

Evaluating the Effects of Effluent and Heavy-Metals on the Physicochemical Parameters of Ikpoba River Benin City, Nigeria

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Abstract

Around the world, water bodies are the primary location for the disposal of waste. Down the Ikpoba river gradient, water samples were taken from stations A1, A2, B1, and B2. Atomic Absorption Spectrometry (AAS) was used to measure the concentrations of heavy metals, like Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), and Cadmium (Cd) and the physicochemical characteristics of the water detected. The results revealed varying concentrations of contaminants, which can cause deterioration of aquatic ecosystem, waterborne illnesses from ingestion of contaminated aquatic life. The ANOVA result, revealed a strong positive relationship between BOD and COD across the full dataset which confirms that organic waste is the dominant driver of both parameters. Notably, the COD values are disproportionately higher than the corresponding BOD values at downstream. The high BOD at downstream drives microbial oxygen consumption, explaining the dissolved oxygen depletion observed at B1 and B2. The extreme COD at B1, points to a direct effluent discharge point in close proximity to this station. The COD:BOD ratio of 10:1 to 28:1 at downstream confirms that a substantial fraction of the organic load is refractory, meaning it will persist in the river long after the readily biodegradable fraction has been consumed. Upstream stations show considerably higher EC values than their downstream counterparts: A1 records 497 and 459 mS/m, and A2 records 466 and 233 mS/m. The slightly elevated iron at A2 (0.621-0.780mg/L) and the anomalous alkalinity at A1(pH 9.65-9.9) B1 records the most extreme values across nearly every parameter (BOD up to 20mg/L, COD up to 560mg/L, iron up to 2.687mg/L) indicating it is the proximity to the discharge point. B2, located further downstream, shows partial attenuation (mean COD 311 vs 388mg/L at B1), which is consistent with dilution and self-purification processes operating between the two stations. High levels of iron in both station A1, this 6:2 split means that 75% of all samples collected from the Ikpoba River exceeded the WHO guideline. The pH in upstream station A1 clearly exceeds the WHO limit: its two readings of 9.9 and 9.65, shows alkalinity and above the safe maximum for drinking water. The existence of heavy metals is harmful to aquatic life, and does move up in the food chain; even when present at a steady rate. This indicates the pressing need for reinforcement of systematic effluent treatment and pollution control measures to preserve the Ikpoba river and protect human health.

Keywords: Ecology, Effluent, Heavy metals, pollutant, Aquatic Organisms, Human health.

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INTRODUCTION

Around the world, water bodies are the primary location for the disposal of waste, especially the effluents from nearby businesses. These entities, where water exists are being contaminated by both liquid and solid materials. Osibanjo *et al.*, (2011). Consequently, an outflow from a sewage treatment plant, waste discharge from a commercial farm, or wastewater discharges from industrial facilities, abattoir slaughter Houses, could all be considered effluents in a synthetic sense; water bodies become contaminated and polluted as a result WHO, (2011). Accordingly, water contamination is a significant issue in the international community today and has been proposed as the primary cause of diseases and mortality globally. Olubinmi and Ndubuisi, (2011; Etem and Onianwa, (2013). Humans are positively impacted from rivers, as the primary source of surface water for drinking, household, agricultural, and commercial purposes; water bodies essentially, because of human activities that undermine their biological viability, they are among the most vulnerable environments in the globe. Reid *et al.*, (2019). Hautier *et al.*, (2015) state that rivers are valuable freshwater resources for human usage since they supply water for many purposes and for human existence and progress, rivers are vital resources of water. Şener *et al.*, (2017).

Effluent, containing industrial, agricultural and domestic waste, causes severe damage to aquatic systems, primarily through nutrient enrichment, chemical contamination and oxygen depletion WHO, (2011). Pollutants at levels harmful to the environment and the health of the resulting water sources may be present in the wastewater generated by these various production processes and disposal techniques. Şener *et al.*, (2017). The manufacturing industries has long been associated with the deliberate discharge of waste materials into the environment. Salem, (2021). Boussaha and Laifa (2017), claim that commercial waste, poses a serious risk to recipient ecosystems and it's contributing to an increase in water quality problems. According to Attoui *et al.* (2016) "the frequent use of artificial nutrients in agriculture, along with both industrial and household wastes, contributes significantly to the continuous decline in water quality across the globe,". According to Vijayamma and Sajitha; (2019). In 2016, a survey on the Water Quality Index was used to investigate the Physicochemical Parameters and Pond Water Quality Evaluation in Athiyanthoor Panchayath, Kerala, India; and in 2019, Pazarsuyu Stream in Turkey was assessed for water quality and contaminants from sediment using multivariate statistical methods and pollutant indicators. Vijayamma and Sajitha; (2019). The water quality index (WQI) method is one of various ways to determine the water quality state of rivers. According, to Goher, *et al.*, (2014) Benin City, Nigeria, is becoming more technologically advanced in the area of production; the fact remains that some of these companies are located far from rivers, and their wastewater is diverted into rivers like the Eruvbi stream and the Ikpoba River (Imoobe and Okoye 2011); (Ovie, 1997). The brewing facility is one of these sectors, and the wastewater from its operations is transported into the Ikpoba River via a hidden conduit. The physical, chemical, and biological components of the environment as well as human health, maybe adversely affected by this wastewater, which are rich in both organic and inorganic chemicals. Akhrame, and Onu, (2024).

A 2014 study, looked at the effects of effluent discharged by breweries on the water quality and sediment of the Ikpoba River, Ustaoglu and Tepe, (2016). The consequences of abattoir wastewater on the physicochemical and microbiological characteristics of the Effurun River and Eburu Canal in Warri, Nigeria, were documented by Ogbeibu and Erhirhi (2021) According to Halim *et al.* (2018), development, manufacturing, and cultivation of land all had, significantly increase in a number of African countries in recent times, combined with a notable increase in population. This has led to a significant increase in the discharge of a

variety of pollutants into bodies of water that absorb them, as well as cause detrimental effects on fisheries and other elements of an aquatic environment. According to Amah-Jerry *et al.* (2017), liquors that are pressed from grains and yeast fermentation processes, are the source of outflow from the brewing industries. It's fermented and malty smell and hint of acidity; result in microbiota change by the introduction of effluent that is rich in biological material and essential nutrients (Kariu *et al.*, 2006; Ekhaize and Anyasi, 2005). This scientist, discovered a high concentration of bacteria in the Ikpoba River in Benin City, Nigeria, which receives industrial wastewater from breweries.

Regarding the effects of brewery effluent entering Nigeria's Eziama River Aba, Kariu (2006) discovered similar results. Nonetheless, Egwuonwu *et al.* (2012) evaluated the effect of industrial discharge flow on surface water entering the Ajali River using Nigerian Breweries Plc Enugu as a case study. The amounts of Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD) were ascertained, by doing this; he noted that, there was a higher levels of pollutants in the river ecosystem that causes increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), toxic metals like cadmium (Cd), chromium (Cr), nickel (Ni), and lead (Pb), as well as fecal coliform. This makes the water unfit for drinking, irrigation, and aquatic life. Other studies further state that floating particles in untreated brewery effluent typically ranged from 10 to 60 mg/L, phosphorus (10–30 mg/L), nitrogen (30–100 mg/L), chemical oxygen demand (COD) (800–3000 mg/L), and biological oxygen demand (BOD) (1000–1500 mg/L). Othue *et al.*, (2005), stated that, High levels of biochemical oxygen demand (BOD) are seen in commercial effluents which include recyclable materials from pulp and paper, factory farms, tanneries, chemical plants, and human waste products. Other substances come from textiles, which can be hazardous and need to undergo physicochemical preliminary processing on-site before being dumped into the communal sewer line, Anyanwu and Ihediwah, (2015). This industrial effluent contains a variety of pollutants, petroleum hydrocarbons, chlorinated hydrocarbons, heavy metals, various acids, alkalizes, colours, and other compounds are a few examples of materials that drastically alter water quality. Salem (2021). Water becomes contaminated if these contaminants are released into aquatic areas without being properly treated (Chowdhary *et al.*, 2020). Arsenic, cadmium, and chromium are among the major pollutants discharged in wastewater, and the industrial sector is a major source of these dangerous elements. Chen *et al.*, (2019). The National Environmental Standards and Regulations Enforcement Agency (NESREA) was created by the Nigerian government on July 30, 2007, as a result, to control pollution amount as stated by NESREA's guidelines, certain manufacturing sectors choose to take short cuts or disregard the effluent treatment plants, despite the government's extensive efforts to oversee these procedures. Still, numerous physicochemical features of the Ikpoba River were discovered to have levels beyond the internationally accepted standards.

The two most common hazardous contaminants in effluent products are complex organic compounds and heavy metals. Osa-Igwehide *et al.*, (2016), state that dumping effluent into streams and rivers might result in acid mine drainage, which lowers the quality of the receiving waterbody. These activities have altered the water cycle, causing alarm worldwide due to potential long-term effects on people, wildlife, and the ecosystem. For instance, it has been found that the effluent from the Seven-Up Bottling Company in Benin City contains high concentrations of zinc (5.65 mg/L), nickel (6.65 mg/L), and iron (6.68 mg/L), all of which are higher than those allowed for secure discharge Ochu *et al.*, (2025) Lead (Pb) levels exceeding 0.09 mg/L, which surpass the WHO recommended limit of 0.01 mg/L, have also prompted concerns about the Ikpoba river's suitability for use by farmers and homes Agerstrand *et al.*,

(2015). As such, numerous municipalities and factories discharge wastewater into the Ikpoba River, new compounds referred to as "developing toxins" have been found in aquatic ecosystems and wastewater. However, nothing is known about the existence and future of these toxins in our environment. Osa-Igwehide *et al.*, (2016). The impact of wastewater discharge on the Ikpoba River's ecosystem and physiochemical characteristics will be highlighted in this study, along with the urgent need for effective waste management techniques and stringent rules and regulations to solve these issues. It will accomplish this by considering the composition of wastewater, assessing how they affect the natural environment, and examining potential pathways that lead to pollution.

MATERIALS AND METHODS

Study Location

Benin City is located in Edo State, in the southern part of Nigeria. It serves as the capital and largest city of Edo State, and is situated about 40 kilometers (25 miles) north of the Benin River with coordinate, 6° 20' 21.0660" N and 5° 37' 2.8092" E. Benin City has a hot and humid tropical monsoon climate with high temperatures year-round. The population according to the latest data is -1.1 million (0.6% of the total population). Obayagbona and Odigie, (2025). The study location is centred around River Ikpoba, a significant watercourse flowing through Edo State, Nigeria. It serves as a vital water resource for communities along its banks, including the city of Benin. River Ikpoba faces environmental challenges such as pollution from domestic waste, industrial effluents, and agricultural runoff, impacting the water quality and ecosystem health. Ojeah and Oriakhi, (2022).

