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Research article

Agricultural-Derived organochlorine pesticide residues impact on macroinvertebrate community in an Afrotropical Stream

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ABSTRACT

This study evaluated the impact of pesticide application through agricultural activities in Chanchaga River, Nigeria, using macroinvertebrate data sets obtained for six months (September 2021–February 2022). Four (4) stations, characterized by various agricultural activities, were sampled along the river. Analysis of the water samples for organochlorine pesticide residues (OCP) using Gas Chromatography-Mass Spectrometry (GC/MS) at the peak of the two seasons revealed a high concentration of eleven isomers of organochlorine, which ranged from 0.01 to 0.81 μg/L, and a mean concentration that was above international drinking water standards set by the World Health Organization, the Federal Environmental Protection Agency, and the European Union. The mean concentration of detected OCP was recorded as DDT (0.72 μg/L), Dieldrin (0.59 μg/L), Paraquat (0.54 μg/L), Aldrin (0.49 μg/L), Metribuzin (0.48 μg/L), Butachlor (0.47 μg/L), Alachlor (0.28 μg/L), Atrazine (0.23 μg/L), Phenol (0.10 μg/L), Endrin (0.09 μg/L), and Benzene (0.08 μg/L). Atrazine, alachlor, metribuzin, aldrin, phenol, and endrin showed significant differences across the two seasons ($p < 0.05$), while dieldrin, butachlor, paraquat, benzene, and DDT showed no significant differences across the two seasons ($p > 0.05$). A total of 622 macroinvertebrate individuals from 19 species in 18 families from 8 orders were collected. More individuals were collected during the dry season (58.17 %) and the wet season (41.83 %). Canonical Correspondence Analysis (CCA) ordination revealed a strong relationship between species abundance and some organochlorine pesticide residues such as DDT, endrin, metribuzin, atrazine, benzene, and dieldrin. The response of macroinvertebrates to OCP indicates that Chanchaga River is a disturbed river, and the indicator organisms (Lestes sp., Coenagrion sp., Zyxomma sp., Appasus sp., Chironomus sp., Lymnaea natalensis, and Caridina nililotica) can also be used for further biomonitoring.

1. Introduction

The ever-present problems of pesticides in aquatic environments continue to receive global concern and attention as the residues are prone to heap up in mass in the bodies of organisms in water bodies such as fish and also accumulate in sediment soil, which poses

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health risks to organisms and human beings [1]. Chemical contamination of rivers has been an issue of global interest and has continued to be a serious challenge in developing countries. The modern occurrence of urbanization, population increase, and an increase in anthropogenic activities are contributing factors. Continuous monitoring of chemical pollutants (pesticide residues) in rivers in developed countries has been a platform for the formulation of policy and control of water pollution to ensure a safe aquatic ecosystem [2].

The increase in agricultural activities (crop production) to meet the world population projected to reach 10 billion by 2050 [3], has resulted in global degradation or a decrease in river quality. From the various stressors derived from agricultural activities that affect river systems, pollutants from farming activities (pesticide contamination) have received the most attention from hydrobiologists because of their effect (water quality degradation, bioaccumulation) on river water, aquatic organisms, and humans [4]. The reason for pesticide application is to kill the target pest, but they end up being poisons (endocrine disruption, nervous system disorder, cancer) to other organisms, including aquatic organisms, birds, animals, and humans, because they are not specific to their target organism; for example, herbicides applied to kill weeds end up killing soil organisms such as earthworms. A high percentage of pesticides applied in an area find their way into healthy environmental components such as aquatic reserves (ponds, lakes, rivers, and oceans), where they eventually accumulate into fish within a range value of 0.126 μg/kg to 0.397 μg/kg [5].

Organochlorine pesticides (OCPs) were widely used in agriculture and mosquito control in Nigeria and across Africa from the 1940s to the 1960s [6]. The presence of pesticide residues like organochlorines (OCs) in aquatic ecosystems is a big challenge because of their ability for long-range transport. Organochlorine pesticides (OCPs) are one of the group of agrochemicals with a bioaccumulation potential [7], as recorded by Edjere et al. [8], of 0.00–0.620 μg/L in a water sample and 0.00–36.00 μg/kg in a fish sample. The use of OCPs such as DDT has been outlawed in Nigeria since the year 1990.

