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ECOGENOTOXICOGICAL ASSESSMENTS OF SOME SELECTED FISH SPECIES FROM APODU RESERVOIR, MALETE, NORTH CENTRAL, NIGERIA

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ABSTRACT

Increased agricultural and domestic activities around and within aquatic ecosystem could pose serious threats to the habitat quality and ichthyofauna diversity. Nigeria is a country notable for the alarming rate of water pollution. On the other hand, increased human populace around the Apodu Reservoir has led to an intensifying rate of pollutants' influx into the water body. To date, there is limited information on the habitat quality and associated genotoxic effects of pollutants on physiology of fish communities from the Apodu Reservoir. To infer these, water samples were collected randomly, and fish species were assayed for genotoxicity using micronucleus and histological assays. In this study, the *in situ* genotoxic potential of different species of fish (*Clarias gariepinus, Synodontis gambiensis, Saraetherodon galilaeus,* and *Protopterus annectins*) present in the Apodu Reservoir on the somatic cells using MN assay was evaluated. The kidney, liver, and gills of the fishes (*Clarias gariepinus, Auchenoglanis occidentalis, Tilapia mariae, Mormyrops deliciosus*, *Saraetherodon galilaeus,* and *Hemichromis fasciatus*) found in the reservoir and the physicochemical parameters of both the reservoir and borehole water (negative control) were also examined. The physico-chemical and heavy metals analyzed (Ca > Ni > Cl > P > Mg > Fe > Zn > Mn > Cu > Pb = Cr) were below the proposed limit by standard organizations. The different species of fish thriving in the reservoir show varying level of micronuclei and nuclear abnormalities in the order (*S. gambiensis* > *C. gariepinus* > *P. annectins* > *S. galilaeus*), and the histopathological assessment of the kidney, liver, and gills amidst the fish shows mild alterations when compared to the control fish. The histopathology of the kidney *of M. deliciosus* shows severe changes amidst other species. The cortex in the renal tissue shows numerous glomeruli and tubules lying back to back and lined by cuboided epithelium cells. The livers of fish in the reservoir showed irregular plates of hepatocytes while the gills showed mild distortion of epithelia lining, cartilage, and lymphatic cells. The flowing of water alongside agricultural and domestic activities around the reservoir might be attributed to the micronuclei deformities and histopathological alterations. Proper management of the habitat quality of the Apodu Reservoir appears necessary.

Keywords: ecogenotoxicology, Apodu Reservoir, fish species, micronucleus, histopathology

INTRODUCTION

Reservoirs are very useful ecological resources that serve numerous human needs such as water conservation (irrigation water supply for domestic needs), flood control, hydroelectric power generation, etc. However, majority of water reservoirs in developing countries are often polluted. This could be attributed to the daily influx of pollutants from domestic agricultural waste and industrial wastes which have adverse effects on ecosystem health (Kushwaha et al., 2012).

The Apodu community and other nearby settlements close to Malete Town of North Central Nigeria consist majorly of farmers and hunters that solely depend on surrounding water bodies for daily activities including fishing, washing, etc. Thus, the Apodu dam was constructed in 1980s to improve the water availability to the human populace. The expansion of the dam was carried out about a decade ago, and since then, the reservoir has not been functioning appropriately, which brings about improper and unhygienic activities to be carried out within and close to the reservoir. The herdsmen bring their cattle near the water for feeding and to drink water. Likewise, some urinate into the water during recreational activities. Also, subsistence farming and commercial fishing activities were being carried out around the dam (Oladipo et al., 2018). However, due to limited information on the habitat quality and possible effects of genotoxic effects of pollutants on fish physiology, particularly Nigeria, humans living close to these reservoirs still rely heavily on the water body and fish community.

Pollution arising from heavy metals such as copper (Cu), chromium (Cr), lead (Pb), and manganese (Mn) among others have been reported. These pollutants possess potential geno-ecotoxicological risks to fish community (Vargas et al., 2001). Previous studies have focused on the examination of contaminants' levels of aquatic habitat. Few studies have investigated the effects on these pollutants on the fish biology. Fish serve as a genetic model for the evaluation of aquatic ecosystem health due to its close association with the aquatic environment (Mitchell & Kennedy 1992). Hence, they could be used in assessing potential risk associated with increasing rate of intrusion of pollutants in aquatic environment (Cavas & Ergene-Gozükara 2005). Recent studies have focused on the combined use of genetic and histopathological approaches in examining possible effects of pollutants in fish communities. The micronucleus is one the biomarkers indicators of pollution and environmental contamination that are reliable (Okoro et al., 2016). It has been used for assessing the potential genotoxicity of various toxicant and effluents using different animal models (Nwani et al., 2011; Bücker et al., 2012;

Nwani et al., 2013; Okoro et al., 2016). The reliability and sensitivity of the assay make it possible to detect any nuclear lesions caused by exposure of living organisms such as fish to potential environmental contaminants.

To date, physico-chemical parameters of the Apodu Reservoir in Malete, Nigeria, and possible effects of the genotoxic pollutants on the fish physiology are poorly known. To advance knowledge on this, we investigated physico-chemical parameters of the Apodu Reservoir and further examined the physiology of some selected fishes from the reservoir using histopathological analyses and peripheral blood micronucleus assays. Analyses improved knowledge on the possible genotoxic effects of pollutants on the fish communities.

