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Research Paper

COMPARATIVE STUDY OF THE EARTHWORM RESOURCES OF BENGHAZI, LIBYA, A CHAPPARAL BIOME, AND KOLLAM DISTRICT, KERALA, INDIA, A TROPICAL HUMID BIOME

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Abstract

A comparative study was conducted on the earthworm resources of Benghazi, Libya (Chapparal biome) and Kollam district, Kerala, India. (Tropical humid biome). Both these regions were blessed with contrasting ecosystems which were ideal for the colonization of different families and species of earthworms. Earthworms were sampled during February – March, 2012, from 13 stations in Benghazi and the same were sampled during February – March, 2013, from 13 stations in Kollam District, employing standard techniques. The habitat and the density of earthworms in each station were noted. There existed a significant difference ($P<0.05$) on the density of earthworm population, soil temperature, pH, organic matter, % of sand and % of silt between the two regions. The pH of the soil of Benghazi was near neutral to alkaline, whereas the same of Kollam District was near neutral to acidic. Textural analysis of soil revealed that a majority of sampled stations in Benghazi had loamy sand followed by sandy loam, whereas 12 out of 13 stations sampled in Kollam District had sandy clay soils. A significant positive correlation existed between the density of earthworms and % of sand, and a significant inverse correlation existed between the density of earthworms and organic matter and % clay in Benghazi, whereas a significant inverse correlation existed between density of earthworms and soil temperature in Kollam district. A total of three peregrine earthworm species belonging to two families were sampled from Benghazi. They were Family 1: Lumbricidae; Species 1. *Allolobophora caliginosa* (Savigny, 1826), 2 Allolobophora rosea (Savingny, 1826), Family 2: Acanthodrilidae; Species: *Microscolex dubius* (Fletcher, 1887). *A caliginosa* was the dominant earthworm species in Benghazi. On the other hand a total of six families and ten species of earthworms were sampled from Kollam district. These were Family 1: Glossoscolecidae; Species: *Pontoscolex corethrurus* (Muller, 1856), Family 2: Acanthodrilidae; Species: *Plutellus variabilis* Aiyer, 1929, Family 3: Almidae; Species 1: *Glyphidrilus annandalei* Michaelsen, 1950, Species 2: *Glyphidrilus*

achenkoili Cognetti,1911, Family 4: Megascolecidae; Species 1: *Lampito mauritii* (Kinberg, 1867), Species 2: *Megascolex Konkanensis* Fedrab, 1898, Species 3: *Megascolex travancorensis* Michaelsen, 1913. Family 5: Moniligastridae; Species 1: *Drawida pellucida* Michaelsen, 1910, Species 2: *Drawida travancorensis* Michaelsen, 1910. Family 6: Eudrilidae; Species: *Eudrilus enginiae*, Kinberg, 1867. *P. corethrurus* was the dominant species in Kollam district. *P. variabilis* and *E. euginiae* were epigeic, *L. mauritii* was anecic and all the remaining earthworms were endogeics. The importance, contributions and roles played by the earthworms in their respective ecosystems of Benghazi and Kollam district, on soil structure, fertility, aeration and vermicomposting were discussed in detail.

Key words: Benghazi and Kollam district, correlation coefficients, earthworms, Mediterranean and tropical humid, physico-chemical factors of soil, soil composition and texture.

INTRODUCTION

Earthworms (Annelida: Oligochaeta) play an important role in improvement of soil physical structure, nutrient cycling and organic matter dynamics through their feeding, burrowing and easting activities. They form one of the major macrofauna among soil biota to maintain dynamic equilibrium and regulate soil fertility [1]. The present study investigated the presence and habitat preferences of these worms in the soils of Benghazi, Libya, and in Kollam district in Kerala State, India. The aim of the study was to compare the occurrence and habitat preferences of the earthworms dwelling in these two regions and to verify their roles and contributions in their respective soil ecosystems.

Reviewing the literature, one can find that not much information is available on the earthworms of Libya in general and Benghazi in particular, except for the publications [2, 3, 4, 5, 6]. On the other hand, the literature on the tropical earthworms of western ghats in India, which included Kollam district also, is rich [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

MATERIALS AND METHODS

2.1. Place of study

Benghazi (32°10'N, 20° 06'E) (Fig. 1), the coastal Mediterranean city in Libya is a part of Chapparal biome and is bordered on the north by the Mediterranean sea, on the east by Jebel Akdar (Green Mountains) and on the south and west by plain landscapes. The region experiences moderate Mediterranean climate, and the monsoon and winter seasons start form the end of October and last till May with frequent drizzles and cold wind lashing the region. The summer is moderate to severe from June/July till the middle of October with the mean temperatures rising to 35 to 38°C. The temperature rises occasionally to 45 to 50°C in summer when sand storms (Gibli) coming from Sahara in the South lashes the region. The major crops grown in Benghazi as olive, orange, apple, spinach and cabbage.

Kollam district (8.80°N, 76.60°E) (Fig. 2) is located on the south-west coast of Kerala, India. It is a part of tropical humid biome and the climate is characterized by excessive humidity (>70%) and moderate temperature (mean 25 to 35°C) during the greater part of the year. The district is bordered on the west by the Lakshadweep (Arabian) sea, and on the east by the Sahyadri hills of the western ghats. The district experiences summer from January/February to May, and monsoon from June to November. Agriculture is the primary source of income of the population other than income from fishery and mineral resources. Paddy, coconut, tapioca, rubber, pepper, mango, banana and cashew are the major crops. The district is blessed with coastal region, estuaries, brackish and freshwater lakes, wetlands and forests. Two Ramsar sites, Ashtamudi and Sasthamkotta lakes are located within the district.

2.2 Earthworm sampled stations

Earthworms were sampled from 13 stations in Benghazi and from 13 stations in Kollam district (Figs. 1 and 2). The stations selected in Benghazi were 1. Sidi Khalifa, 2. El-Koefia, 3. Sidi Hussain, 4. Boutani, 5. Benina canal, 6. Benina grassland, 7. Benina farm, 8. Fuwayhat, 9. Garyounis, 10.

