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# Biotolerance of *Orechromis niloticus* to Nickel (*Ni*) Inside the Agodi Reservoir at Ibadan, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author OP designed the study and wrote the first draft. Author AAJ reviewed the draft and performed statistical analysis. Author TOO wrote the protocol and managed the analyses of the study. Author OO managed the literature searches. All the authors read and approved the final manuscript.*

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## ABSTRACT

*Orechromis niloticus* (Tilapia) that was rarely found in feeder Ogunpa River was more invasive in the receiving Agodi Reservoir and this provoked an examination of the remote causes. .Sampled water temperature and pH were measured with standard analytical methods while Ni, Co and Cr concentrations in water and fish were selectively tested using Atomic Absorption Spectrophotometer (AAS).Data obtained were subjected to analysis of variance and linear regression to establish clear relationships. On the average, temperature was 27.15ºC, pH 7.56, Ni 0.27 mg/L, Co 0.75 mg/L and Cr 0.005 mg/Lin Ogunpa River, while in Agodi Reservoir, temperature was 27.42ºC, pH 7.57, Ni 0.17 mg/L, Co 0.19 mg/L and Cr 0.005 mg/L. The temperature and pH values were higher in Agodi Reservoir than in the Ogunpa River but only the concentrations of Ni and Co in Ogunpa River were higher than in Agodi Reservoir. Using the FAO/WHO permissible limits, only the Ni concentration appeared potent in influencing Tilapia eco-dynamics. Ni accumulation could be lethal and must have affected the fish relocation and distribution, thus, a conclusion that Ni concentration and its synergistic effects with temperature could be responsible for the migration of the fish into the Agodi Reservoir.

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## 1. INTRODUCTION

Bio-tolerance is a measure of adaptation to heavy metal toxicity by organisms coexisting in the same environment. Heavy metal can enter the environment naturally through weathering of minerals and through anthropogenic activities. Ni occurs in the earth's crust as sulphide ores and larger quantities could enter the environment through combustion of fossil fuels and through run-offs from the roads. Ni is used in electro-plating, production of metal alloys, stainless steel, currency and alkaline storage batteries [1,2]. When found at low concentrations in natural waters, Ni is an essential trace element for aquatic organisms but may be toxic at higher concentrations. The effect may feature as acute or chronic on aquatic organisms and acute toxicity may result in death of the animals. Ni may end up in water from both point source and non-point sources and it may be directly emitted from various sources and discharged on surface waters [3]. In natural freshwaters, the dominant form of Ni soluble is $Ni^{2+}$, but other forms also exist predominantly as complexes with sulphate and chloride [4].

Nickel is recognized as a contaminant having long term consequences in aquatic systems [5]. Other investigators also reported the toxic effects of heavy metals on freshwater organisms [6,7]. There are factors that affect the toxicity of metal in fish for example; temperature can affect eco-toxicity of chemicals to aquatic organisms. Nickel showed decreasing chronic toxicity to *Daphnia magna* with increasing temperature between 15 and 25ºC [8]. They found a wide range of sensitivity among species, with 96-h $LC_{50}$ values at 17ºC ranging from 6.2 to 46.2 mg Ni/L while at 28ºC each species showed very little variation in sensitivity at lower temperatures. It was reported that toxicity of nickel increases as pH decreases [9]. Low pH had a slight protective effect against Ni toxicity relative to neutral conditions [10]. At pH 5.5 the 96-h. $LC_{50}$ was 0.69mg Ni/L compared to 0.54mg Ni/L at pH 7.0. However, Ni toxicity was significantly reduced at pH 8.5 where the 96-h $LC_{50}$ was 2.21 mg Ni/L. Metals are generally considered more toxic to fish in low pH water than in high-pH water. At low pH, metals are generally in their most bioavailable form as divalent. Cu and Zn accumulated is observed to be less in rainbow trout tissues at pH 5.0 than at pH 7.0. This reduction of metal accumulation at low pH amounts to concurrent decrease in toxicity [11].

It is on record that water hardness impair toxicity to fish [12,13,14,15,16]. Water hardness and pH are known to influence metal toxicity to fish [14,16]. Water hardness reduces metal toxicity by saturating gill surface binding sites with $Ca^{2+}$ to the exclusion of metal cations [10]. On the other hand, pH alters metal speciation. This study therefore set out to investigate the effects Ni toxicityon the survival, migration and distribution of *Orechromis niloticus*, commonly called 'Tilapia' fish, in the water ecosystem. Striking adaptation pattern was observed from upstream Ogunpa River down into the Agodi Reservoir that ultimately cropped the water inflow from the river. The concentration and effects of Ni, Co and Crand complimentary influence of temperature and pH were assessed for the Agodi Reservoir and the feeder Ogunpa River.

