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FROM ABUNDANCE TO ADVERSITY: UNDERSTANDING THE CHANGING DYNAMICS OF LAKE ALAU'S WATER QUALITY

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ABSTRACT

Lake Alau, a critical water resource in the region, was subject to an extensive water quality assessment with the aim of assessing the impact of human activities on the physico-chemical parameters of Lake Alau, with a specific focus on water quality potentials of the Lake. The study spanned over a year, capturing variations in several physicochemical parameters using standard laboratory techniques. The data were computed and analysed using ANOVA. The findings reveal that the lake generally maintains water quality within permissible limits for aquatic ecosystems. The physical parameters of the lake, including Temperature, Total Solids (TS), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS), were within the range of a productive lake, but higher concentrations of TDS (365.68g/L) and TSS (171.95g/L) might have altered the ecological balance of the lake. The chemical parameters, including pH, biochemical oxygen demand (BOD), Chemical Oxygen Demand (COD), Nitrite, Nitrate, and Phosphate, were within the permissible limit for a productive lake, supporting the biological parameters of the lake However, phosphate concentrations exceed 0.1mg/l which is the limit for drinking water. The observed variations underscore the lake's vulnerability to human activities and seasonal changes. Despite some concerns, Lake Alau remains suitable for aquatic life, with certain water quality management practices recommended to maintain its intergrity.

Keywords: Lake Alau, Physico-chemical, Ecological, Anthropogenic, Biodiversity, Icthyofauna, Pisciculture, Eutrophication

INTRODUCTION

The imperative of comprehending the status of freshwater ecosystems, notably focusing on Lake Alau, is underscored (Fierro *et al*., 2017). In recent decades, human activities such as agriculture, land use alterations, increased surface waterproofing resulting in amplified runoff and concentrated pollutants, unprocessed wastewater discharges, and the influence of climate change have collectively precipitated a widespread deterioration in the quality of surface waters. The degradation we observe underscores the critical importance of effective management practices encompassing hygiene, environmental sanitation, storage, and disposal. These factors are pivotal in preserving our valuable water resources (Smith *et al*., 2020).

Lake Alau have been a critical fluvial resource that plays a multifaceted role in supporting both human and ecological systems. Its waters serve as a primary source for irrigation, sustaining local agriculture and ensuring food security for the surrounding communities. The lake's rich aquatic life supports a thriving fishing industry, providing livelihoods for numerous households. Additionally, Lake Alau have been for years a good fluvial source of potable water, meeting the drinking and domestic water needs of the local population.

Beyond its immediate economic and subsistence value, Lake Alau holds ecological significance. It offers a habitation for a diverse variety of aquatic species and plays a role in maintaining local biodiversity. Moreover, it contributes to the region's overall environmental balance, acting as a reservoir for freshwater and supporting various ecosystem services such as flood regulation and water purification.

However, the continued health and sustainability of Lake Alau are threatened by a range of human-induced factors, including pollution, climate change, and unsustainable resource use. Understanding and addressing these challenges are paramount to preserving the lake's importance for current and future generations."

Aquatic ecosystems, including lakes, rivers, and estuaries, undergo continuous transformation due to geological factors. "These ecosystems epitomize a constant interplay of energy and matter, underscored by the actions of living organisms. The equilibrium, however, is perturbed by human interventions, ushering in pollution and its attendant consequences—manifesting in fish fatalities, repugnant odors, discoloration, and uncontrolled aquatic weed proliferation.

Of grave concern are anthropogenic sources. The repercussions are profound, yielding transformations in water quality, the loss of aquatic flora and vital ichthyofauna, and the imposition of health and ecological risks when pollutants accumulate in life-sustaining functions and ecosystem services (Oluowo and Isibor, 2016).

The primary aim of this study is to assess the impact of human activities on the physico-chemical parameters of Lake Alau, with a specific focus on water quality potentials of the Lake.

MATERIALS AND METHOD

Study Area

Lake Alau, situated in Borno State, Nigeria, is the second largest lake in the region. It was formed in 1985 by damming the Ngadda River, sourced from the Mandara Plateau. The lake spans between Latitude 12°N and 13°N, and Longitudes 11°E and 13°E, covering a total area of 56 km². Originally intended for supplying water to Maiduguri Metropolis and irrigating over 8,000 hectares of farmland, the lake's creation was overseen by the Chad Basin Development Authority. The region experiences a Sahelian climate, characterized by three distinct seasons: a rainy season from June to September, a harmattan season from October to February, and a dry, hot season from March to May. Water levels are lowest in March and April, leading to exposed lakebeds of sand and rocks. The dam, with a height of 9 meters and a reservoir area of 50 km², stores up to 112 million cubic meters of water.