MATERIALS AND METHOD

Sampling Site

The study site is the Apodu Reservoir, in Apodu Village, about 7 km away from Malete Town, Kwara State, North Central Nigeria (Fig. 1). It lies between the longitude 8°45'25.9" N, 45'27.7" N and latitude 4°27'41.4"E, 4°27'35.5"E. Decreases in water flow rate especially in the dry season are often encountered.

Sample Collection

Fish species samples that were common in the reservoir between the months of

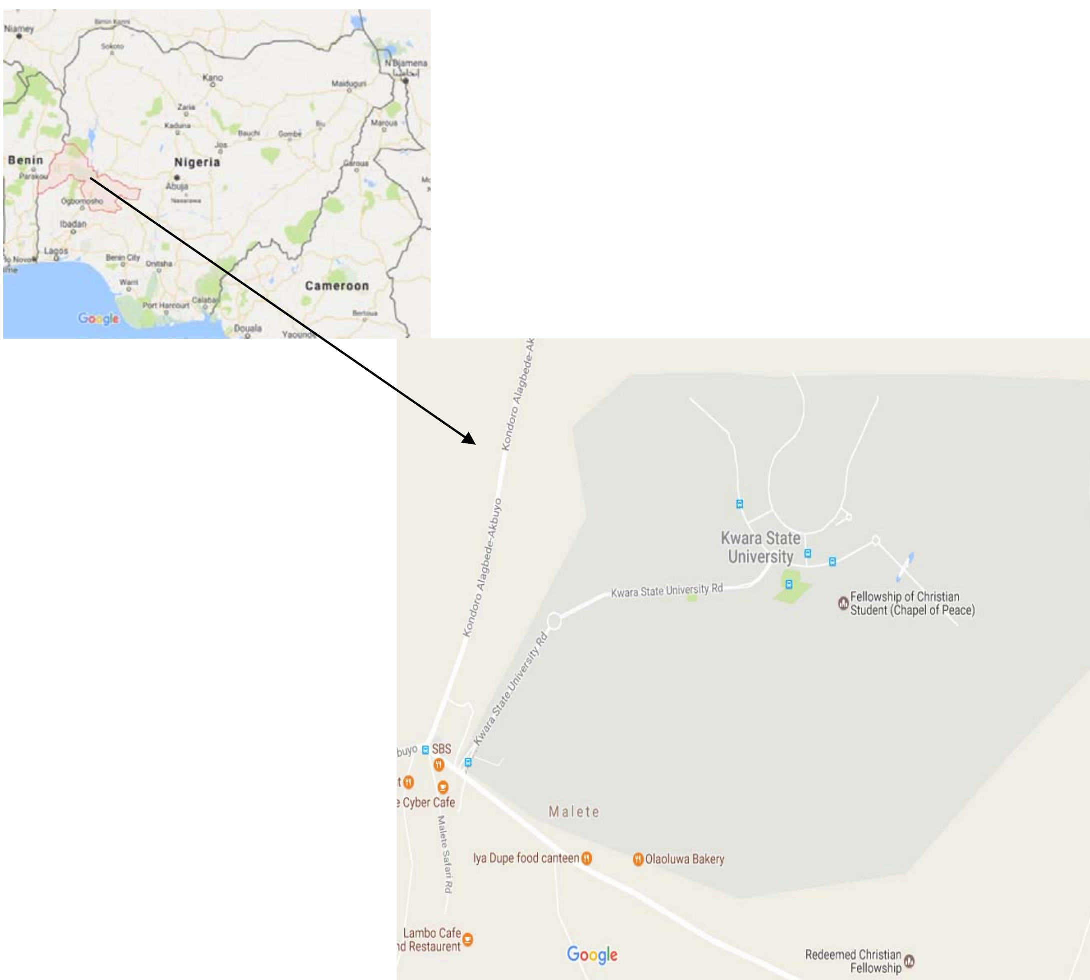

Figure 1. The map of Nigeria with the Kwan State map inset showing the study area

February and March 2017 were caught with gill nets of 5.00- to 10.10-cm mesh sizes in a fleet that were set the previous evening and harvested at about 6:00–8:30 am, with the help of local fishermen. A number of 2–12 samples per species were collected based on the availability. The sampled fishes were transported in transparent 50-L plastic aquaria with net covers to the Department of Zoology, University of Ilorin, Ilorin, Nigeria. The fish were sorted and identified into species level following Idodo-Umeh (2003) and Olaosebikan and Raji (1998) and also with the help of a fish taxonomist.

Fishes were acclimatized to ambient laboratory conditions prior to caudal venipuncture for MN analysis. Gills, kidney, and liver tissues were also sampled for histopathological analysis.

For the negative control, we obtained 20 juveniles of African catfish (*Clarias gariepinus*) of about 8–9 weeks old, of mean body weight of 16 g, and of 11.5-cm length from Ige farm, Nigeria. Juveniles were acclimatized for 3 weeks in the laboratory of the Department of Zoology, University of Ilorin, under normal laboratory condition prior to the commencement of the experiment. The fishes were fed ad-libitum with commercial feed pellets prior to the commencement of the experiment for micronucleus and histopathological analysis.

