Aquatic Macroinvertebrates as Bio-indicators for the Assessment of Water Quality of the Vaughan Pond, Ghana.

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Abstract— The study was conducted to assess the water quality of the Vaughan Pond using the Hilsenhoff's Family Biotic Index (FBI) from February to April 2019 at (6) sampling stations. Physiochemical parameters were measured at the six stations. Macroinvertebrates were sampled using a 500µm mesh size net. Altogether, 864 individuals from 38 families and 13 Orders were sampled. The observed diversity indices were 2.298, 0.7052, 0.8154, respectively for Shannon-Wiener diversity index, Pielous evenness, and Simpson's index in February; 2.058, 2.984, 0.8313 in March 2.829, 0.849, 0.9288 in April. Out of the Order and family of Macroinvertebrates encountered, 51% Hemiptera with 22% Gerridae, 15% Vellidae and 7% Mesoveliidae; 19% Gastropoda with 15% Thiaridae and 4% Physidae; 8% Dipterans with 4% Chironomidae and 1% Culicidae; 7% Odonata with 3% Coenogrinidae, 2% each of Libullelidae of Aeshnidae; 1% Gomphidae. Lesser Orders (less than 2%) included Trichopterans and Coleopterans. The Vaughan Pond, according to the FBI system, was 7.69, indicating a severe organically polluted pond. Measures are therefore needed to minimize the organic load.

Index Terms— Macroinvertebrates, Bio-indicators, Water Quality, Family Biotic Index (FBI)

1 INTRODUCTION

The exponential increase in the world's population accompanied by uncontrolled migration of rural settlements to urban areas and increased industries and agricultural activities to augment higher demands for food [1] have all contributed to increased environmental pollution. The waste generated by humans moves from its origin to matrices such as the air, water bodies, and soil [2].

Water is an indispensable resource that plays a vital role in the environment. Its importance spans economic, ecological, to biological applications. Water bodies, especially freshwater systems indeveloping countries, face many pollution problems due to anthropogenic activities. These activities tend to make the water unsafe for its essential purpose or applications. Freshwater systems in developing countries have not been fully exploited for their benefit, for which Ghana is no exception [3]. The anthropogenic activities that impact the freshwater systems tend to deteriorate the water quality. According to the Environmental Protection Agency [4], water quality is described as a water body's chemical, physical and biological characteristics. Pollution of water bodies is either point or non-point source. Point source pollution originates from regular discharges from industries and community wastewater systems, while non-point sources commonly originate from scattered avenues that channel into freshwater systems [5]. This indicates that the quality of water bodies needs to be monitored to ensure they are within the required standards that will make them safe. Water quality standard limits differ by the purpose of the water. Thus, the standard limits for agriculture, domestic, industrial, etc., are not the same. The quality of freshwater systems reflects the biological, physical, and chemical parameters of the water and thus can affect the organisms inhabiting the system [6].

The use of the chemical method of assessing water quality is a laudable technique. However, this method only gives you a fair idea of how polluted the water is in terms of primarily chemical composition and not making any reference to the effects on biodiversity [7]. The biological approach employs the use of the organisms living in the environment as bioindicators to ascertain the biotic integrity of the aquatic system. This method provides more details about the overall condition of the water system, referring to the biodiversity, abundance, physicochemical parameters, and even the level of pollution in particular seasons. This creates a clearer picture of what is happening in the freshwater system, considering how the organisms in the water system are affected [8]. Limitation to the use of the biological approach has to do with its difficulty in finding sync between observed effects to specific contaminants or natural phenomena [8]. Consequently, organisms may respond differently due to their life cycle, such as biological normalcy. Like other approaches, biomonitoring must be perfected and analyzed by a professional bio-ecologist [9].

Most fresh lotic systems provide habitat for both plants and animals and contribute to water sources for use for domestic, industrial, and agriculture purposes [3]. Therefore, the need to protect them is very crucial. The Vaughan Pond provides a habitat for diverse flora and fauna, including migratory waterbirds, fishes, insects, and other organisms. Also, the use of the Vaughan Pond as a research site for most students at the University of Ghana adds up to the benefits it renders to the public. Finally, the pond adds to the recreational amenities available at the botanical garden and thus, provides income as well. Therefore, this study was conducted to assess the water quality and the level of organic pollution of the pond using the Hilsenhoff's Family Biotic Index FBI.