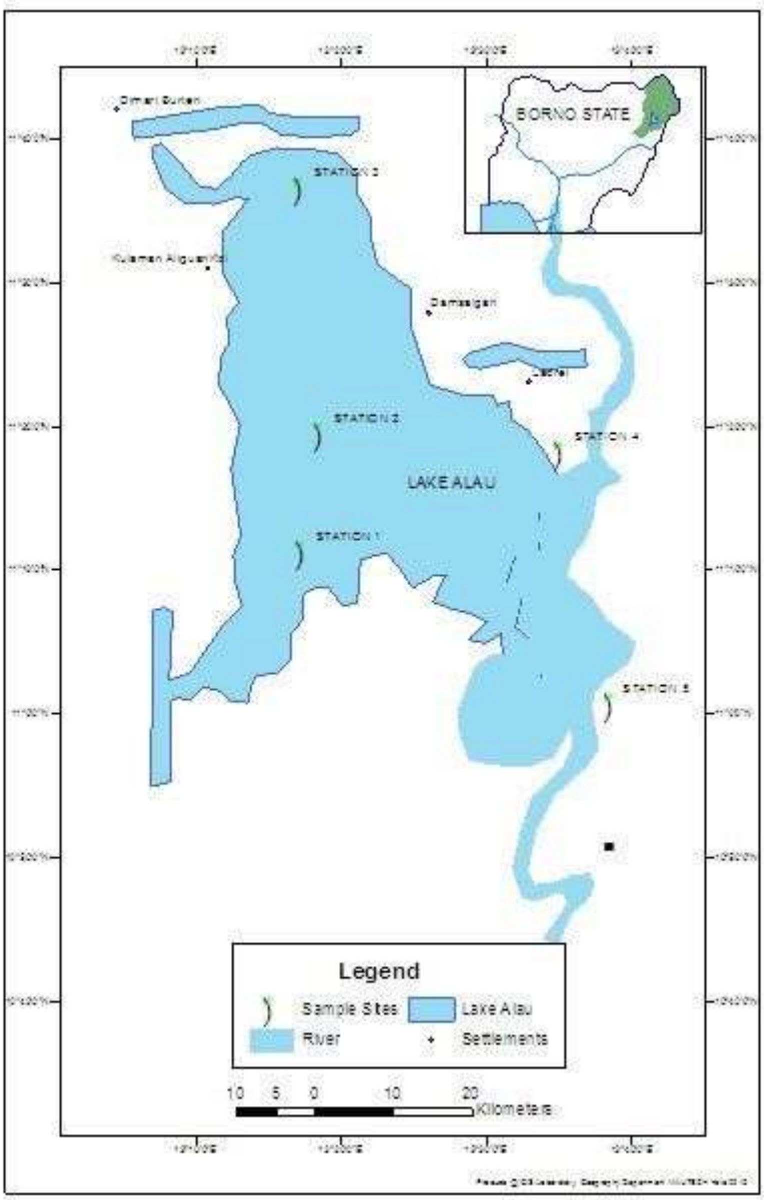

Figure 1: Map of Lake Alau Showing the Sampling Stations

Sampling Stations

Sampling Station were chosen after preliminary surveys of the Lake based on such factor as volume of water, accessibility, security and the various activities taken place in and around the Lake. Five sampling Station were marked at intervals of 1. 5 to 3 km to form the head region but as a result of the insurgency, activities at two (2) were later restricted.

The study was conducted through assessment of monthly variation of some water quality parameters in the Lake from January 2019 to June 2020. Water samples were collected at 08:00Hrs local time at a depth of 30cm below the water surface. Wastewater samples were collected at three different points (Station 1, 2 and 3) in triplicate, which the Lake is divided into for the purpose of this study. Station 1 is the general landing site for all fishermen of the lake as a result of the insurgency and consist of some farm lands for rain fed agriculture and irrigations and serve as the general camp for all fishermen (high human activities), Station, 2 this Station is located Close to the community of Alau Town, low farming activities' take place, the water is deep and flow fast. The water body is about 102 m wide, and is supported by a big dyke surrounded by heavy stones, which act as pathway for farmers and villagers around the area. The water is used for domestic activities such as washing and bathing and as drinking spots for cattle's as well as for irrigation of the surrounding farmland. Rain fed agriculture is also a common feature in the surrounding farmlands and high fishing activities take place in this Station using different low technology fishing gears like dragnets, cast nets, hook and line and Malian traps, Station: 3, This Station is located 500 meters away to northward of daban Ali Zaki; farming activities such as irrigation are carried out here at small-scale level. This is the only waterway (for navigation) that leads to Station 4. It is a prominent centre for canoeists, fishermen and women crossing over to the other Stations especially Station 4. The littoral areas encompass burrow pits where sand for road construction and building purposes are tunneled out.

Determination of physico-chemical parameters

In this study, water samples were meticulously collected and preserved in labeled 100ml containers. Various key water characteristics were directly measured at the sampling sites. Specifically, water temperature, pH levels, and Dissolved Oxygen (DO) concentrations were assessed on-site using specialized instruments. Temperature readings were obtained using an in-situ Mercury bulb thermometer (Glaswekwer Tien Model), while pH measurements were conducted with a pH meter (Model: Hanna Instrument Model No H18915ATC). Additionally, the concentration of Dissolved Oxygen (DO) was determined utilizing a digital Dissolved Oxygen meter model FT 607.

The analysis of total solids involved determining the residues left behind after evaporating unfiltered water samples, while total dissolved solids were ascertained by evaporating filtered water samples. Total Suspended Solids (TSS) were calculated as the difference between total solids and total dissolved solids (TSS (mg/l) = TS (mg/l) – TDS (mg/l)). Furthermore, Dissolved Oxygen measurements were recorded after a five-day incubation period, and Biochemical Oxygen Demand (BOD) was calculated using the formula:

BOD = DO1 - DO2 (mg/l)

Where

DO1 stands for the initial dissolved oxygen concentration.

DO2 represents the dissolved oxygen concentration after a five-day incubation period.

Chemical Oxygen Demand (COD) was determined according to the standard method described in Ademoroti (1996), which involved refluxing a mixture containing 20 ml of the surface water sample, 0.4 g of $HgSO_4$, 2 ml of sulfuric acid, and 10 ml of standard $K_2Cr_2O_7$ solution.

