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EFFECTS OF APPLICATION OF COPPER-BASED FUNGICIDES IN COCOA PLANTATIONS ON THE ABUNDANCE AND DIVERSITY OF MACROINVERTEBRATES IN ADJACENT RIVERS IN SOUTHWESTERN NIGERIA

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ABSTRACT

This study investigated the relationship between the levels of fungicide pollution and the abundance and diversity of macroinvertebrate fauna in three river systems: Aponmu, Oruwo, and Owena in south-western Nigeria, which are in close proximity to cocoa plantations. For each river, three sites were selected for the collection of water and sediment samples from April to July, 2018. Prior to sample collection, the physicochemical parameters (electrical conductivity, total dissolved solutes, pH, temperature, and dissolved oxygen) were determined. Also, aquatic macroinvertebrates were collected, and were identified to generic level, where possible. The levels of copper and sulphate in the samples were determined following standard procedures. The range of mean values for the physicochemical parameters were: 0.07-0.20 mS/cm, 60.00 – 154.00 ppm, 24.60 – 28.13 °C, 6.97 – 7.43, and 0.87 – 2.87 mg/L for electrical conductivity, total dissolved solutes, temperature, pH, and dissolved oxygen respectively. The range of mean values for copper and sulphate in sediment samples were 30.58 – 56.63 mg/Kg and 787.12 – 978.33 mg/Kg respectively while those for the water samples were 2.86 – 6.93 mg/L and 476.6 – 685.58 mg/L respectively. A total of nineteen (19) macroinvertebrate genera comprising Insecta (14), Gastropoda (3), Crustacea (1), and Bivalvia (1) were recorded. Taxa richness and species diversity were higher in river Owena in comparison to rivers Aponmu and Oruwo. The high abundance of the taxa: Potamididae, Gerridae, Notonectidae, Libellulidae, and Platycnemididae in the sampled rivers notwithstanding the pollution levels is an indication that these taxa are capable of thriving in polluted aquatic systems.

Keywords: Aquatic pollution; Copper-based fungicides; Black pod disease; Macroinvertebrates; Diversity indices

INTRODUCTION

Cocoa is one of the most important exportable cash crops in Nigeria, and the main source of income especially in southwestern Nigeria until the discovery of crude-oil in 1958. It is now being grown in other parts of southern Nigeria. One of the challenges facing the profitable production of cocoa in most parts of the world is infestation by pests and diseases (Hebbar, 2007). The major prevalent disease of cocoa is the black pod disease caused by the fungus *Phytophthora* in which at least two species: *P. palmivora* and *P. megakarya* have been implicated (Opoku *et al.,* 1999; Ebewore, 2020). Globally, black pod disease was found to be responsible for the loss of about 700,000 metric tons of cocoa annually, which constitutes 20-40% of the annual global production (Adeniyi, 2018). Cocoa farmers have relied over the years on the use of chemical pesticides (fungicides and insecticides) to reduce the threat of yield loss due to diseases and pests. In Nigeria as in most African countries, copper-based fungicides such as copper (II) sulphate, copper (I) oxide and cuprous oxide are the most common approach to combat the black pod disease of cocoa (Opoku *et al.,* 2007), thus resulting in elevated levels of these chemicals in the environments.

There are reports of continuous contamination of freshwater ecosystems with synthetic chemicals from agricultural farmlands through natural processes such as leaching and runoff (FAO, 2017; Issaka and Ashraf, 2017; Pérez-Lucas *et al.,* 2018). Also, there is the potential for these chemicals to bioaccumulate in the aquatic ecosystems to the levels where they affect the abundance and diversity of aquatic fauna, especially macroinvertebrates. The use of benthic macroinvertebrates as bioindicators of pollution in aquatic systems is quite popular (Patang *et al.,* 2018; Oguma and Klerks, 2020; Outa *et al.,* 2020). Mello *et al.* (2018) showed that the contamination of freshwater systems with agrochemicals altered the macroinvertebrate community in southeastern Brazil. Cochard *et al.* (2014) reported a significant negative impact of contamination by agrochemicals on the abundance and diversity of phytoplankton, fishes and waterfowls in Thailand aquatic systems that were in close proximity to rice farmlands.

The increased usage of agrochemicals in agriculture warrants that efforts are made to assess the impacts of such practices on the environments, by relating the levels of environmental pollution to changes in community structure. With frequent use of copper-based fungicides in cocoa farming in Nigeria, it is anticipated that these chemicals will be detected in high levels in aquatic ecosystems that are in close proximity to such cocoa plantations. However, not many studies have related aquatic pollution due to fungicides to the community structure of resident macroinvertebrates in these areas. The present study is therefore aimed at quantifying the levels of copper sulphate fungicide in the surface water and sediments from polluted river systems and relating their levels to the diversity and abundance of macroinvertebrate fauna in Rivers Owena, Aponmu, and Oruwo that are in close proximity to cocoa plantations.

