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Abundance and Distribution of MacroInvertebrates in Relation to Physicochemical Properties of Pindiga Lake, Akko Local Government Area, Gombe State

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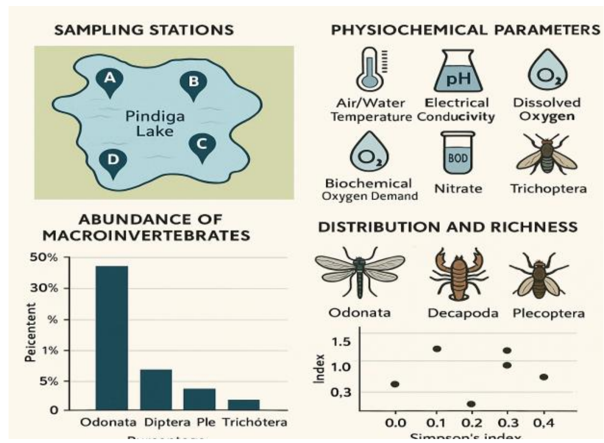

Abstract: The distribution and abundance of aquatic macroinvertebrates, along with physicochemical parameters, were meticulously examined in Pindiga Lake. The primary objectives were to identify the families of aquatic macroinvertebrates, to assess their abundance across selected sampling locales, and to investigate the influence of physicochemical parameters—namely air and water temperature, pH, electrical conductivity, dissolved oxygen, biochemical oxygen demand, turbidity, nitrate, and phosphate—on their distribution and abundance. The lake was stratified into four sampling stations designated as A, B, C, and D. Samples were meticulously collected using aquatic nets from each sampling station biweekly over a span of six months. Physical and chemical parameters were measured in situ and duly recorded. The total count of individual macroinvertebrates was classified into various orders and families. Analysis of Variance (ANOVA) was employed to ascertain any significant variations among the four sampling stations within the lake. All measured physicochemical parameters were observed to be within tolerable limits conducive to aquatic productivity. The collected aquatic macroinvertebrates were identified utilizing taxonomic keys, and their distribution and abundance were estimated using Simpson's and Margalef's richness indices. The results revealed a total of 200 individual species of aquatic macroinvertebrates belonging to 9 genera across five taxa: Odonata, Decapoda, Diptera, Plecoptera, and Trichoptera. The Order Diptera constituted 74%, Decapoda 3.5%, Trichoptera 0.5%, while Plecoptera and Odonata each comprised 11% of the total identified macroinvertebrates. The Simpson's species diversity index for the five taxa were as follows: Odonata (0.01), Decapoda (0.001), Plecoptera (0.01), Diptera (0.5), and Trichoptera (0). The Margalef index of genera richness yielded the following results: Odonata (0.434), Decapoda (0), Plecoptera (0), Diptera (1.3), and Trichoptera (0). The findings of this study indicate that Pindiga Lake is a highly productive ecosystem capable of supporting extensive ecological studies; therefore, the imperative to maintain its integrity is of paramount importance.

Keywords: Macroinvertebrates, Physicochemical parameters, and Pindiga Pond

1. Introduction

Wetland ecosystems account for 5-8% of the Earth's surface area (Sui et al., 2017). They exhibit the most remarkable biodiversity, highest productivity, and greatest ecological impact of all terrestrial ecosystems due to their distinctive amalgamation of land and water (Sui et al., 2017). According to Galloway et al. (2004), wetlands are crucial for mitigating greenhouse gas emissions, conserving biodiversity, and regulating the equilibrium of the Earth's ecosystems.

Furthermore, Dudgeon et al. (2016), Carlson et al. (2013), and Narangarvuu et al. (2014) posited that aquatic ecosystems are significantly affected by large-scale agricultural expansion, which adversely influences their overall quality by directly altering habitats, channel structures, and water quality, thereby posing a formidable threat to aquatic biodiversity.

Nevertheless, water remains one of the most indispensable resources for all forms of life. It plays a vital role in agriculture, transportation, manufacturing, and numerous other human endeavors. According to Fakayode and Ajeam-Ragae (2005), despite its paramount importance, water is among the most poorly managed resources globally and is contaminated by various sources. However, due to the escalation of diverse human activities and certain natural processes, water quality is continually deteriorating, thereby posing a significant threat to all forms of life, including humans (Khan et al., 2012). The primary environmental issues affecting water quality stem from both point and non-point sources of pollution, a situation exacerbated by the inadequate treatment of domestic waste.

In agricultural regions, for instance, the routine application of chemical fertilizers, pesticides, and herbicides constitutes a major source of contamination (Altman et al., 1995; Emongor et al., 2005). Although the abundance of aquatic macroinvertebrates is substantially bolstered by high-quality water, as evidenced by balanced physicochemical parameters, urban areas suffer from the indiscriminate disposal of industrial effluents and other waste products, which further contribute to water contamination and degradation (Emongor et al., 2005; Belay, 2013). Rivers and lakes serve as the primary sources of both drinking water and irrigation for agriculture, and they also play a crucial role in transportation, soil fertility maintenance, forest resource development, and wildlife conservation, as articulated by Sikder et al. (2013).

Moreover, Sumuk et al. (2001) and Gebrekidan et al. (2011) reported that inappropriate disposal of industrial effluents and other municipal wastes significantly contributes to poor water quality, adversely affecting numerous aquatic organisms; consequently, many rivers in urban centers of developing countries become the final destination for industrial effluents and municipal discharges. Despite this, regular monitoring of the physicochemical parameters of water bodies has been conducted for decades in various developed nations, as noted by Akan et al. (2008) and Ugwu et al. (2012). The assessment of overall water quality and dissolved metal concentrations in aquatic ecosystems has been extensively studied (Kido et al., 2009; Turekian, 1969). However, there exists a paucity of research regarding water quality and pollution status of rivers in developing countries (Belay, 2013; Akan et al., 2008).

Pindiga Lake serves predominantly as a vital source of drinking water and irrigation for the local populace. However, due to anthropogenic activities, numerous adverse impacts ensue on the abundance and distribution of aquatic macroinvertebrates, posing significant threats to the ecosystem and overall water quality. It is thus imperative to monitor the abundance of aquatic macroinvertebrates in relation to physicochemical parameters to maintain the ecological balance and water quality of the lake. The objective of this study is to determine the distribution and abundance of aquatic macroinvertebrates in relation to the physicochemical parameters of Pindiga Lake, situated in the Akko Local Government Area of Gombe State.

2. Materials and Method

2.1 Study Area

The study was conducted at Pindiga Lake, situated between latitude 10.13’150N and longitude 11.11’190E. The lake is approximately 1 km from Pindiga town (see Figure 3.1) within the Akko Local Government Area of Gombe State. Pindiga is located at a latitude of 9.98 and a longitude of 10.93, at an elevation of 523 meters above sea level. According to the 2006 census, the town has a population of 106,322, making it the second most populous town in the Akko Local Government Area of Gombe State.

2.2 Sampling Stations

For the purpose of this study, the lake was stratified into four sampling stations labeled A, B, C, and D, based on preliminary investigations conducted along the lake. The surrounding villages utilize the entire lake for various activities, including bathing, washing, livestock consumption, and water collection, encompassing all four sampling stations.

2.3 Water Sampling and Regime

Water samples were collected biweekly from each of the four sampling stations, and the mean values across these stations were calculated and recorded. The study was

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conducted from March to August 2019, with sampling occurring between 8 AM and 10 AM twice each month.

2.4 Determination of Physico-Chemical Parameters

Air Temperature

A bulb mercury thermometer was exposed to the air at each sampling station for approximately 1-2 minutes (Saidu et al., 2016), and the temperature reading was recorded in degrees Celsius (°C).

Water Temperature

A bulb mercury thermometer was employed in situ by submerging it in the water at each sampling station for around 1-2 minutes to ascertain the water temperature (Mohammed et al., 2017), with readings duly noted.

Water pH

To assess the pH levels of the water across all sampling stations, a pH meter was utilized by immersing it for 2-3 minutes in a beaker containing 100 ml of water from each station (Saidu et al., 2016), with readings recorded promptly.