To assess the concentrations of nitrates (NO_3^-), the Cadmium Reduction Method as outlined in APHA (1998) was employed. The determination of nitrite and phosphates (PO_4^{-3}) concentrations was carried out using a spectrophotometer.

Statistical analyses were performed using the SPSS software package. The collected data on water quality parameters underwent ANOVA and Correlation for comparative analysis.

RESULTS AND DISCUSSION

The Physical parameters of the three sampling Stations are summarized in Table 1. The monthly mean variation for temperature ranged from 17.33 ± 0.66 ºC in January 2019 to 28.11 ± 1.01 ºC in September 2019. This variation in monthly mean water temperature agrees with the range of 22.7 ± 0.78 ºC to 28.5 ± 0.04 ºC reported by Wakil (2015) in Lake Alau and 18.63 ºC to 27.45 ºC reported by Yakubu *et al* (2018) in river Ngadda. The differences in variability of Stations were significant ($p>0.05$). The variation in monthly mean may be due to seasons of the year in which the lowest mean temperature was recorded during the harmattan season (November 2019 to February 2020), which also coincide with some of the highest mean of dissolved oxygen (DO) concentration recorded. The fluctuation in water temperature usually is controlled by some factors namely: season, geographic location, sampling time and temperature of effluents entering the water body from allochthonous sources (Ahipathy and Puttaiah, 2006; Ramanathan and Amsath, 2018). A warming of the environment due to a changing climate has also been found to affect hydrologic and thermal regimes of water bodies, having a direct impact on freshwater ecosystems (Van Vliet *et al*., 2013). Fabian and Abubakar (2015) also reported that cold-water hold more dissolved oxygen (DO) than warm water. Seasonal changes in the water temperature are closely related to seasonal

Table 1: Physical Parameters of Lake Alau

Month	Temperature	Total Solid	Total Dissolved Solid	Total Suspended Solid
January 2019	17.33 ± 0.66 °C	340.59 g	131.71 g	211.69 g
February	23.09 ± 0.88 °C	415.91 g	193.12 g	224.18 g
March	20.73 ± 0.84 °C	365.28 g	145.50 g	216.77 g
April	23.00 ± 0.65 °C	365.70 g	132.10 g	214.33 g
May	26.97 ± 1.10 °C	442.21 g	262.46 g	179.49 g
June	27.85 ± 0.84 °C	417.37 g	292.56 g	188.87 g
July	27.76 ± 0.66 °C	335.96 g	181.41 g	152.72 g
August	26.91 ± 0.99 °C	328.09 g	116.37 g	199.47 g
September	28.11 ± 1.01 °C	354.01 g	181.66 g	165.92 g
October	26.26 ± 0.92 °C	394.39 g	243.58 g	172.09 g
November	20.07 ± 1.77 °C	405.06 g	200.53 g	190.97 g
December	19.88 ± 0.30 °C	244.79 g	127.36 g	115.61 g
January 2020	18.20 ± 0.40 °C	260.06 g	169.89 g	97.83 g
February	18.29 ± 0.48 °C	296.97 g	186.64 g	118.11 g
March	21.26 ± 0.27 °C	360.83 g	244.81 g	135.89 g
April	23.92 ± 0.28 °C	421.24 g	259.84 g	178.70 g
May	26.31 ± 0.88 °C	418.17 g	248.96 g	170.32 g
June	24.74 ± 0.54 °C	415.59 g	245.77 g	162.06 g
Mean	23.40 ± 3.64 °C	365.68 g	192.99 g	171.95 g

Trends in mean monthly air temperature

Daily fluctuations occur more often in small water bodies, especially unshadowed, due to day/night changes in the air temperature and absorption of the solar radiation during the day. These variations are particularly important during low flows in the dry season, because unshaded lakes and streams can become too warm for many invertebrates and fish to survive (Chirag, 2016). Despite the temperature ranged observed in the lake different Stations, the concentration of dissolved oxygen are less than the value of 24.00 to 46.00 mg/l reported by Akan *et al* (2012) in lake Chad and TSS is below the recommended limit of 1500 mg/l WHO, (2010). BOD is within the acceptable recommended limit that supports aquatic life. During the rainfall events, the flowing generated storm water find its way towards the water bodies, because it carries the hazardous pollutants in the form of organic compounds, heavy metals, and other suspended solids to receiving body, the flow now becomes a major environmental issue (Ma *et al.*, 2015). The toxic pollutants and disruptive nutrients are delivered together with the suspended solids that are generated through runoff to the water channels (Mamun and An, 2018) which not only affects the water quality but are considered responsible to cause harmful impacts on the flora and fauna (Yahyapour *et al*., 2013) and increased the water temperature. Temperatures outside of an acceptable window affect the ability of aquatic organisms to grow, reproduce, escape predators, and compete for habitat (Djurichkovic *et al*., 2019). The temperature is one of the most important physical characteristics of the lake. It influences other properties of lake like oxygen concentration and suspended solid content as well as has significant effect on chemical and biochemical reactions occurring in the lake waters (Wakil, 2015; Chirag, 2017). Temperature in clean water may not be as important factor because of the wide range of temperature tolerance in aquatic life, but in polluted water, temperature can have greater profound effects on dissolved oxygen (DO) and biological oxygen demand (BOD).

