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Impact of human activities on organ histology, serum biochemistry and oxidative status of Male *Clarias gariepinus* capture from Ureje River

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ABSTRACT

A total of 240 matured Male *Clarias gariepinus* were caught from different fishing points of Ureje river as it flows through Ado Ekiti metropolis (waterworks, Ajebamidele, Emirin, Erinfun and Aduloju fishing locations) and an Earthen Pond. Blood samples were collected from fish samples farmed from different fishing point, and thereafter were slaughtered, organ characteristics and histology assessed. The live weight of fish from earthen pond was significantly ($p<0.05$) higher than that of Aduloju, with the least value obtained in those from Emirin and Erinfun. The weight of liver of fish from Aduloju is significantly (0.05) higher, while Albumin of catfish from Erinfun has a significantly ($p<0.05$) higher value compared to other fishing points, with lowest in Earthen Pond. Alkaline phosphatase of male catfish from Water Works, Emirin, and Aduloju were significantly ($p<0.05$) higher than other fishing points. Lipid peroxidation was significantly ($p<0.05$) higher in Erinfun and Earthen Pond. While Glutathione Peroxidase and Catalase of male catfish from Erinfun and Earthen Pond had significantly higher values than those from other fishing points. Tissue analysis reveals varying degrees of pathology of the liver, heart gill and kidney of fish from the different fishing points, demonstrate the river's poor health, especially in Erinfun and Emirin.

Keywords: Aduloju, Necrosis, Inflammation, Pathophysiology, Peroxidation

INTRODUCTION

Human activities have profound effects on aquatic ecosystems, often leading to the degradation of water quality and the disruption of aquatic life. Rivers are essential sources of freshwater and habitats for numerous aquatic species are particularly vulnerable to anthropogenic influences. In this study, we investigate the impact of human activities on the organ histology, serum biochemistry, and oxidative status of male catfish captured from the Ureje River. Understanding the physiological responses of fish to environmental stressors can inform regulatory measures aimed at mitigating the impacts of pollution and preserving. Freshwater biodiversity is strategic to improving wastewater treatment, implementing land-use regulations, and promoting sustainable practices in agriculture, and industry can help reduce the degradation of water quality and protect vulnerable aquatic species (Adhikari et al., 2018). Additionally, monitoring programs focused on biomarkers of fish health can serve as early warning systems for detecting environmental pollution and guiding remediation efforts, wherefore the histology of fish organs provides valuable insights into the physiological effects of environmental stressors, together with human activities such as industrial discharge, agricultural runoff, and urbanization, which can introduce a myriad of pollutants into aquatic environments, potentially affecting the health of aquatic organisms (Daw et al., 2009; Hedayati 2018). In the case of male catfish from the Ureje River, histological examination may reveal abnormalities in organs such as the liver, gills, and kidneys. Histopathology tends to give an in-depth knowledge on the wellbeing of fishes as it pertains to extent of tissue damage, lacerations and organ functionality (Raibeemol et al., 2020). Liver, gut and kidney functions are crucial aspect of pathological changes in relation to endogenous and exogenous xenobiotics whose source could be nutritional (Van Dyk et al., 2009). Reports on pathological changes in fishes (tilapia, turbot, sharp snout sea bream, carp, rainbow trout, etc.) have been documented (Pereira et al., 2002; Mérida et al., 2010; Bian et al., 2017; Ali et al., 2018; Parmar and Shah, 2020).

However, information on progressive activities on fishing points along river Chenab is still in dart. These abnormalities could include inflammation, necrosis, and fibrosis, indicative of exposure to toxins or pollutants due to the day-to-day activities by users. Assessment of physiological parameters and biomarkers is indicative of the overall health status of fish. Elevated levels of certain enzymes such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST) in the serum may indicate liver damage or dysfunction, often associated with exposure to environmental contaminants. Additionally, alterations in parameters such as glucose, cholesterol, and electrolyte levels may provide further insights into the metabolic and homeostatic responses of fish to environmental stressors. By comparing serum biochemistry profiles of catfish from the Ureje River to those from less impacted environments, the extent of human-induced disturbances can be elucidated. Oxidative stress, resulting from an imbalance between the production of reactive oxygen species (ROS) and the antioxidant defence mechanisms of organisms, is a common consequence of exposure to environmental pollutants (Schlenk, 2003). Fishes are particularly susceptible to oxidative stress due to their high metabolic rates and relatively low antioxidant capacities compared to mammals, including oxidative stress biomarkers such as lipid peroxidation, antioxidant enzyme activities, and levels of antioxidant molecules can provide valuable insights into the oxidative status of fish exposed to anthropogenic pollutants (Farombi et al., 2007). Increased oxidative stress in male catfish from the Ureje River may indicate heightened susceptibility to oxidative damage, potentially leading to physiological impairments and decreased fitness. This study aimed to conduct extensive analysed of the impacts of human activities in the Ureje River region of Ado Ekiti on *Clarias gariepinus*. It emphasized the river's multifaceted role supporting livelihoods such as fishing, industrial laundry, and agriculture, alongside significant pollution inputs from industrial and agricultural runoff. The study's comprehensive approach provides valuable data on the physiological responses of fish to environmental stressors, underscoring the complex interactions between human-induced pollution and aquatic organism health in the Ureje River ecosystem.

MATERIALS AND METHODS

Study area

Ureje which is located on the southern part of Ado-Ekiti between longitudes 70035’55.20N and latitude 50018’12.91E (Okoro et al., 2015) Ureje River is the main river that flows through Ado Ekiti and its environs. It is received in a Dam at water works, and flows through numerous tributaries, as source of livelihood for fishermen, motor and industrial laundry services, irrigation for crop fields, while also receiving domestic wastes, industrial waste and run-off from agricultural fields. As a result of human activities, vast amount of toxic industrial and domestic wastes as well as chemical (herbicide, pesticides) run-off from various crop fields are disposed in the river as it flows through. These could be well sufficient for disparaging change in water quality by changing the physio-chemical properties of the river. This habitat degradation can result in retarded growth of aquatic organisms and affect their quality of life. Fish fishing points along the river were identified, including the Dam holding the river before it enters the communities, where human activities interphase as shown in Figure 1. An earthen pond was selected inland, whose source of water is a borehole which has no direct or indirect connection to the river as a control.