MATERIALS AND METHODS

Study Area

The study was carried out in three states (Osun, Ondo and Ekiti States) in southwestern Nigeria; which are acclaimed to be the largest producers of cocoa in Nigeria. The three rivers that were sampled in the study include River Owena (latitude 7° 24' 06" N; longitude 5° 00' 47" E) in Osun State, River Aponmu (latitude 7° 13' 37" N; longitude 5° 03' 33" E) in Ondo State, and River Oruwo (latitude 7° 29' 55" N; longitude 5° 03' 48" E) in Ekiti State. These rivers were selected based on their proximity to cocoa plantations. The map of the study area is shown in Figure 1.

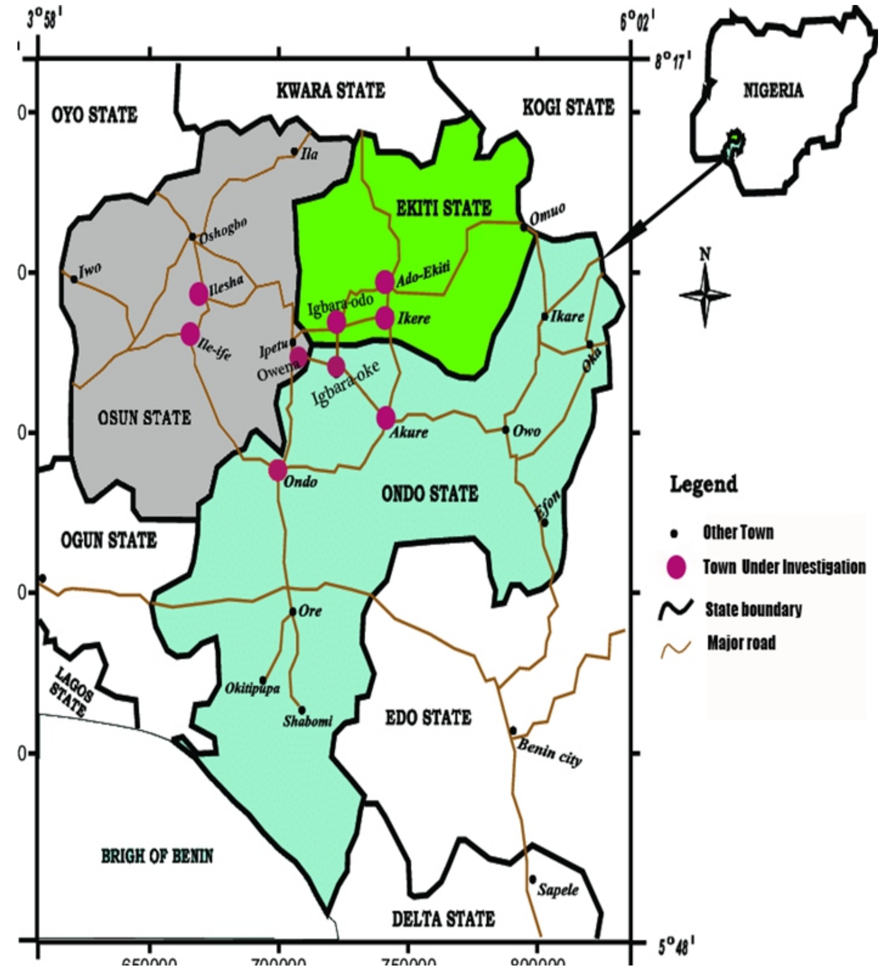

Figure 1: Map of Parts of Southwestern Nigeria Showing the Study Sites

Sediment and Water Samples Collection and Fungicide Analysis

The following physicochemical parameters: electrical conductivity, dissolved oxygen, total dissolved solute, temperature, and pH were recorded at each sampling location prior to sample collection. Sample collection spanned four months from April to July, 2018 since personal interaction with local farmers indicated that these are the months in which pesticide applications in cocoa farmlands are mostly performed. Also, the period falls within the wet season in which rainfall is frequent, hence more runoff into the rivers. Water samples (n = 3) were collected into 20 ml acid-washed universal sample bottles at three different sites for each river; upstream, midstream and downstream. Sediment samples were also collected into clean zip-lock bags at each sampling locations using the Eckman grab. The collected samples were transported to the laboratory under mild aeration for the determination of copper (Cu) and sulphate (SO_4^{2-}) levels. The levels of copper in water and sediment samples were determined using atomic absorption spectrophotometry following the procedures of Mohamed *et al.* (2012), while the sulphate levels were determined using titrimetric method as reported in Fritz and Freeland (1954).

