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Assessment of Nematode Diversity and Abundance as Bioindicators of Pollution in Open Waste Dumpsites in Makurdi Metropolis, Nigeria

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Abstract

Soil nematodes are sensitive bioindicators of soil health and environmental pollution. This research investigated the diversity, abundance, and ecological functions of nematodes in soils from active and abandoned dumpsites, comparing them with control (unpolluted) sites in Makurdi, Nigeria. The impact of open waste dumping on nematode community structure was studied by observing the nematode community structure at seven open waste dumpsites and a control (reference) site. Seven active dumpsites were selected for this study during the 2024 rainy season in Makurdi. The dumpsites were found in Government Reserved Area (GRA), Nigerian Army School of Military Engineers (NASME), Wurukum, Judges Quarters, North-Bank, Wadata Market and High-level areas. A total of 140 soil samples were randomly collected from the seven dumpsites and an additional 140 soil samples from the reference sites in each location 5 km away from each dumpsite. Twenty-four nematode genera were isolated from the total samples collected and belonged to 15 nematode families. The reference site had the highest nematode abundance (953 nematodes/composite sample) compared to the waste dumpsites. It also had the highest number of nematodes in each colonizer-persistent (c-p) group, especially of c-p 1 (181) and c-p 2 (405), suggesting a more natural or less disturbed environment. Among the seven dumpsites, the High-Level area dumpsite had the highest nematode abundance (245 nematodes/composite sample) followed by the dumpsites in GRA and Wurukum. These areas had relatively high numbers of c-p 1 and c-p 2 nematodes, indicating potential environmental conditions favouring colonizers. The dumpsites in Judges Quarters and NASME had a population of 58 and 52 relatively low nematode abundance compared to High level, GRA and Wurukum area. The least nematode abundance was observed in Wadata (Site 6) with a population of 48 nematodes/composite sample. The low numbers suggest factors such as soil disturbance, pollution, or habitat degradation affecting nematode populations. The reference site had the highest maturity index (MI) of 2.55 closely followed by the dumpsite of North Bank with an index of 2.35 suggesting more developed and stable soil conditions. The least MI was recorded in High Level (2.00) area indicating more disturbed environment. Using nematode-based indices this study present empirical evidence of the pollution levels of the dumpsites and the urgent need for government intervention, especially considering the crucial need for more sustainable land use.

Keywords: Nematode, Open waste dumpsites, Environment, Ecology, Pollution

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1. Introduction

Nematodes are microscopic unsegmented round worms and comprise a very large group of diverse but relatively simple multicellular eukaryotic organisms belonging to the phylum Nematoda (Bongers and Bongers, 1998; Mahmud et al., 2017). Their diversity serves as a valuable indicator of soil quality due to their sensitivity to various soil health parameters (Deepak et al., 2023). Studies have shown that nematodes, with their trophic diversity and abundance, are commonly used as indicators of soil health (Mahboob and Tahseen, 2023). Yeates et al. (1993) categorized nematodes based on their feeding habits into eight groups i) plant feeder, ii) hyphal feeder, iii) bacterial feeder, iv) substrate ingester, v) carnivores, vi) unicellular eucaryote feeder, vii) dispersal or

infective stage of parasites, and viii) omnivore. Plant feeders comprise nematodes with a tylenchoid stomatostylet or a dorylaimoid odontostyle, mouth structures that are used to feed on vascular plant tissue and fluids. Hyphal feeders pierce fungal hyphae with a stomatostylet or odontostyle. Bacterial feeders feed on prokaryotes and usually ingest bacterial cells whole. Substrate ingesters ingest an organic substrate together with its associated microflora and microfauna. Carnivorous nematodes feed on a variety of invertebrate metazoa by means of buccal adaptations such as teeth, stylet and mandibles. Ingestion of nematode prey by other nematodes with 'unarmed' buccal cavities has also been observed, but is probably rather occasional (Moens and Vincx, 1997). Unicellular eukaryote feeders feed on microalgae, fungal spores, yeasts, flagellates, ciliates and/or other protozoa. Other stages of animal parasitic nematodes outside their alternate or definitive hosts may occur in the soil or vertebrates. Omnivorous nematodes feed on a wide range of foods sometimes combining types ii to vi.