## 2. METHODOLOGY

### 2.1 Study Area

The study sites were Ogunpa River and Agodi Reservoir, located in Ibadan, Oyo State, Nigeria (Fig. 1). The city of Ibadan in southwestern Nigeria lies between 7º 23' N and 3º 5' E. It is the largest urban centre in Africa, South of Sahara. The Ogunpa River took its source from Ashi village and flows in a north south direction across the city of Ibadan. The length of the river source to the point where it enters the reservoir is about 4.87 km. The reservoir covers an area of about 5.2 hectares of land. The reservoir is about 1km long and 5 m deep. The reservoir was constructed in the 1980s following the great flood of August 1980 in Ibadan. The purpose of the construction was to serve as retention basin for excess run-off from upper section of Ogunpa River so as to prevent flooding downstream of the river due to the increase in population and uncontrolled urbanization. It has been subjected to erosion from catchment areas as well as dumping of solid waste into the river that leads to blockage and pollution of the water body. The river traverses' major parts of Ibadan city where it flows across many markets, eateries, schools, residential areas, abattoirs mechanic workshops parking lots, waste damps and other areas where wastes are generated before discharging into the reservoir. The river has significantly been encroached by housing, commercial and industrial developments and numerous gutters and run-offs drain into the smaller streams that *ipso facto* get emptied into the river. The river receives a lot of wastes ranging from industrial, agricultural and domestic sources including organic and inorganic matter. Agodi reservoir is therefore subject to enormous anthropogenic stress, the overall impact of which has resulted in the deterioration of the water quality, accumulation of toxic chemicals and sediments, shrinkage of the reservoir and loss of aesthetic value.

## 2.2 Sterilization of Sampling Apparatus

Two litre plastic bottles meant for collecting the samples were thoroughly washed with non-ionic detergent, rinsed with tap water and then soaked in $HNO_3$ for 48 hours prior to sampling for chemical analyses. Furthermore, the containers were rinsed with distilled water and also rinsed thrice at the site with water to be sampled. All glass wares were washed with non-ionic detergents, rinsed with tap water soaked in 10% $HNO_3$ for 48 hours and finally rinsed with distilled water to rule out metal contamination.

## 2.3 Sample Collection and Preparation

Figures 2 and 3 illustrate the sampling location for collection of water and fish (*Orechromis niloticus*) carried out during the study. The test locations along Ogunpa River were spaced 1km interval from the river source to the point where it enters the Reservoir .Sampling locations A, B, C, D and E in Ogunpa River and sampling locations comprising the inlet (F), centre (G) and outlet (H) parts of Agodi Reservoir.

## 2.4 Collection of Water Samples

Water samples were collected from all the test locations along Ogunpa River and Agodi Reservoir labeled and taken to the laboratory for analyses using three (3) plastic containers per location. In Ogunpa River water samples were collected from A, B, C, D and E while in Agodi Reservoir, water samples were collected from

