ABSTRACT

Benthic aquatic insects receive the most direct impact when surface waters are perturbed. However, scarce data and understanding about activities’ effects on surface water ecosystems remain a critical challenge for water resource managers and policymakers in tropical regions. In this study, we surveyed the implications of deteriorating physical and chemical parameters on aquatic insects’ structural assemblage to ascertain the ecological health of River Hadejia in North-Western Nigerian. We sampled aquatic insects and physicochemical parameters in three stations influenced by various land-use activities such as informal settlements and agricultural activities for six months. The two-way analysis of variance (ANOVA) revealed physicochemical parameters such as transparency, depth, and nitrate were not significantly affected by sites’ land-use activities ($p > .05$) in the six months sampled. However, mean electrical conductivity was lowest in Station 3 (104.3 ± 8.04 μS/cm). Dissolved oxygen (DO), five days biochemical oxygen demand (BOD), values recorded portray a relatively perturbed water system. We recorded four aquatic insects orders belonging to 11 families and taxa. Dytiscus sp. was the most abundant taxon in the study area. A total of 44, 37, and 35 individuals of aquatic insects were recorded in stations 1, 2, and 3 in the river. The Post hoc test performed for all the diversity indices were not significantly different between the studied stations ($p > .05$). Canonical correspondence analysis (CCA) revealed poor relationship between the physicochemical parameters and the aquatic insects. However, Gyrinus sp. was positively affected by increased water depth, showing a strong negative association with depth. Cluster analysis revealed that aquatic insects’ assemblage structures were mainly grouped by temporal factors (months) rather than spatial differences between the sites. Overall, this study provides further insights and understanding regarding land-use impacts on the ecological health of the River Hadejia, and we recommend more stringent regulations to control human pressure on the river systems within the studied area to enable surface waters in the area to sustain the provision of desired and valued ecosystem services.

Introduction

When surface waters are perturbed, benthic aquatic insect communities are among the most directly affected (Lubanga, Manyala, Siati, Yegon, & Masese, 2021). Their distribution, diversity, abundance, and composition are often used in assessing the ecological status of aquatic habitats (Arimoro, Odume, Uhunoma, & Edegbene, 2015; Edegbene, 2020). Among the taxa used for monitoring water bodies, the Ephemeroptera, Plecoptera and Trichoptera (EPT) are frequently employed (Akama-gwuna et al., 2019a; Al-Zankana, Matheson, & Harper, 2020). The EPT groups of aquatic insects are termed to be pollution-sensitive species whose presence portrays relatively clean, unperturbed and/or mildly disturbed waters (Abebe et al., 2009; Eriksen et al., 2021; Feio et al., 2021; Yung-Chul et al., 2016). Aquatic insects are found almost in every aquatic habitat, including lakes, streams, highly saline pools, coastal waters and estuaries, groundwater, and hot springs (Yule & Yong, 2004). Because of their diverse sensitivities to deteriorating water quality, they respond differently to pollution resulting from human activities (Firmiano, Castro, Linares, & Callisto, 2021).

Most freshwater bodies in Nigeria, River Hadejia inclusive, have been subjected to increasing human disturbance, resulting in changes in the environmental variables, consequently affecting the structural and functional ecology of the freshwater systems (Garba, Ekanem, & Garba, 2017; Umara, Ramlib, Arisc, Jamilb, & Tukur, 2019). Hence, biomonitoring method that employs aquatic insects’ structural assemblage can provide us with good insights to environmental management of freshwater ecosystems, allowing us to make quality decision toward accurate
and justifiable actions regarding ecological status of freshwater ecosystems (Abowei & Sikoki, 2005; Asonye, Okolie, Okenwa, & Iwuanyanwu, 2007).

