Asian Journal of Water, Environment and Pollution, Vol. 9, No. 4 (2012), pp. 25–32.

Quality Assessment of Soils in Thiruvananthapuram District, South India Using Nematodes as Bio-indicators

K.S. Lakshmy, D.S. Jaya* and C. Mohandas[1]

Department of Environmental Sciences, University of Kerala, Karyavattom P.O.
Thiruvananthapuram – 698 851
[1]Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram – 695 017
✉ jayads64@yahoo.com

Received July 14, 2011; revised and accepted September 7, 2012

Abstract: Nematodes represent a very abundant group of soil organisms in the food web and are important for soil quality. They are both taxonomically and functionally diverse, respond quickly to soil perturbation and have much potential as indicators of soil health. In the present study, the impact of contaminants on soil health has been addressed through the measurement of nematode abundance. Different categories of land use areas in the rural and urban sites of Thiruvananthapuram District receiving different types of contaminants were selected for this study after conducting a reconnaissance survey of the study area. Control areas which are in a benign environment were also identified in both rural and urban areas of Thiruvananthapuram District. Soil samples were collected from the selected stations in pre-monsoon, monsoon and post-monsoon seasons during the period April 2009 to January 2010 from the selected stations, and the physico-chemical characteristics, heavy metal content and nematode abundance were determined. The results showed that the soils of market area having the highest amount of decaying matter were rich in nematode density. The reason for this may be due to the fact that saprophytic nematodes can flourish well in that environment. It was also noted that the nematodes were scarce in the soils of gasoline station area contaminated with hazardous wastes and chemicals which will unfavourably affect the nematode population. The nematode abundance in the soils of the study stations are in the order: market area > sewage disposal area > agricultural area > benign environment > industrial area > road-side area > gasoline station area > coastal area. Nematodes were abundant in areas where the heavy metal concentrations were low, thus indicating a negative correlation.

Key words: Bio-indicator, contaminants, soil, nematodes, heavy metals.

Introduction

The soil has been for ages a major medium for the disposal of a variety of wastes, owing to its colloidal organic matter and other related properties. Organic compounds and natural wastes added to the soil are usually destroyed in the upper zones or are retained in the surface horizons long enough for them to be entirely mineralised. Many toxins added to the soils by different anthropogenic activities can build up to concentrations that become serious threats to plant and animal health. The quality of soil can be badly affected by the presence of metal pollutants (Alloway, 1996). The use of indicators and indices for the evaluation and assessment of the environmental status of different ecosystem is becoming a widespread procedure to analyse the various and often complex components of a system. The utilization of nematodes as a useful monitor of environmental conditions and ecosystem function was popular (Bongers, 1990).

*Corresponding Author

The nematodes play an important role in the breakdown and recycling of organic matter, so they are analysed as an integrated measure of the functional state of soils. The diversity and abundance of nematodes can be significantly reduced by air-borne pollutants and by heavy metal contaminated wastes (Richard et al., 2002). Excess heavy metal accumulation in soils is toxic to humans and other animals. Only few studies has been undertaken to assess the heavy metal status in the soils of Thiruvananthapuram District (Sathyanarayana, 1997). The objectives of the present study are to determine the soil physico-chemical properties, heavy metal content, abundance of nematodes and to find out the present soil quality in the selected urban and rural areas of Thiruvananthapuram District using nematodes as bio-indicators.

Materials and Methods

The study area is the Thiruvananthapuram District in Kerala state, South India which covers an area of 2192 square kilometres. Reconnaissance surveys were conducted to select the study stations in various urban and rural areas of Thiruvananthapuram District, and located using the Survey of India toposheets. Sixteen sampling stations were selected including coastal areas, market areas, sewage disposal areas, industrial areas, road-side areas, gasoline station areas, agricultural areas and undisturbed areas i.e. eight in the rural areas (S1 - Vizhinjam, S2 - Vilappilssala, S3 - Kochuveli, S4 - Mangalapuram, S5 - Palode, S6 - Balaramapuram, S7 - Pallichal and S8 - Anappara) and eight in the urban areas (S9 - Shangumugham, S10 - Valiathura, S11 - Peroorkkada, S12 - Thampanoor, S13 - Sreekaryam, S14 - Chalai, S15 - Karamana and S16 - Ambalathara) for the present study. Soil samples (0-15 cm depth) from each sampling station 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 soil samples collected from five different sites in each station. Soil sampling and analysis of soil physico-chemical characteristics were carried out according to the standard procedures of Michael (1984) and Gupta (1999). The concentration of the heavy metals viz. lead, chromium, manganese, copper and zinc in the acid digested soil samples were determined (Saxena, 1994) using an Atomic Absorption Spectrophotometer (Model, GBC 932 AA). Density of free-living nematodes in the soils of the study areas was determined and calculated following the standard procedures of Dasgupta (1998) and Goodey (1963). The data given in the tables and figures are expressed as the mean ± S.D.

