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Diversity and Distribution of Earthworms in Relation to Altitude and Soil Factors of Kollam District, Kerala State, India

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ABSTRACT

Kollam District, Kerala State, India, is bordered on the west by the Lakshadweep (Arabian) Sea, and on the east by the hills of western ghats. The district was broadly divided into three regions of coastal zone, midland and highland. Earthworms and soil were sampled from 38 stations located within these regions during February-April, 2013. There was a difference on the major soils of three regions. A significant difference existed between the three regions on mean values of soil temperature, moisture, sand, silt and clay. Positive correlations were observed between the density of earthworms and sand and calcium, and an inverse one between density and soil temperature and clay. The pH of the soil was near neutral to acidic, and majority of stations had sandy clay loam soils. A total of six families and twelve species of earthworms were sampled from different stations. The earthworms were either epigeics, endogeics or anecies, and two species of earthworms were exotic and ten natives. Their diversity and distribution in relation to soil and geographic factors were described. The Shannon diversity

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and evenness indices were higher in highland. The roles played by the earthworms of Kollam district on soil fertility, aeration and vermicomposting were discussed.

***Key words*:** Earthworms, Kollam district, Coastal zone/midland/highland, Physico-chemical analysis of soil, Soil composition and texture, Epigeic/endogeic/anecic, Soil fertility and vermicomposting.

INTRODUCTION

Earthworms (Annelida: Oligochaeta) form one of the major macrofauna among soil biota to maintain dynamic equilibrium and regulate soil fertility (Tomati and Galli, 1995). They are designated as 'Ecosystem Engineers' and play an important role in improvement of soil physical structure, organic matter dynamics and nutrient cycling rate through their feeding, burrowing and casting activities. Some earthworms are used for composting the waste organic matter also.

In Indian sub-continent, earthworms form the bulk of Oligochaeta fauna and are represented by 590 species and 67 genera with different ecological preferences, but the functional role of majority of species and their influence on the habitat are lacking (Julka, 2001). The earliest record of Indian earthworms was published by Bourne (1888) from western Himalayan region. A general description on earthworms and their role in the soil ecosystem, an overview of biodiversity of Indian earthworms were furnished by Julka (2010) and Julka *et al*. (2009). A comprehensive check-list of earthworms of Indian sub-continent was prepared and documented in the website (2006). The description of the earthworm diversity on the western ghats in India stretching from Kerala in the South to Gujarat State in the North is furnished by Stephenson (1915, 1923, 1925), Gates (1945), Soota and Julka (1972), Jamicson (1977), Julka and Rao (1982), Blachart and Julka (1997), Kale and Karmegam (2010), Mahesh Mohan *et al*. (2011), Shylesh Chandran *et al*. (2012) and Siddaraju *et al*. (2013).

Not much information is available on the occurrence, distribution and diversity of earthworms in relation to geographic and edaphic factors of different regions of Kerala State in general and southern Kerala in particular. The present study, therefore, was undertaken with a view to know the earthworm resources of Kollam district located in southern Kerala, India. The aim of the study was to gather information on the distribution of different species of earthworms in relation to geographic and edaphic factors of the district. Such a study is important to know the roles played by these worms on the structure and fertility of soils of Kollam district.

MATERIALS AND METHODS

Place of Study

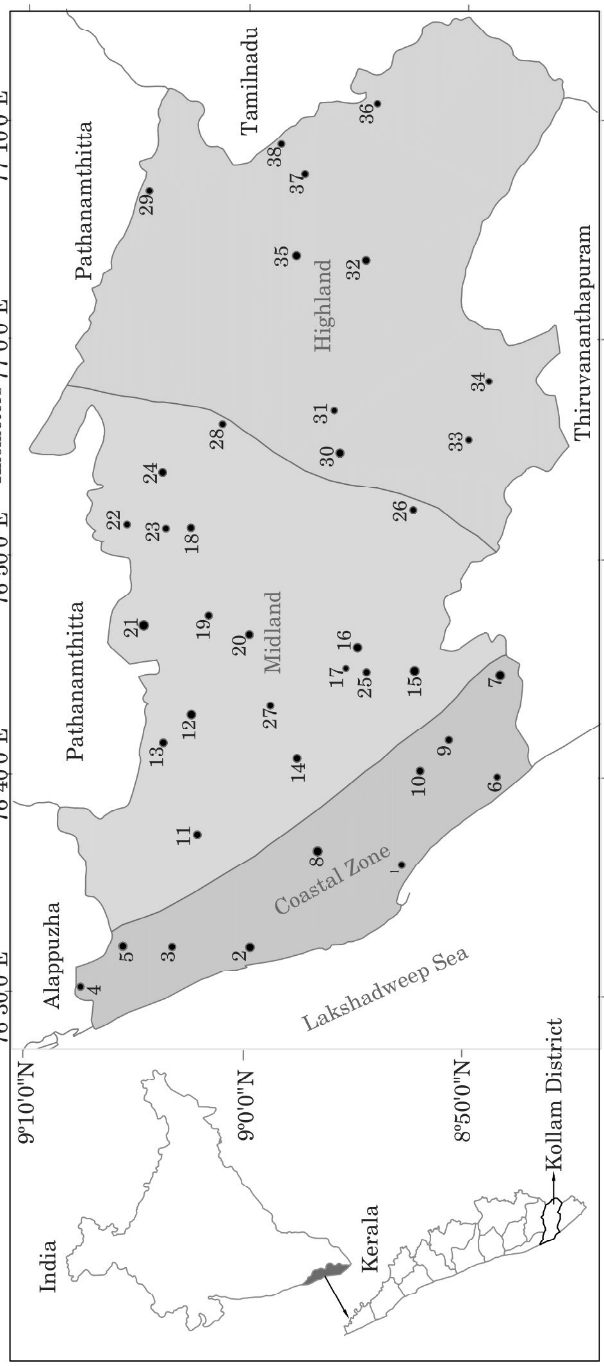
Kollam district (8.8000°N, 76.6000°E) is located in the south-west coast of Kerala, India. It is a tropical humid region and the climate is characterized by excessive humidity (>70%) during the greater part of the year. It is bordered on the west by the Lakshadweep (Arabian) sea, on the north by Alappuzha and Pathanamthitta districts, on the east by part of Pathanamthitta district and Tamil Nadu and the hills of Sahyadri hills of the western ghats, and on the south by Thiruvananthapuram district (Fig. 1). Kollam district occupies an area of 2483 m^2, population of 26, 353, 75 population density of 1061 people/km^2 and literacy rate of 94.6% (all values of 2011 census). The district can be divided into three zones based on the elevation of land from sea level. They are (1) Coastal zone (elevation ranges from 0 to 20 m), (2) Midland (elevation ranges from >20 m to 50 m), and (3) Highland (elevation of greater than 50 m). Agriculture is the primary source of income of the population, other than the income from fishery and mineral resources. Paddy, coconut, tapioca, rubber, pepper, mango, banana and cashew are grown here. The district is blessed with coastal region, estuaries, brackish waters, rivers, ponds, lakes, wetlands and forests. Two Ramsar sites, Ashtamudi and Sasthamkotta lakes are located within the district.

Earthworm Sampled Stations

Earthworms were sampled from 38 stations in Kollam District (Fig. 1). Out of these, 10 stations (Kollam, Chavara, Karunagappally, Oachira, Thazhava, Paravoor, Parippally, Perinad, Chathannoor and Kottiyam) were located in the coastal zone. Another 18 stations (Sasthamkotta, Puthoor, Kunnathoor, Kundara, Mukkadavu, Veliyam, Nedumankavu, Neduvathoor, Mylom, Kottarakkara, Pattazhi, Pathanapuram, Avaneeswaram, Piravanthur, Alimukku, Chadayamangalam, Ezhukone and Punalur) were located in the midland. Ten stations (Achankovil, Anchal, Yeroor, Kulathupuzha, Kadakkal, Chithara, Thenmala, Aryankavu, Edapalayam and Palaruvi) were located in the Highland.

