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Abundance and distribution of nematodes in petroleum hydrocarbon polluted soil in Okrika Local Government Area, Rivers State, Nigeria

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Abstract

This study examined the abundance of nematodes in petroleum hydrocarbon polluted soils in Okrika region. A total of 80 soil samples were collected at various depths in several sites of the region during the dry and rainy seasons. Three of the sites (Ekerekana, Ogoloma and Okari) were polluted by petroleum hydrocarbon while the control (Abam) was unpolluted. A total of 15 genera containing 749 individual nematodes were extracted from both polluted and unpolluted sites. The highest abundance was recorded at the control site, Abam with 327 (43.7%), followed by Ekerekana with 272 (36.3%), Ogoloma with 97 (12.9%) and Okari with 53 (7.1%) nematodes. In comparison to the dry season, more nematodes, 561 (74.9% out of total population) individuals were extracted during the wet season. During the wet season, nematode abundance was considerably higher ($p<0.05$) in the unpolluted site than those in polluted sites, but during the dry season, there was no significant difference ($p>0.05$) between the seasons. Similarly, more nematodes (51.3%) were extracted from the core depth of 0-5 cm than 6-10 cm (33.2%) and 11-15 cm (15.5%). At the depth of 0-5 cm, the control site had a significant ($p<0.05$) nematode abundance than the polluted sites while at the depths of 6-10 cm and 11-16 cm, although there was a higher numerical abundance of nematodes in the unpolluted sites than the control site, but these were not significant ($p>0.05$). This study showed that nematodes at the studied sites were relatively sensitive to petroleum hydrocarbon pollution especially at the depth of 0-5 cm in both dry and rainy seasons.

Keywords: Abundance; Hydrocarbon; Nematodes; Pollution

1 Introduction

Among the most valuable resources, soil serves as a means of providing food for plants as well as habitat for edaphic organisms. It provides home for several life forms including bacteria, fungi, algae, protozoa, arthropods and nematodes. Soil also drives and boosts numerous biogeochemical processes that sustain the ecosystem (Wagg et al., 2014; Brussard et al., 1997). The presence and activities of these organisms in addition to the physicochemical properties of the soil influence the ecological health of the soil. A healthy soil is able to support ecological yield, quality of environment and to encourage animal and plant health (Weil & Magloff, 2004; Bileva et al., 2013; Osarokaka et al., 2021).

One of the most important faunas in edaphic food web is the nematodes community which are group of invertebrate animals that exist in parasitic, predatory and free-living life styles. They are found in the soil, marine and fresh water habitats (McSorley, 2003; Brussard et al., 1997). The free-living forms are especially important in the improvement of soil vitality through the decomposition of organic matters needed for plant growth and productivity (Neher, 2001a). In essence, the diversity, abundance and distribution of soil nematodes are major factors in assessment of the integrity of the soil (Osarokaka et al., 2021; Visser & Parkinson, 1992). Using their trophic traits, soil nematodes are divided into five major groups: bacterial feeders, omnivores, plant feeders, predators, and fungi feeders (Yeates et al., 1993). Nematodes can also be categorized into five groups based on a colonizer-persister (cp) scale which takes into consideration the characteristics of their lifecycle and sensitivity to agitation (Bongers, 1990). The scale, according to

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Chauvin et al. (2020), ranges from cp1- opportunistic feeders with a fast generation time and a high reproduction rate up to cp5- persisters with a lengthy life time, a little reproduction rate, and more sensitivity to ecological agitations. According to Bongers (1998), functional guilds are described using a mix of the cp scale and feeding preferences. These traits can be utilized to create indicators that can be used to examine the community structure of nematodes (Ferris, 2010) and any alterations brought on by environmental disturbance (Pen-Mouratov et al., 2004).

Anthropogenic activities such as farming, construction and mining resulting into environmental pollution may alter the richness, diversity and distribution of soil nematodes (Chauvin et al*.,* 2020). Although several techniques have been adopted in determination of soil integrity (Cortet et al., 1999; Edwards, 2002; Cadwell, 2005), the biological approach of using nematode communities as bioindicators for assessing ecological disturbances, especially heavy metal pollution has been very effective (Bonger & Ferris, 1999; Neher, 2001a; Georgiera et al., 2002). Nematodes are known to be very sensitive to minor alteration in the physico-chemical properties of the soil (Moura & Franzener, 2017; Osarokaka et al., 2021), including oil spills, leakages and radiation (Beyrem et al., 2010; Wei et al., 2012). In addition to having this characteristic, the fact that nematodes can easily be extracted from the soil enhancing their usage as bioindicators of environmental pollution (Ferris & Matute, 2003).

