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Soil Quality Mapping Studies Using Nematodes as Bioindicators

Lakshmy Kamala Sthanu[1*], Jaya Divakaran Sarasamma[2], Radhakrishnan Thanu Iyer[3], Mohandas Chellappan[4]

[1]Centre for Environment and Development, Thozhuvancode, Vattiyoorkavu P.O., Thiruvananthapuram, India; [2]Department of Environmental Sciences, University of Kerala, Kariavattom Campus, Thiruvananthapuram, India; [3]Division of Geo Informatics, Indian Institute of Information Technology and Management, Kerala, Techno Park Campus, Thiruvananthapuram, India; [4]Division of Crop Protection, Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram, India.
Email: [*]hariluxmi@gmail.com, jayvijayds@gmail.com, rkequinox@gmail.com, drcmohandas@gmail.com

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ABSTRACT

Soil quality is one of the most important factors in sustaining the global biosphere and developing sustainable agricultural practices. Land use and management practices greatly impact the direction and degree of soil quality changes in time and space. Understanding the effects of land use and management practices on soil quality and its indicators has been identified as one of the most important goals for modern soil science. Soil quality mapping study represents a method for assessing and mapping soil quality changes in time and space in small units. For the present study, changes in the physical, chemical parameters and nematode density of the soils in the rural and urban areas of Thiruvananthapuram district, Kerala, were determined. The soil samples were collected from seven different categories of contaminated soils namely coastal area, sewage disposal area, industrial area, road-side area, agricultural area, market area and gasoline station area, and also from two control stations in rural and urban areas. The soil physico-chemical parameters and nematode density were determined. Geostatistics combined with GIS was applied to analyze the spatial variability of soil physico-chemical characteristics and nematode density. This soil quality mapping study provides a basis for identifying tension zones and serves as a triggering mechanism for implementation of soil contamination mitigating strategies.

Keywords: Soil Quality; Mapping Studies; Nematode Density; Spatial Variability; Contaminated Soils

1. Introduction

Industrialization and urbanization have a strong impact on the environment, and its biotic and abiotic components. Many toxins added to the soils by different anthropogenic activities can build up to concentrations that become serious threats to plant and animal health (Alloway, 1996) [1]. The presence or absence of indicator species or indicator community reflects environmental conditions. Bio monitors provide a direct measurement of a biological effect rather than inferring values using soil extractions (Tarazona *et al.*, 2005) [2]. The study of regional variations and the anthropogenic contamination by metals of soils is very important for environmental planning and monitoring in urban areas. Mapping allows for more efficient approach to remediation and monitoring of soil contaminants (Fortin and Dale, 2005) [3]. Geographical Information System (GIS) is used for the mapping of the contaminants in the study area soils. Based on the GIS analysis, the highest risk sites are identified in which majority of the remediation and monitoring should take place. The major objective of the present study was to monitor the soil quality of selected rural and urban areas in Thiruvananthapuram District, Kerala, using nematodes as bioindicators, and also aimed to provide base line information on the soil health status of rural and urban areas of the capital district of Kerala.

2. Materials and Methods

2.1. Study Area

The rural and urban areas in Thiruvananthapuram District, Kerala were selected for the present study (http: www. censusindia.net/2001census results). Thiruvananthapuram

[*]Corresponding author.

District is located at 8˚26'25" N latitude and 76˚55'25"E longitude. Thiruvananthapuram, the southernmost District in the State of Kerala is the study area. Its southern most extremity, Kaliaikkavila, is only 54 kms away from Kanyakumari (Cape Comarin), the land's end of India. The district stretches 78 kms along the shores of the Arabian Sea on the west, Kollam district lies on the north with Thirunelveli and Kanyakumari districts of Tamil Nadu on the east and the south respectively. The district can be divided into three geographical regions; highlands, midlands and lowlands. The large forest reserves favorably affect the climate and induce rain. Cold weather is experienced in the mountain ranges whereas lower down, the weather is bracing and in the plains, it is generally hot. Though the mean maximum temperature is only around 900F, it is oppressive in the moisture-laden atmosphere of the plains. Humidity is high and rises to about 90 percent during the south-west monsoon. The average rainfall is around 150 cm per annum. It is significant that the district gets rainfall both from the south-west and the north-east monsoons. According to the final figures of 2011census (Census of India, 2011), the population of the district is 3,307,284. The Taluks in Thiruvananthapuram District are Neyyattinkara, Thiruvananthapuram, Nedumangad and Chirayinkeezhu. The district has three major rivers, several freshwater lakes and more than 300 ponds. The eastern region is forested, northern regions are mostly under rubber cultivation and the remaining areas have mixed dry land crops of coconut, plantain, tapioca, etc. Built up areas and rice fields complete the land use. Based on the land use pattern, Thiruvananthapuram District has been classified into different categories namely, coastal areas, sewage disposal areas, industrial areas, road-side areas, agricultural areas, market areas, gasoline station areas, benign environment, etc. These areas will be receiving different types of wastes based on the source of contamination. The contaminated sites due to different anthropogenic activities were identified in both rural and urban areas of Thiruvananthapuram District after conducting a reconnaissance survey. Sixteen sampling stations in the rural and urban areas of the Thiruvananthapuram District were selected. These include seven different categories of contaminated soils selected in the rural and urban areas namely coastal area, sewage disposal area, industrial area, roadside area, agricultural area, market area and gasoline station area. Control soil samples were collected from comparatively benign environments in both rural and urban areas which were selected as control stations (**Table 1**).

2.2. Soil Collection

Soil samples (0 - 15 cm depth) from the sampling stations were collected during the pre-monsoon, monsoon and post-monsoon seasons of the study period (April 2009 to January 2010). Composite samples were taken by mixing the samples collected from five different sites of each station. Soil sampling and analysis of soil physico-chemical characteristics were carried out according to the standard procedures (Gupta, 1999) [4]. The concentration of the heavy metals viz. lead, chromium, manganese, copper and zinc in the acid digested soil samples were determined (Saxena, 1994) [5] using an Atomic Absorption Spectrophotometer (Model, GBC 932 AA). Karl Pearson's Product Moment Correlation is used for finding significant correlation between nematode densities with all other soil quality parameters in the three different seasons (SPSS v - 16 for WINDOWS).

The Geographical coordinates of the sampling stations were collected using Hand-held GPS (Garmin eTrex Vista HCx). The Coordinate values were entered into a spreadsheet with properly assigning IDs for each location. Another spreadsheet was prepared with physico-chemical characteristics and nematode density. In this spreadsheet, the same IDs were entered against respective stations. Both spreadsheets were added in GIS software (Arc GIS version 10) as tables. The table with Geographic coordinate values were plotted as point layer using "Display XY" method and subsequently exported as a shape file with WGS84 as reference ellipsoid. The physico-chemical characteristics and nematode density table was joined with the attribute table of the point layer using ID as the foreign key using JOIN method in GIS software (Korte, 2001) [6]. The resultant layer comprised the geometry of stations as points and all the results as associated attribute table (**Figure 1**). The soil physico-chemical characteristics were analyzed and mapping of significantly correlated soil physico-chemical characteristics with nematode density was plotted.