Results and Discussion

The results of the physico-chemical characteristics of soils in different seasons are given in Tables 1-6, and the soil nematode densities are depicted in Figures 1, 2 and 3 respectively. The results of nematode density/abundance in soil show a positive correlation with the soil moisture content. Papendick and Campbell (1985)

Table 1: Soil physical characteristics in the pre-monsoon season

St. No.	*pH*	*Conductivity (mho/cm)*	*Temperature (°C)*	*Pore space (%)*	*Water holding capacity (%)*	*Bulk density (g/cc)*
S1	7 .0 ± 0.07	0.07 ± 0.09	32.6 ± 002	57.80 ± 0.01	0.04 ± 0.02	1.56 ± 0.09
S2	5 .0 ± 0.06	1.52 ± 0.09	30.0 ± 0.003	30.19 ± 0.09	1.33 ± 0.05	0.71 ± 0.01
S3	5.7 ± 0.01	0.26 ± 0.03	32.5 ± 0.002	38.32 ± 0.05	0.15 ± 0.06	1.14 ± 0.03
S4	6.1 ± 0.02	0.26 ± 0.07	31.6 ± 0.006	40.12 ± 0.07	0.15 ± 0.02	1.23 ± 0.03
S5	5.3 ± 0.07	1.09 ± 0.06	29.9 ± 0.003	30.28 ± 0.06	0.79 ± 0.02	0.50 ± 0.01
S6	4.7 ± 0.04	3.14 ± 0.01	31.1 ± 0.009	25.43 ± 0.01	1.84 ± 0.05	0.20 ± 0.01
S7	6.2 ± 0.05	0.14 ± 0.02	33.0 ± 0.007	45.25 ± 0.05	0.13 ± 0.07	1.26 ± 0.03
S8	5.4 ± 0.08	0.44 ± 0.02	29.5 ± 0.004	32.45 ± 0.09	0.27 ± 0.01	1.09 ± 0.08
S9	5.7 ± 0.06	0.06 ± 0.05	32.6 ± 0.006	58.87 ± 0.03	0.02 ± 0.09	1.58 ± 0.05
S10	8.7 ± 0.03	1.33 ± 0.08	32 .0 ± 0.001	30.19 ± 0.01	1.23 ± 0.03	0.80 ± 0.08
S11	5.7 ± 0.06	0.27 ± 0.04	32.2 ± 0.005	35.45 ± 0.09	0.18 ± 0.07	1.11 ± 0.04
S12	6.1 ± 0.01	0.25 ± 0.05	31.3 ± 001	42.02 ± 0.03	0.13 ± 0.03	1.24 ± 0.05
S13	5.3 ± 0.05	0.52 ± 0.04	32.0 ± 0.006	31.33 ± 0.03	0.54 ± 0.01	0.93 ± 0.09
S14	4.8 ± 0.02	1.6 ± 0.06	31 .0 ± 0.004	29.26 ± 0.01	1.84 ± 0.06	0.30 ± 0.07
S15	6.9 ± 0.01	0.07 ± 0.01	33 .0 ± 0.007	48.3 ± 0.03	0.11 ± 0.06	1.28 ± 0.02
S16	5.7 ± 0.07	0.33 ± 0.03	31.1 ± 0.009	35.09 ± 0.03	0.25 ± 0.01	1.11 ± 0.03

Table 2: Soil physical characteristics in the monsoon season

St. No.	*pH*	*Conductivity (mho/cm)*	*Temperature (°C)*	*Pore space (%)*	*Water holding capacity (%)*	*Bulk density (g/cc)*
S1	7.7 ± 0.07	0.049 ± 0.09	30.0 ± 0.002	57.80 ± 0.06	0.05 ± 0.01	1.58 ± 0.03
S2	5.7 ± 0.01	0.880 ± 0.01	29.7 ± 0.001	30.20 ± 0.01	1.34 ± 0.01	0.72 ± 0.03
S3	6.4 ± 0.03	0.150 ± 0.06	30.0 ± 0.002	38.25 ± 0.03	0.17 ± 0.03	1.14 ± 0.07
S4	7.1 ± 0.01	0.082 ± 0.03	30.0 ± 0.003	40.13 ± 0.07	0.15 ± 0.03	1.24 ± 0.01
S5	6.0 ± 0.07	0.245 ± 0.05	29 .0 ± 0.006	30.30 ± 0.04	0.75 ± 0.04	0.90 ± 0.02
S6	5.0 ± 0.05	1.350 ± 0.01	30.0 ± 0.002	25.40 ± 0.02	1.87 ± 0.08	0.30 ± 0.01
S7	7.3 ± 0.07	0.072 ± 0.05	30.0 ± 0.002	45.30 ± 0.06	0.13 ± 0 04	1.25 ± 0.04
S8	6.2 ± 0.01	0.225 ± 0.02	29.8 ± 0.001	32 .00 ± 0.05	0.27 ± 0.09	1.10 ± 0.01
S9	8.3 ± 0.04	0.042 ± 0.05	30.0 ± 0.002	58.86 ± 0.09	0.03 ± 0.06	1.60 ± 0.06
S10	5.7± 0.09	0.528 ± 0.06	30.0 ± 0.002	30.20 ± 0.04	1.25 ± 0 09	0.80 ± 0.04
S11	6.3 ± 0.01	0.174 ± 0.09	30.0 ± 0.001	35.50 ± 0.01	0.20 ± 0.03	1.12 ± 0.07
S12	7.3 ± 0.04	0.073 ± 0.05	30.0 ± 0.001	42.10 ± 0.06	0.14 ± 0.08	1.25 ± 0.09
S13	6.2 ± 0.09	0.225 ± 0.04	29.9 ± 0.001	31.34 ± 0.03	0.54 ± 0.06	1.00 ± 0.05
S14	5.3 ± 0.09	1.305 ± 0.03	30.0 ± 0.002	30 .00 ± 0.07	1.84 ± 0.02	0.50 ± 0.03
S15	7.5 ± 0.03	0.064 ± 0.01	30.0 ± 0.002	48.30 ± 0.04	0.12 ± 0.05	1.28 ± 0.02
S16	6.2 ± 0.06	0.197 ± 0.06	29.8 ± 0.003	35.10 ± 0.04	0.26 ± 0.07	1.10 ± 0.03