Numerous studies have documented nematodes' great sensitivity to contamination of the ecosystem by heavy metals resulting in alteration of nematode composition, distribution and abundance (Shukurov et al., 2005; Sanchez & Navas, 2007; Osarokaka et al., 2021; Nzeako et al., 2011; Pen-Mouratov et al., 2011; Briar et al., 2012; Zhang et al., 2012) and according to Chauvin et al. (2020), the most impacted nematode communities are those classified as cp4 and cp5. The effects of heavy metal pollution on the edaphic ecology impact negatively on the functionality of the soil resulting in poor respiration and nutrient cycling (Komulainen & Mikola, 1993; Kandeler et al., 1996). Crude oil pollution has reportedly caused the soil pores to become clogged, which hinders physical processes including capillarity, aeration and drainage leading to an increase in bulk density. Trophic diversity, genus count and the amount of time spent on petroleum exploration in oil fields are all negatively correlated, which has aggressive influence on the community composition of soil nematodes (Wang et al., 2009; Savin et al., 2015).

The Niger Delta of Nigeria is endemically characterized by incessant crude oil pollution either due to equipment failure or sabotage (Nzeako et al., 2011; Osarokaka et al., 2021), with its resultant impact on the ecosystem and biodiversity (Zhang et al., 2012; Nzeako et al., 2011; Osarokaka et al., 2021).

Okrika is an oil producing area located on latitude 4^0 44’ 26’’ N and longitude 7^0 5’ 5’’ with an elevation of 6.028 meters on the north of the Bonny River. The area has an estimated population of 222,026 (National Population Commision, 2006). Fishing is the major occupation of the aborigines; however, crude oil exploration has become the major strength of the economy of the area, with its consequent pollution of the ecosystem. The research area, which has a mean daily temperature of 18^0c, a wind speed of 5 km/h, and a relative humidity of 95%, is essentially a mangrove ecosystem. The annual rainfall ranges from 3500 to 4000 mm and majority of the rainy season occurs between June and September (Chukwumati & Asiegbu, 2023).

The aims of this study were to; *i:* assess the effect of hydrocarbon pollution on the abundance and distribution of soil nematodes in petroleum crude oil impacted sites in Okrika Local Government Area, Rivers State, Nigeria. *ii:* provides data on edaphic biodiversity in relation to nematodes as a results of petroleum hydrocarbon pollution and add value to similar studies conducted in this area.

2 Material and methods

2.1 Study Area

The study was conducted in Okrika Local Government Area, Rivers State (Fig. 1). Four major sites were randomly selected for this study. The sites were selected based on confirmed observation that there is active presence of illegal refining activities, popularly known as “kpo-fire” among Niger Deltans. The sites were designated as A, B, C and D representing Ekerekana (Latitude $4^0$45’0.53’’N, Longitude $7^0$5’59.64’’E), Ogoloma (Latitude $4^0$44’42.93’’N, Longitude $7^0$5’59.64’’E), Okari (Latitude $4^0$44’19.97’’N, Longitude $7^0$5’52.51’’E) and Abam (Latitude $4^0$45’42.17’’N, Longitude 7^0 5’6.93’’E), respectively. Site D (Abam) served as the control, where there was no hydrocarbon pollution.

