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Physicochemical Parameters, Heavy Metal Concentrations and Wellbeing of *Oreochromis niloticus* (Nile Tilapia) in Hadejia River, Jigawa State, Nigeria

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ABSTRACT
Background and Objective: Freshwater is one of the major natural resources used for myriad of purposes. This research was conducted to assess the presence of some pollutants in Hadejia River Jigawa State and their potential toxic effects on *Oreochromis niloticus* (Nile tilapia). **Materials and Methods:** Water and fish samples were collected fortnightly for four months, between March and June 2022, from four designated stations. The samples were analysed for heavy metal contamination, physicochemical parameters and the haematological indices of fish blood. **Results:** The physicochemical parameters such as temperature, pH, conductivity, dissolved oxygen, turbidity, total dissolved solids and total suspended solids were within acceptable limits, except for turbidity which exceeded the recommended level. The haematological indices indicated lower than normal packed cell volume (PCV) and varying levels of haemoglobin (Hb). The concentrations of lead (Pb), chromium (Cr), cadmium (Cd) and nickel (Ni) exceeded the permissible limits set by WHO/USEPA, while zinc and copper levels were below the permissible limits. **Conclusion:** These findings highlight the contamination present in the surface water and emphasize the urgency for implementing measures to control these pollutants.

KEYWORDS
Freshwater, physicochemical parameters, pollutants, absorption spectrophotometry, GCMS, haematology, histopathology

INTRODUCTION
Freshwater is a crucial natural resource that is essential for drinking, fishing and recreational activities. However, the rise in pollution levels has detrimental effects on the ecosystem, including the aquatic biota

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and living organisms[1]. Pollutants such as pesticides, insecticides, heavy metals, mill waste and crude oil contaminate water bodies and significantly harm aquatic life. Fish species, for example, accumulate contaminants in their bodies, leading to various diseases and impairments[1].

Heavy metals are particularly concerning pollutants in aquatic ecosystems due to their toxicity, persistence and potential for bioaccumulation[2-4]. These substances pose health risks to humans even at low concentrations[5,6]. Organochlorine pesticides (OCPs), which were extensively used in agricultural practices, also contribute to the pollution of aquatic ecosystems. The OCPs can accumulate in the sediments of water bodies and pose risks to fish and other organisms[7-9].

The increased pollution in aquatic ecosystems is primarily attributed to population growth, urbanization, industrialization and improper waste management[10]. These pollutants disrupt the hydrology, physicochemical characteristics and faunal composition of water bodies, posing significant threats to the organisms[10]. Fish, being sensitive to pollution, exhibit histo-cytological changes that act as biomarkers for water pollution monitoring[11]. The decline in fish populations and the cessation of commercial fishing are indicative of significant shifts in aquatic ecosystems[12].

The research problem lies in the extensive use of pesticides, their residual effects on aquatic animals and human health and the accumulation of heavy metals in the environment[13]. It is crucial to research to assess and mitigate the impact of these pollutants on fish health and the overall freshwater ecosystem[14]. By understanding and addressing the impact of pollutants, more sustainable measures can be implemented to protect aquatic life[15].
This study aims to conduct physicochemical analysis to detect pollutants and evaluate their occurrence and concentrations in the Hadejia River, Jigawa State.

MATERIALS AND METHODS

Study area: Hadejia River is located in Hadejia Local Government Area, Jigawa State. Hadejia is a town in Eastern Jigawa State, Northwestern Nigeria. It has a projected population of 139,400 people as of 21st March, 2016[16]. The town lies to the North of the Hadejia River and is upstream from the Hadejia-Nguru Wetlands, an internationally important ecological and sensitive zone. Hadejia River is located at Latitude: 12°13'-13°60' N and Longitude 9°22'-11°00' E and it is 361 m above sea level with an area of 32.0 km^2. Most of the flow in the Hadejia River system is controlled by Tiga Dam and Challawa Dam.

Sample station: The research was conducted at four designated stations in Hadejia River, Jigawa State. These stations were as follows:

- Station A: Located beneath the bridge where people wash and bathe, with a depth of 300.7 cm
- Station B: Situated in the Yayari Yan' Wanki area, primarily used for fishing and washing, with a depth of 250.5 cm
- Station C: Found in the Guddiccin area, where agricultural and fishing activities are prominent, with a depth of 350.4 cm
- Station D: Known as Aguyaka, where fishing and irrigation activities take place, with a depth of 345.8 cm

Duration of the study: The study was conducted over 4 months, from March to June 2022. Sampling was carried out bi-weekly, collecting water and fish samples for the analysis of physicochemical parameters.

