



Research Article

Aquatic Pollution in Lake Alau: Investigating the Role of Heavy Metals in Water Quality Degradation

<sup>1</sup>Fabian Zira Lawrence, <sup>2</sup>Abasiryu Apagu and <sup>3</sup>Luka Lawrence

<sup>1</sup>Department of Zoology Modibbo Adama University Yola, Adamawa State, Nigeria

<sup>2</sup>Department of Biological Sciences, Federal University Dutsin-Ma, Kastina State, Nigeria

<sup>3</sup>Department of Chemistry, Adamawa State College of Education, Hong

\*Corresponding author's Email: [ziralawrencefabian@gmail.com](mailto:ziralawrencefabian@gmail.com), [doi.org/10.55639/607.02010012](https://doi.org/10.55639/607.02010012)

ARTICLE INFO:

ABSTRACT

**Keywords:**

Heavy Metals,  
Water Quality,  
Lake Alau  
Degradation  
Contamination

This study assesses the concentrations of heavy metals, including zinc (Zn), copper (Cu), manganese (Mn), cadmium (Cd), lead (Pb), and their impacts on the aquatic ecosystem of Lake Alau. The metal concentrations in the lake's surface water were found to follow the order: Zn > Cu > Cd > Mn > Pb. Zinc, an essential element for growth and development in living organisms, was detected in higher concentrations ( $0.58 \pm 0.15 \text{ mg/L}$ ) due to anthropogenic activities, including agricultural runoff, industrial discharges, and urban waste. However, its levels did not exceed the permissible limits set by the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA). The study highlights that while zinc is vital for aquatic organisms, excessive concentrations can be toxic, posing risks to both fish and aquatic biodiversity. Other metals, including copper ( $0.33 \pm 0.08 \text{ mg/L}$ ) and cadmium ( $0.35 \pm 0.17 \text{ mg/L}$ ), also exceeded safety thresholds, presenting significant risks to water quality and aquatic life. Elevated levels of manganese and lead ( $0.09 \pm 0.02 \text{ mg/L}$ ) were similarly linked to industrial pollution, vehicular emissions, and military activities around the lake. Water samples were collected over an eighteen-month period (January 2019 to June 2020) at a depth of 10 cm below the surface using cleaned 1-liter plastic bottles. Heavy metal concentrations were analyzed using an Atomic Absorption Spectrophotometer (FAAS) after digesting samples with concentrated nitric acid. The findings emphasize the need for improved monitoring and management to mitigate the environmental and health risks posed by heavy metal contamination in Lake Alau. Specifically, targeted environmental monitoring and regulation, impactful policy development, risk mitigation for aquatic life, public health initiatives, and support for future research are essential actions for safeguarding the lake's ecosystem and the health of surrounding communities.

**Corresponding author:** Fabian Zira Lawrence **Email:** [ziralawrencefabian@gmail.com](mailto:ziralawrencefabian@gmail.com)  
Department of Zoology Modibbo Adama University Yola, Adamawa State, Nigeria

## INTRODUCTION

Water is an essential requirement for all life forms on Earth (Bytyçi *et al.*, 2018). As a critical environmental component, water quality remains a significant concern globally. The primary sources of water include rivers, lakes, glaciers, rainwater, and groundwater, which support both ecological health and human needs. Despite its importance, water is one of the most poorly managed resources and faces serious threats due to various anthropogenic activities (Islam *et al.*, 2013).

Lake Alau, an important inland water ecosystem, plays a vital role in maintaining regional ecological balance. It not only supports ecological health but also contributes to the sustainable development of the local economy and society (Ding *et al.*, 2021). However, the lake, like many other water bodies, is under threat from human activities such as agricultural activities, population increase, and urbanization among others, which have become major contributors to global water pollution. These threats are particularly evident in urban environments where lakes and rivers often serve as the final destination for industrial effluents (Saha and Paul, 2019; Pandey *et al.*, 2019; Kumar *et al.*, 2020).

Lakes play a significant role in absorbing toxic pollutants from both point sources, such as industrial and mining activities, and non-point sources, like urban runoff and agriculture (Tenebe *et al.*, 2017). Moreover, lakes are a cost-effective source of water compared to alternatives like groundwater and seawater desalination, making their protection even more critical.

Surface waters in Lake Alau, are crucial for human recreation, consumption, and maintaining critical aquatic habitats. However, water quality criteria for aquatic biota have often been overlooked, and water is frequently considered adequate for fish as long as there is no evident mortality linked to pollutants (Julius *et al.*, 2015). This oversight is problematic, as pollutants such as pesticides, pharmaceuticals, and heavy metals can severely impact aquatic ecosystems, with heavy metals being particularly harmful to fish, a key protein source (Mahino *et al.*, 2014).

Trace elements (TEs), which include metals and metalloids with a density greater than 5 g/cm<sup>3</sup>, such as lead (Pb), copper (Cu), and cadmium (Cd), are of great concern. These elements are persistent in the environment, bioaccumulate in the food chain, and at elevated concentrations, become toxic to both aquatic organisms and humans (Monisha *et al.*, 2014). While some metals, such as calcium (Ca) and magnesium (Mg), are essential for health, others pose significant risks, primarily due to the presence of free metal ions that drive toxicity.

Research on heavy metals in water bodies have been conducted extensively in Lake Alau and other aquatic systems worldwide (Bwala, 2023; Hati *et al.*, 2008; Dimari *et al.*, 2008; Ahmed *et al.*, 2023). This study focuses specifically on heavy metals' role in degrading Lake Alau's water quality. This approach highlights localized ecological threats, providing insights into metal persistence, bioaccumulation, and ecosystem impacts essential for environmental management. Heavy metal contamination in Lake Alau poses risks to both aquatic life and public health, as concentrations are rising due to agricultural runoff, industrial discharge, and urban waste. These pollutants disrupt ecological balance and pose bioaccumulation threats in fish and other resources.

Lake Alau's water quality provides critical insights into the health of its ecosystem. Key parameters monitored over the past year indicate that the lake's water quality generally falls within acceptable ranges for supporting aquatic life (Fabian *et al.*, 2023). However, studies have also reported concerning levels of metal concentrations (Hati *et al.*, 2008; Bukar *et al.*, 2016; Bwala, 2023). This study investigates the role of heavy metals in the degradation of water quality, focusing on their impact on the lake's ecosystem health.

This study aims to assess heavy metal concentrations (Zn, Cu, Mn, Cd, Pb) in the surface water of Lake Alau, analyze their ecological impact on the aquatic ecosystem and biodiversity, and provide data-driven insights to inform local environmental policies for pollution mitigation and water quality protection. Ultimately, this study aims to enhance environmental protection efforts and ensure the

health and safety of communities reliant on Lake Alau's resources.

Monitoring heavy metal concentrations in water is essential for assessing and maintaining water quality. Such monitoring enables timely corrective actions and protects both aquatic ecosystems and human health. Monitoring should be comprehensive, including microbiological, chemical, physical, and radiological parameters, to ensure the early detection of pollutants and prevent waterborne diseases. By adopting a preventive approach to water quality management, we can better safeguard Lake Alau and similar ecosystems.

This emphasizes the urgency of effective water management and pollution control in Lake Alau and the broader context of water quality protection.

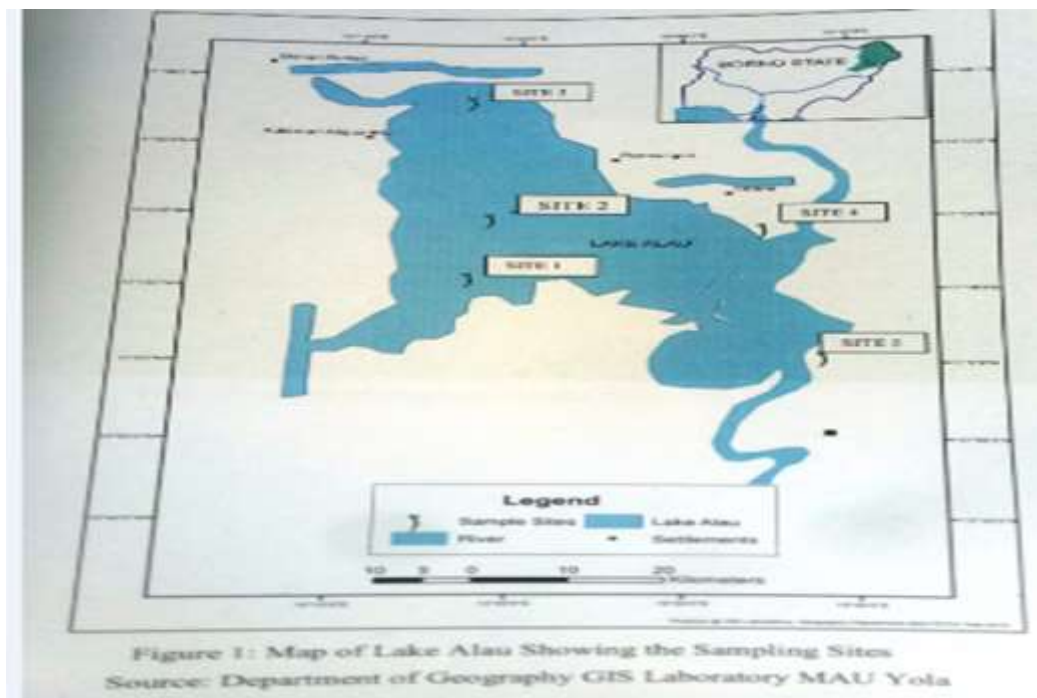
## MATERIALS AND METHODS

### Study Area

Lake Alau, located in Borno State, Nigeria, was created in 1985 by damming the River Ngadda.

