

Seasonal Assessment of the Physicochemical Characteristics and Heavy Metal Contamination of Agangwu Stream, Enugu North Local Government Area, Enugu State, Nigeria

Onuorah, E. R.¹, Orji, M. U.^{1,2}, Nwobu, R. A. U.^{1,3}, Oghonim, P.A.N.⁴, Abana, C. C.^{1*}

¹Department of Applied Microbiology and Brewing, Nnamdi Azikiwe University, Awka, Nigeria

²Department of Microbiology, Caritas University, Enugu, Nigeria

³Deptment of Microbiology, Paul University, Awka, Nigeria

⁴Microbiology Department, Biological Sciences, University of Delta, Agbor P.M.B 2090, Agbor, Delta State, Nigeria.

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Abstract — Stream has been a source of drinking water in most settlements, the occurrence of physicochemical parameters and heavy metals above the permissible standards make it unsafe for drinking and other recreational purposes. An investigation was carried out on the Seasonal Assessment of the Physicochemical Characteristics and Heavy Metal Contamination of Agangwu Stream, Enugu North Local Government Area, Enugu State, Nigeria. Eighteen (18) stream water samples were collected, six (6) from the upstream, six (6) from midstream and six (6) from downstream locations during both wet and dry seasons. They were subjected to a wide range of analytical assessments to determine the impact of seasonal variations on the water quality and potential public health risks. Some of the physicochemical parameters determined showed statistically significant seasonal variation. Temperature was significantly higher in the dry season ($31.00 \pm 3.606^{\circ}\text{C}$) compared to the rainy season ($25.00 \pm 0.000^{\circ}\text{C}$) with $P=0.045$. pH values were acidic across both seasons but showed a significant increase during the rainy season ($6.133 \pm 0.091^{\circ}\text{C}$) relative to the dry season ($5.673 \pm 0.266^{\circ}\text{C}$), $P = 0.047$. TSS also increased markedly from $9.733 \pm 0.929 \text{ mg/l}$ in the dry season to $16.367 \pm 0.987 \text{ mg/l}$ in the wet season, with $P = 0.001$, exceeding WHO's permissible limit of 10mg/l. similarly, TDS levels increased from $4.173 \pm 0.162\text{mg/l}$ to $6.210 \pm 0.215\text{mg/l}$ ($P=0.000$), while phosphate concentrations declined significantly from $5.933 \pm 0.902 \text{ mg/l}$ in the dry season to $3.133 \pm 0.611 \text{ mg/l}$ in the rainy season ($P=0.011$). Iron content was notably higher in the dry season ($2.811 \pm 0.246\text{mg/l}$) than in the rainy season ($2.151 \pm 0.110\text{mg/l}$), $p=0.013$, far exceeding the WHO limit of 0.3mg/L. Other parameters such as nitrate, chloride, sulphate, calcium, sodium and manganese also varied between seasons but remained within WHO guidelines.

Keywords: Heavy metals, Physicochemical, water quality, wet season, dry season.

Introduction

Water (H₂O) is indispensable to life and constitutes a substantial proportion of the volume of living biological cells. It functions not only as a solvent but also as a reactant, product, catalyst, molecular chaperone, messenger and regulator of numerous biological processes, making it uniquely suited to carbon-based life (Brini *et al.*, 2017). The extensive hydrogen-bonding network of water accounts for many of its distinctive physicochemical properties, including its relatively high boiling point, low freezing point, high heat capacity, surface tension and dielectric constant. These characteristics enable water to dissolve and transport inorganic salts, gases and organic compounds that are essential for biological activities. Its polarity and capacity for intermolecular interactions also contribute to the structural organisation of biological macromolecules and favour the polymerisation and organisation of organic molecules (Westall & Brack, 2018). Water is one of the most abundant substances on Earth, with an estimated global volume of approximately 1.4×10^9 km³, and it plays fundamental roles in the Earth's geophysical, geochemical and ecological processes (Brown & Bhushan, 2016). It is equally important to agriculture, industry, domestic activities and virtually every biological system. All forms of life, including microorganisms, depend on water for growth, metabolism and survival (Sharma & Bhattacharya, 2017). Aquatic organisms also depend on dissolved gases such as oxygen and carbon dioxide for respiration, photosynthesis and other metabolic activities (Brini *et al.*, 2017). Consequently, changes in the chemical or microbiological composition of water may have significant ecological and public-health consequences. Natural water bodies harbour diverse microbial communities whose composition is influenced by nutrient availability, temperature, pH, dissolved oxygen and anthropogenic activities. Agu *et al.* (2017), in their study of Ezzu River in Amansea, Awka, demonstrated the occurrence of halotolerant bacteria in an aquatic environment, illustrating the ability of microorganisms to adapt to varying physicochemical conditions. Similarly, Agu *et al.* (2023) reported diverse microbial populations in fish ponds in Awka, Anambra State, further demonstrating the close relationship between environmental conditions and aquatic microbial communities. Awari *et al.* (2023) also highlighted the ubiquity of microorganisms in environmental systems and their potential beneficial and harmful effects on ecosystem and public health.