Sample collection

Water sample collection: Water samples were collected in duplicate at each station. A 1 L plastic sampling bottle was used to collect water from the surface. The bottle was dipped into the water, allowing it to fill unimpeded by pressing it against the current. The collected water samples were then taken to the laboratory for evaluation of physicochemical parameters.

Fish sample collection: Five fresh, matured adult fish of the species *Oreochromis niloticus* (Nile tilapia) were collected from each of the four sampling stations. The fish were stored in clean sample containers at the optimal temperature to prevent spoilage. The collected fish were labeled according to their respective sampling stations (Hadejia under bridge, Yayari 'Yan wanki, Gudiccin Village and Aguyaka Village). The identification of fish species was done using standard freshwater fish guides specific to Nigeria[17].

Physicochemical parameters analysis

Water temperature: Water temperature was measured using a mercury-filled glass thermometer. The thermometer was immersed in the water sample for one to two minutes and the temperature was recorded when the mercury stabilized[18].

Water pH: The pH of each water sample was measured using a digital pH meter instrument (model pHS-25). The electrode of the pH meter was inserted into the water sample for 1-2 min and the measurement was taken when the value stabilized on the LCD screen.

Electrical conductivity: The electrical conductivity of each water sample was measured using INE-EC100B mrclab digital conductivity meter with a specified range of 0-1999 μS and 0-19.99 mS. The electrode was inserted into the water sample and the reading was taken when the value stabilized on the LCD screen. Plastic beakers were used to minimize any electromagnetic interference[18].

Turbidity: Turbidity was determined using turbidity meter WGZ-B. The electrode of the meter was inserted into the water sample and the reading was taken when the value stabilized on the LCD screen[18].

Dissolved oxygen: A modified portable digital dissolved oxygen meter (model JPB-607A) was used to measure the dissolved oxygen in the water samples. The electrode of the meter was inserted into the water sample and the reading was taken when the value stabilized on the LCD screen[18].

Total dissolved solids: Approximately 200 mL of each water sample were filtered using a vacuum pump, glass beaker, membrane filter paper and glass fiber filter disk. About 100 mL of each filtrate sample were transferred into evaporating dishes using graduated cylinders. The evaporating dishes were heated on a hot plate (manufactured by Bionics Scientific, Delhi, India) at 550°C for an hour. After cooling in desiccators, the weight of each dish was measured. The TDS was determined using the equation[19]:

$$\text{TDS (mg / L)} = \frac{(\text{A - B}) \times 1000}{\text{Volume of sample}}$$

Heavy metals analysis: The analysis of heavy metals in water was conducted at Chemistry Laboratory, Sule Lamido University Kafin Hausa Jigawa State; with AAS machine model BUCK SCIENTIFIC 210 VGP, heavy metals in water and fish samples were analyzed; with a Buck Scientific 210 VGP AAS machine. Using a standard curve for each metal, an Atomic Absorption Spectrophotometer (BUCK SCIENTIFIC 210 VGP) was used to measure the heavy metals lead, copper, nickel, zinc and chromium. White, low-density polyethene bottles with a volume of 1000 cm^3 were used to collect water samples from the sampling stations at each of the four locations[20]. The sample containers were submerged for 0.5 m and allowed to slowly fill with water to collect the water samples. Between the beginning of March and the end of June 2022, samples were collected. All of the samples were transported to the laboratory, labelled appropriately and stored in a large plastic container with ice blocks. After being filtered with Whatmann filter paper of 0.7 mm, the water samples were kept at 4°C in the refrigerator[20].

Sample digestion: A hot plate was used to evaporate approximately 50 cm^3 of the 1000 cm^3 of the filtered water sample. After allowing it to cool, it was transferred to a 250 cm^3 beaker. After adding 5 cm^3 of concentrated HNO_3, the solution was heated to 85°C until it became clear. Deionized water was added to a 100 cm^3 volumetric flask after the digested sample was allowed to cool[20]. The Agilent Technologies 200 series Atomic Absorption Spectrometer 240FS by Stevens's dreek Blvd. Santa Clara, CA95051 United States of America was then used to analyze the solution for heavy metals.