El-Guarsha, 11. Ganfuda, 12. Hawari, 13. Nuwagia. Out of these, stations 1, 2, 3, 8, 9, 11 were located in the coastal region, whereas stations 4, 5, 6, 7, 10, 12, 13 were located on the plain landscapes. (Fig. 1). On the other hand, the stations selected for earthworm sampling in Kollam district were 1. Chavara, 2. Oachira, 3. Kottiyam, 4. Sasthamkotta, 5. Mukkadavu, 6. Kottarakkara, 7. Pathanapuram, 8. Chadayamangalam, 9. Achankovil, 10. Yeroor, 11. Kulathupuzha, 12. Chithara, 13. Edapalaym. Out of these, stations 1, 2, 3 were located in the coastal zone (elevation 0-20m), stations 4, 5, 6, 7, 8 were located in the midland (elevation >20 to 50m), and stations 9, 10, 11, 12, 13 were located in the highland (elevation >50m).

2.3 Earthworm sampling and preservation

Earthworms were sampled from different stations of Benghazi during February and March, 2012 and from different stations of Kollam district during February and March, 2013, following the procedure [20]. A plot of 30cm x 30cm was measured first within each station where the earthworms were present in large numbers, and a hole of 10cm 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, 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 5m apart. Added up the number of earthworms in five holes and doubled it and expressed as the number of earthworms/m^2.

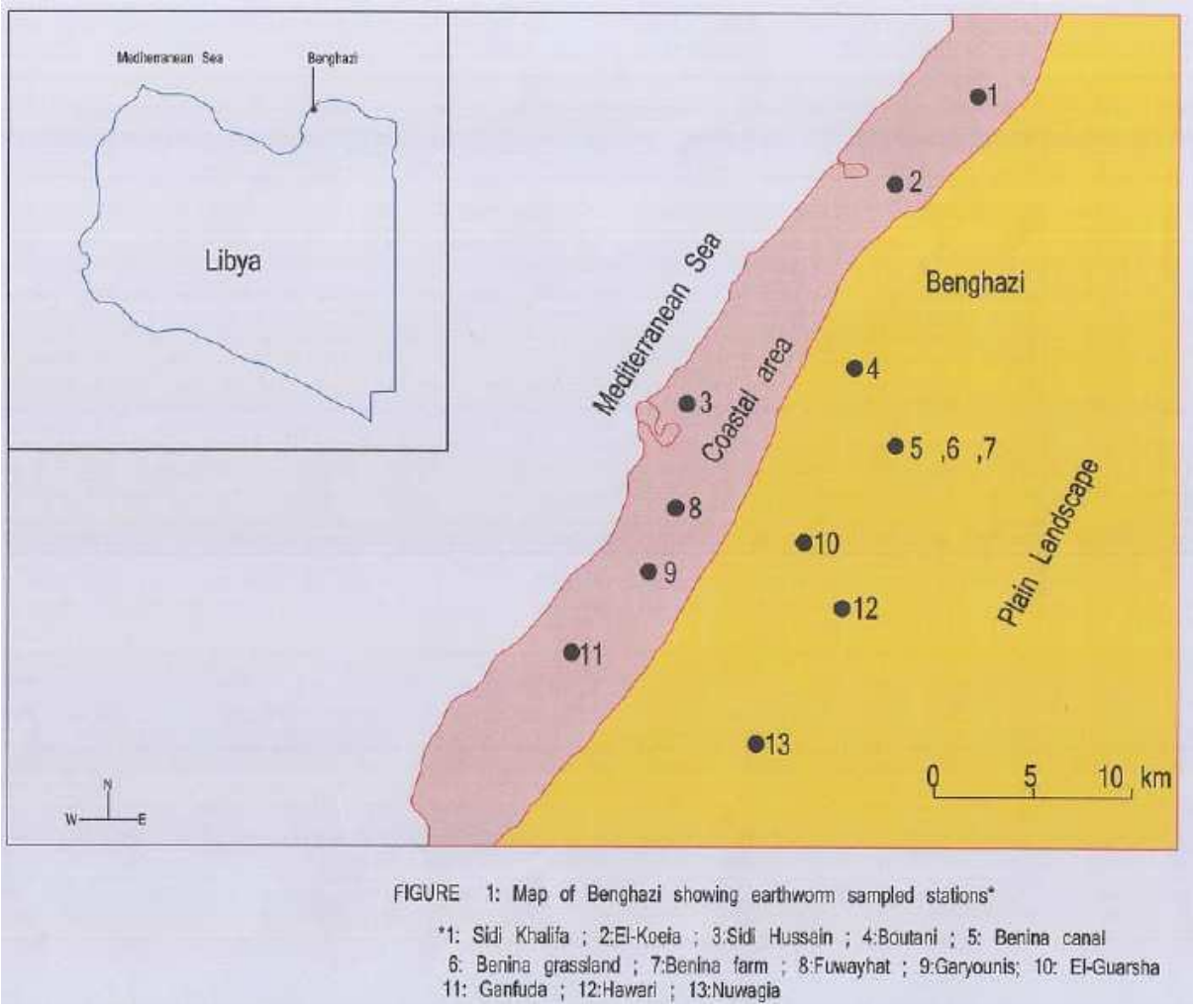

FIGURE 1: Map of Benghazi showing earthworm sampled stations*

*1: Sidi Khalifa ; 2:El-Koeia ; 3:Sidi Hussain ; 4:Boutani ; 5: Benina canal 6: Benina grassland ; 7:Benina farm ; 8:Fuwayhat ; 9:Garyounis; 10: El-Guarsha 11: Ganfuda ; 12:Hawari ; 13:Nuwagia