3. Results and Discussion

3.1. Mapping of Physico-Chemical Characteristics and Nematode Density in Soil

The results of physical characteristics of the soils in the study stations are given in **Tables 2(a)** and **(b)** respectively and the soil chemical characteristics analyzed are given in **Tables 3(a)** and **(b)** respectively. The results of heavy metal (Pb, Zn, Mn, Cu, Cr) content in soil are given in **Tables 4(a)** and **(b)** respectively. Correlation studies of soil physico-chemical characteristics with nematode density were done.

3.2. Nematode Sampling, Extraction and Density Calculation

One kg soil samples from 0 - 15 cm depth were collected. For soil nematode identification studies, 100 cc (approx. 150 gms) of soil samples were washed and the soil solutions were passed through 60 mesh (250 μ) and 350 mesh

Table 1. Portrait of sampling stations in the study area.

Rural Stations			Urban Stations		
Name	Location		Name	Location	
	Latitude	Longitude		Latitude	Longitude
Vizhinjam (Station 1)	8˚33'51"	76˚53'25"	Shangumugham (Station 9)	8˚27'50"	76˚55'55"
Vilappilssala (Station 2)	8˚30'18"	76˚53'45"	Valiathura (Station 10)	8˚33'51"	76˚53'25"
Kochuveli (Station 3)	8˚30'18"	76˚53'45"	Peroorkkada (Station 11)	8˚31'35"	76˚58'03"
Mangalapuram (Station 4)	8˚30'18"	76˚53'45"	Thampanoor (Station 12)	8˚29'15"	76˚57'12"
Palode (Station 5)	8˚28'53"	76˚57'08"	Sreekaryam (Station 13)	8˚30'18"	76˚53'45"
Balaramapuram (Station 6)	8˚27'06"	76˚57'21"	Chalai (Station 14)	8˚28'52"	76˚57'08"
Pallichal (Station 7)	8˚27'06"	76˚57'31"	Karamana (Station 15)	8˚28'56"	76˚57'36"
Anappara (**Control Station** 8)	8˚28'53"	76˚57'08"	Ambalathara (**Control Station** 16)	8˚27'06"	76˚57'21"

S1 - S8: Rural Sampling Stations; S9 - S16: Urban Sampling Stations.

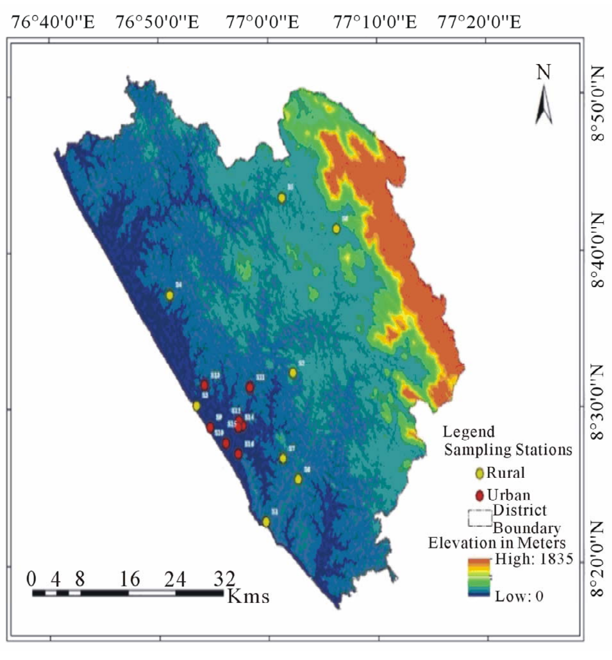

Figure 1. Base map showing the sampling stations in the rural and urban areasof.

(45 µ) sieves (ASTM Endecott Sieves) respectively. The residues from 350 mesh sieve was washed and collected into a beaker and allowed to settle for one hour. Then decanted the supernatant and poured the rest on a wet tissue paper placed on metal gauze in a Petri dish containing water. After two days, collected the nematode containing solution, allowed to settle for decanting and added equal quantity of boiled 4% formalin to kill and fix it. 10 ml of this solution was placed in a nematode Perspex counting dish (Cobb, 1917) [7] and were observed under a Stereomicroscope (Model, Leica LED3000 NVI) and their abundance was calculated (Southwood and Henderson, 2000) [8] during the three seasons as shown in **Figures 2(a)-(c)**. The soil sample solution was made up to 100 ml and stirred well. Pipetted 10 ml of this soil solution from three different depths of this 100 ml soil sample solution kept in a beaker and placed in Doncaster's circular mounting tray (Goodey, 1963) [9]. Nematode density is expressed in Number per 100 ml soil.

Electrical conductivity, water holding capacity, moisture content, organic matter, total nitrogen content, phosphorus content, potassium and copper contents showed positive correlation with nematode density in soil. pH, temperature, pore space, bulk density, chloride, lead, zinc, manganese and chromium contents showed negative correlation with nematode density in soil samples collected from both rural and urban area as shown in **Tables 5(a)** and **(b)** respectively. Of the different physicochemical characteristics studied, water holding capacity, moisture content, organic matter content, pH, zinc and manganese contents only showed significant level of correlation with nematode density. Mapping of significantly correlated soil physico-chemical characteristics with nematode density was plotted. The significance level of correlation coefficient is given in **Table 6**.

3.3. Mapping of Significantly Positively Correlated Physico-Chemical Characteristics and Nematode Density in Soil

Water holding capacity of soils in the selected stations of

Table 2. (a) Physical characteristics of rural and urban soils; (b) Physical characteristics of rural and urban soils.

(a)

St.No.	pH			Conductivity (mho/cm)			Temperature (˚C)		
	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-Monsoon season	Monsoon season	Post monsoon season
S1	7**	7.7**	7.1**	0.07**	0.049**	0.032**	32.6**	30**	31.5**
S2	5**	5.7**	5**	1.52	0.88**	0.463**	30	29.7	31
S3	5.7**	6.4**	6.3**	0.26**	0.15**	0.094**	32.5**	30**	31.5**
S4	6.1**	7.1**	6.5**	0.26**	0.082**	0.057**	31.6**	30**	31.48*
S5	5.3*	6*	5.5*	1.09**	0.245**	0.326**	29.9**	29**	31**
S6	4.7**	5**	4.9**	3.14**	1.35**	1.343**	31.1**	30**	31.4**
S7	6.2**	7.3**	6.7**	0.14**	0.072**	0.048**	33**	30**	31.4**
S8	5.4	6.2	5.9	0.44	0.225	0.211	29.5	29.8	31
S9	8.7**	8.3**	7.3**	0.06**	0.042**	0.028**	32.6**	30**	31.5**
S10	5.7	5.7**	5.3**	1.33**	0.528**	0.451**	32**	30**	31.3**
S11	5.7	6.3	6.2	0.27**	0.174**	0.099**	32.2**	30**	31.1
S12	6.1**	7.3**	6.7	0.25**	0.073**	0.049**	31.3**	30**	31.4**
S13	5.3**	6.2	5.7**	0.52**	0.225**	0.214**	32**	29.9	31.2**
S14	4.8**	5.3**	4.9**	1.6**	1.305**	0.865**	31*	30**	31.3**
S15	6.9**	7.5**	7*	0.07**	0.064**	0.04**	33**	30**	31.4**
S16	5.7	6.2	6	0.33	0.197	0.118	31.1	29.8	31