Electrical Conductivity (EC)

An electrical conductivity meter was employed to measure the conductivity at all sampling stations. A wide-mouthed beaker containing the water sample was utilized, with the tip of the conductivity meter submerged for 2-3 minutes to allow for stable readings (Saidu et al., 2016).

Total Dissolved Solids (TDS)

A TDS meter was utilized to ascertain the total dissolved solids across all sampling stations. The tip of the TDS meter was immersed in a beaker containing 100 ml of water from each station for a duration of 2-3 minutes to ensure consistent readings (Saidu et al., 2016).

Turbidity

Turbidity measurements among the four sampling stations were conducted using a black and white Secchi disk (Isah et al., 2018). The disk was gradually lowered at each sampling station, and the depths at which it disappeared (X1) and reappeared (X2) were recorded, with averages estimated for both points.

Dissolved Oxygen

To determine the levels of dissolved oxygen at the four sampled stations, a Hanna Dissolved Oxygen microprocessor (HI 98186) was utilized. The electrode was submerged in a 100 ml beaker containing water from each station for 2-3 minutes (Isah et al., 2018), and the readings were recorded in parts per million (ppm).

Biochemical Oxygen Demand

The biochemical oxygen demand of the sampled water was also determined using the Hanna Dissolved Oxygen microprocessor (Isah et al., 2018). Water samples from each station (100 ml) were kept in a dark cupboard at room temperature and incubated for five days. After the incubation period, the difference between the initial and final oxygen demand values was recorded as the biochemical oxygen demand of the water samples.

Nitrate

Nitrate concentrations in the samples were assessed using the HACH multiparameter model DR900 colorimeter. Nitra ver. 5 nitrate reacto reagent was added to a 20 ml colorimeter vial containing the collected samples, which were then placed in the colorimeter compartment, covered, and allowed sufficient time for stable readings to be obtained (APHA, 2005). The resulting values were recorded in mg/l.

Phosphate

To measure phosphate concentrations across the four sampling stations, the HACH multiparameter model DR900 was employed. Armstrong reagent was added to the collected sample in a 20 ml colorimeter vial, which was then placed in the colorimeter compartment, covered, and allowed adequate time for stable readings (APHA, 2005). The resulting values were recorded in mg/l.

2.5 Aquatic Macroinvertebrates

Sampling

Aquatic macroinvertebrates were collected using an aquatic insect net with a mesh size of 55 µm, by sweeping horizontally and dragging in various directions at each of the four sampling stations. The collected samples were preserved in a 4% formalin solution and transported to the Gombe State University Biological Sciences Laboratory for subsequent sorting, identification, and enumeration.

Preservation

The collected samples of aquatic macroinvertebrates were transferred into transparent plastic bottles and preserved with a 4% formalin solution (Isah et al., 2018).

Transportation

The collected samples were transported in a cooler containing ice blocks to the laboratory for further analysis.

Labeling

The transparent bottles containing the collected aquatic macroinvertebrates were labeled with the date, time of sampling, study area, and the name of the sampling station

(A, B, C, or D) affixed prominently for further analysis (see Figure 3.6).

Sorting

Using hand gloves, each individual aquatic macroinvertebrate was sorted from the plastic bottles onto a white laboratory tray for enhanced identification.

Identification

The collected samples of aquatic macroinvertebrates from each station were identified through taxonomic classification based on their physical appearance and characteristics. A hand lens was utilized to identify the collected larvae and smaller organisms not visible to the naked eye.

Counting

The aquatic macroinvertebrates collected from each bottle were counted and recorded according to their respective stations for further analysis.

2.6 Statistical Analysis

Microsoft Excel software was employed to analyze the abundance and distribution of aquatic macroinvertebrates in the study area. To assess the species diversity of the collected aquatic macroinvertebrates, Simpson's biodiversity index was applied. The formula for Simpson's index is expressed as follows:."""

$$D = \frac{[\mathrm{n}(\mathrm{n}-1)]}{[\mathrm{N}(\mathrm{N}-1)]}$$

Where: n = the number of individuals in genera and

N = the total number of individuals.

To scrutinize the community structure, the Genera Richness Index (d) was utilized in accordance with the methodology established by Margalef (1958). The equation employed is delineated below:

$$D1 = \frac{(\mathrm{S}-1)}{(\mathrm{LogN})}$$

Where:D1 = Genera richness index
S = Number of Genera within a population
N = Total number of individuals across S genera.

A one-way analysis of variance was employed to ascertain the significant differences in mean physico-chemical characteristics among the sampling stations, while the least significant difference method was utilized to delineate the means where significant disparities were identified. In examining the correlation between physico-chemical parameters and the abundance and distribution of aquatic macroinvertebrates, correlation analysis was conducted at a significance level of P<0.05.

3. Results

3.1 Physico-chemical Characteristics

The analysis of the physico-chemical parameters across the four sampling stations in Pindiga Lake revealed no statistically significant variations (P≤0.05). As delineated in Table 1, the mean values for Air Temperature (34.45±1.29°C), Water Temperature (24.68±1.19°C), Water pH (7.32±0.51), Electrical Conductivity (296.10±9.35 µS/cm), Dissolved Oxygen (4.70±0.38 mg/l), Biochemical Oxygen Demand (2.39±0.24 mg/l), Nitrate (10.9±0.47 mg/l), and Phosphate (2.99±0.25 mg/l) all fell within acceptable limits, as the least significant differences exceeded the mean differences among the sampling stations.

Air Temperature

The lowest mean Air Temperature (32.13°C) was observed in August, while the highest mean (38.2°C) was recorded in March. However, it is noteworthy that almost all stations exhibited a comparable mean Air Temperature of 34°C, with the lowest value (34.15±1.4°C) documented at Station C and the highest value (34.94±1.12°C) at Station D, respectively. Water Temperature Although all four stations demonstrated nearly identical temperature readings as presented in Table 1, the lowest mean water temperature of 24.39±0.94°C was recorded at Station A. Notably, the lowest mean water temperature (21.38°C) occurred in June, while the highest water temperature (28.88°C) was observed in March, as detailed in the data. Water pH The lowest pH value (7.07) was recorded in March, whereas the highest (7.49) was noted in August, as illustrated in Figure 2. However, analysis of the standard error of the mean indicates that there was no statistically significant difference at P<0.05 among the sampling stations, as the least significant difference exceeded the variations between the means, as presented in Table 1. Electrical Conductivity The lowest Electrical Conductivity (264.5 µm/S) was recorded in July, while the highest value (321.25 µm/S) was noted in April (Figure 3). The highest mean value of 300.25±10.4 µm/S was observed at Station B, in contrast to the lowest mean value of 292.08±8.8 µm/S recorded at Station D, as revealed in Table 1.

Total Dissolved Solids

As presented in Table 1, the highest Total Dissolved Solids Mean value (150.13±5.2mg/l) was recorded in Station B and the least value (146.04±4.4mg/l) was recorded in Station D. Nevertheless, the Total Dissolved Solids mean value was observed to have recorded the highest value (160.63mg/l) in April while in July the lowest value (132.25mg/l) was recorded as presented in Figure 4

Table 1: Average Values of Physico-Chemical Characteristics Across the Four Sampling Stations in Pindiga Lake, Gombe State, Nigeria.