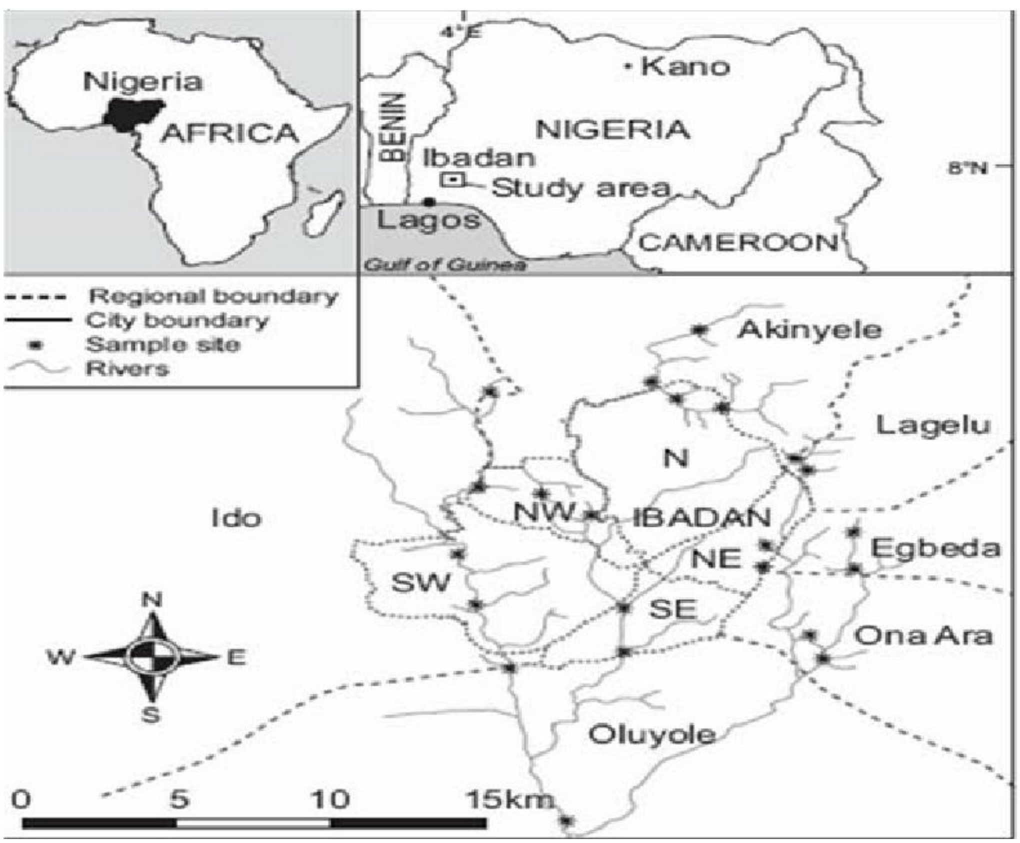


**Fig. 1. Map of Ibadan**
*Source: Google*

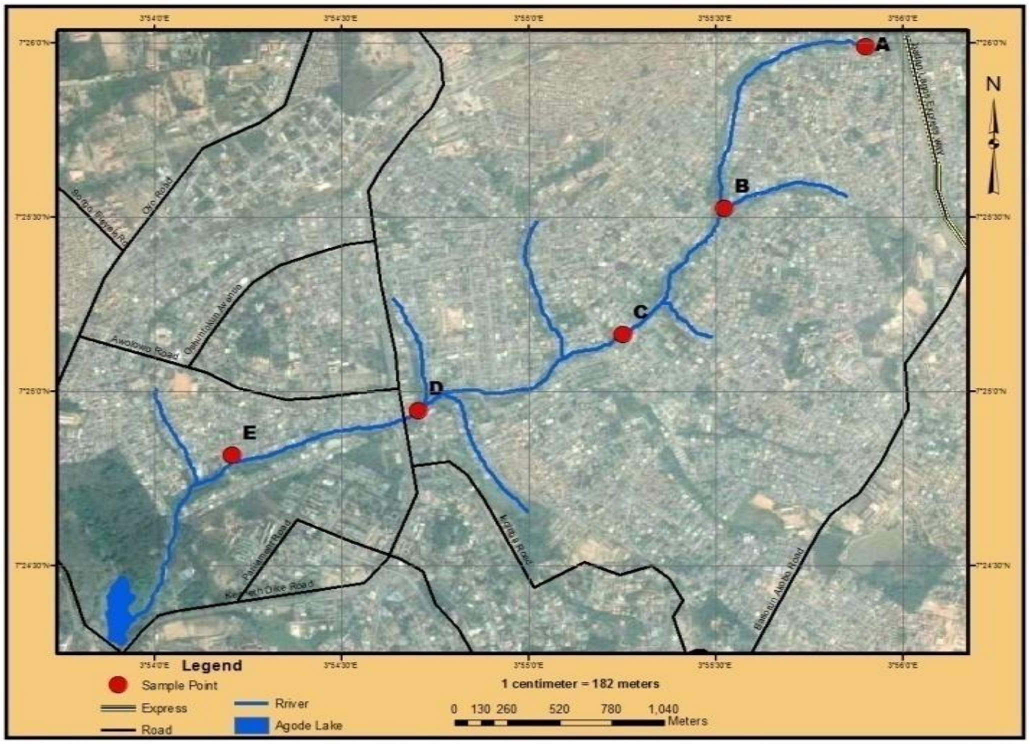


**Fig. 2. Sampling locations A, B, C, D and E in Ogunpa River**

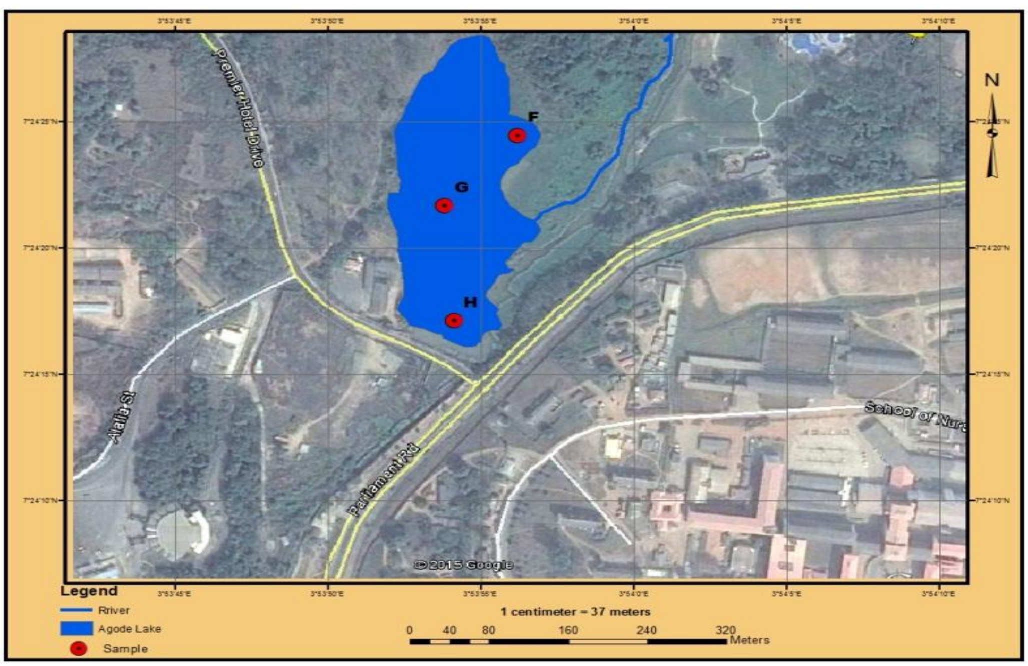


**Fig. 3. Sampling locations F, G and H on Agodi Reservoir**

three sampling locations comprising the inlet (F) centre (G) and outlet (H) parts of Agodi Reservoir. The sampling were carefully labeled and taken to the laboratory to assess their physico-chemical and heavy metal quality. The procedure employed demand immediate acidification with 5 ml conc. $HNO_3$ and transport to the laboratory for digestion which was done within 24 hours of collections. All samples, both for metals were stored in the refrigerator set at 4ºC to in-activate any bacteria and prevent change in volume due to evaporation.

### 2.5 Collection of Fish Samples

The fish (*Orechromis niloticus*) was noted to be readily available in Agodi Reservoir but not in the river. Test samples of the fish were kept inside polythene bags after capturing and their length and weights recorded. The fish samples were individually dried to constant weight in an oven set at 105ºC and dried samples grounded into fine powder with mortar and pestle, made ready for digestion. In all the cases listed above test samples were collected throughout the experimental year comprising of wet and dry seasons.

### 2.6 Sample Analyses

The collected water samples were analyzed for temperature, pH, Ni, Cobalt (Co) and Chromium (Cr) concentrations. The temperature and pH readings were taken in accordance with the standard analytical methods [17] while the digested samples of water and fish were analyzed for Ni, Co and Cr using Atomic Absorption Spectrophotometer (Buck 2000 AAS model). The instrument setting and operational conditions were done in accordance with the manufactures specifications.

### 2.7 Statistical Analyses

The data collected were subjected to one-way analysis variance (F-statistic). Linear regression lines were plotted to determine slopes, gradients effects, test location differences seasonal variations of test indices and correlation coefficients.

## 3. RESULTS AND DISCUSSION

The temperature and pH values in Ogunpa River/Agodi Reservoir waters and the concentrations of Ni, Cr and Co in water and fish provided insight for evaluating the impact of their concentrations on fish location and distribution in the water bodies. The summary of data needed to evaluate the test indices are presented in Tables 1, 2 and 3.