(b)

St.No.	Pore Space (%)			Water holding capacity (%)			Bulk density (g/cc)		
	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season
S1	57.8**	57.8**	57.8**	0.04**	0.05**	0.03**	1.56**	1.58**	1.57**
S2	30.19**	30.2**	30*	1.33**	1.34**	1.32**	0.71**	0.72**	0.71**
S3	38.32**	38.2**	38.1**	0.15	0.17**	0.15**	1.14**	1.14**	1.2
S4	40.12**	40.13**	40.1**	0.15**	0.15**	0.14**	1.23**	1.24**	1.23**
S5	30.28**	30.3**	30.2**	0.79**	0.75**	0.74**	0.5**	0.9**	0.9**
S6	25.43**	25.4**	25.3**	1.84**	1.87**	1.86**	0.2**	0.3**	0.3**
S7	45.25**	45.3**	44.9**	0.13	0.13**	0.11**	1.26**	1.25**	1.25**
S8	32.45	32	32	0.27	0.27	0.25	1.09	1.1	1.11
S9	58.87**	58.86**	58.84**	0.02**	0.03**	0.03**	1.58**	1.6**	1.6**
S10	30.19**	30.2**	30.1**	1.23**	1.25**	1.23**	0.8**	0.8**	0.78**
S11	35.45**	35.5**	35.2**	0.18**	0.2	0.2	1.11**	1.12	1.15**
S12	42.02**	42.1**	41.9**	0.13**	0.14**	0.12**	1.24**	1.25**	1.23**
S13	31.33**	31.34**	31.3**	0.54**	0.54**	0.51**	0.93**	1	0.97**
S14	29.26**	30**	30**	1.84**	1.84**	1.83**	0.3**	0.5**	0.46**
S15	48.3**	48.3**	48.19**	0.11**	0.12**	0.11**	1.28**	1.28**	1.28**
S16	35.09	35.1	34.8	0.25	0.26	0.23	1.11	1.1	1.11

*Significant at $p < 0.05$; **Significant at $p < 0.01$ level.

Table 3. (a) Chemical characteristics of rural and urban soils; (b) Chemical characteristics of rural and urban soils.

(a)

St.No.	Chloride (mg/g)			Moisture content (%)			Organic matter (g %)		
	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season
S1	0.34**	0.338**	0.339**	1.74**	1.81**	1.76**	0.517**	0.591**	0.569**
S2	0.046**	0.046**	0.045**	12.54**	12.6**	11.8**	3.034**	3.839**	3.836**
S3	0.053**	0.052**	0.052**	5.46**	5.55**	5.54**	1.569**	1.772**	1.765**
S4	0.045**	0.045	0.044**	4.78**	4.9**	4.9**	1.397**	1.626**	1.562**
S5	0.046**	0.046**	0.046**	9.42**	9.62**	9.62**	2.569**	3.696**	3.6**
S6	0.046**	0.047**	0.046**	15.17**	15.25**	15.11**	5.655**	5.769**	4.448**
S7	0.046**	0.044**	0.046**	2.38**	2.4**	2.36**	1.155**	1.579**	1.155**
S8	0.046	0.046	0.045	8.55	8.61	8.59	1.69	2.081	2.512
S9	0.41**	0.406**	0.407**	0.19**	0.22**	0.22**	0.345**	0.367**	0.335**
S10	0.047**	0.047**	0.046**	11.85**	11.9**	11.5**	2.672**	2.838**	3.836**
S11	0.046	0.046	0.045	6.79**	6.82**	6.76**	1.569**	1.94**	1.867**
S12	0.044**	0.044**	0.043**	2.7**	2.9**	2.9**	1.328**	1.688**	1.455**
S13	0.046**	0.046**	0.046	8.67**	8.69**	8.6	2.207**	2.491**	2.255**
S14	0.046**	0.047**	0.046**	13.3**	14**	13.6**	3.5**	3.881**	3.87**
S15	0.046**	0.045**	0.046**	2.35**	2.36**	2.29**	0.69**	0.909**	0.905**
S16	0.046	0.046	0.046**	8.06	8.1	8	1.69	2.081	2.41

(b)

St.No.	o			Total Phosphorus (g %)			Total Potassium (g %)		
	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season
S1	24.5**	42**	12.6**	4.42**	3.75**	3.62**	66.52**	64.67**	25.6**
S2	63.1**	105**	182.7**	52.46**	89.82**	75.31**	189.73**	147.41**	106.1**
S3	44.8**	70**	132.3**	6.21**	30.56**	14.41**	125.45**	145.54**	99.33**
S4	43.5**	63**	119.7**	5.31**	27.68**	13.15**	106.25**	143.53**	90.3**
S5	59.6**	91**	157.5**	43.57**	64.11**	69.21**	163.39**	184.6**	100.7**
S6	70**	168**	252**	159.82**	106.43**	76.36**	189.73**	187.32**	155**
S7	30.1**	56**	107.1**	4.45**	7.86**	5.68**	83.48**	128.46**	60.2**
S8	49.2	77	144.9	25.76	44.64	41.65	133.04	168.86	102.88
S9	20.3**	42**	40.8**	3.53**	0.71**	0.78**	34.38	17.08**	25.59**
S10	61**	98**	182.7**	52.46**	66.07**	50.2**	174.55**	398.44**	301**
S11	47**	70	138.6**	10.67**	33.21**	16.41**	127.23	64.51**	102.34**
S12	35.4**	56**	107.1**	5.31**	14.64**	7.78**	85.27	43.53**	84.28**
S13	49.6**	77**	157.5**	40.09**	63.04**	67.95**	144.2**	178.35**	155**
S14	64.4**	154**	195.3**	159.82**	92.14**	75.52**	189.73**	434.82**	415.5**
S15	29.6**	49**	103.83**	4.45**	4.11**	2.73**	66.52	26.56**	52.68**
S16	47.6	70	144.9	12.46	41.96	27.24	130.8	85.38	106.86

*significant at $p < 0.05$; **significant at $p < 0.01$ level.

Table 4. (a) Heavy metal content in rural and urban soils; (b) Heavy metal content in rural and urban soils.