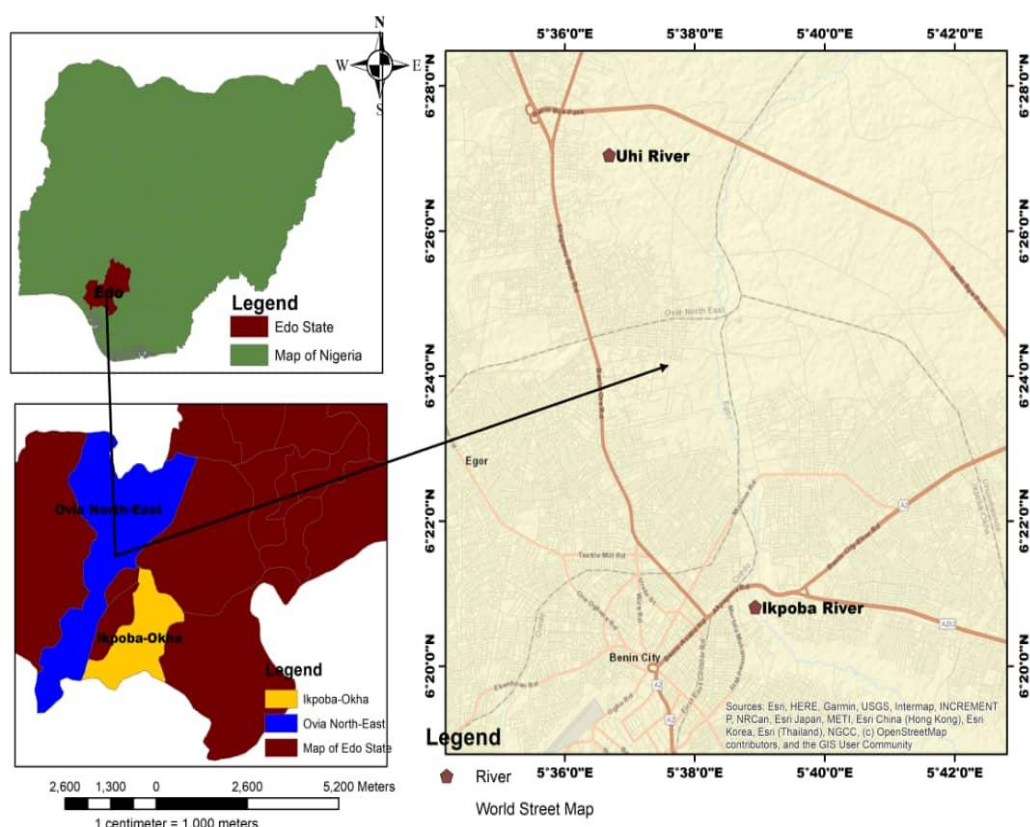


Figure 1: Map showing the study area (River Ikpoba)

SAMPLE COLLECTION

Water samples were collected from four stations A1, A2, B1, B2, the stations placement follows a classical Upstream, Midstream and Downstream design intended to isolate effluent impact. At each research station, one-liter plastic container with labels were used to collect surface water, from Ikpoba river. Using an IPC-Pen multifunction water quality tester with a Temp-PH-EC-TDS probe (Model P-3), was use for in-situ measurements of temperature (°C), pH (salinity), electrical conductivity (EC), and total dissolved solids (TDS). Before being used in the field, the equipment was calibrated in the laboratory. Dissolved oxygen (DO) was analyzed in accordance with APHA (1992) recommendations, water samples were collected in 250 ml amber bottles for Biochemical oxygen demand (BOD) which was carried out, after incubation is done in the laboratory for five days and then analyzed. The study collected water samples from the Ikpoba River, based on the data structure (two replicates by station), sampling was conducted during a single campaign yielding $n = 2$ replicates per station per parameter, giving a total of 8-individual samples readings across 4 stations. Sampling occurred during the wet season, (May) when most aquatic medias are mostly diluted by the rains. A critical distinction in Nigerian environmental studies, as seasonal variation in river flow substantially affects pollutant dilution, BOD and Heavy metal concentrations.

Determiration of heavy metals in effluent

At 7up and Guinness companies' a pre-labeled 1-liter plastic containers were used to collect samples in order to quantify the level of heavy metals in the effluent, Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), and Cadmium (Cd). Samples were collected at an effluent discharge point between Ikpoba River and Uhi River. This effluent was transported to the laboratory to guarantee the accuracy and dependability of the results, collecting and analyzing effluent samples for heavy metals requires a meticulous and exacting procedure. To avoid contamination, water samples were taken in sterile, acid-washed containers. A $0.45\ \mu\text{m}$ filter was used to filter the samples in order to eliminate particle debris. To stabilize the heavy metals in the filtered water samples, a few drops of strong nitric acid were added. Atomic Absorption Spectrometry (AAS) was used to measure the concentrations of heavy metals.

Data Analysis

The independent samples T-test was applied to compare mean parameter values between the upstream group (A1+A2; $n=4$) and downstream group (B1 +B2; $n=4$) the choice is appropriate under the assumption that the two groups are independent. R software was used to do a comprehensive exploratory data analysis, Chi-sq test and ANOVA, was used in parametric inferential statistics to ascertain whether there was a significant difference between Effluent and River samples. The concentration of the measured water quality parameters in the river water sampled at both sampling locations (7up and Guinness companies') and the released of effluent were compared.

Data Design

Heavy-metal analysis was done using Atomic Absorption Spectroscopy (AAS), a popular method for identifying and measuring heavy metals. The sample is vaporized, and the absorption of particular light wavelengths by the metal atoms is measured.

Figure 2: Water samples being collected with the help of the Ikpoba-river guide.

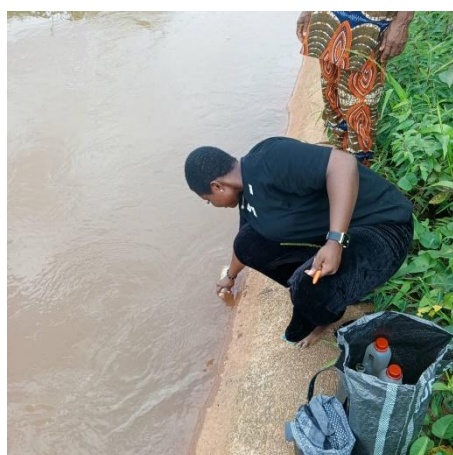


Plate a: Water sample collection A1



Plate b: Water sample collection A2



Plate c: Water sample collection B1



Plate d: Water sample collection B2

RESULTS AND DISCUSSION

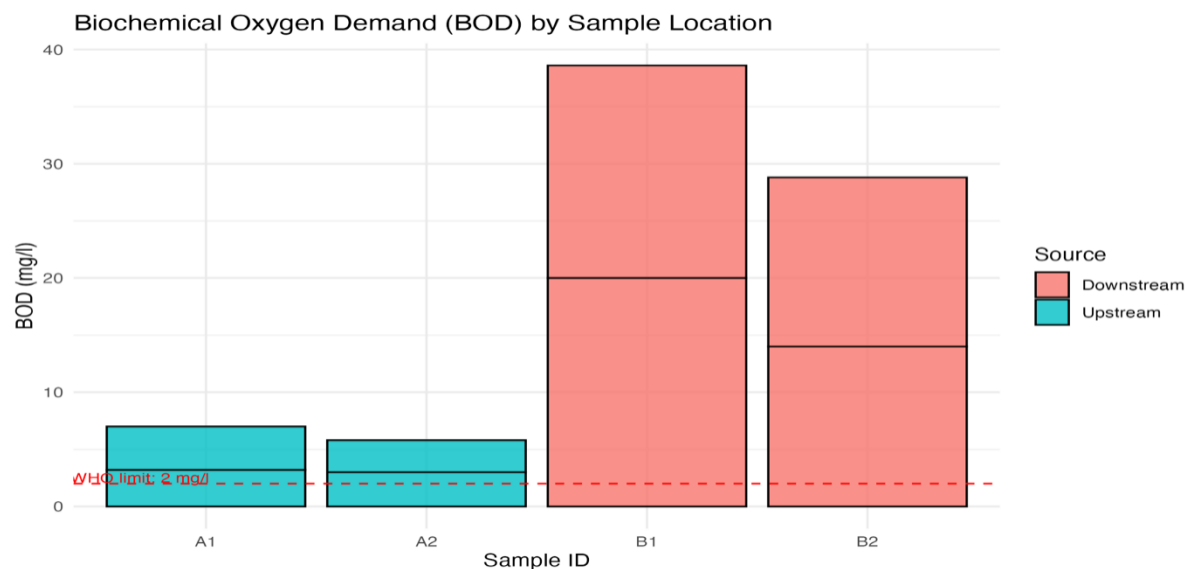


Figure 2: Biochemical Oxygen Demand (BOD) by Sample Location

Figure 2 presents BOD values as a stacked bar chart across the four sampling sites — A1, A2, B1, and B2 — colour-coded to distinguish upstream (teal) from downstream (salmon) stations, with a red dashed WHO limit line at 2 mg/L. The upstream stations A1 and A2 show modest

BOD values of 3.2 and 3.8 mg/L, and 3.0 and 2.8 mg/L respectively. While slightly above the WHO guideline, these values are relatively low and indicative of minor organic enrichment typical of a river receiving some diffuse runoff. The downstream stations B1 and B2, however, tell a dramatically different story. B1 records BOD values of 20 and 18.6 mg/L, producing a combined bar height of approximately 38.6 mg/L – nearly 20 times the WHO limit per individual reading. B2 records 14.0 and 14.8 mg/L, giving a combined bar of approximately 29 mg/L. This steep increase from upstream to downstream unambiguously signals the entry of a large quantity of biodegradable organic matter into the river between the two sampling zones, consistent with the discharge of brewery or food-processing effluent. The high BOD at downstream sites drives microbial oxygen consumption, explaining the dissolved oxygen depletion observed at B1 and B2.

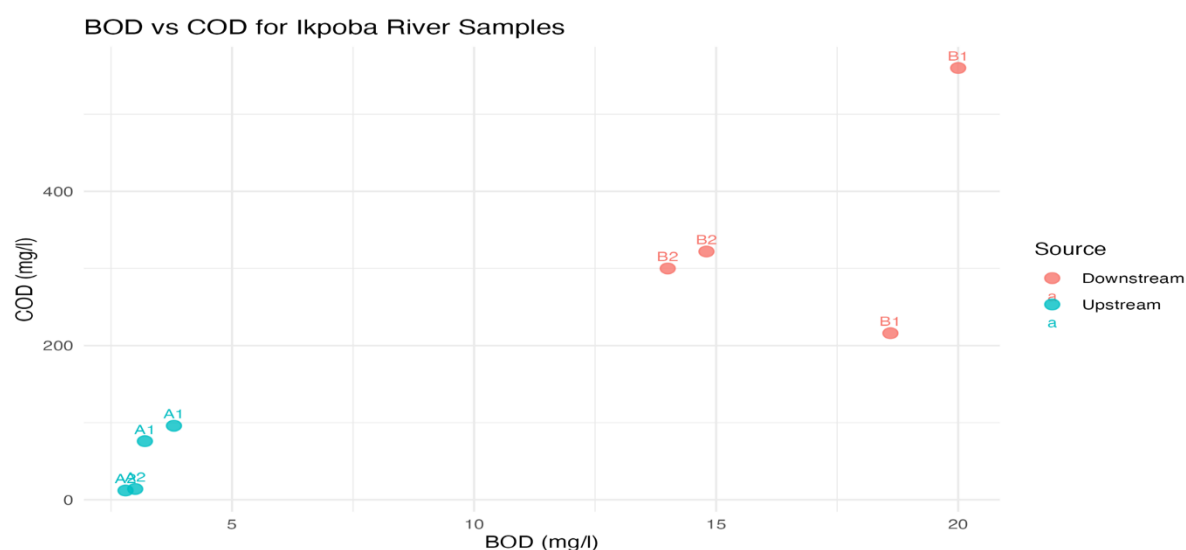


Figure 3: BOD vs COD Scatter Plot for Ikpoba River Samples

Figure 3 is a scatter plot that places each of the eight individual sample readings on axes of BOD (x) and COD (y), with upstream samples shown in teal and downstream samples in salmon, labelled by their station ID. The four upstream data points are tightly clustered in the bottom-left corner of the plot, with BOD values between 2.8 and 3.8 mg/L and COD values between 12 and 96 mg/L. This tight clustering reflects uniformly low organic contamination in the upstream reach. In sharp contrast, the four downstream data points are spread across the upper-right region, with BOD values between approximately 14 and 20 mg/L and COD values between 216 and 560 mg/L. The wide spread of downstream points indicates variable effluent composition or dilution between replicate sampling events at B1 and B2. The strong positive relationship between BOD and COD across the full dataset confirms that organic waste is the dominant driver of both parameters. Notably, the COD values are disproportionately higher than the corresponding BOD values at downstream sites – for instance, B1 records a COD of 560 mg/L against a BOD of just 20 mg/L – suggesting the presence of chemically oxidisable but biologically resistant (refractory) compounds in the downstream effluent that cannot be broken down through biological decomposition alone.