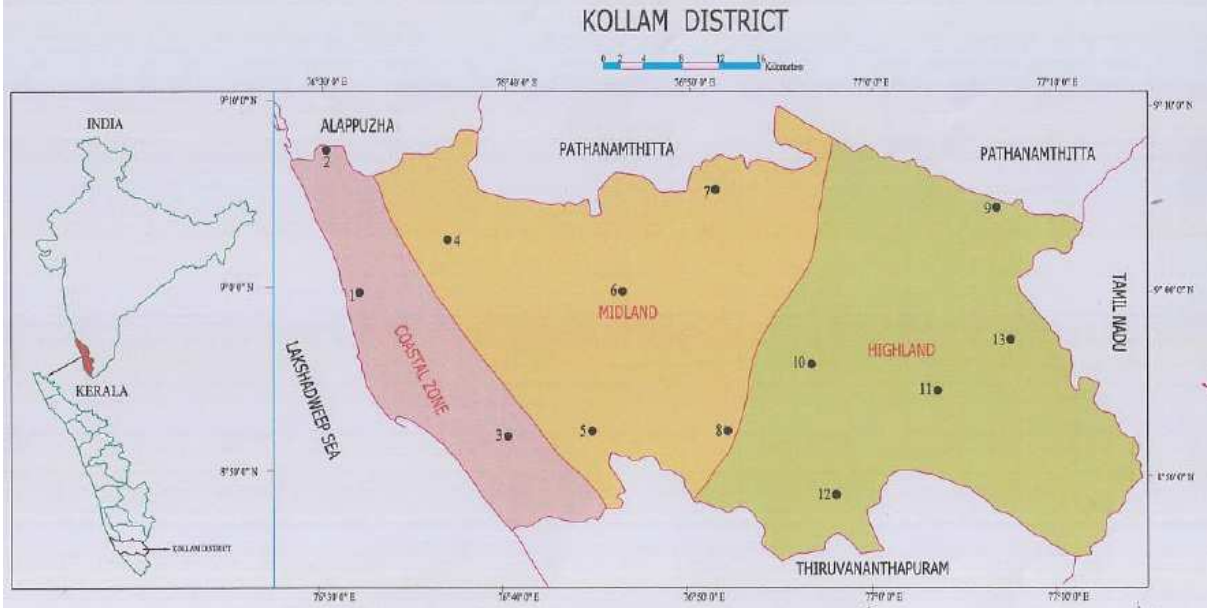

Figure .2. Map of Kollam District , Kerala , showing earthworm sampled stations*

*1-Chavara , 2 -Onchiri , 3 - Kottiyam , 4 -Sasthamkotta , 5 -Mukkadavu , 6 - Kottarakkara , 7-Pathanapuram , 8 - Chadayamangalam , 9 - Achankovil , 10 - Yeroor , 11- Kulathupuzha , 12 - Chithara , 13 - Edapalayam .

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.

2.4 Data analysis and information

The geographical details of Benghazi and Kollam district were provided by the Meteorological stations of Benghazi and Kollam respectively. The soil factors were analysed in the Soil Testing Laboratory, Garyonnis, Benghazi, for Benghazi soils, and in the Central Soil Analysis Laboratory, Government of Kerala, Thiruvananthapuram, for the soils collected from Kollam district. The temperature (^{o}C) of the soil (5cm deep) was measured with 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^{o}C) soil and expressed as a percentage.

2.5 Earthworm identification

Earthworms sampled from Benghazi were identified upto the species level by Prof.Dr.Maria Iglesias Briones, a Mediterranean earthworm taxonomist, University of Vigo, Spain, and the earthworms of Kollam district were identified upto species level by Dr.(Mrs.) P.Kathireswari, an Indian earthworm taxonomist, Tamil Nadu, India. The identified earthworms of Benghazi and Kollam district were deposited in the Museums of Zoology Departments of University of Benghazi, and Baby John Memorial Government College, Chavara, Kollam, respectively.

2.6 Statistical analysis

Relevant statistical analysis of the data were carried out following the procedures [21].

RESULTS

3.1 Habitats and density of earthworms

The habitats and the density of earthworms sampled from different stations of Benghazi and Kollam district are presented in Table 1. The habitats of earthworms sampled from Benghazi consisted of vegetable farm, vegetable and fruit farm, lemon and orange farm, rose and flower gardens, croplands, plain landscapes having grasses, wild plants and trees, and ground having patches of water. On the other hand, in Kollam district, earthworms were sampled from paddy fields, crop and grasslands, banana plantations, marshy lands, open fields having thick growth of grasses, and forests.

The density of earthworms in Benghazi ranged from 30 earthworms/m^2 in plain water logged landscape in Nuwagia to 104 earthworm/m^2 in vegetable farm of Sidi khalifa. The mean density of earthworm in Benghazi was 71$\pm$6 earthworms/m^2. Except Nuwagia, all other stations had more than 50 earthworms/m^2. The density of earthworms in Kollam district was lower when compared to the same of Benghazi. Here the density ranged from 16 earthworms/m^2 in open field with patchy grasses in Chadayamangalam to 92 earthworms/m^2 in forest soil of Kulathupuzha. Mean density of earthworms in Kollam district was 42$\pm$6 worms. Only 4 stations out of the total 13, recorded density of earthworms of more than 50/m^2. A significant difference ($t=3.67$; $p<0.01$) in mean values of density of earthworms of Benghazi and Kolam district was discernible.

3.2 Physico-chemical factors of soil

The physico-chemical factors of soil such as temperature, moisture, pH and organic matter of different earthworm sampled stations of Benghazi and Kollam district are given in Table. 2.

Soil temperature varied from 12^{o}C in Garyounis to 19.1^{o}C in Bontani (mean value of temperature was 16.5$\pm$0.6^{o}C) in Benghazi. On the other hand, the same varied from 22^{o}C recorded in Yeroor, Kulathupuzha and Edapalayam stations to a maximum of 28^{o}C recorded in Chadayamangalam in Kollam district (mean: 25.1$\pm$0.5^{o}C). The differences in mean values of soil temperature between Benghazi and Kollam district were highly significant ($t=10.59$; $p<0.01$). High moisture contents of soil were recorded in the sampled stations of Benghazi and Kollam district. In Benghazi, the highest value of soil moisture was recorded in Hawari (26.8%) and the lowest in Sidi Khalifa (11.7%). The mean value of soil moisture in Benghazi was 20.3$\pm$1.2%. In Kollam district, the highest (33.9%) and the lowest (12.2%) values of soil moisture were recorded in Oachira and Pathanapuram stations respectively. The mean value of soil moisture was 22.3$\pm$1.9%. A significant difference in the mean values of soil moisture between Benghazi and Kollam district was not found ($t=0.84$; $p>0.05$).