Among the list of aquatic animals, macroinvertebrates have been widely used to track or determine river water quality because they possess some advantages compared to other aquatic organisms. They are commonly used as bioindicators to assess the quality of freshwater ecosystems due to their high diversity and sensitivity to anthropogenic activities, their relatively low cost, and the fact that they're time-effective [9]. Their abundance offers valuable insights into the health of the ecosystem based on taxonomic diversity, position in the food web, and sensitivity to water pollution and disturbances [10]. They are known to be an important and integral part of many aquatic ecosystems, and any negative effects caused by pollution in the aquatic community can in turn affect higher trophic levels like fish and birds [11]. The ecological health status of a water body can be examined by the quality of the water, its taxonomic composition, and the abundance of living components such as macroinvertebrates in the river [12]. The ecological state is derived by assessing environmental characteristics and biological or biotic components, which macroinvertebrates are inclusive of. Environmental variables, including pesticide residues, are factors commonly used to determine the quality of water systems under observation [13,14]. These environmental variables have for a long time been used to determine the ecological status and health status of freshwater systems in various research studies [15–17]. The combination of the two variables (pesticide residue variables and biological assemblages) gives a clear view of the ecological state and health of the water systems. In choosing biological components (biotic variables) for assessing the ecological state and health of a water body, several factors are considered, namely, sensitivity level to disturbances like agriculture, easy sampling or collection, diversity, pattern of life cycle, structural morphology, and easy identification to a taxa level [14]. Among the aquatic animals used for ecological assessment of river water health status, macroinvertebrates are one of the most frequently used biota [18,19].

The Chanchaga River is situated in the lower Niger-Benue ecoregion of Nigeria. It is a city river that supplies water to the Niger State Water Board and its neighboring households and villages. The river water also serves as a source of water for irrigation farming during the dry season and other domestic uses (bathing, washing of clothes, cooking utensils, car wash centers, and block industry), contributing to the increase in human activities around the river catchment. Aside from the aforementioned uses of the river water, for many households around the neighborhood, the river also serves as a source of potable drinking water [20]. Despite the aforementioned importance of the river and the continued degradation of water quality as a result of various anthropogenic activities around the river bank, which include agricultural activities, no studies have explicitly investigated the impact of these agricultural activities (organochlorine pesticide application) on the macroinvertebrate communities and distribution in the river. It was also observed that locals engaged in the use of pesticides to kill fish in large quantities in some parts of the river; therefore, this study is aimed at evaluating the impact of agricultural-derived organochlorine pesticide residues on the macroinvertebrate community in the Chanchaga River.

2. Materials and methods

2.1. Research area and stations

The research was carried out in the Chanchaga River near the Niger State water board in the Chanchaga Local Government Area, located in the north-central region of Niger State, Nigeria. This river, positioned in the southern part of Niger State, spans approximately 215.61 km and originates from Mutundaya. It is situated between latitudes 8°43′N–9°59′N and longitudes 6°12′E–6°67′E, and it is supplemented by various tributaries such as the Guduko River, Gorax River, and Gbako River. Approximately 45 % of the primary stressors affecting the river's ecosystem in this area are agricultural activities, particularly the application of pesticides. Additionally, water quality degradation stems from various sources, including domestic, household, industrial, mining, and urban activities. The people of the area are predominantly farmers who practice both subsistence and commercial agriculture annually and during the two major seasons. Irrigation is usually carried out during the dry season for vegetable crops. Crops such as rice, guinea corn, millet, sweet potatoes, yam, and cassava are cultivated during the rainy season. From interaction with local farmers during the period of sampling, it was confirmed that there is a high use of pesticides on the various farms, as low as the subsistence vegetable farm, as also reported by Edegbene et al. [20]. The soil type on most farmlands is sandy-loamy.

Four (4) study stations/points designated S1 to S4 (Fig. 1) with coordinates S1 (latitude 9°5314′N and longitude 6°5936′E), S2 (latitude 9°5346′N and longitude 6°5895′E), S3 (latitude 9°5351′N and longitude 6°5812′E), and S4 (latitude 9°5338′N and longitude 6°5752′E) were marked out for this study based on the degree of agricultural activities. Water samples were collected from points of high (numerous crop production) agricultural activities to points of sparsely distributed agricultural activities. Water samples were collected at specific points at least 1 km apart, approximately 2 m away from the bank of the river, and at points with high flow velocity. High flow velocity was observed during the rainy season (0.49 m/s) compared to the dry season (0.19 m/s).

