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Sublethal toxicity effects of cadmium (Cd^{2+}) on serum biochemistry in fingerlings and juveniles of fresh water catfish, *Clarias gariepinus* (Burchell, 1822)

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Abstract
The extensive use of cadmium in industry and the degree of its toxicity indeed pose an environmental problem. The objective of the present work is to study the sub-lethal toxicity effects of cadmium (Cd^{2+}) on serum biochemical changes in the fresh water fish *(Clarias gariepinus)* fingerlings and juveniles. The experiment was carried out in the laboratory for a period of 56 days. Fish were exposed to sub lethal concentrations of cadmium (Cd^{2+}) 0.41, 0.81, 1.62 mg/L and control (0.00) for the fingerlings and 0.51, 1.02, 2.03 mg/L Cd^{2+} and control (0.00) for the juveniles respectively. However, blood samples were collected for assessing some biochemical changes after 56 days. Glucose level, Cholesterol values, Glutamic oxalo-acetic transaminase (GOT/AST), Glutamic pyruvate transaminase (GPT/ALT) and Alkaline phosphate (ALP) increased with increase in concentrations of the toxicant compare with the control in both stages of the fish compare with the control, on the other hand, values of Total protein (TP) and Triglyceride decreased with increase in concentration of Cadmium (Cd^{2+}) in the fingerlings stage. However, protein level increased with increase in concentration of cadmium (Cd^{2+}) in the Juveniles stage. The study has shown that the exposure of the fish *C. gariepinus* fingerling and juveniles to cadmium can inflict unfavourable alterations in the biochemical parameters which could lead to the death of fish.

Keywords: Serum biochemistry, cadmium, *Clarias gariepinus*, sub lethal concentrations, heavy metals

1. Introduction
Intensive agricultural operations and industrial activities release enormous amount of heavy metals into aquatic ecosystem [1]. The heavy metals after reaching the aquatic habitats cause serious problem due to bioaccumulation, biomagnification in the food chain and toxicity to the organisms [2]. The toxicity of heavy metals to aquatic organisms particularly on freshwater fishes is well documented [3]. Cadmium (Cd) is one of the biologically non-essential, most toxic heavy metal widely used in Ni-Cd batteries manufacture, metal and mining, dentistry etc, because of its noncorrosive nature [4]. Cadmium (Cd), a well known heavy metal which is extremely toxic, has a specific gravity 8.65 times greater than water. It is usually rare in natural form and is concentrated in argillaceous and shale deposits as green rocks (Cds) or otavite ($CdCO_3$) and it is naturally associated with zinc, lead or copper in sulphide form [5]. It has been listed in the 'black list' of European community and classified as b-class (soft) metal [6]. Due to its non-biodegradable nature; it gets into the aquatic ecosystems and ultimately enters the human and animal's blood stream [7]. The major sources of contamination include electroplating, paper, PVC manufactures, Plastic, paint pigments, fumicides and ceramic industries [8]. It is also entering into aquatic bodies through sewage sludge and with runoff from agricultural fields, as it is one of the major components of the phosphate fertilizers [9]. In 2016, global aquaculture production accounted for almost 50% of the world's fish products destined for food, including 80.0 million tonnes of food fish and 30.1 million tonnes of aquatic plants [10]. Fish is highly nutritious, easily digestible and a much sought after food. Nutritional value of fish depends on their biochemical composition, which is affected by water pollution [11]. It nutrient composition depends on fish species, age, gender, health, nutritional status, and time of the year [12]. It is characterized by 15%–30% proteins, 0%–25% lipids, and 50%–80% moisture [10]. However, African catfish has been the most popular choice as test organism because it is cheap and a rich source of animal protein, hardy, found in all fresh waters sources

and widely cultured everywhere in Nigeria [13]. Blood chemistry indices including enzymes, nutrients, metabolites, waste products, and inorganic ions have been used to detect cellular damage and measure the responses to metals [14]. Various responses were recorded in the plasma of fish chemistry due to metal species, metal concentration, and exposure duration [15]. Plasma enzymes such as alkaline phosphatase (ALP), alanine transaminase (ALT), and aspartate transaminase (AST) are considered important plasma markers to investigate the health of animal species in concern [16]. Likewise, other plasma biomarkers such as glucose, triglyceride, total protein, and urea commonly are used to detect health of animals. Environmental stressors, such as metal exposures, may change any of the above-mentioned parameters [17]. Therefore, measurement of plasma biochemical parameters can be useful as a diagnostic tool in fish toxicology to identify their general health status and target organs affected by toxicants [18]. Cadmium is one of the most toxic heavy metals with a wide distribution. Estimation of responses to heavy metals may provide sensitive indicators on which to predict the effects of heavy-metal pollution on fish health and populations [19].