Stations	AT	WT	Water pH	EC	TDS
Station A	34.24±1.24[a]	24.39±0.94[a]	7.31±0.9[a]	298.8±8.81[a]	149.67±4.5[a]
Station B	34.48±1.3[a]	24.91±1.2[a]	7.45±0.06[a]	300.25±10.4[a]	150.13±5.2[a]
Station C	34.15±1.4[a]	24.95±1.3[a]	7.28±0.08[a]	293.83±9.4[a]	146.92±4.7[a]
Station D	34.94±1.21[a]	24.95±1.28[a]	7.24±1.0[a]	292.08±8.8[a]	146.04±4.4[a]
Mean	34.45±1.29[a]	24.68±1.19[a]	7.32±0.51[a]	296.10±9.35[a]	148.19±4.7[a]
LSD Value	2.037	3.74	2.09	73.93	29.48
Stations	Turbidity	DO	BOD	Nitrate	Phosphate
Station A	20.33±1.34[a]	4.88±0.29[a]	2.33±0.21[a]	9.16±0.7[a]	2.86±0.19[a]
Station B	18.5±0.9[a]	4.5±0.54[a]	2.23±0.29[a]	10.46±0.4[4]	2.99±0.2[a]
Station C	19.8±0.72[a]	4.63±0 .42[a]	2.35±0.26[a]	10.23±0.35[a]	3.10±0.18[a]
Station D	21.0±0.58[a]	4.78±0.26[a]	2.64±0.24[a]	10.49±0.39[a]	2.99±0.25[a]
Mean	19.9±0.89[a]	4.70±0.38[a]	2.39±0.24[a]	10.09±0.47[a]	2.99±0.25[a]
LSD Value	7.19	3.05	2.27	3.74	1.59

AT = Air Temperature. WT = Water Temperature. EC = Electrical Conductivity TDS = Total Dissolved Solids. DO = Dissolved Oxygen. BOD = Biochemical Oxygen Demand

Turbidity

Turbidity was observed to have recorded lowest value (16.88) in the month of May and the highest value (22.75) was recorded in March as revealed by figure 4.6. however, Table 1 presented the highest Turbidity mean value of 21.0±0.50 at Station D and the lowest mean value of 18.5±0.9 at Station B.

Dissolved Oxygen

In Table 1 Dissolved Oxygen was observed to have the highest mean value (4.88±0.29mg/l) at Station A and the lowest mean value (4.50±0.54mg/l) at Station B. However, 3.6mg/l was the lowest value recorded in the month of March while the highest value of 5.7mg/l was recorded in August as presented in figure 4.7 **Biochemical Oxygen Demand**

The highest mean value of 2.64±0.29mg/l was recorded in Station D and the lowest mean value of 2.23±0.29mg/l was recorded in Station B (Table 4.1). However, the highest Biochemical Oxygen Demand value of 3.18mg/l was recorded in the month of July while the lowest value of 1.89mg/l was observed to have been recorded in March

Nitrate

The highest mean value of 10.49±0.39mg/l was recorded in Station D and the lowest mean value of 9.16±0.7mg/l was recorded in Station A as revealed by Table 1. However, Figure 4.8 revealed the highest Nitrate mean value of 10.98mg/l in the month of May while the lowest mean value of 8.79mg/l was recorded in July.

Phosphate

Table 1 revealed the highest mean value (3,10±0.1mg/l) of phosphate in Station C while the lowest value (2.86±0.19mg/l) was recorded in Station A. The highest mean value of 4.1mg/l however, was recorded in the month of August while in March, the lowest mean value of 2.4mg/l of phosphate was recorded

Aquatic Macroinvertebrates distribution and abundance in Pindiga lake, Gombe State, Nigeria.

A total of 200 individuals' aquatic macroinvertebrates comprising of nine different species among the five orders of: Odonata, Decapoda, Plecoptera, Diptera and Trichoptera were recorded during the study period. Order Diptera were the most abundant taxon comprising of 74% of the total aquatic macroinvertebrates discovered during the period of this study. The order Odonata and Plecoptera comprises 11% each of the total macroinvertebrates discovered during the period under review. Also, the study revealed 3.5% and 0.5% abundance of the order Decapoda and Trichoptera respectively. However, in Station A, 20 individual macroinvertebrates, comprising 6 different species out of four Orders were discovered. In Station B, 15 individual Macroinvertebrates were observed comprising of six different species out of four Orders and in Station C 101 individuals were recorded comprising five species out of five Orders while in Station D, 64 individuals were observed comprising five species out of four Orders as presented in Table 2.

However, the Simpson species diversity index for the five Aquatic Macroinvertebrates taxa of Odonata, Decapoda, Plecoptera, Diptera and Trichoptera were: 0.012, 0.0011, 0.012, 0.055 and 0.00 respectively (Table 3) while the Margalef index of genera richness of Odonata, Decapoda, Plecoptera, Diptera and Trichoptera were: 0.434, 0, 0, 1.3 and 0 respectively.

Table 2: Checklist of the Aquatic Macroinvertebrates' abundance in Pindiga lake, Gombe State, Nigeria.

Aquatic Macroinvertebrates Taxa	Station A	Station B	Station C	Station D	Total
Odonata					
Zygoptera	1	4	0	1	6
Anisoptera	4	4	3	5	16
Decapoda					
Gastropoda	3	0	2	2	7
Plecoptera					
Stoneflies	9	3	6	4	22
Diptera					
Trueflies	1	1	0	0	2
Culicidae	0	2	89	52	143
Tipulidae	1	0	0	0	1
Cerotopogonidae	1	0	1	0	2
Trichoptera					
Hydropsychidae	0	1	0	0	1
Grand Total	20	15	101	64	200

3.2 Relationship among the Physico-chemical Characteristics

The correlation matrix showing the relationship among the physico-chemical characteristics of the study area is presented in Table 3. It was observed that, Water pH, Dissolved Oxygen, Biochemical Oxygen Demand and Phosphate correlated negatively to Air Temperature while Water Temperature, Electrical conductivity, Total Dissolved Solids and Turbidity correlated positively with Air Temperature. Also, Water Temperature correlated negatively with Water pH, Dissolved Oxygen, Biochemical Oxygen Demand and Phosphate whereas, Water pH correlated negatively with Turbidity and positively correlated to Biochemical Oxygen Demand, Nitrate and Phosphate.

However, it was also observed that, the Electrical Conductivity correlated highly positively to Total Dissolved Solids while highly negatively correlated to Dissolved Oxygen and the correlation between Nitrate and Phosphate is also observed to have been highly positive during the period of the study.

Table 3: Simpson and Margalef index of Aquatic Macroinvertebrates abundance in Pindiga lake, Gombe State, Nigeria.

Aquatic Macroinvertebrates	Station A	Station B	Station C	Station D	Total	Simpson	Margalef
Odonata	5	8	3	6	22 11%	0.012	0.434
Decapoda	3	0	2	2	7 3.50%	0.0011	0
Plecoptera	9	3	6	4	22 11%	0.012	0
Diptera	3	3	90	52	148 74%	0.55	1.3
Trichoptera	0	1	0	0	1 0.50%	0	0
Total	20	15	101	64	200		
Genera number	4	4	4	4			
Distribution (%)	10	7.5	50.5	32	100		

3.3 Relationship between Physico-chemical Characteristics and Aquatic Macroinvertebrates' Abundance in Pindiga Lake, Gombe State, Nigeria.

Order Odonata

Figure 3 illustrates the correlation between the abundance of aquatic macroinvertebrates and various physico-chemical characteristics within the study area. The Order Odonata exhibits a pronounced negative correlation with Air Temperature, Water Temperature, Electrical Conductivity, and Total Dissolved Solids. Conversely, the correlation between Odonata and Nitrate is negligibly negative. In stark contrast, the relationships between Dissolved Oxygen, Biochemical Oxygen Demand, and Phosphate with Odonata are markedly positive, whereas pH and Turbidity demonstrate a minimal positive correlation with the Order Odonata throughout this investigation.

Order Decapoda

The correlation between the order Decapoda and air temperature, water temperature, and turbidity is markedly positive, whereas electrical conductivity and total dissolved solids exhibit a positive correlation with the order Decapoda, albeit with negligible values, as illustrated in Figure 1. Conversely, phosphate, nitrate, and pH demonstrate a negative correlation with Odonata, while their relationship with dissolved oxygen and biochemical oxygen demand is significantly negative, according to this study.

Order Plecoptera

The correlation between the order Plecoptera and air temperature, electrical conductivity, total dissolved solids, turbidity, biochemical oxygen demand, and phosphate is negligibly positive. In contrast, nitrate, dissolved oxygen, pH, and water temperature exhibit a negative correlation with Plecoptera, also characterized by negligible values, as presented in Figure 1.