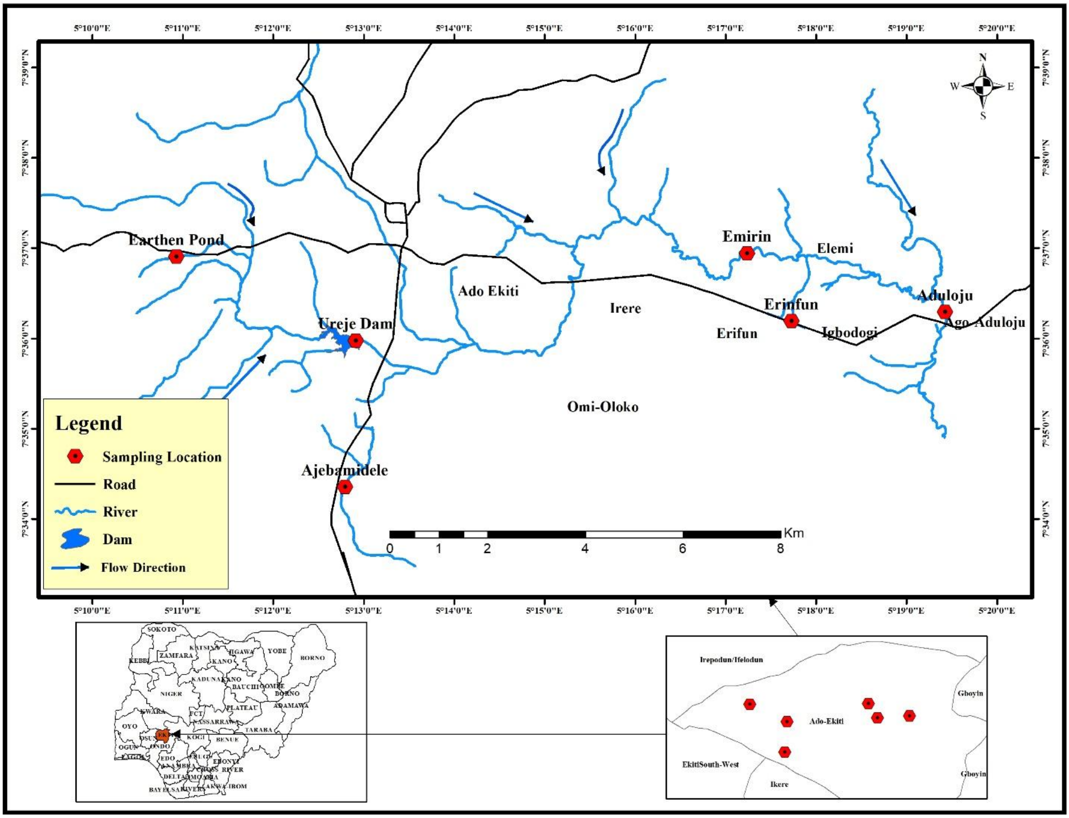

Figure 1: Map showing the location of the sampling points and the earthen pond

Water analysis

Water samples were meticulously collected and analysed for heavy metals and various water quality parameters using advanced techniques like atomic absorption spectrophotometry. A total of 240 adult male African Catfish were sampled from different points along the river and from a control pond, enabling comparative analysis of serum biochemical profiles and oxidative stress markers. Histopathological examinations of fish organs provided crucial insights into tissue health and damage, complemented by statistical methods to assess differences among sample groups.

Water samples were collected from each fishing point into sterile bottles and analysed for water quality parameters; electrical conductivity, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), (Boyd, 1981). The concentration of each metal was detected by heavy metal kits (Merck) and atomic absorption spectrophotometry (APHA, 1998).

Sampling of fish species

A total of 240 adult male African Catfish samples (80 per fishing point) were collected using gill nets and drag nets by fishermen from each fishing point (Singh et al., 2021) and from the earthen pond before 0800hrs between May and September 2023. The fish were sorted and identified as males at the species level by a fish taxonomist. They were transport in plastic tanks to the Animal Production Laboratory, Department of Agricultural Technology, Federal Polytechnic Ado Ekiti and allowed to rest for 2 hours.

Serum analysis

Blood samples were collected from the caudal vein near the ventral fin of each specimen into plain bottles and were centrifuged immediately to obtain serum using standard procedures. Serum biochemical assay; glucose, total protein, albumin, creatinine, urea, alanine amino transferase (ALT), Aspartate amino transferase (AST), cholesterol, triglyceride, high density lipoprotein (HDL), bilirubin was carried out using fortress diagnostics commercial assay kits and its procedures. Determination of serum total antioxidant capacity activities, superoxide dismutase, glutathione peroxidase (GPx), catalase (CAT) activities and lipid peroxidation were assay as outlined in Jimoh et al., (2019).

Organ characteristics and Histopathology

The fish were dissected and organs weighed, dressed weight were obtained. Data obtained were used to compute gonadosomatic index. Sections were collected from gills, kidney, liver, heart and spleen were removed and quickly fixed in 4% formaldehyde solution for histopathological analysis.

Statistical Analysis

Data obtained were subjected to Shapiro-Wilk test to check if data are normally distributed and Levene's test to check if variances are homogeneous. Thereafter descriptive statistics and one-way ANOVA were conducted and means separated with Duncan multiple range test at p=0.05 using the IBM SPSS software package.

RESULTS

Water Analysis of sample from the different fishing sites is shown in Table 1. Erinfun region registered a notably elevated TDS value, while the earthen pond exhibits the lowest TDS concentration. The Total Suspended Solids (TSS) in Erinfun demonstrated the highest value, whereas both Ajebamidele and Aduloju had the lowest TSS levels. Total Solids (TS) encompasses the aggregate quantity of both dissolved and suspended solids found in the water, which can be calculated by adding TDS and TSS values. Within this region, Erinfun had the highest TS measurement, reaching 210.17 mg/l, while Aduloju had an exceptionally low TS measurement of 5.55 mg/l. Dissolved oxygen (DO) ranged from 3.63 mg/l in Ajebamidele to 7.16 mg/l in the Aduloju fishing community, reflecting varying oxygen concentrations. Aduloju also exhibited the highest Biochemical Oxygen Demand (BOD), while Emirin recorded the lowest BOD measurement at 7.16 mg/l. Chemical Oxygen Demand (COD) were higher as observed in Aduloju, whereas Waterworks reported the lowest COD measurement.

Table 1: Water analysis of samples from different fishing points of Ureje river in Ado Ekiti

Parameters (mg/l)	Waterworks	Ajebamidele	Emirin	Erinfun	Aduloju	Earthen pond
Total dissolved solids	96.82	175.65	152.20	208.11	175.65	77.46
Total suspended solids	1.22	0.52	0.74	2.06	0.52	0.67
Total solids	98.04	176.17	152.94	210.17	5.55	78.12
Dissolved oxygen	6.12	3.63	5.55	4.85	7.16	4.16
Biochemical oxygen demand	6.56	13.14	7.16	8.63	17.51	10.24
Chemical oxygen demand	13.89	27.18	16.25	17.51	31.30	21.76

The result of live weight, organ weight and gonadosomatic index stress of male catfish from different fishing point of Ureje river in Ado Ekiti is shown in Table 2. Liveweight of male catfish gotten from earthen pond were significantly ($p<0.05$) higher than Aduloju, while the statistically ($p>0.05$) least value were obtained in those from Emirin and Erinfun. Liver weight from Aduloju were significantly ($p<0.05$) higher than that of Emirin and Erinfun with lowest in the Erinfun (2.48g) and Aduloju (3.16g) fishing points, and highest in the Aduloju (13.58g) fishing point, while values obtained for heart of those from earthen pond were significantly ($p<0.05$) higher than that of Emirin and Erinfun. Dressed weight of male catfish gotten from earthen pond were significantly ($p<0.05$) higher than other fishing point with significantly ($p<0.05$) least values from Emirin and Erinfun. Kidney of male catfish from Aduloju and earthen ponds were significantly ($p<0.05$) higher than fish gotten from Emirin and Erinfun, with lowest values in Erinfun (1.36g) and Emirin (1.58g) fishing points, and highest in Earthen Pond (4.39g). Mesenteric fat from Water Works, Ajebamidele, and Earthen ponds were similar and significantly ($p<0.05$) higher compared to mesenteric fat of catfish gotten from Emirin, Erinfun, and Aduloju. Estimated intestinal weight of male catfish from Earthen Pond were significantly ($p<0.05$) higher than intestine of catfish gotten from Ajebamidele, Emirin, and Erinfun. Gills of male catfish from Ajebamidele were significantly ($p<0.05$) higher than the gills of catfish from Erinfun. Brain of male catfish from Aduloju were significantly ($p<0.05$) higher than other fishing point. Milt of catfish from Water works, Ajebamidele, Emirin, Erinfun, and Earthen ponds were significantly ($p>0.05$) the same and were significantly ($p<0.05$) lower compared to Milt of male catfish from Aduloju. Gonadosomatic index of male catfish from Emirin, Erinfun and Aduloju were significantly ($p<0.05$) higher than Gonadosomatic index of catfish gotten from Water works and Earthen Pond.