Some interesting observations were made on the values of soil pH of Benghazi and Kollam districts. The pH of earthworm sampled stations of Benghazi were alkaline to near neutral and it ranged from 7.9 in Garyounis to 6.6 in Benina grassland (mean pH was 7.5$\pm$0.1). On the other hand, the soil pH of earthworm sampled stations of Kollam district were acidic to near neutral and it varied from to 4.4 in Yeroor to 6.4 in Pathanapuram. (mean pH was 5.4$\pm$0.2). The difference in the mean values of pH between Benghazi and Kollam district ($t=12.45$; $p<0.01$) was highly significant. High organic matter was recorded in Benghazi soils when compared to the same of Kollam district. Thus, in Benghazi, the highest value (7.7%) of organic matter was noted in the soil of Boutani and the lowest (2.1%) in the soil of Sidi Khalifa. The mean value of soil organic matter in Benghazi was 5.0$\pm$0.5%. In Kollam district, the highest (3.3%) and lowest (0.9%) values of organic matter were recorded in the soils of Sasthamkotta and Achenkovil respectively and the mean value was 1.67$\pm$0.2%. A significant difference in soil organic matter content ($t=6.02$; $p<0.01$) existed between the earthworm sampled stations of Benghazi and Kollam district.

Table 1: Habitats and density of earthworms sampled from different stations of Benghazi and Kollam district.

Benghazi				Kollam district			
Sl. No.	Name of Station	Habitat	Density (No. of worms/m^2)	Sl. No.	Name of Station	Habitat	Density (No. of worms/m^2)
1	Sidi Khalifa	Vegetable farm	104	1	Chavara	Paddy field	40
2	El-Koefia	Vegetable and fruit farm	84	2	Oachira	Grass covered wetland	60
3	Sidi Hussain	Plain landscape on the bank of a lake	70	3	Kottiyam	Abandoned paddy field	34
4	Boutani	Cropland	66	4	Sasthamkotta	Bank of a freshwater lake covered by grass	44
5	Benina canal	Plain landscape covered by grass on the two sides of a freshwater canal	82	5	Mukkadavu	Cropland	40
6	Benina grassland	Open grassland	56	6	Kottarakkara	Banana plantation	44
7	Benina farm	Lemon and orange farm	60	7	Pathanapuram	Grassland	26
8	Fuwayhat	Cropland	100	8	Chadayamangalam	Open field having patchy grass	16
9	Garyounis	Plain landscape covered by grass and wild plants	80	9	Achankovil	Paddy field in the midst of forest	50
10	El-Guarsha	Plain landscape around a water reservoir	56	10	Yeroor	Cropland	56
11	Ganfuda	Plain landscape having wild grass and trees	74	11	Kulathupuzha	Forest	92
12	Hawari	Rose and flower garden	60	12	Chithara	Marshy land covered by plants	24
13	Nuwagia	Plain landscape having water-logged patches	30	13	Edapalayam	Forest	26

Table 2 : Physico – chemical analyses of soil of different earthworm sampled stations of Benghazi and Kollam district

Benghazi						Kollam district					
Sl. No.	Station	Temperature (°C)	Moisture (%)	pH	Organic matter (%)	Sl. No.	Station	Temperature (°C)	Moisture (%)	pH	Organic matter (%)
1	Sidi Khalifa	15.0	11.7	7.8	2.1	1	Chavara	26	18.3	5.5	1.5
2	El-Koefia	17.6	18.3	7.6	4.0	2	Oachira	25	33.9	6.0	1.6
3	Sidi Hussain	18.4	22.9	7.4	6.4	3	Kottiyam	27	25.1	5.5	1.9
4	Boutani	19.1	16.5	7.6	7.7	4	Sasthamkotta	27	14.1	4.8	3.3
5	Benina Canal	14.2	21.3	6.8	3.4	5	Mukkadavu	25	18.4	6.1	2.4
6	Benina grassland	14.6	17.2	6.6	6.2	6	Kottarakkara	26	26.1	5.1	0.9
7	Benina farm	18.6	17.5	7.1	4.8	7	Pathanapuram	25	12.2	6.4	1.0
8	Fuwayhat	16.8	19.1	7.3	4.4	8	Chadayamangalam	28	17.2	5.5	1.6
9	Garyounis	12.0	24.2	7.9	4.6	9	Achankovil	25	30.8	5.8	0.9
10	El-Guarsha	18.2	17.7	7.6	3.8	10	Yeroor	22	16.9	4.4	1.7
11	Ganfuda	18.3	25.4	7.8	5.9	11	Kulathupuzha	22	27.2	4.9	2.2
12	Hawari	15.1	26.8	7.6	3.3	12	Chithara	26	19.7	5.4	1.7
13	Nuwagia	16.6	25.8	7.7	8.9	13	Edapalayam	22	29.4	5.0	1.0

3.3 Soil composition and texture

The soil composition and texture of different earthworm sampled stations of Benghazi and Kollam district are presented in Table 3.

The percentages of sand in different earthworm sampled stations of Kollam district were much higher when compared with the percentages of sand of Benghazi. In Benghazi, the highest and the lowest percentages of sand in soils were recorded in Benina canal (42%) and in Nuwagia (14%) respectively. The mean value of sand in Benghazi soils was 32$\pm$2%. However, in Kollam district, the highest value of sand (86%) in soil was noted in Achenkovil and the minimum (54%) was recorded in Sasthamkotta. The mean value of sand in the soils of Kollam was 68$\pm$3%. A highly significant difference ($t=9.95$; $p<0.01$) existed in the percentages of sand in the earthworm sampled stations of Benghazi and Kollam district.