S1 and S2 were heavily surrounded by farmlands that make use of pesticides such as star combi, atrazine, agri-force, gramazol, force-up, punch, and force-upon all year round during the two major seasons in the study area. Subsistence and commercial farming activities are carried out at these stations. Farmers also practice irrigation farming during the dry season. The common crops grown here include guinea corn, millet, sweet potatoes, yam, cassava, maize, melon, okra, and cowpea. S3 and S4 have sparsely distributed farmlands and are prone to one or all of these environmental stressors, such as illegal mineral mining (gold mining) and industrial and urban activities. The Niger State Water Board Authority plant is located between S3 and S4, and these stations are also surrounded by residential buildings.

2.2. Water sample collection and storage

The river water samples were collected using 1L plastic bottles that were thoroughly cleaned by washing with detergent, rinsed, and finally distilled water before being used. During collection, sample bottles were rinsed with river water and then filled to the brim at a depth of 1 m below the water surface from each of the four designated study stations (S1 to S4). At each station, water samples were collected in triplicate from three different spots. The labeled samples were then taken to the laboratory and stored in a refrigerator at 4 °C to avoid pesticide degradation until extraction. Sampling was done during the peak of two seasons in the study area: September, which is the active farming period for the wet season, and February, for the dry season.

2.3. Water samples extraction

Liquid-liquid extraction was carried out on the water samples to concentrate the compounds present using Method 3510 as described by the United States Environmental Protection Agency [21], with some modifications. In a 1000-ml separating funnel, 400 ml of the sample was measured using a measuring cylinder, and 80.0 ml of dichloromethane and n-Hexane mixture (40;60; v:v) was added. The mixture was shaken vigorously for 30 s, and this was repeated after 5 min to achieve an even mixture. It was then left to stand for 30 min until two layers were formed. The liquid (upper) layer was decanted, while the aqueous (lower) layer was transferred into pre-labeled glass centrifuge tubes. The extract was then evaporated to dryness using an evaporating system. Organochlorine pesticide residue levels in the extract were determined using Gas Chromatography coupled with Mass Spectrometry (GC/MS) which is often preferred for the measurement of organochlorine compounds due to its high sensitivity, accuracy, selectivity, and ability to separate and identify complex mixtures of compounds. The method was standardized for accuracy by developing the method, calibration, and validation.

The level of pesticide residues was determined using the Varian Gas Chromatograph, Model 3700, using an Electron Capture Detector. The following conditions were maintained: Gas pressure was 60 psi, injector temperature was 220 °C, column temperature was 190 °C, detector temperature was 270 °C, the carrier gas was nitrogen (at 30 ml/min), column length was 200 cm, id was 2 mm, and the glass spiral column was packed with 1.5 % OV–17 and 1.95 % OV–210 on chromo sorb WHP 80/100 mesh. There were no peaks