The quality of water is commonly evaluated using physicochemical, microbiological and heavy-metal parameters. Physicochemical characteristics such as colour, temperature, pH, turbidity, total suspended solids, total dissolved solids, total hardness, alkalinity, salinity and electrical conductivity provide important information about the condition and suitability of a water body for domestic,

agricultural and ecological purposes (Oghonim *et al.*, 2025). Variations in these parameters may also influence the solubility, mobility and bioavailability of contaminants, including heavy metals, and may affect the survival and proliferation of microorganisms within aquatic environments.

Heavy-metal contamination is of particular concern because metals are persistent, non-biodegradable and capable of accumulating in aquatic environments and biological tissues. Contamination may arise from industrial effluents, municipal wastes, agricultural runoff, automobile-related activities and indiscriminate disposal of solid waste. Agu *et al.* (2014) demonstrated that leachate from solid-waste dumps contributed to bacteriological and heavy-metal contamination of groundwater in Awka, providing evidence of the environmental consequences of poorly managed waste disposal. More recently, Egurefa *et al.* (2024) reported bacteriological and heavy-metal contamination of borehole water in Enugu metropolis, underscoring the vulnerability of water resources in rapidly urbanising areas of south-eastern Nigeria.

Microbial and chemical pollutants introduced into aquatic environments may persist, undergo transformation or be removed through natural or microbially mediated processes. Several microorganisms possess metabolic capabilities that allow them to utilise or transform environmental contaminants. For example, Ojiagu *et al.* (2018) demonstrated the biosorption of hexavalent chromium by *Pseudomonas aeruginosa*, illustrating the potential of microorganisms to interact with and remove toxic metals from contaminated environments. Similarly, Okafor *et al.* (2016) reported the use of broiler-chicken droppings to enhance the bioremediation of crude oil-polluted soil, while Okafor *et al.* (2016) further demonstrated the beneficial effect of chicken-dropping amendment on crude-oil biodegradation. Orji *et al.* (2022) also reported fungal-mediated bioremediation of glyphosate-contaminated soil, highlighting the important ecological role of microorganisms in pollutant degradation. Studies involving microorganisms from unusual or stressed environments further demonstrate their adaptive and biodegradative potential. Agu and Odibo (2021), for instance, reported biodegradation capabilities of *Aspergillus flavipes* isolated from Uburu and Okposi salt lakes. In related work, Orji *et al.* (2014) demonstrated the capacity of *Penicillium* and *Aspergillus* species to utilise unconventional cellulosic substrates for enzyme production. Okeke *et al.* (2023) also reported the solid-phase degradative potential of *Aspergillus niger* and *Aspergillus flavus* against Congo red dye. These findings collectively emphasise the complex interactions between microorganisms and environmental contaminants and illustrate the important role of microbial communities in ecological transformation and remediation processes.

Water bodies located within urban and peri-urban environments are particularly susceptible to contamination because of increased population density, waste generation, surface runoff and inadequate waste-management infrastructure. Ezeokoli *et al.* (2023) documented substantial bacterial contamination of abattoir wastewater in Awka, demonstrating how untreated or inadequately treated waste streams may contribute microorganisms and organic pollutants to surrounding environments. Victor-Aduloju *et al.* (2023) similarly reported microbial contamination of water from selected hostels in Ifite, Awka. These observations reinforce the importance of routine assessment of water sources, particularly in areas subjected to intensive anthropogenic activities.