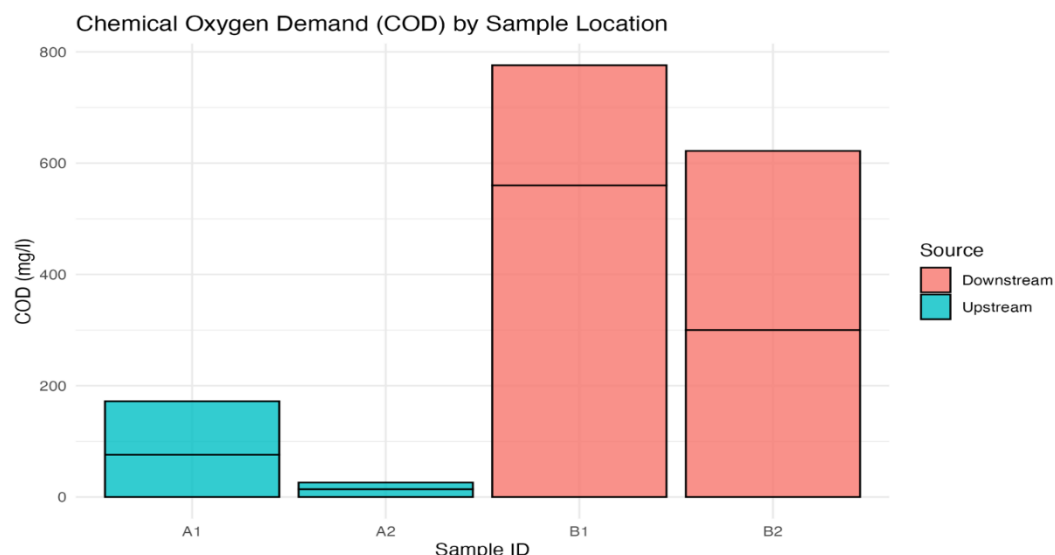


Figure 4: Chemical Oxygen Demand (COD) by Sample Location

Figure 4 displays COD values as stacked bar charts across all four sample sites. The upstream stations again show relatively modest values: A1 records 76 and 96 mg/L, while A2 records 14 and 12 mg/L. The considerably higher COD at A1 compared to A2 is noteworthy and suggests localised organic enrichment at the A1 station even within the upstream reach. Downstream, the COD levels are extraordinary. B1 records the single highest individual COD in the entire dataset at 560 mg/L, with its replicate at 216 mg/L, yielding a combined bar exceeding 776 mg/L. B2 records COD values of 300 and 322 mg/L, for a combined bar of 622 mg/L. These values are not merely elevated – they represent severe organic and chemical contamination that would render the water completely unfit for any direct human use. The extreme COD at B1 in particular points to a direct effluent discharge point in close proximity to this sampling station. The COD:BOD ratio of approximately 10:1 to 28:1 at downstream sites confirms that a substantial fraction of the organic load is refractory, meaning it will persist in the river long after the readily biodegradable fraction has been consumed.

Dissolved Oxygen (DO) by Sample Location

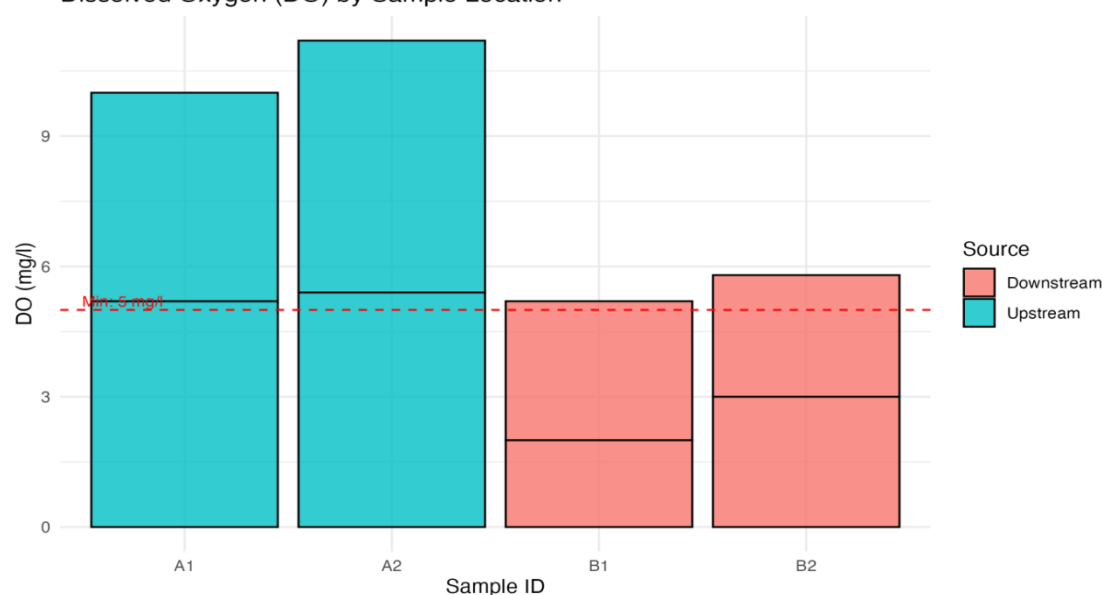


Figure 5: Dissolved Oxygen (DO) by Sample Location

Figure 5 shows DO concentrations as stacked bar charts across all sampling sites, with a red dashed line marking the minimum acceptable threshold of 5 mg/L for supporting aquatic life. The upstream stations A1 and A2 display healthy DO values – A1 records 5.2 and 4.8 mg/L, and A2 records 5.4 and 5.8 mg/L – with mean values hovering just at or above the 5 mg/L threshold, indicating marginally adequate oxygenation for aquatic organisms. The downstream stations B1 and B2, however, fall far below this critical threshold. B1 records DO values of just 2.0 and 3.2 mg/L, and B2 records 3.0 and 2.8 mg/L – all representing hypoxic conditions that are acutely harmful to fish, macroinvertebrates, and other oxygen-dependent aquatic life. The visual contrast between the tall teal bars of the upstream stations and the notably shorter salmon bars of the downstream stations is striking, and the position of all downstream bars below the red dashed line makes the severity of oxygen depletion immediately apparent. This DO deficit is a direct consequence of the high BOD loading seen at B1 and B2, where microbial decomposition of organic effluent consumes dissolved oxygen faster than natural reaeration can replenish it.

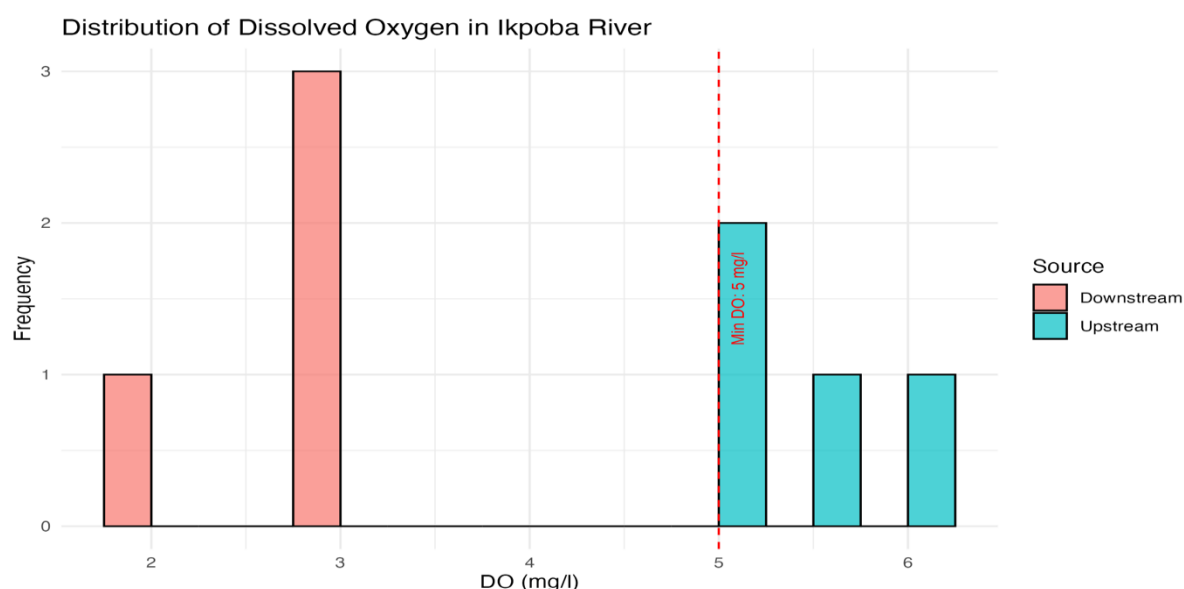


Figure 6: Distribution of Dissolved Oxygen in Ikpoba River

Figure 6 presents a frequency histogram of DO concentrations for all eight samples, separating upstream (teal) from downstream (salmon) readings, with the WHO minimum of 5 mg/L indicated by a vertical red dashed line. The histogram produces a clear bimodal distribution, with two entirely separate clusters falling on opposite sides of the threshold. All four downstream samples cluster to the left of the 5 mg/L line, with one reading at 2 mg/L and three readings between 2.8 and 3.2 mg/L. All four upstream samples fall at or to the right of the threshold, with two readings at approximately 5.4 and 5.8 mg/L and two readings at approximately 5.2 and 4.8 mg/L. This clean spatial separation – with no overlap whatsoever between the upstream and downstream distributions – powerfully demonstrates that oxygen depletion at the downstream stations is a systematic and consistent phenomenon, not an isolated anomaly. The concentration of three downstream readings in a narrow 2.5–3.5 mg/L band underscores that the hypoxic conditions at B1 and B2 are stable and persistent, suggesting a continuous rather than episodic effluent discharge.

Table 1: Ecological Risk Classification by Sample Site and Metal

Sample_ID	Sample_Source	Cd_Risk	Cu_Risk	Fe_Risk	Pb_Risk	Zn_Risk
A1	Upstream	Low	Low	Low	Low	Low
A1	Upstream	Low	Low	Low	Low	Low
A2	Upstream	Low	Low	High	Low	Low
A2	Upstream	Low	Low	High	Low	Low
B1	Downstream	Low	High	High	Low	Low
B1	Downstream	Low	High	High	Low	Low
B2	Downstream	Low	High	High	Low	Low
B2	Downstream	Low	High	High	Low	Low

Table 1 presents a binary risk classification – High or Low – for each of the eight individual water samples across five heavy metals: cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn), based on WHO-derived threshold values. Reading across the table, it is immediately clear that cadmium, lead, and zinc are uniformly classified as Low risk across all eight samples, reflecting concentrations that fall below their respective WHO guideline values throughout the study area. Copper presents a spatially structured pattern: both A1 and A2 upstream samples are Low risk for Cu, while all four downstream samples (B1 and B2) are classified as High risk, confirming that copper contamination is an exclusively downstream phenomenon linked to the effluent source. Iron tells the most concerning story: only the two A1 upstream samples are classified as Low risk for Fe, while both A2 upstream samples and all four downstream samples are High risk. This means that iron exceeds safe limits at six of the eight sampling points, making it by far the most widespread heavy metal hazard across the study area, with contamination extending even into part of the upstream reach.