Earthworm Sampling and Preservation

Earthworms were sampled from different stations from February to April, 2013, following the procedures of Baker and Barrett (1994), Bennour and Nair (1997) and Nair *et al.* (2005). A plot of 30 cm × 30 cm was measured first within each station where the earthworms were present in large numbers, and a hole of 10 cm deep was dug in the plot and the soil was removed and spread on a white enamel tray and hand-sorted the soil removing earthworms as they were found. When all the soil was sorted,



*1-Kollam, 2-Chavara, 3-Karunagappally, 4-Oachira, 5-Thazhava, 6-Paravoor, 7-Parippally, 8-Perinad, 9-Chathanoor, 10-Kottiyam, (COASTAL ZONE); 11-SasthamKota, 12-Puthoor, 13-Kunnathoor, 14-Kundara, 15-Mukkadavu, 16-Veliyam, 17-Nedumankavu, 18-Neduvathur, 19-Mylom, 20-Kottarakkara; 21-Pattazhi, 22-Pathanapuram, 23-Avaneeswaram, 24-Piravanthur, 25-Alimukku, 26-Chadayamangalam, 27-Ezhukone, 28-Punalur (MIDLAND); 29-Achankovil, 30-Anchal, 31-Yeroor, 32-Kulathupuzha, 33-Kadakkal, 34-Chithara, 35-Thenmala, 36-Aryankavu, 37-Edapalayam; 38-Palaruvi, (HIGHLAND)

Fig. 1: Map of Kollam District, Kerala, showing different earthworm sampled stations*

counted the number of earthworms found and placed them in a small plastic bag with soil. Dug four more holes in the same way at least 5 m apart. Added up the number of earthworms in five holes and doubled it and expressed as the number of earthworms/m^2. The soil from where the earthworms were sampled were placed in a separate plastic bag for further analyses.

The earthworms were initially immersed in a mixture of equal parts of 100% formalin + 100% ethanol. In this mixture, the worms were killed and stretched aiding for easy identification. Later, they were carefully removed from the mixture and placed in 10% formalin and preserved. The 10% formalin preservative was changed after every 24 hours two times, and later they were permanently preserved in this solution. (this fixing and preservation methods of earthworms were communicated by Professor Maria Iglias Briones, a Mediterranean taxonomist, University of Vigo, Spain).

Data Analyses and Information

The geographical details such as latitude and longitude and elevation of each sampling station were provided by the Regional Meteorological Station, Kollam. The soil factors such as pH, nitrogen, phosphorus, potassium, calcium and magnesium and the textural analyses such as % of sand, % of silt and % of clay of each station were analyzed in the Central Soil Analytical Laboratory, Govt. of Kerala, Thiruvananthapuram. The temperature (°C) of the soil (5 cm deep) was measured with the soil thermometer at each station at the time of earthworm sampling, and the water content of the soil was calculated as the difference between the weights of the initial (measured in the field itself) and oven dried (55°C) soil and expressed as a percentage. Information on the major soil types of each sampling station was provided by State Land Use Board, Govt. of Kerala, Thiruvananthapuram.

Earthworm Identification

Earthworms were identified upto the species level by Dr (Mrs) P. Kathireswari, an earthworm taxonomist and one of the authors of the paper, and also by referring the descriptions and keys of identification of earthworms published by Stephenson (1915, 1923), Michaelsen (1910) and Julka (1988). The identified earthworms were deposited in the Museum of Zoology Department, Baby John Memorial Government College, Chavara, Kollam, Kerala.

Statistical Analyses

Relevant statistical analyses of the data were carried out following the procedures given by Fowler and Cohen (1997) and Rao and Richard (2012).

RESULTS

Geographical Details, Habitats and Density of Earthworms

The latitude and longitude, elevation, habitats from where the earthworms were sampled and the density of the earthworms of 38 stations of Kollam district divided into coastal zone (stations 1 to 10), midland (stations 11 to 28) and highland (stations 29 to 38) are given in Table 1.

The earthworms were sampled mostly from the paddy fields and from grass covered wetlands in the coastal zone. In the midland, however, the earthworms were sampled from marshy lands, banana plantations, paddy fields, croplands, grasslands, open fields, and from the bank of a lake (Sasthamkotta lake, the Ramsar site). Earthworms were sampled in highland (10 stations) from forest soils, paddy fields, marshy lands, croplands and wetlands.

The density (total number/m^2) of the earthworms ranged from 20 to 62/m^2 (mean 39 $\pm$ 4/m^2) in coastal zone, 16 to 84/m^2 (mean 40 $\pm$ 4/m^2) in midland, and 14 to 92/m^2 (mean 49 $\pm$ 7/m^2) in highland. A significant difference in the density of earthworms between the three regions ($F=0.98$; $p>0.05$) was not discernible.

Major Soils

The major soils (designated as codes K01, K07, K09, K12, K31, K32, K36 and K38) and the detailed descriptions of each code are presented in Table 2. It was observed that 20% stations in coastal zone had major soils of K01 and the remaining 80% stations had major soils of K07. In the midland, 22% stations had K09, 72% stations had K12, and 6% stations had K31 major soils. In the highland, where the majority was forest soil, 10% stations each had K09, K12, K32 and K36 major soils, 40% stations had K31 and 20% stations had K38 major soils.

Physico-chemical Analyses of Soil

The physico-chemical characters of soil such as temperature, moisture, pH, nitrogen (% OC), phosphorus, potassium, calcium and magnesium of 38 earthworm sampled stations of Kollam district of the coastal zone, midland and highland are presented in Table 3.

Soil temperature varied from 25°C to 30°C (mean 27 $\pm$ 0.5°C) in coastal zone, from 24°C to 29°C (mean 26.7 $\pm$ 0.5°C) in midland, and from 22°C to 27°C (mean 23.7 $\pm$ 0.6°C) in highland. A significant difference in soil temperatures ($F=13.46$; $p<0.01$) existed between the three regions. Almost a similar trend was observed in soil moisture also. Soil moisture varied

Table 1: Geographical details, habitats and density of earthworms of 38 stations of Kollam district

Regions	*Sl. no.*	*Stations*	*Latitude*	*Longitude*	*Elevation (m)*	*Habitat description*	*Density of earthworms/m²*
Coastal zone	1	Kollam	8°53'07.72"N	76°35'56.50"E	3	Paddy field	36
	2	Chavara	8°59'43.68"N	76°32'14.14"E	4	Paddy field	40
	3	Karunagappally	9°03'38.82"N	76°31'23.91"E	5	Paddy field	54
	4	Oachira	8°53'29.98"N	76°45'55.19"E	6	Grass covered wetland	60
	5	Thazhava	9°01'40.40"N	76°35'20.89"E	12	Paddy field	26
	6	Paravoor	8°48'31.69"N	76°40'02.14"E	15	Paddy field	62
	7	Parippally	8°48'43.57"N	76°45'34.64"E	18	Paddy field	20
	8	Perinad	8°56'50.23"N	76°37'15.79"E	20	Paddy field	24
	9	Chathannoor	8°51'55.03"N	76°42'52.11"E	20	Paddy field	40
	10	Kottiyam	8°51'55.74"N	76°40'12.53"E	20	Abandoned paddy field	34
Midland	11	Sasthamkotta	9°02'11.26"N	76°37'26.19"E	24	Bank of lake	44
	12	Puthoor	9°02'32.83"N	76°42'48.42"E	25	Marshy land	62
	13	Kunnathoor	8°58'11.35"N	76°36'37.87"E	30	Banana plantation	34
	14	Kundara	8°57'36.66"N	76°40'43.71"E	30	Marshy land	44
	15	Mukkadavu	9°02'31.39"N	76°55'17.89"E	30	Cropland	40
	16	Veliyam	8°54'58.15"N	76°46'00.61"E	35	Paddy field	40
	17	Nedumankavu	8°51'13.46"N	76°44'06.34"E	35	Banana plantation	84
	18	Neduvathoor	8°59'43.79"N	76°45'06.97"E	35	Marshy land	66
	19	Mylom	9°01'44.34"N	76°47'18.50"E	35	Cropland	46
	20	Kottarakkara	8°59'50.61"N	76°46'32.42"E	35	Banana plantation	44
	21	Pattazhi	9°05'03.32"N	76°46'49.61"E	40	Banana plantation	18
	22	Pathanapuram	9°05'27.51"N	76°51'27.66"E	40	Grassland	16
	23	Avaneeswaram	9°03'27.00"N	76°51'07.30"E	40	Grassland	52
	24	Piravanthur	9°03'55.43"N	76°53'52.93"E	40	Paddy field	36
	25	Alimukku	9°01'24.39"N	76°52'29.54"E	40	Marshy land	24
	26	Chadayamangalam	8°52'29.42"N	76°51'56.22"E	42	Open field	16
	27	Ezhukone	8°58'43.26"N	76°42'38.62"E	44	Cropland	36
	28	Punalur	9°01'03.64"N	76°55'59.47"E	50	Cropland	16
Highland	29	Achankovil	9°05'29.06"N	77°07'30.72"E	70	Paddy field	50
	30	Anchal	8°55'43.91"N	76°54'47.88"E	80	Wetland	52
	31	Yeroor	8°55'59.83"N	76°56'22.89"E	90	Cropland	56
	32	Kulathupuzha	8°54'32.46"N	77°03'33.57"E	125	Cropland	92
	33	Kadakkal	8°49'53.86"N	76°55'27.58"E	140	Paddy field	28
	34	Chithara	8°48'50.51"N	76°58'01.87"E	155	Marshy land	14
	35	Thenmala	8°57'47.68"N	77°03'54.29"E	175	Forest soil	46
	36	Aryankavu	8°58'30.23"N	77°08'57.99"E	190	Forest soil	26
	37	Edapalayam	8°57'55.80"N	77°06'48.07"E	200	Forest soil	58
	38	Palaruvi	8°57'51.50"N	77°08'35.25"E	210	Forest soil	74