Covering 56 km<sup>2</sup>, the lake provides potable water for Maiduguri and supports irrigation for over 8,000 hectares of farmland. The region experiences a sahelian climate with three seasons: a rainy season (June to September), a harmattan season (October to February), and a hot dry season (March to May). Water levels are lowest in the dry season, exposing much of the lakebed.

Lake Alau's water inflow primarily comes from the seasonal flow of the River Ngadda and runoff from surrounding areas. The Rivers Yedzeram and Gombole contribute additional inflow through a connection in the Sambisa Swamps. The lake's average annual inflow is 239 million cubic meters, and its maximum storage capacity is 112 million cubic meters. Agricultural runoff has led to pollution in the lake, which is also used for commercial fishing activities.



### Sampling Station

Sampling stations in Lake Alau were selected based on factors like water volume, accessibility, security, and activities in and around the lake. Five stations were initially

identified, but due to insurgency, activities were restricted at two.

Station 1: Located 500 meters from the shore, this station is a hub for artisanal fishing, with no closed fishing season. It also serves as the main landing site for fishermen, a practical site for

students from the University of Maiduguri, and a livestock watering point. The Borno State Water Board operates a pumping station here. The water width is approximately 255 meters.

Station 2: Situated near Alau town, this station experiences low farming activities and is used for domestic tasks, irrigation, and livestock watering. The water here is deeper and flows faster, with a width of about 102 meters. Fishing is common, utilizing traditional methods like dragnets and cast nets.

Station 3: This station lies 500 meters north of Daban Ali Zaki and serves as a key navigation route to Station 4. It is a center for canoe paddlers and artisanal fishermen. The surrounding area contains burrow pits used for extracting sand for construction purposes.

#### **Sample Collection and Preservation**

The sample bottles used for collecting and storing water samples underwent thorough cleaning. After washing with detergent and rinsing, the bottles were soaked in 1.3 M Nitric acid for 2 days, followed by a thorough wash with deionized distilled water. They were then soaked for an additional 48 hours in deionized distilled water acidified with Nitric acid to a pH of less than 1. This cleaning process, as described by Streumpler (1973), effectively removes trace metals and other contaminants from the bottle surfaces, preventing potential sample contamination. The cleaned bottles were then used directly for sampling.

Water samples were collected over an eighteen-month period, from January 2019 to June 2020, at 8:00 am local time. Sampling was conducted at a depth of 10 cm below the surface, in triplicate, using 1-liter plastic bottles at three designated stations (Stations 1, 2, and 3) within the lake. These stations were selected using a simple randomized design. A total of 15 samples per station were collected at random points prior to analysis of chemical properties and heavy metal concentrations.

The plastic bottles were rinsed with lake water before being filled to the brim, ensuring no air bubbles were trapped. The samples were preserved on ice and transported to the laboratory for analysis. All sample bottles were properly labeled and fixed for further chemical analysis.

#### **Determination of Heavy Metals in Water Samples**

Zinc, lead, copper, cadmium, and manganese were analyzed using an Atomic Absorption Spectrophotometer (FAAS Buck Scientific Model 210 VGP). The water samples were prepared for analysis through the following digestion process:

The water samples were digested as follows. A 100 cm<sup>3</sup> water sample was placed in a beaker, and 5 mL of concentrated HNO<sub>3</sub> was added. The mixture was heated on a hot plate until the volume was reduced to about 20 cm<sup>3</sup>. After cooling, another 5 mL of concentrated HNO<sub>3</sub> was added, and the heating process continued, with small amounts of HNO<sub>3</sub> being added until the solution became light-colored and clear. The beaker walls and watch glass were rinsed with distilled water, and the sample was filtered to remove any insoluble materials that could clog the atomizer. The sample volume was adjusted to 100 cm<sup>3</sup> with distilled water, following the procedure by Radojevic and Bashkin (1999). Dissolved concentrations of the heavy metals in the water samples were then determined using the Atomic Absorption Spectrophotometer according to the manufacturer's instructions. The spectrophotometer used a light source specific to each metal, measuring the absorption at wavelengths characteristic of zinc, copper, manganese, cadmium, and lead. The absorption values were then compared against a calibration curve to quantify the metal concentrations in the water samples.

Data generated for heavy metals were subjected to analysis of variance (ANOVA), standard deviation and correlation matrix. Means and standard deviations were calculated following established statistical procedures. The results were given in the form of Mean±SD. The data was subjected to ANOVA across the stations with the help of SPSS software (Graph pad software). The p value for ANOVA if non-significant if P > 0.05 (ns), significant if P < 0.05(\*), significantly significant (\*\*) if P is < 0.001 and highly significant (\*\*\*) if P < 0.0001.

#### **RESULTS**

Table 1: presents the monthly and station-wise mean variation of zinc (Zn) concentrations in the surface water of Lake Alau during the study

period (January 2019 to June 2020). The results show the following: The total mean concentration of zinc in the water was highest at  $0.59 \pm 0.17$  mg/L. Station 1 recorded the highest mean zinc concentration, with  $1.04 \pm 0.22$  mg/L in May 2019, while the lowest concentration was observed at  $0.34 \pm 0.05$  mg/L in Station 3 in December 2019. The monthly mean variation of

zinc ranged from  $0.39 \pm 0.02$  mg/L in February 2020 to  $0.94 \pm 0.10$  mg/L in May 2019. Station 1 had the highest overall mean concentration of  $0.62 \pm 0.19$  mg/L, while Station 3 had the lowest at  $0.51 \pm 0.15$  mg/L. The statistical analysis indicated significant variations in zinc concentrations both within the stations and across the months ( $P < 0.05$ ).

**Table 1:** Monthly and Station Mean Variation of Zinc (Zn) Concentration in Surface Water of Lake Alau

Month	Station 1	Station 2	Station 3	Mean
January 2019	$0.48 \pm 0.09^b$	$0.59 \pm 0.17^a$	$0.48 \pm 0.12^b$	$0.52 \pm 0.06$
February	$0.46 \pm 0.17^a$	$0.41 \pm 0.13^a$	$0.43 \pm 0.06^a$	$0.44 \pm 0.02$
March	$0.35 \pm 0.04^c$	$0.64 \pm 0.05^a$	$0.50 \pm 0.01^b$	$0.50 \pm 0.15$
April	$0.81 \pm 0.07^a$	$0.55 \pm 0.06^c$	$0.67 \pm 0.11^b$	$0.78 \pm 0.10$
May	$1.04 \pm 0.22^a$	$0.84 \pm 0.05^b$	$0.93 \pm 0.18^{ab}$	$0.94 \pm 0.10$
June	$0.88 \pm 0.08^a$	$0.81 \pm 0.06^{ab}$	$0.78 \pm 0.12^b$	$0.82 \pm 0.05$
July	$0.65 \pm 0.07^a$	$0.68 \pm 0.13^a$	$0.45 \pm 0.09^b$	$0.59 \pm 0.12$
August	$0.60 \pm 0.10^a$	$0.54 \pm 0.09^a$	$0.47 \pm 0.04^b$	$0.53 \pm 0.07$
September	$0.61 \pm 0.14^a$	$0.64 \pm 0.08^a$	$0.46 \pm 0.04^b$	$0.57 \pm 0.10$
October	$0.81 \pm 0.13^a$	$0.58 \pm 0.14^b$	$0.59 \pm 0.05^b$	$0.66 \pm 0.13$
November	$0.67 \pm 0.13^a$	$0.57 \pm 0.06^b$	$0.40 \pm 0.07^c$	$0.55 \pm 0.13$
December	$0.60 \pm 0.10^a$	$0.59 \pm 0.07^a$	$0.34 \pm 0.05^b$	$0.51 \pm 0.15$
January 2020	$0.39 \pm 0.02^a$	$0.46 \pm 0.06^a$	$0.34 \pm 0.06^b$	$0.40 \pm 0.06$
February	$0.40 \pm 0.06^a$	$0.39 \pm 0.05^a$	$0.37 \pm 0.04^a$	$0.39 \pm 0.02$
March	$0.39 \pm 0.03^a$	$0.47 \pm 0.10^a$	$0.42 \pm 0.06^a$	$0.48 \pm 0.04$
April	$0.59 \pm 0.05^a$	$0.57 \pm 0.16^a$	$0.50 \pm 0.11^a$	$0.55 \pm 0.04$
May	$0.80 \pm 0.12^a$	$0.62 \pm 0.05^b$	$0.62 \pm 0.04^b$	$0.68 \pm 0.10$
June	$0.70 \pm 0.12^a$	$0.51 \pm 0.05^b$	$0.48 \pm 0.04^b$	$0.56 \pm 0.12$
Mean	$0.62 \pm 0.19$	$0.60 \pm 0.13$	$0.51 \pm 0.16$	$0.58 \pm 0.15$

Different letters (e.g., a, b, c) indicate statistically significant differences between the means at each station within the same month.