Table 3: Soil physical characteristics in the post-monsoon season

St. No.	*pH*	*Conductivity (mho/cm)*	*Temperature (°C)*	*Pore space (%)*	*Water holding capacity (%)*	*Bulk density (g/cc)*
S1	7.1 ± 0.05	0.032 ± 0.09	31.5 ± 0.001	57.8 ± 0.01	0.03 ± 0.02	1.57 ± 0.03
S2	5.0 ± 0.05	0.463 ± 0.03	31.0 ± 0.002	30.0 ± 0.03	1.32 ± 0.01	0.71 ± 0.01
S3	6.3 ± 0.03	0.094 ± 0.04	31.5 ± 0.001	38.19 ± 0.03	0.15 ± 0.03	1.20 ± 0.03
S4	6.5 ± 0.04	0.057 ± 0.05	31.4 ± 0.001	40.1 ± 0.05	0.14 ± 0.04	1.23 ± 0.03
S5	5.5 ± 0.03	0.326 ± 0.03	31.0 ± 0.002	30.2 ± 0.03	0.74 ± 0.01	0.90 ± 0.03
S6	4.9 ± 0.02	1.343 ± 0.03	31.4 ± 0.002	25.3 ± 0.01	1.86 ± 0.06	0.30 ± 0.09
S7	6.7 ± 0.01	0.048 ± 0.07	31.4 ± 0.003	44.9 ± 0.01	0.11 ± 0.02	1.25 ± 0.07
S8	5.9 ± 0.01	0.211 ± 0.02	31.0 ± 0.002	32.0 ± 0.05	0.25 ± 0.01	1.11 ± 0.02
S9	7.3 ± 0.04	0.028 ± 0.03	31.5 ± 0.005	58.84 ± 0.06	0.03 ± 0.02	1.60 ± 0.03
S10	5.3 ± 0.09	0.451 ± 0.01	31.3 ± 0.003	30.1 ± 0.01	1.23 ± 0.03	0.78 ± 0.02
S11	6.2 ± 0.03	0.099 ± 0.05	31.1 ± 0.002	35.2 ± 0.08	0.20 ± 0.08	1.15 ± 0.09
S12	6.7 ± 0.05	0.049 ± 0.01	31.4 ± 0.004	41.9 ± 0.02	0.12 ± 0.09	1.23 ± 0.03
S13	5.7 ± 0.05	0.214 ± 0.01	31.2 ± 0.001	31.3 ± 0.06	0.51 ± 0.02	0.97 ± 0.06
S14	4.9 ± 0.04	0.865 ± 0.05	31.3 ± 0.002	30.0 ± 0.02	1.83 ± 0.02	0.46 ± 0.01
S15	7.0 ± 0.01	0.040 ± 0.06	31.4 ± 0.003	48.19 ± 0.01	0.11 ± 0.01	1.28 ± 0.05
S16	6.0 ± 0.05	0.118 ± 0.02	31.0 ± 0.001	34.8 ± 0.02	0.23 ± 0.01	1.11 ± 0.09

observed that the existence and activities of soil organisms especially nematodes depend on the availability of water. Soil pore space negatively influences nematode abundance. Studies by Kazunori et al. (2003) had shown that water-filled pore space allowed greater mobility of nematodes but reduced the numbers remaining in the space. Nematodes were completely absent in the coastal areas (S1 and S9) and this may be due to the high soil chloride content in these areas. Fitter and Hay (1987) found that excess salt content seriously affects soil water balance and subsequently the growth of soil micro fauna. Water-holding capacity of soils in different stations of the study area showed positive correlation with nematode abundance. Smiles (1988) 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.

In the present study, the highest population densities of nematodes were observed in the market areas (S6 and S14) where the soils are rich in organic content. Studies by Kogel-Knabner (2000) also confirmed that soil