Table 2: Liveweight, organ weight and gonadosomatic index stress of male catfish from different fishing point of Ureje river in Ado Ekiti

	Water Works	Ajebamidele	Emirin	Erinfun	Aduloju	Earthen Pond	SEM
Liveweight (g)	535.06^{bc}	603.10^{bc}	398.98^{c}	372.26^{c}	773.66^{b}	1058.96^{a}	54.54
Liver (g)	6.24^{bc}	6.78^{bc}	3.16^{c}	2.48^{c}	13.58^{a}	9.66^{ab}	0.88
Heart (g)	0.70^{ab}	0.64^{ab}	0.50^{b}	0.56^{b}	0.80^{ab}	1.17^{a}	0.08
Dressed weight (g)	454.82^{bc}	522.54^{bc}	320.60^{c}	326.02^{c}	667.04^{b}	928.57^{a}	49.55
Kidney (g)	1.86^{bc}	2.28^{bc}	1.58^{c}	1.36^{c}	3.54^{ab}	4.39^{a}	0.29
Mesenteric fat (g)	12.50^{ab}	14.00^{ab}	2.52^{c}	1.62^{c}	11.34^{b}	19.89^{a}	1.51
Intestine (g)	21.64^{ab}	16.24^{bc}	11.04^{c}	10.70^{c}	16.94^{abc}	24.60^{a}	1.32
Gills (g)	16.34^{ab}	48.90^{a}	10.50^{ab}	3.62^{b}	17.78^{ab}	29.09^{ab}	5.43
Brain (g)	5.12^{bc}	5.54^{abc}	4.22^{c}	3.26^{c}	8.66^{a}	8.06^{ab}	0.53
Milt (g)	1.02^{b}	3.08^{b}	2.32^{b}	2.18^{b}	5.56^{a}	2.18^{b}	0.35
Gonadosomatic index	0.22^{b}	0.55^{ab}	0.71^{a}	0.70^{a}	0.83^{a}	0.27^{b}	0.06

$^{a,\,b,\,c}$ Mean in the same row with different superscripts are significantly ($p<0.05$) different.

Serum biochemistry from different fishing point of Ureje river in Ado Ekiti is presented in Table 3. Total Protein had highest values in Earthen Pond (48.10 g/dl), and the lowest in Emirin (29.15 g/dl). Glucose values of male catfish from Ajebamidele were significantly ($p<0.05$) higher than glucose of male catfish from other points, which share significantly ($p>0.05$) similar values. Values of Albumin from fishes in Erinfun had significantly ($p<0.05$) higher value compared to Albumin of catfish from other fishing points, which share statistically ($p>0.05$) similar values, Aduloju (215.63 g/l) had highest albumin value, and the lowest was in Earthen Pond (126.25 g/l).

Table 3: Serum biochemistry of male catfish from different fishing point of Ureje river in Ado Ekiti

	Water Works	Ajebamidele	Emirin	Erinfun	Aduloju	Earthen Pond	Normal Range	SEM
Glucose (mmol/L)	12.16 [b]	24.05[a]	19.03 [b]	12.49 [b]	20.35 [b]	15.99 [b]	3.5-18.0	3.42
Total Protein (g/dl)	43.01[a]	39.18[ab]	29.15[b]	36.08[ab]	48.10[a]	30.86[b]	30-55	5.33
Albumin (g/l)	166.67[b]	140.83 [b]	155.83 [b]	215.63[a]	156.67 [b]	126.25 [b]	120-200	15.05
Alkaline phosphatase (U/I)	63.48[a]	46.00[b]	79.12[a]	46.23[b]	62.56[a]	11.73[c]	20-80	56.83
Aspartate amino transferase (U/I)	4.03[b]	13.67[ab]	17.75[ab]	16.90[ab]	29.81[a]	30.15[a]	10-35	5.47
Alanine amino transferase (U/I)	21.25	20.50	23.85	21.50	23.29	26.68	15-45	1.56
Bilirubin (mg/dl)	2.63[c]	3.64[b]	2.51[c]	1.75[c]	3.57[b]	5.66[a]	1.5-5.0	0.64
Urea (mmol/l)	3.47	3.12	3.95	4.07	4.33	5.52	2.0-6.0	0.36
Creatinine (mg/dL)	1.11[c]	6.22[b]	171.33[a]	5.83[b]	2.89[c]	51.00[b]	0.5-3.0	25.07
Cholesterol (mmol/l)	1.57	1.88	2.34	2.48	1.86	1.87	1.0-2.5	0.14
Triglyceride (mmol/l)	28.99	37.17	22.51	17.51	16.18	35.45	15-40	4.50
High density lipoprotein (mmol/l)	3.85	3.46	2.73	2.84	3.11	3.31	2.5-4.0	0.22

[a, b, c]Mean in the same row with different superscripts are significantly ($p<0.05$) different. Normal range values are culled from studies of Farombi et al., (2007); Hedayati (2018); Ali et al., (2018); Jimoh et al., (2015)

Alkaline phosphatase of male catfish from Water works, Emirin and Aduloju were significantly ($p<0.05$) higher than Alkaline phosphatase of fish from other fishing points, with catfish from earthen pond having the statistically ($p<0.05$) least value. Aspartate amino transferase of catfish from Aduloju and Earthen ponds were significantly ($p<0.05$) higher than catfish from Water Works. Alanine amino transferase, Urea, Cholesterol, Triglyceride, high density lipoprotein of male catfish was not influenced by the sites. Bilirubin of male catfish from Earthen Pond was significantly ($p<0.05$) higher than Bilirubin of catfish from Aduloju and Ajebamidele, while those from Water works, Emirin and Erinfun had statistically least bilirubin. Creatinine of male catfish from Emirin was significantly ($p<0.05$) higher compared to other fishing point.

Oxidative stress of male catfish from different fishing point of Ureje river in Ado Ekiti is presented in table 4. Total Antioxidant activity of male catfish from Water works, Ajebamidele, Emirin, Erinfun and Earthen Pond were significantly ($p>0.05$) same and had significantly ($p<0.05$) higher values compared to the Total Antioxidant activity of male catfish from Aduloju. The result showed that Lipid peroxidation was significantly ($p<0.05$) higher in male catfish from Erinfun and Earthen Pond compared to other fishing point. Superoxide Dismutase of male catfish from Earthen pond was significantly ($p<0.05$) higher than other fishing point, with the significantly ($p>0.05$) least value obtained in those from Aduloju, recording highest in the Earthen Pond (6.46 U/min/mg protein) fishing point, and lowest in the Aduloju (0.23 U/min/mg protein), Water Works (0.40 U/min/mg protein), and Ajebamidele (0.18 U/min/mg protein) fishing points. Glutathione Peroxidase and Catalase of male catfish from Erinfun and Earthen Pond were significantly ($p<0.05$) higher than those from other fishing point.