Matching letters indicate no significant difference in Zn concentration between stations within that month.

Table 2: presents the monthly and station-wise mean variation of lead (Pb) concentration in the surface water of Lake Alau. The key findings are: The overall mean lead concentration in water was relatively low, with a mean value of  $0.09 \pm 0.02$  mg/L. The highest lead concentration recorded was  $0.21 \pm 0.10$  mg/L, observed in Station 2 during September 2019. The lowest concentration,  $0.01 \pm 0.02$  mg/L, was

observed in both Station 1 and Station 2 during June and July 2019. The highest total station mean concentration was  $0.10 \pm 0.03$  mg/L in Station 1 and  $0.10 \pm 0.04$  mg/L in Station 3, while the lowest total station mean of  $0.09 \pm 0.05$  mg/L was recorded in Station 2. The analysis revealed a significant variation in lead concentrations both within the stations and across the months ( $P < 0.05$ ).

**Table 2: Monthly and Station Mean Variation of Lead (Pb) Concentration in Surface Water of Lake Alau**

Month	Station 1	Station 2	Station 3	Mean
January 2019	0.09±0.06 <sup>b</sup>	0.14±0.07 <sup>a</sup>	0.06±0.08 <sup>c</sup>	0.10±0.04
February	0.07±0.05 <sup>a</sup>	0.07±0.03 <sup>a</sup>	0.03±0.03 <sup>b</sup>	0.06±0.03
March	0.03±0.04 <sup>b</sup>	0.04±0.04 <sup>b</sup>	0.07±0.03 <sup>a</sup>	0.05±0.02
April	0.15±0.04 <sup>a</sup>	0.10±0.09 <sup>b</sup>	0.12±0.11 <sup>ab</sup>	0.12±0.03
May	0.11±0.12 <sup>a</sup>	0.10±0.08 <sup>a</sup>	0.06±0.06 <sup>b</sup>	0.09±0.03
June	0.10±0.09 <sup>ab</sup>	0.01±0.02 <sup>c</sup>	0.12±0.04 <sup>a</sup>	0.08±0.06
July	0.01±0.02 <sup>b</sup>	0.00±0.00 <sup>b</sup>	0.09±0.03 <sup>a</sup>	0.03±0.05
August	0.11±0.07 <sup>a</sup>	0.10±0.07 <sup>a</sup>	0.08±0.04 <sup>b</sup>	0.10±0.01
September	0.06±0.03 <sup>c</sup>	0.21±0.10 <sup>a</sup>	0.17±0.07 <sup>b</sup>	0.15±0.08
October	0.11±0.04 <sup>a</sup>	0.03±0.03 <sup>c</sup>	0.13±0.13 <sup>a</sup>	0.09±0.05
November	0.17±0.11 <sup>a</sup>	0.10±0.10 <sup>b</sup>	0.08±0.09 <sup>b</sup>	0.11±0.05
December	0.09±0.08 <sup>a</sup>	0.09±0.08 <sup>a</sup>	0.05±0.08 <sup>b</sup>	0.08±0.02
January 2020	0.15±0.05 <sup>a</sup>	0.10±0.12 <sup>b</sup>	0.10±0.12 <sup>b</sup>	0.12±0.03
February	0.12±0.06 <sup>a</sup>	0.08±0.07 <sup>b</sup>	0.10±0.08 <sup>ab</sup>	0.10±0.02
March	0.13±0.04 <sup>a</sup>	0.10±0.02 <sup>b</sup>	0.10±0.10 <sup>b</sup>	0.11±0.02
April	0.13±0.06 <sup>a</sup>	0.08±0.06 <sup>b</sup>	0.11±0.06 <sup>ab</sup>	0.11±0.03
May	0.11±0.09 <sup>a</sup>	0.02±0.04 <sup>c</sup>	0.11±0.08 <sup>a</sup>	0.08±0.05
June	0.07±0.07 <sup>b</sup>	0.06±0.06 <sup>b</sup>	0.13±0.03 <sup>a</sup>	0.09±0.04
Mean	0.10±0.04	0.09±0.05	0.10±0.03	0.09±0.02

Different superscripts (e.g., a, b, c) indicate significant differences in lead concentration between stations for each month

Matching letters indicate no significant difference in Pb concentration between stations within that month

Tables 3 reveals the monthly and station-wise mean variation of copper (Cu) concentration in the surface water of Lake Alau. The results show: The overall total mean concentration of copper in surface water was  $0.33 \pm 0.08$  mg/L. The highest recorded mean value was  $0.59 \pm 0.13$  mg/L in Station 2 during October 2019, while the lowest value was  $0.16 \pm 0.05$  mg/L, also in Station 2. Monthly mean variation ranged

from  $0.19 \pm 0.03$  mg/L in August 2019 to  $0.48 \pm 0.09$  mg/L in October 2019. Among the stations, Station 2 had the highest total mean concentration of  $0.35 \pm 0.12$  mg/L, while Station 1 recorded the lowest total mean concentration at  $0.30 \pm 0.07$  mg/L. The study indicates significant variation in copper concentrations in the surface water of Lake Alau, both within the stations and across the months ( $P < 0.05$ ).

**Table 3: Monthly and Station Mean variation of Copper (Cu) Concentration in Surface Water of Lake Alau**

Month	Station 1	Station 2	Station 3	Mean
January 2019	0.20±0.03 <sup>a</sup>	0.21±0.13 <sup>a</sup>	0.21±0.02 <sup>a</sup>	0.21±0.00
February	0.21±0.13 <sup>a</sup>	0.16±0.05 <sup>b</sup>	0.24±0.19 <sup>a</sup>	0.20±0.04
March	0.26±0.10 <sup>b</sup>	0.21±0.04 <sup>c</sup>	0.30±0.14 <sup>a</sup>	0.25±0.05
April	0.29±0.08 <sup>b</sup>	0.28±0.04 <sup>b</sup>	0.34±0.11 <sup>a</sup>	0.30±0.03
May	0.31±0.09 <sup>b</sup>	0.32±0.06 <sup>b</sup>	0.38±0.10 <sup>a</sup>	0.33±0.04
June	0.24±0.07 <sup>b</sup>	0.28±0.05 <sup>b</sup>	0.35±0.08 <sup>a</sup>	0.29±0.05
July	0.21±0.02 <sup>b</sup>	0.20±0.08 <sup>b</sup>	0.31±0.03 <sup>a</sup>	0.24±0.06
August	0.17±0.06 <sup>b</sup>	0.22±0.05 <sup>a</sup>	0.19±0.32 <sup>a</sup>	0.19±0.03
September	0.38±0.07 <sup>b</sup>	0.44±0.12 <sup>a</sup>	0.39±0.05 <sup>b</sup>	0.40±0.03
October	0.42±0.06 <sup>c</sup>	0.59±0.13 <sup>a</sup>	0.45±0.10 <sup>b</sup>	0.48±0.09
November	0.38±0.07 <sup>b</sup>	0.50±0.11 <sup>a</sup>	0.37±0.10 <sup>b</sup>	0.41±0.07
December	0.34±0.09 <sup>b</sup>	0.44±0.08 <sup>a</sup>	0.33±0.08 <sup>b</sup>	0.37±0.06
January 2020	0.29±0.05 <sup>b</sup>	0.39±0.05 <sup>a</sup>	0.28±0.04 <sup>b</sup>	0.32±0.06
February	0.34±0.07 <sup>b</sup>	0.36±0.04 <sup>a</sup>	0.30±0.04 <sup>b</sup>	0.33±0.03
March	0.35±0.09 <sup>b</sup>	0.45±0.08 <sup>a</sup>	0.36±0.07 <sup>b</sup>	0.39±0.06
April	0.38±0.10 <sup>b</sup>	0.49±0.09 <sup>a</sup>	0.40±0.08 <sup>b</sup>	0.42±0.06

May	0.39±0.12 <sup>b</sup>	0.43±0.02 <sup>a</sup>	0.43±0.06 <sup>a</sup>	0.41±0.02
June	0.32±0.12 <sup>b</sup>	0.40±0.02 <sup>a</sup>	0.34±0.02 <sup>b</sup>	0.35±0.04
Mean	0.30±0.07	0.35±0.12	0.33±0.07	0.33±0.08

Different superscripts (e.g., a, b, c) indicate significant differences in copper concentration between stations for each month.

Matching letters indicate no significant difference in Cu concentration between stations within that month

Table 4 presents the monthly and station-wise mean variation of cadmium (Cd) concentration in the surface water of Lake Alau. Key findings include: The overall mean concentration of cadmium in the surface water was  $0.35 \pm 0.17$  mg/L. The highest concentration of  $0.84 \pm 1.27$  mg/L was observed in Station 3 during March 2020, while the lowest concentration of  $0.04 \pm 0.04$  mg/L was recorded in Station 1 in January 2020. Monthly mean concentrations fluctuated, ranging from  $0.15 \pm 0.10$  mg/L in April 2020 to  $0.58 \pm 0.34$  mg/L in March 2019. Station-wise, Station 3 recorded the highest total mean concentration of  $0.42 \pm 0.05$  mg/L, while Station 1 had the lowest mean at  $0.30 \pm 0.18$  mg/L. There was significant variation in cadmium concentrations in Lake Alau's surface water both between stations and across months ( $P < 0.05$ ).