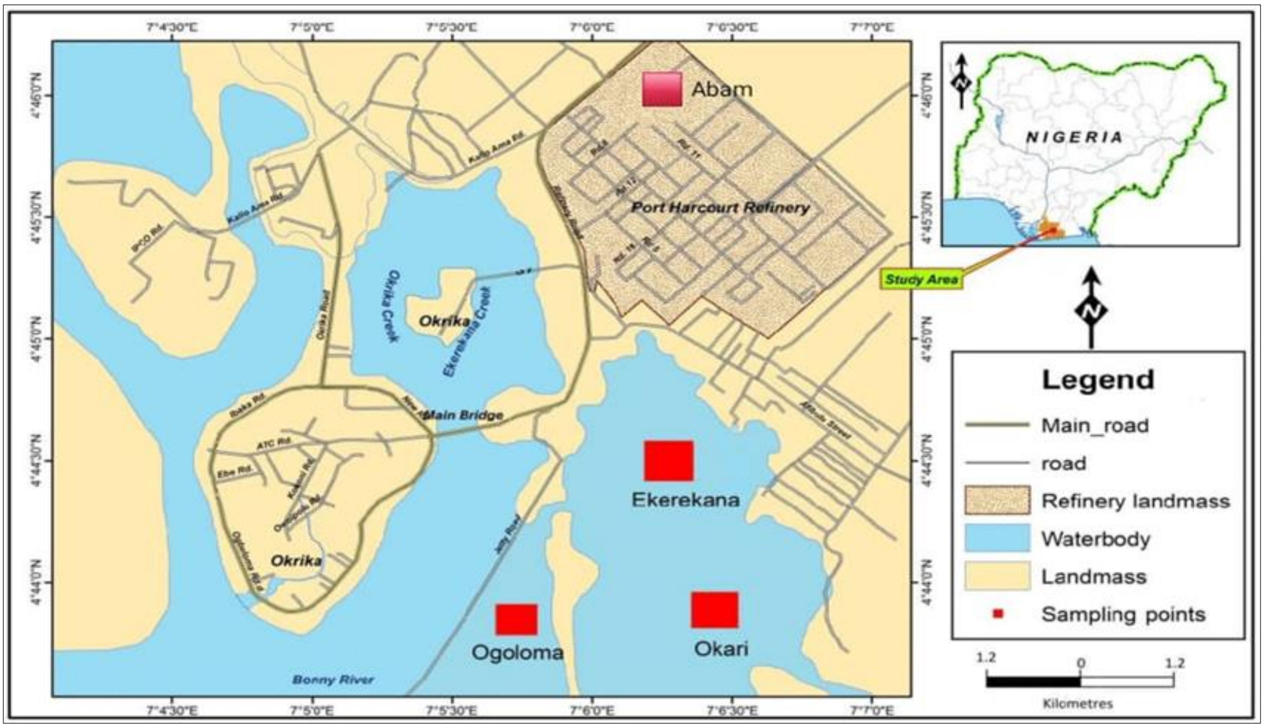

Figure 1 Map of Okrika LGA showing sampling sites (in red)

2.2 Sample Collection

A calibrated soil corer was used to randomly collect soil samples, at a vertical depth range of 0-15 cm from the various sites, including the control. Eighty (80) soil samples (20 samples from each location) were collected at depths of 0-5 cm, 6-10 cm, and 11-15 cm and placed in labeled black polythene bags, kept in a cooler with ice bags and brought to the research facility of Ignatius Ajuru University of Education, Port Harcourt for laboratory analysis. The samples were collected both in the wet season (May-September) and in the dry season (October-April). The collection of samples was done between May, 2022 and April, 2023.

2.3 Laboratory Analysis

The sieving centrifugal floatation techniques by Swart and Marais (2017) was adopted for nematode extraction from the soil and the nematodes were identified to the genus level using the methods of Yeates et al. (1993) and Hooper et al. (2005). Shape of stylet knobs, head, pointed or knobbed tail, length of spicule and its shape, length of the body, absence or presence of spermatheca and length of stylet were some of the criteria used to identify nematodes.

2.4 Statistical analysis

The association between the nematode population densities with communities at various sites was examined using Spearman's correlation coefficient. To examine the significance, statistical correlations at the level of $P>0.05$ was used.

3 Results and discussion

3.1 Overall Nematode Abundance and Distribution

The results indicated that an overall abundance of nematode population densities were 749 individual nematodes belonging to 15 genera which were extracted at various depth from the selected sites in both dry and rainy seasons. The highest abundance was recorded at the control site, Abam with 327 nematode density (43.7%), followed by Ekerekana with 272 (36.3%), Ogoloma with 97 (12.9%) and Okari with 53 (7.1%) nematode densities (Fig. 2). There was a statistically significant difference in nematode frequency between the different locations with

(μ=9.305, df=3, p=0.025) with mean ranks of 20.92, 21.75, 17.83 and 7.79 for Abam (control), Ekerekana, Ogoloma and Okari, respectively. Abam (control) had no significant difference in nematode abundance from Ekerekana (μ=56, p=0.791) and Ogoloma (μ =30.5, p=0.605) but had a significant difference with Okari (μ =8.5, p=0.003). Ekerekana also showed no significant difference with Ogoloma (μ =25, p=0.586).