### 3.1 Temperature

The mean annual temperatures of the waters in Ogunpa River and Agodi Reservoir were 27.15ºC and 27.42ºC respectively (Table 1). One-way analysis of variance (F-statistic) showed that temperature was not significantly different between the locations thus no gradient effect. Linear regression of temperature along sample locations showed weak correlation. A linear regression of TºC along the sample locations showed positive correlation (Eqn. 1). In the dry season, average temperatures on Ogunpa River and Agodi Reservoir were 27.12ºC and 27.71ºC respectively. In the wet season, it was 27.18ºC in Ogunpa River and 27.13ºC in Agodi Reservoir. T-test statistic at 95% C.I showed no significant difference in temperature for the two seasons.

TºC $Y = 0.043X + 27.02$ (1)
$r^2 =$ 13%.

Note: that equations 1 and 2 to be represented

Y = Specific physical parameter (dependent variable)
X=Distance from source in meters (independent variable)

### 3.2 pH

The pH of Ogunpa River and Agodi Reservoir were generally alkaline. The pH in Ogunpa River and Agodi Reservoir were 7.56 and 7.57 respectively (Table 1). One-way analysis of variance (F-statistic) showed no significant difference in all the sampling locations which signifies no significant no gradient effect. A linear regression of pH along the sample locations showed weak negative correlation (Eqn. 2). T-test statistic at 95% C.I showed no significant difference in pH for the two seasons.

pH: $Y = -0.020X + 7.564$ (2)
$r^2 = 5\%$

### 3.3 Nickel in Water

Nickel concentration in the waters during the test period at Ogunpa River and Agodi Reservoir were 0.27 mg/L and 0.17 mg/L respectively (Table 1). One-way analysis of variance (F-statistic) at P <0.05 showed no significant difference in values in between the test locations. The mean values of Nickel in dry season in Ogunpa River was 0.09 mg/L and 0.18 mg/L in Agodi Reservoir (Table 1), while the mean values in wet season was 0.45 mg/L in Ogunpa River and 0.16 mg/L in Agodi Reservoir. A linear regression of Ni in the water bodies along the sample locations showed weak negative correlation (Eqn. 3). T-test statistic at 95% C.I showed no significance in the two seasons.

Ni (in water) $Y = -0.56X + 0.525$ (3)
$r^2 = 40\%$

Note:- that in equations 3 to 5

Y = specific heavy metal measured in mg/L (dependent variable)
X = distance from source in meters (independent variable)

### 3.4 Cobalt in Water

The mean concentration of Co in both Ogunpa River and Agodi Reservoir were 0.75 mg/L and 0.19 mg/L respectively (Table 1). The mean concentration of Co in the dry season in Ogunpa River and Agodi Reservoir were 0.02 mg/L and 0.37 mg/L, while in the wet season the mean values was 0.13 respectively. The value of Cobalt in Ogunpa River during the wet season was 0.13 mg/L, and was below detectable level in Agodi Reservoir (Table 1). Analysis of variance (ANOVA) of Cobalt data showed no significant difference at all the test locations which imply no gradient effect. A linear regression of Co in the water bodies along the sample locations gave a negative correlation (Eqn. 4). The T-test statistic at 99% C.I. showed no significant seasonal variation.

Co: $Y = -0.001X + 0.111$ (4)
$r^2 = 0\%$

### 3.5 Chromium in Water

Chromium was below detectable levels in both Ogunpa River and Agodi Reservoir (Tables 1 and 2). One-way ANOVA (F-statistic) at P<0.05 showed no significant difference at the various locations. The mean concentrations of Cr in dry season in both Ogunpa River and Agodi Reservoir were 0.00 mg/L while Cr in wet season in the water bodies were 0.01 mg/L. A linear regression of Cr in the water body along the

**Table 1. Mean temperature, pH and heavymetal concentrations in Ogunpariver, Agodi reservoir and the fish compared**

| Measured Parameters | Ogunpa River | | | Agodi reservoir | | |
|---|---|---|---|---|---|---|
| | Wet season | Dry season | Mean | Wet season | Dry season | Mean |
| Temp ($^oC$) | 27.18 | 27.12 | 27.15 | 27.13 | 27.71 | 27.42 |
| pH | 7.57 | 7.55 | 7.56 | 7.56 | 7.58 | 7.57 |
| Ni in water (mg/L) | 0.45 | 0.09 | 0.27 | 0.16 | 0.18 | 0.17 |
| Ni in Tilapia (mg/kg) | NA | NA | NA | 0.98 | 0.48 | 0.73* |
| Co in water (mg/L) | 0.13 | 0.02 | 0.75 | 0.0 | 0.37 | 0.19 |
| Co in Tilapia (mg/kg) | 1.04 | NA | 0.52 | 1.04 | 3.69 | 2.37 |
| Cr in water (mg/L) | 0.01 | 0.0 | 0.005 | 0.01 | 0.0 | 0.005 |
| Cr in Tilapia (mg/kg) | 1.9 | NA | 0.95 | 1.9 | 0.0 | 0.95 |