Table 4: Oxidative stress of male catfish from different fishing point of Ureje river in Ado Ekiti

	Water Works	**Ajebamidele**	**Emirin**	**Erinfun**	**Aduloju**	**Earthen Pond**	**SEM**
Total Antioxidant activity (mmol/L)	0.81 ^{a}	0.81 ^{a}	0.81 ^{a}	0.95 ^{a}	0.22 ^{b}	0.80 ^{a}	0.09
Lipid peroxidation (x10^{-5}MDA/mg protein)	1.05^{b}	1.95^{b}	3.41^{b}	16.65^{a}	0.88^{c}	12.56^{a}	3.47
Superoxide Dismutase (U/min/mg protein)	0.40^{c}	0.18^{c}	4.28^{b}	1.59^{b}	0.23^{c}	6.46^{a}	1.22
Glutathione Peroxidase (mg GSH/min/mg protein)	1.96^{c}	1.24^{c}	3.60^{b}	15.56^{a}	0.55^{c}	9.99^{a}	2.93
Catalase (nm H_2O_2/min/mg protein)	3.2^{c}	2.7^{c}	0.4^{c}	36.0^{a}	3.30^{b}	43.3^{a}	11.2

$^{a, b, c}$ Mean in the same row with different superscripts are significantly ($p<0.05$) different

Histopathology of fish organs from different fishing points is shown in Table 5 and micrographs presented in Fig 1-9 presented. At waterworks gills had hyperplastic epithelia of the lamellae with abnormal growth of cells. Observations in the gill in fishes in Ajebamidele, showed accumulation of fluid in body tissues, inflammation and possible cell damage. With the increase in the gill size, loss of secondary lamella occurs, as there seem to be displacements in the epithelium. Those captured in Erinfun had loss of secondary laminae in the gills with necrosis or inflammation. In Waterworks the liver had accumulation of lipid droplets or glycogen in the cytoplasm of liver cells. The presences of piknotic nucleus were also observed. Excessive amount of fats in the liver was observed for, can be caused by hepatic disorders, due to toxin, or toxic substances.

At Emirin, Liver of those captured in Ajebamidele, with accumulation of blood in the liver. Fishes in Erinfun had liver steatosis and congestion within the liver. At Aduloju, there is the presence of giant cells in the liver with vacuolated hepatosis. There was also presence of thrombus (a thrombus can be formed when there is adhesion of leukocytes to vessel walls, causing narrowing of portal veins. The live in Earth Pond revealed congestion of vessels and accumulation of fats (steatosis). Histopathological analysis in the cardiovascular region showed that Water works showed injuries within the blood vessels close to the heart. Ajebamidele had mild infiltration of heart with inflammatory cells.

Emirin had mild haemorrhages and mild cellular infiltrations in the fish, with heammorhages. In Aduloju there were mild lymphocytes infiltrations, with an inflammation going on within the heart. In the kidney, water works showed infiltration of cells, while Ajebamidele had massive infiltration of epithelial cells. Emirin had an influx of inflammatory cells, with tubular epithelial necrosis. Fishes in Erinfun revealed coagulative necrosis of the tubular epithelial cells and macrophages. Aduloju recorded severe influx of inflammatory cells into the kidney with mild inflammation.

Table 5. Histopathology of fish organs from different fishing sites

Location	**Organs**			
	Gills	**Liver**	**Heart**	**Kidney**
Water Works	Hyperplastic epithelia of the lamellae Mating of the secorndary lamillae	Centrilobular vacuolation of hepathocytes Presence of piknotic nucleus of some cells (necrosis)	Widespread Haemorrhages	Moderate cellular infiltration within the interstitia Mild necrosis of the tubular epithelial cells

Ajebamidele	Oedema Loss of secorndary lamellae Necrosis of the epithelia	Severe steatosis	Mild lymphocytes and macrophages infiltration	Massive infiltration of the interstitium with inflammary cells Coagulative necrosis of the tubular epithelial cells
Emirin	There is no visible changes	Congestion Coagulative necrosis of the hepatocytes Severe macrophage and lymphocytes infiltration	Mild haemorrhages Mild cellular infiltrations	Loss of architecture Mild cellular infiltration in the interstitium Mild necrosis of the tubular epithelial cells
Erinfun	Loss of secorndary lamillae	Steatosis congestion	No changes	Coagulative necrosis of the tubular epithilia cells Infiltration of the interstitial with lymphocytes and macrophages
Aduloju	No changes	Presence of giant cells Vacoulation of hepatocytes Coagulative necrosis Loss of architecture Presence of thrombus	Mild lymphocytic infiltrations	Severe infiltration of the interstitium with inflammatory cells
Earthen Pond	mild sloughing of the lamilae and necrosis of the epithelial cells	Congestion of blood vesels Generalized steatosis Severe degeneration of hepathocytes and necrosis	No visible changes	Severe cellular infiltration (macrophages, lymphocytes and plasma cells) of the interstitium Mild necrosis of the tubular epithelial cells

DISCUSSION

Water quality is a critical factor influencing the health and sustainability of aquatic ecosystems and the organisms inhabiting them. The analysis of water parameters from different fishing points along the Ureje River in Ado Ekiti provides valuable insights into the environmental conditions and potential stressors impacting the aquatic habitat. Elevated TDS levels can indicate increased salinity or the presence of dissolved minerals, potentially due to agricultural runoff, industrial discharge, or natural geological processes. TDS values seem to be elevated in the context of this study, in contrast with documented report in the rain and mangrove forest zones in Nigeria (Orobator et al., 2020; Keremah et al., 2014) and this observation may be heightened by the presence of dissolved solids within the aquatic environment of the Ureje River. Total Suspended Solids (TSS) levels also show variability among the fishing points, while High TSS levels can impair water clarity, reduce light penetration, and negatively impact aquatic organisms by smothering benthic habitats and affecting respiratory structures as reported (Adjovu et al., 2023). DO levels are crucial for supporting aquatic life, with higher concentrations indicating better water quality and habitat conditions. Erinfun region recorded the highest levels of TDS, TSS, and TS, indicating a substantial presence of pollutants. This region's high BOD and low DO levels suggest a heavily polluted environment, likely due to extensive human activities and waste disposal. Low DO in Ajebamidele could lead to hypoxic conditions, impacting fish respiration and overall ecosystem health. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are indicators of organic pollution and the oxygen-consuming capacity of water (Boyd and Hanson, 2010). A high BOD and COD level in Aduloju indicates a significant organic pollution, possibly from anthropogenic sources such as sewage discharge or agricultural runoff. Elevated BOD and COD were higher than documented report in Tigoni in Limuru sub-county in Kenya (Wanja et al., 2020) and fell within the range as reported by Olopade (2013), leading to oxygen stress and impaired aquatic life. The analysis of water parameters from different fishing points in Ureje River highlights variations in water quality and potential stressors affecting the aquatic ecosystem. Understanding these variations is essential for implementing effective management and conservation strategies to mitigate the impacts of pollution and ensure the health and sustainability of the river ecosystem and its associated biodiversity. Continued monitoring and assessment of water quality parameters are necessary to track changes over time and inform adaptive management practices for the preservation of freshwater resources (Rytwinski et al., 2017).