2 MATERIALS AND METHODS

2.1 Study Area

The Vaughan Pond

The University of Ghana, Legon campus (005°39'03''N 000°11'13''W) is found about 13 kilometers north-east of Accra (Fig 2.0) in the Greater Accra Region, at an altitude of 91 me-

ters and 122 meters within an area of 12 kilometers square. The average annual rainfall ranges from 733 to 1118 millimeters. The biome of the university is predominantly grass, thicket, and forest. The university has a botanical garden located at the university (Fig 2.0) near the Haatso Atomic Road established in 1950. Facilities such as canopy walkways, Restaurant, children playing grounds, and a Pond, the Vaughan Pond, are found at the botanical gardens. The Vaughan Pond is in the northern part of the botanical gardens (005°33''N 000°15''W). The pond was created primarily to serve as housing for the university's sewage effluents, but the system broke down some years ago. There is no source of a river or a stream emptying into the pond; water sources come utterly from rainfall. Surrounding the ponds are trees and vegetation that serve as habitats for diverse water birds.

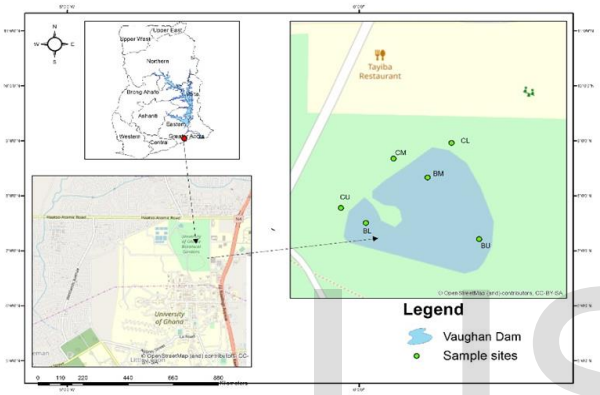

Figure 2.1 Map of the study Area Showing the Vaughan Pond and sampling station source.

The coordinates for the six sampling stations CU, CM, CL, BU, BM, and BL are lat N 05°39'56.3'' long W000°11'19.7', lat N 05°39'56.3'long W000°11'19.4'', lat N 05°39'56.3'' longW000°11'18.4'', lat N 05°39'56.3'' longW002°16'10.3'', latN 05°39'56.3''long W000°11'10.2''

lat N 05° 39'57.2'' long W000°11'18.7'' respectively using a CASIO handheld GPS.

CU- Upper stream channel, CM-Middle stream channel, CL- Lower stream channel BU- Upper reaches of the pond, BM-Middle reaches of the pond, BL- Lower reaches of the pond.

Three sampling stations (BU, BM, and BL) were in the main pond, and three (CU, CM, and CL) at the channel area, made up of channels of running water flowing from the pond's outlet. Each is using a yellow bowl to attract Macroinvertebrates. The sampling design used was both random and stratified sampling techniques.

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2.2 Sampling

2.2.1 Fieldwork

The sampling method used was based on the Protocols for sampling Aquatic Macroinvertebrates in Freshwater Wetland DEPLW0640 May [10] by the Department of Environmental Protection, State of Maine, and Bureau of Land and Water Quality Monitoring Assessment manual. Sampling was done once a month for three months (February, March, and April). The sampling took place between 7:00 am to 12 noon at the end of each month.

The physiochemical parameters measured at the stations were, Dissolve oxygen (DO), Temperature, Salinity, Total dissolved solids (TDS), Conductivity, and pH. These parameters were measured using the HANNA H1 98194 Ph/EC/DO Multiparameter probe. Three replicates of measurement were taken at each of the six sampling stations.

A sampling of Macroinvertebrates was done using a 46 by 46 cm square-framed 500 microns net. The sampling was done at six sampling stations. The sampling net was scooped at every sampling station within a stretch of 5m long using a canoe. The square frame net was scooped through the water at the surface and about 50 cm below the surface. The random visual technique was employed within the 5m long stretch at each sampling station of the pond. These included locating areas where some of the invertebrates were seen and where vegetation was seen on the water surface and vegetations along the banks of the pond. An estimated time of 3 minutes was spent when sampling the open water column. Net sampling was also used at the channel, which is an outlet from the pond. The frame of the sampling net was used to disturb the sediment to dislodge invertebrates to be sampled.