Sample extraction (water and sediment samples) for Cu determination was carried out following the procedures of Siaka *et al.* (1998). Briefly, the water samples were digested by addition of 1 ml of HNO_3/HCl mixture (3:1) to 10 ml of the sample and placed on hot plate at approximately 60 ºC for 1 h. For the sediment samples, approximately 1 g of the sample was carefully weighed into acid-washed beaker, after which 5 ml of HNO_3 was added, and placed on hot plate at approximately 60 ºC for 1 h. The digested samples were allowed to cool, and centrifuged at 3000 rpm. The aliquots were transferred into clean tubes for Cu analysis. Each sample was analyzed in triplicate. For quality assurance purpose, reagent blanks were prepared, and processed along with the samples. Sample analysis was done using flame atomic absorption spectrometry with the aid of a BUCK 211 VGP (Buck Scientific, USA). The analysis was done by directly introducing the aliquots into the flame atomic absorption spectrophotometer, and the absorbance was read. The working standards (0.1 – 10 μg/ml) were prepared from the 1000 μg/ml stock solution. The calibration curve was obtained by plotting the recorded absorbance values against the concentrations of the working standards.

The limit of detection (LOD) was calculated using the equation:

$$LOD = 3 SD/m,$$

where SD is the standard deviation of 10 blank determinations
and m is the slope of the calibration curve.

The LOD of the analyses was determined to be 21.04 ± 4.26 ìg/L. Sulphate levels were determined from the water and sediment digestates which were obtained earlier during Cu analysis. The aliquots of the digestates were diluted in 30% alcohol and were titrated against 0.01 M $BaCl_2$ using Alizarin Red as an indicator. The titration was stopped when the colour changed from yellow to pink.

Macroinvertebrates Collection and Identification

The collection of benthic macroinvertebrates at each sampling locations was done using the kick-sampling method with the aid of sampling net of 500 μm mesh size. Other macroinvertebrates were collected from vegetation and rocks by hand picking. The collected macroinvertebrates were counted and transported from the field in sterile universal bottles containing 70% ethanol. Samples were identified to family and generic levels in the laboratory using hand lens, dissecting microscope and identification guides/keys.

Data Analyses

The data on physicochemical parameters, copper and sulphate levels were presented as mean ± standard deviation. The differences in the means for each parameter at the different sampling locations for each sampling duration were determined using a one-way analysis of variance (ANOVA) with the general linear models procedure of the Statistical Package for Social Sciences (SPSS), and means were separated using the least significant difference at $p<0.05$. Macroinvertebrates diversity indices were determined using Paleontological Statistics

(PAST) statistical analysis (version 3.1). The relationship between the physicochemical parameters, copper levels, sulphate levels and macroinvertebrate diversity indices were assessed using the Pearson correlation statistics.

RESULTS

Physicochemical Parameters of Water

The physicochemical parameters of water from the sampled rivers are presented in table 1. There were significant differences in the values of physicochemical parameters determined for the sampling locations except for the water temperature, which was not statistically different for the three rivers. Also, the values of the measured physicochemical parameters fluctuated markedly during the sampling durations at each of the sampling locations. Generally, the lowest values for most of the physicochemical parameters were recorded in the month of July while the highest values were recorded either in April or May. The mean values for the physicochemical parameters ranged from 0.07-0.20 mS/cm, 60.00 – 154.00 ppm, 24.60 – 28.13 °C, 6.97 – 7.43, and 0.87 – 2.87 mg/L for electrical conductivity, total dissolved solutes, temperature, pH, and dissolved oxygen respectively across the locations.

Table 1: Physicochemical Parameters of the Sampled Rivers during the Sampling Periods

	Location	April	May	June	July
Electrical Conductivity (mS/cm)	Aponmu	0.20 ±0.01^{cD}	0.17 ±0.01^{aC}	0.14 ±0.01^{bB}	0.10 ±0.00^{aA}
	Owena	0.11 ±0.00^{aA}	0.14 ±0.02^{aA}	0.10 ±0.00^{aA}	0.07 ±0.06^{bB}
	Oruwo	0.19 ±0.00^{bC}	0.18 ±0.00^{aC}	0.14 ±0.00^{bB}	0.09 ±0.00^{aA}
Total dissolve solutes (ppm)	Aponmu	154.00 ±1.00^{cD}	125.67 ±0.67^{bC}	104.00 ±2.31^{bB}	78.00 ±1.00^{cA}
	Owena	80.00 ±1.00^{aB}	90.00 ±0.00^{aC}	80.00 ±0.00^{aB}	60.00 ±0.58^{aA}
	Oruwo	140.67 ±0.33^{bD}	136.33 ±0.33^{cC}	108.00 ±0.00^{bB}	70.33 ±0.88^{bA}
Temperature (°C)	Aponmu	27.97 ±0.03^{aC}	26.07 ±0.07^{aB}	25.53 ±0.07^{aA}	25.40 ±0.06^{aA}
	Owena	28.10 ±0.12^{aD}	26.87 ±0.13^{cC}	25.93 ±0.03^{bB}	25.50 ±0.58^{aA}
	Oruwo	28.13 ±0.57^{aC}	26.50 ±0.06^{bB}	26.53 ±0.03^{cB}	24.60 ±0.06^{aA}
pH	Aponmu	7.30 ±0.06^{abA}	7.30 ±0.06^{aA}	7.40 ±0.12^{bA}	7.30 ±0.06^{bA}
	Owena	7.43 ±0.03^{bC}	7.23 ±0.03^{aB}	7.37 ±0.03^{bC}	7.00 ±0.00^{aA}
	Oruwo	7.23 ±0.03^{aB}	7.20 ±0.06^{aB}	6.97 ±0.03^{aA}	7.30 ±0.00^{bB}
Dissolved oxygen (mg/L)	Aponmu	1.40 ±0.06^{aA}	2.57 ±0.12^{cB}	2.30 ±0.12^{bB}	1.67 ±0.03^{bA}
	Owena	2.87 ±0.03^{cC}	2.17 ±0.09^{bB}	2.07 ±0.03^{bB}	1.70 ±0.06^{bA}
	Oruwo	1.93 ±0.07^{bD}	1.60 ±0.06^{aC}	0.87 ±0.03^{aA}	1.30 ±0.06^{aB}