Liveweight, organ weight, and gonadosomatic index (GSI) are essential indicators of the physiological condition, growth, and reproductive status of fish populations. In this study, male catfish captured from various fishing points along the Ureje River in Ado Ekiti were analyzed for these parameters. Liveweight and dressed weight exhibited significant variability among fishing points, reflecting differences in growth rates and nutritional status. The highest liveweight and dressed weight displayed in fishes reared in earthen pond indicated better growth conditions and nutritional availability as there is no much competition for food among the population compared to other fishing points where there is scavenging for food. Fishes in Emirin and Erinfun displayed the lowest liveweight and dressed weight, suggesting potential environmental stressors or resource limitations impacting growth performance. Pollutants adversely affect the growth and health of fish, evidenced by reduced live weights and organ dysfunctions, which can lead to decreased fish populations and biodiversity. The variations in liver, heart, kidney, mesenteric fat, intestine, gills, brain, and milt weights among fishing points is indicating differences in organ development and physiological adaptation (Abanikannda et al., 2019). Fish from Aduloju exhibited the highest liver weight, suggesting potential metabolic activity or storage functions. Erinfun showed the lowest liver weight, indicating potential nutritional deficiencies, metabolic stress or hypertrophy due to pollutants. Similar patterns were observed for heart, kidney, mesenteric fat, intestine, gills, brain, and milt weights, reflecting the influence of environmental conditions on organ development and functionality as also observed in Syngnathus abaster in Lake Bafa (Gurkan and Innal, 2018). Gonadosomatic Index (GSI) reflects the reproductive investment of fish and provides insights into the spawning readiness and reproductive potential of male individuals. Fish from Aduloju displayed the highest GSI which is higher than that obtain in North East Nigeria and Calabar (Eze et al., 2022 and Eyo et al., 2014), indicating advanced reproductive development and readiness for spawning. Fish from Waterworks exhibited the lowest GSI, suggesting delayed or inhibited reproductive maturation, possibly due to environmental stressors or suboptimal conditions. The observed variations in GSI highlight the importance of environmental factors in regulating reproductive processes and population dynamics in fish species. Environmental stressors such as poor water quality, habitat degradation, and resource availability can impact fish growth, organ development, and reproductive performance. Fish populations experiencing favorable conditions, such as abundant food resources and suitable habitat, exhibit better growth rates, organ development, and reproductive readiness, as seen in Earthen Pond and Aduloju. In contrast, populations facing environmental stressors or resource limitations may show reduced growth, impaired organ development, and delayed reproductive maturation (Hedayati 2018), as observed in Emirin and Erinfun. The liver, heart, kidney, mesenteric fat, intestine, gills, brain, and milt play crucial roles in metabolic regulation, nutrient processing, osmoregulation, and reproduction in fish. Variations in organ weights among fishing points reflect the adaptive responses of fish to environmental conditions and resource availability. Understanding these physiological adaptations is essential for assessing the overall health and fitness of fish populations and informing management strategies for sustainable fisheries. The gonadosomatic index provides valuable information on the reproductive status and potential of fish populations. Monitoring GSI can help assess the reproductive health and resilience of fish populations to environmental stressors and guide conservation efforts to maintain viable breeding stocks (Ekanem et al., 2012).

Elevated glucose levels, as seen in Ajebamidele and Emirin, may indicate stress responses or metabolic dysregulation due to environmental factors such as poor water quality or nutritional imbalances. However, lower levels, as observed in Waterworks and Aduloju, may suggest relatively less stressful conditions. Total protein and albumin levels showed considerable variability among fishing points. High total protein levels at Waterworks and Earthen Pond could be indicative of dehydration or increased protein synthesis in response to stressors. Similarly, variations in albumin levels reflect differences in nutritional status and liver function among fishing points. Alkaline phosphatase (ALP) levels were highest at Emirin and lowest at Ajebamidele, indicating potential liver or bone pathology. Elevated ALP levels often suggest liver dysfunction or bone disorders. Aspartate aminotransferase (AST) and alanine aminotransferase (ALT) levels showed moderate variations among fishing points, indicating potential liver damage or metabolic stress, these values were however lower than that recorded for aquatic organism (Farah et al., 2010) . Higher AST and ALT levels at Aduloju and Earthen Pond may reflect increased liver enzyme activity due to environmental stressors or toxic exposure. Bilirubin levels varied significantly among fishing points, with the highest levels observed at Earthen Pond and the lowest at Erinfun. Elevated bilirubin levels may indicate liver dysfunction or hemolytic disorders. The observed variations suggest differences in the prevalence of liver pathology or hemolytic processes among fishing points. Urea and creatinine levels reflect renal function and metabolic waste clearance in fish. While urea levels showed minimal variation among fishing points, creatinine levels exhibited significant differences. Elevated creatinine levels at Emirin and Aduloju suggest renal impairment or metabolic disturbances, possibly due to toxin exposure or renal dysfunction. Cholesterol, triglyceride, and HDL levels showed moderate variations among fishing points, reflecting differences in lipid metabolism and nutritional status. Higher cholesterol and triglyceride levels at Emirin and Erinfun may indicate dyslipidemia or nutritional imbalances Analysis of serum biochemistry in male catfish from different fishing points along the Ureje River highlights significant variations in metabolic profiles and physiological health among fish populations. These variations likely result from the diverse environmental conditions, water quality parameters, and potential stressors present at each fishing point. Understanding these biochemical changes is crucial for assessing the overall health status of fish populations and implementing targeted management strategies to mitigate environmental impacts on aquatic ecosystems.

When the biochemical values obtained in the present study were compared with established normal reference ranges for healthy male *Clarias gariepinus* (Farombi et al., 2007; Jimoh, Adebayo & Fapohunda, 2015; Hedayati, 2018; Ali, Khalil, Abd El-Kader & Abumourad, 2018; Farah, Ateeq, Ali, Sabir & Ahmad, 2010), distinct deviations were observed across sampling sites. Glucose concentrations in fish from the Ureje River ranged between 12.16 and 24.05 mmol/L, which exceeded the normal range of 3.5–18.0 mmol/L, indicating a pronounced hyperglycemic response. This elevation reflects a typical metabolic stress condition arising from exposure to pollutants or fluctuations in dissolved oxygen levels. Similarly, serum alanine aminotransferase (ALT) activity, which normally ranges from 15 to 45 U/L, increased markedly at Erinfun and Aduloju, signifying hepatocellular membrane damage and enzyme leakage linked to contaminant exposure. In contrast, aspartate aminotransferase (AST) values were below the reference range of 10–35 U/L, suggesting enzyme inhibition or reduced metabolic turnover under chronic stress conditions.

Total protein and albumin concentrations fell within normal limits (30–55 g/L and 120–200 g/L respectively), implying that hepatic synthetic function was not severely impaired. However, the albumin-to-globulin ratio exceeded the typical range of 0.8–1.4, reaching up to 2.3 in some locations, which may indicate dehydration or plasma protein imbalance associated with sublethal pollutant exposure. Elevated alkaline phosphatase (ALP) values observed at the same sites further confirm hepatobiliary stress and possible adaptive detoxification processes. Urea levels, which normally range from 2.0–6.0 mmol/L, were higher at polluted downstream stations (up to 8.42 mmol/L), suggesting increased protein catabolism and mild renal impairment. Creatinine concentrations remained within the physiological limit (0.5–3.0 mg/dL), implying that renal function was only mildly affected.