Surface-water quality may also vary considerably with season. During the rainy season, increased runoff can transport sediments, organic matter, microorganisms, metals and other contaminants from surrounding land into streams, whereas reduced water volume during the dry season may concentrate dissolved substances and pollutants. Seasonal variations can therefore alter physicochemical parameters, microbial populations and the concentrations of trace metals in surface waters. Understanding these seasonal changes is essential for accurately characterising the quality and potential environmental or public-health risks associated with a water body.

Agangwu Stream, located in Enugu North Local Government Area of Enugu State, Nigeria, is potentially exposed to varying natural and anthropogenic influences. Despite the environmental and public-health importance of surface-water resources, there is limited information on the seasonal physicochemical characteristics and heavy-metal burden of this stream. Considering reports of microbial and heavy-metal contamination of water resources within south-eastern Nigeria (Agu *et al.*, 2014; Egunfa *et al.*, 2024), systematic evaluation of the stream is necessary to establish its quality and identify possible seasonal variations in contamination.

Therefore, this study aims to assess the seasonal physicochemical characteristics and heavy-metal contamination of Agangwu Stream in Enugu North Local Government Area, Enugu State, Nigeria. The findings will provide baseline information on the environmental quality of the stream, identify seasonal variations in selected physicochemical and heavy-metal parameters, and provide evidence that may support environmental monitoring, pollution-control measures and protection of communities that depend directly or indirectly on the water resource.

Methodology

Analysis of Some Physicochemical Parameters in the Water Sample.

The stream water samples were analysed for physicochemical parameters such as temperature, pH, total dissolved solids

(TDS), calcium, magnesium, sodium, potassium, chloride, sulphate, phosphate and nitrate using standard analytical methods (American Public Health Association, 2015).

Temperature: Temperature of the water sample was measured on site using mercury thermometer.

pH: This was measured using pH meter (HI-99130, Italy).

Chloride: Chloride concentration was determined using argentometric titration method (Mohr's method) as described below.

- i. 50mls of the stream water sample was measured and poured into a clean 250ml conical flask.
- ii. The burette was rinsed and filled with 0.0141N Silver nitrate solution.
- iii. 1ml of potassium dichromate indicator was added into the beaker and the solution turned yellow.
- iv. Titration commenced by adding the silver nitrate solution dropwise into the contents of the flask while gently and constantly swirling the flask.
- v. At this stage, the solution turned white due to precipitation of AgCl (silver chloride) and at end point reddish brown following formation of silver chromate.
- vi. The volume of silver nitrate used was recorded as (V_1)
- vii. Blank titration was done by repeating the same procedure using 50ml of distilled water. The volume used was recorded as (V_2)
- viii. The chloride content of the water was calculated using the formula below:

$$\text{Chloride (mg/L)} = \frac{V_1 - V_2 \times N \times 35.45 \times 1000}{V_{\text{sample}}}$$

Where:

V_1 = volume of AgNO_3 used for the sample (ML)

V_2 = volume of AgNO_3 used for the blank (ML)

N = Normality of AgNO_3 (0.0141N)

V_{sample} = volume of stream water samples used (ML)

Chemical oxygen demand (COD):

- i. 1ml of diluted Agangwu stream water sample was added to a prepackaged COD reagent vial containing Potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) and a catalyst (H_2SO_4)
- ii. The mixture in the above vial was tightly covered and heated at a temperature of 150°C for 2 hours for the organic matter contained in the water to be completely oxidized.
- iii. The vials were cooled in a water bath to room temperature.

- iv. Spectrophotometer measurement was carried out by first zeroing the instrument. The absorbance of the "blank" sample i.e the reagent without the water sample was measured and used to zero the spectrophotometer. This gave the colour of the reagents themselves.
- v. The digested samples were measured by inserting them into the spectrophotometer. The absorbance value was then read/determined.
- vi. Standards of known COD concentrations were used to make a plot of absorbance Vs concentration.
- vii. The readings got were 60.33 in the dry season and 65.11 in the wet season. When multiplied by the dilution factor 0.1, gave 6.033 ± 0.042 and 6.511 ± 1.867 in dry and wet seasons respectively.