Table 4: Soil chemical characteristics in the pre-monsoon season

St. No.	*Moisture content (%)*	*Chloride (mg/g)*	*Organic matter (%)*	*Total nitrogen (%)*	*Phosphorus (%)*	*Potassium (%)*
S1	1.74 ± 0.03	0.340 ± 0.04	0.517 ± 0.03	24.5 ± 0.03	4.42 ± 0.05	66.52 ± 0.04
S2	12.54 ± 0.02	0.046 ± 0.01	3.034 ± 0.08	63.1 ± 0.06	52.46 ± 0.03	189.73 ± 0.09
S3	5.46 ± 0.06	0.053 ± 0.01	1.569 ± 0.01	44.8 ± 0.05	6.21 ± 0.01	125.45 ± 0.05
S4	4.78 ± 0.05	0.045 ± 0.01	1.397 ± 0.04	43.5 ± 0.03	5.31 ± 0.01	106.25 ± 0.08
S5	9.42 ± 0.01	0.046 ± 0.04	2.569 ± 0.04	59.6 ± 0.01	43.57 ± 0.03	163.39 ± 0.03
S6	15.17 ± 0.01	0.047 ± 0.02	5.655 ± 0.01	70.0 ± 0.01	159.82 ± 0.01	189.73 ± 0.02
S7	2.38 ± 0.06	0.046 ± 0.02	1.155 ± 0.03	30.1 ± 0.09	4.45 ± 0.01	83.48 ± 0.03
S8	8.55 ± 0.01	0.046 ± 0.05	1.690 ± 0.01	49.2 ± 0.03	25.76 ± 0.01	133.04 ± 0.01
S9	0.19 ± 0.04	0.410 ± 0.02	0.345 ± 0.05	20.3 ± 0.01	3.53 ± 0.09	34.38 ± 0.02
S10	11.85 ± 0.06	0.047 ± 0.04	2.672 ± 0.06	61.0 ± 0.03	52.46 ± 0.03	174.55 ± 0.04
S11	6.79 ± 0.05	0.046 ± 0.01	1.569 ± 0.08	47.0 ± 0.05	10.67 ± 0.07	127.23 ± 0.05
S12	2.70 ± 0.02	0.044 ± 0.01	1.328 ± 0.09	35.4 ± 0.03	5.31 ± 0.02	85.27 ± 0.02
S13	8.67 ± 0.06	0.046 ± 0.06	2.207 ± 0.08	49.6 ± 0.02	40.09 ± 0.06	144.20 ± 0.01
S14	13.3 ± 0.02	0.046 ± 0.01	3.500 ± 0.02	64.4 ± 0.05	159.82 ± 0.06	189.73 ± 0.05
S15	2.35 ± 0.06	0.046 ± 0.02	0.690 ± 0.06	29.6 ± 0.06	4.45 ± 0.08	66.52 ± 0.09
S16	8.06 ± 0.02	0.046 ± 0.03	1.690 ± 0.09	47.6 ± 0.04	12.46 ± 0.02	130.8 ± 0.09

Table 5: Soil chemical characteristics in the monsoon season

St. No.	*Moisture content (%)*	*Chloride (mg/g)*	*Organic matter (%)*	*Total nitrogen (%)*	*Phosphorus (%)*	*Potassium (%)*
S1	1.81 ± 0.02	0.338 ± 0.01	0.341 ± 0.06	42 ± 0.09	3.75 ± 0.04	64.67 ± 0.01
S2	12.6 ± 0.01	0.046 ± 0.06	3.139 ± 0.08	105 ± 0.05	89.82 ± 0.03	147.41 ± 0.02
S3	5.55 ± 0.03	0.052 ± 0.06	1.672 ± 0.01	70 ± 0.04	30.56 ± 0.01	45.54 ± 0.07
S4	4.90 ± 0.05	0.045 ± 0.03	1.126 ± 0.06	63 ± 0.02	27.68 ± 0.09	43.53 ± 0.01
S5	9.62 ± 0.01	0.046 ± 0.03	2.696 ± 0.01	91 ± 0.03	64.11 ± 0.01	284.6 ± 0.06
S6	15.25 ± 0.01	0.047 ± 0.02	5.769 ± 0.06	168 ± 0.01	106.43 ± 0.03	187.32 ± 0.05
S7	2.40 ± 0.03	0.044 ± 0.04	0.579 ± 0.05	56 ± 0.05	7.86 ± 0.01	28.46 ± 0.06
S8	8.61 ± 0.02	0.046 ± 0.02	2.081 ± 0.03	77 ± 0.03	44.64 ± 0.01	168.86 ± 0.05
S9	0.22 ± 0.09	0.406 ± 0.05	0.167 ± 0.03	42 ± 0.06	0.71 ± 0.02	17.08 ± 0.09
S10	11.9 ± 0.05	0.047 ± 0.08	2.833 ± 0.02	98 ± 0.07	66.07 ± 0.07	398.44 ± 0.05
S11	6.82 ± 0.09	0.046 ± 0.02	1.740 ± 0.08	70 ± 0.08	33.21 ± 0.05	64.51 ± 0.09
S12	2.90 ± 0.03	0.044 ± 0.05	0.688 ± 0.05	56 ± 0.01	14.64 ± 0.04	43.53 ± 0.02
S13	8.69 ± 0.04	0.046 ± 0.01	2.491 ± 0.03	77 ± 0.01	63.04 ± 0.02	178.35 ± 0.03
S14	14.00 ± 0.01	0.047 ± 0.04	3.481 ± 0.01	154 ± 0.01	92.14 ± 0.02	434.82 ± 0.01
S15	2.36 ± 0.06	0.045 ± 0.03	0.409 ± 0.01	49 ± 0.07	4.11 ± 0.08	26.56 ± 0.03
S16	8.10 ± 0.09	0.046 ± 0.09	2.081 ± 0.03	70 ± 0.01	41.96 ± 0.03	85.38 ± 0.02

organic matter influences the availability of nutrients for the growth of soil micro fauna. This indicates active decomposition, as the saprophytic, bacterial and fungal feeding nematodes grow and multiply which encourages predaceous type *Mononchus* spp. Results of this study also show that the nematodes were abundant in soils rich with nitrogen, phosphorus and potassium. The nematode abundance in the soils of the study stations are in the order: market area > sewage disposal area > agricultural area > benign environment > industrial area > road-side area > gasoline station area > coastal area. The studies by Lee and Foster (1991) also showed that the nematodes were abundant in fertile soils. The nutrient status of urban soils were found to be more degraded compared to the rural soils of corresponding sampling stations of the study area.