The relatively uniform antioxidant activity suggests a consistent response to oxidative stress across the study area, with variations at Earthen Pond possibly attributed to local environmental conditions or stressors (Moreno et al., 2010). LP indicated by the formation of malondialdehyde (MDA), is a common marker of oxidative damage to cell membranes (Cordiano et al., 2023 and Ayala et al., 2014)). The highest levels of lipid peroxidation were observed at Erinfun and Aduloju, indicating elevated oxidative stress and membrane damage in fish from these locations, there values were higher than that obtained in the Swedish river salmon (Keinänen et al., 2022). The significant variation in lipid peroxidation among fishing points highlights differences in environmental stressors and the susceptibility of fish to oxidative damage

(Forman and zhang, 2021). GPx is another important antioxidant enzyme involved in the detoxification of hydrogen peroxide and organic hydroperoxides. Fish from Erinfun and Aduloju showed the highest GPx activity, indicating increased oxidative stress the need for enhanced antioxidant defenses. Lower activity levels were observed at Waterworks and Ajebamidele, suggesting relatively lower oxidative stress levels or differences in antioxidant enzyme regulation. The variations in GPx activity highlight the dynamic response of fish to environmental stressors and oxidative challenges. CAT is a key enzyme involved in the breakdown of hydrogen peroxide into water and oxygen, thus protecting cells from oxidative damage. Fish from Aduloju and Earthen Pond exhibited the highest CAT activity, indicating increased hydrogen peroxide detoxification capacity in response to elevated oxidative stress levels. The significant differences in CAT activity underscore the importance of this enzyme in mitigating oxidative stress in fish exposed to environmental challenges (Shahbaz et al., 2021). Elevated oxidative stress markers suggest that fish in polluted areas are under significant physiological stress, which can impair immune function and reproductive capacity. These findings highlight the importance of understanding oxidative stress dynamics in assessing the health and resilience of fish populations in aquatic ecosystems. The high levels of lipid peroxidation observed at Erinfun and Aduloju indicate elevated oxidative damage to cell membranes, potentially resulting from exposure to pollutants, contaminants, or other stressors, although values from this study was lower than that reported for mrigala fingerlings in the middle east (Iqbal et al., 2016), but they were in line with that obtained for Oreochromis niloticus as reported by (Atli et al., 2006). There were relatively lower lipid peroxidation levels at Waterworks and Ajebamidele suggest better environmental quality or lower oxidative stress levels in these locations. The differences in antioxidant enzyme activities among fishing points reflect adaptive responses to oxidative stress, with fish modulating their antioxidant defenses based on local environmental conditions and stressor exposure (Espinal-Carrión, & López-López, 2010). Assessment of oxidative stress parameters in male catfish from different fishing points in Ureje River highlights variations in antioxidant defenses and oxidative damage among fish populations. These variations reflect differences in environmental conditions, stressor exposure, and the adaptive responses of fish to oxidative challenges. The histopathological analysis of fish organs provides valuable insights into the health status of aquatic ecosystems, especially concerning environmental stressors, water quality, and potential impacts on aquatic organisms.

Histopathological examinations revealed severe tissue damage in the gills, liver, heart, and kidneys of fish from polluted sites. Observations included necrosis, inflammation, fatty degeneration, and cellular infiltration, particularly in fish from Erinfun and Emirin. In line with the report of Roberts

(2001) that hyperplasia may be as a result of the fish's response to blockage and irritation both externally or internally especially response to unpleasant substances in the feed or water. At waterworks, observation on the gills exhibited hyperplastic epithelia of the lamellae, edema, and erosion, suggesting gill damage possibly due to poor water quality and environmental stressors. Sulem et al (2023) recorded hyperplasia of interlamellar epithelia, fusion of lamellae, curling of secondary lamellae, edema of primary lamellae, and erosion of secondary lamellae in gills of fish reared in tanks in Cameroon. Ajebamidele samples showed fluid accumulation, inflammation, and necrosis, likely due to low oxygen intake as compared to Emirin samples with loss of secondary lamellae, congestion, and hemorrhages, indicative of tissue damage and hypoxia. Fishes sampled from Erinfun had necrosis, hyperplasia, and sloughing off of lamellae, indicating exposure to toxins, parasites, or physical trauma lamellar sloughing and necrosis occurred in earthen pond, possibly due to gill irritation from toxins or pathogens (Abdel-Moneim et al., 2012). Within the liver, waterworks samples showed lipid accumulation and piknotic nucleus, suggesting injury or inflammation. Ajebamidele samples displayed excessive fat deposition and inflammatory infiltrates, possibly due to hepatic disorders or toxin exposure. Emirin exhibited blood congestion and coagulative necrosis, indicating hypoxia and ischemia. Erinfun samples displayed steatosis and hepatocyte degeneration, likely triggered by infections or toxins. Earthen Pond samples showed vessel congestion and severe hepatocyte degeneration, possibly due to heart failure or immune responses. However, Ezemonye and Ogbomida (2011) reported swelling of hepatocytes with mild necrosis, pyknosis, and vacuolation in *Clarias gariepinus* fingerlings exposed to lethal and sublethal concentrations of Gammalin 20 elsewhere in Southwest, Nigeria. Cardiac examination in fishes in Ajebamidele displayed mild infiltrations, suggesting inflammation from infections or toxins. Emirin samples showed mild hemorrhages and infiltrations, indicative of tissue damage from viral infections or toxins. Erinfun samples exhibited mild lymphocytic infiltrates, indicating active inflammation. Waterworks samples exhibited ongoing vascular disease, possibly due to environmental stressors or viral infections. Earthen Pond samples showed abrupt cell death and necrosis, possibly from toxin exposure or infections. Kidney examinations on waterworks samples displayed cell infiltration, likely due to inflammation from toxic substances or infections (Perrichon et al., 2017). Ajebamidele samples exhibited massive cell infiltrates and necrosis, indicative of severe inflammation and ischemia. Emirin samples showed inflammatory cell influx and tubular necrosis, possibly due to infections or toxins. Erinfun samples displayed necrosis and hyperplasia, suggesting exposure to toxins or pathogens. Earthen Pond samples exhibited inflammatory infiltrates and degeneration, possibly from chronic inflammation or toxin exposure. However, across all fishing points, common histopathological alterations included inflammation, necrosis, and cellular degeneration, indicating the pervasive impact of environmental stressors, toxins, and infections on fish health. Although the severity and specific histological changes varied among locations, reflecting differences in environmental conditions and contaminant levels. Waterworks and Ajebamidele samples exhibited signs of gill damage and liver inflammation, likely influenced by poor water quality and oxygen levels. Emirin and Earthen Pond samples showed indications of hypoxia, congestion, and tissue damage in various organs, possibly due to ischemia and toxin exposure. Erinfun samples displayed a range of histopathological alterations, suggesting multiple stressors affecting fish health. The histopathological damage underscores the detrimental effects of pollutants on fish health, reflecting broader ecosystem degradation, thus calls for immediate remediation efforts to restore water quality and protect aquatic life. Chronic exposure to pollutants can lead to long-term population declines in sensitive species, altering the ecological balance. The biochemical deviations—particularly elevated glucose, ALT, ALP, and urea with reduced TAC—demonstrate that fish populations from Erinfun and Aduloju were under significant physiological and oxidative stress. This pattern correlates with histological alterations observed in the liver, kidney, and gills, providing strong evidence of anthropogenic impact on the health status of *Clarias gariepinus* in Ureje River.