These nematodes are found in diverse ecological niches, some specific to their substrate for example, plant-parasitic nematodes which mostly occur inside the root, leaves or rhizosphere of plant. Others may exist freely in terrestrial, meiobenthic or in aquatic environments (Carrascosa et al., 2014; Xu et al., 2020). For the most part, studies have shown that these nematodes occur in assemblages consisting of a plethora of genera or species. The species richness of such assemblages mostly depends on the nature of the niche inhabited. From a polluted landscapes to a pollution-free site certain nematodes have been found to be associated with each distinctly characterized microcosm. Studies for example the one conducted by Renčo et al. (2022) have shown that nematode communities are sensitive to environmental changes, including pollution from heavy metals. For instance, research conducted along the Litavka River in the Czech Republic found that areas with higher heavy metal contamination had significantly fewer nematodes, reduced diversity, and a more degraded soil food web. This suggests that nematode populations can serve as bioindicators of soil health in polluted environments. In urban settings, food waste dumping sites can create unique microenvironments that influence nematode populations. The decomposition of organic matter in these sites provides a rich food source for bacterivorous and fungivorous nematodes (Freckman, 1988). However, the accumulation of pollutants, such as heavy metals or other contaminants, can adversely affect nematode diversity and abundance (Gutiérrez et al., 2016).

While specific studies on nematode populations in urban food waste dumping sites are limited, the general sensitivity of nematodes to soil conditions suggests that their communities would be influenced by the organic enrichment and potential pollutants present in such environments. Waste dumping sites, especially those with organic matter such as food waste, agricultural refuse, and yard trimmings, support a wide variety of nematode species (Tóthné et al., 2021). Monitoring nematode populations in these areas could provide valuable insights into the ecological impact of urban waste management practices and the overall health of urban soil ecosystems. It is against this back drop that this study was conducted to assess the population dynamics of nematodes in waste dumpsites in Makurdi metropolis of Benue State, Nigeria. The study of nematodes in waste sites provides valuable insights into the ecological health of these environments and their potential use in waste management and bioremediation.

2. Materials and Methods

2.1 Study Area

Makurdi, the capital of Benue State in Nigeria is geographically located between latitude 7°38'N and 7°50'N and longitude 8°24'E and 8°38'E. it is situated in the North Central region of Nigeria (Figure 1) and is traversed by the River Benue which is the second largest river in Nigeria. The elevation of Makurdi Metropolis ranges from approximately 75 meters (246 feet) to 125 meters (410 feet) above sea level with the city center situated at an average elevation of around 100 meters (328 feet) above sea level. The areas along the banks of the River Benue tend to be at the lower end of the elevation range, while the outskirts of the city are at slightly higher elevations. There are some minor variations in the elevation within the metropolitan area, with occasional low-lying areas and gentle undulations in the topography.