Means with the same lower case alphabet down the column and upper case alphabet across the row are not significantly different ($p<0.05$).

Table 2: Copper and Sulphate Levels in Sediment Samples from Rivers Owena, Aponmu, and Oruwo at Different Sampling Periods

Elements (mg/kg)	Locations	Months			
		April	May	June	July
Cu	Aponmu	35.15 ±0.15^{bA}	42.85 ±0.23^{bAB}	54.00 ±0.46^{bB}	56.63 ±8.36^{aB}
	Owena	30.58 ±0.58a^{A}	35.9 ±50.75^{aB}	46.03 ±0.41^{aD}	41.10 ±0.27^{aC}
	Oruwo	37.30 ±0.40^{cA}	41.42 ±0.28^{bB}	54.49 ±1.71^{bD}	48.20 ±0.76^{aC}
SO_4^{2-}	Aponmu	787.12 ±0.78^{aA}	865.52 ±0.70^{cB}	978.33 ±3.05^{bD}	921.73 ±1.81^{cC}
	Owena	817.78 ±0.41^{bA}	848.52 ±0.59^{aB}	956.80 ±3.65^{aD}	902.62 ±1.66^{aC}
	Oruwo	826.88 ±0.16^{cA}	853.98 ±1.51^{bB}	964.53 ±2.79^{aD}	909.23 ±0.93^{bC}

Means with the same lower case alphabet down the column and upper case alphabet across the row are not significantly different ($p<0.05$).

Copper and Sulphate Levels in Water and Sediment

The levels of copper and sulphate in sediment and water samples are shown in tables 2 and 3 respectively. The levels of copper and sulphate differed significantly among the sampling locations and for each sampling periods. Generally, copper and sulphate levels were highest in the month of June and lowest in the month of April. The mean values for copper and sulphate in sediment samples ranged from 30.58 – 56.63 mg/Kg and 787.12 – 978.33 mg/Kg respectively, across the locations while for the water samples, the values ranged from 2.86 – 6.93 mg/L and 476.6 – 685.58 mg/L for copper and sulphate respectively.

Table 3: Copper and Sulphate Levels in Water Samples from Rivers Owena, Aponmu, and Oruwo at Different Sampling Periods

Elements (mg/kg)	Locations	Months			
		April	May	June	July
Cu	Aponmu	2.86 ±0.01^{aA}	4.87 ±0.06^{aB}	5.70 ±0.24^{aC}	5.28 ±0.15^{aBC}
	Owena	2.97 ±0.01^{aA}	5.03 ±0.01^{bB}	6.41 ±0.34^{abD}	5.71 ±0.17^{abC}
	Oruwo	3.27 ±0.06^{bA}	5.34 ±0.05^{cB}	6.93 ±0.03^{bD}	6.01 ±0.01^{bC}
SO_4^{2-}	Aponmu	488.95 ±0.19^{bA}	542.03 ±0.59^{aB}	665.93 ±19.77^{aD}	603.97 ±9.68^{aC}
	Owena	476.60 ±1.49^{aA}	565.83 ±0.94^{bB}	677.42 ±2.97^{aD}	621.60 ±1.23^{abC}
	Oruwo	567.07 ±0.20^{cA}	584.62 ±0.78^{cB}	685.58 ±1.72^{aD}	634.58 ±0.77^{bC}

Means with the same lower case alphabet down the column and upper case alphabet across the row are not significantly different ($p<0.05$).

Faunal Composition and Diversity

The results of the faunal composition and diversity indices at the sampling locations are presented in tables 4 and 5. A total of nineteen (19) macroinvertebrate genera were recorded from the water and sediment sampled in the three rivers. The fauna comprised fourteen (14) genera of Insecta, three (3) genera of Gastropoda, one (1) genus of Crustacea, and one (1) genus of Bivalvia.