(a)

St.No.	Pb (mg/kg)			Zn (mg/kg)			Mn (mg/kg)		
	Pre-monsoon season	Monsoon season	Post-monson season	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season
S1	BDL	BDL	BDL	43.2	73.1	40.3	140	100.2	130.3
S2	0.6	0.3	0.44	70.2	352.1	245.4	105.2	310.5	310.6
S3	0.6	0.7	0.56	220.4	100.2	310.1	78.6	69.7	78.3
S4	0.9	0.6	0.76	510	220.9	535.4	401	225.6	512.6
S5	BDL	BDL	BDL	70.4	52.3	92.3	88.6	78.4	89.3
S6	0.6	0.6	0.4	90.1	70	186.5	111.4	142.5	127.9
S7	0.9	0.9	0.86	340.2	470.1	752	540.2	398.6	567
S8	BDL	BDL	BDL	75.4	40.4	72	70.3	63.2	70.2
S9	BDL	BDL	BDL	52.3	86	42	157.4	109.5	510
S10	0.8	0.3	0.4	69	314	252	146.4	152.3	152.1
S11	0.6	0.7	0.61	320	112.3	312.3	65.4	310.5	361.9
S12	0.6	0.6	0.7	360	216.9	502.9	512	213.9	509.4
S13	BDL	BDL	BDL	220	67.5	89.5	88.6	86.5	86.5
S14	0.4	0.5	0.38	98.1	72.7	182.9	115	152.3	138
S15	1	0.8	0.9	360.3	508	760.4	569.8	396.5	538
S16	BDL	BDL	BDL	74.4	52.3	77.1	78.6	68.6	65.8

(b)

St.No.	Cu (mg/kg)			Cr (mg/kg)		
	Pre-monsoon season	Monsoon season	Post-monsoon season	Pre-monsoon season	Monsoon season	Post-monsoon season
S1	19.2	18.7	20.5	0.2	BDL	BDL
S2	90.4	70.6	88.5	0.3	0.2	0.26
S3	79.6	71.9	77.9	0.4	0.2	0.33
S4	78.2	74.7	75.0	0.4	0.4	0.4
S5	79.6	76.2	77.5	0.2	BDL	0.57
S6	80.3	98.4	99.8	0.2	0.3	0.28
S7	95.2	90.5	93.6	0.7	0.6	0.8
S8	90.2	88.1	89.2	BDL	BDL	0.32
S9	20.2	18.9	20.0	0.2	BDL	BDL
S10	92.6	89.8	90.6	0.4	0.3	0.28
S11	86.8	85.4	85.6	0.4	0.2	0.38
S12	82.2	81.2	82.0	0.3	0.3	0.38
S13	87.2	83.7	86.5	0.3	BDL	0.6
S14	95.6	93.3	94.3	0.3	0.3	0.26
S15	98.3	84.1	87.4	0.8	0.6	0.82
S16	88.2	83.3	85.3	0.20	BDL	0.31

BDL-Below Detected Level.

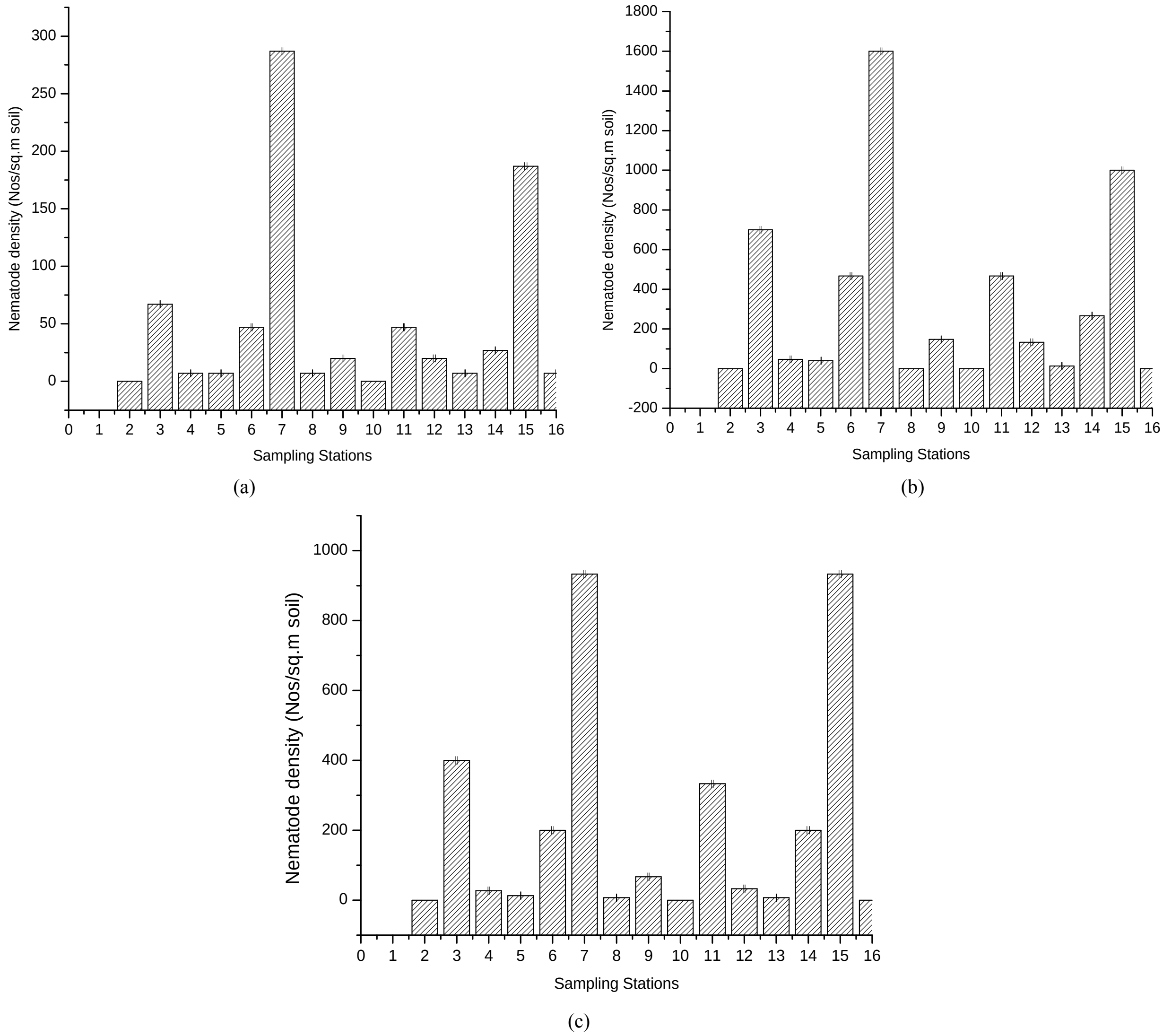

Figure 2. Nematode abundance in the Soils of Study stations during different seasons. (a) Pre-monsoon season; (b) Monsoon season; (c) Post-monsoon season.

the study area showed significant and positive correlation with nematode density. Smiles (1988) [10] in his studies concluded that the rate of soil water movement controls many biological activities such as wilting and germination of plants and hatching of nematode cysts and spores. The spatial variability of water holding capacity and nematode density during the pre-monsoon, monsoon and post monsoon seasons were plotted and the results are shown in **Figure 3**. Water holding capacity showed very high positive correlation with nematode density during the pre monsoon season in all the stations. But in the monsoon season due to the dilution factor, this positive correlation was very high in most of the study stations except in the stations S1, S2, S3, S4 and S16 where this positive correlation was only high. In the post-monsoon season, this positive correlation showed the same pattern as that in the monsoon season except for the stations—S3 and S4 where the positive correlation was reverted back to very high.