The riffle part of the channel was sampled by using the net to sweep through the water column, the vegetative zones of the upstream, midstream, and downstream regions of the channel. From this, the net was placed so that the inlet faced the upstream, where the water flows for the dislodged materials including the invertebrate to move into the net whose hard base was placed on the benthic part of the water column. Rocks were in the water column of the riffle and were checked for attached invertebrates like mollusks and other invertebrates that hide beneath the rocks. These invertebrates were picked with my hands into the net at each point of the riffle. Due to the nature of some macroinvertebrates spending a part of their life cycle in or around the water, six yellow bowls, one each was placed at the banks of each sampling station. These bowls were filled with water to about one-fifth of the bowl volume. A few drops of liquid soap were smeared at the water's surface. These bowls were left there for 24 hours, and they were picked on the following day; their content was poured into a labeled container and preserved with 70% ethanol.

2.2.2 Storage and transportation

The storage and labeling method were done using Protocols for sampling Aquatic Macroinvertebrates in Freshwater Wetland DEPLW0640 [10] by the Department of Environmental protection, State of Maine, and Bureau of Land and water quality monitoring assessment manual.

All materials, including debris and the invertebrates, were collected into the sampling containers. Each container for each station. Thus 12 containers for the six sampling stations were sampled. After which, 10% of formalin was poured into each of the samples to prevent decomposition of the invertebrates and preserve them. Using masking tape and a permanent marker, each of the containers was labeled.

The sampling stations of the pond were labeled with the letter B, with the upstream been BU, BM been a middle stream, and BL lower stream. The channel was labeled with the letter C, CU, CM, and CL being upstream, midstream, and lower or downstream. The labeling was done in the format of the station name, then the date of sampling using a black permanent marker on a masking tape.

2.3 Laboratory work

Each of the samples collected was poured into a 500-micron mesh size collector, after which it was washed with water thoroughly to wash away most of the formalin. A large white container was used to sort out the debris as smaller portions of the sample were taken into the container. The container is filled with water to wash off macroinvertebrates hiding on leaves, debris, or stone. After the samples were sorted to provide clear water in the container, long forceps were used to pick up macroinvertebrates into the labeled sampling containers. The macroinvertebrates sorted out into the containers were preserved with 70% ethanol and sent to ARPPIS (AFRICAN REGIONAL POSTGRADUATE PROGRAM IN INSECT SCIENCE) for identification.

Identification was made using a Leica dissecting microscope. A specialist at ARPPIS assisted in the identification using the Identification key provided in [11]. Each Macroinvertebrate was identified to the family level. Smaller samples collected from each sample were poured into a plate under the microscope to identify each Macroinvertebrate seen to the family level. They were then counted and recorded. This was done until all the macroinvertebrates in a sample were fully identified.

2.4 Data Analysis

All statistical tests were based on a p= 0.05 level of significance. Analysis of variance (ANOVA) was used to analyze the physicochemical variables and macroinvertebrate distribution. Pie charts, bar graphs, and tables were made using excel. Averages of the physiochemical parameters were also estimated using excel 2006.

2.5. 1indices Of Species Diversity

PRIMER 5 was used to estimate the Shannon-wiener index, Pielous evenness, and Simpson's index.

2.5.1 Family Biotic Index

The family biotic index was used to calculate the degree of pollution of the Vaughan Pond system. The FBI is calculated by multiplying the number in each family by the tolerance value for that family and dividing by the total arthropods in the sample. The index was calculated using LEVEL3METRICS excel software.

FBI= $\Sigma \frac{ni \times ai}{N}$

n= Number of Specimens in taxa i

a= Tolerance value of taxa i

N= Total number of specimens

2.6 Quality Control and Assurance

The probe used for the physicochemical parameters was calibrated before use. The sensor was placed in the liquid used for calibration. The GPS location was used to locate each sampling point each month to ensure accuracy. The sensor was placed in the sampling stations for about 30s-1min until the screen's values are constant.

The net was cleaned after sampling from each sampling station to prevent the transfer of macroinvertebrates from one sample station to another. A long stretch of sampling area having the six sampling stations was used to ensure a good representation of the population of Macroinvertebrate. The sampling was done for three months to provide a representation of the macroinvertebrate population. The method used included a 3min kick method and 3min sampling in open water.

During sorting, a minimum of 2 hours and a maximum of 4hours were used per sample. This is to ensure that almost 95% of the macroinvertebrates are sorted out. A white container was used during sorting for easy identification of the invertebrates. The sorted-out invertebrates are placed in their respective bottles. During the identification of each sample, individuals were identified using keys and counted per family to get the total individuals belonging to a family.