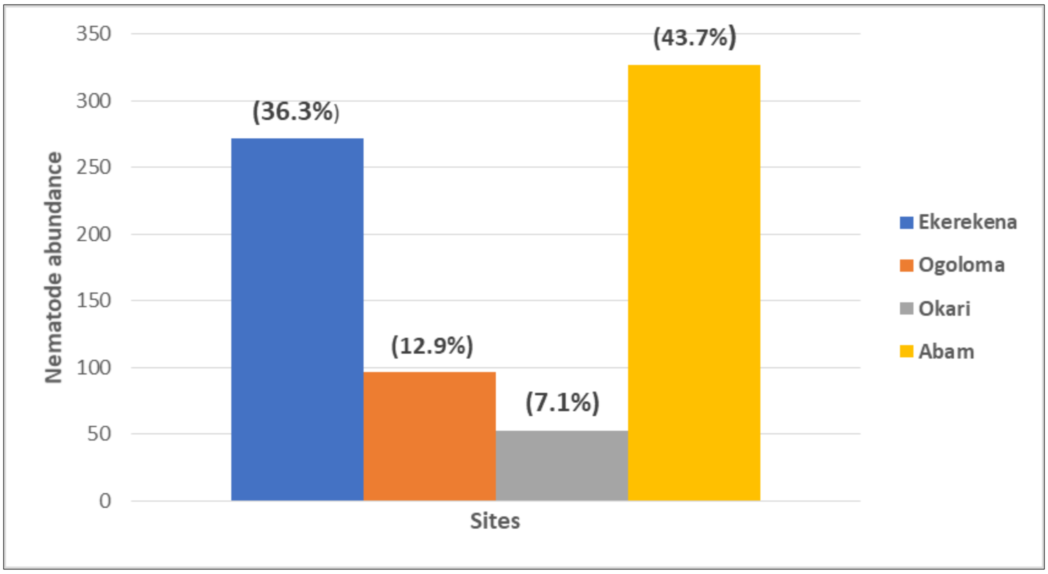

Figure 2 Overall abundance of nematodes in the studied areas

3.2 Nematode Richness and Distribution in Relation to Seasonal Variation

The total number of the nematodes recorded were 749 out of which 561 (74.9%) and 188 (25.1%) were extracted in the wet and dry seasons, respectively. In the rainy season, a total of 199 (26.57%), 85 (11.35%), 40 (5.34%) and 237 (31.64%) nematodes were extracted from Ekerekana, Ogoloma, Okari and Abam, respectively; while in the dry season, a total of 73 (9.75%), 12 (1.60%), 13 (1.74%) and 90 (12.01%) of nematodes were identified from Ekerekana, Ogoloma, Okari and Abam, respectively (Table 1).

3.3 Nematode Abundance and Distribution in Relation to Nematode Population Density

A total of 749 individual nematodes belonging to 15 genera were extracted from the studied sites and identified. The nematode genera were *Hirschmanniela* spp., *Pratylenchus* spp., *Gracilacus* spp., *Tylenchorhynchus* spp., *Trichodorus* spp., *Aphelenchus* spp., *Longidorus* spp., *Hemicycliophora* spp., *Dolichodorus* spp., *Ditylenchus* spp., *Helicotylenchus* spp., *Xiphinema* spp., *Rotylenchus* spp., *Paratylenchus* spp and *Rhabditis* spp. (Table 1). *Pratylenchus* spp. with a number of 154 (20.56%) individuals was the most abundant nematode genus, followed by *Hirschmanniela* spp. 145 (19.36%), *Gracilacus* spp. 86 (11.48%), *Tylenchorhynchus* spp. 55 (7.34%), *Trichodorus* spp. 55 (7.34%), *Hemicycliophora* spp. 52 (6.94%), *Longidorus* spp. 34 (4.54%), *Xiphinema* spp. 30 (4.01%), *Ditylenchus* spp. 29 (3.87%), *Helicotylenchus* spp. 26 (3.47), *Aphelenchus* spp. 19 (2.54%), *Rotylenchus* spp. 18 (2.40%), *Dolichodorus* spp.17 (2.27), *Rhabditis* spp. 17 (2.27%) and *Paratylenchus* spp. 12 (1.60%).