Table 2: Major soils of 38 earthworm sampled stations (three regions) of Kollam district together with the explanation of codes

Reg-ions	***Sl. no.***	***Stations***	***Code*****		*****Explanation of codes***
Coa-stal	1	Kollam	K 07	K 01	Mixed, aquic ustipsamments, mixed typic ustipsamments (*Inclusions*: Fine-loamy, mixed
zone	2	Chavara	K 07		typic dystropepts; coarse, loamy, mixed, aquic
	3	Karunaga-ppally	K 01		ustorthents)
	4	Oachira	K 01	K 07	Clayey-skeletal, kaolinitic, typic kandiustults;
	5	Thazhava	K 07		Clayey-skeletal, kaplinitic, typic kanha-
	6	Paravoor	K 07		plustult (*Inclusions*: Loamy skeletal mixed,
	7	Parippally	K 07		Ustoxic dystropepts; typic kandiustults)
	8	Perinad	K 07	K 09	Clayey-skeletal, kaolinitic, oxic humitropepts;
	9	Chathannoor	K 07		Clayey-skeletal, kaolinitic, ustic haplohumults
	10	Kottiyam	K 07		(*Inclusions*: clayey-skeletal, kaolinitic, ustic kandihumults; fine-loamy, mixed, typic kandistults)
Mid-	11	Sasthamkotta	K 12	K 12	Clayey-skeletal, kaolinitic, ustic kanhaplo-
land	12	Puthoor	K 12		mults; clayey, kaolinitic, typic kandiustults
	13	Kunnathoor	K 12		(*Inclusions*: Fine-loamy, mixed, aquic ustif-
	14	Kundara	K 09		lubents; clayey- skeletal, kaolinitic, typic kanhaplustults)
	15	Mukkadavu	K 12	K 31	Fine-loamy, mixed, ustic humitropepts;
	16	Veliyam	K 12		Clayey-mixed, ustic pale humults (*Inclusions*:
	17	Nedumankavu	K 12		Rock land; clayey mixed, ustic haplohumults
	18	Neduvathoor	K 12		
	19	Mylom	K 12	K 32	Fine-loamy, mixed, ustic humitropepts; fine-
	20	Kottarakkara	K 12		loamy, mixed, ustic haelohumults (*Inclusions*:
	21	Pattazhi	K 09		Fine, mixed, ustic humitropepts, clayey-
	22	Pathanapuram	K 12		Skeletal, mixed, ustic humitropepts
	23	Avaneeswaram	K 12	K 36	Clayey, mixed, ustic haplohumults; fine-
	24	Piravanthur	K 09		loamy, mixed, oxic humitropepts (*Inclusions*:
	25	Alimukku	K 09		Fine, mixed ustic humitropepts; rockland)
	26	Chadayama ngalam	K 12	K 38	Clayey, mixed, ustic palehumults; rockland (*Inclusions*: Fine, mixed, ustic humitropepts;
	27	Ezhukone	K 12		Fine-loamy, mixed ustic humitropepts)
	28	Punalur	K 31		
Hig-	29	Achankovil	K 31		
hla-	30	Anchal	K 31		
nd	31	Yeroor	K 32		
	32	Kulathupuzha	K 31		
	33	Kadakkal	K 09		
	34	Chithara	K 12		
	35	Thenmala	K 31		
	36	Aryankavu	K 38		
	37	Edapalayam	K 38		
	38	Palaruvi	K 36		

Table 3: Physico-chemical analyses of soil of 38 earthworm sampled stations of Kollam district

Regions	*Sl. no.*	*Stations*	*Soil temperature (⁰C)*	*Moisture (%)*	*p^H*	*N (OC %)*	*P (ppm)*	*K (ppm)*	*Ca (ppm)*	*Mg (ppm)*
Coastal zone	1	Kollam	27	17.0	3.7	1.9	52	15	240	88.3
	2	Chavara	26	18.3	5.5	1.5	17.5	21	217.9	68.1
	3	Karunagappally	26	26.4	6.6	0.6	10	182.5	1154	215.6
	4	Oachira	25	33.9	6.0	1.6	10	1.5	230.3	198.6
	5	Thazhava	27	12.6	5.1	0.7	5	11.5	274.3	76.8
	6	Paravoor	28	11.2	6.3	1.6	29	79.5	254.6	100.1
	7	Parippally	30	30.0	5.5	2.1	5	12	85.8	27.7
	8	Perinad	28	27.6	5.5	0.5	21.5	5.5	241.5	70.6
	9	Chathannoor	26	38.2	6.1	2.0	11.5	23.5	259.9	64.1
	10	Kottiyam	27	25.1	5.5	1.9	17.5	20	147.9	71.5
Midland	11	Sasthamkotta	27	14.1	4.8	3.3	20	85.5	174.9	163.4
	12	Puthoor	28	28.2	5.4	3.8	33.5	255.5	897.5	202.2
	13	Kunnathoor	27	10.9	5.4	1.9	13.5	54	257.2	183.4
	14	Kundara	28	21.0	5.3	1.1	26	3	91.1	33.7
	15	Mukkadavu	25	18.4	6.1	2.4	55	121.5	1055.8	222.6
	16	Veliyam	28	14.1	5.4	1.2	3	152	187.6	90.1
	17	Nedumankavu	28	16.3	4.6	1.4	30	3.5	123.9	38.8
	18	Neduvathoor	27	17.1	5.7	1.4	35.5	12	282.9	46.2
	19	Mylom	29	19.9	4.8	2.4	15	50	189.7	74.9
	20	Kottarakkara	26	26.1	5.1	0.8	10	100	221.4	165.1
	21	Pattazhi	24	13.5	5.4	2.2	65	34.5	172.8	85
	22	Pathanapuram	25	12.2	6.4	1.0	20	177.5	942	111.6
	23	Avaneeswaram	25	20.7	5.3	2.7	15.5	205.5	863.3	182.9
	24	Piravanthur	24	34.4	4.9	1.2	10	203.5	210	118.9
	25	Alimukku	26	35.2	4.9	2.9	10	72.5	221.9	112.4
	26	Chadayamangalam	28	17.2	5.5	1.6	16.5	8	162.4.	82.5
	27	Ezhukone	29	18.4	4.5	1.5	26	21.5	120.4	73.7
	28	Punalur	26	23.9	5.9	3.3	15.5	33	944	191.2
Highland-	29	Achankovil	25	30.8	5.8	0.9	13.5	40.5	116.9	220.4
	30	Anchal	24	18.2	4.3	1.5	11.5	5	91.6	18.5
	31	Yeroor	22	16.9	4.4	1.7	11.5	27.5	91.3	61.6
	32	Kulathupuzha	22	27.2	4.9	2.2	32.5	46	166.5	173.1
	33	Kadakkal	27	22.7	6.1	1.4	12.5	2	217.9	71.9
	34	Chithara	26	19.7	5.4	1.7	15	24.5	96.7	23.8
	35	Thenmala	24	24.5	5.6	3.6	3	238	1014.3	255.9
	36	Aryankavu	23	17.3	6.4	0.9	25	385	159.2	292.5
	37	Edapalayam	22	29.4	5.0	1.0	8	14.5	291.1	122.8
	38	Palaruvi	22	15.8	5.3	1.3	63	46	294.3	300.4

from 11.2% to 38.2% (mean 24.0 $\pm$ 2.9%) in coastal zone, from 10.9% to 35.2% (mean 20.1 + 1.7%) in midland, and from 15.8% to 30.8% (mean 22.3 $\pm$ 1.7%) in highland. Here also, a significant difference ($F=11.85$; $p<0.01$) in soil moisture was apparent between the three regions.