Moisture content in the soils of study stations showed a significant and positive correlation with nematode density. Townshend and Webber (1971) [11] showed that the movement and survival of nematodes was maximum in soils with maximum moisture retention. The spatial variability of moisture content and nematode density during the pre-monsoon, monsoon and post-monsoon seasons were plotted and the results are shown in **Figure 4**. Moisture content showed high positive correlation with nematode density during the pre monsoon season in most of the study stations except in the stations, S11, S12, S13, S14 and S15 where this positive correlation was very high. But in the monsoon season due to the dilution factor, this positive correlation was very high all the stations. In the post monsoon season, this positive correla-

Table 5. (a) Correlation of nematode density with physico-chemical characteristics in rural area; (b) Correlation of nematode density with physico-chemical in urban area.

(a)

Parameters	Pre monsoon	Monsoon	Post monsoon
pH	−0.680(**)	−0.841(**)	−0.820(**)
Conductivity	0.974(**)	0.967(**)	0.992(**)
Temperature	−0.223	−0.202	0.000
Pore space	−0.612(**)	−0.692(**)	−0.662(**)
Water holding capacity	0.845(**)	0.972(**)	0.965(**)
Bulk density	−0.817(**)	−0.933(**)	−0.923(**)
Moisture content	0.798(**)	0.892(**)	0.875(**)
Chloride	−0.245	−0.288	−0.277
Organic matter	0.958(**)	0.967(**)	0.804(**)
Total nitrogen	0.719(**)	0.980(**)	0.821(**)
Phosphorus	0.990(**)	0.907(**)	0.766(**)
Potassium	0.680(**)	0.567(**)	0.497(**)
Lead	−0.563(**)	−0.436(*)	−0.774(**)
Zinc	−0.311	−0.183	−0.254
Manganese	−0.275	−0.020	−0.237
Copper	0.333	0.450(**)	0.458(**)
Chromium	−0.464(**)	−0.405(*)	−0.434(**)

(b)

Parameters	Pre monsoon	Monsoon	Post monsoon
pH	−0.307	−0.796(**)	−0.819(**)
Conductivity	0.856(**)	0.989(**)	0.990(**)
Temperature	−0.616(**)	−0.016	−0.059
Pore space	−0.551(**)	−0.641(**)	−0.558(**)
Water holding capacity	0.915(**)	0.978(**)	0.961(**)
Bulk density	−0.893(**)	−0.902(**)	−0.886(**)
Moisture content	0.741(**)	0.875(**)	0.806(**)
Chloride	−0.266	−0.305	−0.256
Organic matter	0.828(**)	0.860(**)	0.756(**)
Total nitrogen	0.711(**)	0.991(**)	0.700(**)
Phosphorus	0.988(**)	0.903(**)	0.814(**)
Potassium	0.693(**)	0.929(**)	0.948(**)
Lead	−0.570(**)	−0.528(**)	−0.767(**)
Zinc	−0.354(*)	−0.254	−0.262
Manganese	−0.313(*)	−0.274	−0.537(**)
Copper	0.342(*)	0.438(**)	0.377(*)
Chromium	−0.138	−0.261	−0.455(**)

Table 6. Significance level of correlation coefficient.

Range	Significance
0.00 - 0.200	Negligible
0.200 - 0.400	Low
0.400 - 0.600	Moderate
0.600 - 0.800	Substantial
0.800 - 1.00	Very high

tion showed the same pattern as that in the monsoon season except for the stations, S7 and S8 where the positive correlation was high.

Organic matter content in the soils of study stations showed a significant and positive correlation with nematode density. This is in agreement with the studies by Gorres *et al.* (1998) [12] which showed that the soils rich in organic matter were reported with the highest nematode density.

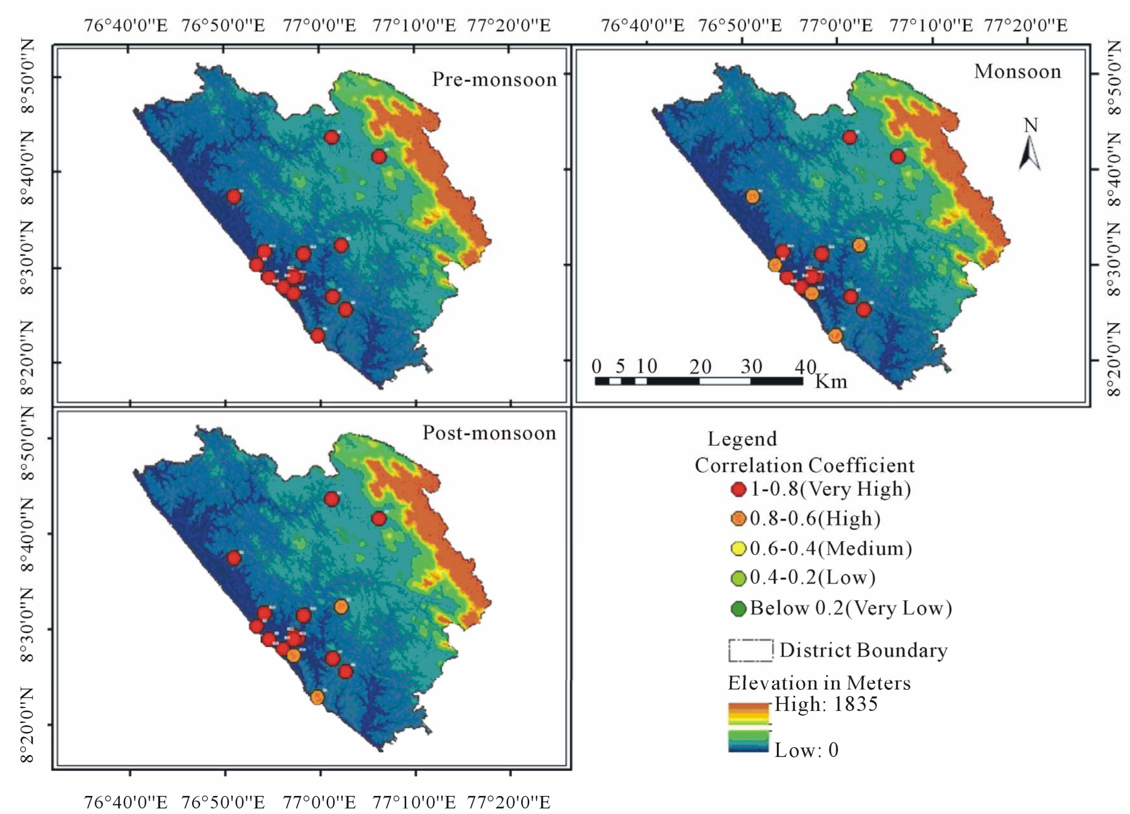

Figure 3. Mapping of water holding capacity and nematode density.