Some of the physiological effects of chronic exposure to waterborne cadmium at sub lethal levels are manifested in the form of disturbances in respiration, [20] reduction in growth, [21] disruption in whole-body or plasma ion regulation, [22] changes in haematology, [23] enzyme activity [24] and other blood parameters, such as glucose, total protein, triglyceride and cortisol that reveal the stress response in fish [25]. Cadmium concentration at sub-lethal levels have been found to decrease in growth in juvenile and adult rainbow trout (*Oncorhynchus mykiss*), [21] as well as to mortality and reduced growth in juvenile bull trout (*Salvelinus confluentus*) [26] and guppy (*Poecilia reticulate*) [27]. Serum enzymes such as alkaline phosphatase (ALP), alanine transaminase (ALT) and aspartate transaminase (AST) are important serum markers to study the health of animal species in question. The aim of the study was to determine the toxicity effects of cadmium (Cd^{2+}) to fingerlings and juveniles of the African catfish (*Clarias gariepinus*).

2. Materials and methods

2.1 Experimental Fish

Fingerlings of *Clarias gariepinus* of average mean weight 8.70±2.11g and standard length 9.53±0.92 cm, and juveniles of *Clarias gariepinus* of mean weight 15.00±00 g and standard length 16.43±0.85 cm were obtained through artificial reproduction of *C. gariepinus (*brood stocks) according to De Graaf and Janssen [28] method, carried out in the Fishery Laboratory, Department of Biology, Ahmadu Bello University, Zaria, Nigeria.

2.3 Preparation of Metal Test Solutions

Analytical grade Cadmium chloride ($CdCl_2.2.5H_2O$) was obtained from Kaduna central market (Merck Company, Darmstadt, Germany, Glaxo India Limited, Bombay, India (No. 17584) and used without further purification. Cadmium chloride solutions were prepared with distilled water to the desired concentrations and introduced into glass tanks. The concentration of cadmium chloride was expressed in terms of Cd^{2+} ion in mg/L. De-chlorinated tap water which is stored in a large overhead tank for about ten days was used for conducting the toxicity experiments. A stock solution of 1000 mg/L (1g/L) of the cadmium (Cd^{2+}) ion was prepared by adding 2.0 g of cadmium chloride to 1litre of distilled water [29]. The stock solution was used for preparing different strengths of the test solutions by diluting measured volumes with de-chlorinated tap water. The dechlorinated tap water used had the same physical and chemical properties as the one used in acclimatizing the fish. The control solutions were made up of only de-chlorinated tap water. The amount of cadmium chloride which contained 1.0 g of cadmium (Cd^{2+}) ion was determined from the molecular and atomic weights as:

$$\frac{\text{Molecular weight of cadmium chloride (CdCl2)}}{\text{Atomic weight of cadmium (Cd)}}$$

The different concentrations required for the bioassay were calculated as follows:

$$\frac{\text{Wt of cadmium required x molecular wt of cadmium}}{\text{Atomic weight of cadmium}}$$

Reish and Oshida [29].

2.4 Experimental Design

Completely randomized design was used in this experiment, with the same fish species making for one fish level. One hundred and twenty (120) fish each of *Clarias gariepinus* fingerlings and juveniles respectively were randomly placed into each test plastic tank of size 30.5 x 30.5 x 46.25 cm containers at a stocking rate of ten (10) fish with four treatment levels Cd^{2+} and three replicates, this gives 12 experimental set-up as described by (Simeon *et al.,* 2013). Three different concentrations of the heavy metal Cadmium (Cd^{2+}) and a control for the sub-lethal bioassay were prepared based on the already 96 h LC_{50} values of 8.12 mg/L and 10.15 mg/L for fingerlings and juveniles of *C. gariepinus* respectively. The nominal concentrations of Cd were derived from a fraction of (1/5 of 96 h LC_{50} 8.12 mg/L) 0.41 mg/L, (1/10 of 96 h LC_{50} 8.12 mg/L) 0.81 mg/L, (1/20 of 96-h LC_{50} 8.12 mg/L) 1.62 mg/L and control (0.00) for the fingerlings of *Clarias gariepinus* and (1/5 of 96 h 10.15 mg/L) 0.51 mg/L, (1/10 of 96 h 10.15 mg/L) 1.02 mg/L, (1/20 of 96 h 10.15 mg/L) 2.03 mg/L for juveniles of *Clarias gariepinus*. The exposure period lasted for 56 days during which each plastic container was well aerated. Physico-chemical parameters such as pH, temperature, electrical conductivity and dissolved solids were measured with the help of a multi parameter HANNA instrument (Model: HI98129), while dissolved oxygen (DO) and water hardness were determined following the methods of APHA (2005). The fish were fed with commercial feed (2mm coppens) at 5% of their body weights.