Water samples used for control (borehole water) in the laboratory and Apodu Reservoir were taken randomly for physicochemical assessment. Water temperature, pH, electrical conductivity, and total dissolved solids were measured *in situ* on the water surface using a Hanna portable pH/EC/TDS/Temperature combined waterproof tester, model HI 98129. Electrical conductivity was measured in microseconds per centimeter, temperature was measured in degree Celsius, and total dissolved solids values were measured in milligrams per liter. Transparency levels were also determined using a Secchi disc with a calibrated rope attached, and surface water velocity was measured by the floatation method (Adoni, 1985). The dissolved oxygen, nitrate, phosphate, iron, total chlorine, and COD were determined using a Hanna multiparameter bench photometer for laboratories, model HI 83200, and an AAS (Atomic Absorption Spectrophotometer) (model: Buck scientific ACCUS-IS 211) was used to determine the heavy metals in the sample.

Micronucleus Test

A thin smear of blood was made onto clean, grease-free slides and air-dried for 24 hours at room temperature before being fixed with 10% methanol for 20 minutes and subsequently stained in 10% May-Grunwald and 5% Giemsa stains. A total number of 2,000 erythrocytes were examined for each specimen under a light microscope with oil immersion at 1000× magnification for micronucleus (MN) and nuclear abnormalities. The nuclear abnormalities were scored along with MN as biomarkers of cyto-genotoxicity in accordance with Carrasco et al. (1990) and Ergene et al. (2007).

Histopathological Analysis

Different tissues such as kidney, liver, and gill were dissected from both control (*Clarias gariepinus*) and selected fish species (*Clarias gariepinus, Auchenoglanis occidentalis, Tilapia mariae, Mormyrops deliciosus*, *Saraetherodon galilaeus,* and *Hemichromis fasciatus*) from the Apodu Reservoir. The standard method of Gobinath and Ramanibai (2014) was used with little modification. Briefly, the isolated tissue samples were fixed in formalin for 24 hours and washed with distilled water before being taken to the histopathology laboratory at the University of Ilorin Teaching Hospital for further analysis. The samples were dehydrated in different grades of alcohol series and processed further. Sections of 5- to 6-µm thickness were taken using a microtome and stained using hematoxylin and eosin, respectively; mounted using DPX; and observed under a light microscope.

Statistical Analysis

The SPSS software package version 21.0 (SPSS 21.0) was used to evaluate the micronucleus abnormalities and the differences between the negative (fish exposed to borehole water) and test groups (Apodu fish species). The differences were analyzed by comparing them with the use of one-way ANOVA, and the level of statistical significance was estimated at $p < 0.05$ using the Duncan multiple range test (DMRT).

RESULTS

The physico-chemical and heavy metals analyzed (Ca > Ni > Cl > P > Mg > Fe > Zn > Mn > Cu > Pb = Cr) were lower than the maximum level approved by standard organization (Table 1).

The micronucleus test shows statistically significant ($p < 0.05$) induction of micronuclei (MNi) and nuclear abnormalities (NA) (notched, nucleus without cytoplasm, binucleated and blebbed) in fishes residing in

Table 1. Physical and Chemical Properties of the Water Assessed for Genotoxicity

Parameter	Borehole Water	Apodu Reservoir	WHO	FME	NESREA
pH (mol/L)	7.61	7.05	6.5–8.5	6.5–8.5	6–9
Transparency	—	26.81	—	—	
Current (A)	—	5.40	—	—	—
Conductivity (µs/cm)	71	88.25	—	—	—
Temperature (°C)	25.20	29.17	—	—	
TDS (ppm)	38	44.74	—	—	200
DO (mg/L)	6.80	5.80	>2		
BOD	1.5	1.0	>6		
Phosphate (mg/L)	1.2	1.50	5		
Chloride (mg/L)	17.85	23	25		
Calcium (mg/L)	70	75	75		
Nitrate (mg/L)	12.2	27.2	20		
Manganese (mg/L)	0.01	0.03	5	0.05	
Magnesium(mg/L)	0.01	0.53	200	—	200
Lead (mg/L)	0	0	<1	0.1	<1
Zinc (mg/L)	0.02	0.07	<1	—	<1
Iron (mg/L)	0	0.14	20	0.3	20
Copper (mg/L)	0	0.02	<1	1.3	<1
Chromium (mg/L)	0	0	—	0.1	<1

Note: TDS—total dissolved solid, DO—dissolved oxygen, BOD—biochemical oxygen demand, WHO—World Health Organization, FME—Federal Ministry of Environment, NESREA—National Environmental Standards and Regulations Enforcement Agency.

the Apodu Reservoir as compared to the control (*Clarias gariepinus*) exposed to borehole water (Table 2). The inductions was in the order *Synodontis gambiensis* > *Clarias gariepinus* > *Protopterus annectins* > *Sarotherodon galilaeus* (Table 3). Figure 2 shows different abnormalities observed in the species of fish. The MNi was higher in *S. gambiensis* and lower in *P. annectins*. Also, the NA such as nucleus with cytoplasm was higher in *S. gambiensis* while the lowest was observed in *S. galilaeus*. No NA was observed in the fish in the negative control.

