent material. A better understanding of the spatial variability of soil nutrients is useful for refining soil management practices and for improving sustainable land use in Thrissur district.