Order Diptera

The correlation between the order Diptera and pH, as well as electrical conductivity, is highly positive. Meanwhile, air temperature, water temperature, total dissolved solids, and nitrate show a positive correlation with the order Odonata, though with negligible values. However, turbidity is highly negatively correlated with Odonata, while its correlation with biochemical oxygen demand and phosphate is negligibly negative, as demonstrated in Figure 4.16.

Order Trichoptera

The order Trichoptera exhibits a strong positive correlation with phosphate, biochemical oxygen demand, dissolved oxygen, and pH, while its correlation with nitrate and turbidity is weakly positive. Conversely, the relationship of Trichoptera with air temperature, electrical conductivity, total dissolved solids, and nitrate is negligibly negative, yet it demonstrates a significant negative correlation with water temperature, as shown in Figure 1

Table 4: Correlation matrix showing relationship among the Physico-chemical characteristics in Pindiga lake Gombe State, Nigeria

	Air Temp	Water T.	pH	E.C	TDS	Turbidity	DO	BOD	NO3	PO4
Air Temp	1									
Water T.	0.98*	1								
Water pH	-0.14	-0.31	1							
E.C.	0.84*	0.7*	0.32	1						
TDS	0.84*	0.71*	0.31	0.99*	1					
Turbidity	0.14	0.21	-0.64*	-0.11	-0.1	1				
DO	-0.95*	-0.95*	0.35	-0.71*	0.72*	-0.19	1			
BOD	-0.89*	-0.85*	0	-0.75*	0.76*	0.06	0.19	1		
Nitrate	0.25	0.06	0.9*	0.68*	0.68*	-0.42	-0.02	0.28	1	
PO3	-0.29	-0.44	0.64*	0.17	0.17	0.05	0.49	0.41	0.66*	1

Note: Correlations with asterisk implies significance at $P<0.05$

4 Discussion

4.1 Physico-chemical Parameters

The elevated mean values of air temperature recorded in May during this study can be attributed to the prevailing vegetation cover at that time and the atmospheric conditions preceding the onset of the rainy season. Conversely, the peak values observed in March may be a consequence of the intense heat characteristic of the dry season. Water temperature was notably higher in March, April, and May, which could elucidate the diminished number of individual macroinvertebrates identified across all sampling stations compared to the months of June, July, and August. This assertion aligns with the findings of Pelczar and Noel (2005), who noted that the temperature of aquatic environments significantly influences the proliferation and survival of aquatic organisms, as well as the solubility of gases and salts.

Nevertheless, the study revealed a low pH in March, potentially due to the concentration of acid-forming chemicals such as phosphate and nitrate during that period. pH serves a crucial role in determining water quality, as it influences the solubility and toxicity of various chemicals. In concordance with Fakayode's (2005) assertion that "freshwater with pH ranges of 6.0 - 9.0 has been noted to be productive and suitable for fish culture," this study demonstrated an average pH of approximately 7 across all sampling stations, rendering Pindiga Lake conducive for fish cultivation based on its pH value.

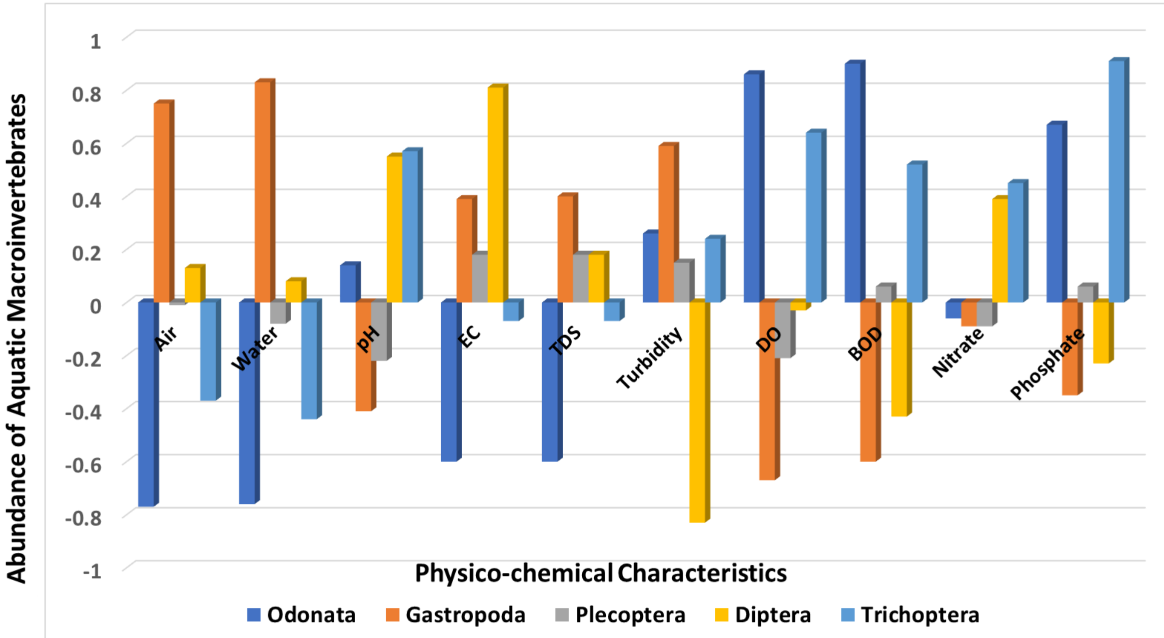

Figure 2: Relationship between Physico-chemical characteristics and Aquatic Macroinvertebrates' abundance in Pindiga lake Gombe State, Nigeria.

The heightened turbidity values observed in July and August across all sampling stations may be ascribed to the influx of turbid floodwaters from nearby streams, channels, and runoff into the lake, which in turn diminishes light penetration within the water body. This phenomenon may also stem from the prevalence of heavy cloud cover during the rainy season, further impeding light penetration.

These findings resonate with the reports of Ugwumba and Ugwumba (1993), Koloanda and Oladimeji (2004), and Ayoade et al. (2006), who investigated various man-made water bodies. The highest mean concentrations of phosphate and nitrate recorded in August across all sampling stations during this study are likely attributable to runoff or flooding during the rainy season, a finding corroborated by Ibrahim et al. (2009) and Patil et al. (2011). The peak concentrations of dissolved oxygen observed during this study in June, July, and August, contrasted with the lower concentrations recorded in March, April, and May, could be linked to the aeration of the lake during the rainy season and the elevated temperatures during the dry season, which consequently reduce the oxygen concentration in the lake. Similar observations have been reported by Mason (1990), Idowu and Ugwumba (2005), Ikomi et al. (2005), and Chakraborty et al. (2013).

Conversely, the diminished biochemical oxygen demand recorded in March and April during this study may result from increased water temperatures and the subsequent rise in the metabolic rates of aquatic organisms during the majority of the dry season. This contradicts the observations made by Ayoola and Ajani (2009) and Idowu et al. (2013), who reported elevated rates of biochemical oxygen demand.

It was further observed throughout the study period that the mean values of total dissolved solids and conductivity in March and April were relatively elevated compared to those in July and August, a phenomenon likely attributable to lower water levels resulting from evaporation due to the intense heat associated with elevated temperatures.

4.2 Biological Parameters

This study observed a pronounced concentration of dragonflies at station B, potentially attributable to the rich vegetation present in the area. This finding aligns with the report by Fulan et al. (2010), which elucidated that the concentration of dragonflies is influenced by the type of vegetation within aquatic ecosystems, as alterations in marginal vegetation can significantly impact the species composition of dragonflies due to ecological overlap. Nevertheless, the Odonata species documented in this study exhibited a relatively widespread distribution across all sampling stations, suggesting that the study area accommodates both generalist and habitat specialist species. Consequently, the identified species may be classified as widespread generalists, capable of thriving throughout the entire lentic ecosystem, including open tracts of land where ephemeral water bodies are prevalent during the rainy season. This observation, however, contradicts the assertions made by Subramanian et al. (2008), which indicated that several Odonata species, such as Libellago lineata and Aciagrion hisopa, are confined to specific habitats.