The pH of the soils at all stations of Kollam district were acidic. It varied from 3.7 to 6.6 (mean 5.6 ± 0.3) in coastal zone, from 4.5 to 6.4 (mean 5.3 ± 0.2) in midland, and from 4.3 to 6.4 (mean 5.3 ± 0.2) in highland. The differences in the means in pH between the three regions, however, were not statistically significant ($F=0.67$; $p>0.05$). The nitrogen (% OC) content of the soil of coastal zone ranged from 0.5% to 2.1% (mean 1.4 ± 0.1%), whereas the values ranged from 0.8% to 3.8% (mean 2.0 ± 0.2%) in midland, and from 0.9% to 3.6% (mean 1.6 ± 0.3%) in highland. A significant difference ($F=0.03$; $p>0.05$) was not found in the mean values of nitrogen (%OC) between the three regions.

The phosphorus content of the soil ranged from 5 ppm to 52 ppm (mean 17.9 ± 4.5 ppm) in coastal zone, while in midland it ranged from 3 ppm to 65 ppm (mean 22.4 ± 4.1 ppm), and in highland from 3 ppm to 63 ppm (mean 19.6 ± 5.5 ppm). The difference in phosphorus contents of the soil between the three regions was not statistically significant ($F=0.44$; $p>0.05$). The potassium content of the soil in coastal zone ranged from 12 ppm to 182.5 ppm (mean 37.2 ± 17.6 ppm), while in the midland and in the highland the corresponding values ranged from 3 ppm to 255.5 ppm (mean 88.5 ± 18.8 ppm) and from 2 ppm to 385 ppm (mean 82.9 ± 39.9 ppm) respectively. The differences in potassium between the three regions were not statistically significant ($F=1.13$; $p>0.05$).

The calcium content of the soil, one of the major components necessary for the survival and activity of earthworms, ranged from 85.8 ppm to 1154 ppm (mean 310.6 ± 95.5 ppm) in coastal zone, from 91.1 ppm to 1055 ppm (mean 335.9 ± 83.2 ppm) in midland, and from 91.3 ppm to 1014.3 ppm (mean 253.9 ± 64 ppm) in highland. The differences in calcium in soils between the three regions were not significant ($F=0.67$; $p>0.05$) showing that calcium content in the soil was not a major limiting factor for the distribution of earthworms in Kollam District. The magnesium content of the soil ranged from 27.7 ppm to 215.6 ppm (mean 98.1 ± 19.1 ppm) in coastal zone, from 33.7 ppm to 222.6 ppm (mean 120.9 ± 14.2 ppm) in midland, and from 23.8 ppm to 292.5 ppm (mean 154.2 ± 34.6 ppm) in highland. The differences in the mean values of magnesium observed between the three regions were not significant ($F=1.38$; $p>0.05$).

Soil Composition and Texture

The percentage of sand, silt and clay in the soils of 38 earthworm sampled stations (coastal zone, midland and highland) together with the texture of the soil are presented in Table 4.

In coastal zone, the percentage of sand in 10 stations ranged from 57.9% to 88.8% (mean 73.9 ± 3.3%), whereas the values of the same ranged from 40.8% to 75.7% (mean 56.1 ± 5.3%) in 18 stations of midland. The corresponding figures in 10 stations in highland ranged from 56.3% to 93.2% (mean 71.4 $\pm$ 3.9%). A significant difference in the percentages of sand between the three regions were discernible ($F=4.22$; $p<0.05$). In the case of silt, it was observed that in the coastal zone it ranged from 1.3% to 13.5% (mean 5.8 $\pm$ 1.2%), in midland it ranged from 2.0% to 14.9% (mean 7.1 $\pm$ 0.9%), and in highland the values ranged from 1.5% to 13.1% (mean 4.9 $\pm$

Table 4: Soil composition and texture of 38 earthworm sampled stations of Kollam district

Regions	*Sl. no.*	*Stations*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Texture*
Coastal zone	1	Kollam	81.4	13.5	5.1	Loamy sand
	2	Chavara	88.7	3.9	7.3	Sand
	3	Karunagappally	62.5	6.5	30.9	Sandy clay loam
	4	Oachira	77.6	2.1	20.3	Sandy clay loam
	5	Thazhava	63.6	5.4	31.1	Sandy clay loam
	6	Paravoor	68.6	9.8	21.6	Sandy clay loam
	7	Parippally	82.3	2.8	14.9	Loamy sand
	8	Perinad	73.4	1.3	25.3	Sandy clay loam
	9	Chathannoor	82.6	8.9	8.5	Loamy sand
	10	Kottiyam	57.9	4.0	38.2	Sandy clay
Midland	11	Sasthamkotta	53.9	6.0	40.1	Sandy clay
	12	Puthoor	60.0	8.9	31.1	Sandy clay loam
	13	Kunnathoor	61.3	8.1	30.6	Sandy clay loam
	14	Kundara	71.1	2.2	26.7	Sandy clay loam
	15	Mukkadavu	67.3	2.0	30.6	Sandy clay loam
	16	Veliyam	75.7	5.1	19.1	Sandy clay loam
	17	Nedumankavu	74.0	14.9	11.0	Loamy sand
	18	Neduvathoor	72.0	2.5	25.5	Sandy clay loam
	19	Mylom	30.5	13.7	55.8	Clay
	20	Kottarakkara	65.3	8.3	26.4	Sandy clay loam
	21	Pattazhi	67.5	8.4	41.6	Sandy clay
	22	Pathanapuram	55.6	3.0	42.9	Sandy clay
	23	Avaneeswaram	55.1	4.4	40.5	Sandy clay
	24	Piravanthur	40.8	11.6	47.6	Clay
	25	Alimukku	53.9	9.2	36.8	Sandy clay
	26	Chadayamangalam	56.5	8.2	35.3	Sandy clay
	27	Ezhukone	53.0	5.4	41.6	Sandy clay
	28	Punalur	50.3	5.8	43.9	Sandy clay
Highland	29	Achankovil	86.4	1.9	11.7	Loamy sand
	30	Anchal	64.9	4.7	30.3	Sandy clay loam
	31	Yeroor	68.0	6.7	25.3	Sandy clay loam
	32	Kulathupuzha	63.6	8.8	27.5	Sandy clay loam
	33	Kadakkal	64.6	2.6	32.8	Sandy clay loam
	34	Chithara	66.3	2.2	31.5	Sandy clay loam
	35	Thenmala	56.3	3.6	40.1	Sandy clay
	36	Aryankavu	66.0	13.1	20.9	Sandy clay loam
	37	Edapalayam	85.1	1.5	13.4	Loamy sand
	38	Palaruvi	93.2	4.6	2.2	Sand

1.2%). A highly significant difference (F=17.82; $p<0.01$) existed in the percentages of silt between the three regions. The clay content in soil in coastal zone ranged from 5.1% to 38.2% (mean 20.3 $\pm$ 3.5%) and in the midland the same ranged from 11.0% to 55.8% (mean 34.8 $\pm$ 2.5%). In the highland the corresponding figures ranged from 2.2% to 40.1% (mean 23.6 $\pm$ 3.6%). The differences in the percentages of clay between the three regions were highly significant (F=6.62; $p<0.01$).

Textural analyses of the soil revealed that 47% stations had sandy clay loam, 27% had sandy clay, 16% had loamy sand and 5% each had sandy and clayey soils. The majority of stations of coastal zone and highland had sandy clay loam, whereas an equal proportions of stations of midland had sandy clay loam and sandy clay soils. Two stations in midland had clayey soils and one each from coastal zone and highland had sandy soils.