Table 2: Summary of Mean Chemical Parameters by Source

Sample_Source	Mean_DO_mg_l	Mean_BOD_mg_l	Mean_COD_mg_l	Mean_Cu_mg_l	Mean_Fe_mg_l	Mean_Pb_mg_l	Mean_Zn_mg_l
Downstream	2.75	16.85	349.5	0.047	1.9577	0.0045	0.115
Upstream	5.3	3.2	49.5	0.0185	0.4912	0.0012	0.0805

Table 2: Summary of Mean Chemical Parameters by Source

Sample_Source	Mean_DO_mg_l	Mean_BOD_mg_l	Mean_COD_mg_l	Mean_Cu_mg_l	Mean_Fe_mg_l	Mean_Pb_mg_l	Mean_Zn_mg_l
Downstream	2.75	16.85	349.5	0.047	1.9577	0.0045	0.115
Upstream	5.3	3.2	49.5	0.0185	0.4912	0.0012	0.0805

Table 2 condenses the chemical parameter data into mean values for upstream and downstream groups, providing a clear statistical summary of the pollution gradient. The mean dissolved oxygen (DO) falls from 5.3 mg/L upstream to just 2.75 mg/L downstream – a drop of nearly 50% that confirms chronic hypoxia at the downstream stations. Mean BOD rises more than fivefold, from 3.2 mg/L upstream to 16.85 mg/L downstream, and mean COD increases sevenfold, from 49.5 mg/L upstream to 349.5 mg/L downstream, reflecting the enormous organic and chemical loading associated with the downstream effluent. For heavy metals, mean copper (Cu) rises from 0.0185 mg/L upstream to 0.047 mg/L downstream – exceeding the WHO aesthetic guideline of 0.03 mg/L – while mean iron (Fe) increases nearly fourfold, from 0.4912 mg/L upstream to 1.9577 mg/L downstream, both values already exceeding the WHO limit of 0.3 mg/L. Mean lead (Pb) rises modestly from 0.0012 to 0.0045 mg/L, and mean zinc (Zn) increases from 0.0805 to 0.115 mg/L, with both remaining below their respective WHO thresholds. This table leaves no statistical ambiguity: the downstream reach is simultaneously impacted across oxygen dynamics, organic loading, and heavy metal contamination.

Table 3: Summary of Mean Physical Parameters by Source

Sample_Source	Mean_pH	Mean_TDS_mg_L	Mean_Temp_C	Mean_EC_mS_m
Downstream	6.03	217.25	29.18	184
Upstream	8.58	177	28.82	413.75

Table 3 summarises the mean physical parameters – pH, TDS, temperature, and EC – for upstream and downstream stations. The mean pH of upstream samples is 8.58, comfortably within or slightly above the WHO acceptable range of 6.5–8.5, while the downstream mean of 6.03 falls below the WHO minimum of 6.5, confirming significant acidification of the river in the downstream reach attributable to acid-generating effluent. Mean TDS is higher downstream (217.25 mg/L) than upstream (177.00 mg/L), though the absolute values for both groups remain individually below the WHO limit of 500 mg/L – the high raw TDS at B1 being moderated in the mean by the very low B2 values. Temperature is marginally higher downstream (29.18°C vs 28.82°C), a negligible difference that rules out thermal pollution as a significant stressor in this system. Most striking is the reversal in electrical conductivity (EC): the upstream mean of 413.75 mS/m is more than double the downstream mean of 184.00 mS/m, a counterintuitive finding given that TDS is higher downstream. This paradox suggests that the dissolved solids introduced by the downstream effluent are predominantly non-ionic or poorly ionised organic compounds, which contribute mass but not electrical charge – a pattern consistent with organic brewery or food-processing waste rather than mineral or inorganic salt discharge.

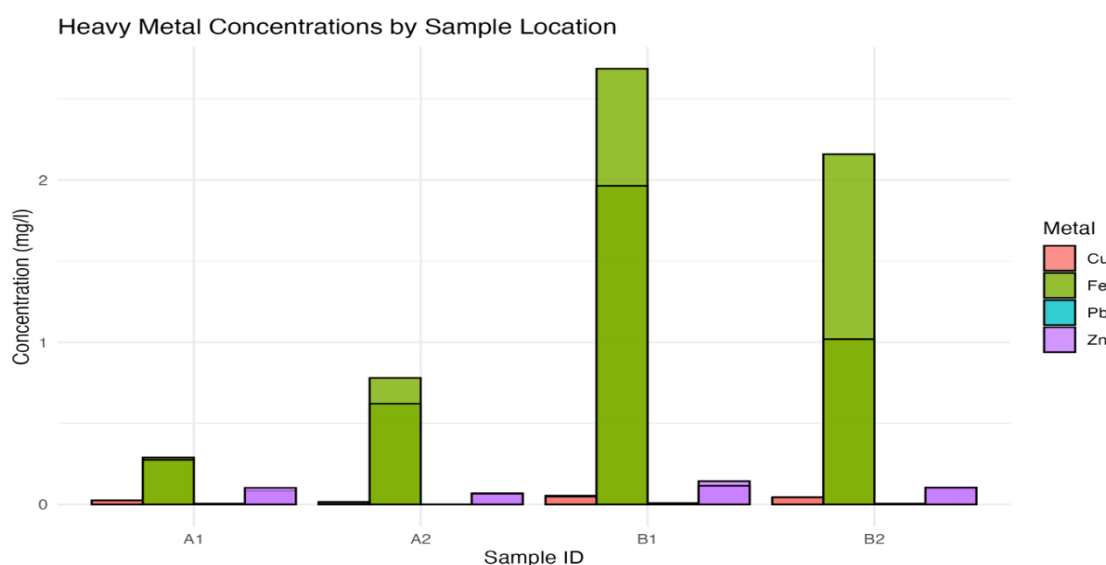


Figure 7: Heavy Metal Concentrations by Sample Location

Figure 7 is a grouped bar chart showing the concentrations of all four detected heavy metals – copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) – side by side for each of the four sampling sites. Iron (Fe), shown in green, utterly dominates the chart at every location, with its bars standing far taller than those of any other metal. At B1, the Fe bars reach 2.687 and 1.965 mg/L, the highest iron values in the dataset, while at B2, Fe registers 2.160 and 1.019 mg/L. Even at the upstream site A2, Fe concentrations of 0.780 and 0.621 mg/L already substantially exceed the WHO limit of 0.3 mg/L. Copper (Cu, orange-red) is consistently present as a small but identifiable segment across all sites, visibly higher at B1 and B2 than at A1 and A2. Zinc (Zn, purple) appears as a modest but detectable bar particularly at B1 and B2. Lead (Pb, teal) is barely visible due to its very low concentrations. The chart makes immediately clear that iron

is not a localised downstream problem but a pervasive issue across most of the sampling area, and that the downstream effluent amplifies iron loading substantially beyond what is already elevated in the upstream reach.

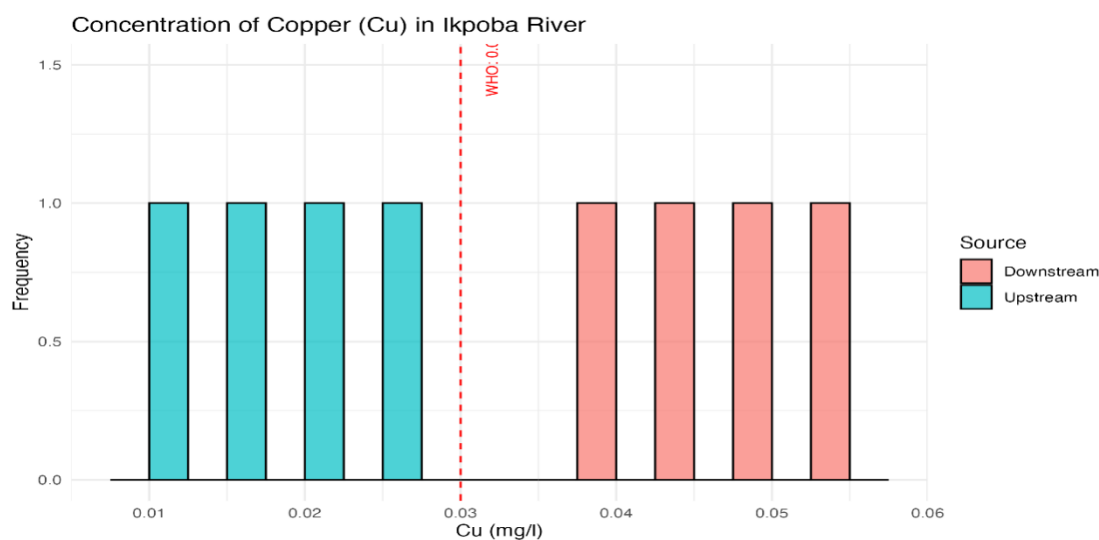


Figure 8: Concentration of Copper (Cu) in Ikpoba River

Figure 8 presents a frequency histogram of copper concentrations for all eight samples, separated by source, with the WHO aesthetic guideline of 0.03 mg/L marked by a red dashed vertical line. The histogram produces a perfectly clean spatial separation: all four upstream readings (A1 and A2, ranging from 0.012 to 0.025 mg/L) fall entirely to the left of the WHO threshold, while all four downstream readings (B1 and B2, ranging from 0.042 to 0.054 mg/L) fall entirely to its right. Each individual bar has a frequency of 1, indicating that all eight copper values are distinct and evenly spread across the two groups. The downstream copper exceedances, while modest in absolute terms, are significant because they are consistent across all four downstream replicates, confirming that copper contamination from the effluent source is a persistent and reliable feature of the downstream water quality. Copper at these concentrations is of particular ecological concern for aquatic invertebrates such as molluscs and crustaceans, which are sensitive to copper at concentrations as low as 0.005 mg/L, well below the measured downstream values.

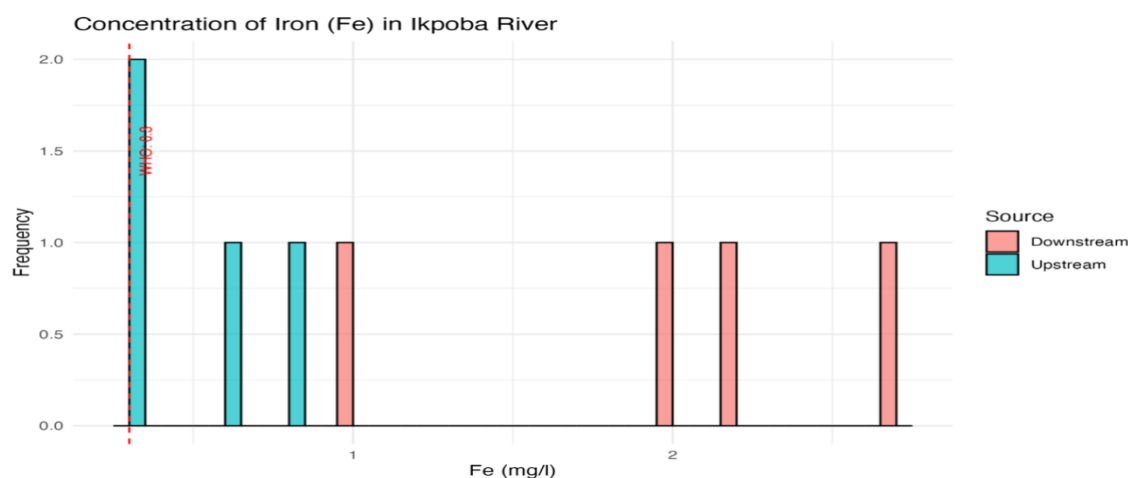


Figure 9: Concentration of Iron (Fe) in Ikpoba River

Figure 9 shows the frequency histogram for iron concentrations across all eight samples, with the WHO guideline of 0.3 mg/L shown by the red dashed line positioned at the far left of the x-axis. This positioning is itself visually instructive – only two readings (the A1 upstream replicates at 0.289 and 0.275 mg/L) fall below or at the threshold, barely missing the guideline limit. The remaining six readings extend across a wide range from approximately 0.6 mg/L at A2 up to 2.687 mg/L at B1, all in the High risk zone to the right of the dashed line. The histogram bars for downstream samples (salmon) extend far to the right, with B1 values reaching the highest iron concentrations in the entire dataset. The two A2 upstream readings (0.780 and 0.621 mg/L) also fall well above the WHO limit, demonstrating that iron contamination is not confined to the downstream effluent zone. Iron at these elevated levels is associated with visible brown discolouration of water, metallic taste, precipitation of iron hydroxide flocs that smother riverbed habitats, and potential interference with aquatic photosynthesis by reducing light penetration.