Table 5 presents the monthly and station-wise mean variation of manganese (Mn) concentration in the surface water of Lake Alau. Key findings include: The overall mean concentration of manganese in the surface water was  $0.29 \pm 0.10$  mg/L. The highest observed concentration was  $0.51 \pm 0.03$  mg/L in Station 2 during May 2020, while the lowest observed concentration was  $0.11 \pm 0.03$  mg/L, also in Station 2, in August 2019. Monthly mean concentrations ranged from  $0.14 \pm 0.00$  mg/L to  $0.48 \pm 0.03$  mg/L, with the highest occurring in May 2020. Station-wise, Station 3 recorded the highest total mean concentration of  $0.30 \pm 0.11$  mg/L, while Station 1 observed the lowest total mean concentration at  $0.25 \pm 0.10$  mg/L. There was a significant variation in manganese concentrations across both stations and months ( $P < 0.05$ ).

**Table 4:** Monthly and Station Mean Variation of Cadmium (Cd Concentration mg/L) in Surface Water of Lake Alau

Month	Station 1	Station 2	Station 3	Mean
January 2019	0.23±0.16 <sup>b</sup>	0.11±0.10 <sup>c</sup>	0.30±0.37 <sup>a</sup>	0.21±0.10
February	0.24±0.18 <sup>a</sup>	0.14±0.08 <sup>b</sup>	0.13±0.14 <sup>b</sup>	0.17±0.06
March	0.96±1.16 <sup>a</sup>	0.31±0.10 <sup>b</sup>	0.47±0.56 <sup>b</sup>	0.58±0.34
April	0.14±0.12 <sup>a</sup>	0.12±0.03 <sup>a</sup>	0.19±0.12 <sup>a</sup>	0.15±0.03
May	0.63±0.43 <sup>a</sup>	0.39±0.31 <sup>b</sup>	0.44±0.25 <sup>b</sup>	0.49±0.13
June	0.32±0.15 <sup>b</sup>	0.68±0.18 <sup>a</sup>	0.43±0.34 <sup>b</sup>	0.48±0.18
July	0.56±0.21 <sup>b</sup>	0.46±0.27 <sup>b</sup>	0.62±0.19 <sup>a</sup>	0.55±0.08
August	0.24±0.10 <sup>a</sup>	0.19±0.11 <sup>a</sup>	0.24±0.08 <sup>a</sup>	0.22±0.03
September	0.24±0.17 <sup>b</sup>	0.21±0.16 <sup>b</sup>	0.44±0.32 <sup>a</sup>	0.30±0.13
October	0.54±0.27 <sup>b</sup>	0.65±0.15 <sup>a</sup>	0.47±0.15 <sup>b</sup>	0.55±0.09
November	0.13±0.06 <sup>b</sup>	0.22±0.02 <sup>a</sup>	0.32±0.03 <sup>a</sup>	0.22±0.10
December	0.46±0.22 <sup>b</sup>	0.19±0.01 <sup>c</sup>	0.51±0.02 <sup>a</sup>	0.39±0.17
January 2020	0.04±0.04 <sup>c</sup>	0.18±0.13 <sup>b</sup>	0.41±0.27 <sup>a</sup>	0.21±0.19
February	0.06±0.04 <sup>b</sup>	0.14±0.09 <sup>b</sup>	0.31±0.09 <sup>a</sup>	0.17±0.13
March	0.55±0.47 <sup>b</sup>	0.35±0.04 <sup>b</sup>	0.84±1.27 <sup>a</sup>	0.58±0.24
April	0.15±0.10 <sup>a</sup>	0.16±0.07 <sup>a</sup>	0.15±0.13 <sup>a</sup>	0.15±0.01
May	0.39±0.31 <sup>b</sup>	0.31±0.28 <sup>b</sup>	0.76±0.23 <sup>a</sup>	0.49±0.24
June	0.37±0.37 <sup>b</sup>	0.52±0.25 <sup>a</sup>	0.52±0.21 <sup>a</sup>	0.47±0.08
Mean	0.35±0.24	0.30±0.18	0.42±0.19	0.35±0.17

Different superscripts (a, b, c) within each row indicate significant differences in cadmium concentration between stations for each month.

Matching letters indicate no significant difference in Cu concentration between stations within that month

**Table 5:** Monthly and Station Mean Variation of Manganese (Mn) Concentration in Surface Water of Lake Alau

Month	Station 1	Station 2	Station 3	Mean	
January 2019	0.25±0.13 <sup>a</sup>	0.19±0.16 <sup>b</sup>		0.18±0.07 <sup>b</sup>	0.21±0.04
February	0.29±0.09 <sup>a</sup>	0.14±0.13 <sup>c</sup>		0.16±0.03 <sup>b</sup>	0.17±0.03
March	0.36±0.15 <sup>a</sup>	0.14±0.09 <sup>c</sup>		0.26±0.14 <sup>b</sup>	0.25±0.11
April	0.14±0.07 <sup>a</sup>	0.14±0.07 <sup>a</sup>		0.13±0.01 <sup>a</sup>	0.14±0.00
May	0.17±0.09 <sup>b</sup>	0.11±0.04 <sup>c</sup>		0.22±0.15 <sup>a</sup>	0.17±0.06
June	0.34±0.19 <sup>a</sup>	0.27±0.12 <sup>b</sup>		0.42±0.23 <sup>a</sup>	0.34±0.08
July	0.14±0.03 <sup>b</sup>	0.11±0.07 <sup>c</sup>		0.24±0.19 <sup>a</sup>	0.16±0.07
August	0.18±0.13 <sup>a</sup>	0.11±0.03 <sup>b</sup>		0.16±0.04 <sup>a</sup>	0.15±0.04
September	0.21±0.03 <sup>a</sup>	0.12±0.08 <sup>b</sup>		0.18±0.05 <sup>a</sup>	0.16±0.04
October	0.37±0.09 <sup>a</sup>	0.36±0.11 <sup>a</sup>	0.31±0.29 <sup>b</sup>		0.35±0.03
November	0.28±0.06 <sup>a</sup>	0.26±0.12 <sup>b</sup>		0.30±0.17 <sup>a</sup>	0.28±0.02
December	0.87±0.04 <sup>a</sup>	0.46±0.10 <sup>b</sup>		0.39±0.05 <sup>b</sup>	0.31±0.20
January 2020	0.20±0.06 <sup>b</sup>	0.46±0.08 <sup>a</sup>		0.41±0.02 <sup>a</sup>	0.36±0.14
February	0.29±0.25 <sup>b</sup>	0.42±0.08 <sup>a</sup>		0.37±0.02 <sup>a</sup>	0.36±0.07
March	0.25±0.13 <sup>b</sup>	0.45±0.07 <sup>a</sup>		0.41±0.03 <sup>a</sup>	0.37±0.10
April	0.22±0.06 <sup>b</sup>	0.49±0.07 <sup>a</sup>		0.40±0.08 <sup>a</sup>	0.37±0.14
May	0.49±0.26 <sup>b</sup>	0.51±0.03 <sup>a</sup>		0.45±0.03 <sup>a</sup>	0.48±0.03
June	0.25±0.08 <sup>b</sup>	0.34±0.09 <sup>a</sup>		0.33±0.06 <sup>a</sup>	0.31±0.05
Mean	0.25±0.10	0.28±0.15		0.30±0.11	0.28±0.10

Different superscripts (a, b, c) within each row indicate significant differences in manganese concentration between stations for each month.

Matching letters indicate no significant difference in Cu concentration between stations within that month

Table 6: provides insights into the relationships between the heavy metal concentrations, indicating potential co-occurrence patterns and dependencies among certain metals in the water body. Notable positive correlations are seen

between Copper and Manganese (0.606) and between Lead and Copper (0.421). Zinc and Lead show a weak negative correlation (-0.032), while Lead and Cadmium are moderately negatively correlated (-0.490).

**Table 6:** Pearson Correlation Matrix for the Monthly Mean Concentration of Heavy Metals in Lake Alau:

	Zinc	Lead	Copper	Cadmium	Manganese
Zinc	1				
Lead	-0.032	1			
Copper	0.141	0.421	1		
Cadmium	0.335	-0.490	0.214	1	
Manganese	-0.168	0.052	0.606	0.230	1

## DISCUSSION

Heavy metals are classified as specific pollutants due to their high toxicity, bioaccumulation, biomagnification, and their participation in biogeochemical cycles (Amic and Tadic, 2018). While these elements naturally occur in small quantities in the environment, anthropogenic activities have significantly elevated their concentrations. The total trace metals exhibited varying behaviors in Lake Alau, with concentrations either remaining constant or increasing further up the lake.

The generally high and variable concentrations of zinc (Zn) are likely associated with agricultural practices, domestic waste disposal, and Saharan dust loaded with metals being released into Lake Alau (Hati *et al.*, 2008; Masindi and Muedi, 2018). This study established that metal concentrations in the lake's surface water typically follow the order: Zn > Cu > Cd > Mn > Pb. This trend is likely influenced by the natural abundance of the metals, although this order may not be consistently observed across all studies.