The pollution of freshwater bodies caused by domestic and industrial effluents is a common anthropogenic impact on watercourses globally, including freshwater ecosystems in Nigeria. Pollution modifies the physico-chemical properties of water, affecting aquatic insects community distribution in a given water body. Lately, River Hadejia has had its fair share of anthropogenic disturbances due to incessant defecation, washing, urination, dumping of refuse, and runoff of fertilizers from nearby farming settlements, among others. This pollution problem is exacerbated by high population growth occasion by migration from neighboring communities surrounding Hadejia. Hadejia town is the headquarter of one of the five Emirates in the Jigawa State of Nigeria, with a high rate of rural-urban migration due to its commercial state. The rural-urban migrations have implications on the ecological health of the river system and its constituent’s aquatic communities. For example, previous studies in the study area have reported severe deterioration of water quality in the Hadejia River system and the surrounding wetlands, with deleterious effects on aquatic biodiversity (Ahmed, Agodzo, Adjei, Deinmodei, & Ameso, 2018; Umar, Ramli, Aris, Jamil, & Abdulkareem, 2018; Umar et al., 2019). The degradation of ecological health and biodiversity of the river system because of human activities have affected the sustainable delivery of desired ecosystem services for livelihood and wellbeing, drawing us back from achieving the global goals of clean water and sanitation for all. Rural-urban migration has been reported to be increasing exponentially in sub-Saharan Africa (Edegbene, Arimoro, & Odume, 2019; Parienté, 2017), and such migratory activities grossly affect negatively the structural and functional assemblage and diversity of aquatic biota which include plankton, macroinvertebrate and fish (Gieswein, Hering, & Lorens, 2019). In this study, we aimed to ascertain the implication of deteriorating physical and chemical parameters on the aquatic insect structural assemblage to determine the health of the Hadejia River. This study is pertinent due to the continued anthropogenic disturbance along the River Hadejia catchments. The study will unravel the present health status of the river, enabling river managers and other appropriate authorities to manage the river sustainably.

**Materials and methods**

**The study area**

The River Hadejia is a tributary of the Yobe River situated in Jigawa State within the administrative boundaries of North-western part of Nigeria. The river and surrounding wetlands cover a catchment area of about 3500 km² at an altitude of 152–305 m above sea level (BirdLife International, 2016). The River Hadejia flows through major cities including Hadejia and Nguru with various land uses that lie on or near its banks (Abubakar, 2009), and as such, the river is in local municipality of Hadejia and its environs. It lies between

![Figure 1. Map of River Hadejia showing the sampled stations.](image-url)
latitude 12°27’12.49”N and longitude 10°02’28.14’’E in the north eastern corner of Jigawa State (Figure 1). The climate in the study area is semi-arid, with average annual rainfall ranging between 600 mm to 762 mm, and the humidity is range between 25-41% (Abubakar, 2009; Edegbene, 2020). The Hadejia area temperature varies substantially between 12°C in December and January, and 40°C in March and April. Geology of the area is underlined by rock and younger sediments of the Chad formation. Vegetation in the area falls within the Sudan Savannah with extensive open grassland and a few scattered trees (Abubakar, 2009).

**Sampling sites**

We selected three study sites from the study area, based on accessibility and human activities around the area (i.e. community location). Selected sites include Station 1 located at the Aguyaka community, Hadejia Local Municipal Area (Plate 1). Human activities include washing of clothes, bathing, and subsistence fishing. Farming is the major occupation of the populace here. The biotopes are characterized by sand and loamy soil. Station 2 was located in the Yan Wanki quarters in Hadejia Local Government (Plate 2). This station is about 2 km away from station 1. Human activities include agricultural activities, washing of clothes, bathing, and fishing. The substrates here are mainly loam and clay with a sparse distribution of stones and boulders. Whereas Station 3 was located in the Bakin Gada, which is very close to the bridge that connects Hadejia to Bulangu in Kafin Hausa Local Government Area of Jigawa State (Plate 3). This station is about 1 km away from Station 2. Subsistence fishing and cattle grazing are the main land uses in this station. Other land uses include, sand dredging, bathing, defecation and washing of cars, clothes, and other household. These activities represent the leading anthropogenic disturbance that affects this site.