A clear spatial trend in water quality and fish health indicators was observed along the Ureje River, demonstrating progressive deterioration from the upstream (Waterworks) to the downstream stations (Erinfun and Aduloju) when compared with the borehole control. The control borehole, representing uncontaminated baseline conditions, exhibited the lowest concentrations of heavy metals, optimal physicochemical parameters, and normal biochemical and histological profiles in *Clarias gariepinus*. Similarly, fish from the Waterworks site, located near the river's source with minimal human influence, showed biochemical values largely within normal reference ranges and well-preserved tissue architecture, confirming low ecological stress.

In contrast, downstream sites—particularly Erinfun and Aduloju—showed markedly higher concentrations of sodium, magnesium, potassium, arsenic, nickel, lead, and cadmium in water samples, exceeding those recorded upstream. These elevated concentrations corresponded with significant physiological alterations in captured fish, including increased glucose, ALT, ALP, and urea levels, reduced total antioxidant capacity, and histopathological lesions such as hepatic vacuolation, gill hyperplasia, and renal tubular necrosis. Such biochemical and histological deviations are classical biomarkers of pollutant-induced oxidative stress and metabolic disruption.

The pronounced degradation at these downstream points reflects cumulative anthropogenic inputs from agricultural runoff, domestic wastewater, and industrial effluents that enter the river after passing through urban settlements. The gradient of contamination thus establishes a strong cause–effect relationship between pollutant load and biological response. Fish from downstream sites are therefore under higher oxidative and physiological stress compared to those from upstream and control locations. This pattern underscores that the Ureje River functions as a pollution sink, with pollutant concentration and biological impact intensifying along its flow path from the source to discharge zones. Consequently, Erinfun and Aduloju emerge as critical monitoring points requiring urgent mitigation to restore ecological balance and protect aquatic biodiversity.

CONCLUSION

This study highlights the significant water quality degradation of Ureje River due to extensive human activities, leading to elevated levels of pollutants and substantial impacts on aquatic life. Variations in physico-chemical parameters, fish growth, serum biochemistry, oxidative stress markers, and histopathological findings across different fishing points demonstrate the river's poor health, especially in regions like Erinfun and Emirin. These results underscore the urgent need for effective waste management, pollution control, and continuous monitoring to protect the river's ecosystem and ensure the sustainability of its resources for local communities. Immediate remediation efforts and stringent regulatory measures are essential to mitigate these adverse effects and restore ecological balance.

REFERENCES

Abanikannda, O. T. F., Jimoh, A. A., Giwa, A. O., & Awosanya, L. A. (2019). Sexual dimorphism in body weight, morphometric measures and indices of African Catfish (Clarias gariepinus). Aquaculture, 502, 148–152. https://doi.org/10.1016/j. aquaculture.2018.12.040.

Abdel-Moneim, A.M., Al-kahtani, M.A. and Elmenshawy, O.M (2012). Histopathological biomarkers in gills and liver of Oreochromis niloticus from polluted wetland environments, Saudi Arabia. Chemosphere, vol. 88, no. 8, pp. 1028-1035.

Adhikari, S., Keshav, C. A., Barlaya, G., Rathod, R., Mandal, R. N, Ikmail, S., et al. (2018). Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India. J. Fish. 12, 016–021.

Adjovu GE, Stephen H, James D, Ahmad S. (2023). Measurement of Total Dissolved Solids and Total Suspended Solids in Water Systems: A Review of the Issues, Conventional, and Remote Sensing Techniques. Remote Sensing.; 15(14):3534. https://doi.org/10.3390/rs15143534

Ali, T.E.S.; El-Sayed, A.M.; Eissa, M.A.R. andHanafi, H.M. (2018). Effects of dietary Biogen and sodium butyrate on hematological parameters, immune response, and histological characteristics of Nile tilapia (Oreochromis niloticus) fingerlings. Aquaculture International. 26(1): 139-150.

Atli G, Alptekin O, Tükel S, Canli M. Response of catalase activity to Ag+, Cd2+, Cr6+, Cu2+ and Zn2+ in five tissues of freshwater fish Oreochromis niloticus. Comp Biochem Physiol C Toxicol Pharmacol. 2006 Jun;143(2):218-24. doi: 10.1016/j.cbpc.2006.02.003.

Ayala, A., Muñoz, M. F., & Argüelles, S. (2014). Lipid peroxidation: production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. Oxidative medicine and cellular longevity.

Bian, F.; Zhou,H.; He, G.; Wang, C.;Peng, H.; Pu, X.; Jiang, H.;Wang, X. andMai, K. (2017). Effects of replacing fishmeal with different cottonseedmeals on growth, feed utilization, haematological indexes, intestinal and liver morphology of juvenile turbot (Scophthalmus maximus L.). Aquaculture Nutrition,23(6): 1429-1439.

Cordiano, R., Di Gioacchino, M., Mangifesta, R., Panzera, C., Gangemi, S And Minciullo, P.L (2023). Malondialdehyde as a Potential Oxidative Stress Marker for Allergy-Oriented Diseases: An Update. Molecules, 28 (16), 59-79; https://doi.org/10.3390/molecules28165979

Boyd CD, Hanson T. Dissolved-oxygen concentration in pond aquaculture. Global Aquaculture Advocate. 2010; 13:40-41.

Daw, T., Adger, W. N., Brown, K., and Badjeck, M. C. (2009). "Climate change and capture fisheries: potential impacts, adaptation and mitigation," in Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530, eds K. Cochrane, C. De Young, D. Soto, and T. Bahri (Rome: FAO), 107–150.

Espinal-Carrión, T., & López-López, E. (2010). Helminths and lipid peroxidation in Astyanax aeneus (Pisces: Characidae) from a river in the humid subtropics of southeastern Mexico. Diseases of aquatic organisms, 88(3), 215-224.

Eze, F., Haruna, M. Y and Abraham, V. O. (2022). A Comparative Study on the Gonadosomatic Index and Milt Volume of Four Populations of Clarias gariepinus (Burchell, 1822) Broodstock Strains from North-East Nigeria. Asian Journal of Fisheries and Aquatic Research 17(5):8-19. DOI:10.9734/ajfar/2022/v17i530415

Ezemonye, L. and Ogbomida, T.E., 2010. Histopathological effects of Gammalin 20 on African catfish (Clarias gariepinus). Applied and Environmental Soil Science, vol. 2010, pp. 1-8. http://dx.doi.org/10.1155/2010/138019.

Eyo, V. O., Ekanem, A. P and Jimmy, U. U. (2014). A Comparative study of the Gonadosomatic index (GSI) and Gonad Gross Morphometry of African Catfish (Clarias gariepinus) fed Unical Aqua Feed and Coppens commercial feed. Croatian Journal of Fisheries. 72:63-69

Ekanem, A. P., Eteng, S. U., Nwosu, F. M., Eyo, V. O. (2012): Comparative Study of the Growth and Gonad Development of Clarias gariepinus (Burchell 1822) Fed Diets with Plant and Animal-based Ingredients in Concrete Tanks. Journal of Agricultural Science and Technology, 2, 1203-1210

Forman, H. J., & Zhang, H. (2021). Targeting oxidative stress in disease: Promise and limitations of antioxidant therapy. Nature Reviews Drug Discovery, 20(9), 689-709.