Furthermore, while Fulan et al. (2008) noted that the distribution and abundance of Zygoptera were predominantly influenced by reed vegetation, and Anisoptera were largely affected by shade, the findings of this study revealed a preference for open tracts of land with minimal or absent shade among Anisoptera species, with 22 individuals recorded herein. In contrast, Ameen and Nessa (1985) documented twenty-three species of aquatic Hemiptera from ponds and lakes in and around Dhaka City, which starkly contrasts with the findings of this study that recorded zero Hemiptera species across the four sampling stations of Pindiga Lake. Additionally, the report by Khan et al. (1997), which noted the presence of larvae from thirty Chironomidae of the order Diptera in central, eastern, and southeastern Bangladesh, diverges from this study's findings, which highlighted an increased abundance of Culicidae at stations C and D, while Ceratopogonidae, Tipulidae, and Trueflies were distributed across stations A and B. The solitary species of Hydropsychidae from the order Trichoptera observed at Station B throughout the study period may be indicative of minimal anthropogenic activities in the vicinity, which likely mitigated environmental stress. This observation resonates with Armitage's (1983) assertion that Ephemeroptera, Plecoptera, and Trichoptera taxa are particularly sensitive to environmental stressors. The study observed a widespread distribution of Plecoptera across all sampling stations, which is inconsistent with their findings.

In agreement with the research conducted by Dinakar and Anbalagan (2006), which highlighted the anthropogenic impacts on aquatic insects in six streams of the southwestern Ghats of India, this study documented a complete absence of Trichoptera in stations A, C, and D, likely due to heightened anthropogenic pressures in those areas compared to station B, which exhibited comparatively lower anthropogenic influences. Thani and Phalaraksh (2008) investigated the diversity of aquatic insects and water quality in the Mekong River of Thailand, reporting that the highest diversity of aquatic insects was attributed to the order Ephemeroptera, Plecoptera, and Trichoptera (EPT taxa). This finding contradicts the present study, which recorded no Ephemeroptera throughout the study period across all sampled stations. However, the abundance of Plecoptera in all four sampling stations in this study is consistent with their findings, potentially validating the water quality of Pindiga Lake. Suhaila et al. (2014) also reported a high abundance of EPT taxa, which peaked during the wet season and remained elevated during the dry season (27°C) in the Tupah River, Kedah.

According to Wihazatul et al. (2011), Culicidae likely represent the most diverse and abundant group among all stream macroinvertebrates. This assertion is corroborated by this study's findings, which indicated that Diptera comprised over 70% of the total macroinvertebrates identified throughout the study period, with Culicidae species constituting more than 90% of the identified Diptera. The findings of this study stand in contrast to Pinder's (1986) report, which characterized the family Chironomidae as the most abundant group in freshwater communities in Thailand. Excluding the order Ephemeroptera, a variety of individuals from the orders Odonata, Decapoda, Diptera, and Plecoptera were recorded across nearly all four sampling stations, while Trichoptera was exclusively identified at station B.

It was also observed during the course of this study that the highest number of macroinvertebrate individuals (172), accounting for 86% of the total 200 individuals observed throughout the study period, were recorded during the months of March, April, May, and June, whereas the remaining individuals (28), constituting 14%, were noted during the peak rainy months of July and August. This observation aligns with the findings of Ohiokhioya et al. (2009), which indicated that the community composition of aquatic macroinvertebrates exhibits seasonal variability, characterized by a trend toward a declining proportion during the rainy season and an increasing proportion during the dry or low-water season.

The solitary species of Trichoptera observed during the study period in Pindiga Lake was identified in August, likely due to the heightened water volume in the lake during that time, which is consistent with the findings of Ghosh and Singh (2005), who noted that the daily abundance of adult Trichoptera reached a maximum in September. It is widely believed that the influence of the rainy season may enhance feeding opportunities and facilitate access to breeding sites, as well as meet the various ecological requirements conducive to the survival of macroinvertebrates within the aquatic ecosystem. Contrary to this assertion, however, of the seven gastropod species identified during this study, three were observed in March, while the remaining four were recorded at a rate of one per month, with the exception of July, during which no Gastropoda species were documented. Okafor (1990) posited that rainfall influences the quality of snail habitats, rendering them suitable or otherwise for molluscan populations and their abundance within aquatic environments. This observation is consistent with the findings of this study, which revealed a higher number of snails in March compared to the remaining months under review.

Moreover, the monthly pattern of snail abundance in this study aligns with the observations made by Obureke (1990), Okafor (1990), and Omudu and Iyough (2005). The pronounced distribution and abundance of snails recorded in this study during March may be ascribed to the availability of food, shelter, and oviposition sites. This finding corroborates the reports of Whitton (1975) and Omudu and Iyough (2005), who noted that water bodies abundant in organic and silt matter are known to support thriving populations of macroinvertebrates.

According to this study, temperature emerges as one of the most critical factors influencing the abundance and distribution of mollusks in Pindiga Lake, as the highest mean values for both air and water temperatures were recorded in March, coinciding with the peak number of snails observed. As documented by Arad et al. (1992, 1993), Okafor (1991), and Idowu et al. (2005), climate and microhabitats are the primary determinants of species resistance to desiccation, as well as the availability, distribution, and abundance of mollusks in freshwater environments. These factors were likewise observed to play a pivotal role in the distribution of snails in this study.

4.3 Correlation between Physico-chemical Parameters and Aquatic Macroinvertebrates' Abundance

As articulated by Martinez-Sanz et al. (2004) and Orwa et al. (2014), the variability in the functional organization of aquatic macroinvertebrate communities reflects alterations in physico-chemical characteristics, such as diminished dissolved oxygen concentration and the availability of food sources in certain streams in Ethiopia. This assertion aligns with the findings of the current study, wherein the abundance of Trichoptera and Odonata was augmented by elevated levels of nitrate and phosphate across all sampling stations. The EPT taxa exhibited a relative decline in response to increasing nutrient concentrations (Martinez-Sanz et al., 2004). Consistent with this observation, the present study revealed a decrease in the abundance of the Order Plecoptera concomitant with rising nutrient levels, whereas Trichoptera abundance exhibited an increase correlated with heightened nitrate concentrations, as illustrated in Figure 3.

During this investigation, it was noted that higher dissolved oxygen concentrations facilitated an increase in the abundance and distribution of the order Odonata across all sampling stations. Seshi-Kala (2012) elucidated that aquatic macroinvertebrates and microorganisms are dependent on dissolved oxygen, which is essential for their growth and reproductive success. Elevated biochemical oxygen demand signifies reduced dissolved oxygen levels; consequently, low oxygen concentrations induce stress, disease, stunted growth, and, in extreme cases, mortality. The oxygen requirements of freshwater macroinvertebrates vary among species. Organisms necessitating high concentrations of dissolved oxygen, such as mayfly nymphs, stonefly nymphs, and caddisfly larvae, tend to migrate away or perish under unfavorable conditions. Notably, the order Ephemeroptera was found to be entirely absent from all sampling stations throughout this study, while Plecoptera was observed in negligible quantities; conversely, Trichoptera abundance increased in relation to rising pH, nitrate, and phosphate levels, corroborating the findings of Martinez-Sanz et al. (2004). The elevation of nitrate and phosphate levels, leading to diminished dissolved oxygen, adversely affects the viability of certain macroinvertebrates, as evidenced in this study, which is consistent with the conclusions drawn by Martinez-Sanz et al. (2004). The absence of critical taxa such as Ephemeroptera across the sampling stations substantiates this explanation. In the polluted sites of water bodies, the heightened nutrient enrichment and organic loading result in the presence of only those organisms possessing specialized physiological and morphological adaptations, thereby agreeing with the report of Sultana and others.