**Physicochemical analysis**

We measured temperatures using mercury in a glass thermometer, whereas transparency was determined using Secchi disc with black and white paints. Depth was measured with a calibrated rod in centimeters. Three locations where strategically marked out for the measurement of water flow velocity by timing a float (average of three trials) as it moved over distance of 10 m; the flow velocity was computed by dividing the distance measurement by the time (Gordon, McMahon,

![Plate 1. Station 1 (Aguyaka community)](image1)

![Plate 2. Station 2 (Yan wanki quarters)](image2)
& Finlayson, 1994). We determined turbidity in nephelometric turbidity unit (NTU) and pH with the Portable Turbidity meter model WGZ-B and pH meter (HANNA HI 9828 multi-probe meter manufactured by HANNA instruments), respectively. On the other hand, we took electrical conductivity (EC), and total dissolved solids (TDS) readings with Conductivity meter DDSJ-308A. Dissolved oxygen (DO) in water, five days biochemical oxygen demand (BOD₅) and nutrient variables, including phosphate and nitrate were analyzed following APHA (American Public Health Association) (1998).

**Sampling of aquatic insects**

Aquatic insects sample collections were carried out early in the morning between the month of January and February then April to July 2018. Sampling was not done in March 2018 due to logistic problems. Kick net method techniques were employed for the collection of aquatic insects. The Kick net used in this collection is a square-shaped instrument with a long metal handle (Merritt & Cummins, 1998).

During sampling, the kick-net was inserted in the river at the littoral zone and approached by walking upstream to disturb the substrate for sample collection. Five kicks were done in each station on every sampling expedition. After kicking, each sample was placed inside a white enamel tray for sorting using forceps.

**Identification and preservation of the samples**

The specimens collected in the field were preserved in 10% formalin before being taken to the laboratory for identification and enumeration. In the laboratory, samples were placed in a slide and viewed using a binocular microscope for proper identification, following (Javier, David, & Rafael, 2011) pictorial guide. After which, voucher samples of the aquatic insects were preserved in 40% formalin for future reference.

**Data analyses**

We computed the descriptive statistics of physicochemical parameters, including range, mean and standard error for each station, and two-way analysis of variance (ANOVA) was used to test the level of significant differences between stations and months. We then further used post hoc (honestly significance difference; HSD) test to determine stations that differed from each other. The descriptive statistics, ANOVA and HSD, were calculated using the PAST statistical package (Hammer, Harper, & Ryan, 2001). The Structural-assemblage of aquatic insects was presented in a table. We used ANOVA to test the statistical significant differences in biological metrics, including abundance, number of taxa, Shannon diversity index, evenness, Simpson dominance, Margalef’s index between the sampled stations, and we used the post hoc HSD test to indicate metrics that differed statistically, and these tests were conducted in PAST software package (Hammer et al., 2001). Canonical correspondence analysis (CCA) evaluated the relationships between aquatic insect communities and analyzed environmental variables in PAST software package (Hammer et al., 2001). We log (x + 1) transformed physical and chemical parameters dataset used for the CCA model to prevent the undue influences of extreme values on the final CCA model. The statistical significance of the CCA model was revealed by a Monte Carlo permutation test at 999 permutations argument (Jckel, 1986). Cluster analysis based on Bray–Curtis similarity index ascertained if spatial (stations) or temporal (months) factors primarily influenced aquatic insects’ assemblage distribution in the study area.

We run cluster analysis on log (x + 1) transformed aquatic insect abundance data in PAST statistical package (Hammer et al., 2001).
Table 1. Summary of physical and chemical parameters measured at the study stations of River Hadejia.