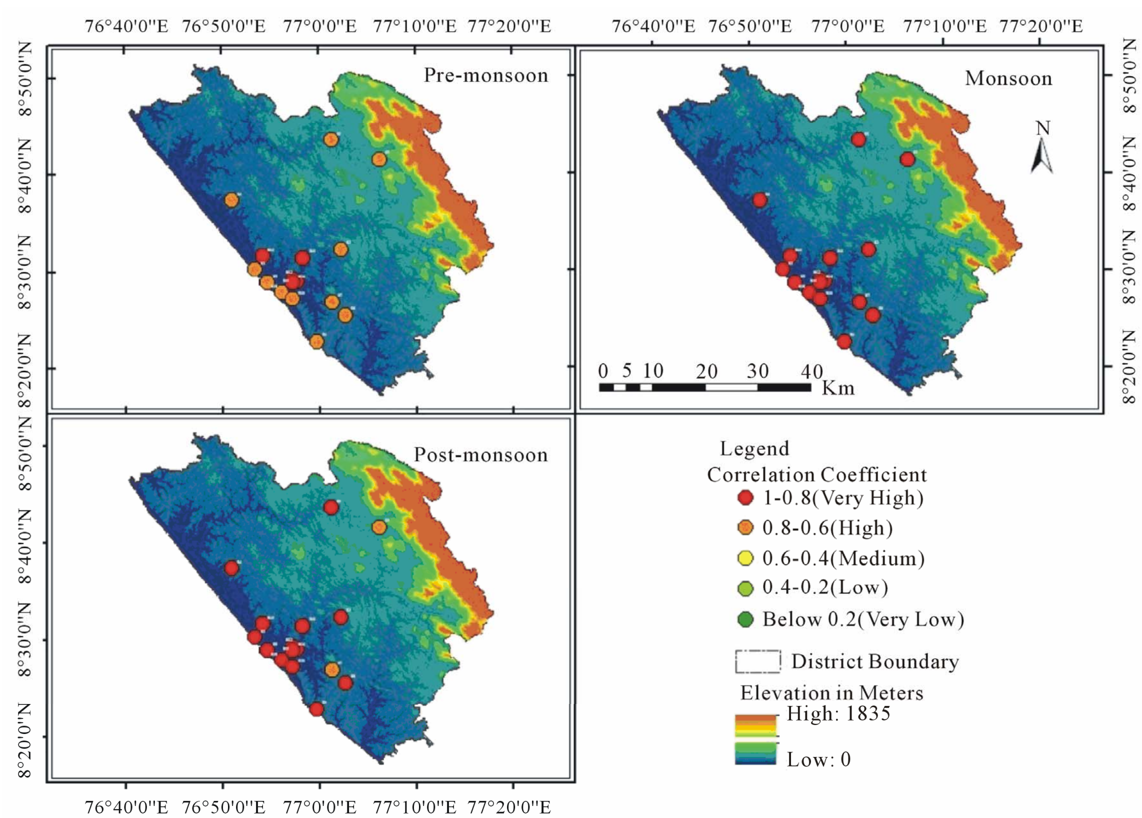

Figure 4. Mapping of moisture content and nematode density.

The spatial variability of organic matter content and nematode density during the pre monsoon, monsoon and post monsoon seasons were plotted and the results are shown in **Figure 5**. Organic matter content showed very high positive correlation with nematode density during the pre monsoon and monsoon seasons in all the stations. In the post monsoon season, this positive correlation showed the same pattern as that in the pre monsoon and monsoon seasons except for the stations, S7 and S9 where the positive correlation was high.

3.4. Mapping of Significantly Negatively Correlated Physico-Chemical Characteristics and Nematode Density in Soil

There is a significant and negative correlation between soil pH and nematode density. This is in agreement with the studies conducted by Murialdo *et al.* (2002) [13] which showed that when the soil pH was high, nematode density was low. The spatial variability of pH content in soil and nematode density during the pre monsoon, monsoon and post monsoon seasons were plotted and the results are shown in **Figure 6**. Soil pH showed very high negative correlation with nematode density during the pre monsoon season in stations, S13, S11, S12, S14 and S15. But in the monsoon season due to the dilution factor, this negative correlation was reduced. In the post monsoon season, the correlation showed the same pattern as that in the monsoon season.

Zinc content in the soils of study stations showed a significant and negative correlation with nematode density. Studies by Shao *et al.* (2008) [14] showed that nematode densities were negatively correlated with zinc concentrations as their population densities decreased with increased zinc concentrations. The spatial variability of zinc content and nematode density during the pre monsoon, monsoon and post monsoon seasons were plotted and the results are shown in **Figure 7**. Zinc content showed high negative correlation with nematode density during the pre monsoon season in the stations, S10, S11, S12 and S13. Due to the dilution factor in the monsoon season, this negative correlation was reduced in all the stations. But this negative correlation was very high in the stations, S14 and S15 in the monsoon season. The effect of raised water holding capacity and moisture content in the monsoon season influenced the soils in the station, S14 resulting in very high negative correlation. In the station, S15 the retention of zinc content in soil will be more due to the dilution factor resulting in the high negative correlation with nematode density. But in the post monsoon season due to the less water content in these soils, the negative correlation will be lesser.

Manganese content in the soils of study stations showed a significant and negative correlation with nematode density. Studies by Norton and Hoffmann (1974) [15] had shown that a negative correlation was observed between manganese content and egg/cyst ratio of nematodes which in turn will be reflected in their population densities. The spatial variability of manganese content in the soils and nematode density during the pre monsoon, monsoon and post monsoon seasons were plotted and the results are shown in **Figure 8**. Manganese content in soils showed the same negative correlation pattern with nematode density in both the pre monsoon and monsoon seasons. But in the post monsoon season, this negative correlation was very high in the station, S14 as these clayey soils were with less water content at this season as compared to that in the monsoon season and will augment the manganese content in soils. This is in agreement with the studies conducted by Rajmohan and Elango (2005) [16] which concluded that soils with high clay content will retain more manganese especially in the post monsoon season. In stations, S4, S6 and S9, the negative correlation was high. In station, S6 with high clay content in soils, the manganese retention will be more in this season. As S6 is a rural market area and S14 is an urban market area, the manganese contamination will be more in the urban market area due to different anthropogenic activities compared to the corresponding rural area. So station, S6 showed only high level of correlation with nematode density in the post monsoon season. In station, S4 which is a road-side area, the manganese deposition will be more in the post monsoon season. Previous studies by Singh and Singh (2006) [17] had shown that the manganese deposition in soils will be more in the post monsoon season in the road-side soils in India. Station, S9 which is an urban coastal area, this negative correlation will be more due to the hyper saline nature of these soils. This is in agreement with the studies by Alongi *et al.* (2005) [18] which showed that hyper saline soils will retain more manganese content in soils during the post monsoon season.