Taxa richness was highest in river Owena (19 taxa; Margalef: 3.047) but similar in rivers Aponmu (14 taxa; Margalef: 2.23) and Oruwo 14 taxa; Margalef: 2.325). Similarly, river Owena had the highest number of individuals (368) followed by Aponmu (340) while Oruwo had the lowest number of individuals (268). Species diversity was highest in river Owena (Simpson: 0.8977; Shannon: 2.466) while the diversity indices were nearly the same for rivers Aponmu (Simpson: 0.8754; Shannon: 2.312) and Oruwo (Simpson: 0.8834; Shannon: 2.329). In terms of abundance, the families Gerridae, Platycnemididae, Macromiidae, Potamididae, and Notonectidae were the most abundant with frequency of occurrence more than 100 across the sampling locations while the families Hydrometridae, Hydrophilidae, Nepidae, Neptageniidae, and Etheriidae were the least abundant.

Table 4: Abundance of Macroinvertebrates in Rivers Owena, Aponmu, and Oruwo

MACROINVERTEBRATES		LOCATIONS			
		APONMU	OWENA	ORUWO	
Family	Genus	Frequency			Total
Pilidae	*Lanistes*	11	9	4	24
Potamididae	*Potadoma*	87	16	4	107
Planorbidae	*Bulinus*	6	1	6	13
Etheriidae	*Etheria*	1	3	0	4
Potamonotidae	*Sudanonautes*	4	8	5	17
Heptageniidae	*Austrophlebiodes*	0	3	0	3
Chironomidae	*Chironomus*	10	7	7	24
Gerridae	*Aquarius*	42	55	51	148
Naucoridae	*Pelocoris*	0	11	4	15
Hydrometridae	*Hydrometra*	0	1	0	1
Nepidae	*Renatra*	0	2	0	2
Notonectidae	*Notonecta*	29	50	27	106
Veliidae	*Macrovelia*	23	24	21	68
Gyrinidae	*Dineutus*	20	41	29	90
Hydrophilidae	*Hybrobiomorpha*	0	1	0	1
Gomphidae (a)	*Progomphus*	21	32	17	70
(b)	*Macrogomphus*	20	13	23	56
Macromiidae	*Macromia*	35	54	22	111
Platycnemididae	*Drepanosticta*	31	37	48	116

Table 5: Diversity Indices of Macroinvertebrates in Rivers Owena, Aponmu, and Oruwo

	APONMU	OWENA	ORUWO
No. of Taxa	14	19	14
No. of Individuals	340	368	268
Simpson_1-D	0.8754	0.8977	0.8834
Shannon_H	2.312	2.466	2.329
Margalef	2.23	3.047	2.325

Correlation between Physicochemical Parameters, Copper and Sulphate Levels, and Macroinvertebrates Diversity in Rivers Aponmu, Oruwo, and Owena

The correlation matrices show the interaction among the variables in Rivers Aponmu, Owena, and Oruwo in tables 6, 7 and 8 respectively. In River Aponmu, there was a strong negative correlation between the abundance of *Lanistes sp* and pH (r = -0.778), copper level (r = -0.599), and sulphate level (r = -0.581). *Bulinus sp* (r = -0.577), and *Chironomus sp* (r = -0.577) negatively correlated with pH. Also, as electrical conductivity (r = -0.8), total dissolved solutes (r = -0.772), copper level (r = -0.947) and sulphate level (r = -0.731) negatively correlated with abundance of *Etheria sp.* In river Oruwo, the abundance of *Potadoma sp.* negatively correlated with pH (r = -0.675) and dissolved oxygen (r = -0.825) while *Progomphus sp.* negatively correlated with temperature (r = -0.578). In river Owena, abundance of *Potadoma sp.* (r = -0.588), *Aquarius sp* (r = -0.633), *Macromia sp.* (r = -0.629) and *Drepanostista sp.* (r = -0.636) correlated negatively with electrical conductivity. The abundance of *Pelocoris sp.* correlated negatively with dissolved oxygen (r = -0.73) and pH (r = -0.8). *Renatra sp.* correlated negatively with pH (r = -0.831) dissolved oxygen (r = -0.623) while *Hydrometra sp.* correlated negatively with pH (r = -0.874), dissolved oxygen (r = -0.674), total dissolved solutes (r = -0.925), copper level (r = -0.906), and sulphate level (r = -0.846).