Farah M.A., Ateeq B., Ali M.N., Sabir R., Ahmad W. (2010). Studies on lethal concentrations and toxicity stress of some xenobiotics on aquatic organisms. Chemosphere. 55, 257,

Hedayati, A. (2018). Fish Biomarkers, Suitable Tools for Water Quality Monitoring. International Journal of Veterinary and Animal Research Uluslararası Veteriner ve Hayvan Araştırmaları Dergisi E-ISSN:2651-3609 1(3): 63-69.

Farombi, E. O.; Adelowo, O. A.; Ajimoko. Y. R., 2007. Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African Cat fish (Clarias gariepinus) from Nigeria ogun river. Int. J. Environ. Res. Public Health., 4 (2), 158-165.

Gurkan, S., & Innal, D. (2018). Some morphometric features of congeneric pipefish species (Syngnathus abaster Risso 1826, Syngnathus acus Linnaeus, 1758) distributed in Lake Bafa (Turkey). Oceanological and Hydrobiological Studies, 47(3), 239–247. https://doi.org/10.1515/ohs-2018-0023.

Iqbal, M., Afzal, M., Anjum, K M., Yaqub, A., Shah, S.Z.H. and Fatima, M., 2018. Growth response, antioxidant status and fatty acid profile of Cirrhinus mrigala fingerlings fed on practical diets after treated with Vitamin E supplementation. Pakistan J. Zool., 13(Suppl.): 120-128

Jimoh, W.A.; Sodamola, M.O.; Adebayo, M.D.; Banjo, O.T.; Ayeloja, A.A. and Adeleke, A.B. (2015). Histological changes in the liver and kidney of Clarias gariepinus fed Chrysophyllum albidum seedmeal as maize replacer. International Journal of Zoological Research,11(1): 29-36.

Keremah RI, Davies OA, Abezi ID (2014). Physico-Chemical Analysis of Fish Pond Water in Freshwater Areas of Bayelsa State, Nigeria. Greener Journal of Biological Sciences. 4(2):033-038.

Keinänen M, Nikonen S, Käkelä R, Ritvanen T, Rokka M, Myllylä T, Pönni J, Vuorinen PJ. High Lipid Content of Prey Fish and n-3 PUFA Peroxidation Impair the Thiamine Status of Feeding-Migrating Atlantic Salmon (Salmo salar) and Is Reflected in Hepatic Biochemical Indices. Biomolecules. 2022 Mar 30;12(4):526. doi: 10.3390/biom12040526.

Mérida, S.N.; Tomás-Vidal, A.;Martínez-Llorens, S. andCerdá, M.J. (2010). Sunflower meal as a partial substitute in juvenile sharpsnout sea bream (Diplodus puntazzo) diets: Amino acid retention, gut and liver histology. Aquaculture,298(3-4):275-281.

Moreno D.H.F, Soler M.P, Míguez López MP. "Brain acetylcholinesterase, malondialdehyde and reduced glutathione as biomarkers of continuous exposure of tench, Tinca tinca, to carbofuran International Journal of Chemical Engineering and Applications, 4 (4), August 2013 207 or deltamethrin," Science of the Total Environment, 408, 4976, 2010

Okoro, H.K., Ikumapayi, A.O. and Folorunsho, I.O. Seasonal Variation and Determination of Some Heavy Metals in the Sediment from Ureje River in Ado-Ekiti, Nigeria. Al-Hikmah Journal of Pure & Applied Sciences 2 (2015): 14-19

Olopade O. Assessment of water quality characteristics for aquaculture uses in Abeokuta North local government Areaogun State, Nigeria. Romanian Limnogeographical Association. 2013; 7(1):9-19

Orobator, P. O., Akiri-Obaroakpo, T. M. and Orowa, R (2020). Water Quality Evaluation from Selected Aquaculture Ponds in Benin City, Nigeria. Journal Of Research in Forestry, Wildlife and Environment. Volume 12:1-11

Parrmar,A.I.and Shah,A.I.(2020). Haematological parameters and histopathological alterations in the gills of fish,Catla catlaexposed to Azo dye acid red-97. Advances in Zoology and Botany, 8(4): 342-350. Doi: 10.13189/azb.2020.080406.

Pereira, O.; Rosa, E.; Pires, M. and Fontaınhas-Fernandes, A. (2002). Brassica by-products in diets of rainbow trout (Oncorhynchus mykiss) and their effects on performance, body composition, thyroid status and liver histology. Animal Feed Science and Technology, 101(1-4): 171-182.

Perrichon P, Grosell M, Burggren WW. Heart Performance Determination by Visualization in Larval Fishes: Influence of Alternative Models for Heart Shape and Volume. Front Physiol. 2017 Jul 4; 8:464. doi: 10.3389/fphys.2017.00464.

Rytwinski, T., Taylor, J.J., Bennett, J.R. et al. What are the impacts of flow regime changes on fish productivity in temperate regions? A systematic map protocol. Environ Evid 6, 13 (2017). https://doi.org/10.1186/s13750-017-0093-z

Raibeemol, K.P. andChitra, K.C. (2020). Fish and shellfish immunology induction of immunological, hormonal and histological alterations after sublethal exposure of chlorpyrifos in the freshwater fish, Pseudetroplus maculatus (Bloch,1795). Fish Shellfish Immunology, 102: 1–12.

Schlenk, D., 2003. Use of biochemical endpoints to determine relationships between contaminants and impaired fish health in a freshwater stream. Human Ecology and Risk Assessment 9, 59-66

Singh, A.K., Ansari, A. & Srivastava, S.C. Morpho-meristics, maturity stages, GSI and gonadal hormone plasticity of African catfish Clarias gariepinus (Burchell 1822) that invaded into the Ganga River, India. JoBAZ 82, 30 (2021). https://doi.org/10.1186/s41936-021-00231-0

Shahbaz, M., Abdullah, S., Naz, H., Abbas, K., Ahmed, T., Mehmood, S., and Hussan, M.A., 2021. Evaluation of catalase activity in organs of fresh water fish, Ctenopharyngodon idella fed with vitamin E. Punjab Univ. J. Zool., 36(2): 171-174. https://dx.doi.org/10.17582/journal.pujz/2021.36.2.171.174

Sulem Yong Nina Nindum, Tchiedjo Marie Laure D., Essoh Etouke AdrienM.Mengue Ngadena Y. Sandrine, Owona P. Emmanuel, Etchu A. Kingsley, Nola Moïse,Zebaze Togouet Serge H.1, Effect of feeds on histopathology of gills, skin, liver and kidneys of Clarias gariepinus (Burchell, 1822) reared in plastic tanks. Egyptian Journal of Aquatic Biology & Fisheries, Vol. 27(4): 893–903

Van Dyk, J.; Marchand, M.; Pieterse, G.; Barnhoorn, I.E.,and Bornman, M. (2009). Histological changes in the gills of Clarias gariepinus (Teleostei: Clariidae) from a polluted South African urban aquatic system. African Journal of Aquatic Science,34(3): 283-291.

Wanja W. Daniel, Paul G. Mbuthia, Robert M. Waruiru, Janet M. Mwadime, Lilly C. Bebora, Philip N. Nyaga, Helena A. Ngowi (2020). "Fish Husbandry Practices and Water Quality in Central Kenya: Potential Risk Factors for Fish Mortality and Infectious Diseases", Veterinary Medicine International, vol. 2020, Article ID 6839354, p10