The histopathological assessment of the kidney (Fig. 3A–G), liver (Fig. 4A–G), and gill (Fig. 5A–G) amidst different species of fish (*Auchenoglanis occidentalis, Tilapia mariae, Hemichromis fasciatus, Mormyrops deliciosus, Sarotherodon galilaeus*, and *Clarias gariepinus*) revealed mild alterations to its architecture when compared with the control. The section of kidney of *A. occidentalis* found in the Apodu Reservoir shows that the renal tissue composed of numerous glomeruli and renal tubules lying back to back. The glomeruli show normal

Table 2. Summary of Different Micronuclei Induction and Nuclear Abnormalities Observed in different Species of Fish Present in Apodu Reservoir

Species	Micronuclei	Binucleated	Notched	Lobed	Blebbed	NWC	Total Abnormalities	% Abnormalities	Mean ± SD
Control	2	0	0	0	0	0	2	0.05	0.05 ± 0.71
C. gariepinus	18	6	2	4	20	76	126	3.15	34.25 ± 27.22
S. gambiensis	65	2	11	4	13	82	177	4.425	41.75 ± 3.18
S. galilaeus	20	14	0	5	6	31	76	1.9	20.00 ± 0.71
P. annectins	7	2	2	1	1	75	88	2.2	24.50 ± 4.95

Note: Final values expressed as mean of the replicates ± standard deviation. NWC–nucleus without cytoplasm.

Table 3. Mean Frequencies of Micronuclei Induction (MNi) and Other Nuclear Abnormalities (NAs) Amidst Different Species of Fish in Apodu Reservoir

Species	Micronuclei Mean ± SE	Nuclear Abnormalities Mean ± SE	Total Abnormalities (MNi and NAs) Mean ± SE
Clarias gariepinus (NC)	1.0 ± 1.4142	0.0 ± 0.0000	0.50 ± 0.050
Synodontis gambiensis	32.5 ± 5.5000*	56.0 ± 14.0000*	41.75 ± 2.25*
Sarotherodon galilaeus	10.0 ± 5.0000	28.0 ± 6.0000*	20.00 ± 0.50*
Clarias gariepinus	9.0 ± 5.0000	54 ± 28.0000*	34.25 ± 19.25*
Protopterus annectins	3.5 ± 0.5000	40.5 ± 1.5000*	26.00 ± 3.50*

Note: *Statistical difference from total negative control ($p < 0.05$). Results expressed as mean of the duplicate standard error. Total no. of cell counted per slide = 1,000.

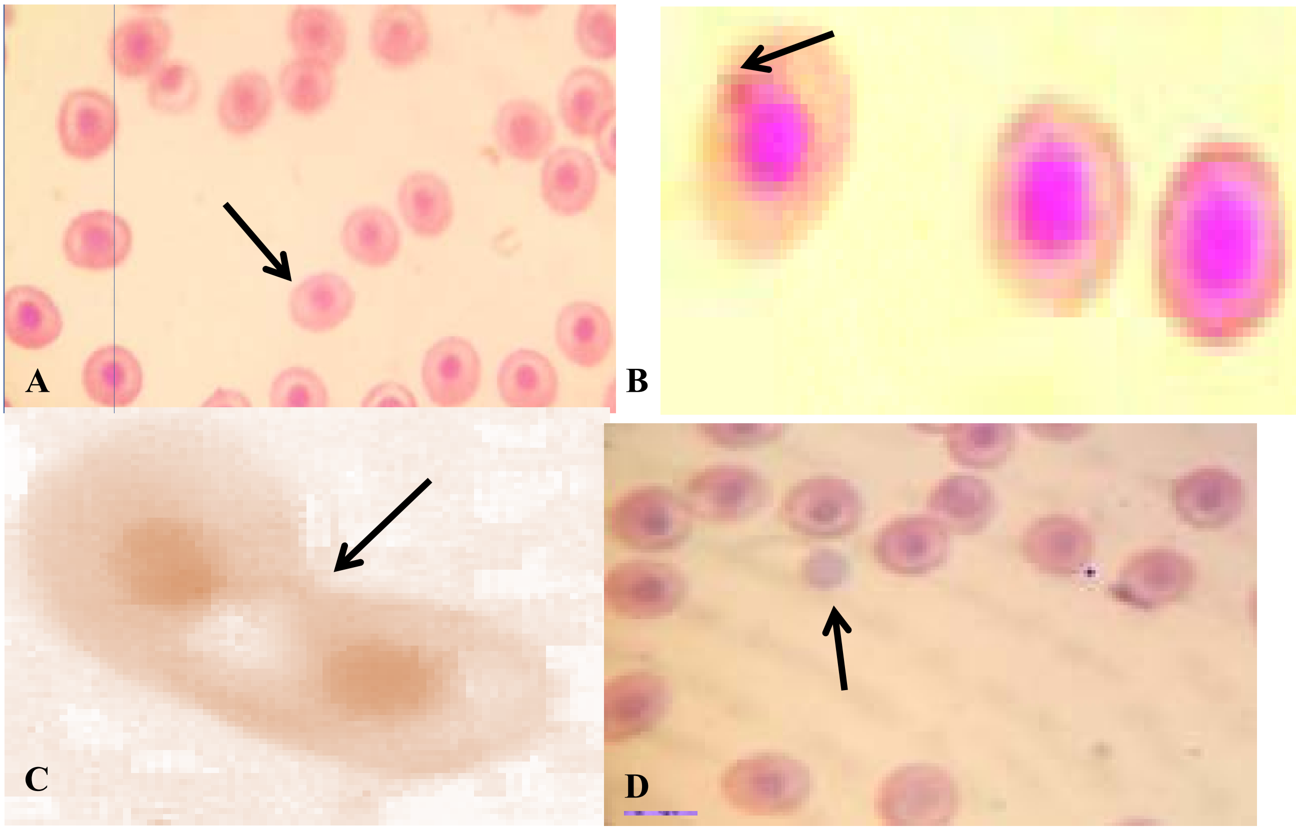

Figure 2. Normal erythrocyte, micronucleated erythrocyte, and nuclear abnormalities in some selected fish species from the ApoduReservoir (mag. ×1000). A. Normal. B. Micronucleus. C. Binucleated with notched cytoplasm. D. Nucleus without cytoplasm.