5. Conclusion

The findings regarding the physico-chemical characteristics obtained in this study fall within the permissible thresholds for freshwater ecosystems and support the coexistence of benthic aquatic macroinvertebrates, thereby fostering enhanced productivity. The relatively low abundance of aquatic macroinvertebrates in Pindiga Lake, with a total of 200 individuals—of which 89, constituting 44.5%, are mosquito larvae, while the remaining 111, representing 55.5%, comprise other aquatic macroinvertebrates—indicates that the lake is experiencing considerable stress due to pollution from organic contaminants of anthropogenic origin by the surrounding community. Nonetheless, the observed distribution and abundance of aquatic macroinvertebrates may serve as a reliable indicator in characterizing the lake as a low-productivity ecosystem, possessing limited potential for comprehensive ecological studies. The 200 individual aquatic macroinvertebrates were categorized into nine genera across five orders: Odonata, Decapoda, Diptera, Plecoptera, and Trichoptera. Notably, the order Diptera, encompassing four genera—Culicidae, Tipulidae, Ceratopogonidae, and Trueflies—emerged as the predominant group, accounting for 74% of the total individuals, with the highest count of 101 individuals recorded at Station C. While the order Plecoptera exhibited negligible correlation with any physico-chemical parameters, Decapoda demonstrated a positive correlation with both air and water temperature, as well as turbidity, yet showed a negative correlation with dissolved oxygen and biochemical oxygen demand. Conversely, the order Odonata exhibited a negative correlation with temperature while positively correlating with dissolved oxygen, biochemical oxygen demand, and phosphate levels. Diptera displayed a strong positive correlation with electrical conductivity, coupled with a negative correlation to turbidity. Furthermore, Trichoptera was positively correlated with nitrate, phosphate, and pH, yet negatively correlated with temperature. This suggests a robust relationship between the physico-chemical characteristics of Pindiga Lake and the distribution and abundance of aquatic macroinvertebrates throughout the study period..

Authors contribution

Umar M. conceptualized the study, designed the methodology, and coordinated sample collection and laboratory analysis. Abbati contributed to data analysis, interpretation of results, and assisted in literature review and drafting of the manuscript. Umar, D.M. was responsible for supervision, referencing, and manuscript formatting.

Declaration of competing interest

The authors declare no competing interests.

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References

Ahmad, Md. K., Islam, S., Rahman, S., Haque, M. R., Islam, M. M. (2010). Heavy Metals in Water Sediment and Some Fishes of Buriganga River, Bangladesh. *International Journal of Environmental Resources.* 4(2): pp 321-332.

Akan, C., Abdulrahman, I., Oiman, A., Ogugbuaja, O. (2008) *European Journal of Science.* Res. (23) pp 122.

Altman, S. J., Parizek, R. R. (1995) *Journal of Environmental Quality* (24) pp 707.

Amarasinghe, F. P., Indrajith, N. G., Ariyasena, T. G. (1995). Physico-chemical characteristics of mosquito breeding habitat in an irrigation development area in Sri lanka, *Ceylon Journal of Biological Science,* volume 2, pp. 13-29

Ameen, M., Nessa, S. K. (1985). A preliminary identification key to the aquatic Hemiptera of Dhaka city. *Bangladesh Journal of Zoology.* 13(1): 49-60.

Antonio, T., Barros, M. (2001). Seasonality and relative abundance of Tabanidae (Diptera) captured on Horses in the Pantanal, Brazil. Mem. Inst. Oswaldo cruz. Rio de Janeiro.96(7) pp.917-923.

APHA (2005). Standard method for the examination of water and waste water", American Public Health Association, Washington D.C.

Arad, Z., Goldenberg, S. and Heller, J. (1992). Intraspecific variation in resistance to desiccation and climate gradients in the distribution of the land snails, *Xeropicta vestails, Journal of Zoology,* 226: pp. 643-656.

Arad, Z., Goldenberg, S. and Heller, J. (1993). Intraspecific variation in resistance to desiccation and climate gradients in the distribution of the land snails, *Trochoidae simulata*. *Journal of Zoology,* 229: pp. 249-265.

Araoye, P. A. and Owolabi, O. (2008). Some Changes in the Animals and Fish Species Composition due to the Construction of Kampe (Omi) Dam and irrigation project in Kogi State, Nigeria. *Nigerian Journal of pure and applied Sciences,* 20(1): pp. 1781-1789.

Arimoro, F. O., Ikomi, R.B., (2008). Ecological integrity of upper Warri River, Niger Delta using aquatic insects as bioindicators. Ecological Indicator (395) pp. 1-7.

Armitage, P. D. (1983). The effects of mine drainage and organic enrichment on benthos in the river Nent system, Northern Pennines. *Hydrobiology*. 74: pp. 119-128

Belay, A.; Sahile, S. (2013) World Environ. pp. 3-29.

Bilgin, S., Fidanbas, Z. U. C. (2011). Nutritional properties of crab (*Potamon potamios Olivier, 1804*) in the lake of Egirdir (Turkey). *Palistan Veterinary Journal,* (31) pp. 239-243.

Blair, D., Agatsuma, T., Wang, W. (2008). Chapter 3, Paragonimiasis. In: Murell, K. D., Fried, B. (Eds), Foodborne Parasitic Zoonoses. Springer, New York, pp. 117-150.

Blakely, T.J., Eikaas, H. S., Harding, J.S. (2014). The SingScore: A Macroinvertebrates Biotic Index for Assessing the Health of Singapore's Streams and Canals. *Raffles Bull. Zool.* (62) pp. 540-548

Bonada, N., Rieradevall, M., Prat, N. (2007). Macroinvertebrate community structure and biological traits related to flow permanence in a Mediterranean river network. *Hydrobiology*. (589) pp 91–106.

Carlson, P. E., Johnson, R. K., Mckie, B. G. (2013): Optimising stream bio assessment: habitat, season and the impacts of land use on benthic macroinvertebrates. – *Hydrobiologia.* (704) pp 363-373.

Chae, S.J., Purstela, N., Johnson, E., Derock, E.S., Lawler, P., Madigan, J.E. (2000). Infection of aquatic insects with trematode metacercariae carrying *Ehrilichia risticii*, the case of the Potomac house fever. *Journal of Medical Entomology* (37) pp 619-625

Cover, M. R., Resh, V. H. (2008). Global diversity of dobsonflies, fishflies, and alderflies (Magaloptera; Insecta) and spongillaflies, nevrorthids and osmylids (Neuroptera: Insecta) in freshwater. *Hydrobiologia.*595(1) pp 409-417.

Cumberlidge, N., Fenolio, D. B., Walvoord, M. E., Stout, J. (2005). Tree climbing crabs (Potamonautidae and Sesarmidae) from phytotelmic microhabitats in rainforest canopy in Madagascar. *Journal of Crustaceans Biology.* (25) pp 302-308.

Darwall, W., Smith, K., Lowe, T., Vie, J. C. (2005). The Status and Distribution of Freshwater Biodiversity in Eastern Africa. IUCN SSC Freshwater Assessment Programme.

DeGrandpre, M. D. (1993). Measurement of seawater pCO_2 using a renewable-reagent fiber optic sensor with colorimetric detection, Analytical Chemistry. (65), pp 331-337.

Dinakar, S., Anbalagan, S. (2006). Seasonal variation and substrate selection of aquatic insects in a small stream Sirumalai hills of southern western Ghats. *Journal of Aquatic Biology.* 21: pp. 37-42.

deMoor, F. C., Ivanov, V. D., 2008. Global diversity of caddisflies (Trichoptera: Insecta) in freshwater, *Hydrobiologia,* (595) pp 393-407

Dickson, A., Goyet, C. (1994). DOE Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water, Version 2.

Dobson, M. K., Magana, A. M., Lancaster, J., Mathooko, J. M. (2007). A seasonality in the abundance and life history of an ecologically dominant freshwater crab in rift Valley, Kenya. Freshwater Biology (52). pp 215-225.

Dudgeon, D., Arnthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Leveque, C., Naiman, R. J., Pricur-Richard, A. H., Soto, D., Stassny, M. L. J., Sullivan, C. A. (2016): Freshwater biodiversity: importance, threat, status and conservation challenges. – Biol. Rev. (81) pp 163-182.

Emongor, V., Kealotswe, E., Koorapetse, I., Sankwasa, S., Keikanetswe, S. (2005). *Journal of Applied Science.* (5) pp 147.