The results of the heavy metal content in the rural and urban soils in the study area during the pre-monsoon, monsoon and post-monsoon seasons are given in Tables 7, 8 and 9 respectively. In all the sampling stations, concentration of lead is below the standard permissible levels of 100 mg/kg (Awashthi, 2000). The concentration of zinc in ten stations studied was below the permissible level of 300 mg/kg (Ewers, 1991) except in sampling stations S3 and S11 (industrial areas), S4 and S12 (road side areas) and S7 and S15 (gasoline station areas) which were areas prone to high levels of pollution. High concentrations of heavy metals (Pb, Zn and Mn) were recorded in the soils of urban and rural study stations (S4, S7, S12 and S15) with different anthropogenic activities compared to that in the benign environment (S8 and S16). In all the sampling stations, the concentration of manganese is below the permissible level of 2000 mg/kg (Ewers, 1991). The concentration of manganese recorded high values in sampling stations S4 and S12, which were road side areas and may be due to the heavy traffic intensity in these areas. Studies showed that prolonged exposure to high concentrations of manganese will induce severe defects of life span, development and reproduction in nematodes possibly by affecting the stress response and expression of antioxidant genes in *Caenorhabditis elegans* (Jing et al., 2009). Sara et al. (2006) studied the impact of residual heavy metals on soil nematodes in the Guadiamar River Basin and zinc was responsible for the major negative impact. In all selected stations of Thiruvananthapuram District studied, the concentration of chromium was detected below the standard permissible level of 100 mg/kg (Ewers, 1991).

Table 6: Soil chemical characteristics in the post-monsoon season

St. No.	*Moisture content (%)*	*Chloride (mg/g)*	*Organic matter (%)*	*Total nitrogen (%)*	*Phosphorus (%)*	*Potassium (%)*
S1	1.76 ± 0.05	0.339 ± 0.03	0.169 ± 0.03	12.6 ± 0.05	BDL	25.60 ± 0.02
S2	11.8 ± 0.03	0.045 ± 0.01	3.836 ± 0.09	182.7 ± 0.06	75.31 ± 0.03	316.10 ± 0.07
S3	5.54 ± 0.01	0.052 ± 0.02	1.765 ± 0.05	132.3 ± 0.09	14.41 ± 0.05	99.33 ± 0.05
S4	4.90 ± 0.07	0.047 ± 0.09	1.562 ± 0.08	119.7 ± 0.04	13.15 ± 0.06	90.30 ± 0.08
S5	9.62 ± 0.05	0.046 ± 0.03	3.700 ± 0.05	157.5 ± 0.07	69.21 ± 0.01	210.70 ± 0.03
S6	15.11 ± 0.05	0.046 ± 0.02	4.448 ± 0.02	252 ± 0.02	76.36 ± 0.06	155.00 ± 0.03
S7	2.36 ± 0.06	0.046 ± 0.01	1.155 ± 0.05	107.1 ± 0.05	5.68 ± 0.08	60.20 ± 0.02
S8	8.59 ± 0.04	0.045 ± 0.03	2.512 ± 0.03	144.9 ± 0.01	41.65 ± 0.04	112.88 ± 0.04
S9	0.22 ± 0.06	0.407 ± 0.01	0.135 ± 0.06	BDL	0.78 ± 0.01	25.59 ± 0.02
S10	11.5 ± 0.03	0.046 ± 0.04	3.836 ± 0.05	182.7 ± 0.03	50.2 ± 0.02	301.00 ± 0.01
S11	6.76 ± 0.01	0.045 ± 0.05	1.867 ± 0.02	138.6 ± 0.06	16.41 ± 0.07	102.34 ± 0.07
S12	2.90 ± 0.01	0.046 ± 0.05	1.155 ± 0.01	107.1 ± 0.02	7.78 ± 0.03	84.28 ± 0.05
S13	8.60 ± 0.04	0.045 ± 0.07	3.055 ± 0.05	157.5 ± 0.03	67.95 ± 0.01	155.00 ± 0.04
S14	13.60 ± 0.02	0.046 ± 0.02	3.870 ± 0.01	195.3 ± 0.02	75.52 ± 0.03	415.50 ± 0.03
S15	2.29 ± 0.02	0.045 ± 0.01	0.915 ± 0.05	43.83 ± 0.06	2.73 ± 0.05	52.68 ± 0.02
S16	8.00 ± 0.01	0.046 ± 0.04	2.410 ± 0.03	144.9 ± 0.01	27.24 ± 0.09	106.86 ± 0.01

BDL: Below Detected Level

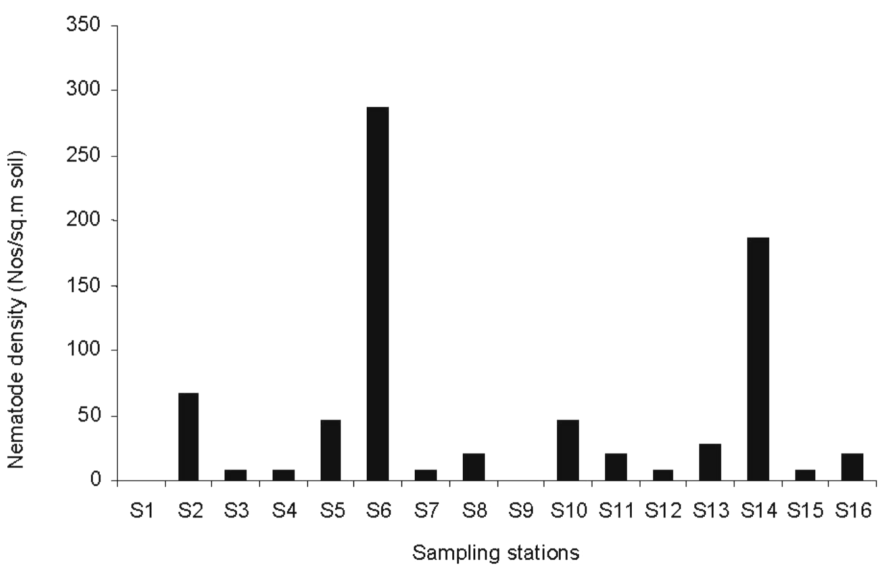

Figure 1: Nematode density in soils during pre-monsoon season.