3 RESULTS

3.1 Physiochemical Parameters

The highest (7.85) and the lowest (7.20) pH values were both recorded in February. The mean value of pH for the entire study period was 7.57±0.15, as seen in Table 3.1 was estimated for the entire study period. The p-values for the ANOVA were greater than 0.05 among months and sampling sites. Temperature values recorded ranged (21.22-30.44) °C with an average of (28.38±7.05°C). Salinity was recorded to have an average value of (0.64±0.14ppt) for the entire three months sampling period. The average value concentration of Conductivity was (1.32±0.30ms/cm), and its highest and lowest values recorded were (1.32±0.30ms/cm) and (1.27ms/cm), respectively. The highest and lowest values for TDS were (0.69ppt) and (0.64ppt) respectively. The estimated average value for TDS was (0.66±0.15ppt), as shown in table 3.1.

Table 3.1 Mean values with standard deviations of the Physiochemical parameters

		ANOVA		
		Sitem Variation	Monthly Variation	US-EPA (2009)
PHYSIOCHEMICAL PARAMETERS	MEAN VALUES	P-VALUE	P-VALUE	6.5
Ph	7.57±0.15	0.866311131	0.1843065	8.5
DO (mg/L)	4.92±1.5	0.491220491	0.00096238	5
Temperature (°C)	28.38±7.05	0.845188131	0.10862223	13-22
Salinity(ppt)	0.64±0.14	3.105875239	0.00015815	-

Conductivity (µs/cm)	1.32±0.30	0.763554191	0.00088443	2.5
Total dissolved solids (TDS) (ppt)	0.66±0.15	0.995506937	2.8227E-08	0.5

3.2 MACROINVERTEBRATES DISTRIBUTION, ABUNDANCE AND DIVERSITY

3.2.1 Macroinvertebrate Assemblages and Abundance

A total of 864 individuals, 38 Families, and 13 Orders of Macroinvertebrates were sampled during the study period. As seen in Table 3.2, 164 macroinvertebrates were sampled at site CU, 98 individuals at site CM, 106 at site CL, 198 at site BU, 170 at site BM, and 128 at site BL. In Table 4.2, the family with the highest number of individuals sampled over the study period was from the Family Gerridae with an abundance of 191, followed by the Thiaridae having an abundance of 131, then the Veliidae recording an abundance of 129 individuals. The ten families recorded the lowest abundance, with an abundance of 1 individual; they include the Belosstomatidae, Reduriidae, Braconidae, Evanidae, Sarcophigidae, Syrphidae, Blattidae, Polycentropodidae, Carabidae, and the family Cervidae. Other families recorded are listed in Table A in Annex A with their respective Abundances.

Similarly, the macroinvertebrates sampled over the three-month study period had the highest abundance recorded in February with 340 individuals, followed by March with 298 individuals and April recording 226 individuals, as seen in Table B in Annex B.

Figure C.1 in Annex C indicates the percentage abundance of macroinvertebrates sampled over the study period among the sampling sites. The BU site recorded 23%, with the second highest been BM with 20% abundance, 19% recorded for site CU, and 15% recorded for BL. 12% and 11% was the percentage abundance sampled in site CL and CM, respectively.

Figure C.2 in Annex C is the monthly representation of abundances of the Macroinvertebrate sampled among the various months. In February, the highest abundance sampled was 39%, 35% in March, and 26% in April.

Figure D in annex D below indicates the respective percentage abundance of the individual orders sampled over the three month period; with Hemiptera (51%), Gastropoda (19%), diptera (8%), Odanata and collembola (7%) each, Hymenoptera (5%), and some few orders (≤1%).

3.2.2 Diversity Indices

Table 3.4 shows the various indexes estimated using the PRIMER 5 software. February had a Shannon-wiener index that was highest (2.829) in April, February (2.298), followed by March (2.058). Pielous evenness(J') was also high (0.849) in April, March (0.7119) estimated, and February (0.7052). Simpson's index (D) was highest (0.9288) for April, followed by March (0.813) and February (0.813), as seen in Table 3.2. The ANOVA calculated for the Macroinvertebrates abundance among the various sites and Months across the Families sampled had a p-value of more than 0.05.