Pearson's Correlation Coefficient (r)

The values and their inferences of Pearson's correlation coefficient (r) between the density of earthworms and various soil factors at 38 earthworm sampled stations in Kollam district are presented in Table 5.

Table 5: Pearson's (r) correlation coefficients between density of earthworms and soil factors.

Sl. no.	*Parameters*	*'r'*	*P-value*	*Inference*
1.	Density and % of sand	0.27	p< 0.05	A significant positive correlation exists
2.	Density and % of silt	0.23	p> 0.05	A positive correlation, though not significant, exists
3.	Density and % of clay	–0.49	p<0.01	A highly significant inverse correlation exists
4.	Density and temperature	–0.74	p<0.01	A highly significant inverse correlation exists
5.	Density and moisture	0.04	p>0.05	A very weak positive correlation exists
6.	Density and P^H	–0.21	p>0.05	An inverse correlation, though not significant, exists
7.	Density and N (% OC)	–0.03	p>0.05	A very weak inverse correlation exists
8.	Density and phosphorus	0.21	p<0.05	A positive correlation, though not significant, exists
9.	Density and potassium	0.01	p>0.05	A very weak positive correlation exists
10.	Density and calcium	0.31	p<0.05	A significant positive correlation exists
11.	Density and magnesium	0.24	p>0.05	A positive correlation, though not significant, exists

A significant positive correlation between the density of earthworms and the percentage of sand (r = 0.27) and calcium (r = 0.31) were evident. The percentage of silt (r = 0.23), phosphorus (r = 0.21) and magnesium (r = 0.24) were also positively correlated (though not significant) with the density of earthworms. A very weak positive correlation of soil moisture (r = 0.04) and potassium (r = 0.01) with the density of earthworms was evident. On the other hand, a significant inverse correlation existed between the density of earthworms with those of the % of clay (r = –0.49) and soil temperature (r = –0.74). Weak inverse correlation, though not significant, existed between the density of earthworms with that of pH (r = –0.21) and nitrogen (%OC) (r = –0.03) of the soil.

Earthworm Fauna

A list of different families and species of earthworms sampled from Kollam district together with the information on whether each species sampled was native or exotic, and the ecological category in which they belonged are given in Table 6. A detailed description of the different species of earthworms sampled from 38 stations of Kollam District is presented in Table 7.

A total of 12 species of earthworms belonging to six families were sampled from 38 stations of Kollam District. These were (1) *Pontoscolex corethrurus* (Muller, 1856), (Family: Glossoscolecidae); (2) *Plutellus variabilis* Aiyer, 1929 (Family: Acanthodrilidae); (3) *Glyphidrilus annandalei* Michaelsen, 1910, (4) *Glyphidrilus achencoili* Cognetti, 1911, (Family: Almidae); (5) *Lampito mauritii* (Kinberg, 1863), (6) *Megascolex konkanensis* Fedrab, 1896, (7) *Megascolex travancorensis* Michaelsen, 1913, (8) *Notoscolex tenmalai* Aiyer, 1929 (Family: Megascolecidae); (9) *Drawida pellucida* Michaelsen, 1910, (10) *Drawida travancorensis* Michaelsen, 1910, (11) *Drawida ghatensis* Michaelsen, 1910 (Family: Moniligastridae), and (12) *Eudrilus eugeniae* Kinberg, 1867 (Family: Eudrilidae).

Of the total 12 species of earthworms sampled, *Pontoscolex corethrurus* and *Eudrilus eugeniae* were exotic species and all the remaining ten species

Table 6: List of families and exotic/native species of earthworms sampled from 38 stations (3 regions) of Kollam district together with their ecological categories

Sl. no.	*Family*	*Species*	*Exotic/ Native*	*Ecological category*
1.	Glossoscolecidae	*Pontoscolex corethrurus*	Exotic	Endogeic
2.	Acanthodrilidae	*Plutellus variabilis*	Native	Epigeic
3.	Almidae	1. *Glyphidrilus annandalei*	Native	Endogeic
		2. *Glyphidrilus achencoili*	Native	Endogeic
4.	Megascolecidae	1. *Lampito mauritii*	Native	Anecic
		2. *Megascolex konkanensis*	Native	Endogeic
		3. *Megascolex trarancorensis*	Native	Endogeic
		4. *Notoscolex tenmalai*	Native	Endogeic
5.	Moniligastridae	1. *Drawida pellucida*	Native	Endogeic
		2. *Drawida travancorensis*	Native	Endogeic
		3. *Drawida ghatensis*	Native	Endogeic
6.	Eudrilidae	*Eudrilus eugeniae*	Exotic	Epigeic

Table 7: Earthworms sampled from 38 stations of Kollam district

Regions	*Sl. no.*	*Stations*	*Species of earthworms*
Coastal zone	1	Kollam	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae) *Plutellus variabilis* (Aiyer, 1929) (Family: Acanthodrilidae)
	2	Chavara	1. *Glyphidrilus annandalei* (Michaelsen, 1910) (Family: Almidae)
	3	Karunagappally	1. *Glyphidrilus annandalei* (Michaelsen, 1910) (Family: Almidae)
	4	Oachira	1. *Lampito mauritii* (Kinberg, 1867) (Family: Megascolecidae) 2. *Plutellus variabilis* (Aiyer, 1929) (Family: Acanthodrilidae)
	5	Thazhava	1. *Pontoscolex ceorethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	6	Paravoor	1. *Lampito mauritii* (Kinberg, 1867) (Family: Megascolecidae)
	7	Parippally	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	8	Perinad	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	9	Chathannoor	1. *Glyphidrilus annandalei* (Michaelsen, 1910) (Family: Almidae)
	10	Kottiyam	1. *Glyphidrilus annandalei* (Michaelsen, 1910) (Family: Almidae)
Midland	11	Sasthamkotta	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae) 2. *Megascolex konkanensis* (Fedrab, 1898) (Family: Megascolecidae)
	12	Puthoor	1. *Drawida pellucida* (Michaelsen, 1910) (Family: Megascolecidae)
	13	Kunnathoor	1. *Megascolex travancorensis* (Michaelsen, 1913) (Family: Moniligastridae)
	14	Kundara	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae) 2. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	15	Mukkadavu	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	16	Veliyam	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae)
	17	Nedumankavu	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae)
	18	Neduvathoor	1. *Lampito mauritii* (Kinberg, 1867) (Family: Megascolecidae)
	19	Mylom	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	20	Kottarakkara	1. *Drawida pellucida* (Michaelsen, 1910) (Family: Moniligastridae) 2. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae)
	21	Pattazhi	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae)
	22	Pathanapuram	1. *Megascolex konkanensis* (Fedrab, 1898) (Family: Megascolecidae)

Table 7: (*Contd...*)

Table 7: (*Contd...*)

Reg-ions	***Sl. no.***	***Stations***	***Species of earth worms***
	23	Avaneeswaram	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	24	Piravanthur	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	25	Alimukku	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae)
	26	Chadayamangalam	1. *Drawida travancorensis* (Michaelsen, 1910) (Family: Moniligastridae)
	27	Ezhukone	1. *Drawida travancorensis* (Michaelsen, 1910) (Family: Moniligastridae)
	28	Punalur	1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
Highland	29	Achankovil	1. *Glyphidrilus achencoili* (Cognetti, 1911) (Family: Almidae) 2. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae) 3. *Plutellus variabilis* (Aiyer, 1929) (Family: Acanthodrilidae)
	30	Anchal	1. *Drawida travancorensis* (Michaelsen, 1910) (Family: Moniligastridae)
	31	Yeroor	1. *Drawida pellucida* (Michaelsen, 1910) (Family: Moniligastridae)
	32	Kulathupuzha	1. *Drawida ghatensis* (Michaelsen, 1910) (Family: Moniligastridae)
	33	Kadakkal	1. *Megascolex konkanensis* (Fedrab, 1898) (Family: Megascolecidae) 2. *Drawida ghatensis* (Michaelsen, 1910) (Family: Moniligastridae)
	34	Chithara	1. *Plutellus variabilis* (Aiyer, 1929) (Family: Acanthodrilidae) 2. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	35	Thenmala	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae) 2. *Notoscolex tenmalai* (Aiyer, 1929) (Family: Megascolecidae)
	36	Aryankavu	1. *Megascolex konkanensis* (Fedrab, 1898) (Family: Megascolecidae)
	37	Edapalayam	1. *Eudrilus eugeniae* (Kinberg, 1867) (Family: Eudrilidae) 2. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae)
	38	Palaruvi	1. *Megascolex travancorensis* (Michaelsen, 1910) (Family: Megascolecidae) 2. *Notoscolex tenmalai* (Aiyer, 1929) (Family: Megascolecidae)

were natives. Some interesting observations were made on the distribution of different species of earthworms of Kollam district. The exotic *P. corethrurus* was widely distributed in all the three regions. They were sampled from 4 stations in the coastal zone, from 7 stations in the midland, and from 3 stations in the highland. This species was found in the paddy fields, bank of a lake, marshy and croplands, grasslands and forest soils. They were sampled from sandy clay loam, sandy clay, loamy sand and clayey soils. The other exotic worm *E. eugeniae* were sampled from a station in the highland in the forest soil where the soil was loamy sand.