Fakayode, S. O. (2005). Impact of industrial effluents on water quality of the receiving Alaro River in Ibadan, Nigeria.

Fakayode, S.O., Ajeam-Ragee, (2005). 10, 1. Gebrekidan, M., Samuel, Z., *Momona Ethiopian Journal of Science.*2011, (3) pp 105.

Fulan, J. A., Raimundo, R., Figueiredo, D. (2008). Habitat Characteristics and Dragonflies (Odonata) Diversity and Abundance in the Guadiana River, eastern of the Alentejo, Portugal, Boln. Asoc. esp. Ent.32(3-4), 327-340.

Fulan, J. A., Raimundo, R., Figueiredo, D., Correia, M. (2010). Abundance and diversity of dragonflies four years after the construction of a reservoir. Limnetica,29(2) pp. 279-286.

Galloway, J. N., Dentener, F. J., Capone, D. G. (2004): Nitrogen cycles: past, present and future fruit present and future, - Royal Hortic. Soc. 153-226.

Ghosh, M., Singh, S. P. (2005). Review on phytoremediation of heavy metals and utilization of its byproducts, *Journal of Applied Ecology.* 3(1): pp. 1-8.

Gran, G., (1952), Determination of the equivalence point in potentiometric titrations. Part II. Analyst, 77, pp 661-671.

Grimaldi, D. and Engel, M. S. (2005). Evolution of the Insects. Cambridge University press, New York.

Gupta, D. P., Sunita, J. P. (2009). Physiochemical Analysis of Ground Water of Selected Area of Kaithal City (Haryana) India. Researcher. 1(1), pp 1-5.

Gunathilaka, N., Fernando, T., Hapugoda, M., Wickremasinghe, R., Wijeyerathne, P. and Abeyewickreme, W. (2013). Anopheles culicifacies breeding in polluted water bodies in Trincomalee District of Sri lanka, *Malaria Journal,* volume 12(1), article 285.

Gunathilaka, N., Karunaraj, P. (2015). Identification of Sibling species status of Anopheles culicifacies breeding in polluted water bodies in Trincomslee district of Sri lanka, *Malaria Journal,* volume 14(1), article ID 214.

Hepp, L.U., Restello, R.M. & Milesi, S.V. (2013). Distribution of aquatic Insects in Urban Headwater Streams. Acta Limnologica Brasiliensia25(1): pp 1-9.

Hopkinson, C.S., (1985). Shallow-water and pelagic metabolism: Evidence of heterotrophy in the near-shore Georgia Bight, Marine Biology, 87, pp 19.

Idowu, R. T., Inyang, N. M. and Mgbenka, B. O. (2005). Macroinvertebrates studies of the littoral region in an arid Zone Lake Alau, Maiduguri, Borno State. Pecop Resources, 11: pp. 13-18.

Inoue, K. (2004). Critical Species of Odonata in Japan. In Clausnitzer, V., Jodicke, R. (eds), Guardians of the Watershed. Global Status of Dragonflies: Critical Species, Threat and Conservation. *International Journal of Odonatology,* 7: 311-324

Isah, Z., Abubakar, K.A., Umar, D. M and Hassan, S. K. (2018): a study on phytoplanktonic composition in Dadinkowa Dam, Gombe State, Nigeria. *General Journal of Biological Sciences* 8(2): 45-50.

Khan, M. A. G., Rahman, M., Islam, S. (1997). Chironomid larvae of central-east and south-east, Bangladesh-keys and diagnosis with notes on ecology and distribution. *Bangladesh Journal of Zoology.* 25(1) pp. 29-46.

Karanth, K. R., (1987). Groundwater Assessment Development and Management Tata McGraw Hill publishing company Ltd., New Delhi, pp 725-726.

Kataria, H. C., Quershi, H. A., Iqbal, S. A. and Shandilya, A. K. (1996), Assessment of water quality of Kolar reservoir in Bhopal (M.P.). Pollution Research. 15(2), pp 191-193

Khan, M.Y., Shabeer, M., Raja, I.A., Wani, N.A. (2012). *Global Journal of Science Front. Res. Interdisciplinary*, pp 12

Kido, M., Yustiawati, M., Syawal, S., Hosokawa, T., Tanaka, S., Saito, T., Iwakuma, T., Kurasaki, M. (2009). Environmental Monitoring Assessment. pp 156, 317.

Krishnamurthy, R., (1990), Hydro-biological studies of Wohar reservoir Aurangabad (Maharashtra State) India, *Journal of Environmental Biology*, 11(3), pp 335-343.

Kristensen, N. P., (1991). Phylogeny of extant hexapods. Pages 125-140 in CSIRO (editors). The Insects of Australia. Cornell University Press. Ithaca.

Lenat, D. R., (1993). Abiotic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality ratings, *Journal of the North American Benthological Society,* 12: pp 279-290.

Mackay, R. J. and Wiggins, G. B., (1979). Ecological diversity in Trichoptera. Ann. Rev. Entomol., 24: pp 185-208.

Margalef, R. (1958). Temporal succession and spatial heterogeneity in phytoplankton. In: Buzzati-Traverso, A. (ed) Perspective in Marine Biology. CA, University of California Press, Princeton, New York. pp. 179.

Maleewong, W. (2003). Paragonimus species. In: Milotis, M. D., Bier, J. W. (Eds), Internatinal Handbook of foodborne Pathogens. Mercel Dekker, Inc, Newyork, pp. 601-611.

Martinez-Sanz, C., Puente-Garcia, S. M., Rebolled, E. R., Jimenez-Prado, P. (2014). Macroinvertebrates richness importance in coastal tropical streams of Esmeraldas (Equador) and its uses and implications in environmental management procedures. *International Journal of Ecology.* 2014; pp 253-263.

Merritt, R.W. & Cummins, K.W. (1996). Aquatic Insects of the North America. Dubuque: Kendall Hunt Publishing Company.

Mohammed, S., Mosses, N., Saidu, H., Galadima, A. L., Umar, D. M., Abubakar, K. A., Kefas, S. and Billah, C. (2017). Determination of Physico-chemical parameters and riparian land effect on Kwadon stream, *Journal of advanced research design* 36(1):13-24

Mohiuddin, K.M., Ogaway, Z.H., Otomo, K. and Shikazono, N. (2011). Heavy metals contamination in water and sediments of an urban river in a developing country. *International Journal of Environmental Science Technology.*8: pp 723-736.

Murphy, D. H. (1997). Odonata biodiversity in the Nature Reserves of Singapore. Gard. Bull. Singapore 49(2): pp 333-352

Narangarvuu, D., Hsu, C. B., Shieh, S. H., Wuc, F. C., Yang, P. S. (2014): Macroinvertebrates assemblage patterns as indicators of water quality in the Xindian watershed, Taiwan. – *Journal of Asia-pacific Entomology* 17: pp 505-513.

National Population Commission (2016). Nigerian National Population Census, a document of the federal ministry of Interior, Abuja, Nigeria.

Navneet, Kumar, D. K. Sinha, (2010), Drinking water quality management through correlation studies among various physicochemical parameters: A case study, *International Journal of Environmental Sciences,*1(2), pp 253-259.

N'Diaye, A. D., El Kory, M. B., Sid, M. O., Kankou, A. O. (2013). Study of water quality during rainy season using Physico-chemical and Metallic Parameters of Senegal River in Mauritania. *Science Africa Journal of Scientific issues, Research and Essay.* 1(1): pp. 1-10.

Ng, P. K. L., Corlett, R. T. & Tan, H. T. W. (eds) (2011). Singapore biodiversity: an encyclopedia of the natural environment and sustainable development. Singapore: Editions Didier Millet.

Ngiam, R. W. J. & Cheong, L. F. (2016). The dragonflies of Singapore: An updated checklist and revision of the national conservation statuses. Nat. Singapore9: 149-163.

Norma-Rashid, Y., Cheong, L. F., Lua, H. K. & Murphy, D. H. (2008). The dragonflies (Odonata) of Singapore: Current status record and collections of the Raffles Museum of Biodiversity Research. Singapore: Raffles Museum of Biological Research, Department of Biological Sciences, National University of Singapore.