Table 3.2 Diversity indices of the Respective months and ANOVA

DIVERSITY INDICES Shannon-wiener(H')	MONTHS			ANOVA	
				SITE VARIATION	MONTHLY VARIATION
	FEB	MAR	APRIL	p-value	p-value
Pielous evenness (J')	2.298	2.058	2.829	0.684	0.731
Simpson's index (D)	0.7052	0.7119	0.849		
DIVERSITY INDICES	0.8154	0.8313	0.9288		

3.2.3 Hilsenhoff's Family Biotic Index (Fbi)

FBI was calculated using the LEVEL3METRICS Excel software. A total of 29 taxa was used, 2 EPT Taxa was also recorded, 69.4% of tolerant taxa among the sampled individuals was also estimated. The metrics calculated also show 23.4% dominance, EPT (Ephemeroptera, Plecopteran, and Trichoptera) taxa of 0.4% with a percentage of Macroinvertebrate that is Net spinners was also 0.4%.

The total number of Trichoptera taxa was 2, long-lived taxa 18, Diptera taxa was 8, Odonata Taxa was 4, COET (Coleoptera, Odonata, Ephemeroptera, and Trichoptera) Taxa was 9. The percentage of sensitive taxa was 1%, and the percentage of Chironomidae was 4.7%, with a percentage of individuals that are clingers was 20.8%.

The total number of individuals used for the FBI was 816, and the total families used was 29. The rest of the organisms had no tolerance values. The stream water condition integrity rating was 46.0, and the FBI calculation was 7.69.

4 DISCUSSIONS

The monthly variations in the relative abundances of macroinvertebrates were not significantly different as the p-value estimated was above 0.05. The higher abundance of individuals sampled in February may be due to the monthly fluctuation of the invertebrates and or physiochemical parameters influence [12]. Usually, February is the driest month among the three months. The water volume may be at its ebbs during the study period compared to March and April when the rainfalls are much more in the area and thus spread out the macroinvertebrates in the larger volume of water. The second month, March, also recorded a lower abundance compared to February but recorded higher abundance compared to April. The samples recorded in March and April further support the fact that water volume in the reservoir as the rains increased accounts for the number recorded during the study.

Though April recorded the lowest abundance, it had the highest Shannon-wiener diversity index, more than March and February. This is because more families of the macroinvertebrates were recorded in April than in March and February. This agrees with the results [13]. This may be attributed to an abundance of food with the rains and subsequent vegetative

cover. The Pielous evenness was also the highest in April than the other months due to no significant difference among the abundance of families recorded [14]. Simpson's index was highest in April than the other two sampling months. This may be due to more families recorded and having an individual family (Gerridae) showing dominance in terms of abundance [15].

The Order with the highest percentage of 51% abundance was the Hemipterans, similar to research done by [16] at the Vaughan Pond. The family Gerridae, Veliidae, and Mesoveliidae dominated. Gerridae recorded about 22% of the total abundance of individuals sampled, which was not the case with the study [16]. However, this was in concordance with the study by [3] and [17]. The family Gerridae have a very high tolerance value of 10 [17] and hence cannot strive even when water quality conditions are not suitable [18]. Individuals of the Family Gerridae were seen at all the sampling sites, indicating their dominance and tolerance to a wide range of physicochemical conditions [19]. The family Veliidae and Mesoveliidae all had 15% and 9% abundance, respectively. Their presence and abundance also indicate a water body with lots of organic pollution.

The second higher Order, but with a low abundance of individuals, was the Gastropoda (19%). The families sampled in this Order were the Thiaridae and the Physidae with percentages of 15% and 4%, respectively. Gastropoda is noted to inhabit substrate [1]. The Thiaridae and Physidae were found at all the sampling sites and indicate their dominance and ability to withstand a wide range of microhabitat conditions. Thiaridae and Phyidae in a water body have a tolerance level of 10 [17] and thus indicate a very tolerant organism to organic pollution [20].

The Order Dipterans were the third-highest abundance in the individuals sampled. They dominated with 8% in abundance. The families with high abundance in this Order were the Chironomidae and the Culicidae with 4% and 3% abundance, respectively. Chironomidae was also recorded in the Nima creek as the most abundant family with a percentage of 98% and was found at all the sampling sites [6]. The abundance of Chironomidae and that recorded by [6] and [3] at all the sampling sites indicates the existence of Chironomidae in most shallow freshwater bodies in Ghana. The order Culicidae is also an indicator of a poor freshwater body [21]. The other families have about 1-2% abundance. These may be new entrants or being dominated by other macroinvertebrates.