Statistical analysis: The results were presented in tables and figures. The ANOVA was used to determine the level of significance at $p \leq 0.05$ among the measured parameters. The Pearson correlation coefficient was used to determine how the various parameters related to one another. The data were analysed with the help of SPSS 23.0 software for the social sciences.

RESULTS

Physicochemical parameters: The results of physicochemical parameters measured during the study period between March and June 2022 are presented in Table 1. The result showed a significant difference ($p<0.000$) where the highest temperatures were recorded in May and June (28.25±0.7 and 28.63±0.5°C) while the lowest was in March (23.13±0.8). The highest mean pH value recorded was in April (7.347±0.3) and the lowest was in May (7.007±0.1) the value across the months of the study indicates no significant difference with the $p<0.345$. Dissolved oxygen concentration was also found to be highest in May (7.113±0.1 mg/L) and lowest in April (7.013±6.3) the values were not significant across the study period with regard to a p-value of (0.905). For electric conductivity, the highest mean value was recorded in March (158.3±6.1 µS/cm) and the lowest in April (145.6±16) the mean showed no significant difference (p-0.124). The highest mean turbidity value recorded was in June (164.5±3.2 NTU) which showed a significant difference (p-0.000). The mean values of total dissolved solid were not significantly different across the research period with the highest and lowest mean values recorded in May (450.5±33 mg/L) and June (397.3±42) respectively. Lastly, the mean value of total suspended solid was higher in March (231.9±7.754 mg/L) when compared with other months, the lowest value was recorded in June (200.1±1.885).

From Table 2 below the result revealed that the mean temperature of almost the same across stations A, B, C and D with a slight increase recorded in station D (26.75±2.8°C). The pH mean value for all the stations was also within the same range, the highest recorded is in station C (7.35±0.3) and D (7.35±0.3). The mean value of dissolved oxygen concentration of stations B, C and D (7.13±0.1, 7.25±0.1 and 7.1±0.0 mg/L) were found to be statistically within the same range, the lowest recorded in station A (6.85±0.2 mg/L). Highest electric conductivity mean value was recorded in station B (156.15±5.3 µS/cm). Turbidity values of stations A, B and D were within the same range while station C had the lowest value recorded (148.43±8.1 NTU).

Table 1: Monthly Mean±Standard Deviation of the physicochemical parameters recorded in Hadejia River Jigawa State

Parameter	March	April	May	June	$p \leq 0.05$	p-value
Temp. °C	23.13±0.8	27.25±0.8	28.25±0.7	28.63±0.5[a]	0.000	0.000
pH	7.260±0.3	7.347±0.3	7.007±0.1	7.133±0.3	0.345	0.345
D.O (mg/L)	7.065±0.4	7.013±6.3	7.113±0.1	7.076±0.1	0.905	0.905
E.C (µs/cm)	158.3±6.1	145.6±16	150.8±9.1	152.4±5.4	0.124	0.124
Turb. NTU	146.8±10	154.1±4.8	155.5±4.9	164.5±3.2[a]	0.000	0.000
TDS (mg/L)	419.3±23	406.3±54	450.5±33	397.3±42	0.630	0.630
TSS (mg/L)	231.9±7.7[a]	208.3±1.8	211.5±5.9	200.1±1.8	0.000	0.000

Temp.: Temperature, D.O: Dissolved oxygen, E.C: Electric conductivity, Turb.: Turbidity, TDS: Total dissolved solid and TSS: Total suspended solid

Table 2: Mean±Standard Deviation of physico-chemical parameters for all stations recorded in Hadejia River Jigawa State

Station	Temp. °C	pH	D.O (mg/L)	E.C (μs/cm)	Turb. (NTU)	TDS (mg/L)	TSS (ppm)
A	26.13±3.1[a]	7.13±0.2[a]	6.85±0.2[b]	150.95±6.0[a]	156.63±5.3[a]	182.20±46[a]	434.63±27[a]
B	26.63±3.1[a]	7.08±0.1[a]	7.13±0.1[ab]	156.15±5.3[a]	159.13±5.4[a]	213.75±11[a]	406.63±56[a]
C	26.75±2.9[a]	7.35±0.3[a]	7.25±0.1[a]	148.43±8.1[a]	151.25±5.4[a]	215.25±13[a]	403.25±39[a]
D	26.75±2.8[a]	7.35±0.3[a]	7.18±0.0[a]	151.70±8.8[a]	154.63±11[a]	402.50±20[a]	214.00±18[b]