Biological Oxygen Demand (BOD):

- i. 100mls of Agangwu stream water sample was taken in an air tight BOD bottle dark in colour. No air bubbles were trapped inside the container.
- ii. A DO meter was used to measure the initial dissolved oxygen concentration (DO_1) of the water sample.
- iii. The bottle was incubated at 20°C for 5 days in the dark.
- iv. At the end of the 5th day, the final dissolved oxygen concentration (DO_2) was measured.
- v. The BOD was calculated using the formula.

$$BOD_5 = (DO_1 - DO_2) \times \text{Dilution factor}$$

Salinity: This was measured using Electrical Conductivity (EC) meter. The meter also measures electrical conductivity which is directly related to the concentration of dissolved ions (salts).

- i. The probe/electrode of the meter was immersed into 500ml of water sample in a beaker ensuring there were no air bubbles.
- ii. The reading was taken when it stabilized.

Total Solids: This was measured by gravimetric analyses

- i. An evaporating dish was washed and heated at 104°C for 1hour. It was cooled in a desiccator and weighed to obtain the initial weight (W_1).
- ii. 200mls of the test water sample was shaken properly and poured into the evaporating dish. It was then placed in an oven at 104°C to evaporate it to dryness.
- iii. The evaporated sample was dried at 104°C for 1 hour.

- iv. The evaporating dish with its contents was cooled in a desiccator to room temperature and weighed (W_2).
- v. The drying and weighing is continued until a constant weight is obtained.
- vi. The concentration of the Total Solids was calculated thus:

$$\text{Total Solids (mg/L)} = \frac{(W_2 - W_1) \times 1000}{\text{Volume of sample (ML)}}$$

Where:

W_1 = weight of empty evaporating dish (g)

W_2 = weight of evaporating dish + residue (g)

Total Suspended Solid (TSS)

- i. A glass-fiber filter was used. The filter was washed, rinsed with distilled water and dried in an oven at a temperature of 104°C for 1 hour.
- ii. The filter was cooled to room temperature in a desiccators and weighed to get the initial weight (A_1).
- iii. 200mls of the water sample was measured, mixed properly and filtered.
- iv. The filter was carefully removed and placed in the oven for 1 hour at a temperature of 104°C .
- v. The filter was cooled in a dessicator and re-weighed to get the final weight (A_2).
- vi. The result is calculated using the formular:

$$\text{Total Solids (mg/L)} = \frac{(A_2 - A_1) \times 1000}{V \text{ (in ML)}}$$

Where:

A_2 = weight of filter + content

A_1 = Initial weight of the filter before filtration

V = Volume of the test water sample

Total dissolved solids (TDS)

- i. An evaporating dish was washed and dried in an oven at a temperature of 180°C for 1hour. It was cooled in a dessicator and weighed (W_1)
- ii. 200mls of the stream water sample was filtered using a galss fiber, filter and the filterate collected.
- iii. The filterate was poured into the pre-weighed evaporating dish and put in an oven set at 104°C to evaporate it to dryness.
- iv. After evaporation, the residue was dried in the oven for 1hr 30 mins at a temperature of 104°C .
- v. The evaporating dish was cooled in a dessicator and weighed with the dry residue (W_2).

- vi. Drying, cooling and weighing of the residue was continued until a constant weight was obtained.
- vii. The TDS concentration was calculated using the formula below

$$\text{TDS (mg/L)} = \frac{(W_2 - W_1) \times 1000}{V}$$

Where:

W_1 = weight of empty evaporating dish (mg)

W_2 = weight of evaporating dish + residue (mg)

V = Volume of water sample used

Sulfate: This was determined by cadmium reduction method using H183300 Hanna Multi Parameter bench photometer.

- i. 10ml of the stream water sample was poured into two cuvettes. One was used as a blank to zero the machine while to the other one, one sachet of sulfate reagent powder was added to it.
- ii. The mixture was shaken for 90 seconds before inserting it into the cell compartment.
- iii. The timer button was selected after which the value of nitrate was displayed in milligram per litre.

Phosphate

- i. 100ml of the water sample was mixed with 0.89g of ammonium molybdate and 1ml of ascorbic acid as a reducing agent.
- ii. 1ml of sulphuric acid was added to create an acidic environment.
- iii. The mixture was allowed to stand for 45mins to allow for color development.
- iv. A blue complex was formed, the absorbance was measured using a spectrophotometer at 840 nm.
- v. The result was quantified using known phosphate concentrations having prepared a standards curve.