Table 1 Nematode abundance and distribution (%) in polluted and petroleum free area of Okrika region

Nematode Genera	Abam (Control)		Ekerekana (Polluted)		Ogoloma (Polluted)		Okari (Polluted)		Total
	Nematode Abundance (%)								
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	
Hirschmanniela spp.	52 (35.85)	0 (0)	46 (31.72)	16 (11.03)	19 (13.10)	0 (0)	7 (4.83)	5 (3.45)	145 (19.36)
Pratylenchus spp.	40 (25.97)	33 (21.42)	32 (20.78)	9 (5.84)	22 (14.29)	5 (3.25)	9 (5.84)	4 (2.60)	154 (20.56)
Gracilacus spp.	31 (36.05)	0 (0)	17 (19.77)	4 (4.65)	25 (29.07)	0 (0)	6 (6.98)	3 (3.49)	86 (11.48)
Tylenchorhynchus spp.	13 (23.64)	13 (23.64)	25 (45.45)	0 (0)	4 (7.27)	0 (0)	0 (0)	0 (0)	55 (7.34)
Trichodorus spp.	19 (34.55)	0 (0)	22 (40)	2 (3.64)	12 (21.82)	0 (0)	0 (0)	0 (0)	55 (7.34)
Aphelenchus spp.	3 (15.79)	3 (15.79)	2 (10.52)	0 (0)	3 (15.79)	0 (0)	7 (36.84)	1 (5.26)	19 (2.54)
Longidorus spp.	0 (0)	0 (0)	17 (50)	17 (50)	0 (0)	0 (0)	0 (0)	0 (0)	34 (4.54)
Hemicycliophora spp.	12 (23.08)	7 (13.46)	11 (21.15)	11 (21.15)	0 (0)	7 (13.46)	4 (7.69)	0 (0)	52 (6.94)
Dolichodorus spp.	0 (0)	0 (0)	10 (58.82)	7 (41.18)	0 (0)	0 (0)	0 (0)	0 (0)	17 (2.27)
Ditylenchus spp.	0 (0)	0 (0)	17 (58.62)	7 (24.14)	0 (0)	0 (0)	5 (17.24)	0 (0)	29 (3.87)
Helicotylenchus spp.	12 (46.15)	12 (46.15)	0 (0)	0 (0)	0 (0)	0 (0)	2 (7.69)	0 (0)	26 (3.47)
Xiphinema spp.	22 (73.33)	8 (26.67)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	30 (4.01)
Rotylenchus spp.	9 (50)	9 (50)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	18 (2.40)
Paratylenchus spp.	7 (58.33)	5 (41.67)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	12 (1.60)
Rhabditis spp.	17 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	17 (2.27)
Grand total	237 (31.64)	90 (12.01)	199 (26.57)	73 (9.75)	85 (11.35)	12 (1.60)	40 (5.34)	13 (1.74)	749

3.4 Nematode Abundance and Distribution in Relation to Seasonal Variation

The results of the study indicated that seasonal variation influences the abundance and distribution of nematodes in both the control and polluted sites. During the rainy season, a total of 561 (74.9%) nematode density were recorded while 188 (25.1%) extracted during the dry season. Further analysis of the results showed that during the rainy season, 237 (42.2%), 199 (35.5%), 85 (15.2%) and 40 (7.1%) density of nematodes were extracted from Abam (control), Ekerekana, Ogoloma and Okari, respectively. While during the dry season, 90 (47.9%), 73 (38.8%), 12 (6.4%) and 13 (6.9%) were recorded in Abam (control), Ekerekana, Ogoloma and Okari, respectively (Table 2). There was no significant difference in the distribution of nematodes across the various locations during the dry season. Analysis of the results between the locations showed µ 2=6.409, df=3, p=0.093 with mean ranks of 13.94, 13.00, 9.75, 4.50 for Abam (control), Ekerekana, Ogoloma and Okari, respectively.