Temp.: Temperature, D.O: Dissolved oxygen, E.C: Electric conductivity, Turb.: Turbidity, TDS: Total dissolved solid, TSS: Total suspended solid, values with superscript [a]were within the same range, values with superscript [b]were statistically different with other stations and values with superscript [ab]differed or were the same among within the stations

Table 3: Monthly Mean±Standard Deviation of the heavy metals recorded in Hadejia River Jigawa State

Parameter	March	April	May	June	p-value ($p\leq 0.05$)
Pb (mg/L)	0.123±0.0	0.120±0.0	0.118±0.0	0.145±0.0	0.065
Cr (mg/L)	0.120±0.2	0.102±0.2	0.900±0.0	0.105±0.0	0.161
Zn (mg/L)	1.535±0.2	1.500±0.2	1.568±0.3	1.440±0.3	0.822
Cu (mg/L)	0.260±0.6	0.153±0.4	0.505±0.40[a]	0.305±0.2	0.001
Cd (mg/L)	0.016±0.0	0.042±0.0	0.032±0.0	0.032±0.0	0.305
Ni (mg/L)	0.025±0.0	0.023±0.0	0.020±0.0	0.030±0.0	0.639

Pb: Lead, Cr: Chromium, Zn: Zinc, Cu: Copper, Cd: Cadmium and Ni: Nickel

Table 4: Mean±Standard Deviation of heavy metals of all stations recorded in Hadejia River Jigawa State

Station	Pb (mg/L)	Cr (mg/L)	Zn (mg/L)	Cu (mg/L)	Cd (mg/L)	Ni (mg/L)
A	0.1125±0.0[a]	0.0950±0.0[a]	1.2075±0.0[a]	0.2850±0.2[a]	0.01550±0.0[a]	0.0100±0.0[a]
B	0.1150±0.0[a]	0.1000±0.0[a]	1.4375±0.1[a]	0.2425±0.0[a]	0.01775±0.0[a]	0.0200±0.0[a]
C	0.1375±0.0[a]	0.0900±0.0[a]	1.5625±0.1[a]	0.2050±0.0[a]	0.02500±0.0[a]	0.0200±0.0[a]
D	0.1400±0.0[ab]	0.1325±0.0[ab]	1.8350±0.1[ab]	0.4900±0.2[b]	0.06750±0.0[b]	0.0475±0.0[b]

Values with superscript [a]were within the same range, values with superscript [b]were statistically different with other stations and values with superscript [ab]differed or were the same among within the stations

Heavy metal concentration in water: The results of heavy metals analysis conducted are presented in Table 3. The result revealed that almost all the metals analyzed showed no significant difference across the study period except copper (Cu) which shows significance at a probability level of $p\leq 0.05$ with p-value of (0.001). Highest concentration of copper was recorded in May (0.50±0.40 ppm).

The result from Table 4 revealed that the concentration of heavy metals analyzed in station A, B, C and D where the highest concentration of Lead (Pb) in station D (0.1400±0.007 ppm), high concentration of chromium (Cr) was also recorded in station D (0.1325±0.023ppm). Concentration of zinc, copper, cadmium and nickel in station D was also found to be above the values recorded in stations A, B and C, respectively.

From Table 5, the result shows that the temperature showed a negative correlation with pH (-0.77), electric conductivity E.C (-0.348)*, total dissolved solid TDS (-0.036) and total suspended solid TSS (-0.082).

The pH value showed positive with dissolved oxygen D.O (0.336)* and total suspended solid TSS (0.115) at probability level of $p\leq 0.05$, while a strong negative correlation was observed with electric conductivity E.C (-0.225), turbidity (-0.050) and total dissolved solid TDS (-0.630)**.

Dissolved oxygen concentration showed strong negative interaction with E.C (-0.277), turbidity (-0.116) and TDS (-0.274) respectively.

Electric conductivity showed a strong negative interaction with turbidity (-0.165), while a positive interaction was observed with TDS (0.158) and TSS (0.193) respectively.

Finally, a strong negative correlation was observed between TDS and TSS (-0.124 and -0.664).