histology under light microscopy and non-obsoletes (Fig. 3B) when compared to the negative control (Fig. 3A). Histopathology of the liver of *A. occidentalis* shows irregular polyhedral plates of hepatocytes with central vein and also portal triads at the edge of hepatocytes (Fig. 4A). No alteration was observed in *S. galilaeus* (Fig. 4G).

The histopathology of gill in control fish *C. gariepinus* (Fig. 5A) shows epithelia lining, cartilage, and normal secondary lamellae. Histological analysis of the gill of *S. galilaeus* (Fig. 5B) shows mild distortion of epithelia lining and lymphatic cells while normal epithelia lining with some adipose was observed in *M. deliciosus* (Fig. 5C).

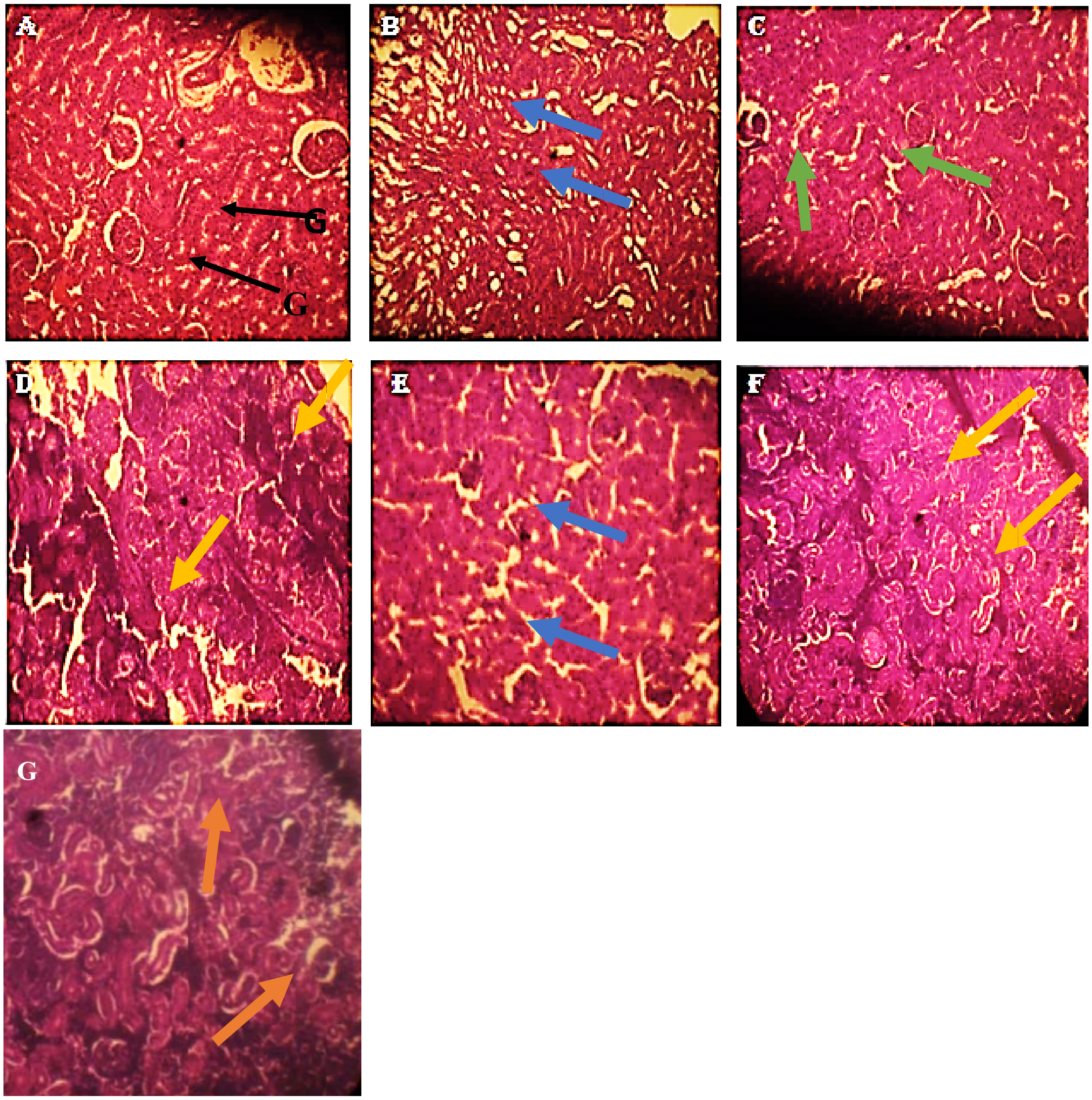

Figure 3. Histopathology of the kidney of different species found in the Apodu Reservoir (mag. ×400). Stained: hematoxylin, and eosin. A. Kidney histopathology of C. gariepinus exposed to borehole water (Negative control). Section shows renal tissue composed of numerous glomeruli (G) and renal tubules. B. Kidney histopathology of A. occidentalis found in the Apodu Reservoir. Section shows renal tissue composed of numerous glomeruli and renal tubules lying back (blue arrows) to back. The glomeruli show normal histology under light microscopy and non-obsoletes. C. Kidney histopathology of *T. mariae* found in the Apodu reservoir. Section shows mild distortion and degeneration of tissue cells **(green arrows)**. D. Kidney histopathology of *M. delicious* found in the Apodu Reservoir. Section shows renal tissue composed of cortex and medulla. The cortex shows numerous glomeruli and tubules lying back to back are lined by cuboided epithelium cells (**yellow arrows**). E. Kidney histopathology of *C. gariepinus* found in the Apodu Reservoir. Section shows renal tissue composed of numerous glomeruli and renal tubules lying back to back. The glomeruli shows normal histology under light microscopy and non-obsoletes (**blue arrows**). F. Kidney histopathology of *S. galilaeus* found in the Apodu Reservoir. Section shows renal tissue composed of cortex and medulla. The cortex is lined by cuboidal epithelium cells **(yellow arrows).** G. Kidney histopathology of *H. fasciatus* found in the Apodu Reservoir. Section shows mild distortion and degeneration of tissue cells **(orange arrows).**