Table 2 Nematode abundance and distribution in relation to seasonal variation

Sites/Location	Nematode Abundance (%)		
	Rainy Season	**Dry season**	**Total**
Abam (Control)	237 (42.2)	90 (47.9)	327 (43.7)
Ekerekana	199 (35.5)	73 (38.8)	272 (36.2)
Ogoloma	85 (15.2)	12 (6.4)	97 (13.0)
Okari	40 (7.1)	13 (6.9)	53 (7.1)
Total	561 (74.9)	188 (25.1)	749

3.5 Nematode Abundance in Relation to Core Depths of Soil

In Table 3 nematode abundance and distribution at various depth in both the polluted and control sites during the rainy and dry seasons are shown. The results indicated that out of 561 nematode individuals extracted from all the sites during the rainy season, a total of 288 (51.3%), 186 (33.2%) and 87 (15.5%) were extracted from the core depths of 0-5 cm, 6-10 cm and 11-15 cm, respectively while during the dry season, out of a total of 188 nematode densities recorded from all the sites, 120 (63.8%), 46 (24.5%) and 22 (11.7%) were recovered from the depth of 0-5 cm, 6-10 cm and 11-15 cm, respectively (Table 4).

During the rainy season, out of the 288 individual nematodes extracted from the depth of 0-5 cm, a total of 123 (51.9%), 97 (48.7%), 41 (48.2%) and 27 (67.5%) were recorded from Abam(control), Ekerekana, Ogoloma and Okari regions, respectively. At the core depth of 6-10 cm, out of the 186 nematodes extracted, 79 (33.3%), 65 (32.7%), 33 (38.8%) and 9 (22.5%) were recorded from Abam(control), Ekerekana, Ogoloma and Okari, respectively, while at a depth of 11-15 cm, out of 87 nematodes extracted, a total of 35 (27.6%), 37 (18.6%), 11 (12.9%) and 4 (10%) were from Abam(control), Ekerekana, Ogoloma and Okari, respectively.

During the dry season, at a core depth of 0-5 cm, out of the 120 extracted nematodes, 54 (60.0%), 48 (65.8%), 9 (75.0%) and 9 (69.2%) were from Abam (control), Ekerekana, Ogoloma and Okari, respectively. At a depth of 6-10 cm, a total of 46 nematodes extracted, out of which 24 (26.7%), 15 (20.6%), 3 (25.0%) and 4 (30.8%) nematodes were recovered from Abam(control), Ekerekana, Ogoloma and Okari, respectively, while at a depth of 11-15 cm, no nematode was recovered from Ogoloma and Okari but a total of 12 (13.3%) and 10 (13.7%) were extracted from Abam (Control) and Ekerekana, respectively (Table 4).

Table 3 Nematode abundance (%) in relation to depths of soil during the wet (rainy) season

	Rainy Season															
	Abam (Control)				**Ekerekana (Polluted)**				**Ogoloma(Polluted)**				**Okari (Polluted)**			
Nematode genera	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total
Hirschmanniela spp.	23 (44.2)	20 (38.5)	9 (17.3)	52	20 (43.9)	14 (30.4)	12 (26.1)	46	10 (52.6)	7 (36.8)	2 (10.5)	19	5 (71.4)	1 (14.3)	1 (14.3)	7
Pratylenchus spp.	25 (62.5)	10 (25.0)	5 (12.5)	40	18 (56.3)	10 (31.3)	4 (12.5)	32	10 (45.5)	8 (36.4)	4 (18.2)	22	5 (55.5)	3 (33.3)	1 (11.1)	9
Gracilacus spp.	14 (45.2)	12 (38.7)	5 (16.1)	31	10 (58.8)	5 (29.41)	2 (11.76)	17	13 (52.0)	10 (40.0)	2 (8.0)	25	4 (66.7)	2 (33.3)	0 (0)	6
Tylenchorhynchus spp.	7 (53.9)	3 (23.1)	3 (23.1)	13	10 (40.0)	10 (40.0)	5 (20.0)	25	2 (50.0)	2 (50.0)	0 (0)	4	0 (0)	0 (0)	0 (0)	0
Trichodorus spp.	9 (47.4)	8 (42.1)	2 (10.5)	19	8 (36.4)	8 (36.6)	6 (27.3)	22	5 (41.7)	4 (33.3)	3 (25.0)	12	0 (0)	0 (0)	0 (0)	0
Aphelenchus spp.	3 (100)	0 (0)	0 (0)	3	2 (100)	0 (0)	0 (0)	2	1 (33.3)	2 (66.7)	0 (0)	3	5 (71.4)	0 (0)	2 (28.6)	7
Longidorus spp.	0 (0)	0 (0)	0 (0)	0	8 (47.1)	5 (29.4)	4 (23.5)	17	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Hemicycliophora spp.	3 (25.0)	7 (58.3)	2 (16.7)	12	5 (45.5)	4 (36.4)	2 (23.5)	11	0 (0)	0 (0)	0 (0)	0	3 (75.0)	1 (25)	0 (0)	4
Dolichodorus spp.	0 (0)	0 (0)	0 (0)	0	6 (60.0)	4 (40.0)	0 (0)	10	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Ditylenchus spp.	0 (0)	0 (0)	0 (0)	0	10 (58.8)	5 (29.4)	2 (11.8)	17	0 (0)	0 (0)	0 (0)	0	5 (100)	0 (0)	0 (0)	5
Helicotylenchus spp.	12 (100)	0 (0)	0 (0)	12	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	2 (100)	0 (0)	2
Xiphinema spp.	10 (45.5)	8 (36.4)	4 (18.2)	22	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Rotylenchus spp.	6 (66.6)	3 (33.3)	0 (0)	9	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Paratylenchus spp.	3 (42.9)	3 (42.9)	1 (14.3)	7	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Rhabditis spp.	8 (47.4)	5 (29.4)	4 (23.5)	17	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Total	123 (51.9)	79 (33.3)	35 (27.6)	237	97 (48.7)	65 (32.7)	37 (18.6)	199	41 (48.2)	33 (38.8)	11 (12.9)	85	27 (67.5)	9 (22.5)	4 (10)	40