The Orders Odonata and Collembola are dominated by 7% abundance each. The families under Odonata sampled were Coenogrinidae having 3%, libellulidae having 2%, and the rest comprising of Gomphidea and Aeshnidae having 1% abundance. Odonata is noted to inhabit very moderately polluted freshwater bodies [18]. The presence of Coenogrinidae may be due to aquatic vegetation and the slower velocity of the water at the site they were sampled [22].

The Order Collembola having only the family Isotomidae in the samples indicates that this specific family finds the environment very favorable for its habitation [23]. Isotomidae have a tolerance value of 10 [20], which indicates their high tolerance to organic pollution in their environment, and thus able to strive in their environment [24].

Trichoptera is Orders of macroinvertebrates that are sensitive to organic pollution generally. But the families sampled during this study have a moderate tolerance value of 6 [20], indicating their somewhat tolerance to organic pollution [24]. The presence of Trichoptera in only the April sampling month may result from the beginning of a new breeding season for the Trichopterans and hence their small number and presence [25].

Coleopterans are Orders whose presence in the aquatic environments indicates a polluted water body [26]. The coleopterans were also only found in the April sampling months. This may be due to new breeding seasons for the Order within the month of April [26].

The annelids were also sampled during the period. The Annelids are substrate-dwelling organisms. They had a lower percentage which is like [18] and [6]. Aquatic polychaetes in high abundance in the substrate of a freshwater body indicate a very polluted water body in the absence of sensitive organisms [27].

The LEVEL3METRICS indicated an FBI of 7.69, indicating a high level of organic pollution. The sources of organic pollution may be due to anthropogenic activities within the environment [25]. The lower percentage of sensitive taxa and the high percentage of Tolerant taxa is also clear evidence of an organically polluted pond.

5.0 Conclusion

The Vaughan Pond physiochemical parameters fluctuated among months and sampling sites. Temperature and TDS values measured were very high and fell outside the limit (state the limit with reference). pH, Salinity, Conductivity, and DO all fell within the permissible limits (same here).

The Vaughan Pond has a high diversity of macroinvertebrates, which tells the complex nature of the food web in its community. The changes in the abundance, presence, or absence of macroinvertebrates within sites and months indicate the effect of seasons and physiochemical parameters on the macroinvertebrates' abundance.

The FBI index of 7.69 indicates that the Vaughan Pond is severely polluted organically. However, this is buttressed with the physicochemical parameters. Previous work done by researchers at the pond reported a very high WQI Water quality index showing an inferior water body quality.

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ANNEX A

Table A Abundance of Macroinvertebrates (Order) Families Sampled among the sampling sites

		FREQUENCY OF MACROINVERTEBRATE OCCURRENCE AT SITES						
ORDER	Family	CU	CM	CL	BU	BM	BL	TOTAL
Hemiptera	*Mesoveliidae*	7	0	0	19	20	31	77
	Gerridae	38	20	25	49	35	24	191
	Veliidae	25	8	12	53	17	14	129
	Notonectidae	13	0	0	1	0	0	14
	Belostomatiidae	1	0	0	0	0	0	1
	Corixidae	5	0	0	6	0	0	11
	Naucoriidae	5	1	0	2	3	4	15
	Reduriidae	0	0	1	0	0	0	1
Hymenoptera	*Formicidae*	3	7	9	3	3	5	30
	Braconidae	0	0	0	1	0	0	1
	Ichumonidae	0	1	2	0	1	0	4
	Evanidae	0	0	0	0	1	0	1
	Vespidae	0	2	1	0	0	0	3
Diptera	*Chironimodae*	4	7	6	6	10	5	38
	Culcidae	0	2	1	6	2	0	11
	Anthomyiidae	0	0	1	1	0	0	2
	Ceratopogoniidae	0	0	4	2	0	0	6
	Stratiomyiidae	0	0	0	0	3	0	3
	Sarcophigidae	0	0	0	0	0	1	1
	Syrphidae	1	0	0	0	0	0	1
	Phonidae	1	2	1	0	2	0	6
Dictyoptera	*Blattidae*	0	1	0	0	0	0	1
Trichoptera	*Hydropsychidae*	0	0	0	2	0	0	2
	Polycentropodidae	0	0	0	0	0	1	1
Odanata	*Caenogrinidae*	11	0	3	3	6	0	23
	Aeshnidae	4	0	2	0	2	0	8
	Gomphidae	0	4	2	2	5	1	14
	Libellulidae	3	1	0	1	3	2	10
Orthoptera	*Grylidae*	0	0	0	1	0	2	3
Coleoptera	*Hydrophilidae*	1	0	0	1	1	0	3
	Chrysomelidae	0	0	0	0	2	0	2