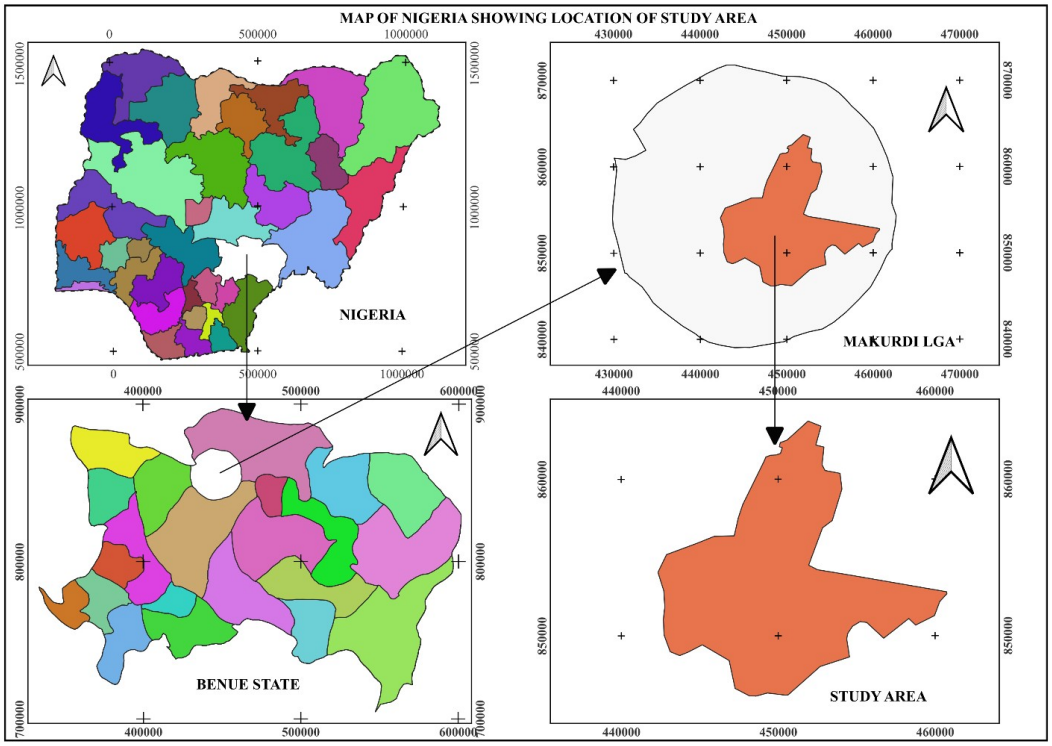

Figure 1: Map of Nigeria Highlighting the Study Area

2.2. Collection of Samples

Field reconnaissance was carried out in order to identify existing dumpsites within Makurdi metropolis. Seven dumpsites that were actively in use and have been operational for more than ten years were selected for this study during the rainy season between May and July, 2024. Reference sites were also selected in each area where a dumpsite exists. Each reference site was at least 5 km away from the dumpsite. The reference site was defined as an area that was not covered by a waste dumpsite and not used for agricultural purpose. One hundred and forty (140) soil samples were randomly collected from the seven dumpsites using Gouge auger (Model: Royal Eijkelkamp – 1 metre). From each dumpsite, a total of 20 samples were collected each time by randomly throwing a 1m x 1m quadrat on the dumpsite and taking one sample from the middle of the quadrant to a depth of 1m. The core-sampler was rinsed sufficiently with clean water and immediately sterilized using 70% isopropyl alcohol, and rinsed again with clean water using a wash bottle after each use. The same procedure was done on the reference sites where a total of 140 samples were also collected, 20 from each reference site.

This process was repeated each time a sample was collected and placed inside sample bag. Samples from same sampling stations were bulked into composite samples from which 250 g of subsamples were drawn from each composite sample. The sampling stations were georeferenced using a handheld Global Positioning System (GPS) device (Model: Garmine Trex 10) as presented in Table 1. Each soil sample was placed in an individual plastic bag and transported to the laboratory in an insulated container. At the laboratory, they were kept in cold storage at 4◦C.

Table 1: Spatial Characteristics of the dumpsite stations

Site code	Location of Dumpsite	Coordinates	Alt (m)	Size (ha)	Age (years) of Dumping Site
S1	Wurukum Area	N 7.730895° E 8.547996 °	71.32	0.2	15-20
S2	High Level Area	N7.728664° E 8.548841°	76.07	0.5	15-20
S3	Government Reserved Area (GRA)	N 7.739782° E 8.536401°	83.21	1.5	15-20
S4	Judges Quarters Area	N 7.713319° E 8.579515°	93.27	0.1	15-20
S5	North Bank Area	N 7.75255° E 8.553614°	126.62	0.2	10-15
S6	Wadata Market Area	N 7.746562° E 8.511768°	67.67	0.2	20-25
S7	NASME Area	N 7.740660° E 8.518279°	82.30	0.25	15-20

Alt= Altitude above sea level, NA= Not applicable, Ha= Hectares, m= meters. NASME = Nigerian Army School of Military Engineers

2.3. Nematode Extraction, identification and community characterization

From each sub-sample of soil 100 g was taken for nematode extraction by modified Cobb's sieving and decantation method (Van Bezooijen, 2006). To ensure complete isolation, nematode samples were collected for two consecutive days and stored at room temperature. Excess water from the samples was removed under an inverted microscope (Kruss, MBL3200), Nematodes were counted from 100 ml of nematode suspension for each subsample using a Syracuse counting dish under a stereomicroscope (Olympus SZ51). Nematodes were identified by direct observation at 100X categorized into trophic groups based upon feeding habits/food source and colonizer-persistent groups (Yeates *et al.* 1993) and grouped into functional and maturity groups based on Bongers (1990). Nematode identification to a genus level was done under a compound microscope at 400 to 1000x magnification. The references for identification were Goodey (1963) and Andrássy (1993). Percentage nematode across each sampling station was calculated using the formula $\frac{S+}{Ns}$ x 100 *where* S^+ = *number of sites where a particular nematode was found; Ns = Total number of study sites*

2.4. *Ecological Indices*

The nematode counting data were entered into Microsoft Excel where the nematode indices were Calculated using established formulas based on the relative abundances of different nematode colonizer-persister (c-p) groups (Table 1).