| Variables                  | Station 1 | Station 2 | Station 3 | Stations | FEPA* | SON* |
|----------------------------|-----------|-----------|-----------|---------|-------|------|
| Air Temperature (°C)       | 28.5 ± 1.36 | 28.05 ± 1.69 | 27.92 ± 1.46 | 30.68 ± 9.30E-06 | 0.444 | 0.6531 |
| Water Temperature (°C)     | 26.0 ± 1.37 | 26.68 ± 1.44 | 25.41 ± 2.31 | 14.06 ± 0.0003 | 0.69 | 0.52 |
| Transparency (cm)          | 35.95 ± 3.05 | 28.33 ± 2.13 | 35.67 ± 1.45 | 0.662 ± 3.12 | 0.660 | 0.089 |
| Depth (cm)                 | 75.5 ± 2.14 | 75.33 ± 4.28 | 76.5 ± 1.93 | 2.32 ± 0.12 | 0.065 | 0.94 |
| Flow velocity (m/s)        | 0.21 ± 0.029 | 0.19 ± 0.027 | 0.21 ± 0.025 | 7.03 ± 0.0046 | 0.31 | 0.74 |
| Conductivity (µS/cm)       | 110.17 ± 7.39 | 115.9 ± 6.98 | 104.3 ± 8.04 | 8.27 ± 0.0025 | 2.057 | 0.179 |
| Turbidity (NTU)            | 118.28 ± 13.42 | 91.37 ± 16.01 | 112.47 ± 6.56 | 4.85 ± 0.016 | 2.87 | 0.1038 |
| TDS (mg/l)                 | 66.57 ± 4.51 | 70.79 ± 4.10 | 68.28 ± 3.18 | 5.948 ± 0.0083 | 0.757 | 0.4941 |
| pH                         | 7.27       | 7.77       | 7.82       | 6.0–9.0 |       | 6.5–8.5 |
| DO (mg/l)                  | 3.14 ± 0.87 | 3.33 ± 0.94 | 3.44 ± 0.80 | 189.69 ± 1.43E-09 | 1.886 | 0.202 |
| BOD₅ (mg/l)                | 0.53 ± 0.23 | 0.62 ± 0.29 | 1.04 ± 0.30 | 1.39 ± 0.31 | 1.14 | 0.36 |
| Nitrate (mg/l)             | 0.47 ± 0.23 | 0.28 ± 0.18 | 0.244 ± 0.022 | 1.095 ± 0.42 | 0.81 | 0.48 |
| Phosphate (mg/l)           | 1.62 ± 0.13 | 1.53 ± 0.081 | 1.56 ± 0.138 | 3.42 ± 0.046 | 0.2977 | 0.7489 |

Note: Values are Mean ± Standard error; range in parenthesis. Different superscript letters in a row show significant differences (p < 0.05) indicated by HSD Tests.

* Nigerian Water Quality Standard for Inland Surface Water, FEPA (Federal Environmental Protection Agency) (1991)
* Nigerian Standard for Drinking Water Quality. Standards Organization of Nigeria (SON) 2007

Table 2. Structural assemblage of aquatic insects in River Hadejia

| Order | Family          | Taxa     | Code | 1 | 2 | 3 |
|-------|-----------------|----------|------|---|---|---|
| Coleoptera | Dryopidae      | -        | Dry  | 3 | 5 | 3 |
| Noteridae | Noterus sp.    | Noteridae | Not | 0 | 2 | 1 |
| Dytiscidae | Dytiscus sp.  | Dytiscidae | Dyt | 23 | 17 | 20 |
| Gyrinidae | Gyrinus sp.    | Gyrinidae | Gyr  | 1 | 1 | 2 |
| Hydrophilidae | Hydrophilus sp. | Hydrophilidae | Hyd | 4 | 0 | 0 |
| Hemiptera | Nepidae        | Nepidae  | Npa  | 7 | 7 | 9 |
| Naucoridae | Naucoris sp.  | Naucoridae | Nau | 3 | 1 | 1 |
| Ephemeroptera | Baetidae      | Baetidae | Baet | 1 | 1 | 0 |
| Ephemeroptera | Ephemerella sp. | Ephemeroptera | Eph | 0 | 1 | 2 |
| Odonata | Libellulidae   | Libellulidae | Lib | 1 | 0 | 2 |
| Platynemidae | -            | Platynemidae | -   | Pla | 1 | 2 |
| **Total** |                  |          |      | 44 | 37 | 35 |

Table 3. Weighted intraset correlations of physicochemical parameters with the first two axes of canonical correspondence analysis (CCA) in River Hadejia, Jigawa State, Nigeria.