2.5 Procedures for Biochemical Studies of Fingerlings and Juveniles of *Clarias gariepinus* Exposed to Sub lethal Concentrations of Cadmium (Cd^{2+})

2.5.1 Fish blood collection and analysis

Five fish per replicate were sampled after 56 days for blood collection. However, collection of blood from fish specimens was done following the procedure of Blaxhall and Daisely [32]. Fish specimens were anaesthetized using tricaine methanesulphonate (MS 222) to ensure easy collection of blood. Blood was collected by severance of caudal peduncle from the caudal artery. The caudal region was cut 2 cm away and blood then collected in 3 ml non-heparinized tubes [33].

2.5.2 Serum Collection for Determination of Biochemical Parameters

The blood samples were immediately taken to ABU Teaching Hospital (Chemical and Pathology Department) for serum extraction and analysis. To obtain the serum, the blood was placed in micro

Centrifuge tubes, and immediately centrifuged at 1500 rpm (revolution per minute) for 10 minutes. Serum was then removed by pipetting and stored at 40℃ prior to immediate determination of biochemical parameters. Glucose, total protein (TP), triglycerides (TG), cholesterol levels, glutamic oxalo-acetic transminase (GOT), glutamate pyruvate transaminase (GPT) and Alkaline phosphatase (ALP) were measured with an automatic biochemical analyzer (Olympus AU 400 biochemical analyzer, Tokyo Japan). Procedure for the analysis was done following the manufacturer's instructions.

2.6 Statistical Analysis

One way Analysis of Variance (ANOVA) was used to test for significant difference between means using IBM Statics Version 20.0 for Windows 8, statistical analysis software and Duncan Multiple Range Test (DMRT) was used to test for significant difference between treatments when (p<0.05).

3. Results

The physicochemical parameters of the test water measured daily during sublethal toxicity bioassay with cadmium concentrations are presented in Table 1 and 2. The Temperature (T) (℃) range was between 19.10 to 25.70 ℃, Hydrogen ion concentration (pH) was between 6.70 to 8.20, Electrical Conductivity (EC) (µS/cm) was between 121 to 403 µS/cm, Total Dissolved Solids (TDS) (mg/L) was between 60 to 199 mg/L and Dissolved Oxygen (DO) (mg/L) was between 3.50 to 5.20 mg/L.

Table 1: Physico-chemical parameters of diluting water monitored during the sub lethal exposure of fingerlings *Clarias gariepenus* to cadmium (Cd^{2+}) for 56 days

Parameters	Range	Mean± S.E
Temperature(T) (℃)	24.80 – 25.70	25.23±0.08
Hydrogen ion Concentration (pH)	7.52 – 7.90	7.72±0.05
Electrical Conductivity (EC) (µS/cm)	141– 235	187.42±10.41
Total Dissolved Solids (TDS) (mg/L)	70 –117	93.33±5.22
Dissolved Oxygen (DO) (mg/L)	3.50 – 4.50	3.98±0.09

Table 2: Physico-chemical parameters of diluting water monitored during the sub lethal exposure of juveniles of *Clarias gariepenus* to cadmium (Cd^{2+}) for 56 days

Parameters	Range	Mean± S.E
Temperature(T) (℃)	19.10 – 24.70	21.78±0.58
Hydrogen ion Concentration (pH)	6.70 – 8.20	7.38±0.16
Electrical Conductivity (EC) (µS/cm)	121– 403	211.00±32.19
Total Dissolved Solids (TDS) (mg/L)	60 – 199	105.17±15.94
Dissolved Oxygen (DO) (mg/L)	4.00 – 5.20	4.46±0.12

Results of biochemical parameters of *C. gariepinus* fingerlings exposed to sub-lethal nominal concentrations of cadmium (Cd^{2+}) after 56 days are presented in Table 3. The values of Glucose, Cholesterol, Glutamic oxalo-acetic transaminase (GOT/AST), Glutamic pyruvate transaminase (GPT/ALT) and Alkaline phosphate (ALP) increased with increase in concentrations of the toxicant, on the other hand, values of Total protein (TP) and Triglyceride decreased with increase in concentration of Cadmium (Cd^{2+}). A significant (p < 0.05) difference (p<0.05) and dose dependent increase in glucose levels, Glutamic oxalo-acetic transaminase (GOT/AST) and ALP compare with the control group was observed. However, the values of Protein, Cholesterol and GPT of the control group were comparable with the exposed group.