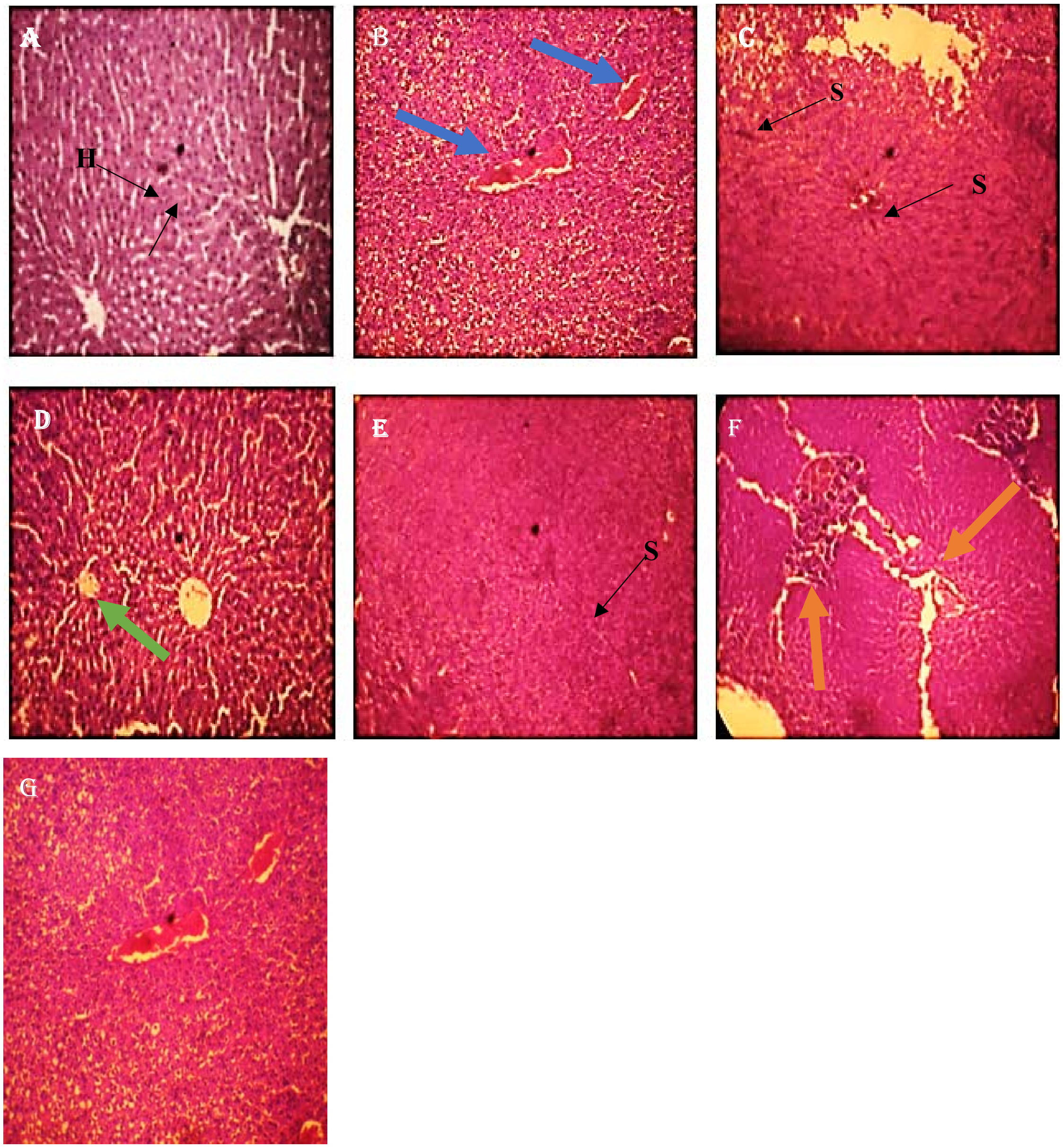

Figure 3. Histopathology of the liver of different species of fish found in the Apodu Reservoir (mag. ×400). Stained: hematoxylin and eosin. A. Histopathology of the liver of *C. gariepinus* exposed to borehole water (negative control) shows normal hepatocytes **(H)** with no interstitial congestion. B. Histopathology of the liver of *A. occidentalis* shows irregular polyhedral plates of hepatocytes with central vein and also portal triads at the edge of hepatocytes (**blue arrows**). C. Histopathology of the liver of *T. mariae* shows irregular hexagonal plates of hepatocytes with central vein and the sinusoid **(S)** at the lobule margin occurs between plates of hepatocytes to converse upon terminal venule. D. Histopathology of the liver of *H. fasciatus* shows normal hepatocytes with little interstitial congestion **(green arrow).** E. Histopathology of the liver of *M. delicious* shows irregular hexagonal plates of hepatocytes with central vein, the sinusoid **(S)** at the lobule margin occurs between plates of hepatocytes to converse upon terminal venule. F. Histopathology of the liver of *C. gariepinus* shows mild distortion of hepatic tissue with interstitial scan **(orange arrows)**. G. Histopathology of the liver of *S. galilaeus* shows normal hepatocytes with no interstitial congestion.

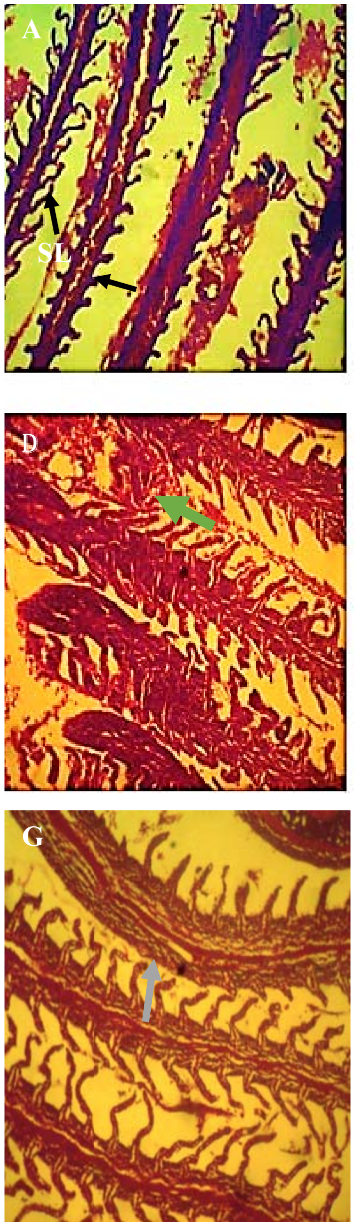

Figure 4. Histopathology of the liver of different species of fish found in the Apodu Reservoir (mag. ×400). Stained: hematoxylin and eosin. A. Histopathology of the gill of *Clarias gariepinus* (negative control) exposed to borehole water. Micrograph shows epithelia lining, cartilage, and normal secondary lamellae (**SL**) **(black arrows).