Total Solid

The monthly mean variation for Stations as shown in Table 1 ranged from 244.79 mg/l in December 2019 to 442.21 mg/l in May 2019. The mean Station value obtained for the Stations are also marked insignificant statistically ($P<0.05$).TS concentrations have been recommended by the US EPA as useful indicators of water quality and are important measurements for a number of reasons. Increased TS indicates erosion which occurs frequently. This fine material can serve as pollutant and pathogen carriers which can clog the gills of fish (Hess *et al*., 2015). The recorded TS value varied significantly between sample Stations, which is also less than the standard value of 500 – 1000 mg/L. The concentration of these solids in the water body deteriorates the water quality for which a higher cost of water treatment is required (Abd Razak *et al.,* 2018). TS can potentially affect the rate of photosynthesis, and therefore the growth of plants or algae in the water body (EPA, 2018). The highest total solid recorded in Station 1, in the month of May 2019 might be as a result of low volume of water in the Lake, and also high human activities taking place in the Station which is the general landing site for all fishermen and all buying and selling activities, fish processing and most domestic activities take place there. It also consist of some farmland were agricultural activities contribute to the total solid input in the Station.

Total Dissolved Solid

The mean value ranged from 116.37 mg/l in August 2019 to 262.46 mg/l in May 2019 as presented in Table 1. The variation was marked significant ($P<0.05$). The difference in the solubility of minerals in different geological locations leads to the variation in the concentration of TDS in water (WHO 2011a). The level of total dissolved solids, in the sampling Stations fluctuates between 116.37 mg/l to 262.46 mg/l, the highest values of TDS were observed in Station 1 while the least values were recorded in Station 2. The significant variation between the sampling Stations might be due to variations in agricultural and other activities taking place most especially Station 1 which is the general landing site and fish camp with high concentration of human activities while Station 2 have least activities (i.e. minimal disturbance). In contrast, in Station 1 due to incoming effluents (especially during the rainy season) and other anthropogenic activities such as settlements, traditional cattle farm, and agriculture areas, which caused significant runoff with high organic content into the lake (Gonzalez *et al*., 2014; Zhang *et al*., 2013). Due to constituent of the total dissolved solids which consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates and possibly nitrates of calcium, magnesium, sodium, potassium, with traces of iron, manganese and other substances. The chemical content of water may be lowered artificially by dilution or raised by the addition of chemical wastes, dissolved salts, acids, alkalis, gas or oil-well brines or drainage waters from irrigated land (Akan *et al*., 2012), thus the pH value recorded throughout the study period were within the neutral scale. However, the TDS levels recorded in the entire sample Stations were below the WHO guideline of 1000 mg/L for the protection of fisheries and aquatic life and for domestic water supply. The highest value recorded in Station 1 in the Month of May 2019, could be because of low volume of water and high human activities at the Station. This will result in increased rate of evaporation thereby increasing the concentration of dissolved solutes in the water column (Samuel *et al*., 2015). It reduces solubility of gases (like oxygen), utility of water for drinking purpose and enhances eutrophication of the aquatic ecosystem (Choudhary *et al*., 2021). The values are below the recommended level of 50 mg/l (US EPA, 2012) for aquatic life, yet aquatic life may suffer under these conditions.

Total Suspended Solid

The monthly Station mean recorded its lowest value of 97.83 mg/l in January 2020 and the highest value of 224.18 mg/l in February 2019 according to Table 1. The mean Station values are statistically insignificant ($P<0.05$). The ability of the water to support the diversity of aquatic life is reduced as levels of TSS increase (Akan *et al*., 2012). Heat from sunlight is absorbed by suspended solids, hence, the temperature increases and subsequently decreases levels of dissolved oxygen in water. Suspended solids may kill fish and other aquatic fauna through the following: abrasive injuries, clogging of the gills and respiratory passages, blanketing of the stream bottom, destroying the spawning beds and by screening out light necessary for the photosynthetic activity of aquatic plants which are the major primary producers. Settling suspended particles may trap bacteria and bring them to the bottom of the lake or river. Excess of organic wastes may lead to anaerobic decomposition by bacteria which can result to anoxic condition in water. Similarly, when the rate of photosynthesis is low, then oxygen concentration become low and CO_2 concentration become higher (Klein *et al*., 2022). the findings of this study shows that the levels of TSS in the entire sample Stations exceeded the WHO guidelines of 50 mg/L for the protection of fisheries and aquatic life (Chapman, 1993). For aquatic life especially fish the concentration of suspended solids is life threatening, which result to troublesome infection among which the abrasion of gills is severe. Solids moving in suspension can reduce the foraging ability of fish, which further makes these species vulnerably available to predators (Packman *et al*., 2013). The highest value of TSS recorded in this study in the month of May in Station 1, might be due to low volume of water (Increase evaporation and increase rate of suspended particulate), high human activities and atmospheric deposit because of wind action in the arid-region. Although there are many several other sources of persistent bio accumulative substances (such as toxic substances in the environment), including agricultural discharges and deposition of atmospheric contaminants (Jiang *et al*., 2012). Both air emissions and wastewaters are sources of pollution (Kalinkina *et al*., 2003). The primary drivers of Total Suspended Solids (TSS) variation in Lake Alau include natural processes like erosion, seasonal changes in weather, human activities such as agriculture and construction, industrial discharges, and climate events, all of which influence the amount of suspended particles and sediments entering the lake.