Zinc enters water bodies through multiple anthropogenic pathways, including by-products from steel production, coal-fired power plants, burning of waste materials, and leaching from fertilizers and industrial effluents during mining and metal processing activities (Damodharan, 2013). Other significant sources include urban runoff and municipal sewage.

Zinc is an essential nutrient for growth and development and is found in virtually all food and potable water in the form of salts or organic complexes (WHO, 2011). However, excessive levels of zinc in drinking water can cause stomach cramps, nausea, and vomiting. The concentrations of zinc in Lake Alau's surface water, observed in this study, did not exceed the World Health Organization's (WHO) recommended limit of 3 mg/L for drinking water (WHO, 2008) or the permissible limit of 5 mg/L set by the Central Pollution Control Board (CPCB, 2000) and the United States Environmental Protection Agency (USEPA, 2002).

Zinc plays a critical role in activating numerous enzymes, particularly those present in the liver (Yacoub, 2007; Authman *et al.*, 2015). It is crucial for aquatic organisms, especially fish, as it affects cellular respiration, oxygen utilization, DNA/RNA expression, and protection against oxidative stress (Sloup *et al.*, 2017). Zinc is also vital for bone growth and reproductive organ functioning, though zinc poisoning is rare. However, excessive zinc concentrations can be harmful to aquatic life, producing antagonistic, additive, or synergistic effects with other elements (Baumann and May, 1984; Kanwal and Saher, 2018).

Zinc is significantly more toxic to aquatic organisms than to humans. For instance, the US EPA freshwater aquatic biological criterion for zinc is 0.12 mg/L, compared to human health standards of 7.4 mg/L (potable water + aquatic organisms) and 26 mg/L (potable aquatic organisms only).

Fish can accumulate zinc from both water and their diet (Eisler, 1993; Garai *et al.*, 2021). At high concentrations, zinc can be toxic to fish, leading to mortality, growth retardation, reproductive impairment, cardiac changes, inhibition of spawning, and a multitude of detrimental effects (Sorenson, 1991; Authman *et*

*al.*, 2015). Zinc's toxicity in aquatic fauna is influenced by factors such as water hardness, oxygen saturation, and temperature. Salts of alkaline-earth elements reduce its toxicity; while increased temperature and lower dissolved oxygen levels heighten its toxic effects. Clinical signs of zinc toxicity in other organisms include diarrhea, bloody urine, liver failure, kidney failure, and anemia (Duruibe *et al.*, 2007). Zinc is vital for many physiological and metabolic processes in aquatic life, but its toxicity poses a significant threat when concentrations exceed essential levels.

Lead (Pb) enters the environment through both natural and anthropogenic sources. It is a natural component of air, water, and the biosphere, and in aquatic environments, lead typically occurs in its +2 oxidation state. Industrial activities such as mining, gasoline combustion (due to tetraethyl lead), and the use of lead-based products contribute significantly to elevated lead concentrations in natural waters, where it is otherwise rarely detected (Asante, 2013). Lead from gasoline combustion is a primary source of atmospheric Pb, much of which eventually ends up in water bodies. Other sources include soil erosion, runoff from municipal and industrial waste, and urban drainage (DWAf, 1996; Bahnasawy *et al.*, 2011).

In Lake Alau, the concentrations of Pb in all sampled water portions exceeded the permissible limit of 0.05 mg/L as set by the World Health Organization (WHO, 1993) and the United States Environmental Protection Agency (USEPA, 2002). The Pb levels also surpassed the WHO (2008) recommended limit of 0.01 mg/L for drinking water, indicating that Lake Alau is polluted with lead. Potential contributors to this contamination include the discharge of automobile waste from vehicles, particularly heavy-duty trucks that transport sand and gravel near Station 5, and military activities within the lake's catchment area, such as those associated with the insurgency in the Sambisa swamp.

The spillage of petroleum products is another significant environmental hazard, especially since used engine oil absorbs heavy metals from engine wear, making its disposal more harmful than crude oil (Abioye *et al.*, 2012). Popoola and Ayodele (2016) emphasized the damaging environmental effects of large-scale petroleum

product spills. Military activities, whether on land or sea, have also been associated with the release of toxic elements like lead, cadmium, and copper, which are well-known for their toxicity (Gebka *et al.*, 2016).

Lead accumulation in water is primarily facilitated through adsorption and the complexation of free lead ions (Denny and Welsh, 1979; Kumar *et al.*, 2020). Lead exposure, even at low levels, can cause severe nerve damage, particularly in infants and children (Wani *et al.*, 2015). It also triggers the excessive production of reactive oxygen species (ROS), which can destroy cellular membranes, lipids, nucleic acids, and proteins (Khan *et al.*, 2018; Kumar *et al.*, 2011). The USEPA recommends a lead criterion of 0.131 mg/L, with a chronic criterion of 0.0051 mg/L.

Lead is highly toxic to aquatic organisms, especially fish (Rompala *et al.*, 1984; Tchounwou *et al.*, 2012). In humans, Pb poisoning affects the kidneys, reproductive system, liver, and nervous system, and can lead to developmental issues such as mental retardation in children and anemia in cases of mild poisoning. Nutritional deficiencies, including a lack of calcium, iron, copper, selenium, and ascorbic acid, can exacerbate lead accumulation in the body. Lead primarily accumulates in the bones, where it replaces calcium. Organic lead compounds can easily penetrate the human body through the skin, posing risks to the central nervous system.

The toxic effects of Pb are linked to its strong affinity for sulfur, reducing enzyme activity and inhibiting cellular oxidation-reduction reactions and protein synthesis. Lead poisoning is more severe in hard water than in soft water. High levels of lead exposure can lead to disruptions in hemoglobin synthesis, kidney damage, gastrointestinal issues, joint and reproductive problems, and acute or chronic damage to the nervous system (Tirkey *et al.*, 2012). Common sources of lead include the combustion of lead-based fuels, commercial products like plastics, storage batteries, bearing alloys, insecticides, and certain paints (Mutwiri, 2001).

Lead contamination in Lake Alau is largely attributed to industrial activities, vehicle emissions, military operations, and petroleum spillage. Its presence poses significant health

risks to both aquatic life and humans, with the potential for serious environmental and biological consequences.

**Copper (Cu):** Copper is an essential element for living organisms and is widely distributed in nature. It is naturally present in soils, rocks, and rivers, and is released into aquatic environments through both natural processes, such as weathering of soil, and anthropogenic sources like industrial discharges and wastewater treatment plants. In aquatic systems, copper can exist in three forms: soluble, colloidal, and particulate. However, Cu is typically rare in natural waters unless introduced by human activities.

One major source of Cu in the surface water of Lake Alau is the extensive use of pesticide sprays containing copper compounds for agricultural purposes. Other contributions come from runoff from surrounding agricultural farmlands and catchment areas. Copper is commonly used in fungicides, algicides, insecticides, wood preservatives, and even in industrial processes such as electroplating, petroleum refining, azo dye manufacturing, and pyrotechnics. Additionally, copper compounds are added to fertilizers and animal feeds to promote growth, and they can also be found as food additives (Abbasi *et al.*, 1998; EFSA, 2018).

Copper, while essential for metabolic processes in humans and animals, affecting enzymes and hemoglobin synthesis, is highly toxic to fish and other aquatic organisms at concentrations that are not harmful to humans. This toxicity is particularly severe for early life stages such as fish larvae, although it is mitigated when copper is bound to particulate matter in water or when the water is hard (Damodharan, 2013). The toxicity of copper is influenced by several water parameters such as alkalinity, pH, and the presence of organic matter. As these factors increase, the bioavailability and toxicity of Cu (II) ions decrease.

In Lake Alau, copper concentrations in all sampled portions of the lake exceeded the World Health Organization's (WHO) permissible limit of 0.05 mg/L for water quality (WHO, 1999). The toxicity of copper to aquatic organisms is significantly higher than its toxicity to humans and terrestrial organisms, with water fleas being

especially susceptible (Zhu, 2006). Copper tends to be more concentrated in harder water bodies with higher dissolved organic matter content (Hong, 2020).

According to the Asian Development Bank (ADB), the standard limits for copper are as follows: 1.0 mg/L for drinking water, 0.40 mg/L for fishing waters, and 5.00 mg/L for livestock drinking water. For irrigation purposes, the permissible limit is 0.20 mg/L, while domestic water supplies have a limit of 1.0 mg/L (USEPA). Though copper is essential for human health, excessive concentrations can lead to health problems such as anemia, liver and kidney damage, and gastrointestinal irritation (Turnland, 1988; Garba *et al.*, 2021).

Copper is remobilized in water through processes like acid-base ion exchange and oxidation (Gomez *et al.*, 2000). Although the effects of high copper concentrations on fish are not fully understood, it has been observed that fish exposed to toxic levels of copper may experience biological dysfunctions and histopathological alterations, such as damage to liver and kidney tissues, stomach irritation, and anemia (Sabullah *et al.*, 2014; Monteiro *et al.*, 2012). Copper toxicity can act as a stressor to aquatic organisms, disrupting biochemical functions and cellular morphology, leading to harmful effects, particularly for invertebrates (Woodward *et al.*, 1994; Tirkey *et al.*, 2012).

While copper is vital for both human and animal life, excessive levels of Cu in aquatic systems can be highly toxic to aquatic organisms, especially fish. In Lake Alau, agricultural runoff and other anthropogenic activities have contributed to elevated copper levels, posing risks to the lake's aquatic ecosystem.