Table 1: Summarized Group Classification of the colonizer-persister nematode groups according to Bongers (1990)

Group	Summarized Group Characteristics
c-p 1	Nematodes with a short generation time and a large proportion of the body occupied by gonads which produce many small eggs. They are tolerant of pollutants and of products of organic matter decomposition.
c-p 2	Nematodes with a short generation time and relatively high reproduction rates, although lower than those in c-p1, consequently, they are slower to respond to environmental enrichment than c-p1 nematodes. They are very tolerant of pollutants and other disturbances.
c-p 3	Nematodes with longer generation time than c-p2 nematodes and greater sensitivity to disturbances. They include bacterial feeders, fungal feeders and some predators.
c-p 4	These nematodes are characterized by a long generation time, permeable cuticle and high sensitivity to pollutants. They are small dorylaims and the large non-dorylaimids with a low ratio of gonad to body volume.
c-p 5	They have a permeable cuticle and are very sensitive to pollutants and other disturbances. They are large dorylaimid nematodes with a long life span, low reproduction rates, low metabolic activity and slow movement. The gonads are small relative to the body volume and produce a small number of large eggs.

(i) Maturity index (MI) = $\sum \frac{vi\ x\ fi}{n}$: Indicates ecosystem stability, with higher values reflecting a more mature and stable nematode community (Bongers ,1990).
Where v_i = c-p value assigned to family; f_i = frequency of family i in sample; n = total number of individuals in a sample

(ii) Shannon's diversity ($H^{'}$) = $-\sum (p_i \ln p_i)$: Measures species diversity, with higher values indicating greater biodiversity (Shannon and Weaver, 1949). Where pi = relative abundance of taxon i.

(iii) Brillouin's relative evenness $J^{'} = H^{'}/\ln S$: Measures species distribution, with higher values indicating more even species distribution (Pielou, 1966). Where $H^{'}$= Shannon's diversity; S= Specie's richness
(iv) Structural index (SI) = $100\ x \frac{s}{s+b}$: Measures ecosystem stability, with higher values indicating a more structured and resilient system (Ferris *et al*., 2001). Where s = number of individuals in the structure-sensitive (c-p 3-5) nematode groups; b = number of individuals in the general opportunistic (c-p 2) nematode groups
(v) Enrichment index (EI) = $100\ x\ \frac{e}{e+b}$: Reflects nutrient enrichment, with higher values indicating greater soil enrichment often due to pollution or organic matter (Ferris *et al*., 2001). Where e = number of individuals in the enrichment opportunistic (c-p 1) nematode groups; b = number of individuals in the general opportunistic (c-p 2) nematode groups.

2.5. Data Analysis

Nematode count data were square-root ($\sqrt{x+1}$) transformed to improve the homogeneity of variance. Data were subjected to analysis of variance (ANOVA) and means separated using Duncan's New Multiple Range Test at 5% level of probability.

3. Results

3.1 Characterization of Nematode Assemblages

A total of 24 nematode genera drawn from 15 families were recovered from the sampled location sensu stricto as shown in Table 2. Of the three putative feeding groups encountered 14 out of the nematode genera were bacterivores, five were predators and four fungivores. Approximately 54% of the recovered nematodes belonged to either the c-p 1 and c-p 2 group as shown in Table 2. Many bacterial feeders belong to c-p groups 1 and 2, indicating they are opportunistic species that thrive in disturbed environments. Predators and fungal feeders tend to have higher c-p values (3-5), suggesting they are more sensitive to environmental changes and thrive in stable conditions.

Table 2: Nematodes recovered from the sampling stations in Makurdi metropolis

S/N	Nematode genera	Family	Putative feeding	c-p group
1	*Mononchus*	Mononchidae Filipjev, 1934	Predator	4
2	*Panagrolaimus*	Panagrolaimus Thorne, 1937	Bacterial feeder	1
3	*Acrobeles*	Cephalobidae Filpijev, 1934	Bacterial feeder	2
4	*Anaplectus*	Plectidae Orley, 1880	Bacterial feeder	2
5	*Prismatolaimus*	Prismatolaimidae Micoletzky, 1922	Bacterial feeder	3
6	*Prothorhabditis*	Rhabditidae Oerly, 1880	Bacterial feeder	1
7	*Metateratocephalus*	Metaterocephalus Eroshenko, 1973	Bacterial feeder	3
8	*Nygolaimus*	Nygolaimidae Thorne, 1935	Predator	5
9	*Paraphelenchus*	Aphelenchidae (Fuchs, 1937)	Fungal feeder	2
10	*Plectus*	Plectidae Orley, 1880	Bacterial feeder	2
11	*Acrobeloides*	Cephalobidae Filpijev, 1934	Bacterial feeder	2
12	*Chiloplacus*	Cephalobidae Filpijev, 1934	Bacterial feeder	2
13	*Parasitorhabditis*	Rhabditidae Oerly, 1880	Bacterial feeder	1
14	*Cervidellus*	Cephalobidae Filpijev, 1934	Bacterial feeder	2
15	*Plectonchus*	Brevibucciidae Paramonov, 1956	Bacterial feeder	1
16	*Pelodera*	Rhabditidae Oerly, 1880	Bacterial feeder	1
17	*Placodira*	Cephalobidae Filpijev, 1934	Bacterial feeder	2
18	*Tylencholaimus*	Tylencholaimidae, Filipjev, 1934	Fungal feeder	4
19	*Meylis*	Leptonchidae Thorne, 1935	Fungal feeder	4
20	*Mylodiscus*	Qudsianematidae Jairajpuri, 1965	Predator	4
21	*Raritobrilus*	Tobrilidae De Coninck, 1965	Predator	3
22	*Paravulvus*	Nygolaimidae Thorne, 1935	Predator	5
23	*Proleptonchoides*	Leptonchidae Thorne, 1935	Fungal feeder	4
24	*Tylencholaimellus*	Tylencholaimellidae, Jairajpuri,1964	Fungal feeder	1