Hydrogen Ion Concentration (pH)

From Table 2, pH recorded its highest mean value of 7.19±0.06 mg/l in June 2020 and the lowest mean of 6.95±0.17 mg/l in August 2019. The Station mean value for the three Stations are statistically significant at ($P<0,05$). The mean pH values of the samples in this study were found to be in the permissible range of pH value recommended by several health and pollution control organizations e.g. World Health Organisation, Central Pollution Control Board, Bureau of Indian Standard i.e. 6.5 to 8.5 mg/L. This is also suitable for fish production (Egeman, 2011; Andong *et al*., 2019) and is within the stipulated values of 6.0 - 9.0 for drinking water and water meant for full contact recreation (DWARF, 1996; Oluyemi *et al*., 2010). The pH of the lake water was showing neutral character throughout the study period at all three Stations. The difference in variability at Stations were not significant ($p<0.05$). The variability in pH levels in Lake Alau is influenced by a range of factors, including seasonal changes, algal blooms, rainfall and runoff, organic matter decomposition, industrial and agricultural discharges, wastewater effluents, geological factors, human activities, aquatic plant diversity, and the lake's buffering capacity. Wakil, (2015) reported pH value of 8.4±0.07 mg/L as the highest in December 2012 and 7.3±014 mg/L as its lowest in June 2013 in Lake Alau. Bhateria *et al* (2016) stated that increase in pH is as a result of reduced photosynthetic activities, carbon dioxide assimilation and bicarbonates are the ultimate reasons. Wongso Diharjo *et al.*, (2022) reported that in most raw water sources pH lies in the range of 6.5 to 8.5 mg/L. Most lakes from the inception are basic (alkaline), and become more acidic over time due to the buildup of organic materials. pH values of about 5.0 to 9.0 can be tolerated by most fishes while a pH level below 4 or above 10 typically leads to unfavorable living conditions.

Table 2: Chemical Parameters of Lake Alau

Month	pH	DO	BOD	COD
January	7.08 ± 0.12 Mg/L	7.14 ± 0.48 Mg/L	4.16 ± 0.21 Mg/L	4.69 ± 0.26 Mg/L
February	7.09 ± 0.07 Mg/L	7.00 ± 0.67 Mg/L	4.38 ± 0.10 Mg/L	4.53 ± 0.12 Mg/L
March	7.07 ± 0.11 Mg/L	6.89 ± 1.00 Mg/L	4.33 ± 0.10 Mg/L	4.45 ± 0.10 Mg/L
April	7.12 ± 0.29 Mg/L	7.40 ± 0.94 Mg/L	4.68 ± 0.04 Mg/L	4.77 ± 0.08 Mg/L
May	7.04 ± 0.07 Mg/L	6.52 ± 0.42 Mg/L	4.45 ± 0.13 Mg/L	4.65 ± 0.18 Mg/L
June	7.12 ± 0.08 Mg/L	6.98 ± 0.47 Mg/L	4.46 ± 0.17 Mg/L	4.58 ± 0.08 Mg/L
July	7.11 ± 0.00 Mg/L	7.80 ± 0.87 Mg/L	4.34 ± 0.12 Mg/L	4.51 ± 0.16 Mg/L
August	6.95 ± 0.17 Mg/L	8.63 ± 1.07 Mg/L	4.32 ± 0.21 Mg/L	4.56 ± 0.15 Mg/L
September	7.01 ± 0.12 Mg/L	6.54 ± 0.72 Mg/L	4.24 ± 0.15 Mg/L	4.53 ± 0.03 Mg/L
October	7.09 ± 0.02 Mg/L	6.71 ± 0.97 Mg/L	4.63 ± 0.12 Mg/L	4.60 ± 0.05 Mg/L
November	6.98 ± 0.24 Mg/L	7.20 ± 0.56 Mg/L	4.42 ± 0.20 Mg/L	4.52 ± 0.06 Mg/L
December	7.13 ± 0.31 Mg/L	6.39 ± 0.24 Mg/L	4.33 ± 0.10 Mg/L	4.53 ± 0.14 Mg/L
January	7.18 ± 0.06 Mg/L	7.47 ± 0.29 Mg/L	4.50 ± 0.05 Mg/L	4.48 ± 0.04 Mg/L
February	7.10 ± 0.07 Mg/L	6.26 ± 0.36 Mg/L	4.31 ± 0.18 Mg/L	4.43 ± 0.04 Mg/L
March	7.14 ± 0.11 Mg/L	7.11 ± 0.39 Mg/L	4.23 ± 0.07 Mg/L	4.43 ± 0.10 Mg/L
April	7.08 ± 0.10 Mg/L	6.96 ± 0.78 Mg/L	4.40 ± 0.05 Mg/L	4.50 ± 0.05 Mg/L
May	7.04 ± 0.27 Mg/L	6.61 ± 0.41 Mg/L	4.31 ± 0.04 Mg/L	4,52 ± 0.17 Mg/L
June	7.19 ± 0.06 Mg/L	7.30 ± 0.27 Mg/L	4.38 ± 0.06 Mg/L	4.53 ± 0.14 Mg/L
Mean	7.80 ± 0.06 Mg/L	7.05 ± 0.56 Mg/L	4.38 ± 0.13 Mg/L	4.55 ± 0.11 Mg/L

Dissolved Oxygen

The mean DO value recorded during the sampling period as revealed by Table 2, ranged from 6.26±0.36 mg/l in February 2020 to 7.80±0.87 mg/l in July 2019. The Station mean value revealed that Station 1 recorded the highest mean value which are statistically insignificant ($P<0.05$). Dissolved oxygen (DO): DO. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms (Clark, 2013). The DO in the 3 sampling Stations during the period of the study ranged from 6.73 to 7.33 mg/L and were above the minimum permissible limit of 4 mg/L and 5 mg/L. Therefore, the parameter DO does not give cause for concern within all the portions of Lake Alau during the period under study. Fabian and

Abubakar (2015) reported a monthly mean concentration value ranged from 9.90±1.42mg/l in July to 14.5±1.31mg/l in December in Coca cola wastewater reservoir in Maiduguri and Akan *et al.*, (2012) reported a higher mean value, ranging from 24.00 mg/L to 46.00 mg/L in Lake Chad. Absalom *et al*., (2002) reported that high dissolved oxygen values during wet season might be due to the prevailing wind action.