Table 3 : Soil composition and texture of different earthworm sampled stations of Benghazi and Kollam district

Benghazi						Kollam district					
Sl. No.	Station	Sand (%)	Silt (%)	Clay (%)	Texture	Sl. No.	Station	Sand (%)	Silt (%)	Clay (%)	Texture
1	Sidi Khalifa	34	43	23	Loamy sand	1	Chavara	81	14	5	Sandy loam
2	El-Koefia	40	35	25	Sandy loam	2	Oachira	78	2	20	Sandy clay
3	Sidi Hussain	32	41	27	Loamy sand	3	Kottiyam	58	4	38	Sandy clay
4	Boutani	26	35	39	Clayey loam	4	Sasthamkotta	54	6	40	Sandy clay
5	Benina Canal	42	37	21	Sandy loam	5	Mukkadavu	67	2	31	Sandy clay
6	Benina grassland	36	35	29	Sandy loam	6	Kottarakkara	66	8	26	Sandy clay
7	Benina farm	37	36	27	Sandy loam	7	Pathanapuram	56	4	40	Sandy clay
8	Fuwayhat	30	47	23	Loamy sand	8	Chadayamangalam	57	8	35	Sandy clay
9	Garyounis	32	45	23	Loamy sand	9	Achankovil	86	2	12	Sandy clay
10	El-Guarsha	32	39	29	Loamy sand	10	Yeroor	68	7	25	Sandy clay
11	Ganfuda	33	37	30	Loamy sand	11	Kulathupuzha	64	9	27	Sandy clay
12	Hawari	26	35	39	Clayey loam	12	Chithara	66	2	32	Sandy clay
13	Nuwagia	14	44	42	Silt clay	13	Edapalayam	85	2	13	Sandy clay

The maximum and minimum percentages of silt in Benghazi soils were recorded in Fuwayhat (47%) and El-Koefia, Bontani, Benina grassland and Hawari (35%) respectively. The mean value recorded was 39$\pm$1.2%. The values of silt in different earthworm sampled stations in Kollam district were low and they ranged from 14% in Chavara to 2% in Oachira, Mukkudavu, Achenkovil, Chithara and Edapalayam. The mean value of silt was 5$\pm$1%. The differences in silt in the soils of Benghazi and Kollam district were highly significant ($t=21.4$; $p<0.01$). The whole trend changed as far as the values of clay in the soils of Benghazi and Kollam district. The mean values of clay in soils of Benghazi and Kollam were 29$\pm$2% and 26$\pm$3% respectively and the differences of the mean values of clay between these two stations were insignificant ($t=0.69$; $p>0.05$).

The texture of the soils of Benghazi consisted mainly of loamy sand (46% stations), sandy loam (31% stations), clay loam (15% stations) and silt clay (8% stations). However, in Kollam district, 12 out of 13 station had sandy clay soils (92% station) and one station had sandy loam soil (8%).

3.4 Pearson's correlation coefficient

The values and their inferences of Pearson's correlation coefficients (r) between the density of earthworms and various soil factors in earthworm sampled stations of Benghazi and Kollam district are presented in Table 4.

A significant positive correlation between the density of earthworm and the % of sand in the soil ($r=0.56$; $p<0.05$), and a significant inverse correlation between the density of earthworms and organic matter ($r=-0.66$; $p<0.05$) and % of clay ($r=-0.75$; $p<0.05$) were discernible in the earthworm sampled stations of Benghazi. On the other hand, a significant inverse a correlation existed in the density of earthworms and soil temperature ($r=-0.56$; $p<0.05$) in the earthworm sampled stations of Kollam district. Moderate to weak positive correlation (though not significant) existed between the density of earthworms and % of silt ($r=0.28$) and pH ($r=0.08$) in Benghazi soils, and the same existed between density of earthworm and moisture ($r=0.41$), % of sand ($r=0.11$) and % of silt ($r=0.20$) in the soils of Kollam district. A moderate to weak inverse correlations (though not significant) were discernible between the density of earthworms and % of moisture ($r=-0.37$) of Bengazhi, and the same of density of earthworms with pH ($r=-0.36$), organic matter ($r=-0.25$) and clay ($r=-0.06$) were apparent in the sampled stations of Kollam district.

Table 4 : Pearson's (r) correlation co-efficients between density of earthworms and soil factors of Benghazi and Kollam district.

		Benghazi			Kollam district		
Sl. No.	Parameters	'r'	P-value	Inference	'r'	P-value	Inference
1	Density and Temperature	-0.19	>0.05	A very weak inverse correlation exists	-0.56	<0.05	A significant inverse correlation exists
2	Density and Moisture	-0.37	>0.05	A moderate inverse correlation exists	0.41	>0.05	A moderate positive correlation exists
3	Density and pH	0.08	>0.05	A weak positive correlation exists	-0.36	>0.05	A moderate positive correlation exists
4	Density and Organic matter	-0.66	<0.05	A significant inverse correlation exists	-0.25	>0.05	A weak inverse correlation exists
5	Density and Sand	0.56	<0.05	A significant positive correlation exists	0.11	>0.05	A weak positive correlation exists
6	Density and Silt	0.28	>0.05	A moderate positive correlation exists	0.20	>0.05	A moderate positive correlation exists
7	Density and Clay	-0.75	<0.05	A significant inverse correlation exists	-0.06	>0.05	A weak inverse correlation exists

3.5 Earthworm fauna

A list of different families and species of earthworms sampled from Benghazi and Kollam district together with the information on the ecological categories in which they belonged are given in Table 5, and a detailed picture on the distribution of different species of earthworms sampled from 13 stations each of Benghazi and Kollam district is presented in Table 6.