**Cadmium (Cd):** Cadmium is a nonessential trace metal that is potentially toxic to most fish and wildlife, particularly freshwater organisms (Robertson *et al.*, 1989; Sfakianakis *et al.*, 2015). Cd is chemically similar to Zn and found in water in the oxidation form +2. It occurs naturally as CdS and followed minerals of Pb and Zn. Food is the main source of Cd poisoning. The effects of acute Cd poisoning in humans are very serious, including hypertension, kidney damage, causing potential prostate cancer, etc. (Durmishi *et al.*, 2016). The physiological effects of Zn with Cd replacement

in some enzymatic reactions hampered the normal functioning of enzymes. The toxic effect of Cd in water decreases with the increasing hardness of the water, due to rising water carbonates content. Heavy metal carbonates are less soluble in water and so a part of dissolved Cd is removed (Bytyci, 2018). Cd is highly toxic and responsible for several cases of poisoning through food. Small quantities of Cd cause adverse changes in the arteries of human kidney. It replaces Zn biochemically and causes hypertension as well as kidney damage. It interferes with enzymes and causes a painful disease called Itai-itai (Rajappa *et al.*, 2010). High concentration of Cd occurs at neutral and alkali pH.

The total mean concentration values in the water samples were highest at station 3 ( $0.42 \pm 0.19$ ), while station 2 shows the least value ( $0.30 \pm 0.18$ ). Higher concentration of cadmium is extremely toxic to fish population. Its effects on the growth rate have been observed even for concentrations between 0.005 and 0.01 mg/L (Green, 1986; Hameed *et al.*, 2019), where fertilizers, pesticides and other agrochemical are used in addition to possible release of sediment bound metal. Apart from natural sources, other probable sources of this metal in surface water include leaching from Ni-Cd based batteries (Huton *et al.*, 1999; Daso and Osibanjo, 2012), runoff from agricultural soils where phosphate fertilizers are used (Steopler, 1991; Daso and Osibanjo, 2012) and other metal wastes. The levels of cadmium in the water samples from the three sampling point were above the (WHO, 2004) standard values of 0.01 mg/L for the survival of aquatic organism. Cadmium has no known physiological role in aquatic organisms and is considered as one of the most toxic metals in the aquatic environment (Obasohan, 2008; Okocha and Adedeji, 2011). This study observed a total mean concentration of  $0.35 \pm 0.17$  mg/L for total water concentration in all the sampling station.

Manganese (Mn) compounds are used in fertilizers, varnish and fungicides and as livestock feeding supplements. It can also bioaccumulate in lower organisms (e.g., phytoplankton, algae, mollusks and some fish) but not in higher organisms; biomagnifications in food chains is not expected to be very

significant. A high concentration of manganese can cause genotoxic damage in fish that are bottom dwellers such as *Clarias gariepinus*, which is present in Alau Lake (Chukwuemeka *et al.*, 2019). The concentrations of Mn within the three sampling point from Lake Alau exceeded the permissible limit of 0.05 mg/L water (WHO, 2004; USEPA, 2002). Mn concentration levels in surface water was found to be lower than recommended limit of 0.40 mg L<sup>-1</sup> for Mn in drinking water (WHO, 2008). Mn is an abundant metal in earth's crust and usually occurs with iron. It is used in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient in various products (WHO 2011). Mn is introduced into aquatic environments mainly through anthropogenic sources, such as sewage sludge, emissions from alloy, iron, and steel industries, municipal wastewater discharges, and mining and mineral processing (Abidemi, 2013). Manganese in trace amount is an essential element. It interferes with iron metabolism, especially haemoglobin formation (Igwemmar *et al.*, 2013).

Mn is present in over 100 common salts and mineral complexes that are widely distributed in rocks, in soils and on the floors of lakes and oceans (Damodharan, 2013). These Mn minerals include sulfides, oxides, carbonates, silicates, phosphates, arsenates, tungstates, and borates. However, the most important Mn mineral is the native black manganese oxide, pyrolusite (MnO<sub>2</sub>). Mn is used for production of ferromanganese steels, electrolytic manganese dioxide for use in batteries, alloys, catalysts, antiknock agents, pigments, dryers, wood preservatives and coating welding rods (Bradi, 2005). It is also used as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient of various products (WHO, 2011). Mn is an essential micronutrient present in all living organisms, because it functions as a co factor for many enzyme activities' (Suresh *et al.*, 1999). Mn is a metal with low toxicity but has a considerable biological significance and seems to accumulate in fish (Kumar *et al.*, 2011). According to (Krishna *et al.*, 2014), high Mn concentration interferes with the central nervous system of

vertebrates; hence, the consumption of Mn contaminated fish potentially resulting in health risks to the consumers is a matter of concern. High concentration of Mn causes liver cirrhosis and also produces a poisoning called Manganese or Parkinson disease (Bradi, 2005).

Heavy metals like lead, cadmium, and copper are prevalent in Lake Alau, likely due to intensive surrounding human activities. Lake Alau's watershed experiences greater agricultural and urban impacts, leading to pollutant accumulation in sediments and degraded water quality over time. Local agricultural practices likely contribute pesticides, fertilizers, and waste products containing metals like cadmium and zinc to Lake Alau (Ahktar *et al.*, 2021). These contaminants enter the lake through runoff, especially during the wet season, thereby increasing metal concentrations in the water and sediment (Liu *et al.*, 2024). The release of lead, manganese, and zinc from vehicular emissions near urban areas surrounding Lake Alau contributes to atmospheric deposition, which settles into the lake (Dantas Arouca *et al.*, 2024). Furthermore, urbanization often leads to untreated or insufficiently treated wastewater entering the lake.

It's essential to focus on both immediate and long-term impacts of heavy metal contamination in Lake Alau, especially as they relate to the ecosystem and public health. Elevated concentrations of heavy metals like zinc, lead, and cadmium can disrupt aquatic life by affecting plankton diversity (Zamora-Ledezma *et al.*, 2021) and reducing food availability for higher trophic levels, such as fish. Over time, bioaccumulation of these metals in fish and other organisms can lead to toxic effects that threaten biodiversity and diminish population resilience (Edo *et al.*, 2024). The loss of sensitive species may ultimately alter the lake's ecological balance, making it more susceptible to algal blooms and other indicators of degraded water quality.

Heavy metals in water systems can pose severe health risks when they enter the food chain or contaminate drinking water supplies (Kapoor and Singh, 2021). Chronic exposure to metals like lead and cadmium is associated with kidney damage, neurological disorders, and other long-

term health conditions (Balali-Mood *et al.*, 2021). Assessing the specific concentrations of these metals and their accumulation in commonly consumed fish species from Lake Alau can help clarify the risk to local communities, guiding both health advisories and consumption recommendations.

### CONCLUSION

This study confirms elevated levels of heavy metals, including zinc, copper, manganese, cadmium, and lead, in Lake Alau's surface water. Zinc, though essential, poses toxicity risks at high concentrations, likely stemming from agricultural runoff, industrial activities, and urban waste, though it remains within safe limits for human consumption. Copper, cadmium, manganese, and lead, however, exceed permissible limits, highlighting a serious pollution risk that threatens aquatic health, growth, and ecosystem stability. To safeguard Lake Alau's water quality and biodiversity, effective management and pollution control measures are critical. Recommended actions include promoting organic or low-input agriculture to reduce runoff, establishing vegetative buffer zones to filter contaminants, and enforcing stricter waste disposal controls. Additionally, dust management efforts, such as reforestation or physical barriers, could mitigate heavy metal input from Saharan dust, especially during harmattan seasons. Regular monitoring of heavy metals, paired with biodiversity and health impact assessments, is essential for tracking contamination trends and enabling early response strategies. Data on bioaccumulation in fish linked to human health outcomes would support stronger regulations and guide public advisories on safe consumption practices, protecting both ecosystem and community health over the long term.

### REFERENCES

Abbasi, S. A. Abbasi, N. and Soni, R. (1998). Heavy Metals in the Environment, 1st Edition. Mittal Publications, p.314.

Abidemi, O. O. (2013). Accumulation and Contamination of Heavy Metals in Soil and Vegetation from Industrial Area of Ikirun, Osun State, Nigeria. *Global Journal of Pure and Applied Chemistry Research*, 1(1), 25-34.

Abioye, O.P., Agamuthu, P and Abdul Aziz, A. R. (2012). Biodegradation of used Motor Oil in Soil Using Organic Waste Amendments. *Biotechnology Research International*, 7(8): 230-238.

Ahmed, M. I., Ambali, A., Karshima, S. N., & Mohammed, K. M. (2023). Heavy metal concentrations, water quality and health risk assessment of freshwater fish from the Lake Chad basin. *Limnologica*, 103, 126135.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, 13(19), 2660.

Amić, A. and Tadić, L. (2018). Analysis of Basic Physical-Chemical Parameters, Nutrients and Heavy Metals Content in Surface Water of Small Catchment Area of Karašica and Vučica Rivers in Croatia. *Environment*, 5(20):27.

Asante, K. (2013). Assessment of Heavy Metal Contamination in Water, Sediment and Fish from the Jimi Reservoir, Obuasi. MSc. Thesis. Institute of Distance Learning Ghana.