Table 3: The effect of sub-lethal doses of Cd^{2+} on some biochemical parameters of fingerlings in *C. gariepinus* after 56 days of exposure

Treatment (mg/L)	0.00	0.41	0.81	1.62
Parameters				
Glucose(mg/dl)	52.67±1.7^{c}	61.10±1.62^{b}	79.53±2.36^{a}	85.57±2.02^{a}
Protein (mg/dl)	7.90±0.74^{a}	5.91±0.43^{a}	5.65±0.98^{a}	5.48±0.66^{a}
Cholesterol (mg/dl)	95.54±17.45^{a}	131.38±46.26^{a}	152.77±58.71^{a}	173.30±66.50^{a}
Triglyceride (mgl/dl)	128.58±19.58^{a}	122.78±14.12^{a}	94.16±14.51^{b}	74.77±5.88^{bc}
GOT/AST (iu/L)	158.67±28.67^{c}	260.00±10.00^{b}	243.33±23.33^{b}	375.33±14.67^{a}
GPT/ALT (iu/L)	19.67±6.01^{a}	28.00±8.74^{a}	29.67±8.65^{a}	33.33±7.84^{a}
ALP (iu/L)	15.53±2.03^{b}	31.60±10.00^{ab}	39.27±3.37^{a}	39.92±0.32^{a}

Means with the same superscript along rows are not significantly different (P≤0.05) (Mean values ±SE) n=3
GOT = glutamic oxalo-acetic transminase, (GPT) = glutamate pyruvate transaminase and ALP = Alkaline phosphatase

Results of biochemical parameters of *C. gariepinus* juveniles exposed to sub-lethal nominal concentrations of cadmium (Cd^{2+}) after 56 days are presented in Table 4. Values of glucose level, total protein (TP), Cholesterol, GOT/AST, GPT/ALT and ALP values of the exposed fish were higher compare to the control group. Values of the same parameters of the exposed group at 2.03 mg/L significantly higher (p < 0.05) compare to the control group, the increase was dose dependent. On the other hand, only Triglyceride values of the control group were higher compare to the expose group of the same toxicant. However, triglyceride values of control group were significantly (p<0.05) higher compare to the expose group at 1.02 and 2.03 mg/L Cd^{2+}. GOT values of control group were significantly lower (p < 0.05) compared to 1.02 and 2.03 mg/L Cd^{2+} concentrations of the same toxicant. GPT values of exposed group were significantly higher (p < 0.05) and dose dependent compared with the control group. While ALP values of the exposed group were only significantly higher at 2.03mg/L Cadmium (Cd^{2+}) compare with the control.

Table 4: The effect of sub-lethal doses of Cd^{2+} on some biochemical parameters of juveniles in *C. gariepinus* after 56 days of exposure

Treatment (mg/L)	0.00	0.51	1.02	2.03
Parameters				
Glucose(mg/dl)	34.16 ± 4.94^{b}	36.77 ± 2.99^{b}	42.10 ± 0.76^{b}	52.87 ± 1.67^{a}
Protein (mg/dl)	5.00 ± 0.50^{b}	5.60 ± 0.58^{ab}	5.80 ± 0.12^{ab}	6.07 ± 0.18^{a}
Cholesterol (mg/dl)	157.50 ± 1.10^{b}	166.66 ± 1.24^{ab}	179.22 ± 2.75^{ab}	244.33 ± 48.43^{a}
Triglyceride (mgl/dl)	152.69 ± 23.66^{a}	113.98 ± 2.15^{a}	67.75 ± 3.22^{b}	43.83 ± 1.33^{b}
GOT/AST (iu/L)	126.33 ± 16.33^{b}	162.33 ± 14.44^{b}	203.00 ± 1.73^{a}	232.00 ± 9.17^{a}
GPT/ALT (iu/L)	19.67 ± 0.33^{d}	25.00 ± 1.15^{c}	32.00 ± 1.00^{b}	41.00 ± 0.58^{a}
ALP (iu/L)	11.52 ± 2.72^{b}	14.04 ± 2.62^{ab}	18.91 ± 3.05^{ab}	23.73 ± 3.84^{a}