Table 6: Correlation Matrices Showing Interaction among Variables in River Aponmu

	EEC	TDS	Temp	pH	DO	Cu	SO4²⁻	Lanistes	Potadoma	Bulinus	Etheria	Chironomus	Aquarius	Notonecta	Macrovelia	Dineutus	Progomphus	Macrogomphus	Macromia	Drepanosticta
EEC	1																			
tds	.996**	1																		
temp	.882**	.905**	1																	
Ph	-.190	-.236	-.397	1																
DO	-.129	-.153	-.520	.377	1															
Cu	.595*	.561	.225	.532	.513	1														
SO_4^{2-}	.208	.160	-.190	.769**	.721**	.822**	1													
Lanistes	-.326	-.295	-.248	-.778**	.086	-.599*	-.581*	1												
Potadoma	.941**	.959**	.971**	-.450	-.370	.319	-.117	-.144	1											
Bulinus	.858**	.873**	.753**	-.577*	.000	.359	-.033	.192	.879**	1										
Etheria	-.800**	-.772**	-.472	-.333	-.377	-.947**	-.731**	.556	-.565	-.577*	1									
Sudanonautes	.622*	.603*	.229	0.000	.657*	.773**	.597*	0.000	.422	.707*	-.816**									
Chironomus	.858**	.873**	.753**	-.577*	.000	.359	-.033	.192	.879**	1.000**	-.577*	1								
Aquariu	.793**	.766**	.640*	.361	-.014	.746**	.536	-.762**	.617*	.417	-.843**	.417	1							
Notonecta	.126	.122	.258	.397	-.466	.187	.033	-.662*	.136	-.229	-.132	-.229	.303	1						
Macrovelia	-.126	-.139	-.258	-.397	.466	-.181	-.034	.662*	-.136	.229	.132	.229	-.303	-.719**	1					
Dineutus	.849**	.836**	.769**	0.000	-.116	.498	.302	-.471	.772**	.612*	-.707*	.612*	.809**	.187	0.000	1				
Progomphus	.738**	.739**	.788**	-.362	-.391	.125	-.150	-.148	.783**	.628*	-.362	.628*	.577*	-.059	.101	.811**	1			
Macrogomphus	.792**	.767**	.470	0.000	.396	.785**	.502	-.192	.608*	.750**	-.866**	.750**	.695*	-.153	.229	.638*	.500	1		
Macromia	.935**	.944**	.876**	-.406	-.142	.374	.051	-.097	.939**	.905**	-.638*	.905**	.622*	-.069	.069	.841**	.792**	.687*	1	
Drepanosticta	.451	.439	.392	-.444	-.064	.032	-.147	.232	.477	.549	-.190	.549	.206	-.311	.579*	.583*	.793**	.476	.563	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7: Correlation Matrices Showing Interaction among Variables in River Owena

	EEC	TDS	Temp	Ph	DO	Cu	$SO4^{2-}$	Lanistes	Potadorma	Bulinus	Etheria
EEC	1										
TDS	-.903**	1									
Temp	-.620*	.557	1								
pH	-.895**	.650*	.700*	1							
Cu	-.911**	.838**	.286	.748**	.359	1					
$SO4^{2-}$	-.851**	.782**	.130	.670*	.218	.970**	1				
Lanistes	-.148	.354	.070	-.044	-.023	.234	.161	1			
Potadorma	-.588*	.738**	.638*	.418	.531	.453	.328	.752**	1		
Bulinus	-.345	.132	.862**	.592*	.899**	.000	-.152	-.174	.309	1	
Etheria	-.460	.681*	-.072	.093	-.168	.600*	.604*	.408	.434	-.469	1
Sudanonaut	.035	.354	-.212	-.399	-.408	.081	.100	.565	.387	-.590*	.783**
Austrophlebi	.179	.186	-.188	-.489	-.400	-.109	-.128	.408	.289	-.469	.707*
Chironomus	.171	-.343	-.138	-.017	.000	-.176	-.174	-.035	-.185	.200	-.469
Aquarius	-.633*	.647*	.602*	.517	.539	.556	.385	.279	.643*	.444	.368
Pelocoris	.729**	-.536	-.646*	-.800**	-.730**	-.534	-.500	.380	-.225	-.566	.063
Hydrometra	.997**	-.925**	-.632*	-.874**	-.674*	-.906**	-.846**	-.174	-.617*	-.333	-.469
Renatra	.617*	-.229	-.415	-.831**	-.623*	-.525	-.489	.302	0.000	-.577*	.271
Notonecta	-.475	.597*	.332	.264	.210	.511	.376	.402	.605*	.101	.581*
Macrovelia	-.024	.006	.372	.080	.302	-.162	-.296	.328	.436	.471	.074
Dineutus	-.071	.322	.093	-.185	-.044	.036	-.031	.633*	.574	-.081	.543
Hybrobiomorpha	-.368	.132	-.383	.367	-.180	.606*	.716**	-.174	-.309	-.333	.156
Progomphus	-.540	.680*	.613*	.407	.534	.430	.303	.788**	.917**	.283	.353
Macrogomphus	-.082	.402	.191	-.179	-.015	.023	-.044	.716**	.720**	-.111	.607*
Macromia	-.629*	.529	.663*	.653*	.666*	.490	.301	.196	.575	.607*	.257
Drepanostict	-.636*	.777**	.719**	.428	.598*	.453	.313	.417	.836**	.432	.460