The study did not observe complete oxygen depletion as also reported by Wakil (2015) among the Stations and between the months because of the moderate polluted nature of the Lake and significant water movement through the lake because of water release from the upstream. The lowest value recorded in Station 3, in the month of September 2019 might be as a result of influx of organic materials due to flooding from the catchment and surrounding areas. The oxygen content in water samples depends on a number of physical, chemical, biological and microbiological processes. Because of industrial, human and thermal activity, DO values show lateral, spatial and seasonal changes which all depends on the activities. For life to be sustainable in water, 5 mg/L of dissolved oxygen is stipulated. Concentration below the value 5mg/L adversely affects aquatic life, while concentration below 2 mg/L may lead to the elimination of most fishes. The statistical analysis showed that there was no significant difference between the 3 sampling Stations ($P<0.05$).

Biological Oxygen Demand (BOD)

The recorded monthly mean BOD ranged from 4.68 ± 0.04 Mg/L in April 2019 to 4.16 ± 0.21 Mg/L in January 2019 as shown by Table 2. Generally, the BOD levels recorded in the entire sampling Stations were within the EU guidelines of 3.00 to 6.00 mg/L (BOD) for the protection of fisheries and aquatic life and for domestic water supply (Chapman, 1993). Statistically, the variation of BOD at the sampling Stations is significant ($P<0.05$) with Station 2 recording the highest mean value of 4.44±0.05 mg/L, while the highest monthly mean value of 4.63±0.12 mg/L was recorded in October which might be as a result of influx of organic materials by flood from the surrounding agricultural lands. Akan (2012) reported that increase in BOD is as a result of discharge of wastewater from settlements along water bodies particularly from abattoirs, hotels and hospitals into the lake and from surface and ground flow that carries chemicals directly from agricultural fields into the lake. Idowu *et al.*, (2004) reported a mean concentration of (5.31 ± 0.25 mg/l) and Wakil (2015) reported a mean concentration of 4.9±0.11 mg/L as the highest observed mean of the study in December 2015 in Lake Alau and stated that the variation between the two observed results might be attributed to decrease or slow decomposition of natural debris that might lead to decrease in the BOD concentration. The biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Abida and Harikrishna, 2008; Yustiani *et al*., 2018). In the present study, BOD level was high 4.81±0.29 mg/L in the rainy season (September, 2019). This might be attributed to several microbes present in the water bodies accelerated their metabolic activities with concentrated amount of organic matter and agricultural waste discharge into water bodies and hence required much amount of oxygen resulting in increased demand for oxygen. This study revealed that lake Alau remain relatively polluted and is a moderately polluted water body. This is in line with Ekubo and Abowei (2011), who reported that fluvial system with BOD levels between 1.0 and 2.0 mg/L are well-thought-out as clean; 3.0 mg /L justly clean; 5.0 mg/ L doubtful and 10.0 mg /L definitely depraved and polluted. Similarly, (Clerk 1986) reported that BOD range of 2 to 4 mg /L does not indicates pollution while levels beyond 5 mg /L are indicative of stern pollution.

Chemical Oxygen Demand (COD)

From Table 2, the monthly mean value ranged from 4.43±0.04 mg/l and 4.43±0.10 mg/l in February and March 2020 to 4.77±0.08 mg/l in April 2019. The observed mean for the three Stations are all marked significant ($P<0.05$). The observed value of COD in this study is highest in Station 2, with a value of 4.39±0.03 mg/l and the lowest in Station 3 with a mean value of 4.33±0.03 mg/l which are statistically significant ($P<0.05$). The values detected in all sampling Stations are less than the WHO recommended standard of 200 mg/l, which is an indication of low rate of influx of organic matter that are completely oxidized. Akan *et al*., (2012) reported concentrations of COD for the five sampling point ranging between 353.00 and 689 mg/L in Lake Chad and is presumed to be a consequence of increased concentration of suspended organic matter, which itself is a consequence of increased soil erosion, increased amount of precipitations and/or increased water flow. He also stated that the increasing trend in COD concentration is an indication of wastewater discharges from settlements along the Chari Logone and Komadugu-Yobe River courses particularly from slaughter houses, hotels and other allochthonous sources into the lake, and from surface and ground flows that carry chemicals directly from agricultural field into the Lake Chad. These results lead to the conclusion that chemical pollutants basically originate from the Lake Alau sub-catchment as a result of wind action and run off that brought about deposit and influx of chemical and organic matter into the lake. Meme *et al*, (2014) stated that high presence of inorganic substances in the water may be the result of high level of COD and not as a result of the contributory effects of chemicals and also the activities of micro-organisms which decomposes the massive inflow of organic waste brought about by wind and run off.