| Variables                  | Axis 1 | Axis 2 |
|----------------------------|--------|--------|
| Eigen value                | 0.126  | 0.054 |
| % variation of species data explained | 70.08 | 29.92 |
| Monte Carlo test p-value   | 0.35   | 0.315 |
| Air temperature (°C)       | 0.99   | -0.15 |
| Water temperature (°C)     | 0.058  | -0.99 |
| Depth (cm)                 | 0.44   | 0.86  |
| Flow velocity (m/s)        | 0.42   | 0.89  |
| Conductivity (µS/cm)       | 0.11   | -0.09 |
| Turbidity (NTU)            | 0.58   | 0.79  |
| Total dissolved solid (mg/l)| -0.75 | -0.64 |
| pH                         | -0.99  | 0.015 |
| Dissolved oxygen (mg/l)    | -0.96  | 0.29  |
| Biochemical oxygen demand (mg/l) | -0.72 | 0.71 |
| Nitrate (mg/l)             | 0.99   | -0.13 |
| Phosphate (mg/l)           | 0.90   | 0.39  |

Note: All canonical axes were not significantly different (p > 0.05) for the two axes.

Results

Physical and chemical parameters of River Hadejia

Mean and standard error of physical and chemical parameters in River Hadejia are presented in Table 1. Two-way analysis of variance (ANOVA) performed showed transparency, depth, and nitrate to be statistically not significantly different (p > 0.05) among the months sampled. At the same time, air temperature and DO were significantly different (p < 0.05) in the sampled months. However, physicochemical parameters mean values did not differ among the stations sampled (p > 0.05). Mean electrical conductivity was lowest in Station 3 (104.3 ± 8.04 µS/cm). The DO and BOD₅ values portray a relatively perturbed water state. The DO value ranged from 1.1 to 5.7 mg/l with the highest mean value (3.44 ± 0.8 mg/l) and BOD₅ (1.04 ± 0.3mg/l) recorded in Station 3. Nutrients (nitrate and phosphate) were relatively low during the study period. The river was slightly alkaline, as revealed by the mean pH value of 7.27, 7.77, and 7.82 for Stations 1, 2, and 3, respectively. Except for DO and BOD₅, all the parameters were
within the permissible limit in the Nigeria Federal Environmental Protection Agency (FEPA) and Standard Organization of Nigeria (SON).

**Aquatic insect community structure of River Hadejia**

Four orders of aquatic insects belonging to 11 families and taxa were recorded during the entire study period. Dytiscidae (*Dytiscus* sp.) was the most abundant taxon in the study area. Pollution-sensitive species were sparingly represented by Ephemeroptera taxa with two representative taxa (Baetidae and Ephemerellidae). A total of 44, 37, and 35 individuals of aquatic insects were recorded in stations 1, 2, and 3 in the river. Generally, a sparse distribution and abundance of aquatic insects were noticed in the River Hadejia.

**Ecological indices of aquatic insect in River Hadejia**

Mean diversity indices of aquatic insects are presented in Table 2. Mean taxa (number of species), Simpson dominance, Shannon Weiner index, and Margalef index (taxa richness) were significantly higher in Station 3. Stations 1, 2, and 3 showed no significant difference in the mean value of Evenness. Abundance (number of individuals) was higher in station 1 (7.83 ± 2.96). Post hoc test performed for all the diversity indices were not significantly different between stations (*p* > .05).