4. Conclusion

The soil physico-chemical characteristics which showed significant (positive and negative) correlations with nematode density were spatially plotted using the Arc GIS 10 to show their spatial variability. Water holding capacity, moisture content and organic matter content showed a significant and positive correlation with nematode density. PH, zinc content and manganese content showed a significant and negative correlation with nematode density. These soil mapping plots showed variations in the monsoon season compared to the pre monsoon and post monsoon seasons due to the dilution factor. In the study area, the organic matter content of urban soils with industrial activities and gasoline service stations was found to be significantly less compared to that of the rural area

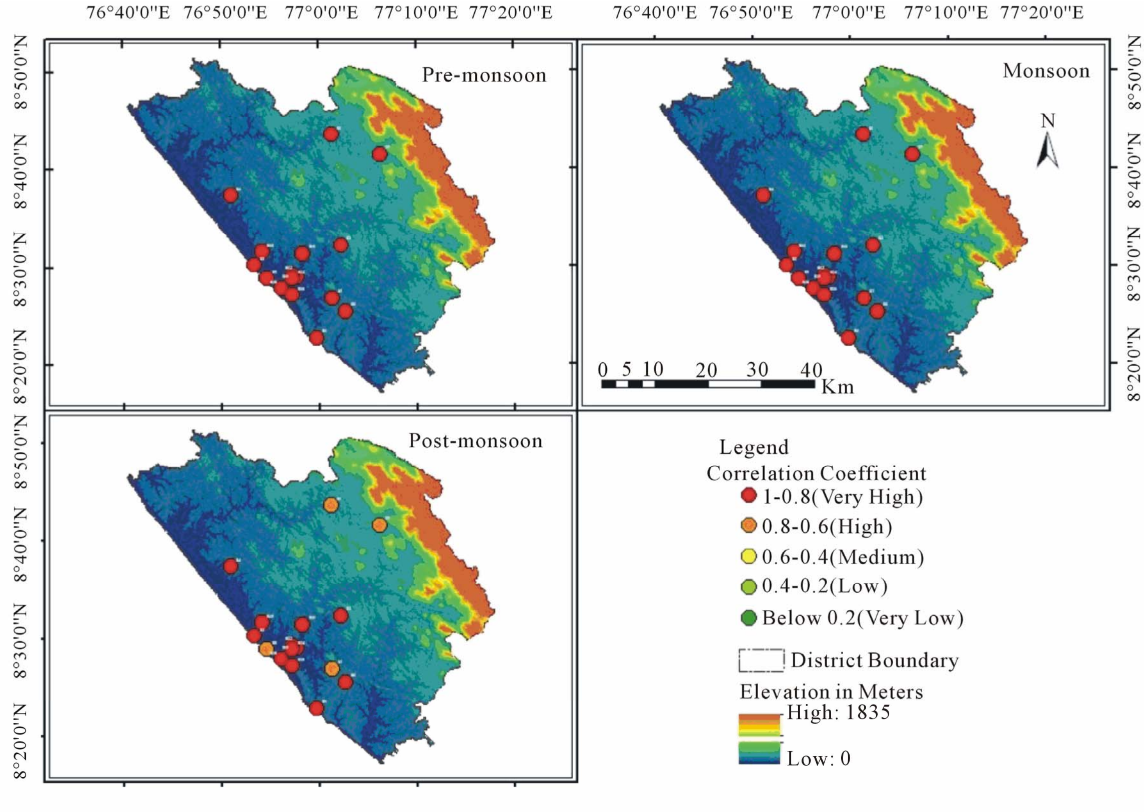

Figure 5. Mapping of organic matter content and nematode density.

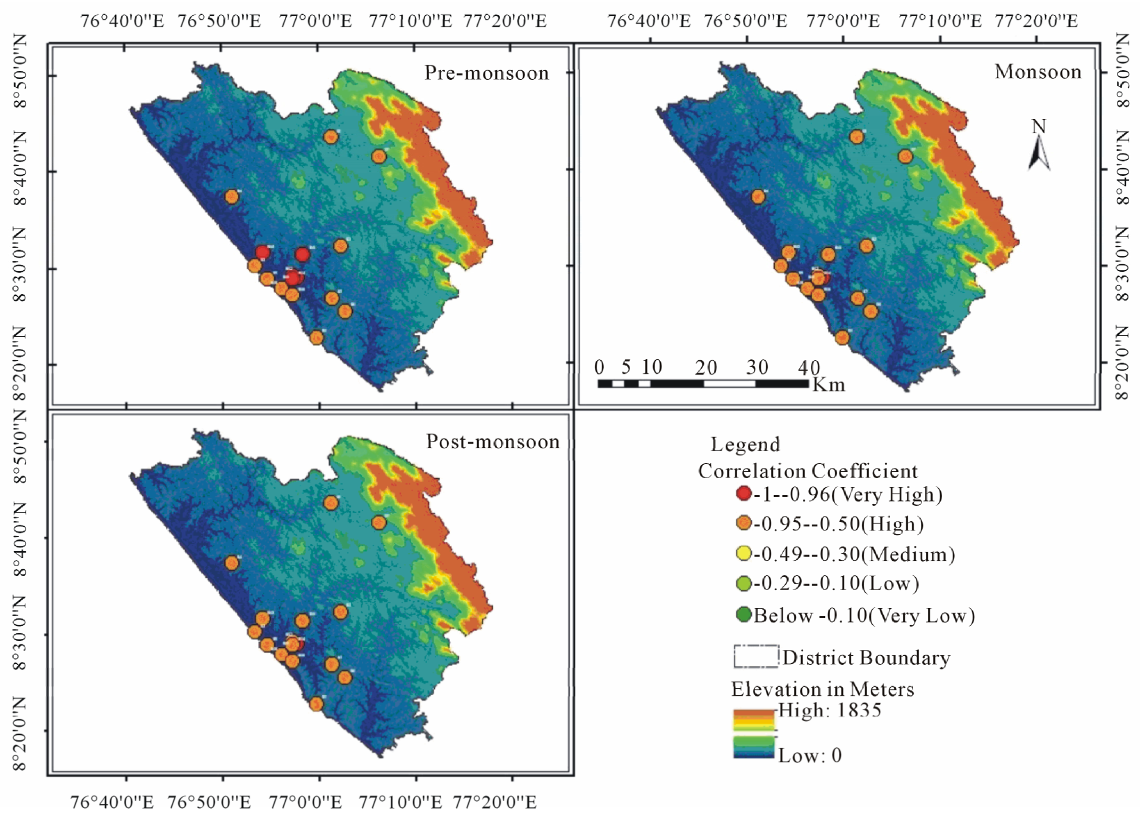

Figure 6. Mapping of pH and nematode density.