	Carabidae	0	0	0	0	1	0	1
Homoptera	*Cercopidae*	0	0	1	0	0	0	1
Collembola	*Isotomidae*	10	4	9	14	13	12	62
Arachnida	*Spiders*	2	2	0	0	0	0	4
Annelida	*Polychaetes*	3	11	0	0	0	0	14
Gastropoda	*Physidea*	7	6	5	7	9	4	38
	Thiaridae	20	19	21	18	31	22	131
Total		164	98	106	198	170	128	864

ANNEX B

Table B Abundance of Macroinvertebrate (Order) Families sampled among the various months

ORDER	Family	FEB	MARCH	APRIL	TOTAL
Hemiptera	*Mesoreliidae*	1	60	16	77
	Gerridae	133	32	26	191
	Veliidae	25	80	24	129
	Notonectidae	13	1	0	14
	Belostomatiidae	0	1	0	1
	Corixidae	3	5	3	11
	Naucoriidae	0	1	14	15
	Reduriidae	1	0	0	1
Hymenoptera	*Formicidae*	16	7	7	30
	Braconidae	1	0	0	1
	Ichumonidae	3	0	1	4
	Evanidae	0	0	1	1
	Vespidae	3	0	0	3
Diptera	*Chironimodae*	16	7	15	38
	Culcidae	4	4	3	11
	Anthomyiidae	1	1	0	2
	Ceratopogoniidae	2	0	4	6
	Stratiomyiidae	2	0	1	3
	Sarcophigidae	1	0	0	1
	Syrphidae	1	0	0	1
	Phonidae	1	0	5	6

Dictyoptera	*Blattidae*	0	1	0	1
Trichoptera	*Hydropsychidae*	0	0	**2**	2
	Polycentropodidae	0	0	1	1
Odanata	*Caenogrinidae*	11	5	7	23
	Aeshnidae	4	1	3	8
	Gomphidae	7	3	0	10
	Libellulidae	0	0	14	14
Orthoptera	*Grylidae*	0	0	3	3
Coleoptera	*Hydrophilidae*	0	0	3	3
	Chrysomelidae	0	0	2	2
	Carabidae	0	0	1	1
Homoptera	*Cercopidae*	0	0	1	1
Collembola	*Isotomidae*	25	22	15	62
Arachnida	*Spiders*	4	0	2	6
Annelida	*Polychaetes*	11	0	1	12
Gastropoda	*Physidea*	13	8	17	38
	Thiaridae	38	59	34	131
Total		**340**	**298**	**226**	**864**

ANNEX C

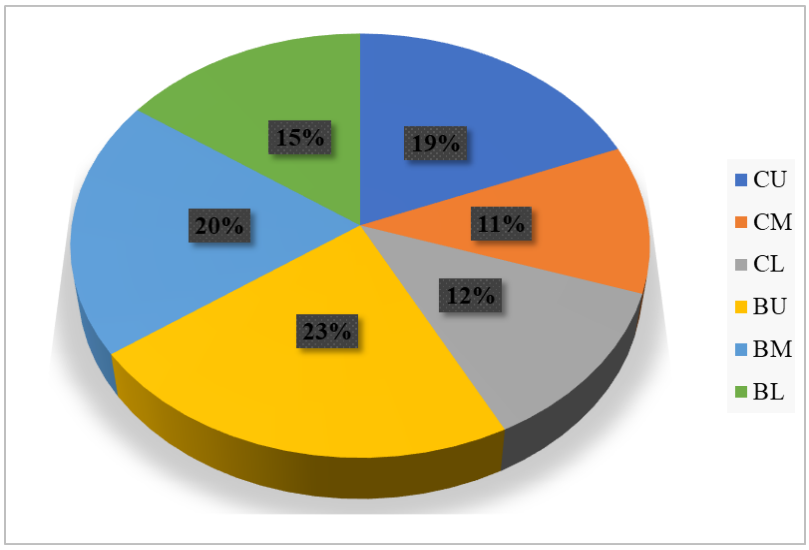

Fig C.1 Macroinvertebrates Percentage Abundance among Sampling Sites.