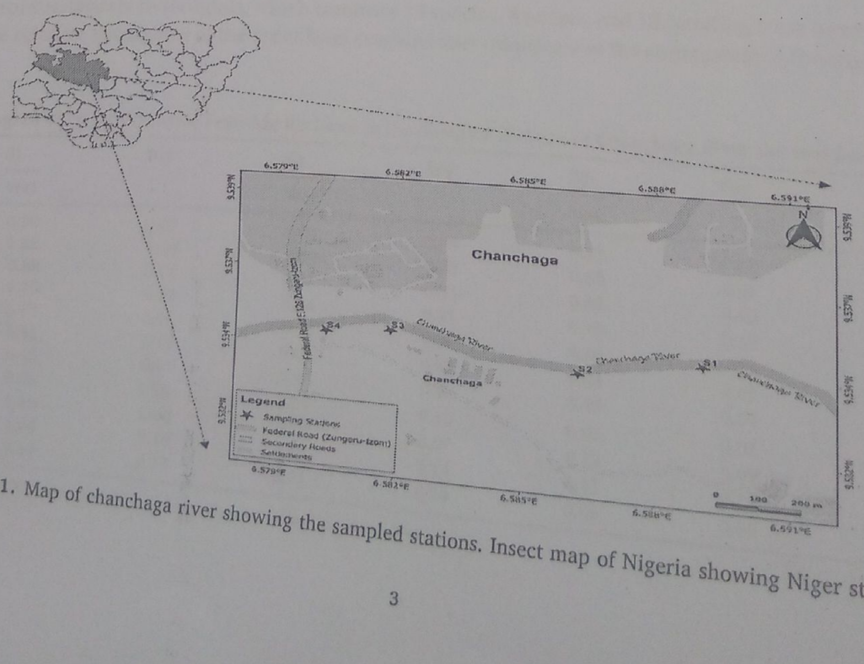

Fig. 1. Map of chanchaga river showing the sampled stations. Insect map of Nigeria showing Niger state.

when solvents and blanks were chromatographed before the samples were analyzed under the same conditions. Known standards were also chromatographed, and the retention time was used to identify the compounds present in the samples.

2.4. *Macroinvertebrate sampling, sorting and identification*

The samples of macroinvertebrates were collected every month for 6 months (September 2021 to February 2022). The method of kick sampling was used for the sampling of macroinvertebrates using a modified kick net of 500 μm mesh size, which was towed against a water current of all the different streambeds from each of the sampled stations. Macroinvertebrates harvested in all the streambeds per station were pooled together to form one composite sample, after which preliminary sorting was done at the field by decanting all the collected samples per station on a white surface, and the use of forceps was employed to pick out moveable organisms into a container with 70 % ethanol. The identified and unidentified macroinvertebrates preserved in separate sample bottles were transported to the laboratory for further identification using identification guides [22,23], and a macroinvertebrate taxonomic expert among the co-authors.

2.5. *Data analysis*

Concentrations of organochlorine pesticide residues were calculated both individually and using the MS Excel 2016 package. A student t-test using the MS Excel 2016 version was used to test the statistical significance differences across the seasons.

Canonical Correspondence Analysis (CCA) was employed to determine the relationships between the abundance of macroinvertebrates and organochlorine pesticide residues using the past 4.03 statistical package. CCA is a statistical tool used to simplify a set of complex data and show the relationship between taxa and environmental characteristics [24]. The Monte Carlo permutation test with 999 permutations [25] was employed to assess the significance of the first and second canonical axes.

3. Results

3.1. *Organochlorine pesticide residues*

Tables 1 and 2 show the eleven types of organochlorine pesticide residues detected in the analyzed water samples. The mean concentration of atrazine ranged from 0.32 to 0.42 μg/L for the wet season and between 0.07 and 0.12 μg/L during the dry season. Alachlor concentration ranged from 0.49 to 0.59 μg/L for the wet season and 0.01–0.05 μg/L during the dry season. The concentration of dieldrin ranged between 0.39 and 0.68 μg/L during the wet period and between 0.53 and 0.72 μg/L during the dry period. Metribuzin concentration ranged between 0.45 and 0.75 μg/L during the wet period and between 0.21 and 0.47 μg/L during the dry period. Butachlor concentration ranged from 0.53 to 0.48 μg/L during the wet season and between 0.23 and 0.61 μg/L during the dry season. Paraquat concentration ranged from 0.34 to 0.81 μg/L during the wet season and 0.41–0.63 μg/L during the dry season. Aldrin concentration ranged from 0.29 to 0.48 μg/L during the wet season and between 0.49 and 0.68 μg/L during the dry season. Benzene concentration ranged from 0.03 to 0.09 μg/L during the wet season and between 0.07 and 0.12 μg/L during the dry season. Phenol concentration ranged from 0.09 to 0.15 μg/L during the wet season and between 0.04 and 0.09 μg/L in the dry season. Endrin concentration ranged from 0.01 to 0.09 μg/L during the wet season and between 0.01 and 0.14 μg/L in the dry season. DDT concentration ranged from 0.66 to 0.79 μg/L during the wet period and between 0.63 and 0.79 μg/L in the dry season.