**Tolerance below permissible level [18]*
*NA - implies no fish found to catch*

**Table 2. Temperature and pH values of sampled waters, also Nickel concentrations in water and Tilapia at different locations for the period of experimentation**

| Measured Parameters | Ogunpa river | | | | | Agodi reservoir | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H |
| Temp ($^oC$) | 25.56 | 27.63 | 26.88 | 27.67 | 27.03 | 27.38 | 27.51 | 27.38 |
| Ph | 7.63 | 7.82 | 7.78 | 7.30 | 7.27 | 7.27 | 7.73 | 7.71 |
| Ni in water (mg/L) | 0.58 | 0.09 | 0.23 | 0.29 | 0.19 | 0.19 | 0.32 | 0.005 |
| Ni in Tilapia (mg/kg) | NA | NA | NA | NA | NA | 0.30 | 0.54 | 1.36 |
| Co in water (mg/L) | 0.02 | 0.02 | 0.0 | 0.02 | 0.07 | 0.23 | 0.88 | 0.01 |
| Co in Tilapia (mg/kg) | NA | NA | NA | NA | NA | 0.11 | 1.11 | 6.37 |
| Cr in water (mg/L) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cr in Tilapia (mg/kg) | NA | NA | NA | NA | NA | 0.0 | 0.0 | 5.85 |

*NA - implies no fish found to catch*

**Table 3. Concentration of heavy metals (mg/L) in Ogunpariver and Agodi reservoir**

| Heavy metals | Ogunpa river (mg/L) | Agodi reservoir (mg/L) | Tilapia fish (mg/kg) |
|---|---|---|---|
| Cd | 0.14 | 0.12 | 1.53 |
| Co | 0.75 | 0.19 | 2.37 |
| Cr | 0.00 | 0.00 | 0.95 |
| Cu | 9.44 | 12.44 | 8.87 |
| Fe | 30.45 | 43.75 | 271.11 |
| Mn | 20.78 | 64.81 | 303.06 |
| Ni | 0.27 | 0.17 | 0.73 |
| Pb | 0.00 | 0.00 | 1.06 |
| Zn | 21.50 | 23.13 | 178.99 |

*Source: Ogungbile et al. (2019).*

sample locations gave a positive correlation (Eqn. 5). T-test statistic at 95% C.I. showed no significant difference in the two seasons.

Cr: $Y = 0.000X + 0.02$ (5)
$r^2 = 57\%$

### 3.6 Nickel in *Orechromis niloticus*

Fish was rare and rarely found to capture in Ogunpa River. Nevertheless, the concentration of Ni in *Orechromis niloticus* sampled in Agodi Reservoir during the test period was 0.73mg/kg (Table 1). At P< 0.05, analysis of variance showed significant difference in Nickel in fish at the various locations which implies a gradient effect. A linear regression of Ni in *Orechromisniloticus* along the sample locations revealed a strong positive correlation of 97% (Eqn. 6). The mean values of Nickel in dry and wet seasons were 0.48 mg/kg and 0.98 mg/kg respectively. T-test statistic at 95% C.I showed seasonal variation as more solid wastes containing Ni dropped in the river during the rainy season.

Nickel in fish $Y = 0.464X - 0.113$ (6)
$r^2 = 97\%$

Note: that equations 6 to 8

Y = specific heavy metal measured in mg/kg (dependent variable)
X = distance from source in meters (independent variable)

### 3.7 Cobalt in *Orechromi sniloticus*

The mean concentration of Co in fish during the experimental year in Agodi Reservoir was 2.37mg/kg (Table 1). Analysis of variance at p<0.05 showed that the mean did not differ across the sample locations, thus no gradient effect. The mean concentration of Co in fish in Agodi Reservoir during the dry season was 3.9 mg/kg and during the wet season was 1.04 mg/kg. A linear regression of Co in*Orechromis niloticus* along the sample locations revealed strong positive correlation (Eqn. 7). T-test statistic showed no significant seasonal variation.