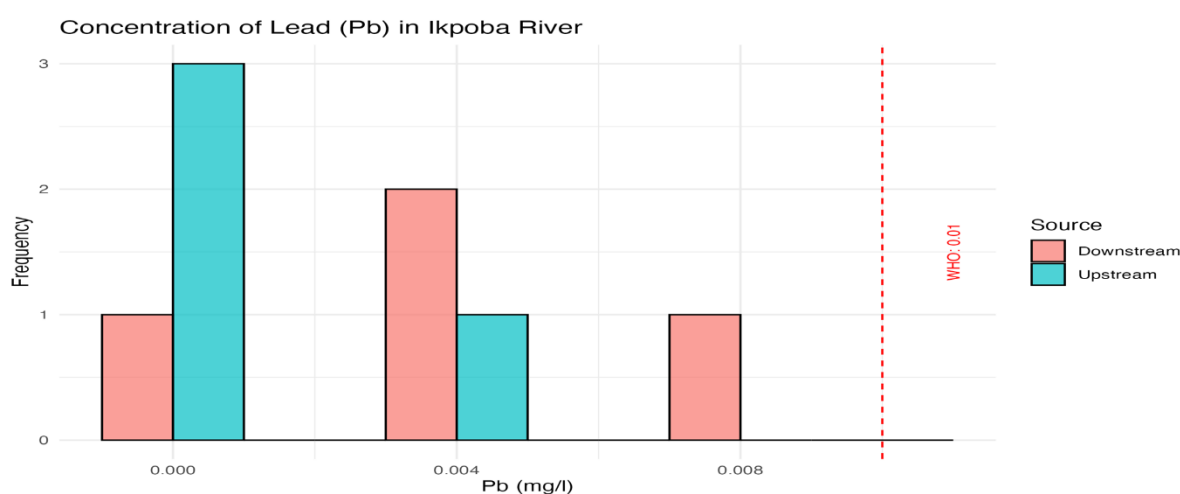


Figure 10: Concentration of Lead (Pb) in Ikpoba River

Figure 10 presents the lead concentration histogram, with the WHO drinking water guideline of 0.01 mg/L shown by a red dashed line positioned at the far right of the x-axis – a placement that immediately signals that all measured values are safely below this threshold. The majority of upstream readings (three of four) recorded no detectable lead (ND, shown as 0), with one upstream sample at 0.005 mg/L. Among the downstream samples, concentrations of 0 (ND), 0.005, 0.005, and 0.008 mg/L are recorded, with the highest downstream value (0.008 mg/L) still comfortably below the 0.01 mg/L WHO guideline. The presence of measurable lead at the downstream stations, where it was largely absent upstream, is nonetheless significant because it confirms that the effluent source introduces trace quantities of lead into the river. Lead is a cumulative neurotoxin with no established safe threshold for human health, and its presence at detectable levels in a river potentially used for subsistence fishing or informal water abstraction warrants continued monitoring, even though no WHO threshold exceedance was recorded in this study.

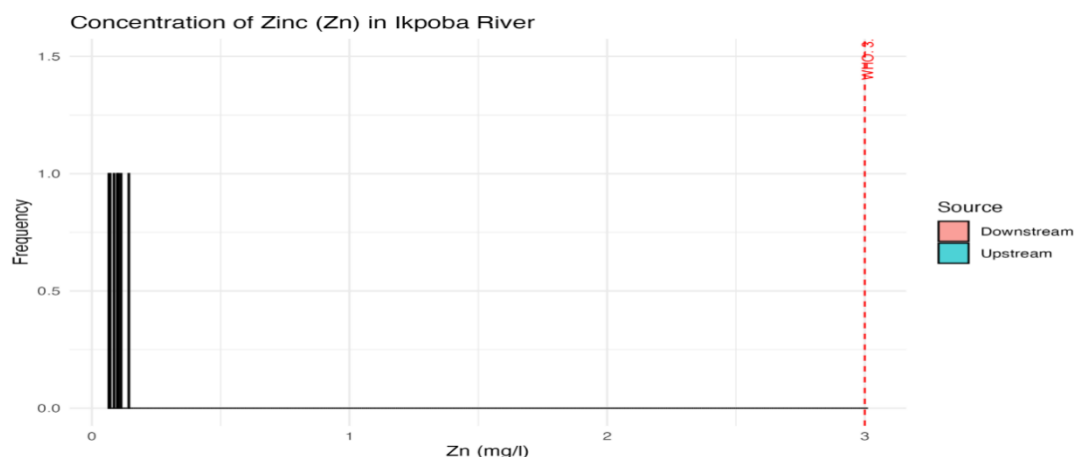


Figure 11: Concentration of Zinc (Zn) in Ikpoba River

Figure 11 displays the zinc concentration histogram for all eight samples, with the WHO aesthetic guideline of 3.0 mg/L indicated by a red dashed line at the far right of the x-axis. All measured zinc values fall between 0.066 and 0.143 mg/L – a narrow range clustered tightly at the extreme left of the x-axis – creating a histogram where all bars appear compressed against the y-axis, with an enormous gap between the data and the WHO threshold. This visual compression reflects how safely below the guideline all zinc readings are, with a safety margin of more than 20 times the highest recorded value. Both upstream and downstream samples show similarly low zinc concentrations, and the downstream values (B1: 0.143 and 0.115 mg/L; B2: 0.098 and 0.104 mg/L) are only marginally higher than upstream (A1: 0.085 and 0.102 mg/L; A2: 0.069 and 0.066 mg/L). While zinc toxicity to aquatic life begins at concentrations of 0.1 to 0.5 mg/L depending on water hardness – a range that some downstream readings are approaching – this parameter does not currently represent a significant risk in the Ikpoba River based on this dataset.

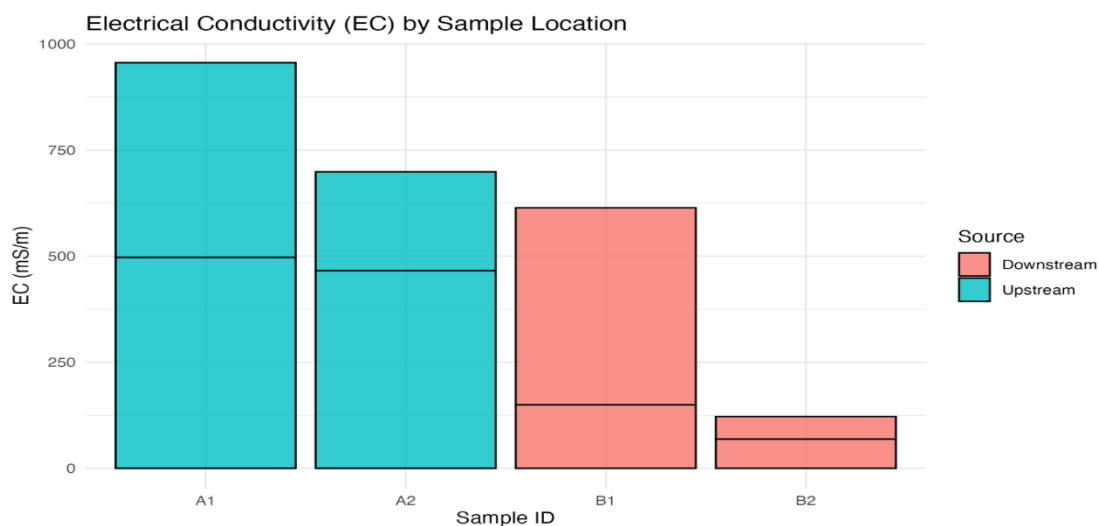


Figure 12: Electrical Conductivity (EC) by Sample Location

Figure 12 displays electrical conductivity (EC) as stacked bar charts across all four sample sites. The upstream stations show considerably higher EC values than their downstream counterparts: A1 records 497 and 459 mS/m, and A2 records 466 and 233 mS/m. Moving downstream, B1 records 150 and 464 mS/m, and B2 records just 69 and 53 mS/m – the lowest

EC values in the entire dataset. The visual pattern produced by this chart is one of generally decreasing conductivity from upstream to downstream, with the exception of one B1 replicate that is unusually high. The high upstream EC is consistent with the presence of dissolved mineral ions – possibly from natural rock weathering, groundwater inputs, or diffuse agricultural runoff – contributing ionisable salts to the upstream reach. The low downstream EC, despite higher TDS, reinforces the conclusion from Table 3 that the downstream effluent introduces electrically neutral organic compounds rather than ionic inorganic contaminants. The unexpectedly high single B1 reading may reflect temporal variability in the effluent composition at the time of that specific sampling event. Figure 11 presents the EC bar chart again in a different visual rendering – here each replicate pair contributes to a combined stacked bar, making it easier to compare the cumulative ionic content of each site. A1 produces the tallest upstream bars (combined EC of 956 mS/m), followed by A2 (combined 699 mS/m), confirming that the upstream reach carries a higher total ionic load than the downstream stations. B1's combined bar of approximately 614 mS/m is largely driven by one high replicate (464 mS/m), while B2 has the lowest combined EC of all sites (122 mS/m). The descending trend from upstream A1 through to downstream B2 – with the exception of one anomalous high B1 reading – tells a consistent story of ionic dilution or replacement downstream. The effluent entering the river at or between the sampling stations appears to add organic matter and metals (as seen in other parameters) without adding appreciable ionic charge, resulting in the counterintuitive inverse relationship between downstream TDS and EC already noted in Table 3.

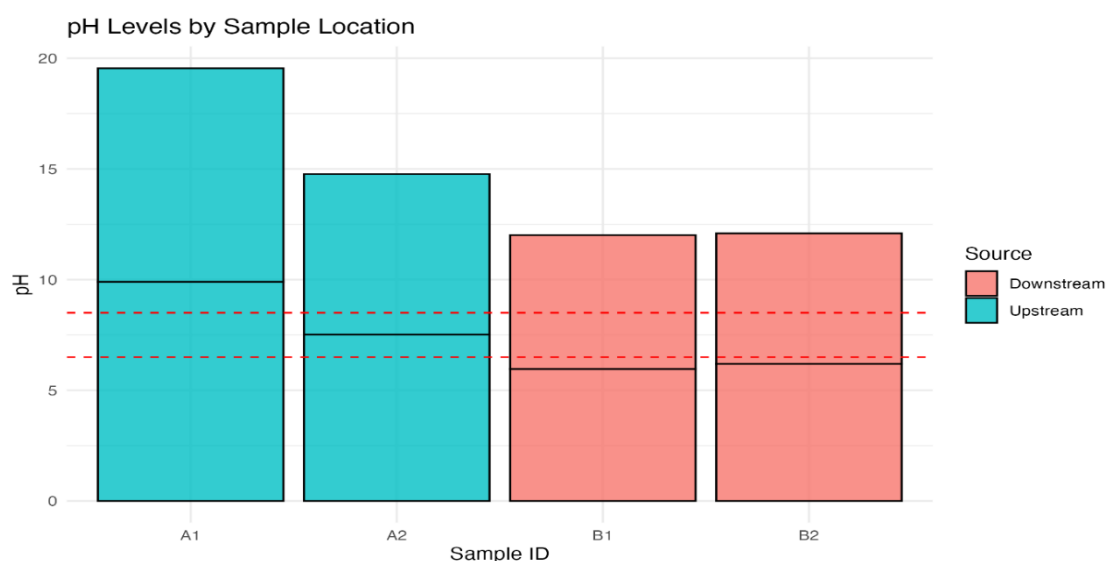


Figure 13: pH Levels by Sample Location

Figure 13 displays pH readings as stacked bar charts for all four sites, with red dashed lines marking the WHO minimum of 6.5 and maximum of 8.5. The upstream station A1 clearly exceeds the upper WHO limit: its two readings of 9.9 and 9.65 produce a combined bar of approximately 19.55, meaning both individual readings are alkaline and above the safe maximum for drinking water – though high pH alone at these levels is not acutely toxic to most aquatic organisms. A2 records readings of 7.52 and 7.25, both within the WHO acceptable range, indicating healthy water quality with respect to pH at this upstream site. Moving downstream, B1 records readings of 5.96 and 6.05, and B2 records 6.19 and 5.90 – all four downstream values falling below the WHO minimum of 6.5. The visual step-down in bar

height from A1 to A2 to B1 to B2 creates a clear descending gradient that maps directly onto the increasing influence of acidic effluent as the river flows downstream. The consistent sub-6.5 pH at both downstream sites indicates chronic acidification of the water body, which increases the bioavailability of heavy metals such as iron and copper already found in elevated concentrations at these stations.