3.2. *Macroinvertebrate abundance*

A total of 622 macroinvertebrate individuals, which comprise 19 species, 8 orders, and 18 families, were recorded during the period of study (Table 3). The relative abundance at the order level revealed that Odonata was the commonest in the study area recorded at all

Table 1
Mean Concentrations (μg/L) of Organochlorine Pesticide Residues in the Sampled Stations of Chanchaga River the two Seasons.

OC(μg/L)	S1		S2		S3		S4	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Atrazine	0.32	0.07	0.42	0.09	0.33	0.12	0.40	0.07
Alachlor	0.52	0.02	0.59	0.05	0.50	0.01	0.49	0.03
Dieldrin	0.68	0.72	0.61	0.53	0.52	0.62	0.39	0.60
Metribuzin	0.75	0.32	0.64	0.24	0.45	0.47	0.71	0.21
Butachlor	0.51	0.61	0.49	0.57	0.48	0.33	0.53	0.23
Paraquat	0.81	0.52	0.62	0.55	0.44	0.63	0.34	0.41
Aldrin	0.45	0.61	0.48	0.68	0.29	0.54	0.32	0.49
Benzene	0.08	0.09	0.09	0.10	0.03	0.07	0.04	0.12
Phenol	0.10	0.08	0.15	0.07	0.12	0.09	0.09	0.04
Endrin	0.09	0.10	0.07	0.14	0.01	0.12	0.05	0.12
DDT	0.69	0.77	0.71	0.79	0.66	0.69	0.79	0.63

Note: S=Station, DDT = Dichlorophenyltrichloroethane, OC= Organochlorine.

Table 2
Summary of the mean concentration (μg/L) of Organochlorine Pesticide Residues in Chanchaga River for the two Seasons with FMenv, WHO and EU Maximum Permissible Limits.

OC (μg/L)	Wet Season	Dry Season	p.value	FMenv	WHO	EU
Atrazine	0.37 ± 0.050[a]	0.09 ± 0.024[b]	0.001	0.1	0.1	0.1
Alachlor	0.53 ± 0.045[a]	0.03 ± 0.017[b]	4.0E-05	0.1	0.1	0.1
Dieldrin	0.55 ± 0.125[a]	0.62 ± 0.078[a]	0.22	0.1	0.1	0.1
Metribuzin	0.64 ± 0.133[a]	0.31 ± 0.116[b]	0.03	0.1	0.1	0.1
Butachlor	0.50 ± 0.022[a]	0.44 ± 0.184[a]	0.27	0.1	0.1	0.1
Paraquat	0.55 ± 0.207[a]	0.53 ± 0.091[a]	0.41	0.1	0.1	0.1
Aldrin	0.39 ± 0.094[a]	0.58 ± 0.083[b]	0.001	0.1	0.1	0.1
Benzene	0.06 ± 0.029[a]	0.10 ± 0.021[a]	0.06	0.1	0.1	0.1
Phenol	0.12 ± 0.026[a]	0.07 ± 0.022[b]	0.02	0.1	0.1	0.1
Endrin	0.06 ± 0.034[a]	0.12 ± 0.016[b]	0.03	0.1	0.1	0.1
DDT	0.71 ± 0.056[a]	0.72 ± 0.074[a]	0.45	0.1	0.1	0.1

Note: Same-letter superscripts along the same row indicate no significant differences ($p > 0.05$), while different-letter superscripts along the same row indicate significant differences ($p < 0.05$). DDT Dichlorophenyltrichloroethane, FMenv = Federal Ministry of Environment, WHO = World Health Organization, EU = European Union.

sampled stations. Hemiptera and Mollusca were the dominant taxa at S1 and S2 (Table 3). A higher number of Ephemeroptera, Mollusca, Hemiptera, Diptera, and Odonata were recorded at S1 compared to S2, S3, and S4. Out of the total number of individuals recorded during the period of study, 41.83 % were recorded in the rainy season (September and October) and 58.17 % in the dry season (November to February). Like in most cases, a highly slight abundance was recorded during the dry season (November to February) compared to the wet season (September to October). The highest number of individuals was observed during the dry season in January at S1.