Concerning the native earthworm species, *Plutellus variabilis* were sampled from 2 stations each in the coastal zone and in the highland. This species was collected from paddy fields, grass covered wetlands and marshy lands and the texture of soils were loamy sand and sandy clay loam. *Glyphidrilus annandalei*, an interesting earthworm, were widespread in the paddy fields of coastal zone and were sampled from four stations. Another species *Glyphudrilus achencoili* were sampled from the paddy field of highland. *Glyphidrilus* sp. were not found in the midland. These two species were found in sandy clay loam, loamy sand, sandy clay and sandy soils. *Lampito mauritii,* and earthworm of the family Megascolecidae, were sampled from 2 stations in coastal zone and from one station in midland. They were found in paddy fields, grass covered wetlands and in marshy lands in sandy clay loam soils.

The earthworms *Megascolex trarancorensis* and *Megascolex konkanensis* (Family: Megascolecidae) were widespread in midland and to a lesser extent in highland. They were not sampled from the coastal zone. *M. travancorensis* were sampled from 7 stations in midland and from 2 stations in highland. This species was found in banana plantations, marshy lands, paddy fields, open fields and in forest soils. Majority of them were found in sandy clay loam and sandy clay soils. *M. konkanensis* on the other hand, in sampled from 2 stations in midland and 2 stations in highland. They were collected from the bank of a lake, grasslands, paddy fields and forest soils and were found in sandy clay loam and sandy clay soils.

Another important earthworms sampled in the present study were *Drawida pellucida*, *Drawida travancorensis and Drawida ghatensis* (Family: Moniligastridae). Out of the three species, *D. pellucida* and *D. travancorensis* were each sampled from 2 stations in midland and from 1 station in highland. The third species *D. ghatensis* were sampled from 2 stations in highland only. *D. pellucida* were found in marshy lands, banana plantations and in croplands and their distribution was restricted in sandy clay loam soil only. *D. travancorensis*, on the other hand, were sampled from open fields, croplands and wetlands and the soils of the habitats of this earthworm were sandy clay and sandy clay loam. *D. ghatensis* were sampled in highland from forest soil and paddy field and the soil of their habitat was sandy clay loam.

Notoscolex tenmalai (Family: Megascolecidae) were sampled from two stations in highland and they were found in forest soils of sandy clay and sandy soils.

Ecological Categories of Earthworms

The 12 species of earthworms sampled from 38 stations of Kollam District were broadly divided into three categories based on the positions they occupied in the soils (Table 6). Thus, the earthworms *Plutellus variabilis* and *Eudrilus enginiae* belonged to epigeic (litter feeder, litter dweller, make no burrows in soil, small size). The earthworms *Pontoscolex corethrurus, Glyphidrilus annandalei, Glyphidrilus achencoili, Megascolex konkanensis, Megascolex travancorensis, Drawida pellucida, Drawida travancorensis, Drawida ghatensis and Notoscolex tenmalai* were endogeic (rich soil feeder, top soil dweller, make horizontal burrows in soil, small to medium size). *Lampito mauritii* was the only earthworm in the present study which was anecic (litter + soil feeder, soil dweller, make extensive vertical burrows in soil, large size). This categorization is important to know the roles played by these worms in the increase in soil fertility and soil aeration. Based on the feeding behaviour, all epigeics are considered as litter feeders, endogeics as geophagous and anecic as geophytophagous. However, according to Dr. P.S. Choudhari, an earthworm taxonomist and ecologist, most of the Indian earthworms are geophagous (Personal Communication).

Diversity Indices

The diversity indices of earthworms sampled from 38 stations in Kollam District with respect to altitude [coastal zone (0-20 m), midland (>20-70 m) and highland (>70 m)] are shown in Table 8.

Table 8: Diversity indices of earthworms sampled from Kollam district with respect to altitude.

Sl. no.	*Diversity index*	*Altitude (m)*		
		Coastal zone (0 – 20)	***Midland (>20 – 70)***	***Highland (>70)***
1.	Number of species (richness)	4	6	10
2.	Shannon diversity index (H^1)	1.334	1.548	2.221
3.	Evenness (E_H)	0.962	0.864	0.965
4.	Similarity (SC_j)	25% (coastal zone and midland)	45.5% (midland and highland)	16.7% (highland and coastal zone)

The total number of species of earthworms sampled from coastal zone were 4, from midland 6, and from highland 10. The similarity of species found between coastal zone and midland was 25%, between midland and highland was 45.5%, and between highland and coastal zone was 16.7%. The Shannon diversity index (H^1) values were 1.334, 1.548 and 2.221 for coastal zone, midland and highland respectively. The evenness (E_H) values wee 0.962 for coastal zone, 0.864 for midland and 0.965 for highland. Diversity (H^1) and evenness (E_H) in highland were higher than the values recorded for the same in the coastal zone and midland.

DISCUSSION

Kollam district, located on the south-west coast of Kerala, India, has a tropical humid climate and blessed with natural scenario, farms, croplands, marshy lands, grasslands, wetlands and forests. These habitats are highly suitable for the earthworms to colonise. The differences in elevation, climate and soils between coastal zone, midland and highland enabled the earthworms to occupy the suitable habitats of their choice. Coming to the density of earthworms in three regions, it was observed that a significant difference in the number of worms/m^2 did not exist between the three regions. However, a difference in species composition and richness was discernible in between the regions due mainly to the adaptability of different species to various climatic, edaphic and environmental factors.

Looking at the aspect of major soils, a clear difference of the same was noted between the three regions. Thus, the major soils of coastal zone were K07 followed by K01, of midland were K12 followed by K09, and of highland were K31 followed by K38 (Explanation of the code K is presented in Table 2). The relationships between the major soils of Kollam district and the earthworm occurrence and distribution need to be studied further.

The soil factors of the three regions revealed some interesting aspects. A significant difference in soil temperature was discernible between the three regions and highland recorded slightly lower temperature when compared with the temperatures of coastal zone and midland. However, the maximum soil temperature never exceeded 30^{o}C and the minimum never came below 22^{o}C, and this range was very well within the tolerable ranges of these tropical worms. The soil temperature plays an important role in the maintenance of earthworm population in an ecosystem and there is a negative correlation of soil temperature to earthworm population (Senapati and Dash, 1984; Karmegam and Daniel, 2009). In tropical humid regions, the temperature fluctuations are minimal when compared to temperate region (Kale and Karmegam, 2010) and tropical species can withstand higher temperature when compared with temperate ones (Ismail and Murthy, 1985). Soil moisture contributes a major share in the distribution and occurrence of various earthworm species (Bahaduria and Ramakrishnan, 1991; Gonzalez *et al.,* 1996). In the present study a significant difference in soil moisture was recorded between the three regions. But this difference in moisture was within the tolerable ranges of these animals. Even in extreme summer season, the district received occasional evening summer showers and thus the soil moisture was never a limiting factor for the surface activity of the earthworms. Moreover, the soil was always wet in paddy fields, marshy lands, plantations and forests from where majority of worms were sampled. Earthworm activity and populations are determined essentially by the moisture content of the soil and that soil moisture and population estimates are positively correlated

(Lavelle, 1988). Grant (1955) pointed out that moisture is a limiting factor for earthworm distribution as water constitutes a major portion of the body weight of an earthworm. Senapati and Dash (1984) opined that there are many indications to show that the population of endogeic earthworms are controlled mainly by soil moisture. This might be applicable to the earthworms of Kollam district also, since a majority of them were endogeics.