Table 4 Nematode abundance (%) in relation to depths of soil during the dry season

	Dry Season															
	Abam (Control)				**Ekerekana (Polluted)**				**Ogoloma (Polluted)**				**Okari (Polluted)**			
Nematode genera	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total	0-5 cm	6-10 cm	11-15 cm	Total
Hirschmanniela spp.	0 (0)	0 (0)	0 (0)	0	10 (62.5)	4 (25.0)	2 (12.5)	16	0 (0)	0 (0)	0 (0)	0	3 (38.5)	2 (40.0)	0 (0)	5
Pratylenchus spp.	22 (66.7)	6 (18.2)	5 (15.2)	33	9 (100)	0 (0)	0 (0)	9	5 (100)	0 (0)	0 (0)	5	4 (100)	0 (0)	0 (0)	4
Gracilacus spp.	0 (0)	0 (0)	0 (0)	0	4 (100)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)	0	2 (66.7)	1 (33.3)	0 (0)	3
Tylenchorhynchus spp.	8 (61.5)	5 (38.5)	0 (0)	13	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Trichodorus spp.	0 (0)	0 (0)	0 (0)	0	2 (100)	0 (0)	0 (0)	2	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Aphelenchus spp.	3 (100)	0 (0)	0 (0)	3					0 (0)	0 (0)	0 (0)	0	0 (0)	1 (100)	0 (0)	1
Longidorus spp.	0 (0)	0 (0)	0 (0)		5 (29.4)	7 (41.2)	5 (29.4)	17	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Hemicycliophora spp.	0 (0)	7 (100)	0 (0)	7	5 (45.5)	3 (27.3)	3 (27.3)	11	4 (57.1)	3 (42.9)	0 (0)	7	0 (0)	0 (0)	0 (0)	0
Dolichodorus spp.	0 (0)	0 (0)	0 (0)	0	6 (85.7)	1 (14.3)	0 (0)	7	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Ditylenchus spp.	0 (0)	0 (0)	0 (0)	0	7 (100)	0 (0)	0 (0)	7	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Helicotylenchus spp.	12 (100)	0 (0)	0 (0)	12	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Xiphinema spp.	3 (37.5)	3 (37.5)	2 (25.0)	8	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Rotylenchus spp.	6 (66.7)	3 (33.3)	0 (0)	9	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Paratylenchus spp.	0 (0)	0 (0)	5 (100)	5	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Rhabditis spp.	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Total	54 (60.0)	24 (26.7)	12 (13.3)	90	48 (65.8)	15 (20.6)	10 (13.7)	73	9 (75.0)	3 (25.0)	0 (0)	12	9 (69.2)	4 (30.8)	0 (0)	13

Nematodes are very sensitive to ecological disturbances and several studies have reported the use of nematodes as bioindicators of soil health (Bongers et al., 2001; Zhang et al., 2007; Chauvin et al., 2020; Nzeako et al., 2011; Neher, 2001b). In this study, the impact of crude oil pollution on the abundance and distribution of nematodes was analyzed. The results showed a significant variation in the abundance and distribution of nematodes between soils that have been contaminated by crude oil and uncontaminated soil (control). There was a high abundance and diversity of nematodes in the non-polluted soil than the polluted sites. Similar results were recorded in Bodo region by Osarokaka et al. (2021), Gokana Local Government area by Nzeako et al. (2011) and in a meta-analysis by Chauvin et al. (2020).