3.3. *Correlation between macroinvertebrate and organochlorine pesticide residues*

The relationship between macroinvertebrate and organochlorine pesticide residues is given in Fig. 2 and Table 4. The eigenvalue was equivalent to 0.047 for the first axis and 0.026 for the second axis. Canonical correspondence analysis (CCA) ordination shows a strong relationship between species abundance and organochlorine pesticide residues. Axis 1 and 2 accounted for over 81 % of the variation. The first axis accounted for 52.49 %, and the second axis accounted for 29.39 % of the variation (Table 4). From the plot (Fig. 2), at S1, the frequency of *Potadoma* sp., *Hydrocanthus* sp., and *Unima* sp. is positively associated with high metribuzin. *Pseudocloeon* sp. and *Lestes* sp. are negatively sensitive to DDT, atrazine, and endrin at S2. At S4 and S3, *Lestinogomphus* sp. is negatively associated with benzene, and *Caridina nililotica* is positively correlated with dieldrin, respectively. Axis 1 was associated with atrazine, DDT, endrin, and metribuzin, while Axis 2 was associated with dieldrin, benzene, and aldrin.

4. Discussions

When compared with international environmental regulation bodies such as the European Union, the Federal Ministry of

Table 3
Distribution and abundance of macroinvertebrates in Chanchaga River, Minna, Niger State, (September2021-February 2022).

Order	Family	Taxa	Code	S1	S2	S3	S4
Odonata	Lestidae	*Lestes sp*	lest	40	45	39	28
	Libellulidae	*Zyxomma sp*	zyx	15	17	9	7
	Gomphidae	*Lestinogomphus sp*	les	9	8	5	10
		Gomphus sp	gom	6	3	4	1
	Aeshnidae	*Aeshnx sp*	aes	3	5	3	2
	Coenagrionide	*Coenagrion sp*	coe	30	32	26	29
Ephemeroptera	Baetidae	*Pseudocloeon sp*	pse	9	7	5	6
	Leptophlebiidrae	*Choroterpes sp*	cho	3	0	0	1
	Heptageniidae	*Afronurus sp*	afr	4	1	2	0
Hemiptera	Belostomatidae	*Appasus sp*	app	20	15	10	17
	Nepidae	*Nepa sp*	nep	6	0	1	2
Tricoptera	Barbarochthonidae	*Barbarochthon sp*	bar	3	0	1	1
Diptera	Chironomidae	*Chironomus sp*	chi	16	10	17	11
Coleoptera	Notonelidae	*Hydrocanthus sp*	hyd	3	0	2	1
Decapoda	Caridinidae	*Caridina nililotica*	car	2	1	2	0
Mollusca	Thiaridae	*Potadoma sp*	pot	8	6	3	4
	Planorbidae	*Biomphalaria sp*	bio	10	12	5	3
	Lymnaeidae	*Lymnaea natalensis*	lym	1	2	1	3
	Unimidae	*Unima sp*	uni	6	0	2	1
TOTAL				194	164	137	127

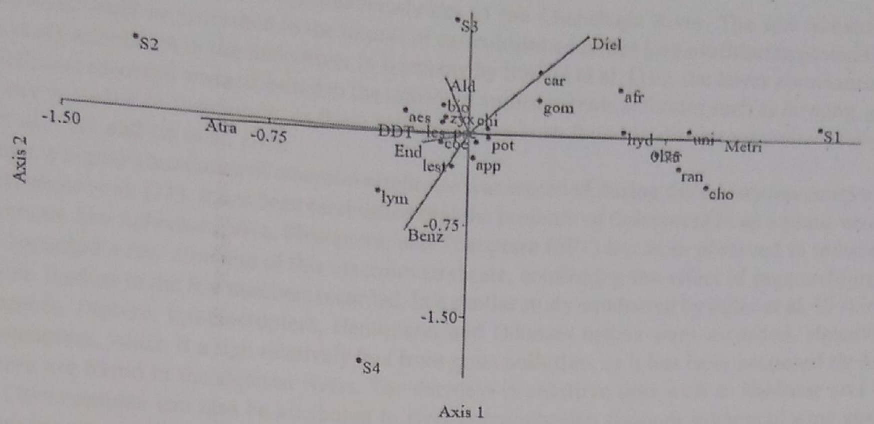

Fig. 2. Triplot of First and Second CCA axes of Macroinvertebrate Species, Organochlorine Pesticide Residues, and their Corresponding Sampling Stations. Full names for abbreviation codes of macroinvertebrate species are listed in Table 3.