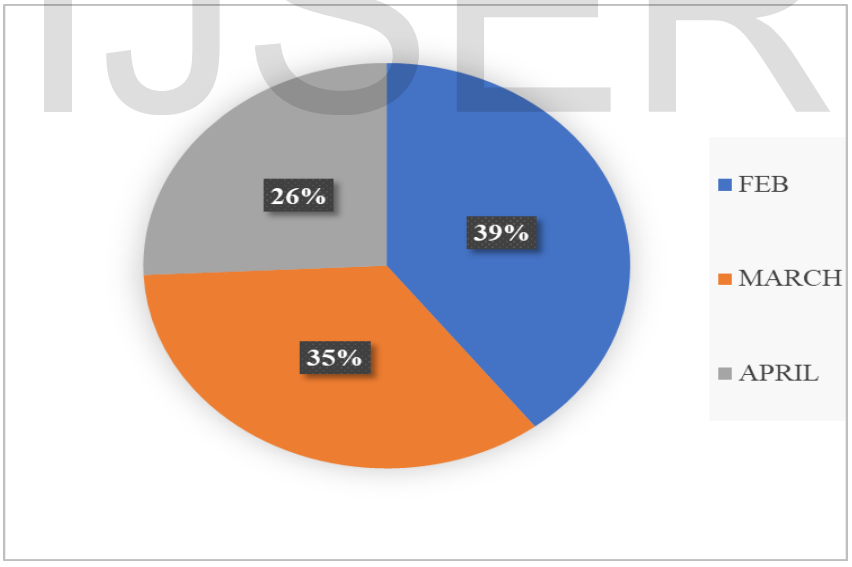

Fig C.2 Percentage Abundance of Total Macroinvertebrates sampled in the Various Months.

Annex D

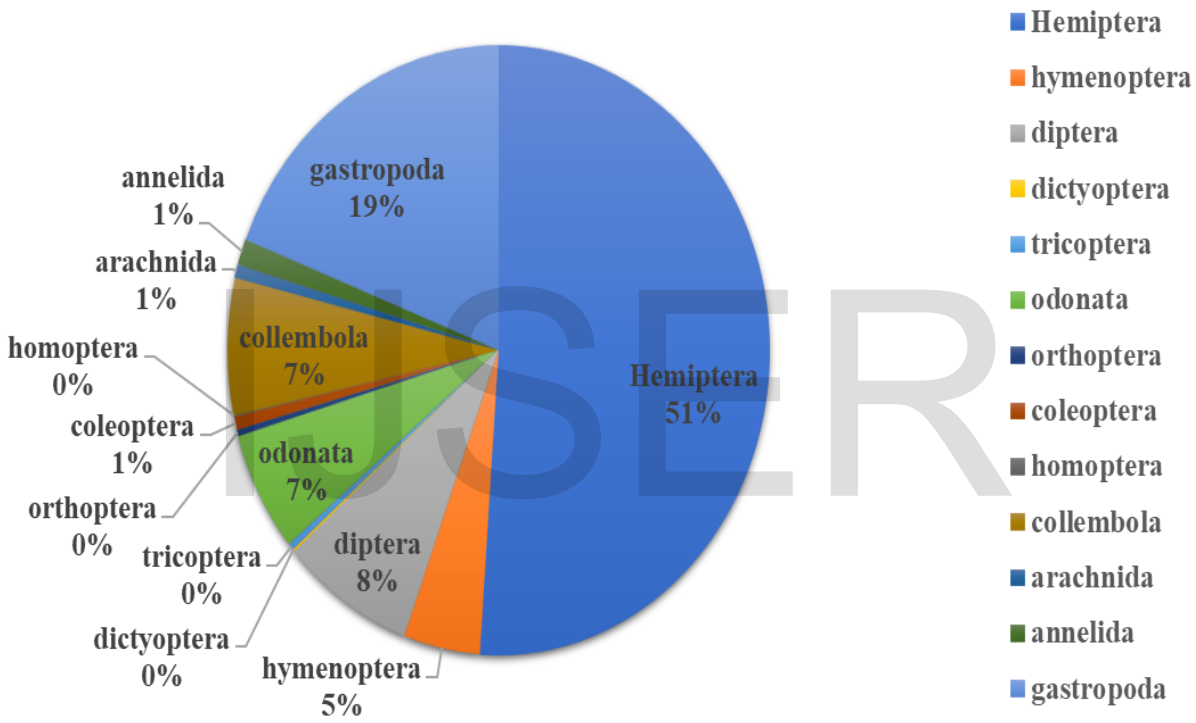

Fig D. Percentage Abundance of Orders of Macroinvertebrates sampled during the study period.