Co: $Y_2 = 2.331X - 2.739$ (7)
$r^2 = 85\%$

### 3.8 Chromium in *Orechromis niloticus*

The mean concentration of Cr in the tested fish was 0.95mg/kg (Table 1). Analysis of variance at p<0.05 showed significant difference across the test locations. A linear regression of Cr in *Orechromis niloticus* along the sampling locations revealed positive correlation (eqn. 8). Chromium concentration during the dry season was O (zero) and in the wet season was 1.90 mg/kg. T-test statistic at 95% C.I. showed significant seasonal variation.

Cr: $Y = 1.903X - 2.537$ . (8)
$r^2 = 75\%$

### 3.9 Relative Concentrations of Tested Heavy Metals

Chromium is virtually non-detectible both in the Ogunpa River and Agodi Reservoir (Tables 1 & 2) and as such could not be a factor of interest in this study. Co and Ni concentrations increased from the reservoir inlet to the outlet locations. The Co concentration is positively correlated with Ni at P<0.01 but the two heavy metals were present in the water bodies in relatively minute quantities (Table 3). This suggests that their overloading could trigger acute and irreversible harms to the surviving fish population. Co in Tilapia inside Agodi reservoir averaged 2.37

mg/kg which is much higher than 0.75 mg/L in the river. That Co concentration is higher in the reservoir, implies that the fish could tolerate the metal at chronic toxicity range. The average concentration of Co is greater than that of Ni in the fish which also suggest that Ni accumulation could be more lethal. In a logical sense, if Co is limiting, migration of the fish would not be towards the reservoir. Incidentally, Ni concentration in the Ogunpa River was much higher than in the Agodi reservoir which points to the increased relevance of Ni in Tilapia ecodynamics, hence the study focused on Nickel concentration and effects on Tilapia.

*Orechromis niloticus* ,in this work, was found to be readily available in Agodi Reservoir but scarce in Ogunpa River. The study discovered that increased temperature and pH reduced Ni toxicity to *Orechromis niloticus*in Agodi Reservoir. The fact that Ni in *Orechromis niloticus*is below the permissible threshold and the Ni is at a higher level in the river compared to the level in the reservoir suggest that Ni loading is significant and could be a strong determinant of why Tilapia virtually disappeared upstream to find relief in the reservoir downstream. This coupled with increase in Ni concentration in Ogunpa River above the value of Ni recorded in Agodi Reservoir may be reasons for the availability of *Orechromis niloticus* in Agodi Reservoir and were deficient in Ogunpa River.

Table 2 showed that temperature increased slightly with a very low correlation and a difference that is not significant at $P<0.05$. The result suggests no serious gradient effect could be established for the temperature. Oxidative stress occurs with increasing temperatures and there seems to be a relation between thermal stress response and oxidative stress response. Thermal and oxidative stress responses in estuarine fish usually bring about alterations with increasing temperature as a result of stress oxidative enzymes [19]. Temperature also affects the physiological state of poikilotherms [20]. That means temperature is important to the general welfare of fishes. It is therefore possible that temperature could impair adaptive response by fish to combat Ni toxicity. Temperature regime of $27^{o}$C recorded in the tested water bodies suggest that test fish populations may have become more susceptible to Ni pollution and, thereby hastening their migration to less stressful zones.

The pH is slightly higher in the reservoir averaging 7.57 compared to 7.56 in the river. The higher pH is supportive and corresponds to lower alkalinity already recorded for the reservoir water during the dry season. pH alters metal speciation and that metals are generally more toxic at a low pH where they occur in their bioavailable free, ionic form [8]. Similarly, low pH had a slight protective effect against Ni toxicity [10]. Ni toxicity was significantly reduced at pH 8.5 in this work supporting the fact that toxicity of Ni increases as pH decreases. Thus the slight higher value of pH in the reservoir may be responsible for lower toxicity of Ni to the fish in the reservoir.