Nitrite (NO_2)

Table 3, shows that the mean value ranged from 0 02±0.00 mg/l in November 2019 to 0.11±0.01 mg/l in August 2019, which fluctuates throughout the sampling period. The mean variation of the sampling Station revealed that both Station 1 and 2 recorded a mean value of 0.07±0.05 mg/l and 0.07±0.03 mg/l while Station 3 recorded a mean value of 0.06±0.03 mg/l all marked statistically significant ($P<0.05$). The nitrite ion (NO_2^-): Ekhande (2015) reported that nitrites along with some toxic aromatic compounds impart brown colour and offensive odour to water, which becomes unfit for irrigation, fish culture and drinking. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate. According to Riordan (1993) maximum acceptable permissible concentration of nitrite for humans, as well as animals including wildlife either for drinking or for recreation and aesthetics is 10 mg/l to 100 mg/l (nitrite and nitrate together). The highest concentration recorded is 0.19±0.08 in Station 3 in the month of October 2019. Increased nitrogen in some of the Stations was likely caused by organic pollutants from anthropogenic activities (agriculture, traditional farms and settlements) thereby increasing the concentration of COD. The low concentration of NO^{2-} is in consonance with its insignificant role in the environment and with its short residence time in water (Malhotra and Zanoni, 1970). The water of Alau Lake showed minimum nitrite level in the study, this is probably due to fresh input through water runoff as well as the agitation of water that helps in oxidation and release of ammonia from sediment. In the study area, the photoperiod is almost throughout the year, the water bodies receive adequate sunlight, which favours growth of macrophytes plants. The utilization of nitrites as nitrogen source by autotrophs (Yang *et al*., 2001; Zhang *et al*., 2015) can be a reason for low level of nitrites in Lake Alau. The concentration of Nitrite in lake Alau throughout the study period does not pose any danger to ecological health of the lake and its fisheries despite all human activities taking place most especially in Station 1.

Table 3: Chemical/Nutrient Parameters of Lake Alau

Month	Nitrite (NO_2)	Nitrate (NO_3)	Phosphate (PO_4)
January 2019	0.08 ± 0.03 Mg/L	0.34 ± 0.03 Mg/L	0.03 ± 0.01 Mg/L
February	0.05 ± 0.03 Mg/L	0.39 ± 0.03 Mg/L	0.04 ± 0.00 Mg/L
March	0.06 ± 0.02 Mg/L	0.43 ± 0.00 Mg/L	0.02 ± 0.00 Mg/L
April	0.08 ± 0.03 Mg/L	0.37 ± 0.05 Mg/L	0.05 ± 0.01 Mg/L
May	0.02 ± 0.00 Mg/L	0.35 ± 0.02 Mg/L	0.07 ± 0.01 Mg/L
June	0.05 ± 0.04 Mg/L	0.29 ± 0.04 Mg/L	0.09 ± 0.04 Mg/L
July	0.09 ± 0.01 Mg/L	0.24 ± 0.10 Mg/L	0.11 ± 0.03 Mg/L
August	0.11 ± 0.01 Mg/L	0.32 ± 0.05 Mg/L	0.13 ± 0.04 Mg/L
September	0.04 ± 0.00 Mg/L	0.47 ± 0.05 Mg/L	0.11 ± 0.00 Mg/L
October	0.13 ± 0.05 Mg/L	0.48 ± 0.08 Mg/L	0.07 ± 0.03 Mg/L
November	0.02 ± 0.00 Mg/L	0.33 ± 0.05 Mg/L	0.12 ± 0.03 Mg/L
December	0.10 ± 0.02 Mg/L	0.32 ± 0.04 Mg/L	0.06 ± 0.03 Mg/L
January 2020	0.06 ± 0.02 Mg/L	0.44 ± 0.03 Mg/L	0.09 ± 0.08 Mg/L
February	0.06 ± 0.03 Mg/L	0.45 ± 0.06 Mg/L	0.17 ± 0.08 Mg/L
March	0.08 ± 0.02 Mg/L	0.32 ± 0.04 Mg/L	0.17 ± 0.10 Mg/L
April	0.09 ± 0.02 Mg/L	0.34 ± 0.04 Mg/L	0.21 ± 0.18 Mg/L
May	0.05 ± 0.03 Mg/L	0.38 ± 0.05 Mg/L	0.07 ± 0.03 Mg/L
June	0.05 ± 0.02 Mg/L	0.32 ± 0.06 Mg/L	0.12 ± 0.08 Mg/L
Mean	0.07 ± 0.03 Mg/L	0.37 ± 0.07 Mg/L	0.10 ± 0.05 Mg/L

Nitrate (NO_3)

Table 3 also shows that the mean value ranged from 0.24±0.10 mg/l in July

2019 to 0.48±0.08 mg/l in October 2019, which there was gradual increase from January to March 2019 and from August to September 2019. The Station mean shows that Station 1 recorded 0.37±0.08 mg/l, Station 2 0.37±0.07 mg/l and Station 3 recorded 0.36±0.08 mg/l and are all significant statistically (P<0.05). Nitrate (NO_3)**:** The mean Nitrate value recorded in all the Stations during this study were within the recommended level for aquatic life as suggested by WHO (2007). Nitrate is commonly found in soil and water and is the most effective form by which plants obtain their nitrogen in aquatic and terrestrial environment. Nitrate level greater than 1mg/l is not healthy for aquatic life. Poor buffering of freshwater systems by the surrounding soils can lead to acidification by increased deposition of nitrate and ammonium. The content of dissolved oxygen (DO) at the water sediment interface is the main factor that affects the degradation of nitrate and its outcome (Ma *et al*., 2021). Minimum dissolved oxygen recorded in Alau Lake throughout the study may be the reason for the minimum nitrate concentration. Further, it can also be due to the denitrification of NO_3- into NO_2- and NH_3 by denitrifying bacteria (Zhou *et al*., 2020) and growth of aquatic plants, which utilize the nitrate for growth (Kannan, 1978; Wierzbicka, 2020). The nitrate levels of Alau Lake water, was within the range of 0.18±0.02 mg/l to 0.55±0.08 mg/l are in the permissible limit given by WHO (i.e. 45 mg/l) for human consumption. Wakil (2015) also reported a lower concentration of nitrate (0.22±0.09 to 0.42±0.06 mg/l), while Idowu *et al*., (2004) recorded a higher concentration of (4.27-6.30 mg/l) which are higher than the value obtained from this study. According to Lonborg *et al*., (2021), a characteristic feature of most of the tropical waters is a low nutrient status with a high turnover rate which results in rapid utilization of the nutrients as soon as they are released by decomposition, so that very little remains in the water. More intensive agricultural production, poor drainage, the spreading of animal manure, sewage sludge effluent all contributed to nitrate influx and leaching.