A total of three species of earthworms belonging to two families were sampled from 13 station of Benghazi, and a total of ten species of earthworms belonging to six families were sampled from 13 stations of Kollam district. The Mediterranean earthworms sampled from Benghazi were 1. *Allolobophora caliginosa* (Savigny, 1826), 2. *Allolobophora rosea* (Savigny, 1826)

(Family: Lumbricidae); and 3. *Microscolex dubius* (Fletcher, 1887) (Family: Acanthodrilidae). On the other hand, the tropical earthworms sampled from Kollam district were 1. *Pontoscolex corethrurus* (Muller, 1856) (Family: Glossoscolecidae); 2. *Plutellus variabilis* Aiyer 1929 (Family: Acanthodrilidae); 3. *Glyphidrilus annandalei* Michaelsen, 1910, 4. *Glyphidrilus achenkoili* Cognetti, 1911 (Family: Almidae); 5. *Lampito mauritii* (Kinberg, 1867), 6. *Megascolex konkanensis* Fedrab, 1898, 7. *Megascolex travancorensis* Michaelsen, 1913 (Family: Megascolecidae); 8. *Drawida pellucida* Michaelsen, 1910, 9. *Drawida travancorensis* Michaelsen, 1910 (Family: Moniligastridae); 10. *Eudrilus enginiae* Kinberg, 1867 (Family: Eudrilidae).

Of the total three species of earthworms sampled from Benghazi, *A.caliginosa* was widespread in Benghazi, followed by *A.rosea* and *M.dubins. A.caliginosa* were sampled from vegetable and fruit farms, rose and flower gardens, plain landscapes, croplands, and lemon and orange farm. *A.rosea* were present in vegetable and fruit farm, croplands, grasslands and plain landscapes. *M.dubius* were sampled from plain landscapes, lemon and orange farms and croplands. The texture of soils from where *A.caliginosa* were sampled included loamy sand, clayey loam, sandy loam and silt clay. *A.rosea* on the other hand were found mainly in sandy loam, clayey loam and loamy sand soils. *M.dubius* were restricted their activities on sandy loam and loamy sand soils.

Concerning the earthworms sampled from Kollam district, the species *P.corethrurus* were widespread and were sampled from 6 out of the total 13 stations. This was followed by *G.annandalei* and *P.variabilis* sampled from 3 stations each, *M.konkanensis*, *D.pellucida* and *D.travancorensis* from 2 stations each, and *G.achenkoili, L.mauritii, M.travancorensis* and *E.euginiae* from 1 station each. *P.corethrurus* and *E.eugininae* were exotic worms and the remaining ones were natives. *P.corethrurus* were sampled from paddy fields, bank of a lake, croplands, marshylands and forests, whereas *G.annandalei* and *G.achenkoili* were present only in paddy fields. *P.variabilis* were sampled from grass covered wetlands, paddy fields and marshy lands, whereas *M.konkanensis* were found on the bank of a lake and on grasslands, and *D.pellucida* in banana plantations and croplands. *D.travancorensis*, on the other hand, were sampled from open grass covered fields and from forests. *L.mauritii* were found in plenty in grass covered wetlands, *M.travancorensis* in banana plantations and *E.euginiae* in forest soils. All the species of earthworms were found in sandy clay soils, and *P.corethrurus* and *G.annandalei* were also found in sandy loam soil in one station (Chavara).

3.6 Ecological categories of earthworms

The three species of earthworms sampled from Benghazi and the ten species of earthworms sampled from Kollam district were broadly divided into three ecological categories of epigeic, endogeic and anecic (Table 5), based on the positions they occupied in the soil. Thus, the earthworm *P.variabilis* and *E.euginiae* sampled from Kollam district were epigeics. These earthworms lived in organic horizons and ingested large amounts of undecomposed litter. They produced ephemeral burrows into the mineral soil for diapause periods only. They were relatively exposed to climatic fluctuations and predator pressures, and tended to be small with rapid generation times. All the three earthworm species viz. *A.caliginosa, A.rosea a*nd *M.dubius* sampled from Benghazi, and the species *P.corethrurus, G.annandalei, G.achenkoili, L.mauritii, M.konkanensis, M.travancorensis, D.pellucida* and *D.travancorensis* sampled from Kollam district were endogeics. These species foraged below the surface, ingested large quantities of soil with a preference towards organic rich soil, and built continuously ramifying burrows that were mostly horizontal. These earthworms were apparently not of major importance in litter incorporation but were important in other soil forming processes including root decomposition, soil mixing and aeration.

L.mauritii, the earthworm sampled from Kollam district was anecic. The species which build permanent vertical burrows that penetrate the soil deeply is termed anecic [22]. *L.mauritii* was a detritirore and came to the surface to feed on partially decomposed litter, manure and other organic matter. It had profound effects on organic matter decomposition, nutrient cycling and soil formation.

Table 5: List of families and species of earthworms sampled from Benghazi and Kollam district together with their ecological categories

Benghazi				Kollam district			
Sl. No.	Family	Species	Ecological category	Sl. No.	Family	Species	Ecological category
1	Lumbricidae	1. *Allolobophora caliginosa* (Savigny, 1826)	Endogeic	1	Glossoscolecidae	*Pontoscolex corethrurus* (Muller, 1856)	Endogeic
		2. *Allolobophora rosea* (Savigny, 1826)	Endogeic	2	Acanthodrilidae	*Plutellus variabilis* Aiyer, 1929	Epigeic
2	Acanthodrilidae	*Microscolex dubius* (Fletcher, 1887)	Endogeic	3.	Almidae	1. *Glyphidrilus annandalei* Michaelsen, 1910	Endogeic
						2. *Glyphidrilus achenkoili* Cognetti, 1911	Endogeic
				4.	Megascolecidae	1. *Lampito mauritii* (Kinberg, 1867)	Anecic
						2. *Megascolex konkanensis* Fedrab, 1898	Endogeic
						3. *Megascolex travancorensis* Michaelsen, 1913	Endogeic
				5.	Moniligastridae	1. *Drawida pellucida* Michaelsen 1910	Endogeic
						2. *Drawida travancorensis* Michaelsen 1910	Endogeic
				6.	Eudrilidae	*Endrilus euginiae* Kinberg, 1867	Epigeic

Table 6: Earthworms sampled from different stations of Benghazi and Kollam district