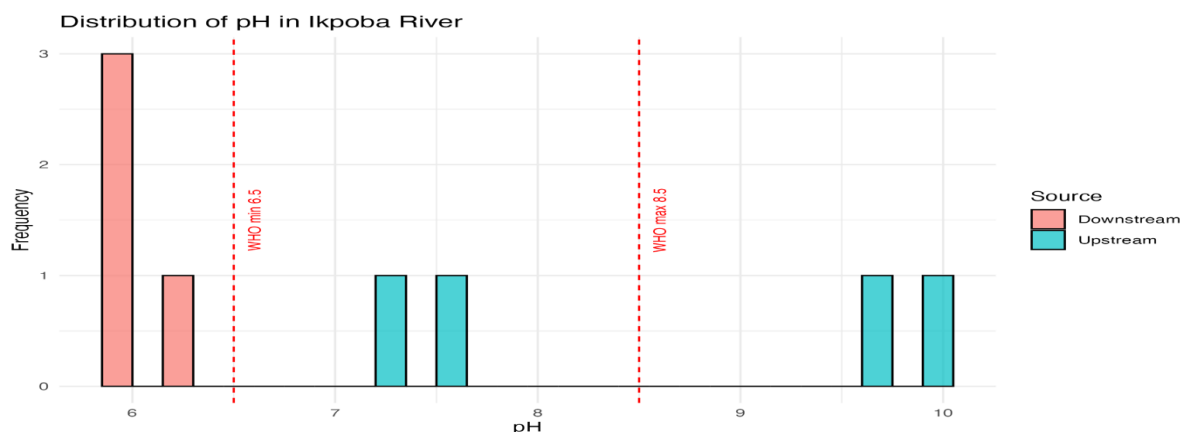


Figure 14: Distribution of pH in Ikpoba River

Figure 14 is a frequency histogram showing the distribution of pH values across all eight samples, with the WHO minimum of 6.5 and maximum of 8.5 indicated by vertical red dashed lines. The downstream samples (salmon) form a cluster at the acidic end of the histogram, with three readings in the pH 5.9–6.2 range and one at approximately 6.2, all to the left of the 6.5 minimum threshold. The upstream samples (teal) are distributed at both ends of the pH spectrum: two readings fall in the neutral-to-slightly-alkaline range of 7.25–7.52, sitting between the two WHO reference lines, while two readings extend above 9.6, well beyond the 8.5 maximum. This bimodal distribution — with upstream samples split between the acceptable range and the alkaline extreme, and all downstream samples below the acceptable minimum — reflects the complex interaction of natural alkalinity inputs in the upstream reach and acid-generating industrial effluent in the downstream section. It also confirms that no single pH value represents the river as a whole, and that spatial sampling across the full channel length is essential for accurate water quality characterisation.

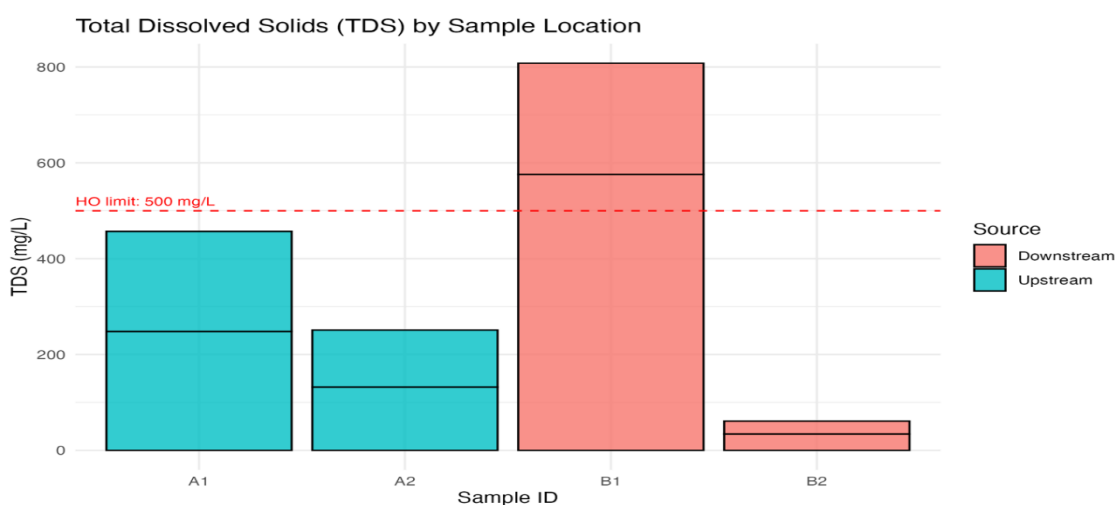


Figure 15: Total Dissolved Solids (TDS) by Sample Location

Figure 15 shows TDS as stacked bar charts across all sample sites, with the WHO limit of 500 mg/L marked by a red dashed line. The upstream station A1 records TDS values of 248 and 209 mg/L, whose combined bar of 457 mg/L approaches but does not breach the threshold on a combined basis (and both individual readings are below 500 mg/L). A2 records much lower TDS values of 132 and 119 mg/L, indicating cleaner water at this upstream point. The most striking feature of Figure 15 is the exceptionally high TDS at B1, which records 576 and 232 mg/L – the highest individual TDS reading in the study. The combined B1 bar exceeds 808 mg/L, and the individual reading of 576 mg/L substantially breaches the WHO limit of 500 mg/L, signalling a direct input of dissolved solid material from the effluent source at or near B1. In contrast, B2 records very low TDS values of 34 and 27 mg/L – the lowest in the dataset – suggesting significant dilution downstream of the main discharge point or a different hydrological pathway at B2. This spatial heterogeneity in TDS highlights the importance of multi-point sampling to capture the full extent and variability of effluent impact.

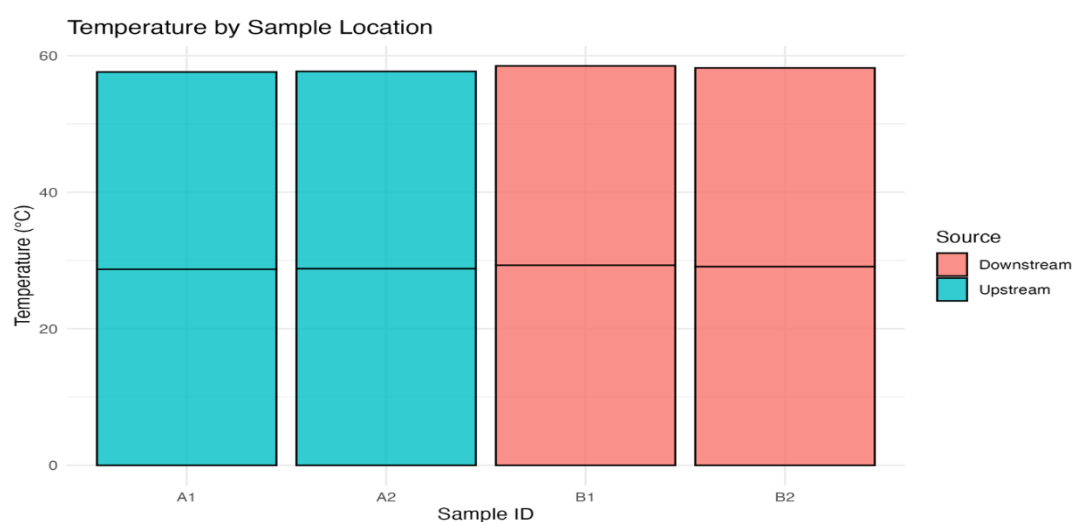


Figure 16: Temperature by Sample Location

Figure 16 displays water temperature as stacked bar charts for all sampling sites. All eight temperature readings fall within a remarkably narrow range of 28.7°C to 29.3°C, producing bars of nearly identical height across all four stations. The upstream sites A1 and A2 show individual readings of 28.7, 28.9, 28.8, and 28.9°C respectively, while the downstream sites B1 and B2 record 29.3, 29.2, 29.1, and 29.1°C. The slight upward shift of approximately 0.4°C in the downstream mean relative to upstream is negligible and falls well within natural diel temperature variation. The uniformity of temperature across the entire sampling area confirms that thermal pollution is not a contributing stressor to the observed water quality deterioration at the downstream stations. However, it is worth noting that even this modest temperature elevation can reduce the saturation capacity of water for dissolved oxygen, slightly amplifying the effect of the biochemical oxygen demand already exerting pressure on DO levels in the downstream reach.

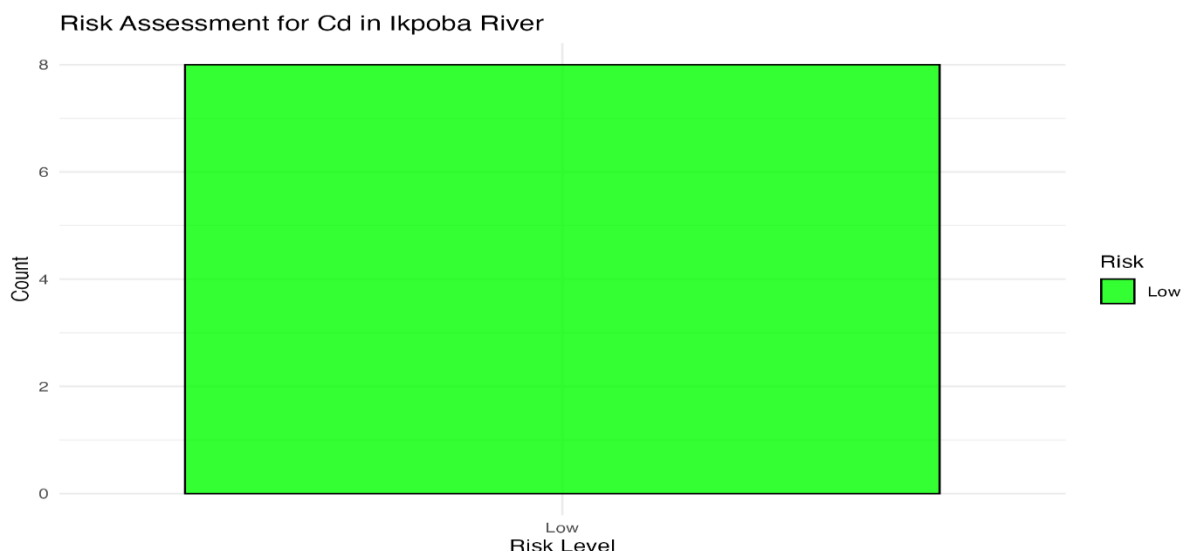


Figure 17: Risk Assessment for Cadmium (Cd) in Ikpoba River

Figure 17 presents a risk classification bar chart for cadmium, showing a single tall green bar at a count of 8 representing the 'Low' risk category, with no red 'High' bar present. This unequivocal result reflects the fact that cadmium was not detected in any of the eight samples collected from the Ikpoba River. The WHO guideline for cadmium in drinking water is 0.003 mg/L – an extremely low threshold reflecting cadmium's high toxicity and carcinogenicity. Its complete absence from all samples is a positive finding, suggesting that cadmium-generating industrial activities such as battery manufacture, nickel-cadmium electroplating, or pigment production are not contributing measurable quantities of this metal to the river at the time of sampling. Continued monitoring is nevertheless advisable, since cadmium is highly persistent in aquatic sediments and can bioaccumulate through the food chain over time, potentially creating ecological risks even at sub-detectable water concentrations.