Table 5: Correlation coefficient matrix of physicochemical parameters of Hadejia River

Parameters	pH	D.O (mg/L)	E.C (μs/cm)	Turbidity NTU	TDS (mg/L)	TSS (mg/L)
Temperature °C						
pH	-0.077					
D.O mg/L	0.118	0.366*				
E.C μs/cm	-0.348*	-0.225	-0.227			
Turbidity NTU	0.604**	-0.05	-0.116	-0.165		
TDS mg/L	-0.036	-0.630**	-0.274	0.158	-0.124	
TSS mg/L	-0.820**	0.115	0.102	0.193	-0.664**	0.189

*Correlation is significant at the 0.05 level (1-tailed) and **Correlation is significant at the 0.01 level (1-tailed)

Table 6: Mean±Standard Deviation of the haematological indices of Tilapia (*Oreochromis niloticus*) during the research period

Months	PCV (%)	HB (g/dL)	WBC (10^9/mL)	RBC (10^{12}/mL)	MCV (c/L)	MCH	MCHC
March	22.32±0.8	7.57±0.0	167.67±24	1.45±0.0	122.43±4.0	51.87±7.3	44.76±3.2
April	22.73±1.6	6.70±0.8	157.02±8.1	1.38±0.0	120.33±7.3	47.39±2.8	44.02±1.6
May	19.23±1.6	7.23±1.6	153.10±5.7	1.36±0.0	140.52±4.8	50.41±4.0	45.00±0.8
June	17.19±0.8	6.74±0.8	159.4±7.3	1.18±0.0	147.38±8.1	55.40±8.1	42.21±0.8

PCV: Packed cell volume, HB: Haemoglobin, WBC: White blood cell, RBC: Red blood cells, MCV: Mean corpuscular volume, MCH: Mean corpuscular hemoglobin, MCHC: Mean corpuscular hemoglobin concentration

Haematological indices: Presented in Table 6 were the haematological indices of *Oreochromis niloticus* from March, 2022 to June, 2022. The lowest packed cell volume (PCV) ranged between 17.19±0.81% in June 2022 and 22.32±0.8% in March. The PCV was observed to differ significantly ($p<0.05$) between the months. Also, *Oreochromis niloticus* had the highest (6.7±0.8 g/dL) in June. The monthly mean values were also significantly different from one another ($p<0.05$). As per monthly mean red blood cells (RBC), the parameter ranged from (1.45±0.08/mL) in March to (1.18±0.08/mL) in June. The monthly differences observed between them were significant ($p<0.05$). The monthly mean white blood cell (WBC) value varied between (167.67±24/mL) in March and (159.4±7.3/mL) in June and the variation was statistically revealed to be significant ($p<0.05$). The mean corpuscular volume (MCV) of the *Oreochromis niloticus* ranged between (122.43±4.0 and 147.38±8.1 (cell/L) in March and June. This variation was also statistically significant across the months ($p<0.05$).

April and June, recorded the lowest and the highest mean corpuscular hemoglobin (MCH) values of 47.39±2.8 and 55.40±8.1 pg/cell, respectively. A significant difference between these monthly values was resulted by analysis of variance ($p<0.05$). Ultimately, June and May recorded the minimum and maximum monthly mean corpuscular hemoglobin concentration (MCHC) of 42.21±0.8 and 45.00±0.8 g/dL, respectively. Analysis of variance revealed a significant difference in mean corpuscular hemoglobin concentration in *Oreochromis niloticus's* ($p<0.05$).

DISCUSSION

Physicochemical parameters of the water sample: The mean temperature of the water samples for both the stations varied between 23.13±0.8 and 28.25±0.7. Temperature affects the amount of dissolved oxygen in water, which is essential for both aquatic life and other oxidation processes that require oxygen[21]. The temperature of the water source does not have direct health implications as it is within the permissible limits[22]. The findings opposed that of Danyaya *et al.*[23], which found that the stunted growth of fish was attributed to an unfavorable temperature that did not support the optimum growth.