The study also found that 21% of the nematodes encountered belonged to the family Cephalobidae, 13% belonged to the family Rhabditidae while 9% and 8% of the identified nematodes belonged to the families Plectidae and Leptonchidae, respectively. The other nematode generas belonged to different families each constituting 4% of the total families of genera recovered (Figure 2). Of the 24 nematode genera identified across the seven dumpsites and the control site, Mononchus, Panagrolaimus, Acrobeles, and Anaplectus had the highest spatial variability and were present in all the sites (Table 3). However, Paravulvus, Proleptonchoides and Tylencholaimellus had the least spatial variability, with each of them appearing at only one dumpsite. Acrobeloides was the most abundance nematode genera with a population of 254 nematodes/100 ml of suspension followed by Panagrolaimus (235 nematodes/100 ml) and Anaplectus (213 nematodes/100 ml).

3.2.

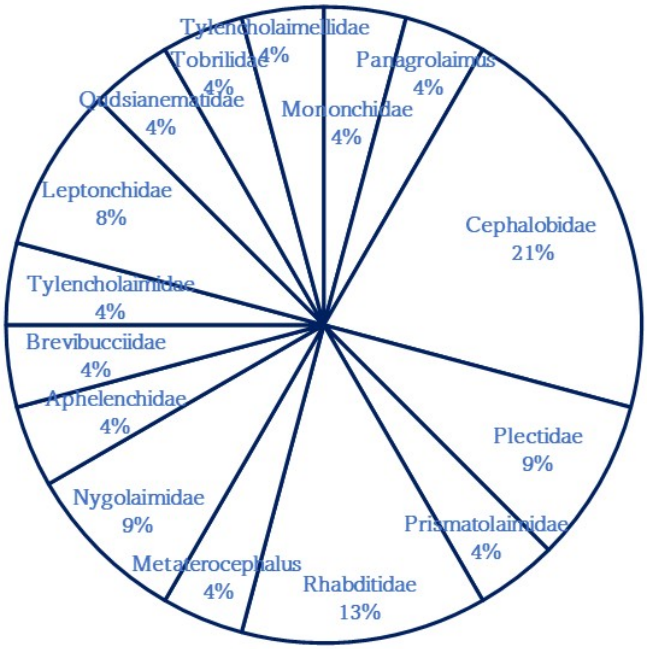

Figure 2: Percentage distribution of nematode families encountered from sampling stations

Nematode Abundance

Table 4 presents the abundance of nematodes across different sampling sites, categorized into five c-p (colonizer-persister) groups. Each site is compared based on the number of nematodes found in these groups, along with the total nematode abundance. The reference site had the highest nematode abundance (953 nematodes/composite sample) compared to the waste dumpsites (Table 4). It also had the highest number of nematodes in each nematode group, especially of c-p 1 (181) and c-p 2 (405), suggesting a more natural or less disturbed environment. Among the seven dumpsites, the High-Level area dumpsite had the highest nematode abundance (245 nematodes/composite sample) followed by the dumpsites in GRA and Wurukum. These areas have relatively high numbers of c-p 1 and c-p 2 nematodes, indicating potential environmental conditions favouring colonizers.

The dumpsites in Judges Quarters and NASME had a population of 58 and 52 relatively low nematode abundance compared to High level, GRA and Wurukum area. The least nematode abundance was observed in Wadata (Site 6) with a population of 48 nematodes/composite sample. The low numbers suggest factors such as soil disturbance, pollution, or habitat degradation affecting nematode populations. In all the sites it was observed that c-p1 and c-p2 nematodes were the highest compared to c-p3, c-p4 and c-p5 in each station. C-p 1 (opportunistic colonizers) was highest in the reference site (181), followed by High Level (75 nematodes/composite samples) and North Bank (43 nematodes/composite sample). C-p 2 (intermediate colonizers) is most abundant across all sites, peaking in the control (405) and GRA (154). C-p 3 to 5 (persisters, sensitive to disturbance) were notably low in disturbed areas but higher in the control site.