	Sudanonautes	Austrophlebiodes	Chironomus	Aquarius	Pelocoris	Hydrometra	Renatra	Notonecta	Macrovelia	Dineutus	Hybrobiomorpha	Progomphus	Macrogomphus	Macromia	Drepanosticta
Sudanonaut	1														
Austrophlebi	.921**	1													
Chironomus	-.472	-.469	1												
Aquarius	.091	.112	-.075	1											
Pelocoris	.501	.518	.081	-.406	1										
Hydrometra	0.000	.156	.200	-.649*	.728**	1									
Renatra	.766**	.812**	-.346	-.296	.700*	.577*	1								
Notonecta	.385	.392	-.261	.910**	-.154	-.503	0.000	1							
Macrovelia	.104	.294	.189	.419	.191	0.000	0.000	.355	1						
Dineutus	.691*	.694*	.049	.395	.412	-.081	.420	.463	.648*	1					
Hybrobiomorpha	-.295	-.469	.200	-.102	-.243	-.333	-.577*	-.101	-.471	-.404	1				
Progomphus	.375	.221	-.170	.483	-.091	-.566	0.000	.412	.333	.526	-.283	1			
Macrogomphus	.819**	.816**	-.289	.361	.350	-.111	.577*	.525	.576*	.871**	-.556	.629*	1		
Macromia	-.089	.014	.087	.820**	-.414	-.607*	-.451	.610*	.613*	.400	-.087	.491	.279	1	
Drepanostict	.336	.313	-.196	.868**	-.359	-.667*	-.068	.785**	.463	.600*	-.353	.699*	.632*	.698*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 8: Correlation Matrices Showing Interaction among Variables in River Oruwo

	EEC	TDS	Temp	Ph	DO	Cu	SO4^{2-}	Lanistes	Potadoma	Bulinus	Etheria	Sudanonautes	Austrophlebiodes	Chironomus	Aquarius	Pelocoris	Hydrometra	Renatra	Notonecta	Macrovelia	Dineutus	Hybrobiomorpha	Progomphus	Macrogomphus	Macromia	Drepanosticta
EEC	1																									
TDS	-.903**	1																								
Temp	-.620*	.557	1																							
pH	-.895**	.650*	.700*	1																						
Cu	-.911**	.838**	.286	.748**	.359	1																				
SO4^{2-}	-.851**	.782**	.130	.670*	.218	.970**	1																			
Lanistes	-.148	.354	.070	-.044	-.023	.234	.161	1																		
Potadorma	-.588*	.738**	.638*	.418	.531	.453	.328	.752**	1																	
Bulinus	-.345	.132	.862**	.592*	.899**	.000	-.152	-.174	.309	1																
Etheria	-.460	.681*	-.072	.093	-.168	.600*	.604*	.408	.434	-.469	1															
Sudanonaut	.035	.354	-.212	-.399	-.408	.081	.100	.565	.387	-.590*	.783**	1														
Austrophlebi	.179	.186	-.188	-.489	-.400	-.109	-.128	.408	.289	-.469	.707*	.921**	1													
Chironomus	.171	-.343	-.138	-.017	.000	-.176	-.174	-.035	-.185	.200	-.469	-.472	-.469	1												
Aquarius	-.633*	.647*	.602*	.517	.539	.556	.385	.279	.643*	.444	.368	.091	.112	-.075	1											
Pelocoris	.729**	-.536	-.646*	-.800**	-.730**	-.534	-.500	.380	-.225	-.566	.063	.501	.518	.081	-.406	1										
Hydrometra	.997**	-.925**	-.632*	-.874**	-.674*	-.906**	-.846**	-.174	-.617*	-.333	-.469	0.000	.156	.200	-.649*	.728**	1									
Renatra	.617*	-.229	-.415	-.831**	-.623*	-.525	-.489	.302	0.000	-.577*	.271	.766**	.812**	-.346	-.296	.700*	.577*	1								
Notonecta	-.475	.597*	.332	.264	.210	.511	.376	.402	.605*	.101	.581*	.385	.392	-.261	.910**	-.154	-.503	0.000	1							
Macrovelia	-.024	.006	.372	.080	.302	-.162	-.296	.328	.436	.471	.074	.104	.294	.189	.419	.191	0.000	0.000	.355	1						
Dineutus	-.071	.322	.093	-.185	-.044	.036	-.031	.633*	.574	-.081	.543	.691*	.694*	.049	.395	.412	-.081	.420	.463	.648*	1					
Hybrobiomorpha	-.368	.132	-.383	.367	-.180	.606*	.716**	-.174	-.309	-.333	.156	-.295	-.469	.200	-.102	-.243	-.333	-.577*	-.101	-.471	-.404	1				
Progomphus	-.540	.680*	.613*	.407	.534	.430	.303	.788**	.917**	.283	.353	.375	.221	-.170	.483	-.091	-.566	0.000	.412	.333	.526	-.283	1			
Macrogomphus	-.082	.402	.191	-.179	-.015	.023	-.044	.716**	.720**	-.111	.607*	.819**	.816**	-.289	.361	.350	-.111	.577*	.525	.576*	.871**	-.556	.629*	1		
Macromia	-.629*	.529	.663*	.653*	.666*	.490	.301	.196	.575	.607*	.257	-.089	.014	.087	.820**	-.414	-.607*	-.451	.610*	.613*	.400	-.087	.491	.279	1	
Drepanostict	-.636*	.777**	.719**	.428	.598*	.453	.313	.417	.836**	.432	.460	.336	.313	-.196	.868**	-.359	-.667*	-.068	.785**	.463	.600*	-.353	.699*	.632*	.698*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