Benghazi			Kollam district		
Sl. No.	Station	Species of earthworm	Sl. No.	Station	Species of earthworm
1	Sidi Khalifa	*Allolobophora caliginosa*	1	Chavara	1. *Glyphidrilus annandalei*
2	El-Koefia	*Allolobophora rosea*			2. *Pontoscolex corethrurus*
3	Sidi Hussain	*Allolobophora caliginosa*	2	Oachira	1. *Lampito mauritii*
4	Boutani	1. *Allolobophora caliginosa*			2. *Plutellus variabilis*
		2. *Allolobophora rosea*	3	Kottiyam	*Glyphidrilus annandalei*
		3. *Microscolex dubius*	4	Sasthamkotta	1. *Pontoscolex corethrurus*
5	Benina Canal	1. *Allolobophora caliginosa*			2. *Megascolex konkanensis*
		2. *Microscolex dubius*	5	Mukkadavu	*Pontoscolex corethrurus*
6	Benina grassland	*Allolobophora rosea*	6	Kottarakkara	1. *Drawida pellucida*
7	Beninafarm	1. *Allolobophora caliginosa*			2. *Megascolex travancorensis*
		2. *Microscolex dubius*	7	Pathanapuram	*Megascolex konkanensis*
8	Fuwayhat	1. *Allolobophora caliginosa*	8	Chadayamangalam	*Drawida pellucida*
		2. *Allolobophora rosea*	9	Achankovil	1. *Glyphidrilus achenkoili*
		3. *Microscolex dubius*			2. *Pontoscolex corethrurus*
9	Garyounis	1. *Allolobophora caliginosa*			3. *Plutellus variabilis*
		2. *Allolobophora rosea*	10	Yeroor	*Drawida pellucida*
		3. *Microscolex dubius*	11	Kulathupuzha	*Drawida travancorensis*
10	El-Guarsha	*Allolobophora caliginosa*	12	Chithara	1. *Plutellus variabilis*
11	Ganfuda	1. *Allolobophora caliginosa*			2. *Pontoscolex corethrurus*
		2. *Allolobophora rosea*	13	Edapalayam	1. *Eudrilus euginiae*
12	Hawari	*Allolobophora caliginosa*			2. *Pontoscolex corethrurus*
13	Nuwagia	*Allolobophora caliginosa*			

DICSUSSION

Benghazi, Libya, a part of the Chapparal biome, and located on the eastern Mediterranean coast of North Africa, has mild temperate climate during winter season which changes, to hot and dusty during summer period. Kollam district, a part of tropical humid biome and located on the south-west coast of Kerala, India, experiences tropical humid climate having summer and monsoon seasons. Both the regions are blessed with natural scenario and ecosystems which are totally different. Both Benghazi and Kollam district are found suitable for the earthworms to

colonise, even though the species of earthworms found in them are quite different. The geographical, climatic and soil factors of Benghazi and Kollam district enabled the temperate and tropical earthworms to occupy the suitable habitats (Benghazi & Kollam district respectively) of their choice.

The soil factors of Benghazi and Kollam district revealed some interesting aspects. Significant differences in the soil temperatures of Benghazi and Kollam district were discernible, whereas such a difference was not observed in the case of soil moisture. The temperature of Benghazi was low during the sampling months of February and March due to the peaks in winter and rainfall. The soil was moist and the surface activity of the earthworms was maximum during this period. This may not be the case in extreme summer months of August and September, when the surface temperature becomes very high compelling many to migrate down the soil [3]. On the other hand, February and March months experienced the peak of summer season in Kollam district with occasional evening summer showers. The maximum soil temperature in Kollam district never exceeded 32^{o}C and the minimum never came down below 20^{o}C, and this range was 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 [23, 24]. In tropical humid regions the temperature fluctuations are minimal when compared to temperate region [16] and tropical species can withstand high temperatures compared to temperate ones [25]. Soil moisture contributes a major share in the distribution and occurrence of various earthworm species [26, 27]. Earthworm activity and population are determined essentially by the moisture content of the soil and that soil moisture and population estimates are positively correlated [28]. There are many indications to show that the population of endogeic earthworms are controlled mainly by soil moisture [23].

The pH of the soil of Benghazi was near neutral to alkaline whereas the soil of Kollam district was near neutral to acidic. This contrasting pH values of the soil of the two regions resulted in colonization of different species of earthworms which could adapt and withstand alkaline and acid soils. Endogeic earthworms have optimum distribution at pH 6 to 7^{+} in temperate areas, and pH 5 to 6^{+} in tropical regions [29]. They further opined that this difference may be due to in part to the differences in the quality of litter produced. In the humid tropics, long-term pedogenetic processes have resulted in the formation of acid soils and selected acid tolerant earthworms become abundant and active [30]. Tropical earthworm species prefer significantly lower pH values than temperate ones and this better tolerance may explain why high earthworm abundance is observed in tropical soils with pH as low as 3.8 to 4.0 [31]. Regarding the correlations of epigeic, endogeic and anecic earthworms with soil pH, it was reported [22] that epigeic earthworms are much more tolerant to acidity than anecic and endogeic species which prefer pH of 6 to 7. This seemed to be partly true in the present study also.

The organic matter of soil greatly influence the distribution of earthworms and soils with low organic matter do not generally support earthworm population [32, 33]. In the present study, the soils of Benghazi recorded high organic matter when compared to the same of Kollam district. Increase in organic matter of semi-arid agricultural soils in Egypt was associated with increased number and biomass of earthworms [34, 35]. This was true in the case of the abundance of earthworms in Benghazi soils also. Even though the organic matter of the soils of Kollam district was quantitatively less when compared with the soils of Benghazi, this decrease never affected the activity of different earthworm species present there. Some of the reports from different parts of India support qualitative dependence of earthworm population on soil organic matter [36, 37, 38]. Due to the influence of organic matter of the soil, the percentage contribution of nitrogen to the earthworm population may have shown a high degree of dependence [39]. Nitrogen rich organic content of the soil helps in rapid growth of earthworms and facilitate more cocoon production [40].