Table 2: Spatial Distribution of the Recovered Nematode Genera Across the Study Sites

S/N	Nematode genera	S1	S2	S3	S4	S5	S6	S7	S8	% Occurrence	Abundance	Mean
1	*Mononchus*	+	+	+	+	+	+	+	+	100.0	175.0	21.9
2	*Panagrolaimus*	+	+	+	+	+	+	+	+	100.0	235.0	29.4
3	*Acrobeles*	+	+	+	+	+	+	+	+	100.0	169.0	21.1
4	*Anaplectus*	+	+	+	+	+	+	+	+	100.0	213.0	26.6
5	*Prismatolaimus*	+	+	-	+	+	+	+	+	87.5	140.0	17.5
6	*Prothorhabditis*	+	+	-	+	+	+	+	+	87.5	95.0	11.9
7	*Metateratocephalus*	+	+	+	+	+	-	-	+	75.0	69.0	8.6
8	*Nygolaimus*	+	-	-	+	+	+	+	+	75.0	125.0	15.6
9	*Paraphelenchus*	+	+	-	+	-	+	+	+	75.0	120.0	15
10	*Plectus*	+	-	+	+	+	+	+	-	75.0	49.0	6.1
11	*Acrobeloides*	+	+	+	-	+	-	+	+	75.0	254.0	31.8
12	*Chiloplacus*	+	-	+	-	+	+	+	+	75.0	61.0	7.6
13	*Parasitorhabditis*	+	-	-	+	+	+	+	-	62.5	41.0	5.1
14	*Cervidellus*	+	+	-	-	+	-	+	+	62.5	65.0	8.1
15	*Plectonchus*	-	-	+	+	+	-	+	-	50.0	21.0	2.6
16	*Pelodera*	-	-	-	+	-	-	+	+	37.5	6.0	0.8
17	*Placodira*	+	+	-	-	-	-	-	+	37.5	27.0	3.4
18	*Tylencholaimus*	-	+	-	+	+	-	-	-	37.5	14.0	1.8
19	*Meylis*	-	-	-	-	+	-	-	+	25.0	13.0	1.6
20	*Mylodiscus*	+	+	-	-	-	-	-	-	25.0	22.0	2.8
21	*Raritobrilus*	-	+	+	-	-	-	-	-	25.0	15.0	1.9
22	*Paravulvus*	-	-	+	-	-	-	-	-	12.5	2.0	0.3
23	*Proleptonchoides*	-	-	+	-	-	-	-	-	12.5	7.0	0.9
24	*Tylencholaimellus*	-	+	-	-	-	-	-	-	12.5	2.0	0.3

S1 = Wurukum, S2 = High Level, S3 = Old G.R.A. S4 = Judges Quarters, S5 = North Bank, S6 = Wadata, S7 = NASME, S8 = Control, (+) = Presence, (-) = Absence

Table 3: Nematode Abundance at sampling sites based on c-p group

Dumpsite	Colonizer-Persister Nematode Groups					Total Nematode Abundance
	c-p 1	c-p 2	c-p 3	c-p 4	c-p 5	
Wurukum	23^{d}	147^{c}	16^{d}	15^{c}	2^{cd}	203^{d}
High Level	75^{b}	120^{d}	26^{c}	24^{b}	0^{d}	245^{b}
GRA	25^{d}	154^{b}	14^{d}	18^{c}	2^{cd}	213^{c}
Judges Qtr.	22^{d}	19^{g}	9^{e}	4^{d}	4^{c}	58^{f}
North Bank	43^{c}	56^{e}	31^{b}	17^{c}	11^{b}	158^{e}
Wadata	14^{e}	23^{f}	1^{f}	6^{d}	4^{c}	48^{g}
NASME	17^{e}	24^{f}	2^{f}	4^{d}	5^{c}	52f^{g}
Control	181^{a}	405^{a}	125^{a}	143^{a}	99^{a}	953^{a}
F.pr (0.05)	0.05	0.01	0.01	0.04	0.01	0.02

GRA = Government Reserved Area; NASME = Nigerian Army School of Military Engineers; Each value is approximated to the nearest whole number

Nematode Ecological Indices

The Table 5 presents ecological indices across the different sampling sites, including Shannon's diversity index (H), Brillouin's evenness (J), Maturity Index (MI), Enrichment Index (EI), and Structural Index (SI). These indices help assess the ecological health and stability of the sampled dumpsites compared to the control (reference) site. Dumpsites at NASME and North Bank had the highest Shannon's diversity of 2.58 and 2.56, respectively, suggesting relatively rich nematode diversity. Sites in GRA and Wadata had the lowest Shannon's diversity of 2.14 and 2.19, respectively, indicating lower species variety. The reference site with an diversity index of 2.48 had a relatively high diversity, suggesting a balanced and stable ecosystem. The dumpsites in NASME and reference site had Brillouin's evenness index of 0.95 and 0.92 indicating that the species in these sites were evenly distributed. However, in GRA and High-Level dumpsites the Brillouin's evenness indices were 0.40 and 0.42, respectively and the least, indicating dominance by a few species and a less balanced ecosystem.