The pH of the soil of the 38 earthworm sampled stations of Kollam district was acidic and ranged from 3.7 to 6.6. Both the minimum and the maximum values of pH were recorded in the coastal zone. In the humid tropics, long-term pedogenetic processes have resulted in the formation of acid soils and selected acid tolerant earthworms became abundant and active (Lavelle and Pashanasi, 1989). Lavelle *et al.* (1995) observed preferences of tropical species at significantly lower pH values than for temperate regions and this better tolerance may explain why high earthworm abundance is often observed in tropical soils with pH as low as 3.8 to 4.0. Nath and Chaudhuri (2010) reported that highly acidic soils (pH<5.0) of rubber plantations favoured the population density and biomass of some exotic species in place of endemic earthworms. Regarding the correlation of epigeic, endogeic and anecic earthworms with soil pH, Bouche (1972) reported that epigeic earthworms that live and feed in litter system are much more tolerant to acidity than anecic and endogeic species which prefer pH of 6 to 7. In the present study, the epigeic worms were sampled from soils whose pH ranged from 3.7 to 5.8 showing that they were much more tolerant to acidic soils when compared with anecic worms (pH range: 5.4 to 6.3). Peterson and Luxton (1982) opined that the endogeic earthworms have optimum distribution at pH 6 to 7 in temperate areas and 5 to 6 in tropical regions. This difference may be due to in part to the differences in the quality of litter produced. In the present study also the majority of endogeic worms were sampled from soils whose pH varied from 5 to 6.

The nitrogen or % organic carbon in soils greatly influence the distribution of earthworms and soils with low nitrogen content do not support earthworm population (Kale and Krishnamoorthy, 1981). In the present study, the nitrogen or organic carbon in soils of 38 earthworm sampled soils varied from 0.49% to 3.84%. Comparatively a high percentage of nitrogen in soils was detected in the midland when compared with the coastal zone and highland, but the differences in nitrogen in soils between the three regions were statistically insignificant. Some of the reports from different parts of India support qualitative dependence of earthworm population on soil nitrogen (Senapati and Sahu, 1993 and Karmegam and Daniel, 2000a). Due to the influence of nitrogen content of the soil, the percentage contribution of nitrogen to the earthworm population may have shown a very high degree of dependence (Kale and Krishnamoorthy, 1981). Evans and Guild (1948) pointed out that nitrogen-rich litter helps in rapid growth of earthworms and facilitate more cocoon production than those with little nitrogen available. Lee (1985) stated that nitrogen mineralization increased in the presence of earthworms either directly through the release of nitrogen by their metabolic process and dead tissues or indirectly through changes in soil physical properties, fragmentation of organic material, and through interactions with other soil organisms.

Greater variations in the values of exchangeable cations of phosphorus, potassium, calcium and magnesium in the soil were discernible in the earthworm sampled stations of Kollam district and also between the three regions, eventhough these variations between regions were not statistically significant. These mineral nutrients showed positive correlations with earthworm density, which indicated the comprehensive roles of earthworms in the process of mineralization. Several studies showed the effects of earthworms on available mineral nutrients and document that soils with many earthworms generally have more exchangeable mineral nutrients than soils without earthworms (Tripathi and Bharadwaj, 2004). This is because earthworms play an important role in litter decomposition and incorporation of plant residues into the soil by their burrowing, feeding and casting activities. This topic has been reviewed comprehensively by Edwards and Lofty (1977), Lee (1985) and Ganihar (1996). Several other researchers also stated that total exchangeable cation concentrations increase the casts, and these casts maintain more nutrient materials than the soil (Dash and Patra, 1977; Kale and Krishnamoorthy, 1980). Further, Krishnamoorthy and Vajranabhaiah (1986) observed positive correlation between soil nutrients and earthworm population density. Haimi and Einbrok (1992) and Curry *et al.* (1995) observed the improvement in the nutrient availability in the surface layer where earthworms inhabit. Ganihar (1996) and Chauhan (2014) stated that edaphic factors which have been linked with earthworm distribution include calcium, magnesium and nitrogen contents, while population can be adversely affected by salt concentration.

The composition and texture of soil have great influence on the distribution and population structure of earthworms (Hatti, 2013). In the present study, a significant difference was observed in the percentage composition of sand, silt and clay between the coastal zone, midland and highland. Also, a significant positive correlation of sand and silt and an inverse correlation of clay with the density of earthworms were evident. Regarding, the texture of soil, 50% or more of the stations sampled in coastal zone and highland had sandy clay loam, whereas sandy clay followed by sandy clay loam dominated in midland. Sandy loam soil is the best medium for earthworms in executing coetaneous mode of respirations (Chaudhuri *et al.,* 2012) and most of the endogeic worms prefer sandy loam soils (Ismail and Murthy, 1985).

Regarding the distribution of earthworms of Kollam district, it was observed that out of the 12 species sampled, 2 were exotics and the remaining 10 were natives. The exotic worms were *Pontoscolex corethrurus* and *Eudrilus enginiae*. *P. corethrurus* was widespread in all the three regions of Kollam district. It is the most common invasive, endogeic and meso-humic earthworm in disturbed lands in tropics and it has colonized most land transformed by human activities in the humid tropics (Marichal *et al.,* 2012). It is also common in the managed ecosystems or in areas subjected to some type of alteration and *P. corethrurus* has exceptional demographic traits (Karmegam and Daniel, 2000b), allowing it to quickly colonize disturbed places from where native earthworms have been removed (Lavelle and Pashanasi, 1989; Tapia-Coral *et al*., 2006). The activity of this species is restricted to the upper 10 to 15 cm. *P. corethrurus* with suitable food substrates gains importance in order to maintain its successful field population for its systematic use in land restoration under specific conditions (Chaudhuri *et al.,* 2012). Occurrence of these earthworms in almost all land uses including degraded lands suggests that this species may have a potential for rapid restoration of soil fertility in degraded lands (Chandrashekara *et al.,* 2008). Also, these earthworms play an important role in the assimilation of phosphorus and in the re-cycling of other nutrients. It is an effective decomposer of organic matter. (Guerra and Asakawa, 1981). *P. corethrurus* is very efficient in nitrogen mineralization process (Tapia-Coral *et al.,* 2006). Thus, the contributions of this species for the enrichment of soil fertility, are enormous.

Eudrilus eugeniae, another exotic and epigeic tropical African nightcrawler, was sampled from one station in highland. How this earthworm was introduced in the soils of the station was not clear, but from the discussion we had with the local inhabitants, we understand that this station had patchy cocoa plantations and that long time back the seeds and seedlings of this plant along with soil were imported from West Africa mainly from Ghana. So, there is a chance that these worms or their cocoons might have been present in the soils brought from there. This species, however, is widespread in warm regions both wild and under vermiculture and is considered as the most efficient epigeic earthworm in the tropics, and it has the best potential for breaking down organic material. (Guerrerro, 2009). However, there is a serious threat of invasion of this species to natural ecosystems causing ecological problems for endemic species (Dash and Senapadi, 1986).

Among the 10 native species of earthworms sampled in the present study, *Lampito mauritii* was anecic, *Plutellus variabilis* was epigeic, and the remaining 8 species were endogeics. In India, *Lampito mauritii* is the most widely distributed earthworm in different agro-ecosystems (Dash and Patra, 1977; Reddy *et al.,* 1995; Sathianarayanan and Khan, 2006 and Karmegam and Daniel, 2009). This species, a geophytophagous, is known to be a voracious feeder of humus in preference to soil. It prefers decomposing grass of paddy (*Oryza sativa*) and finger millet (*Eleusine coracana*) to other leaf litter (Kale and Krishnamoorthy, 1981). It inhabits the sandy loam (Ismail and Murthy, 1985) and the activity of this earthworm remain confined to 20 cm depth (Dash and Patra, 1977). This species takes care of litter and other organic wastes, and being an anecic, it also helps in rejuvenating the soil by burrowing through it. Kale and Karmegam (2010) reported that the grasses when developed in reclamation sites can form an ideal base for establishment of *L. mauritii* to bring out improvement in soil structure and finally chemical and biological activities. Chaudhuri *et al.* (2012) categorized *L. mauritii* along with *P. corethrurus* as euryoecius because of their wide ranges of environmental tolerance, and Kumar (1994) recommended, in the study report of CAPART, both *L. mauritii* and *P. corethrurus* for their contribution in maintaining soil fertility.