The mean values of dissolved oxygen (DO) mean values found in the water samples from all four stations met the WHO threshold of 6.5-8.5 mg/L. This was in line with the findings of Makori *et al.*[24], who in a study of the effects of water physicochemical parameters on tilapia (*Oreochromis niloticus*) growth found that DO was within the permissible level. This suggested that these water sources were not tainted for *Oreochromis niloticus* to grow. An increase in temperature and DO are associated with an increase in the growth of *Oreochromis niloticus*[24]. Thus, *Oreochromis niloticus* in the Hadejia River is safe as per as temperature and DO are concerned. The water samples from both stations had a mean pH of 7.347±0.3 at its highest. This is greater than the 6.20-6.88 range for the physicochemical parameters of Ikwu River, Umuahia, Abia State in South-Eastern, Nigeria for multiple uses, as reported by Danyaya *et al.*[23].

The WHO acceptable guideline value of 6.5-8.5 was met by all study stations. These findings were supported by by Makori *et al.*[24]. The mean conductivity of the surface water of the study area ranged between 145.6±16 and 158.3±6.1 this indicates that there was less mean conductivity than required in the study area as per the WHO standard. This was supported by Makori *et al.*[24], who in their study concluded that the mean conductivity values of the earthen ponds in Teso North Sub-County, Busia County were a bit lower than the WHO standard limit. The higher the mean value of conductivity and pH the less the growth of the *Oreochromis niloticus* as per[24].

Based on this, it is safe to conclude that the pH of Hadejia River needs to be adjusted for the proper growth of Tilapia in the river. As opposed to the high pH mean value detected, the mean conductivity value is lower than the optimal level, thus making the water source good for Tilapia[23]. The turbidity obtained from all the stations was far higher than the 5 NTU (nephelometric turbidity unit) value recommended by WHO, indicating that the water samples for these stations were more turbid than needed. This might be attributable to the open structure nature of the water sources that makes it simple for pollutants that might interfere with light transmission to flow into them. Makori *et al.*[24] opposed this finding by reporting that the turbidity mean value in surface water containing species of *Clarias gariepinus* and *Oreochromis niloticus* is a bit greater than the WHO recommended limits. Anthropogenic activity can increase water turbidity, changing fish behaviour by reducing visibility, injuring their breathing organs, reducing their growth rate or preventing their reproduction[25]. Total dissolved solids content (TDS) levels that are too high induce heart attacks and kidney stone formation in humans, as well as gastrointestinal irritation when consumed in large quantities[26]. It also gives water an alkaline quality as well, which in turn causes a number of clinical problems for aquatic organisms[27]. The mean value of total dissolved solids (TDS) in the study area was found to be above the WHO recommended level. The TSS's mean values fall below the WHO recommended limits of 450-2000 mg/L.

Heavy metals in the water: The life and life span of aquatic organisms can be greatly affected by contamination brought about by high concentrations of heavy metals in the water they live. In some of the toxic effects of heavy metals on fish and aquatic invertebrates include a reduction in developmental growth, an increase in developmental abnormalities, a reduction in fish survival, particularly at the start of exogenous feeding, or even the extinction of the entire fish population[28].

The average mean value of Lead (Pb) in the water sample of this study across all the stations falls above the WHO recommended level of 0.01 mg/L in all the stations. However, the value is lower than the highest level of 0.55 mg/L observed in the surface water sample investigated in Ekiti State, Nigeria, as reported by Joseph *et al.*[29]. The mean chromium levels found in the samples stations were higher than WHO permitted chromium level of 0.05 mg/L observed in the sample stations. This can affect the organs of fish including its gills and liver as reported by Bakshi and Panigrahi[30]. Average concentration levels observed for Zn in the water samples across the stations are lower than the WHO permissible level of 3 mg/L. This agreed with the findings of Hayat *et al.*[31], who reported that Zn value was within the permissible limit as per their study, a holistic review of heavy metals in water and soil in Ebonyi SE, Nigeria; with emphasis on its effects on human, plants and aquatic organisms. They also reported that the Zn value lower than the permissible level had no significant effect on the life and growth of aquatic organisms.

The mean concentration level of Cu detected in the water samples across the stations, all of which are far below the WHO permissible level of 2 mg/L. Water source with less cupper level is safe for aquatic organisms[31]. Cadmium has an average concentration level in the sample stations. It is also higher than the WHO permissible level only in station D. This tells us that fish from this station are at risk of developing clinical issues in their organs like liver, stomach and gill[31]. On the final note, the average nickel level in the water samples across the stations is higher. The highest result of 0.04 mg/L is greater than the value of

0.1 mg/L that Eyankware and Obasi[32], reported for water samples taken from the River Ona and a few hand-dug wells in the Itaogbolu area of Nigeria's Ondo State. As in the case of cadmium, nickel average level in station D falls above the WHO permissible level of 0.02 mg/L which poses health risks to the gills of the fish in the river.