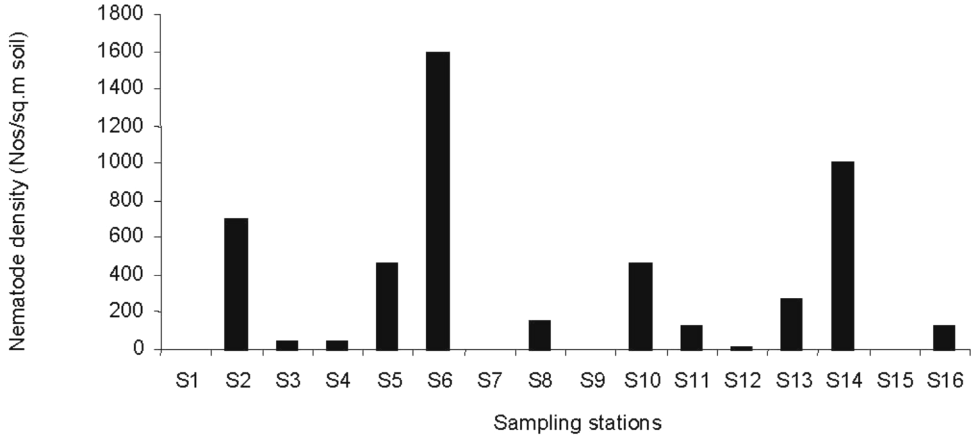

Figure 2: Nematode density in soils during monsoon season.

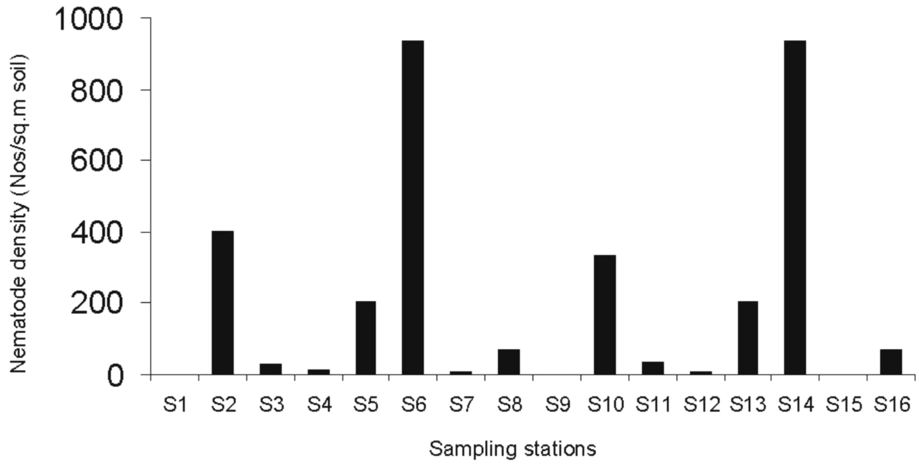

Figure 3: Nematode density in soils during post-monsoon season.

Table 7: Soil heavy metal content in the pre-monsoon season

St. No.	*Pb (mg/kg)*	*Zn (mg/kg)*	*Mn (mg/kg)*	*Cu (mg/kg)*	*Cr (mg/kg)*
S1	BDL	43.2 ± 0.005	140.0 ± 0.008	19.2 ± 0.007	0.2 ± 0.001
S2	0.6 ± 0.006	70.2 ± 0.003	105.2 ± 0.001	90.4 ± 0.001	0.3 ± 0.003
S3	0.6 ± 0.004	220.4 ± 0.006	78.6 ± 0.003	79.6 ± 0.003	0.4 ± 0.003
S4	0.9 ± 0.004	510.0 ± 0.002	401.0 ± 0.007	78.2 ± 0.002	0.4 ± 0.001
S5	BDL	70.4 ± 0.002	88.6 ± 0.002	79.6 ± 0.003	0.2 ± 0.001
S6	0.6 ± 0.006	90.1 ± 0.001	111.4 ± 0.008	80.3 ± 0.006	0.2 ± 0.007
S7	0.9 ± 0.007	340.2 ± 0.007	540.2 ± 0.002	95.2 ± 0.002	0.7 ± 0.005
S8	BDL	75.4 ± 007	70.3 ± 0.005	90.2 ± 0.001	BDL
S9	BDL	52.3 ± 0.005	157.4 ± 0.007	20.2 ± 0.009	0.2 ± 0.006
S10	0.8 ± 0.007	69.0 ± 0.008	146.4 ± 0.009	92.6 ± 0.005	0.4 ± 0.009
S11	0.6 ± 0.005	320.0 ± 0.002	65.4 ± 0.004	86.8 ± 0.007	0.4 ± 0.009
S12	0.6 ± 0.003	360.0 ± 0.005	512.0 ± 0.009	82.2 ± 0.005	0.3 ± 0.002
S13	BDL	220.0 ± 0.004	88.6 ± 0.006	87.2 ± 0.003	0.3 ± 0.008
S14	0.4 ± 0.001	98.1 ± 0.004	115.0 ± 0.006	95.6 ± 0.001	0.3 ± 0.006
S15	1.0 ± 0.001	360.3 ± 0.006	569.8 ± 0.001	98.3 ± 0.001	0.8 ± 0.006
S16	BDL	74.4 ± 0.003	78.6 ± 0.003	88.2 ± 0.005	BDL