Means with the same superscript along rows are not significantly different ($P\leq0.05$) (Mean values ±SE) n=3
GOT = glutamic oxalo-acetic transminase, (GPT) = glutamate pyruvate transaminase and ALP = Alkaline phosphatase

4. Discussion

Blood glucose is a sensitive and reliable indicator of pollutants causing environmental stress in fish [34]. The significant ($p\leq0.05$) elevation in glucose levels (hyperglycaemia), which was dose and duration dependent in the sub lethal exposure of cadmium (Cd^{2+}) to both stages of fish *C. gariepinus* fingerlings and juveniles with reference to the control in the present study, may be as a result of chronic stress caused by prolonged exposure to cadmium. Stress condition is accompanied by the stimulation of plasma cortisol whose role is to maintain allostasis and initiate response to stress by way of regulation [35]. These in turn stimulated the release of amino acids, glycerol and fatty acids present in the blood and increased the synthesis of enzymes in the liver, which converted amino acids and glycerol into glucose (Gluconeogenesis). The synthesis of catecholamine from the chromaffin cells consumes ascorbic acid leading to its decrease. Ascorbic acid (vitamin C) is responsible for the health of the epithelial cells of the fish body such as epidermis, gill lining and mucosa of the gastrointestinal tract [36]. The findings are in agreement with the report obtained by El-Boshy *et al.* [37] who reported hyperglycemia in catfish (*Clarias gariepinus*) exposed to sub-lethal concentrations of Cadmium compare to control group for 3 weeks, and attributed it to increase glycogenolysis. The present study showed no significant ($p\geq0.05$) in serum protein of fingerlings stage of the fish exposed to sub lethal concentration of cadmium compare with the control. This may be that, during the period of study, the fish were acclimatized to the toxicant therefore, could not response to the changes in the water chemistry. Oner *et al.* [18] observed insignificant change in total plasma protein in *Oreochromis niloticus* intoxicated with 0.05 mg/L Cd during 30 day exposured. However, the observed highly significant ($p\leq0.05$) increase in serum protein in the highest concentration 2.03 mg/L in juveniles after 56 days of exposure to Cd, may be due to water loss in the serum. Since there was dose dependent increase in total protein within the exposed groups, the toxicant in the highest nominal concentrations 2.03 mg/L may have induced liver impairment of protein metabolism or protein turn over, in order to compensate for enzymes lost as a result of tissue necrosis, osmoregulatory dysfuction, haemodilution and attempt to meet increase energy demand needed for detoxification of the chemical. Similar findings were reported by Heydernejad *et al.* [38] that serum protein level increased significantly in rainbow trout (*Oncorhynchus mykiss*) to sub lethal concentrations of Cadmium in 30 day period of exposure, and attributed this increase to liver damage, reduction absorption and protein loss, and concluded that, it may be a good indicator of health status in fish. The increasing trend in protein concentration with exposure duration might also be the result of Cd interrupting with cellular mechanisms as it accumulates in liver and conjugates with metallothionine [39]. Cholesterol has been used for demonstrating the nutritional status in animals. The present study showed elevated cholesterol level of *C. gariepinus* juveniles exposed to sub lethal Cadmium concentration after 56 days. Increased cholesterol values by the toxicant could possibly be due to the higher energy demand induced by the chemical in order to get the positive survival value under the imposed toxicant stress. However, in the higher sub lethal concentrations, juveniles of *C. gariepinus* with prolong exposure showed higher values of cholesterol; there may have been severe necrosis of the liver, which led to the inability of the liver to further synthesized cholesterol. Similarly, Oner *et al.* [18] reported an increase in cholesterol level in *Oreochromis niloticus* exposed to cadmium for a period of 21 days. The authors attributed this alteration in cholesterol level to hazardous effects of metals on cell membrane. Triglyceride (TG) functions primarily in providing cellular energy and can be used as an indicator of nutritional status. TG is used to evaluate lipid metabolism; high concentrations may occur with nephritic syndrome or glycogen storage disease [40]. Sub lethal study showed significant ($p\leq0.05$) increased in triglyceride levels in Cadmium exposed fish especially in the lower concentration 0.41 mg/L after 56 day for *C. gariepinus* fingerlings. The increased may be as a result of impairment in the cell membrane organization or higher energy demands of fish to survive the stress induced by the toxicant. The principal function of triglycerides in biochemical systems is the storage of energy. If more energy-rich nutrients are consumed than are required for metabolic processes, much of the excess is converted to neutral triglycerides and stored as triglycerides in fat cells of adipose tissues. When energy is needed, the triglycerides are metabolized by the body and the energy is released [41]. Similarly, Mohiseni *et al.* [16] reported a significant rise in blood TG level of juveniles common carp induced by cadmium and lead through oral exposure of the metals. While the significant ($p\leq0.05$) inhibition of TG observed at the sub lethal exposure of fingerlings at Cd concentrations 0.81 and 1.62mg/L, and juveniles to Cd concentrations 1.02 and 2.03 mg/L compared to the control after 56 days might be due to differences in exposure concentration, lipid metabolism, and glycogen storage impairment in different fish species [16]. Plasma enzymes such as GOT, GPT and ALP, (also known as Aspartate aminotransferase (AST), alanine aminotransferase (ALT) and alkaline phosphatase (ALP) respectively are considered important plasma liver function enzymes also known as biomarkers for assessing health status of the liver of animal species in concern. Prolonged and continuous exposure of both stages of the fish, fingerlings and juveniles of *C. gariepinus*, when compared with the control for 56 days, Cadmium elicited significant ($p\leq0.05$) increase in GOT (AST), GPT (ALT). The observed highly significant ($p\leq0.05$) elevation of GOT and GPT at the sublethal exposure of both