Haematological parameters: Haematology is an acceptable and important technique for evaluating fish health problems[33]. Packed cell volume (PCV) mean values ranged between 17.19% and 22.32%. The observed values are more than the range of 15.2 and 10.4% reported by Clauss *et al.*[34]. As it is evident from the PCV values detected that hematological index is higher in the early dry season, something attributable to a total drop in water volume. The hematological values in fish should be between 20 and 35% and seldom exceed 50%. Gabriel *et al.*[35], opined that the significant decrease in PCV may be due to gill damage and/or poor osmoregulation, which could result in anaemia and haemodilation. Haemoglobin is crucial for fish's physiological survival since it is linked directly to the blood's capacity to bind oxygen. The mean haemoglobin (Hb) levels varied between 6.230 and 7.570 g/dL. The low hemoglobin reported in this study is probably due to those heavy metals that alter haemoglobin's properties by lowering their attraction for oxygen binding ability and making erythrocytes weaker and more porous[35].

According to Chris *et al.*[36], a decline in Hb value may be caused by either a slower rate of red blood cell synthesis or a higher rate of red blood cell oxidation. The *O. niloticus* had mean red blood cells (RBC) ranging from $1.180x10^{12}$/mL to $1.45x10^{12}$/mL. These figures surpassed those reported by Chris *et al.*[36], which varied from 135.08x10.55 to 367.42x 94.88x10^3 cells/mm^3 in value. The range of *O. niloticus's* mean white blood cells (WBC) was $153.100x10^9$/mL to $167.67x10^9$/mL. The increase in fish WBC was thought to be caused by a change in the body's defence against the impacts of highly toxic and bioaccumulated heavy metals in fish tissues, according to previous reports[37]. The MCV, MCH and MCHC of *O. niloticus* were found to change during the months of the research. This may be due to the agricultural activities that occur surrounding the river during the period of the research. Similar results were noted in *Clarias gariepinus* that had been formalin-treated, according to Zaghloul *et al.*[38]. The mean corpuscular hemoglobin concentration, which is the ratio of the mean haemoglobin concentration, is unaffected by blood volume and the number of blood cells; the only situation in which it can be misconstrued is when new cells are released that have a different haemoglobin concentration[39,40].

CONCLUSION

The physicochemical parameters of the surface water under study such as temperature, pH, electric conductivity, turbidity, dissolve oxygen (DO), total dissolve solid (TDS) and total suspended solid (TSS) were investigated, where all the parameters analysed were found to be within permissible limit except for turbidity which was found to be above the recommended limit of 5 NTU (nephelometric turbidity unit). Organic compound and heavy metals concentrations in water and fish samples were also investigated with concentrations of lead (Pb), chromium (Cr), cadmium (Cd) and nickel (Ni) found to be above WHO permissible limit. Haematological indices of fish blood were also examined. The knowledge of these haematological pictures will enhance the overall management of aquatic ecosystems.

RECOMMENDATIONS

It is recommended that:

- Since the source of the river passes through Kano (Challawa and Tamburawa); appropriate treatment of waste (effluent) from industries in the cities should be done before emptying into the river
- Governmental policies on professional use of pesticides, waste disposal and management should be enacted and strictly enforced to prevent our water bodies from contamination

- Proper sanitation should be strictly observed around the vicinity of the various water sources to prevent contamination
- Further studies should be carried out especially on the oxidative stress enzymes (biomarkers) of *Oreochromis niloticus* in the study area

SIGNIFICANCE STATEMENT

This study aimed to assess physicochemical parameters and heavy metal concentrations in the Hadejia River, Nigeria, focusing on their implications for *Oreochromis niloticus* (Nile Tilapia). Findings revealed spatial heterogeneity in water quality and varying levels of heavy metal pollutants, potentially from anthropogenic sources. These variations could affect the health and wellbeing of Nile Tilapia, an economically important species. Continuous monitoring and sustainable water management are crucial for mitigating anthropogenic impacts on aquatic ecosystems and safeguarding aquatic life. This study provides valuable insights for policy makers and environmental agencies to formulate effective strategies for environmental conservation in the region.

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