BDL: Below Detected Level

Table 8: Soil heavy metal content in the monsoon season

St. No.	Pb (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)
S1	BDL	73.1 ± 0.004	100.2 ± 0.001	18.7 ± 0.009	BDL
S2	0.3 ± 0.005	352.1 ± 0.008	310.5 ± 0.008	70.6 ± 0.005	0.2 ± 0.009
S3	0.7 ± 0.006	100.2 ± 0.007	69.7 ± 0.006	71.9 ± 0.001	0.2 ± 0.006
S4	0.6 ± 0.001	220.9 ± 0.003	225.6 ± 0.009	74.7 ± 0.001	0.4 ± 0.003
S5	BDL	52.3 ± 0.005	78.4 ± 0.007	76.2 ± 0.008	BDL
S6	0.6 ± 0.004	70.0 ± 0.004	142.5 ± 0.003	98.4 ± 0.005	0.3 ± 0.001
S7	0.9 ± 0.007	470.1 ± 0.009	398.6 ± 0.002	90.5 ± 0.009	0.6 ± 0.006
S8	BDL	40.4 ± 0.001	63.2 ± 0.005	88.1 ± 0.001	BDL
S9	BDL	86.0 ± 0.005	109.5 ± 0.005	18.9 ± 0.003	BDL
S10	0.3 ± 0.007	314.0 ± 0.009	152.3 ± 0.003	89.8 ± 0.007	0.3 ± 0.001
S11	0.7 ± 0.005	112.3 ± 0.001	310.5 ± 0.008	85.4 ± 0.006	0.2 ± 0.009
S12	0.6 ± 0.006	216.9 ± 0.007	213.9 ± 0.004	81.2 ± 0.003	0.3 ± 0.007
S13	BDL	67.5 ± 0.002	86.5 ± 0.001	83.7 ± 0.005	BDL
S14	0.5 ± 0.003	72.7 ± 0.006	152.3 ± 0.001	93.3 ± 0.002	0.3 ± 0.006
S15	0.8 ± 0.003	508.0 ± 0.005	396.5 ± 0.005	84.1 ± 0.007	0.6 ± 0.005
S16	BDL	52.3 ± 0.001	68.6 ± 0.005	83.3 ± 0.001	BDL

BDL: Below Detected Level

Table 9: Soil heavy metal content in the post-monsoon season

St. No.	Pb (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)
S1	BDL	40.3 ± 0.005	130.3 ± 0.001	20.5 ± 007	BDL
S2	0.44 ± 0.004	245.4 ± 0.004	310.6 ± 0.004	88.5 ± 0.003	0.26 ± 0.005
S3	0.56 ± 0.007	310.1 ± 0.003	78.3 ± 0.007	77.9 ± 0.001	0.33 ± 0.003
S4	0.76 ± 0.005	535.4 ± 0.001	512.6 ± 0.005	75.0 ± 0.008	0.4 ± 0.003
S5	BDL	92.3 ± 0.003	89.3 ± 0.001	77.5 ± 0.002	0.57 ± 0.001
S6	0.40 ± 0.001	186.5 ± 0.009	127.9 ± 0.002	99.8 ± 0.004	0.28 ± 0.008
S7	0.86 ± 0.002	752.0 ± 0.005	567.0 ± 0.001	93.6 ± 0.001	0.8 ± 0.001
S8	BDL	72.0 ± 0.009	70.2 ± 0.001	89.2 ± 0.001	0.32 ± 0.002
S9	BDL	42.0 ± 0.007	510.0 ± 0.009	20.0 ± 0.002	BDL
S10	0.40 ± 0.006	252.0 ± 0.008	152.1 ± 0.002	90.6 ± 0.009	0.28 ± 0.001
S11	0.61 ± 0.006	312.3 ± 0.001	361.9 ± 0.006	85.6 ± 0.005	0.38 ± 0.007
S12	0.70 ± 0.001	502.9 ± 0.001	509.4 ± 0.005	82.0 ± 0.006	0.38 ± 0.006
S13	BDL	89.5 ± 0.003	86.5 ± 0.006	86.5 ± 0.007	0.60 ± 0.001
S14	0.38 ± 0.002	182.9 ± 0.002	138.0 ± 0.009	94.3 ± 0.006	0.26 ± 0.003
S15	0.90 ± 0.007	760.4 ± 0.004	538.0 ± 0.001	87.4 ± 0.003	0.82 ± 0.005
S16	BDL	77.1 ± 0.002	65.8 ± 0.009	85.3 ± 0.001	0.31 ± 0.009

BDL: Below Detected Level

Highest concentration of chromium was noted in stations (S7 and S15), where the density of nematodes were low.

The studies conducted by Stanisiav Pen-Mouratov et al. (2008) in the Angren power plant, a gold refinery plant, farm area and recreation area showed that the pollution effect was highest in the polluted soil ecosystems compared to that in a favourable area. In the present study the nematode abundance is very low in the gasoline station areas (S7 and S15) and it may be due to the high concentrations of heavy metals present in these stations. The soil nematode density showed negative correlation with concentrations of lead, zinc, manganese and chromium in the rural and urban study stations of Thiruvananthapuram District. These findings are also supported by the observations of Dechang et al. (2009) that the soil nematode guilds may act as a prominent indicator to heavy metal pollution. In all the sampling stations, the concentration of copper is below the standard permissible level of 100 mg/kg (Ewers, 1991).