The native epigeic earthworm *Plutellus variabilis* was sampled from two stations in coastal zone and from one station in highland. Not much information is available on this species about its distribution and role in soil structure and fertility. *P. variabilis* was reported earlier from Deccan Penninsula and from Indo-Gangetic plain (Ismail, 1997). Shylesh Chandran *et al.* (2012) reported that morphologically, Indian species of *Plutellus* is similar to North American *Argilophilus* and that Indian *Plutellus* is slightly different from that of Australian species in the nephridia present in each segment. Further studies are required on this species to establish its functional role in Indian soil.

Eight species of endogeic native earthworms were sampled from the three regions of Kollam district. Among them, the two species *viz. Glyphydrilus annandalei* and *Glyphydrilus achencoili* were sampled from the paddy fields of coastal zone and from highland respectively. *G. annandalei* is a mud dweller, hydrophilous and found in more or less submerged habitats. It prefers neutral soil, but can tolerate acid or alkaline soil (Gobi and Vijayalakshmi, 2004). In the present study this species was found in slightly to moderate acid soils (pH range from 5.5 to 6.6). Michaelsen (1910) and Stephenson (1925) recorded this species from Bangalore (Bengaluru), and along the edges of Bhatravathi and Bhavani river (north Tamil Nadu). Gobi and Vijayalakshmi (2004) sampled this species from the edge of Gadana river in South Tamil Nadu. The habitat of *Glyphidrilus* sp are the rice fields in Thailand (Chanabun *et al.,* 2013). These authors further opined that these worms play an important role in the development of rice farming. They are facilitators in the decomposition of organic matter to be a natural fertilizer, and in improving the soil properties for better rice root system. *Glyphidrilus* sp. also assist the release of essential minerals in some chemical fertilizers, though not in pesticides which prove to be lethal to these worms.

The endogeic species *Megascolex travancorensis* and *Megascolex konkanensis* are widespread in the midland and in the highland, but were not sampled from the coastal zone. The same is true with the other endogeic species *Drawida pellucida* and *Drawida travancorensis* which were sampled from midland and from highland regions, and another species *Drawida ghatensis* from highland only. *Megascolex* sp. are large worms found only in tropics and their movements aid in increase of soil aeration and mixing of soils. Some are used as fish feed and in vermicompositing also. The family Moniligastridae has a very large range encompassing south-east Asia, India, Japan, the Philippines, Borneo and Sumatra. The majority of this area is colonized by only one genus *Drawida* (Jamicson, 1977b). This genus of large earthworms is found mostly in South India and Ceylon, apart from scanty reports from Assam hills and eastern Himalayas. The activity of *Drawida* sp will remain confined to 20 cm depth and they are considered suitable for vermicompositing of organic wastes (Dash and Patra, 1977).

Notoscolex thenmala, the endogeic worm, was sampled in the present study from highland. The habitat location of this species indicates an aquatic or semi-aquatic life-style. Blakemore (2011) reported that *Notoscolex* is primarily an Australian genus with representatives in Sri Lanka, South India as well as New Zealand. The functional role of this earthworm in the soil ecosystem in India is not known.

Regarding the role of earthworms sampled in the present study in vermicompositing, vermiculture and vermitechnology, one has to refer the publication of Julka (1986) who listed 20 Indian worms, which could be possible to use as agents for vermicomposting. Among them, *Lampito mauritii, Eudrilus eugeniae* and *Drawida* sp, which were sampled in the present study, were also included. Dash and Patra (1977) and Dash and Senapati (1986) also considered *L. mauritii* and *Drawida* sp as efficient vermicomposters and organic waste decomposers under Indian conditions. *L. mauritii* is also an efficient vermicast producer than other species. With the wastepaper as the principal feed, it was found that *L. mauritii* is not only the most efficient producer of vermicasts but also generated more offsprings within a span of six months (Gajalakshmi and Abbasi, 2004). Dash and Patra (1977) also reported Indian earthworm *Drawida* sp suitable for vermicomposting. Mannali *et al.* (2010) listed *Notoscolex* sp, *L. mauriti, Megascolex* sp, *P. corethrurus* and *E. eugeniae* as commonly adopted worms for vermiculture.

The African worm *Eudrilus eugeniae* is being tried for vermicomposting at different centres in India and is giving encouraging results. This species is better suited for vermicomposting for the southern part of India where the summer temperature does not rise as high as in central and north India (Gajalakshmi and Abbasi, 2004). This earthworm is also reported suitable for waste processing (Dash and Senapati, 1986). However, Kale (1986) opined that it is better to look for endemic species for vermicomposting and vermiprocessing, since exotic species like *E. eugeniae* may carry fungal and other pathogens, brought with them from other countries, which may create additional problems for the Indian crops. Apart from the above, *Megascolex* sp was also tried successfully for vermicomposting in the raw materials of cattle dung + biogas plant effluent + water hyacinth (Gurav and Pathade, 2011).

CONCLUSIONS

The earthworms sampled in the present study were all well adapted to live in the tropical humid climatic conditions of Kollam district, Kerala, India. These worms which were mostly endogeics were all acidophilic and could withstand variations in edaphic factors prevailing in the three regions of coastal zone, midland and highland. Majority of the sampled worms preferred sandy clay loam and sandy clay soils. The relationships of the major soils prevailing in the three regions, on the earthworm density and distribution are worth exploring further. The widespread occurrence and distribution of the exotic *Pontoscolex corethrurus* in Kollam district and its contribution on the enrichment of soil fertility is noteworthy. But its colonizing ability in the disturbed soils from where native species are withdrawn, is a matter of concern since this can lead to the elimination of native species from the habitats, if their recolonization becomes difficult in the presence of these exotic worms. The earthworm *Glyphidrilus annandalei* sampled in the present study from coastal zone are widespread in the paddy fields of Thailand and this species is reported to play an important role in the development of rice farming. Thus, it is worth trying introducing this species in the paddy fields of all the three regions, provided they adapt well in the new habitats. Also the contributions of *Plutellus variabilis* and *Notoscolex thenmala* in soil fertility and soil aeration and their possible utilization in vermitechnology are to be looked into. The worms used for vermicomposting, vermicasts and vermiculture *viz. Lampito mauritii, Drawida* sp and *Eudrilus eugeniae* are sampled from different regions of Kollam district and attempts can be made to determine the feasibility of using other species also in vermicomposting. The report of Kale (1986) suggesting to select the native species of earthworms in place of the exotic *E. euginiae*, because of the possibility of spreading fungal and other pathogens of this species to the crops, is a serious matter which needs urgent attention. It is proposed to establish proper standardization of the methods to be adopted in utilizing the earthworms of Kollam district for the improvement of soil fertility, soil aeration and vermitechnology in the prevailing geographic, climatic and edaphic conditions of the district.

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Environmental Science and Engineering

Vol 2: Biodiversity and Conservation

About the Volume

Biodiversity is the variety of life on earth within and between all the species of plants, animals, micro-organisms and the biosphere in which they live and interact. It includes millions of different species that live on earth besides the genetic differences within species. Extinction is a native process that takes place over long period of times because of natural shifts in the environment. Last century witnessed a large number of species going extinct at an alarming rate due to environmental changes of habitat loss and pollution caused by human activities. Passenger pigeon, paradise parrot, desert rat kangaroo, Tasmanian tiger, Arabian ostrich and hundreds more are now extinct. Biodiversity needs to be conserved because it is essential for life support system and makes life sustainable on earth. Wetlands filter pollutants from water, plants and trees reduce global warming by absorbing CO_2 and micro-organisms break down organic material and fertilize the soil. Medicines originating from plants and animal species save millions of lives and relieve tremendous suffering. In this context, volume 2 presents articles on biodiversity and conservation from biodiversity of medicinal plants and their conservation to bioactivity of mushrooms to molecular diversity of fish to threats to marine and forest biodiversity.

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- Endophytic fungal diversity in medicinal plants
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