Obureke, G. T. (1980). Studies on the feeding biology anatomical variation and ecology of vector of Schistotosomiasis and other freshwater Snails in southwestern Nigeria. PhD Thesis, University of Ibadan. pp. 370.

Ohiokhioya, T., Imboobe, T., Ohiozebae, E. (2009). Pollution status of a trophicak forest river using aquatic insects as indicators. *African Journal of Ecology.* 48(1): pp. 232-238.

Okafor, F. C. (1990). *Schistosoma haematobium* cercariae transmission pattern in Freshwater system of Anambra State Nigeria, Angewandle, 31: pp. 159-166.

Okafor, F. C. (1991). The effect of temperature on embroyonic development and reproduction of Bulinus (Physopsts), globosus (Morelet) and Limnae natalensis (Krauss) (Gastropoda, Pulmonate). *Journal of Aquatic Science,* 6: pp. 7-11.

Okogun, G. R. R. (2005). Life-table analysis of Anopheles malaria vectors: generational mortality as tool in mosquito vector abundance and control studies, *Journal of Vector Borne Diseases,* volume 42(2) pp.45-53.

Omudu, E. A. and Iyough, A. (2005). Ecological Studies of the Gastropod fauna of some minor tributaries of River fauna. Makurdi, *Nigeria Animal Research International,* 2: pp. 306-310.

Orwa, P. O., Omondi, R., Okuku, E., Ojwang, W., Njuguna, S. M. (2014). Composition, abundance and feeding guilds of macroinvertebrates in Lake Kenyatta, Kenya. *International Journal of Environmental Monitoring Anal:* 2: 269-279. pp 468.

Ott, J. (2011). Expansion of Mediterranean Odonata on Germany and Europe: consequences of climate change. In Walther, G. R., Burga, C. A., Edwards, P. J. (eds), 'Fingerprints' of climate change: Adapted behavior and shifted species ranges. Kluwer academic/Plenum publishers, New York, Boston, Dordrecht, London, Moscow: pp. 89-111.

Pelczar, M., Noel, R. (2005). Microbiology. New Delhi, India: Tala McGraw Hill Publishing Company.

Pennak, W.R. (1978). Fresh-water Invertebrates of United States. New York: Willy-Interscience Publishing.

Premlata, V. (2009). Multivariant analysis of drinking water quality parameters of lake Pichhola in Udaipur, India. Biological Forum, Biological Forum- *An International Journal,* 1(2), pp 97-102.

Rinaudo, M. (2006). Chitin and Chitosan: properties and application, Progress in polymer science31, pp 603-652.Romoser, W. S. & Stoffolano, J. G. (1994). The science of entomology. Dubuque: Wm. C. Brown Publishers.

Saidu, H., Usman, B. and Umar D. M. (2016): Studies of Species Distribution for Phytoplankton in Balanga Dam, *Journal of Advanced Research in Applied Sciences and Engeneering Technology,* 3(1)1943-2462.

Sahlen, G. R., Bernard, A. C., Rivera, R. K., Suhling, F. (2004). Critical Species of Odonata in Europe. In Clausnitzer, V. and Jodicke, R. (eds): Guardians of thewatershed. Global status of Dragonflies: Critical Species, threat and conservation. *International Journal of odonatology* 7:385-398.

Sikder, M.T.; Kihara, Y.; Yasuda, M.; Yustiawati; Mihara, Y.; Tanaka, S.; Odgerel, D.; Mijiddorj, B.; Syawal, S.M.; Hosokawa, T.; Saito, T.; Kurasaki, M. (2013). Clean Soil Air Water, pp 41: 60.

Subramanian, K. A., Ali, S., Ramachandra, T. V. (2008). Odonatan as Indicators of Riparian Ecosystem Health, A case study from south western Karnataka, India. *Fraseria* (N.S.) 7, Proceedings of the 18th International Symposium of Odonatology, pp 83-95.

Suhaila A. H., Che S. M. R., and Nurul H. A. (2014). Seasonal Abundance and Diversity of Aquatic Insects in Rivers in Gunung Jerai Forest Reserve, Malaysia. Sains Malaysiana, 43(5): pp 667–674.

Sultana, R., Seshi-Kala, D. (2012). Water body quality analysis by benthic macroinvertebrates. *International Journal of Pharmaceutical Biological Science.* (20): 269-279

Sumok, P. (2001). River Water Quality Monitoring: Sharing Sarawak Experience, 6th Sabah 21 Inter- Agency Tropical Ecosystem (SITE) Research Seminar, Proceedings, Kota 22 Kinabalu, Malaysia, pp 4.

Suthar, S., Sharma, J., Chabukdhara, M., and Nema, A.K. (2010). Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater. *Environmental Monitoring and Assessment*. 165: pp 103-112.

Tang, H. B., Wang, L. K. & Hamalainen, M. (2010). *A photographic guide to the dragonflies of Singapore.* Singapore: Raffles Museum of Biodiversity Research, Department of Biological Sciences, National University of Singapore.

Tran, A. D., Yang, C. M. & Cheng, L. (eds) (2015). *Water bugs of Singapore and Peninsular Malaysia.* Singapore: Lee kong Chian Natural History Museum.

Thani, I., Phalarakash, C. (2008). A preliminary study of aquatic insects' diversity and water quality of Mekong River, Thailand. *KKU Science Journal.*36 (Supplement): pp. 95-106

Turekian, K. K. (2012) *The Oceans, Streams and Atmosphere*, Springer: Berlin; 1969,

Ugwu, A.; Wakawa, R. *Journal of Environmental Sciences.*2012, pp 8, 569.

Vadeboncoeur, V., Vanderzanden, M.J. and D.M Lodge. (2002) putting it all together. Reintegrating benthic pathways into lake food web models. *Bioscience* 52: pp 1-11.

Wahizatul, A. A., Long, S. H., Ahmad, A. (2011). Composition and distribution of aquatic insects' communities in relation to water quality in two freshwater streams of Hulu Terengganu. *Journal os Sustainability Science and Management.* 6(1): pp. 148-155

Wang, Z., Wang, Y. and Cai, W. J. and Liu, S. Y. (2002), A long lathlength spectrophotometric *p*CO2 sensor using a gas-permeable liquid-core waveguide, Talanta, 57, pp 69-80.

Westfall, M. J., May, M. L. (1996). Damselflies of the North America. Scientific Publishers, Gainesville.

Wiggins, G. B., (2004). Caddiesflies: The underwater Architects, University of Toronto Press, pp 292.

Whilhm, J. L. (1975). Biological Indicators of Pollution. pp. 375-403. In: WHTTON, B. A. (ed) Studies in River ecology, volume 1. Blackwell Scientific Publication, Oxford.

Yeo, D. C. J. & Chia, C. S. W. (2010) introduced species in Singapore: and overview COSMOS 6(1): pp 23-37.

Yeo, D. C. J., Ng, P. K. L. (2012). Sodhiana, A new genus of freshwater crab from south asia (Decapoda: Brachyura: Gecarcinucidae). *Raffles Bulletin of Zoology*25, pp 279-284.

Yeo, D. C. J., Ng, P. K. L., Cumberlidge, N., Magalhaes, C., Daniels, S. R., Campos, M. R. (2008). Global diversity of crabs (Crustacea: Decapoda: brachyura) in freshwater. *Hydrobiologia* 595, pp 275-286.

Yeo, D., Puniamoorthy, J., Ngiam, R. W. J. & Meier, R. (in press). Towards holomophology in entomology: rapid and cost-effective larval-adult marching using NGS barcodes. *System of Entomology.*

Yule, C.M. & Young, H.S. (eds). (2004). *Freshwater invertebrates of the Malaysian region.* Kuala Lumpur: Akademi sains Malaysia.

Zakir, H. M., Sharma, S. and Shikazono, N. (2006). Heavy metal pollution assessment in water and sediments of Turag river at Tongi area in Bangladesh. *International Journal of Lakes. Riv*. 1: pp 85-96.