The reference site had the highest maturity index (MI) of 2.55 closely followed by the dumpsite of North Bank with an index of 2.35 suggesting more developed and stable soil conditions. The least MI was recorded in High Level (2.00) area indicating more disturbed environment. Judges Quarters (53.66%) and North Bank (43.43%) had the highest Enrichment Index (EI), suggesting high organic matter input or pollution. NASME (22.67%) and Wurukum (12.78%) had the least EI, indicating lower enrichment, possibly due to less organic waste. With respect to the Structural Index (SI) the dumpsite in High Level area and Reference site had the highest SI - 51.30% and 47.54%, respectively suggesting more stable soil conditions. Lowest SI was recorded in NASME (15.94%) and Wurukum (17.37%), indicating higher disturbance and lower soil health.

The Reference site showed high maturity (MI = 2.55), high diversity (H = 2.48), and evenness (J = 0.92), indicating a well-functioning natural environment. The dumpsite in North Bank and Judges Quarters on the other hand had high Enrichment Index (53.66% and 43.43%, respectively) indicative of significant organic input, likely due to human activity or pollution. However, dumpsite in North Bank had high diversity (H = 2.56) and a high SI of 51.30%, suggesting resilience despite enrichment. The dumpsite in NASME showed high Evenness but Low Stability. It had the highest evenness of 0.95 but the lowest structural index 15.94%, meaning species are evenly distributed but the ecosystem is fragile.

High Level and Wurukum were the most disturbed sites and had a low maturity (MI = 2.00, 2.14), low evenness (J = 0.42, 0.44), and low SI (26.32%, 17.37%) indicating disturbed environments with imbalanced species distribution.

Table 4: Ecological indices for the sampled dumpsites and control site in Makurdi Metropolis

Sampling station	Shannon's diversity	Brillouin's evenness	Maturity index	Enrichment index %	Structural index %
Wurukum	2.37	0.44	2.14	12.78	17.37
High Level	2.31	0.42	2.00	38.46	26.32
G.R.A.	2.14	0.40	2.15	13.97	18.09
Judges Qtr.	2.45	0.60	2.12	53.66	47.22
North Bank	2.56	0.51	2.35	43.43	51.30
Wadata	2.19	0.57	2.23	37.84	32.35
NASME	2.58	0.95	2.15	22.67	15.94
Reference site	2.48	0.92	2.55	30.89	47.54

4. Discussion

The presence and abundance of different nematode trophic groups, such as bacterivores, plant-parasitic nematodes, omnivores, fungivores, and carnivores, reflect the overall soil ecosystem's condition and functionality (Mahboob and Tahseen, 2023). Nematodes vary in terms of their sensitivity to pollutants and environmental disturbances, and the nematode communities are widely accepted as simple indicators of soil quality and soil health (Griffiths et al., 2016). According to Lu et al. (2020), many terrestrial nematode indices are used to measure the health of agricultural and natural soils such as the Shannon index, the maturity index (MI) for free-living nematodes and the plant-parasitic index (PPI) for plant parasitic nematodes. The indices are used to monitor changes in land use, environmental disturbance and the effects of management practices.

To understand the impacts of dumpsites on the nematode assemblages of free-living nematodes in surrounding soils in the study area, the type of nematode genera, their abundance, trophic grouping, colonizer-persister (c-p) values and other ecological indices were looked at. This study showed that there was a significantly higher abundance of the nematode genera at the control site than in the dumpsite environments as fifteen of the nematodes had their highest abundance recorded at the control site. This is consistent with the findings of Renčo et al., (2022) who reported that lower abundance of majority of the nematode taxa was observed at polluted sites than the control site. This decreased abundance of the nematode genera at the dumpsite when compared to the control site is a strong pointer to the environmental disturbances associated with the dumpsite environment.