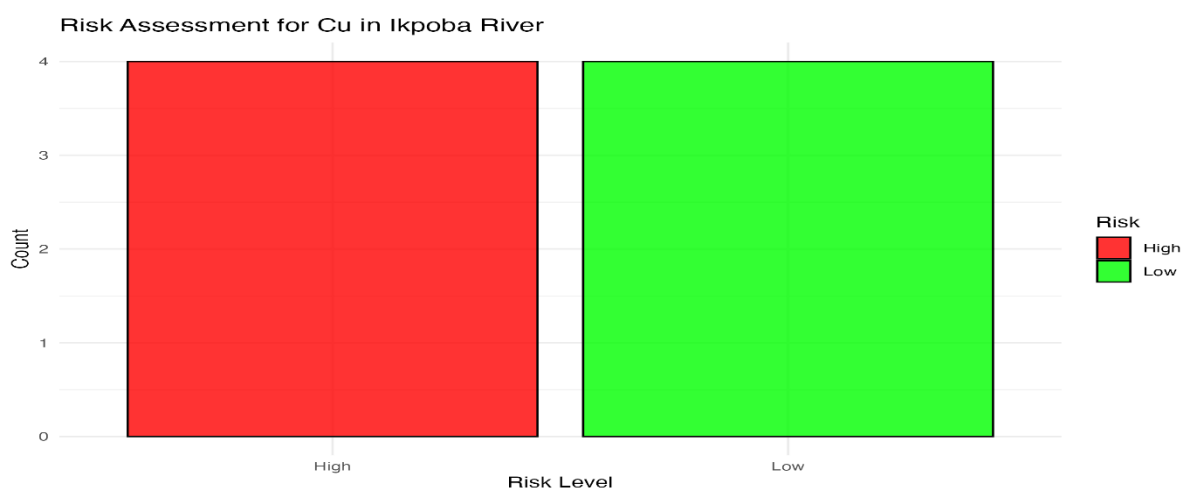


Figure 18: Risk Assessment for Copper (Cu) in Ikpoba River

Figure 18 shows the copper risk classification chart, displaying equal red (High) and green (Low) bars both reaching a count of 4. This precise 50/50 split directly reflects the clean spatial boundary identified in Figure 7 – all four upstream samples are Low risk for copper, and all four downstream samples are High risk. The equal bar heights reinforce that the copper

contamination is a geographically coherent, source-specific phenomenon. The fact that risk shifts from universally Low upstream to universally High downstream, with no mixed results at either end, is consistent with a single point-source effluent discharge introducing copper between the upstream and downstream sampling stations. While the copper concentrations recorded do not constitute an acute human health risk at current levels, the consistent downstream exceedance of the WHO aesthetic guideline of 0.03 mg/L has ecological implications – particularly for the sensitive aquatic invertebrate communities that form a critical part of the river's food web and are used as biological indicators of water quality.

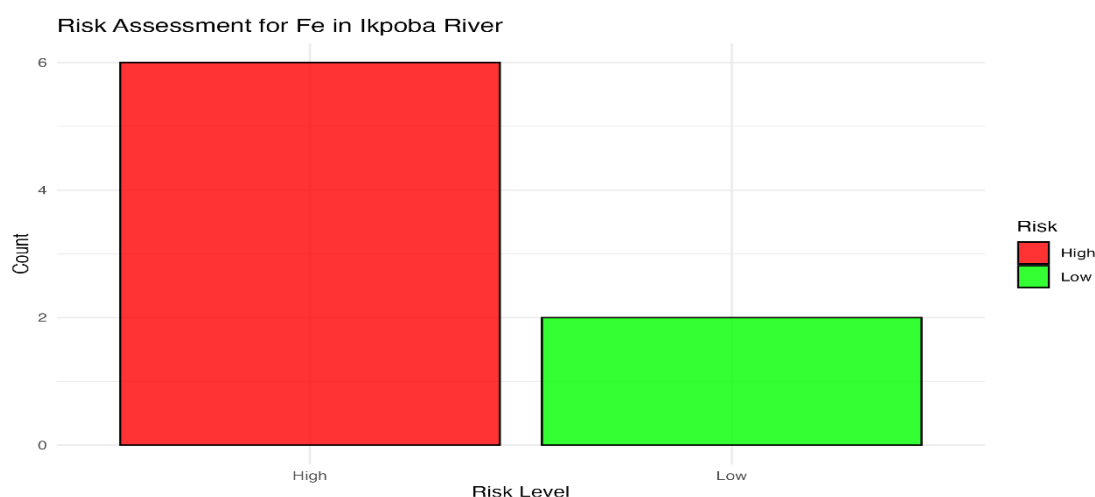


Figure 19: Risk Assessment for Iron (Fe) in Ikpoba River

Figure 19 displays the iron risk assessment chart, which produces the most alarming result of all the risk plots. A tall red bar reaching a count of 6 dominates the left side of the chart, representing the six samples classified as High risk for iron, while a shorter green bar of count 2 on the right represents the only two Low-risk samples – both from station A1. This 6:2 split means that 75% of all samples collected from the Ikpoba River exceeded the WHO guideline for iron, making it the single most pervasive heavy metal risk in this study. The High risk classification extends not only across all four downstream samples (B1 and B2) but also both replicate samples from the upstream A2 station, indicating that iron contamination predates and extends beyond the main downstream effluent discharge zone. This widespread iron exceedance has multiple negative consequences for the river: it degrades the water aesthetically through brown discolouration and metallic taste, creates iron hydroxide precipitates that smother benthic habitats, and increases the overall toxic metal load on aquatic organisms. The extensive spatial reach of iron contamination demands urgent investigation of both the upstream iron source and the downstream effluent contribution.

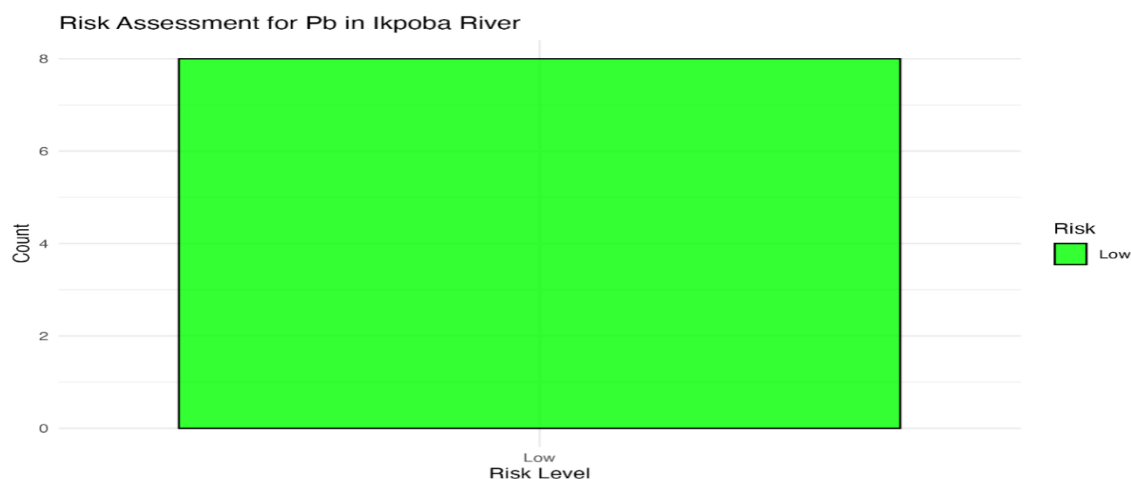


Figure 20: Risk Assessment for Lead (Pb) in Ikpoba River

The lead risk assessment chart in fig 20 displays a single green bar reaching a count of 8, with the risk level labelled as "Low" and no red "High" bar present anywhere in the plot. This unambiguous result confirms that all eight water samples collected from the Ikpoba River – across both upstream stations (A1 and A2) and downstream stations (B1 and B2) – were classified as Low risk with respect to lead contamination. This outcome is based on the WHO drinking water guideline threshold of 0.01 mg/L applied in the risk model, which no sample exceeded. While trace quantities of lead were detected at some downstream sites (with a maximum recorded value of 0.008 mg/L at B1), these concentrations remained below the threshold used to trigger a High risk classification. It is important, however, not to interpret the uniform "Low" classification as a guarantee of complete safety. Lead is a cumulative and irreversible neurotoxin with no established safe threshold for human health, particularly in children. Its detectable presence at downstream stations – where it was largely absent upstream – indicates that the effluent source is introducing trace lead into the river, and continued surveillance is strongly recommended, especially if the river supports subsistence fishing or informal water abstraction communities in the downstream area.

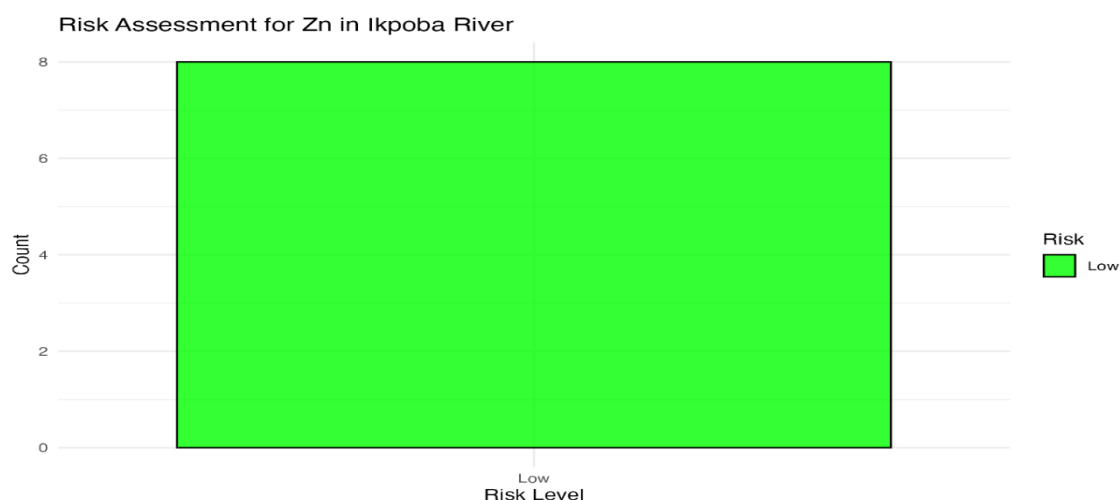


Figure 21: Risk Assessment for Zinc (Zn) in Ikpoba River

Like the lead chart immediately above it, the zinc risk assessment plot displays a single green bar reaching a count of 8, with only the "Low" risk category represented and no "High" bar visible. This result confirms that zinc concentrations across all eight Ikpoba River samples were below the WHO aesthetic guideline threshold of 3.0 mg/L used in the risk classification model. The measured zinc values across all sites ranged from just 0.066 to 0.143 mg/L – a range that is 20 to 45 times below the WHO threshold, explaining why the risk classification is uniformly Low with no exceptions. Both upstream and downstream stations returned Low risk classifications for zinc, indicating that the effluent discharge between the two zones does not introduce zinc at levels that constitute a significant health or ecological risk under current conditions. Nevertheless, it is worth noting that zinc toxicity to sensitive aquatic organisms such as invertebrates can begin at concentrations as low as 0.1 mg/L depending on water hardness – a threshold that the downstream B1 samples (0.143 and 0.115 mg/L) are approaching. Routine monitoring of zinc therefore remains advisable as part of ongoing water quality management for the Ikpoba River.