Phosphate (PO_4)

From Table 3, the monthly mean value recorded ranged from 0.02±0.00 mg/l in March 2019 to 0.21±0.18 in April 2019 with gradual increase from March to August 2019.

Station 2 recorded the highest mean value of 0.11±0.06 mg/l while Station 3 and 1 recorded 0.10±0.02 mg/l, 0.08±0.01 mg/l respectively and are all marked significant (P<0.05). The anthropogenic additions of phosphorus to the lake Alau have a considerable effect on the quality of the water. Such phosphate is derived mainly from domestic activities and the runoff from agricultural areas as a result of the use of phosphate fertilizer and organic manure. Santiago and Alicia (2013) stated that Lakes whose basins are used for agricultural activities tend to be higher in concentration of phosphorus than those influence by waste in cities. They further reported that total phosphorus concentration of some Pampean Lakes surrounded by crops was found to be slightly lower than that in some Lakes located in dune areas sorrounded by natural vegetation whose basins are used for livestock rearing. This could be due to the mechanism of diffuse pollution caused by the dragging of animal feaces, especially during a storm because this is one of the elements with greatest impact on the eutrophication of a water body (Carpenter *et al.,* 1998; Bremigan, 2008). The mean phosphate level recorded throughout this study is lower than the recommended value of 1mg/L by WHO (2007). Phosphate level greater than 1 mg/l is not healthy for aquatic life. If too much phosphate is present, algae grow wildly, choke the waterway, and use up large amounts of oxygen. Many fish and aquatic organisms may die. In waters, phosphorus is often biologically unavailable as it binds readily to particles. Soluble phosphorus that is available for uptake is called phosphate. Phosphates is not harmful to people or animals unless they are present in very high concentrations. The highest value recorded in Station 3, in the month of April 2020 might be as a result of the influx of detergent use in the surrounding environment and influx of water from the surrounding farmland. Mahender *et al*., (2016) reported that Phosphates occur in surface water as a result of domestic sewage, detergents, and agricultural effluents with fertilizers. Angelier (2003) also reported that the content of total Phosphorus had increased during the rainy season, because the water runoff from the upstream and the surrounding vegetation brought sediments and accumulates it at the site. Besides these, organic matters come from fertilizers and traditional farming activities. In natural waters, phosphorus exists as soluble phosphate. The phosphate concentration above 0.5 mg/l indicates pollution (Jain *et al*., 1996; Jane *et al*., 2020). Phosphate concentration of 0.01 mg/l will support plankton, while concentration of 0.03 mg/l to 0.1 mg/l phosphate or higher will trigger bloom. According to Welch (1980), a water body may be considered as eutrophic if total PO_4^{-3} value ranged in between 20 to 30 mg/l. The phosphate value of Alau Lake fluctuating between 0.02±0.01 mg/l to 0.42±0.04 mg/l is much below this level. However, it crossed the permissible limit of drinking water (0.1 mg/l) as given by US Public Health Standards (De, 2002). This indicates that phosphates value in the Alau Lake water are above the permissible limit for drinking water. Akan *et al.*, (2012) reported a higher value of 16.54 to 43.22 mg/L for phosphate in the Lake Chad

Summary

The study of Lake Alau's water quality provides valuable insights into its overall condition. Several key parameters, including pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrite, nitrate, and phosphate, were monitored over a year. In general, the lake's water quality falls within permissible ranges for aquatic life, with DO, BOD, and COD levels indicating good conditions for aquatic organisms. However, the levels of phosphate and nitrate exceed recommended limits for drinking water standards. Seasonal variations and correlations with factors like temperature and total suspended solids were observed. These findings highlight the lake's sensitivity to anthropogenic inputs and seasonal changes. While Lake Alau remains suitable for aquatic life, measures to mitigate phosphate and nitrate pollution are recommended.

CONCLUSION

The comprehensive assessment of Lake Alau's water quality offers valuable insights into its ecological health and the impact of human activities. The study confirms that the lake generally provides a suitable environment for aquatic life, as indicated by physico-chemical parameters like pH, DO, BOD, and COD, etc which fall within acceptable ranges. However, concerning levels of phosphate pose challenges, exceeding recommended limits for drinking water standards. This suggests potential risks to human health and underscores the need for better management of nutrient inputs. Seasonal variations and dynamic nature of the lake's water quality. To preserve Lake Alau's ecological integrity, it is imperative to implement measures aimed at reducing phosphate and nitrate pollution, thereby ensuring the continued well-being of this vital water resource.

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