Nematode maturity indices are also widely utilized to evaluate the state of soil health. Higher MI values often indicate a rather more stable and less unstable environment. (Bongers and Ferris, 1999; Neher, 2001; Chauvin et al., 2020). In This study, Nematode Maturity index recorded the highest value at the control site than at the dumpsites under investigation, indicating a relatively more stable soil ecosystem at the control site than at the dumpsites. Enrichment and structural indices did not exhibit a definitive pattern. Predatory nematodes are usually sensitive to disturbances including heavy metal contamination (Šalamún et al., 2012; Gutiérrez et al., 2016). The community structure of free-living nematodes in this study, proved the intolerance of predatory nematodes with K-selected life strategy to pollution and their low tolerance for unstable soil ecosystems.

The dominance of *r*- strategists (c-p 1 and c-p 2) nematodes groups at the sites under investigation in this research, and the decreased abundance of the *k*-strategists (c-p 4 and c-p 5) which are made up predominantly of predators and fungivores is also a strong indication of the disturbed nature of the dumpsite environments. This is in agreement with prior findings which showed a significant surge in c-p 1 and c-p 2 under anthropogenic disturbances (Shao *et al*., 2008; Gutiérrez *et al*., 2016). A similar trend was however observed at the control site which also showed a greater proportion of opportunistic *r*-strategists than persistent *k*-strategists nematodes. This is an indication that even though the nematode communities at the control site may not be impacted by waste materials usually found at the dumpsites, the control site soils may be exposed to lesser forms of environmental disturbances. This is backed up significant increase in the abundance of predatory nematode genera such as *Mononchus* and *Nygolaimus* at the control site, indicating that the control site is less disturbed in nature compared the dumpsites.

In their study, Mahboob and Tahseen, (2023) evaluated the diversity, and abundance of nematodes and their use

as indicators of soil health in an area strongly influenced by industrial wastes (food, metal and paper industries). The relationships between trophic groups, coloniser-persister scale and nematode community indices as well as nematode indicators of soil elements and the relationships of soil elements with different habitats were investigated. Just like in the current investigation, they also found that bacterial feeders were found to be a highly diverse and most abundant group. The results indicated that the nematode diversity and abundance, trophic groups and coloniser-persister ratio were adversely affected by organically enriched habitats to food, metal and paper industries as compared to natural habitats. Bert et al., (2009) assessed the nematode community structure of several sites with different historical pollution. Long-term polluted municipal waste, tar and sludge-sites were compared with less disturbed annex sites. Identification of three hundred nematodes at each location resulted in the discrimination of 63 genera from 32 different families of which the Cephalobidae, Belonolaimidae, Tylenchidae, Hoplolaimidae, Belonolaimidae and Plectidae were the most abundant families. The sampling sites harboured significantly different nematode communities and significant differences of life-strategy-related parameters (c-p-groups, MI indexes) were observed. The significant augmentation of the proportion of the c-p 2 nematodes in historically-polluted sites was especially informative. Omitting the c-p 1 group from the MI (MI 2-5) better reflects putative historical pollution-induced community changes. However, the study did not reveal significant relationships between historical pollution and the feeding type composition, or the Shannon-Wiener diversity.

Previous studies have demonstrated that waste dumpsites often lead to increased concentrations of some heavy metals (Wunzani *et al*., 2020; Ogoko *et al*., 2021; Aryampa *et al*., 2022; Kolawale *et al*., 2023). It is possible that concentration of heavy metals would have impacted on the nematode community structure of the dumpsites. In similar studies have shown that heavy metals decrease the abundance of herbivorous and predatory nematodes, while bacterivores may show resilience (Martinez et al., 2018; Chauvin et al., 2020; Huo et al., 2023). Martinez et al., (2018) showed a clear correlation between the abundance of nematodes and the concentration of heavy metals in the soil, indicating the sensitivity of nematodes to environmental pollution.

5. Conclusion and Recommendation

In conclusion, this study highlights the significant impact of environmental disturbances, particularly waste dumpsites, on soil nematode communities. The lower abundance of nematode genera at dumpsite environments compared to the control site strongly indicates pollution-induced stress. The dominance of opportunistic r-strategists (c-p 1 and c-p 2) at the dumpsites, along with the decline of predatory and fungivorous nematodes (k-strategists), further confirms the disturbed nature of these environments. These findings align with previous research that associates pollution, including heavy metal contamination, with shifts in nematode community structures. From an environmental regulatory perspective, the study underscores the need for stricter waste management policies and remediation strategies to mitigate soil degradation. Regulatory bodies should integrate nematode-based soil health assessments into environmental monitoring programs to track ecosystem stability in polluted areas. Additionally, controlling heavy metal contamination and enforcing sustainable waste disposal practices can help restore and maintain soil biodiversity, ensuring long-term ecosystem resilience.

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