**Relationship between aquatic insects and physical and chemical parameters in River Hadejia**

The CCA revealed a little or no relationship between the physical and chemical parameters and the aquatic insects. However, the first canonical axis explained over 70% of the variation in the aquatic insect’s data set, indicating a good ordination model. The eigenvalues for axes 1 and 2 were 0.126 and 0.054, respectively (Table 3). The Monte Carlo permutation test performed on the first two canonical axes showed no significant difference (*p* > .05). *Dytiscus* sp. and Platyenemidae were associated to axis 1, while the other remaining aquatic insects were associated to axis 2 except *Naucoris* sp. and *Hydrophilus* sp., which were located at the center of the CCA triplot (Figure 2). *Gyrinus* sp. was positively affected by increased water depth. Biochemical oxygen demand had a relatively strong correlation with *Nepa* sp. From the CCA triplot, Stations 1, 2 and 3 only had *Dytiscus* sp., *Naucoris* sp. and *Nepa* sp. in common, while the other aquatic insects were not linked to any station specifically as seen in the scattered distribution of the biota in the triplot (Figure 2). Generally, no physical and chemical parameters showed correlation with the aquatic insects collected during the study except for TDS that shows a slight association with *Noterus* sp. and *BOD₂* slightly affected the distribution of *Ephemerella* sp. and *Nepa* sp. Cluster analysis indicated that aquatic insects clustering were mainly influenced by month rather than by stations, with insects collected from the same month more closely associated than those collected from stations (Figure 3).

![Figure 2](image-url)  
*Figure 2.* Triplot of the first and second CCA axes of aquatic insect taxa, physicochemical variables and the sampling stations of River Hadejia, Jigawa State, Nigeria. Aquatic insect abbreviation: Dry (Dryopidae), Not (*Noterus* sp.), Dyt (*Dytiscus* sp.), Gyr (*Gyrinus* sp.), Hyd (*Hydrophilus* sp.), Npa (*Nepa* sp.), Nau (*Naucoris* sp.), Bet (*Boetis* sp.), Eph (*Ephemerella* sp.), Lib (*Libellula* sp.), Pla (*Platyenemidae*).
Discussion

Physical and chemical parameters

Deteriorating physical and chemical parameters in a given water body are reported to have a debilitating effect on aquatic macroinvertebrates distribution and abundance (Arimoro et al., 2015; Sundermann, Gerhardt, Kappes, & Haase, 2013). The high EC and BOD$_3$ in the present study indicate a distressed watercourse. This, no doubt, may be occasioned by the incessant human influences on the river. Earlier studies elsewhere in southern Nigeria have reported a similar occurrence in river courses and its catchments (Arends, Okorafar, Eyo, & Ekpo, 2014; Arimoro et al., 2015). Study in selected rivers in Tanzania revealed a perturbed water quality due to the debilitating effect of anthropogenic activities on the water systems (Kaaya et al. 2015). Reduced DO concentration in all the study stations sampled is also a pointer to the river’s heavy alteration. This may be caused by the influx of fertilizer runoff from nearby farmlands as northern Nigeria is known for extensive farming activities for commercial purposes. Most farmers in the area use fertilizer and other chemicals to cultivate their crops. Generally, it may be concluded that the deteriorating water state of River Hadejia is as a result of uncontrolled human disturbance on the river due to unenforced or poorly enforced regulations guiding the water bodies in Nigeria. Hence, the ravaging state of rivers and other water bodies in Nigeria.

Structural-assemblage of aquatic insects

Aquatic insects in various quarters have been used as biomonitoring tools in assessing the ecological health of water bodies (Barman & Gupta, 2015; Edegbene, Arimoro, Odoh, & Ogidiaka, 2015). In this study, Dytiscidae (Dytiscus sp.) was the most predominant species and well represented in the three stations sampled. This may be hinged on favorable environmental or other conditions that enhance this group of aquatic insects in River Hadejia. Studies have suggested structural-assemblage changes due to geomorphological factors and other instream destruction of the physical habitat, as factors that contribute to the abundance and distribution of some macroinvertebrates (Barman & Gupta, 2015; Selvakumar, Sivaramakrishnan, Janarthanan, Arumugam, & Arunachalam, 2014). Pollution-sensitive insect species were sparingly represented in their present study. This is an indication of perturbed ecological health of the river. Various authors have reported that Ephemeroptera, Plecoptera and Trichoptera (EPT) indicate moderately disturbed to clean water (Adakole & Anunne, 2003; Akamagwuna et al. 2019b) depending on their species composition and abundance.