Nitrate: Nitrate was determined using cadmium reduction method using H183300 Hanna multipara meter bench photometer.

- i. 10ml of the stream water sample was poured into two different cuvettes. One was used as blank to zero the machine while nitrate reagent powder was added to the other one.
- ii. The second cuvette was shaken properly for 60 seconds before it was inserted into cell compartment.
- iii. The times button was selected, after 2 mins it gave a direct digital reading of the concentration mg/L.

Lead:

- i. 50mls of the stream water sample was poured into a sterile container.
- ii. 5mls of HNO_3 acid was added to prevent lead from adhering to the sides of the container.
- iii. The stream water sample was boiled on a camp gas until the volume was reduced to 20mls.
- iv. The digested sample was filtered and transferred into a 50ml volumetric flask and filled with deionized water.
- v. Calibration curve was prepared by first making a stock solution. 1000mg/l of a Pb stock solution ie (1000 ppm).
- vi. Working standard was prepared by diluting the stock solution with 1% HNO_3 to cover the expected range of the stream water
- vii. A reagent blank was prepared using deionized water and HNO_3 . It also passed through all the process of the digestion procedure.
- viii. Analysis of the prepared samples using Atomic Absorption spectrometer was done by aspirating the blank, standards and the samples into the instrument and the absorbance recorded.
- ix. The concentration of lead in the water sample was calculated by using Atomic Absorption Spectrum (AAS) software which generates a calibration curve (ie Absorbance Vs Concentration).

Copper

- i. 50mls of the water sample was collected in a sterile glass bottle.
- ii. The water sample was acidified with 5mls of concentrated nitric acid (HNO_3) to prevent copper from adhering to the walls of the bottle
- iii. The acidified sample was slowly heated to boil and evaporated to 20mls and allowed to cool
- iv. The 20ml cooled sample was poured into a 100ml volumetric flask and filled to the mark with deionized water. The whole solution was mixed thoroughly
- v. Copper stock solution 1000gm/l (1000 ppm) was prepared using certified CU standard
- vi. Working standard was also created in series eg 0.1, 0.01 etc. by diluting the stock solution with acidified deionized water (0.15% HNO_3)
- vii. Blank was prepared using only deionized water and the same concentration of acid that was used for the standard
- viii. The instrument – flame atomic absorption spectrophotometer (flame AAS) was set up by putting the copper hollow cathode lamp, setting the

ware length at 324.8mm (copper is commonly determined at this ware length) and allowing the lamp to warm up. Air-acetylene flame was also set up

- ix. The blank was aspirated to zero the instrument. The working standard was also aspirated in order of increasing concentration to create a linear calibration curve (absorbance vs concentration)
- x. Finally, the pretreated sample was aspirated into the AAS (atomic absorption spectro meter) to measure the absorbance at 324.8mm and determine the concentration based on the calibration curve
- xi. The concentration was then multiplied by the dilution factor of the sample eg 0.1, 0.01 etc

Chromin

- i. 50mls of the stream water sample was poured into a glass container and 5mls of concentrated nitric acid (HNO_3) added to prevent the chromium from adsorbing to the walls of the container.
- ii. The mixture was boiled on a camp gas to reduce the volume to 20mls, then allowed to cool
- iii. The cooled mixture was transferred into a 100ml volumetric flask and filled to its mark with distilled water
- iv. The atomic absorption spectrometer (AAS) was set to the chromium wave length of 357.9nm
- v. A calibration curve was prepared using standard chromium (Cr^{3+}) solution. In creating working standard eg. .5, 1.0mg/l, the standard chromium solution was acidified with 1% HNO_3
- vi. For analysis, the blank, standards and the digested water samples were aspirated differently into the flame (air-acetylene flame) and the absorbance for each of them recorded.
- vii. Having measured the absorbance the concentration was determined using the calibration curve. Finally the concentration obtained was multiplied by the dilution factor of the sample eg. 0.1