In the present study, the abundance and diversity of benthic macroinvertebrates were used as indices of pollution of aquatic systems with pesticides from cocoa plantations probably through run-offs. The determination of physicochemical parameters provides reliable data for assessment of health status of aquatic ecosystem (Yazdian *et al.,* 2014; Sarkar *et al.,* 2020). The values of the measured physicochemical parameters fluctuated consistently during the sampling periods and were consistent with the values from other studies in southwestern Nigeria (Etim and Adie, 2012; Aiwerioghene and Adedolapo, 2016). The observed fluctuations in these measurements were probably due to differences in the volume of rainfall during the periods. Also, the measured values for most of the parameters were within the limits set by regulatory agencies except for the dissolved oxygen, which ranged between 0.87 and 2.87 mg/L while the limit set by the United States Environmental protection Agency (USEPA) for dissolved oxygen is ⩾ 4 (WHO, 2011). The low levels of dissolved oxygen in the sampled rivers could be an indication of constant influx of organic minerals into the water bodies which consequently resulted in oxygen depletion.

The levels of copper and sulphate were highest in the month of June compared to the other sampling months. This was probably due to increased rate of application of the pesticides during this period since available records indicated that cocoa fruiting peaked during this period, and this is often associated with higher incidences of cocoa pod rots (Ogunlade and Agbeniyi, 2011). The relatively low levels of copper and sulphate in water and sediment samples in river Owena (in comparison to the two other rivers sampled) is an indication that this river was the least polluted of the sampled rivers, and this assertion was further substantiated by higher abundance and diversity of benthic macroinvertebrates in this river compared to rivers Aponmu and Oruwo.

Aside the effects on ecological diversity, pesticide pollution resulted in contamination of water thus rendering them unsuitable for human consumption. The values of copper and sulphate in the sampled rivers averaged at 6.0 and 648 mg/L respectively for the months of June and July. These values were several magnitudes above the permissible levels for these elements (2 mg/l for Copper; 500 mg/l for Sulphate) by the World Health Organization (2011). The implication of high levels of these elements in river systems on human health could be very serious since various human diseases have been linked with elevated levels of copper and sulphate in humans. Generally, the levels of copper and sulphate were higher in the sediments compared to surface waters. This trend has been reported in literature, and further reiterated the assertion that sediments serve as sink for pollutants in aquatic ecosystems (Shanbehzadeh *et al.,* 2014; Bazrafshan *et al.,* 2015).

Among the 19 taxa that were identified during the sampling periods, Potamididae, Gerridae, Notonectidae, Libellulidae, and Platycnemididae were the most abundant taxa, each with at least 100 individuals. The high abundance of these taxa is consistent with findings from other studies that have reported high abundance of the taxa in polluted rivers (Hossain and Baki, 2015; Edegbene, 2020). This could be an indication that these taxa are tolerant of pesticide pollution in aquatic environments. The relatively high abundance of Hemiptera compared to other insect orders showed that Hemipterans are able to thrive in polluted river systems with poor water conditions (Rasoloariniaina, 2017). The Pearson Correlation analysis showed a strong inverse relationship between most of the physicochemical parameters especially pH and electrical conductivity and abundance of *Lanistes sp., Bulinus sp,* and *Chironomus sp.; Etheria sp. Potadoma sp., Aquarius sp., Macromia sp.; Drepanostista sp. Pelocoris sp., Hydrometra sp.* and *Renatra sp* while increasing copper and sulphate concentrations significantly decreased the population of *Lanistes sp, Etheria sp,* and *Hydrometra sp.*

In conclusion, the results of this study show that pesticide application in cocoa plantations had negative impacts on diversity and abundance of benthic macroinvertebrates residing in rivers adjacent to the farmlands. Of the sampled rivers, river Owena was the least polluted as reflected by the number of taxa and the diversity indices. The occurrence of the taxa Potamididae, Gerridae, Notonectidae, Libellulidae, and Platycnemididae in high frequency in these rivers notwithstanding the pollution levels showed that these taxa are tolerant of poor water conditions. In addition, the detected levels of copper and sulphate in the sampled rivers were above the permissible levels, and renders the water unsuitable for human consumption and other domestic needs. Moderate and regulated use of pesticides is therefore advised in farmlands to promote both environment and human health.

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