** B**.** Histopathology of the gill of *S. galilaeus* found in the Apodu Reservoir**.** Micrograph shows rupture of epithelia lining and lymphatic cells **(blue arrows).** C. Histopathology of the gill of *M. delicious* found in the Apodu Reservoir. Micrograph shows normal epithelia lining with some adipose **(black arrows).** D. Histopathology of the gill of *C. gariepinus* found in the Apodu Reservoir**.** Micrograph shows mild distortion of epithelia lining and area of lymphocytic infiltration **(green arrow).** E. Histopathology of the gill of *T. mariae* found in the Apodu Reservoir**.** Micrograph section shows epithelia lining and area of lymphocytic infiltration with epithelia lining. F. Histopathology of gill of *A. occidentalis* found in the Apodu Reservoir. Micrograph shows epithelia lining and cartilage **(green arrow head).** G. Histopathology of gill of *H. fasciatus* found in the Apodu Reservoir. Micrograph shows section of mildly distorted cartilage with epithelia lining (**ash arrow**).

DISCUSSION

Micronuclei and nuclear abnormalities are considered as a powerful tool for the detection of DNA damage and pollution bioindicators due to it sensitivity. Our study is the first to examine genotoxic potentials of pollutants on some selected species of fish (*Clarias gariepinus, Saroetherodon gambiensis, Saroetherodon galilaeus*, and *Protopterus annectins*) from the Apodu Reservoir using the MN assay. The histopathology of kidney, liver, and gill of the fishes found in the reservoir and the physicochemical parameters of water samples from the reservoir were also examined.