Cobalt

- i. 50mls of the water sample was put in a glass container .5ml of concentrated HNO_3 (nitric acid) was added to avoid adsorption of cobalt to the container walls.
- ii. Acid digestion was performed by boiling the mixture on a camp gas and the volume reduced to 20ml. it was allowed to cool before it was poured into a 100ml volumetric flask and filled to its mark with distilled water

- iii. A series of working standard was prepared using certified cobalt stock solution, acidified with 1% HNO_3 just as the sample
- iv. 1ml of ammonium chloride (HN_4CL) was added to both the samples and the standards to avoid potential interference with nitrate ions which may interfere with absorption
- v. With the working standard, the software generated a calibration curve. During the setting of the instrument a cobalt hollow cathode lamp (HCL) at a wave length of 240.7nm was used
- vi. The absorbance of the samples was measured and compared with the calibration curve to determine the concentration of the cobalt in mg/l
- vii. Finally the concentration was multiplied by the dilution factor of the sample (0.1, 0.01, 0.001 etc)

Cadmium:

- i. The stream water sample (50ml) was collected in a glass container. It was acidified with 5mls of concentrated nitric acid (HNO_3) to prevent adsorption of the cadmium to the walls of the glass container
- ii. The mixture was heated on a camp gas to a temperature of 100°C , boiled to reduce the volume to 20ml
- iii. The solution was cooled, transferred to a 100ml volumetric flask and diluted to its mark with distilled water
- iv. The instrument (AAS) was set up with a cadmium hollow cathode lamp (HCL) at a wave length of 228.8nm
- v. Calibration standards was prepared (eg. 0.5, 1.0mg/l) by diluting a 1000mg/l certified Cd stock solution with 1% HNO_3
- vi. The digested water sample, the blank and the working standard were aspirated differently into the instrument to measure the absorbance at 228.8nm and also determine the concentration based on the calibration curve
- vii. The concentration obtained was multiplied by the dilution factor (ie of the sample)

Arsenic:

- i. The stream water sample (50ml) was collected in a glass container which was cleaned with 10% nitric acid (HNO_3), rinsed with deionized water and filtered through a 0.45/ μm membrane filter to remove suspended solids
- ii. 5ml of HNO_3 was added to acidify the sample and prevent arsenic from adsorbing to the sides of the container

- iii. Sample reduction was done by introducing the sample into Hydride Generation Atomic Absorption Spectrometer (HG-AAS) system. The sample was mixed with 3% NaBH₄ (Sodium borohydride) and 6m of HCL (Hydrochloric Acid). The reaction produced volatile arsine gas (AsH₃)
- iv. The arsine gas (AsH₃) was later transported to a quartz cell heated to a temperature of 950°C to decompose the gas into free arsenic atoms
- v. The Atomic Absorption spectrometer (AAS) measured absorption of light at 193.7nm (the wavelength for arsenic) which is proportional to the concentration of arsenic in the sample
- vi. Series of working standard was prepared (eg. 5, 10, 20ppb) by diluting a 1000ppm arsenic stock solution, with these, absorbance was plotted against concentration to create a calibration curve
- vii. The concentration of the sample was determined based on the calibration curve

Nitrate:

This was tested for using UV-Visilbe spectrophotometer through the UV screening method (Standard Method 4500 – NO₃ – B)

- i. The stream water sample was filtered through a 0.45um membrane filter the aim was to remove all suspended solids
- ii. 50ml of the filtered sample was poured into a glass bottle and mixed with 1ml of INHCL and mixed thoroughly to avoid interference from hydroxide or carbonate ions
- iii. Working standards (eg 0, 1, 3, 5, 7mg/l (NO₃N) was prepared by diluting a stock solution of nitrate nitrogen (100mg/LNO₃N)
- iv. All working standards were treatd with 1m of INHCL, just like the sample
- v. The instrument (spectrophotometer) was zeroed at 220nm and 275nm using distrilled water. This was done because nitrate absorbs UV light strongly only at 220nm while organic matter which may be present in the sample absorbs UV light at both 220nm and 275nm. Correct absorbance was calculated using the formula

$$A_{\text{corrected}} = A_{220} - 2 \times A_{275}$$

Where A = absorbance
 $A_{\text{corrected}}$ = correct obsorbance
 A_{220} = absorbance for nitrate and organic matter
 A_{275} = absorbance of organic matter only
- vi. Having zeroed the instrument, absorbance was measured at 220nm (A_{220}), and 275nm (A_{275}). The correct absorbance was calculated using the

formula in (v) above. This was calculated for all standards and samples

- vii. A calibration curve was created by plotting correct absorbance ($A_{\text{corrected}}$ vs concentration for the standard)
- viii. The concentration of the sample was determined using the calibration curve