Study on heavy metal profile in Agodi reservoir (Table 3) and noted that only Ni, Co and Cd have values lower in the reservoir compared to their concentrations in the river [21]. Ni concentration in Ogunpa River was 0.27 mg/L and in Agodi Reservoir the concentration was 0.17 mg/L. Nickel concentration in *Orechromis niloticus* was 0.73 mg/kg which itself is higher than the reservoir water environment. Tilapia may be incapable of detoxifying Ni taken up from the diet making them sensitive to Ni bioaccumulation. Ni could also increase the level of free amino acids and ammonia in the gill and kidney to a lethal concentration and induce oxidative stress, fish weight loss and decrease locomotive activity. Oxidative stress was already affirmed to occur with increasing temperature as there seems to be a relation between thermal stress response and oxidative stress response. That means, temperature is important to the general welfare of the fishes. It is therefore possible that temperature could impair adaptive response by the fish to combat Ni toxicity. Temperature regime of 27ºC recorded in the tested water bodies suggests that the test fish population may become more susceptible to Ni pollution and, thereby hasten their migration to less stressful zones.

In a work carried out on goldfish *Carassius auratus,* toxic and carcinogenic effects of Ni compounds were found to result from nickel-mediated oxidative damage to macromolecules and/or inhibition of cellular antioxidant defenses [22]. $Ni^{2+}$ exposure had substantial influence on goldfish immune systems causing lymphopenia while Ni accumulation in kidney increased renal iron content and leads to oxidative stress. $Ni^{1+}$ exposure also resulted in antioxidant system activation in the goldfish spleen. Nickel affected the calcium-dependent myogenic gene expression in embryos of *Bombinao rientalis* toad [23]. In the process, Ni affected the functional development of gills leading to embryonic death and mortality.

Study on toxicity of Ni nano- particles in the tilapia fish *Orechromis niloticus* shows that biochemical analyses indicated oxidative stress caused by Ni nano-particles [24]. Histo-pathological alterations also occurred in Ni nano-particles exposed fishes. A significant accumulation of Ni in Ni nano-particles was observed in the gill and skin tissues, with the highest levels found in the liver. Ni nano-particles exposed fish showed nuclear hypertrophy; nuclear degeneration, necrosis and irregular-shaped nuclei in the liver tissue. The hyperplasio of gill epithelium, lamellar fusion of secondary lamellae diluted marginal channel, epithelial lifting and epithelial rupture were observed in gill tissues. Degeneration in muscle bundles, focal area of necrosis vacuolar degeneration in muscle bundles, edema between muscle bundles and splitting of muscle fibers were features noticed in skin tissues [24].

From the above it is clear that the effect of Ni or its combined effects with temperature and pH may be responsible for *Orechromis niloticus* inside Agodi Reservoir but was scarce in Ogunpa River. Heavy metal toxicity is lower in hardwater because of competition between the contaminant metal ions and $Ca^{2+}$ and $Mg^{2+}$ ions uptake sites on the body surface of aquatic organisms [25,26].

## 4. CONCLUSIONS AND RECOMMENDA-TIONS

*Orechromis niloticus* was scarce and rarely found all along Ogunpa River but readily available in the Agodi Reservoir. There was a general bioaccumulation of heavy metals in the fish which was greater than its immediate environment, thus, care must be taken not to assume that heavy metal loading of the contaminated water is same as that of the fish obtained from the same water .Of the heavy metals (Ni, Co and Cr) examined, Ni concentration was more potent in determining the availability, location and distribution of Tilapia in the water body.Ni was higher in the river than in the reservoir and this led to the inference that Ni loadings is significant and could be a strong determinant why the fishes virtually disappeared upstream of Ogunpa River to find relief at the reservoir downstream. Chronic effects of Ni on the growth, development and sustainability of *Orechromis niloticus* is therefore a matter of importance and concern. Ni accumulation could be more lethal as concentration builds up and must have affected the fish relocation and distribution.

Temperature is also important to the general welfare of the fishes as it could impair adaptive response by the fish to combat Ni toxicity. Temperature regime of 27ºC coupled with increase in TSS and slight differences in pH recorded in the tested water bodies suggest that test fish population may become more susceptible to Ni pollution, and thereby hastening their migration to less stressful zones in the reservoir. The combined effect of Ni, temperature and pH could determine the location, migration and distribution of *Orechromis niloticus* inside Agodi Reservoir and also their extinction in the advancing Ogunpa River. It is therefore desirable to carry out intensive reconnaissance survey to pinpoint the source of Ni release into the water bodies and reinforce the hypothesis that Ni bioaccumulation is predictive of acute mortality in *Orechromis niloticus*. Also, for the purpose of confirming differential toxicity of Ni solutions at low and high temperatures, laboratory experiments employing various temperature regimes should be used to substantiate the significance of temperature and its interaction with Ni+ in determining the survival of *Orechromis niloticus* under those conditions.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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