Authman, M. M. N., Zaki, M. S., Khallaf, E. A. and Abbas, H. H. (2015). Use of Fish as bio-indicator of the Effects of Heavy Metals Pollution. *Journal of Aquaculture Research and Development*.6 (4), 328.

Bahnasawy, M. Khidr, A. and Dheina, N. (2011). Assessment of Heavy Metal Concentrations in Water, Plankton, and Fish of Lake Manzala, Egypt. *Turkish Journal of Zoology*, 35. 271-280.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. *Frontiers in pharmacology*, 12, 643972.

Baumann, P.C. and May, T. W. (1984). Nickel Residues in Fish from Inland Waters of the United States. In *Workshop Proceedings, the Effects of Trace Elements on Aquatic Ecosystems*. Electric Power Research Institute, Palo Alto, CA, 7: 1-16.

- Bradi, B. H. (2005). Heavy Metals in the Environment. In: Interface Science and Technology. Hubbard A. (Ed.), Vol. 6, Elsevier Academic Press, Neubrucke.
- Bukar, P. H., Oladipo, M. O. A., Ibeanu, I. G. E., & Zakari, I. Y. (2016). Assessment and distribution of metal pollutants in the water of River Ngadda and Alau Dam used for irrigation farming in Maiduguri, Borno State, Nigeria. *American Journal of Research Communication*, 4(4), 74-84.
- Bwala, M. N. (2023). Assessment of Heavy metals in Sediments, Water and Carias gariepinus from Alau Dam, Borno State Nigeria. *Sahel Journal of Life Sciences FUDMA*, 1(1), 155-162.
- Bytyci, P., Fetoshi, O., Durmishi, B. H., Etemi, F. Z., Çadraku, H., Ismaili, M. and Abaz, A. L. (2018). Status Assessment of Heavy Metals in Water of the Lepenci River Basin, Kosova. *Journal of Ecological Engineering*, 19 (5), 19–32.
- Chukwuemeka, V. I., Jimoh1 , E. A., Olajide, K. O., Auta, Y. I., Auta, H. S. and Erhabor, O. F. (2019). Spatio-Temporal Variation Level of Heavy Metals in Surface Water and Sediment in Tagwai Lake, Minna, Nigeria. *Tropical Freshwater Biology*, 29 (1) 123-131.
- CPCB. (2000). Central Pollution Control Board, Review of Water Quality Objectives, Requirements and Zoning and Classification for Indian Water Bodies,” Government of India, Delhi, pp. 11-17.
- Damodharan, U. (2013). Bioaccumulation of Heavy Metals in Contaminated River Water Uppanar, Cuddalore South East Coast of India. <http://dx.doi.org/10.5772/5334>
- Dantas Arouca, N. G. F., Moreira, L. F. F., Moraes, E. P., & do Nascimento Batista, J. A. (2024). Spatio-temporal variability of potentially toxic elements’ pollution in road-deposited sediments according to health risk thresholds: a meta-analysis. *Environmental Geochemistry and Health*, 46(7), 258.
- Daso, A. P. and Osibanjo, O. (2012). Water Quality Issues in Developing Countries: a Case Study of Ibadan Metropolis, Nigeria. Water Quality Monitoring Assessment. Edited by Kostas Voudouris and Dimitra Voutsas. DOI:10.5772/32301
- Denny, P. and Welsh, R. (1979). Lead Accumulation in Plankton Blooms from Ullswater, the English Lake District. *Journal of Environmental Pollution*, 18: 1-9.
- Ding, Y.F., Sun, S. J., Feng, J., Cui, P., Zhang, D. and Long, Z. Y. (2021). An Assessment of Lake Ecology on the Basis of the Macrobenthos Multi-Metric Index (MMI) in 11 Lakes in the Western Region of Jilin, China. *Water*, 13, 235.
- Durmishi B.H., Abduli S., Reka A.A., Ismaili M., Shabani A. and Durmishi, A. (2016). Determination of the Content of Zn, Cu, Pb and Cd in the River Shkumbini (Pena) with Potentiometric Stripping Analysis. *International Journal of Chemistry and Materials Sciences*, 1(1), 17–32.
- Duruibe J. O., Ogwuegbu M. C., Egwurugwu J. N. (2007). Heavy Metal Pollution and Human Biotoxic Effects. *International Journal of Physical Sciences*, 2, 112–118.
- DWAF. (1996). South Africa Water Quality Guidelines for Domestic Use, 2nd Edition, Pretoria, South Africa.
- Edo, G. I., Samuel, P. O., Oloni, G. O., Ezekiel, G. O., Ikpekoru, V. O., Obasohan, P., ... & Agbo, J. J. (2024). Environmental persistence, bioaccumulation, and ecotoxicology of heavy metals. *Chemistry and Ecology*, 40(3), 322-349.
- EFSA (European Food Safety Authority), (2018). Reasoned Opinion on the Review of the Existing Maximum Residue Levels for Copper Compounds According to Article 12 of Regulation (EC) No 396/2005. *EFSA Journal*, 16(3):5212, 135
- Eisler, R. (1993). Zinc Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Services Biology. Report, 85 (1.10): 90.
- Garai, P, Banerjee P., Mondal P, and Saha, N. C. (2021) Effect of Heavy Metals on Fishes: Toxicity and Bioaccumulation.

- Journal of Clinical Toxicology. 11 (S18):001.
- Garba, M., Dandago, M. A., Igwe, E. C. and Salami, K. D. (2021). Heavy Metals Safety of Ready-To-Eat (RTE) Vegetables Salads (A review). *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, 7 (4a): 21-37.
- Gębka, K., Beldowska, M. and Beldowski, J. (2016). The Impact of Military Practices on the Concentration of Mercury in soils of Military Training Grounds and Marine Medicaments. *Environmental Science Pollution Research*, 23, 23103-23113.
- Gomez-Ariza, J. L., Sanchez-Rodas, D., Morales, E. and Giráldez, I. (2000). Metal Sequential Extraction Procedure Optimized for Heavily Polluted and Iron Oxide Rich Sediments. *Analytica Chimica Acta* 414(1-2):151-164.
- Green, W. J., Canfield, D. E., Lee, G. F. and Jones, R. A. (1986). "Mn, Fe, Cu and Cd Distribution and Residence Times in Closed Basin Lake Vanada (Wright Vally, Antatica)," *Hydrobiologia*, 134(3):237-248.
- Hameed, F., Riaz, M. A., Zahid, U. and Saeed, M. (2019). Hazardous Effects of Cadmium Contaminated Water on Biological Characteristics of Fish; A Review. *RHAZES: Green and Applied Chemistry*, 6, 01-10.
- Hati, S. S., Dimari, G. A., Waziri, M. and Pindiga, Y. N. (2008). Interaction Profile For As, Cd, Cr and Pb in Surface Water, Superficial Sediments and Background Sediments of Lake Alau, Maiduguri, Nigeria. *Terrestrial and Aquatic Environmental Toxicology*, 2(1), 30-33.
- Hong, Y. J., Liao, W., Yan, Z. F., Bai, Y. C., Feng, C. L., Xu, Z. X. and Xu, D. Y. (2020). Review Article. Progress in the Research of the Toxicity Effect Mechanisms of Heavy Metals on Freshwater Organisms and Their Water Quality Criteria in China. *Journal of Chemistry*, 12
- Hutton, M., Chaney, R. L., Krishna, C. R., Murti, M., Olade, A. and Page, A. L. (1999). "Groups Report," In: T. C. Hutchinson and K. M. Meena, Eds., *Lead, Mercury, Cadmium and Arsenic in the Environment*, John Wiley, New York, pp. 35-41.
- Igwegbe, A.O. (2013). Effects of Location, Season, and Processing on Heavy Metal Contents in Selected Locally Harvested Fresh Fish Species from Borno State of Nigeria. A Ph.D. Thesis, Department of Food Sciences and Technology, Faculty of Engineering, University of Maiduguri, Nigeria. PP xii + 160.
- Islam, M. S., Tusher, T. R., Mustafa, M. and Mahmud, S. (2013). Effects of Solid Waste and Industrial Effluents on Water Quality of Turag River at Konabari Industrial Area, Gazipur, Bangladesh. *Journal of Environmental Science and Natural Resources*, 5 (2), 213–218.
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2014). Toxicity, Mechanism and Health Effects of Some Heavy Metals. *Interdisciplinary toxicology*, 7(2), 60-72.
- Julius, K. N., Steven, G. N. and Esther, C. K. (2015). Assessment of Heavy Metal Contamination in Surface Water of Masinga Reservoir, Kenya *Journal of Natural Sciences Research*. 5(2):101-108.
- Kanwal, N. and Saher, N. (2018). Quality Assessment of Marine Shellfisheries: Dietary Exposure to Metal Contaminants in Seafood. *Pakistan Journal of Zoology Supplement Series*, 13:199-204.
- Kapoor, D., & Singh, M. P. (2021). Heavy metal contamination in water and its possible sources. In *Heavy metals in the environment* (pp. 179-189). Elsevier.
- Khan, M. S., Zaidi, A. and Wani, P. A. (2007). Role of Phosphate Solubilizing Microorganisms in Sustainable Agriculture-a review. *Agron Sustainable Development* 27:29–43.
- Krishna P.V., Rao K.M., Swaruparani V. and Rao D. S. (2014). Heavy Metal Concentrations in Fish *Mugilcephalus* from Machilipatnam Coast and Possible