Conclusions

The nematode density diminished in soils with large pore space and high bulk density. Also there is an increase in nematode density with increase in water-holding capacity, moisture content, organic matter content, nitrogen, phosphorus and potassium contents in the urban and rural soils studied. The present study reveals that the abundance of nematodes had a direct relationship with the soil physico-chemical characteristics. It was also found that the nematodes were less abundant in soils rich in heavy metals. The findings of this study validate the potential of nematodes for the bio-indication of the soil health status. The quality of urban soils in Thiruvananthapuram District were found to be more degraded compared to that of rural soils especially in gasoline station areas.

Acknowledgement

The authors gratefully acknowledge the help rendered by Mr. T.N. Jayaprakash, Senior Chemist, Directorate of Mining and Geology, Kesavadasapuram, Thiruvananthapuram for the analysis of heavy metals.

References

Alloway, B.J. (1996). Soil pollution and Land contamination. *In:* Pollution-causes, effects and control. Third edition. Roy M. Harrison (ed.). The Royal Society of Chemistry, Cambridge.

Awashthi, S.K. (2000). Prevention of Food Adulteration Act No. 37 of 1954. Central and State Rules amended for 1999 (3rd edition), Ashoka Law House, New Delhi.

Bongers, T. (1990). The maturity index: An ecological measure of environmental disturbance based on nematode species composition. *Oecologia,* **83:** 14-19.

Dasgupta, M.K. (1998). Nematode counting. *In:* Phyto-nematology. Naya Prakash, Calcutta.

Dechang Han, Xiaoke Zhang, Vijay Vikram Singh Tomar, Qi Li, Dazhong Wen and Wenju Liang (2009). Effects of heavy metal pollution of highway origin on soil nematode guilds in North Shenyang, China. *Journal of Environmental Sciences*, **21(3):** 193-198.

Ewers (1991). Standards, guidelines and legislative regulations concerning metals and their compounds. *In:* Merian E. (ed.). Metals and their compounds in the environment: Occurrence, Analysis and Biological relevance. Weinheim: VCH.

Fitter, A.H. and R.K.M. Hay (1987). Environmental Physiology of Plants. Academic Press, London, UK.

Goodey, J.B. (1963). Soil and Fresh water nematodes. Butler and Tanner Limited, Great Britain.

Gupta, P.K. (1999). Soil, Plant, Water and Fertilizer Analysis. Agro Botanica, Bikaner, India.

Ivana Sochova, Jakub Hofman and Ivan Holoubek (2006). Using nematodes in soil ecotoxicology. *Environment International*, **32(3):** 374-383.

Jing Xiao, Qi Rui, Yuling Guo, Xingya Chang and Dayong Wang (2009). Prolonged Manganese exposure induces severe defects in lifespan, development and reproduction possibly by altering oxidative stress response in *Caenorhabditis elegans*. *Journal of Environmental Sciences*, **21(6):** 842-848.

Kazunori Otobe, Kenji Itou and Takayuki Mizukubo (2004). Micro-moulded substrates for the analysis of structure-dependent behaviour of nematodes. *Indian Journal of Nematology*, **6(1):** 73-77.

Kogel-Knabner, I. (2000). Analytical approaches for characterizing soil matter. *Org Geochem*., **31:** 609-625.

Lee, K.E. and R.C. Foster (1991). Soil fauna and soil structure. *Australian Journal of Soil Research,* **29:** 745-775.

Lytle, C.M., Smith, B.N. and C.Z. McKinnon (1995). Manganese accumulation along Utah roadways: A possible indication of motor vehicle exhaust pollution. *Science of the Total Environment*, **162(2-3):** 105-109.

Michael, P. (1984). Ecological methods for Field and Laboratory Investigations. Tata McGraw-Hill Publishing Company Ltd., New Delhi.

Papendick, R.I. and G.S. Campbell (1985). Theory and measurement of water potential. *In:* Water potential relations in soil microbiology. Parr, J.F., Gardner, W.R., Elliot, L.F. (eds). Soil Science Society of America, Madison, WI.

Richard, G. Burns and P. Dick Richard (2002). Enzymes in our environment activity, ecology and applications. Marcel Dekker, Inc., U.S.A., pp. 614.

Sara Sanchez-Moreno, Julio A. Camargo and Alfonso Navas (2006). Ecotoxicological assessment of the impact of residual heavy metals in the Guadiamar River Basin (Southern Spain). *Environmental Monitoring and Assessment*, **116(1-3):** 245-262.

Sathyanarayana, R. (1997). Distribution of extractable micro-nutrients in soils of selected major land resources areas of Kerala. M.Sc. (Agriculture) Thesis. Kerala Agriculture University, Vellayanikkara, Thiruvananthapuram.

Saxena, M.M. (1994). Environmental Analysis—Water, Soil and Air, Agro Botanica Publishers, Bikaner, India.

Smiles, D.E. (1988). Aspects of the physical environment of soil organisms. *Biology and Fertility of Soils*, **6:** 204-215.

Stanisiav Pen-Mouratov, Nosir Shukurov and Yosef Steingerger (2008). Influence of industrial heavy metal pollution on soil free-living nematode population. *Environmental Pollution*, **152(1):** 172-183.