Table 4
Weighted Intraset correlations of organochlorine pesticide residue) with the axes of canonical correspondence analysis (CCA) in Chanchaga river, Niger state.

Variables	Axis 1	Axis 2
Eigenvalue	0.046984	0.026303
Proportion explained (%)	52.49	29.39
p.value	0.842	0.795
Atra	**−0.9989**	−0.04828
Diel	**0.446621**	**0.843748**
Metri	**0.960264**	0.009314
Ald	−0.09111	**0.440081**
Benz	0.23211	**−0.7969**
End	0.17167	0.08966
DDT	0.19299	0.01306

All canonical axes were significant. Values in bold indicate significant difference at P < 0.05.

Environment, and the World Health Organization, the recorded mean concentration of the organochlorine pesticide residues in the study exceeded recommended guideline values of 0.1 μg/L for pesticides in freshwater bodies for domestic and drinking purposes and also aquatic organisms [26]. Higher concentrations of atrazine, alachlor, metribuzin butachlor, paraquat, and phenol which are class of herbicides were recorded during the wet seasons compared to the dry seasons which could be attributed to the high use of herbicides during the rainy season compared to the dry season. However, higher concentrations of dieldrin, aldrin, endrin, and DDT under the class of insecticide were recorded during the dry season compared to the wet season, which is also attributed to the high use of insecticides during the dry season and also confirmed by farmers around the catchment.

Comparisons with previous studies by Asiegbu et al. [27] showed that the concentrations of aldrin, atrazine, endrin, paraquat, and benzene recorded were lower than values reported in the Ivo River Basin in south-eastern Nigeria. The rather high values are not unconnected with rich arable agricultural lands around the river catchment. The high dependence on pesticides used by the local farmers around the Chanchaga River catchment probably accounts for these organochlorine residues. The detected concentrations of aldrin, endrin, and DDT in the analyzed water samples suggested a lower value when compared to studies carried out by Haruna and Maitera [28] in River Tella in Taraba State, which recorded 500, 20, and 30 μg/L, respectively, but within the same range of concentration when compared to the report of Edjere et al. [8]. The values of organochlorine pesticide residues measured in this study are similar to the concentration recorded in the Vals and Renoster catchment in South Africa [29]; however, atrazine, butachlor, and alachlor concentrations were much higher due to the high use of pesticides in South Africa (25.7 %) compared to Nigeria (15.8 %) [30], where South Africa and Nigeria are the first two leading importers of pesticides in Africa in the period between 2000 and 2017. Concentrations of aldrin, dieldrin, DDT, metribuzin, and phenol in the present study were much lower when compared to those recorded from the Benue River in Vinikilang, Yola Adamawa State [31], and this could be a result of differences in agricultural practices between the two areas or a difference in geographical location. The National Agency for Food and Drug Administration and Control (NAFDAC) has banned the sale and supply of over 30 different agrochemical products in Nigeria, which include most of the recorded organochlorine pesticide residues in this study. Due to the toxicity of this persistent pesticide, which poses an imminent danger to human health and aquatic organisms, NAFDAC has banned the use of dieldrin, atrazine, benzene, DDT, phenol, and aldrin since 2008, but the products are still in use because of their low cost and affordability. The mean concentrations of dieldrin, butachlor, paraquat, benzene, and DDT, which did not show any statistically significant difference across the two seasons, can be attributed to the fact that these residues are persistent and can remain in the water body for a long time [28].

Insects were the most commonly recorded macroinvertebrates in the Chanchaga River. The few individuals and diversity of macroinvertebrates recorded could be attributed to the impact of agricultural activities (organochlorine pesticide application) around the river water. In the study conducted in the Bode River in Germany by Ronald et al. [16], the lower abundance of the order Diptera, Ephemeroptera, and Odonata recorded was attributed to the impact of anthropogenic activities such as farming, gold mining, washing, and bathing, which were recorded in their study, as these activities have been found to disrupt macroinvertebrate abundance as reported by Edegbene et al. [32] and Ge et al. [33].