The composition and texture of soil have great influence on the distribution and population structure of earthworms [41]. In the present study, a significant difference was observed in the percentage of sand and silt between the soils of Benghazi and Kollam district whereas such a difference was not discernible in the case of clay content of the soil. Reports suggest a strong

relationship between the polyhumic species *A.rosea* and high content of clay in the soil [42]. A relationship existed between soil clay content and total abundance of *A.rosea* and *A.caliginosa* [43, 44]. In the present study, however, both these species were sampled from Benghazi from soils having low and high values of clay (range 21-42%) and a clear association between these two could not be established. Regarding the texture, a majority of soils of Benghazi were loamy sand followed by sandy loam, whereas 92% stations of Kollam district had sand clay soils. Sandy loam soil is the best medium for earthworms in executing cutaneous mode of respiration [45] and most of the endogeic worms prefer sandy loam soils [25].

In Benghazi, three species of earthworms *viz. A.caliginesa*, *A.rosea* and *M.dubius* belonging to the families Lumbricidae (first two species) and Acanthodrilidae (third species) were sampled. Among these, *A.caliginosa* was found to be ubiquitons and were present in 11 out of 13 stations sampled. *A.rosea* were sampled from 6 out of 13, and *M.dubius* from 5 out of 13 stations. Regarding species association, all the three species were found to co-exist in croplands and in plain landscapes covered by grass and wild plants. *A.caliginosa* and *A.rosea* were found together in plain landscapes having wild grass and trees, and *A.caliginosa* and *M.dubius* on the two banks of a freshwater canal, and in lemon and orange farms. *A.caliginosa* alone were sampled from vegetable garden, from soils around a water reservoir, rose and flower gardens and from water-logged landscapes. *A.rosea* alone on the other hand were sampled from vegetable gardens and open grasslands. *M.dubius* were always seen together with *A.caliginosa*. These three peregrine species played important roles in soil fertility, soil structure and soil aeration. *A.caliginosa* is considered as a top-soil mixer, whereas the presence of *A.caliginosa* and *M.dubius* improve the soil structure and surface mat of litter [42]. *A.caliginosa* is the dominant species in the arable reclaimed lands accompanied by *A.rosea* [32].

Regarding the earthworms of Kollam district, it was observed that out of the 10 species sampled, 2 were exotics and the remaining 8 were natives. The exotic worms were *P.corethrurus and E.euginiae. P.corethrurus* was widespread in Kollam district and were sampled from 6 out of 13 stations. It co-existed with *G.annandalei, G.achankoili, M.konkanensis, P.variabilis* and *E.euginiae* in the field. This species were collected from paddy fields, banks of a freshwater lake, croplands, marshy lands and forests. *P.corethrurus* is the most common invasive endogeic and meso-humic earthworm in disturbed lands in tropics and it has colonized most of lands transformed by human activities in humid tropics [46]. It is also common in managed ecosystems or in areas subjected to some type of alternation and this species has exceptional demographic trails [38], allowing it to quickly colonise disturbed places from where native earthworms have been removed [30, 48]. *P.corethrurus* gains importance to maintain its successful field population for its systematic use in land restoration under specific conditions [45]. This species has the potential for rapid restoration of soil fertility in degraded lands and is very efficient in nitrogen mineralization process [47, 48]. *E.euginiae,* another exotic and epigeic African nighterawler, was sampled from forest soils and it co-existed with *P.corethrurus*. This species is widespread in warm regions both wild and under vermiculture and it has the best potential for breaking down organic material [49].

Among the eight native species of earthworms sampled in the present study, *L.mauritii* was anecie, *P.variabilis* was epigeic and the remaining six were endogeics. *L.mauritii* was sampled in the present study from the grass covered wetlands and it co-existed with *P.variabilis.* In India, *L.mauritii* is the most widely distributed earthworm in different agro-ecosystems [50, 51, 52, 53, 24]. This species, a geophytophagons, is known to be a voracious feeder of humus in preference to soil and inhabits the sandy loam [51]. Being an anecie, it helps in rejuvenating the soil by burrowing through it [53]. *P.variabilis* was sampled from grass covered wetlands, paddy fields and marshy lands and it co-existed with *L.mauritii, P.corethrurus* and *G.achenkoili* in the field. Not much information is available on this species about its distribution and role in soil structure and fertility. Indian species of *Plutellus* is similar to North American *Agrilophilus* and Indian *Plutellus* is slightly different from Australian species in the nephridia present in each segment [18].

The species *G.annandalei* and *G.achenkoili* were sampled from the paddy fields. These species are mud dwellers, hydrophilous and are found in more or less submerged habitats [59]. They

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 [55]. The other endogeic earthworms sampled from Kollam district were *M.konkanensis, M.travancorensis*, *D.pellucida*, and *D.trvancorensis. M.konkanensis* were sampled from the banks of a freshwater lake and from grasslands, and this species co-existed with *P.corethrurus* in the wild. *M.travancorensis* were sampled from banana plantations and it co-existed with *D.pellucida* which also was sampled from croplands apart from banana plantation. *D.travancorensis* on the other hand were sampled from open fields having patchy grasslands. *Megascolex* sp. were large worms found only in tropics and their movements aided in increase of soil aeration and mixing of soils. Some were used as fish feeds and in vermicomposting also. *Drawida* sp are large worms and are found mostly in South India and Ceylon apart from scanty reports from Assan hills and Eastern Himalayas [56]. The activity of *Drawida* sp will remain confined to 20cm depth and they are considered suitable for vermicomposting of organic matter [51].

CONCLUSION

The present study was the first of its kind on the comparison of the earthworm resources of Benghazi and Kollam district which belonged to two contrasting Chapparal and Tropical humid biomes respectively. The investigation showed how geographic, climatic and edaphic factors, which were quite different in these two regions, regulated the colonization, adaptation and distribution of different species of earthworms, one group adapted to live in temperate and another in tropical humid climates. Such comparative studies on earthworms dwelling in different biomes and in different parts of the world will throw more light on their universal distribution pattern and contribution to soil fertility.

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