CONCLUSION

Effluent discharge points between Ikpoba river and river Uhi the cumulative pattern across BOD, COD, DO, copper, iron, pH, and TDS is strongly consistent with a brewery or organic food-processing effluent discharging between the upstream and downstream sampling zones. The COD, BOD, ratio of approximately 10.1 to 28.1 at downstream stations, indicates a large refractory organic load, and the downstream acidification of (pH 6.9-6.2) is attributed to fermentation waste from brewery and soft-drink manufactures. Hence, it is noteworthy that across all 20 figures and 3 tables, the Ikpoba River data consistently and coherently reveals a river under significant pollution stress, particularly in its downstream reach (B1 and B2). The upstream stations A1 and A2 display generally better water quality, with pH mostly within acceptable limits, adequate dissolved oxygen, and low organic loading – though elevated iron at A2 and notably high alkalinity at A1 indicate that even the upstream reach is not entirely pristine. The downstream stations record simultaneous exceedances across multiple critical parameters: pH below the WHO minimum of 6.5, dissolved oxygen critically below 5 mg/L, BOD and COD values 10 to 15 times the WHO guideline, copper above the aesthetic guideline, and iron up to nine times the safe limit. Cadmium, lead, and zinc, by contrast, remain within acceptable ranges throughout the study area, offering some reassurance that the most acutely toxic heavy metals are not present at harmful levels. The two parameters requiring most urgent remedial attention are iron contamination – pervasive across six of eight sampling points and almost certainly of mixed anthropogenic and natural origin – and organic oxygen demand, reflected in the catastrophic BOD, COD, and DO values at the downstream stations, which point to a high-volume discharge of biodegradable industrial effluent that is actively suffocating the river ecosystem.

Acknowledgments

Above all, I would want to express my heartfelt thanks to my research teams for their essential advice, perceptive criticism, and steadfast support during this endeavor. The course and caliber of this work have been greatly influenced by their deep knowledge and guidance.

Recommendations

1. **Continuous Monitoring:** Regular monitoring of water quality parameters and heavy metal concentrations is essential to detect any changes and address potential risks promptly.
2. **Effluent Treatment:** Implementing effective reinforcement of effluent treatment processes to reduce the levels of pollutants before discharge into the river.

3. **Public Awareness:** Raising awareness among local communities about the potential health risks associated with contaminated water and promoting safe water practices.
4. **Regulatory Enforcement:** Strengthening the re-enforcement of environmental regulations to ensure compliance with effluent discharge standards.
5. **Further Research:** Conducting additional studies to explore the long-term effects of heavy metals and other pollutants on the ecosystem and human health; by using (tissues from aquatic creatures).

REFERENCES

- Akharama, M.O., and Onu., N. A (2024). Water quality index for Elvauating the quality status of Ikpoba river in Benin city Nigeria . NIPES *journal of science and technology research* 6(3) <https://doi.org/10.5281/zenodo.13926212>
- Anyanwu, E. D. and Ihediwah, S. U. (2015). Drinking Water Quality Assessment of Iyinna Spring, Umuariaga, Ikwuano Local Government Area, Abia State. *Journal of Aquatic sciences*, 30(2), pp. 317-328.
- Amah-Jerry, E. B, Anyanwu, E. D and Avoaja, D. A. (2017) Anthropogenic Impacts on the water quality of Aba River, South, East Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 10(3), pp. 299- 314.
- Attoui B., Toumi N., Messoudi S., Benrabah S. 2016. Degradation of water quality: The case of plain west of Annaba (northeast Algeria). *Journal of Water and Land Development*. No. 31 p. 3–10. DOI 10.1515/jwld-2016-0031.
- Boussaha B., Laifa A.L. 2017. Wadi Bounamoussa's waters quality in the north-east of Algeria: Statistical treatment of some physical and chemical parameters. *Journal of Water and Land Development*. No. 34 p. 77–83. DOI: 10.1515/jwld-2017-0040.
- Chen, B., Wang, M., Duan, M., Ma, X., Hong, J., Xie, F., et al. In Search of Key: "Protecting Human Health and the Ecosystem from Water Pollution in China". *J. Clean. Prod.*, 228, 101–111, 2019, doi: 10.1016/j.jclepro.2019.04.228.
- Chowdhary, P., Bharagava, R. N., Mishra, S., and Khan, N., "Role of Industries in Water Scarcity and its Adverse Effects on Environment and Human Health". *Environ. Concerns Sustain. Dev.*, 235–256, 2020, doi:10.1007/978-981-13-5889-0_12[2].
- Egwuonwu, C. C., Uzoije, A. P., Okafor, V. C., Ezeanya, N. C. & Nwachukwu, M. U. (2012). Evaluation of the Effects of Industrial Wastewater Discharge on Surface water (A Case Study of Nigeria Breweries PLC, Enugu). *Greener Journals of Physical Sciences*, 2(3), 056-063.
- Ekhaisc, F.O. and C.C Anyansi. (2005) Influence of Breweries Discharge on the Microbial and Physiochemical Quality of Ikpoba River, Nigeria. *Afri Journal Biotechnology* 4: 1062-1065.
- Etim, E. U. & Onianwa, P. C. (2013). Impact of Effluents of Industrial Estate on Oruku River in South western Nigeria. *World Applied Science Journal*, 12(7), 1075-1083.
- Goher, M. E., Hassan, A. H., Abdel-Moniem, I. A., Fahmy, A. H., & El-sayed, S. M. (2014). Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *The Egyptian Journal of Aquatic Research*, 40, 225–233. [10.1016/j.ejar.2014.09.001](https://doi.org/10.1016/j.ejar.2014.09.001).
- Halim, A., Sharmin, S., Rahman, H., Haque, M., Rahman, S., et al. (2018). Assessment of water quality parameters in baor environment, Bangladesh: A review. *International Journal of Fisheries and Aquatic Studies*, 6(2), pp. 269- 263.
- Hautier, Y.; Tilman, D.; Isbell, F.; Seabloom, E.W.; Borer, E.T.; Reich, P.B.(2015) Anthropogenic environmental changes affect ecosystem stability via biodiversity. *Science* , 348, 336–340.

- Imoobe T.O.T. and Okoye P.I. (2011). Assessment of the impact of effluent from a soft drink processing factory on the physico-chemical parameters of Eruvbi stream Benin City, Nigeria. *Bayero J. of Pure and Appl Sci.* 4(1): 126 – 134.
- Improving environmental risk assessment of human pharmaceuticals *Environ. Sci. Technol.*, 49 (2015), pp. 5336-5345.
- Kariu, I.A, Achi, O.K. Ezeronye, O.U and E.C. Anyanwu (2006) Seasonal variation in heavy metal biosorption in water samples from Eziarna River near soap and brewery industries and environmental health implication. *International Journal of Environmental Science and Technology.* 3(1) 95-102.
- M. Agerstrand, C. Berg, B. Björlenius, M. Breitholz, B. Brunström, J. Fick, L. Gunnarsson, D. Larsson, J. Sumpter, M. Tysklind, C. Ruden (2013) the occurrence and distribution of synthetic organic substances following application of dried and granulated sugar. *National Institutes of health (gov)* <https://pubmed.ncbi.nlm.nih.gov>
- Malik, A. and Ahmad, M. (2002) Seasonal Variation in Bacterial Flora of the Waste Water and Soil in the Vicinity of Industrial Area. *Environmental Monitoring and Assessment*, 7, 263-273. <https://doi.org/10.1023/A:1013186218093>.
- NESREA: National Environmental Standards and Regulations Enforcement Agency: *National Environmental (Surface and Ground water Quality Control) Regulations- Effluent discharges, irrigation and reuse standards.* 2011. (Accessed on 17th of February 2018).
- Obayagbona N.O and Odigie. O, (2025) Land usage /land cover variation at a bridged section of ikpoba river in benun city, mid western Nigeria. *Journal of Bioresources and Environmental Science* 4(1) 8-15, <https://doi.org/10.61435/jbes.2024.19936>
- Osa-Igwehide, I., Anegbe, B., Okunzuwa, I. G., Ighodaro, A., & Aigbogun, J. (2016). Levels of heavy metal concentration in water, sediment, and fish in Ikpoba River, Benin City, Edo State Nigeria. *International Journal of Chemical Studies*, 4(1), 48–53.
- Ochu, A., Chegwe, F. E., Toby, D. T., Okene, D. T., & Akpoufuoma, O. F. (2025). Analyzing toxic heavy metals in industrial discharge: Implications for public health. *IRE Journals*, 8(7), 746.
- Ojeah J. C. and Oriakhi. O, (2022). Spatial analysis for surface water quality assessment of ikpoba river using geographic information system, *Nigerian Journal of Environmental Sciences and Technology*, 6 (2), pp 391-408. <https://dio.org/10.36263/nijest.202202.00374>
- Ogbeibu, A.E. and Erhirhi, A.V. (2021) Assessment of the Impact of Abattoir Effluent on the Physico-Chemical and Microbiological Characteristics of the Effurun River and Eburu Canal, Warri, Nigeria. *Tropical Freshwater Biology*, 30, 45-59.
- Olubunmi A. N. & Ndubuisi A. (2011): Impact of Industrial Effluent and Dumpsite Leachate Discharge on the Quality of Ground Water in Oyo State, Nigeria. *Journals of Biodiversity and Environmental Sciences* Vol.1 No. 3 P 13-18. 19.
- Orhue E.R.'Agbonsalo Osaigbovo; Dennis Vwioko. Growth of maize (*Zea mays* L.) and changes in some chemical properties of an ultisol amended with brewery effluent. 2005, *African Journal of Biotechnology* 4(9) DOI:10.4314/ajb.v4i9.71212.
- Osibanjo, O., Daso, A. P. & Gbadebo, A. M. (2011). The impact of industrial estate, Ibadan, Nigeria. *African Journal of Biotechnology*, 10(4), 696-702.
- Ovie, S.I. (1997). The Ecology and Culture of the Zooplankton of Jebba Lake, Nigeria. Unpublished Ph.D. Thesis University of Benin, Benin City.
- Reid, A.J.; Carlson, A.K.; Creed, I.F.; Eliason, E.J.; Gell, P.A.; Johnson, P.T.J.; Kidd, K.A.; MacCormack, T.J.; Olden, J.D.; Ormerod, S.J.; et al.(2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev.* 94, 849–873.

- Salem, T.A. (2021), Changes in the physicochemical and biological characteristics in the lentic and lotic waters of the Nile river. *Egypt. J. Aquat. Res.* 47, 21–27.
- Sajitha, V. and Vijayamma, S.A. (2016) Study of Physico-Chemical Parameters and Pond Water Quality Assessment by Using Water Quality Index at Athiyannoor Panchayath, Kerala, India. *Emergent Life Sciences Research*, 2, 46-51.
- Şener, Ş.; Şener, E.; Davraz, A. (2017) Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Sci. Total Environ.* 584–585, 131–144.
- Uchegbu S.N. (2002). Environmental management and protection. Enugu. Spotlite Publisher. ISBN 978-37916-5-6 pp. 224.
- Ustaoglu, F. and Tepe, Y. (2019) Water Quality and Sediment Contamination Assessment of Pazarsuyu Stream, Turkey Using Multivariate Statistical Methods and Pollution Indicators. *International Soil and Water Conservation Research*, 7, 47-56.
- V. Singh, C. P. Singh Chandel, Analytical study of heavy metals of industrial effluents at Jaipur, Rajasthan (India), *Journal of Environmental Science and Engineering*, 2006, 48, 103-108.
- WHO. Water quality for drinking: WHO guidelines. In: *Encycl. Earth Sci. Ser.*, pp. 876–883, 2011. https://doi.org/10.1007/978-1-4020-4410-6_184.