- Health Risks to Fish Consumers. *British Biotechnology Journal*, 4(2), 126–135.
- Kumar, A., Cabral-Pinto, M. M. S., Chaturvedi, A. K., Shabnam, A. A., Subrahmanyam, G., Mondal, R., Gupta, D. K., Malyan, S. K., Kumar, S. S., Khan, S. A. and Yadav, K. K. (2020). Lead Toxicity: Health Hazards, Influence on Food Chain, and Sustainable Remediation Approaches. *International Journal of Environmental Research and Public Health*, 17(7), 2179.
- Kumar, B., Mukherjee, D. P., Kumar, S., Mishra, M., Prakash, D., Sigh, S. K., Sharma, C. S. (2011). Bioaccumulation of Heavy Metals in Muscle Tissue of Fisheries from Selected Aquaculture Ponds in East Kolkata lands. *Annals of Biological Research*, 2(5). 125–134.
- Kumar, V., Arya, S., Dhaka, A., Minakshand, A. and Chanchal, (2011). A Study on Physico-chemical Charactersitics of Yamuna River around Hamirpur (UP), Bundelkhand Region Central India. *International Multidisciplinary Research Journal*, 1, 14 - 16.
- Kumar, V., Sharma, A., Kumar, R., Bhardwaj, R., Kumar Thukral, A. and Rodrigo-Comino, J. (2020). Assessment of Heavy-Metal Pollution in Three Different Indian Water Bodies by Combination of Multivariate Analysis and Water Pollution Indices. *Human and Ecological Risk Assessment: an International journal*, 26(1), 1-16.
- Mahino, F., Nazura, U. and Mobarak, M. H. (2014). Heavy Metal in Aquatic Ecosystem Emphasizing its Effect on Tissue Bioaccumulation and Histopathology: A Review. *Journal of Environmental Science and Technology*, 7:1-15.
- Masindi, V. and Muedi, K. L. (2018). Environmental Contamination by Heavy Metals. In H. E. M. Saleh, and R. F. Aglan (Eds.), *Heavy Metals*. IntechOpen..
- Monteiro, S. M., Oliveira, E., Fontaínhas-Fernandes, A. and Sousa, M. (2012). Effects of Sublethal and Lethal Copper Concentrations on the Gill Epithelium Ultrastructure of Nile Tilapia, *Oreochromis niloticus*. *Zoological Studies*, 51(7), 977–987.
- Mutwiri, N. M. (2001). Determination of Cadmium, Chromium, Lead and Mercury in Honey Samples from Mbeere, Meru and Kirinyaga Districts Unpublished, MSc Thesis, Chemistry Department, Egerton University, Nakuru, Kenya
- Obasohan, E. E. (2008). Bioaccumulation of Chromium, Copper, Manganese, Nickel and Lead in a Freshwater Cichlid, *Hemichromis fasciatus*, from Ogba River in Benin City, Nigeria. *African Journal of General Agriculture*. 4(3): 141 – 152.
- Okocha, R. C. and Adedeji, O. B. (2011). Overview of Cadmium Toxicity in Fish. *Journal of Applied Sciences Research*, 7(7): 1195-1207.
- Pandey, L. K., Park, J., Son, D. H., Kim, W., Islam, M. S., Choi, S., Lee, H. and Han, T. (2019). Assessment of Metal Contamination in Water and Sediments from Major Rivers in South Korea from 2008 to 2015. *Science of the Total Environment*, 651, 323-333.
- Popoola, O.O. and Ayodele, F.O. (2016). Effects of Automobile Repair Workshop on Water Quality of Selected Area in Ado-Ekiti , Nigeria. *Journal of Multidisciplinary Engineering Science and Technology*, 3(8): 5363-5365.
- Radojevic, M. and Bashkin, V. N. (1999). *Practical Environmental Analysis*. 2nd Edition. The Royal Society of Chemistry, Cambridge, pp: 466.
- Rajappa, B., Manjappa, S. and Puttaiah E.T. (2010). Monitoring of Heavy Metal in Groundwater of Hakinaka Taluk, India. *Contemporary Engineering Sciences*, 3(4), 183–190
- Robertson, S. M., Gamble L.R. and Maurer, T. C. (1991). Contaminant survey of La Sal Vieja, Willacy County, Texas, 1989. U.S. Fish Wild. Serv., Region 2, Contaminants Program. Fish and Wildlife Enhancement, Corpus Christi Field Office, Campus Box 338, 6300



- Ocean Drive, Corpus Christi, Texas 78412, Study Identifier 89-2-100.
- Rompala, J. M., Rutosky, F.W. and Putnam, D. J. (1984). Concentrations of Environmental Contaminants from Selected Waters in Pennsylvania. United States Fish and Wildlife Service Republic, State College, Pennsylvania, US. Pp: 102.
- Sabullah, M. K., Shukor, M. Y., Sulaiman, M. R., Shamans, N. A., Syed, M. A., Khalid, A. and Ahmad, S. A. (2014). The Effect of Copper on the Ultrastructure of *Puntius javanicus* Hepatocyte. *Australian Journal of Basic and Applied Science*, 8(15), 245–51.
- Saha, P. and Paul, B. (2019). Assessment of Heavy Metal Toxicity Related with Human Health Risk in the Surface Water of an Industrialized Area by a Novel Technique. *Human and Ecological Risk Assessment*, 25 (4), 966–987.
- Sfakianakis, D. G., Renieri, E., Kentouri, M. and Tsatsakis, A. M. (2015). Effect of Heavy Metals on Fish Larvae Deformities: A review. *Environmental Research*, 137: 246-255
- Sloup, V., Jankovská, I., Nechybová, S., Peřinková, P. and Langrová, I. (2017). Zinc in the animal organism: A review. *Scientia Agriculturae Bohemica.*, 48, (1): 13-21.
- Sorenson, E.M., (1991). *Metal Poisoning in Fish*. CRC Press, Inc. Boca Raton, Florida, pp: 119-174.
- Stoeppler, M. (1991). Cadmium. In: Merian E (ed.) *Metals and their Compounds in the Environment: Occurrence, Analyses and Biological Relevance*. VCH, New York. 803-851.
- Streumples, A. W. (1973). Adsorption Characteristics of Ag, Pb, Zn, Ni, on Biosilicate Glass and Polypropylene Container. *Walls and Chemical*. 45: 225-254.
- Suresh, B., Steiner W., Rydlo M. and Taraschewski, H. (1999). Concentrations of 17 Elements in Zebra Mussel (*Dreissena polymorpha*). *Environmental Toxicology and Chemistry*, 18, 2574–9
- Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2012) Heavy Metals Toxicity and the Environment. *Experientia Supplementum*. 101, 133-164.
- Tenebe, I. T., Ogbiye, A. S. and Omole, D. O. (2017). Modeling and Sensitivity Analysis of Varying Roughness effect on Dispersion Coefficient: a Laboratory Study. *Desalination and water treatment*, 87, 209–215.
- Tirkey, A., Shrivastava, P. and Saxena, A. (2012). Bioaccumulation of Heavy Metals in Different Components of Two Lakes Ecosystem. *Current World Environment*, 7(2), 293–297.
- Turnland, J. R. (1988). Copper Nutrition, Bioavailability and Influence of Dietary Factors. *Journal of American Dietetic Association*, 1: 303-308.
- USEPA, (2002). *Risk Assessment: Technical Background Information*. <http://www.epa.gov/reg3hwmd/risk>.
- Wani, A. L., Ara, A. and Usmani, J. A. (2015). Lead Toxicity: A Review. *Interdisciplinary toxicology*, 8(2), 55–64.
- WHO. (1993). *Guidelines for Drinking Water Quality Recommendations*, Vol. 1st,2nd Ed, Geneva.
- WHO. (2004). *Guidelines for Drinking-Water Quality 3rd Ed*. Geneva: World Health Organization
- WHO. (2008). *Guidelines for Drinking-water Quality Third Edition*. WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland.
- WHO. (2011). *Guidelines for Drinking Water Quality*, 4th Ed. World Health Organization, Geneva, pp. 564
- WHO. (2011). *Guidelines for Drinking Water Quality. V-I Recommendations* World Health Organization, Geneva, Switzerland, 145-220.
- Woodward, D.F., Brumbaugh, W. G. Deloney, A. J. Little, E. E. and Smith, C. E. (1994). Effect of Contaminant Metals on Fish in the Clark Fork River in

- Montana. Transaction of American Fisheries Society, 123: 51-62.
- Yacoub, A. (2007). Study on Some Heavy Metals Accumulated in Some Organs of Three River Nile Fishes from Cairo and Kalubia Governorates, African Journal of Biology Science, 3, 9-21.
- Zamora-Ledezma, C., Negrete-Bolagay, D., Figueroa, F., Zamora-Ledezma, E., Ni, M., Alexis, F., & Guerrero, V. H. (2021). Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methods. Environmental Technology & Innovation, 22, 101504.
- Zhu, L. (2006). Environmental Toxicology, vol. 57–69, Higher Education Press, Beijing, China, in Chinese.