stages of fish, fingerlings and juveniles of *C. gariepinus* to Cd after 56 days compared to the control showed that, there was lipid peroxidation induced by the toxicant or its metabolite, which led to decreased membrane fluidity, increasing leakiness of membrane. El-Boshy *et al*. [37] reported elevation in (ALT and AST) in catfish (*Clarias gariepinus*) exposed to sub-lethal concentrations of Cadmium compare to control group for three weeks, the authors attributed it to liver damage. Shakoori *et al*. [42] reported that the increase of blood enzymatic activity is either due to (1) leakage of these enzymes from hepatic cells and thus raising levels in blood, 2) Increased synthesis and (3) enzyme induction of these enzymes. Similarly, Heydernejad *et al*. [38] reported increase levels of AST and ALT activity in rainbow trout (*Oncorhynchus mykiss*) exposed to sub-lethal concentrations of Cadmium in 30 days period of time. ALP is mainly localized at the cell membrane; any damage in hepatic cells may result in alteration in ALP activity. Different factors such as life history, water quality, exposure duration and cadmium concentration influence ALP activity [38]. The increase in the activity of ALT may be related to tissue damage [43]. The behavior of both stages of fish with respect to activity of enzyme ALP after exposure to sub-lethal concentrations of Cd followed similar pattern. Both stages of fish showed significant ($p \leq 0.05$) elevations of ALP in the exposed group compare to the control. The elevations may be due to damage in hepatic cells (necrosis, apoptosis or both). However, Abedi *et al*. [44] reported significant increases in activities of the enzyme ALP of common carp; *Cyprinus carpio* exposed to sub lethal concentrations of cadmium (Cd), lead (Pb) and chromium (Cr) for a period of 33 days. These results suggest that long term exposure to the chemical may cause alterations in the serum enzymes and also, cellular activities of vital organs such as liver, thus inducing changes in the physiological and metabolic activities of the fish.

5. Conclusion

The present study has shown that, prolonged exposure of fish *C. gariepinus* fingerling and juveniles to cadmium (Cd^{2+}) can inflict alterations in the biochemical indices. Sub-lethal concentrations of (Cd^{2+}) induced hyperglycaemia, hypertriglyceridaemia, a combination of hypoproteinaemia and hyperproteinaemia, and hypercholesteridaemia. Also sub-lethal cadmium concentration elicited significant ($p < 0.05$) increased GOT (AST), GPT (ALT) and ALP to both fingerlings and juveniles of *C. gariepinus*, when compared with the control. Therefore, these alterations could induce unfavourable physiological changes in the target organism ultimately leading to death. The study showed that intentional and unintentional release of heavy metals into the aquatic environment could threaten fish survival. This study could therefore be used as a tool to assess the effects of cadmium to fish in the course of the monitoring of waters in Nigeria.

6. Recommendation

It is recommended that treatment of all kinds of wastewaters sewage and Agricultural waste must be conducted before discharge into the aquatic system. Also, enforcement of all articles of laws and legislations regarding the protection of aquatic environments must be taken into considerations.

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