Hemiptera was the second most abundant aquatic insect in the study area. Studies elsewhere have reported a similar trend in the preponderance of this group of macroinvertebrates (Huang, Lock, Chi Dang, De Pauw, & Goethals, 2010; Naranjo, Riviaux, Moreira, & Court, 2010; Takhelmayum, Gupta, &
Singh, 2013). This they ascribed to the ability of hemipteran to utilize atmospheric oxygen as they skate on the surface of the water in the face of deteriorating DO concentration. This may be why Hemiptera was fairly represented in River Hadejia despite the fact that DO concentration was very low. It can be inferred from the structural assemblage of aquatic insects in River Hadejia that the water is fast deteriorating, judging from the weak structural assemblage of the insects.

**Ecological indices and diversity of aquatic insects**

Diversity indices performed confirmed the reaches of the river studied to be perturbed. The mean Margalef index (taxa richness) for the three stations was less than 3. It has been earlier proclaimed by Lenat, Smock, and Penrose (1980) that the Margalef index value greater than 3 indicates clean water condition while a value less than 1 portrays polluted water. In the present study, the taxa richness values for the three stations are less than 1, further confirming the devastating effect of deteriorating water state on the aquatic biota and the ecological health condition of the river. Recently, a study in a dam in Northern Nigeria reported a closely similar trend of taxa richness (Edegbene, 2020). This was reported to be due to poor environmental factors in the dam occasioned by the menace posed by Typha grass and other human activities.

**Relationship between aquatic insects and environmental variables**

Canonical correspondence analysis (CCA) constructed for this study revealed a little or no association between the aquatic insects and the physical and chemical parameters. The eigenvalue in axes 1 and 2 derived from CCA triplot was less than 1.0. Eigenvalues associated with each axis equal the correlation coefficient between species and stations scores (Gauch, 1982; Pielou, 1984). Thus, an eigenvalue close to 1 represents a high degree of correlation between species and stations or any other variable and an eigenvalue close to zero indicates little correlation (Palmer, 1993). For instance, in this present study, the CCA triplot showed that axis 1 had an eigenvalue of 0.126 while axis 2 was 0.054. This indicates a very low correlation between the aquatic insects, the physical and chemical variables, and the sampled stations. Axis 2 in the CCA triplot was weakly associated with aquatic insects, as revealed from the near-zero eigenvalue. We suggest *Nepa* sp. as an indicator of deteriorating ecological health conditions of freshwater systems as they were influenced by increased BOD₅ concentration. At the same time, *Gyrinus* sp. was positively affected by increased water depth. Hence, *Gyrinus* sp. may be affirmed to be a deep water dweller.

**Conclusion and recommendation**

This study serves as a baseline survey on the use of aquatic insects in assessing the health of River Hadejia. The river’s ecological health has been compromised due to the various factors listed above, ranging from poor environmental variables to poor structural assemblage of aquatic insects. For example, air temperature and DO differed significantly between months sampled. Season differences were also more influential in affecting the water quality of the Hadejia riverine system than site spatial differences. Sensitive insects’ species of the orders Ephemeroptera Plecoptera and Trichoptera (EPT) were poorly represented in the study area, with Baetidae and Ephemeriellidae (order Ephemeroptera) being the predominant EPT’s, further indicating poor water quality conditions. Hence, it can be concluded that the influence of human activities has a debilitating effect on the health of River Hadejia. However, we recommend that further studies should be conducted which will involve multiple sites and rivers within the Hadejia emirate and its environs to confirm the results of this study and to understand better the effects of pollution on the functionality of river systems within the emirate. We further recommend that more stringent regulations to control human pressure on the river systems within the studied area to enable surface waters in the area to sustain the provision of desired and valued ecosystem services.

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**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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**Author Contributions**

AOE conceptualized and designed the study. FG and AOE carried out the field sampling, sorting, and identification on monthly basis. FG and AOE performed the data analyses. FG, EO and AOE did the literature review search. AOE, FG and
EO wrote the initial draft of the manuscript. FCA drew the study area map. AOE, FCA and KHN reviewed and polished the final manuscript. AOE supervised the entire research project work. All authors read and approved the final manuscript.

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