The source of heavy metals at the Apodu study sites is mainly of exogenous origin, due to either agricultural influx and/or sewage via surrounding cultivated lands. The estimated heavy metals present in the water sample from the Apodu Reservoir were in the order of Ca > Ni > Cl > P > Mg > Fe > Zn > Mn > Cu > Pb = Cr and were above the maximum limit approved by standard organization in drinking water. In addition, nitrate pollution (NO_3^-) was also observed in the reservoir, and this might be as a result of agricultural practices which utilize various types of pesticides and fertilizers (ammonium nitrate, ammonium sulfate, diammonium phosphate, urea [nitrogenous fertilizer]) in this area (Keskin, 2010). These observations might be the one that provoked the anomalies recorded in this study. Thus, this result implies that since water plays a key role in maintaining human health, indiscriminate discharge of unwanted substances continuously into the water body may elevate the aforementioned physicochemical parameters and therefore may cause a detrimental long-time health effect in people making use of the water. Since aquatic pollutants are determined by measuring their concentration in water, sediment, and/or the organisms (Gundogdu et al., 2016), the constituent can be accumulated, thus inducing MN and other nuclear abnormalities as seen in this study. This result is in accordance with the study of Wallin and Hartly-Asp (1993). The results obtained support the fact demonstrated by Kligerman (1982): that fish inhabiting polluted waters have greater frequencies of micronuclei and the micronuclei frequencies may vary according to the kind of pollution involved and the species of fish. In this study, different species of fish present in the reservoir water show varying levels of micronuclei abnormalities in the order *S. gambiensis* > *C. gariepinus* > *P annectins* > *S. galilaeus*. The increase in frequency of MNi and other NAs might be as a result of association of *S. gambiensis* and *Clarias gariepinus* with vegetation and benthic environment that makes them to prone to any alteration in the ecosystem. According to Bustamante et al. (2003), they demonstrated that lower concentrations of heavy metals usually accumulated in pelagic fish compared to the benthic fish. Thus, the heavy metals in the water might settle down in the benthic region and accumulate more in the bottom dweller fishes than pelagic fishes. This result is also supported by Palhares and Grisolia (2002), who demonstrated that two closely related fish species can respond in different ways to a given genotoxic agent. Therefore, humans consuming these fish are not safe as it is possible for the effects to be able to transfer via food chains.

The differences in the pathological damage levels of the fishes at the respective stations could be attributed to differences in their metabolic rates. It has been reported that different organisms have different metabolic rates and different food requirements and amounts. Organisms with high food intake tend to accumulate more pollutants (Ademoroti, 1996).

The kidney histopathology of the fish result shows alterations in form of mild distortion and degeneration of tissue cells, the cortex lined by cuboidal epithelium cells, renal tissue composed of numerous glomeruli, and renal tubules lying back to back which can be attributed to presence of light trace of disturbance and impact in the Apodu Reservoir, and this is in contrast with a research carried out by Kaoud and El-Dahshan (2010).

The liver is made up of hepatocytes, which are not oriented into distinct lobules but are arranged in branched laminae of two cells thick that are separated by sinusoids. Hepatocytes are said to be polygonal cells with a central spherical nucleus and a densely stained nucleolus (Figueiredo-Fernandes et al., 2007). In this study, it was also demonstrated that the liver of control fish exhibits a normal structure and there were no pathological abnormalities. The histopathological analysis of the liver of fish found in the Apodu Reservoir shows some lesions such as muscle congestion, interstitial distortion, vascular dilation, and lymphocyte infiltration as shown in Figure 4A–G. The histopathological analysis points out that of all the fish species found at the Apodu Reservoir, only *C. gariepinus* shows the mild effect in the liver tissue.

The gill, which is one of the vital organs, participates in many important functions in the fish, such as respiration, osmoregulation, and excretion; remains in close contact with the external environment; and is particularly sensitive to changes in the quality of the water, is considered the primary target of the contaminant (Camargo & Martinez, 2007). In this study, there was moderate alteration in the histopathological assessment of the gills of fish species, which revealed mildly distorted cartilage with epithelia lining, cartilage, and area of lymphocytic infiltration, thus affirming the genotoxicity of the Apodu Reservoir. In a related study, according to Klontz (1972), fish are closely associated with their aqueous environment and physical and chemical changes, which indicate that ecosystem is rapidly reflected as quantifiable physiologic measurements in the fish. In general, reactions of the gills of fish due to an irritant includes inflammation, hyperplasia, lamellar fusion, excessive production of mucus, epithelial lifting, flattening of the secondary lamella, and formation of aneurysms. Inflammation, hyperplasia, secretion of mucus, and aneurysms were also observed in *A. fasciatus and Culter alburnus,* demonstrating that the gills of these individuals had been affected by the action of various stressors. As a consequence of the epithelial lifting, there is an increase in the distance between the water and blood, impairing oxygen uptake. However, in these conditions, the fish increase their rate of respiration by compensating for the low entrance of oxygen (Fernandes & Mazon, 2003). According to Winkaler et al. (2001), these types of histopathologic lesions indicate that the fish respond to the effects of pollutants and disturbance in the water and in the sediment. Thus, the disturbance of living processes at the molecular and subcellular levels of biological organization by xenobiotics can lead to cell injury, resulting in degenerative and neoplastic diseases in target organs (Pacheco & Santos, 2002). In more severe cases, the degenerative process can lead to tissue necrosis (Takashima & Hibiya, 1995).

Therefore, since histopathological biomarkers are valuable indicators of the harmful effects of pollutants, the result of the histopathological analysis of the gills, liver, and kidney of selected fish species from the Apodu Reservoir is an indication of water pollution in the reservoir.

CONCLUSION

Our study shows the impact assessment on different species of fish present in the Apodu Reservoir through induction of MN and other nuclear abnormalities as well as alteration to the normal histological architecture of the kidney, liver, and gills amidst different species when compared to the negative control. These alterations might be as a result of the inability of free flowing of the dam system or anthropogenic activities of the people residing around the reservoir. Thus, effort should be made to control the indiscriminate discharge of harmful substances into the water body to curtail future health effects.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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