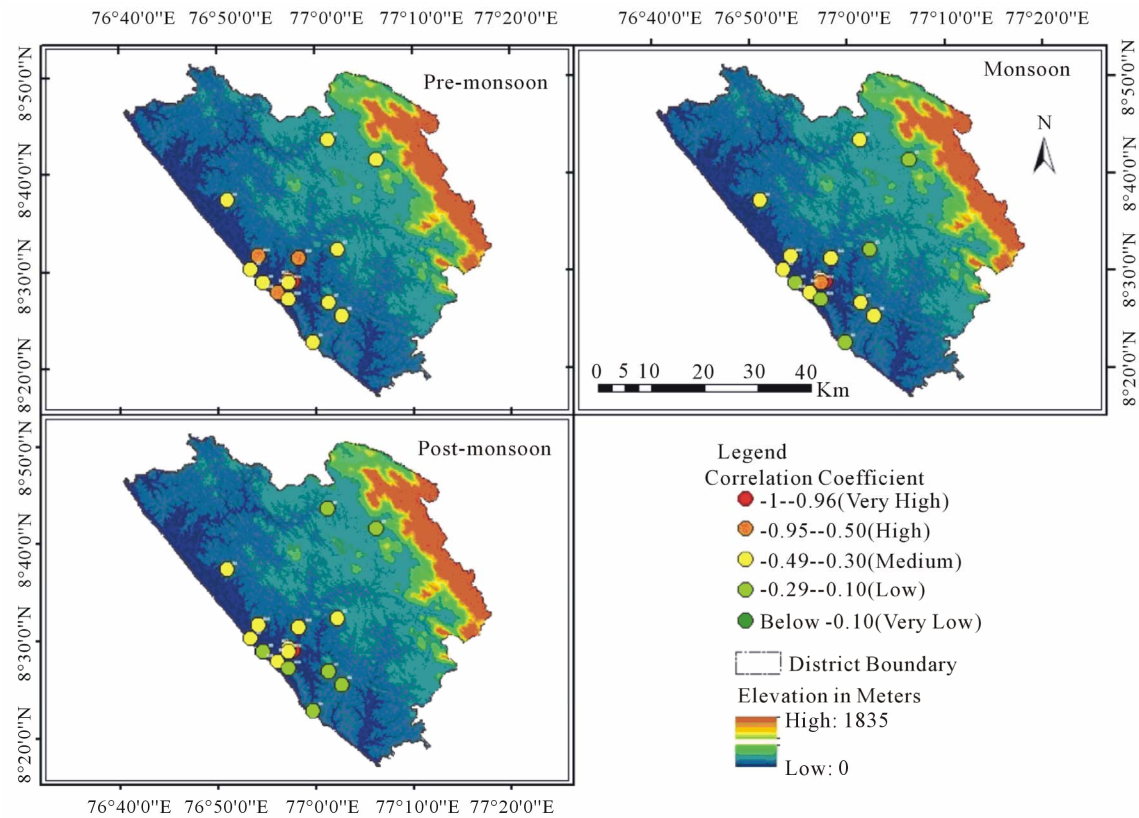

Figure 7. Mapping of zinc content and nematode density.

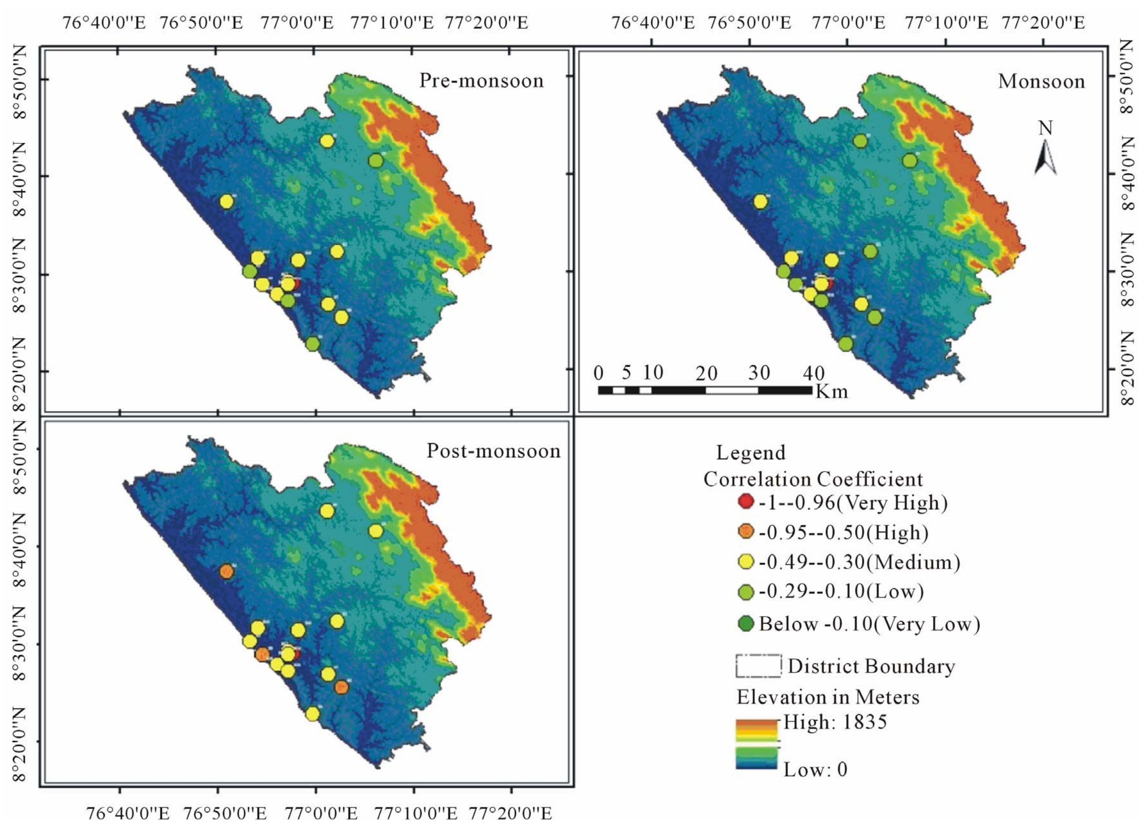

Figure 8. Mapping of manganese content and nematode density.

soils with the same land use patterns. Also the urban area soils were prone to more heavy metal contamination than the rural area soils especially in the gasoline station and roadside areas of Thiruvananthapuram District. This will reduce the soil microbial activity and soil health which in turn will be reflected in the crop production. This soil quality mapping provides a basis for identifying such tension zones and serves as a triggering mechanism for implementation of mitigating strategies.

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