The variation in nematode abundance in the polluted and non-polluted sites could be attributed to the fact that the crude oil contains heavy metals and other contaminants to which the nematodes are sensitive. In addition, polycyclic aromatic hydrocarbons (PAHs), the main hazardous components of oil, are known to diminish biodiversity, cause genetic abnormalities, and impair ecosystem function (Veldkornet et al., 2020). Although, other meiofauna such as copepods may tolerate the pollutants because of their protective exoskeleton, nematodes are vulnerable to crude oil penetration because they have cuticles which allows passage of certain substances (Stringer et al., 2012).

The results of this study are also in consonance with the records of Lindgren et al. (2012), Lv et al. (2011) and Beyrem et al. (2010). The researchers discovered that when sediment was contaminated with lubricating oil, crude oil and diesel, nematode population and species richness are reduced. The variation in nematode abundance at various polluted sites as seen in our study could be the result of presence of multiple contaminates and complex nematode responses to the contaminates (Chauvin et al., 2020). For instance, Georgieva et al. (2002) reported that the additional zinc and copper in an already hydrocarbon polluted soil may impact nematode abundance negatively. The presence of acidifying compounds concentration, type and bioavailability of the contaminants to the nematodes as well as duration of contact at the various sites may influence the results recorded at various polluted sites (Rodriguez-Martins et al., 2014; Clemente et al., 2003; Cappuyns et al., 2004; Ferris & Bongers, 2006; Chauvin et al., 2020).

Studies have shown that pollution decreases the population and species diversity of the most sensitive nematodes, which are usually the carnivores and omnivores (Salamun et al., 2012; Pen-Mouratov et al., 2008; Li et al., 2006). This might explain the reduced population density of nematodes in the polluted sites. Nematodes have been used extensively to evaluate medium- and long-term effects of metal pollution of soil (Bakonyi et al., 2003; Georgieva et al., 2002) and heavy metals have been demonstrated to affect both the diversity and abundance nematodes (Georgieva et al., 2002).

Generally, the reduced abundance and distribution of nematodes in the polluted sites is an indication of the presence of pollutants and poor soil quality. In our study, it was observed that nematode abundance decreased with depth. More nematode densities were extracted from the core depth of 0-5 cm than 6-10 cm and 11-16 cm at both polluted and unpolluted sites. Similar results were reported by Liu et al. (2022) in subalpine forests of China, Zhang et al. (2012) in the Chinese forest, Pen-Mouratov et al. (2008) in biological crust of Negev desert, Israel and Hu et al. (2020) in the North-western Negev desert in Israel and, Nzeako et al. (2019) at Makerere hill in Uganda. These observations may be attributed to the fact that the upper soil is always rich in nutrients and developed plant roots (Mitchel & Kangas, 2018). Several studies suggest that, to a greater extend, the abundance of nematode and other soil biota communities is directly proportional to the availability of essential nutrients, most of which are found at the top soil (Chu et al., 2016; Liu et al., 2017).

There was a significant variation in nematode abundance between the rainy and dry seasons. The rainy season yielded in more nematode count and genera compared to the dry season. Similar observation was made by Thuo et al. (2020). This was expected as rainy season provides the soil with moisture necessary for the survival of the nematode community, and also helps in the circulation of nutrients in the soil. Most cysts of cyst-forming nematodes may hibernate during unfavorable conditions imposed by the dry season and emerge in the more favorable conditions provided by the rainy season, thereby contributing to the greater number of nematodes in the rainy season.

4 Conclusion

The results of this study indicated a significant difference in nematode abundance and species richness in hydrocarbon polluted sites compared to the unpolluted site in the study area across seasons and depth and can be used as bioindicator for assessment of soil health and quality.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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