However, on average, a higher abundance of macroinvertebrates was recorded during the dry season compared to the wet season, as per the findings of Arimoro et al. [17]. It has been established that the presence of Coleoptera in an aquatic ecosystem and other less tolerant macroinvertebrates like Ephemeroptera, Plecoptera, and Tricoptera (EPT) has been observed to indicate clean water conditions [17]. This study recorded a few numbers of this macroinvertebrate, confirming the effect of organochlorine pesticide contamination of the river water, leading to the few numbers recorded. In a similar study conducted by Egler et al. [34] in the Southeast Brazil river basin, the Coleoptera, Diptera, Ephemeroptera, Hemiptera, and Odonata orders were recorded. However, there was a high abundance of order Coleoptera, which is a sign relatively free from gross pollution, as it has been proposed by Andem et al. [15] that the species of Coleoptera are found in the cleanest rivers. The decrease in sensitive taxa such as Baetidae and the increase in some tolerant taxa such as Chironomidae can also be attributed to river contamination through organochlorine pesticides [35]. Several studies have shown that the taxon richness and abundance of macroinvertebrates in a freshwater environment tend to decrease as the concentration of pesticide residues increases [36–39]. According to Thiere and Schulz [40], ephemeropterans are highly responsive to pesticide pollution. In a study conducted by Szöcs et al. [41]

In Australia, it was reported that the Baetidae were among the most pesticide-sensitive families. The abundance can be negatively influenced by pesticide residues in a body of water. On the other hand, chironomids, pollution-tolerant organisms, were the most abundant taxa in streams that recorded high concentrations of pesticides, including OCPs [42]. The occurrence of tolerant taxa such as chironomids and a few indicator species such as dipteran and coleopteran in the river body could be seen as early warning signals of pollution loads that gradually reduce water quality and the overall ecological health of the river water [4].

The CCA ordinations showed that the macroinvertebrates were significantly associated with OCPs. From the CCA ordination plot, Lestes sp. and Pseudocloeon sp. were characteristic indicators or pointers of organochlorine pesticide contamination of DDT, atrazine, and endrin at S2. At S1, Potadoma sp., Hydrocanthus sp., and Unima sp. were associated with metribuzin, which could be the reason for the low abundance recorded at this site [36]. The presence and high abundance of chironomid, mostly at S1 and S2, is indicative of the deteriorating effect of the residues of organochlorine pesticide in the station, as various studies have reported an increase in the abundance of these organisms, which is indicative of polluted water in southern Nigeria [14,43,44] and the north-central region of Nigeria [45]. The presence of a few mollusks (Biomphalaria sp., Lymnaea natalensis., Unima sp., and Potadoma sp.) at S3 and S2 could be regarded as early warning signals of OCP pollution loads that can degrade water quality [37]. The abundance of Lymnaea natalensis, Choroterpes sp., and Aeshnx sp. at S4 and S2 was not influenced by any of the prevailing OCPs; however, their presence or abundance may be connected with the results of other unmeasured environmental variables. The response of macroinvertebrates to organochlorine pesticide residues confirmed that Chanchaga River is a disturbed water body, and the indicator macroinvertebrates recorded could be used in further biomonitoring assessments of other rivers in north-central Nigeria.

5. Conclusion

The presence of organochlorine pesticide residues identified in the Chanchaga River is most likely to be attributed to diverse agricultural activities practiced along the banks of the river, with pesticides running off from nearby farmlands into the water body. In addition to the runoff, the tendency for regional transportation and atmospheric deposition of these pesticides could be factors in the pesticide load. The organochlorine residues detected in this study are said to persist in the environment and are classified as potential cancer-causing agents (carcinogens) by *NAFDAC*. They can lead to environmental degradation and a decrease in biodiversity through long-term exposure. This study offers insights into the current state of water quality in the Chanchaga River and a baseline dataset for further study on the correlation between macroinvertebrates and pesticide residue levels in the river. The results from this study could also serve as a foundation for the ongoing monitoring of river water. In addition, the data obtained is valuable for employing macroinvertebrates as bioindicators in managing river water.

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

CRediT authorship contribution statement

Eunice O. Ikayaja: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Gideon A. Babalola: Writing – review & editing, Visualization, Validation, Formal analysis, Data curation. **Nenibarini Zabbey:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Data curation. **Francis O. Arimoro:** Writing – review & editing, Validation, Supervision, Resources, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Eunice ojoma Ikayaja reports financial support was provided by African Water Resources Mobility Network (AWaRMN). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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