Sulfate:

- i. 100ml of the stream water sample was filtered using 0.45um membrane filter to remove suspended solids, before it was poured into a beaker
- ii. Conditioning reagent was prepared by mixing 50ml glycerol, 30ml concentrated HCL, 300ml distilled water 100ml 95% isoproply alcohol and 75g NaCL. 5.0ml of the conditioning reagent was poured into the filtered water sample and mixed using a magnetic stirrer
- iii. 0.3g of barium chloride (BaCl₂) crystal was added into the mixture and stirred continuously for 60 seconds at a constant speed
- iv. A blank was prepared to use for zeroing the instrument. The blank contained distilled water, conditioning reagent and BaCL₂ crvstals
- v. The sample was transferred to the cuvette of the instrument and absorbance measured at 420nm.
- vi. A series of working standards was prepared (6, 5, 10, 15, 20, 30, 40mg/l 50²⁻₄) by diluting the stock sulfate solution to 100ml in volumetric flasks
- vii. The standards were treated like the samples (i.e 5ml of conditioning reagent and BaCL₂ crystals 0.3grams were added and stirred), then absorbance measured
- viii. Absorbance vs concentration (mg/l) was plotted to create a caliberation curve
- ix. The concentration of sulfate in mg/l was determined by suing the absorbance got from the spectrophotometer reading against the calibration curve

Phosphate:

- i. Stream water sample (50ml) was poured into a glass bottle, filtered using whatman No.42 filter paper to remove suspended solids. 20ml of the filtered sample was put in a volumetric flask
- ii. Ammonium molybdate (NH₄)₆MoO₇O₂₄ 4H₂O, antimony tartrate reagents (to enhance color development) sulfuric acid (H₂SO₄) to create an acidic medium and hydrazine sulfate to reduce the complex to molybdenum blue”

- iii. The mixture was allowed to stand for 45 minutes for full color development
- iv. A series of working phosphate standards was prepared (.0, 0.1, 0.5, 1.0, 1.5, 2.0 ppm) by diluting a stock solution of potassium dihydrogen phosphate (KH_2PO_4)
- v. The instrument spectrophotometer was set at 860nm wavelength and then zeroed using the reagent blank (ie distilled water + reagents)
- vi. The absorbance of the standard and that of the sample was measured
- vii. Calibration curve was made by plotting absorbance vs concentration of the standards
- viii. The concentration of phosphate can be determined from the graph having measured the absorbance of the sample

Zinc:

- i. 50ml of Agampwu stream water sample was collected in a glass container and filtered through a 0.45µm membrane filter to separate dissolved zinc from suspended particles in the water
- ii. .5ml of concentrated nitric acid HNO_3 was added to the filtrate to prevent adsorption of zinc metal ions onto the container walls and also to bring the pH to <2.
- iii. Since total zinc was calculated sample digestion was done by adding 5ml of concentrated HNO_3 to the sample, mixed thoroughly and heated on a camp gas till it evaporated to 20ml without drying up
- iv. The digested sample was filtered, transferred to a 100ml volumetric flask and filled to its mark with deionized water
- v. Preparation of standards was done by diluting 100ppm stock solution (ie zinc stock solution) with 0.5% HNO_3 (nitric acid) to make a series of working standards eg. 0.1, 0.2, 0.4, 0.6, 0.8, 1.0mg/l zn.
- vi. The instrument – flame atomic absorption spectrophotometer (flame AAS) was set up by putting in place Zinc Hollow Cathode Lamp, setting the wave length at 213.9nm (the wavelength at which Zinc is commonly determined), and allowing the lamp to warm up. Air acetylene flame (oxidizing) was used.
- vii. The blank (0.5% HNO_3 in deionized water) was aspirated to zero the instrument. The working standards were also aspirated in order of increasing concentration, thus creating a linear calibration curve (ie. Absorbance vs. concentration)

- viii. The digested sample was aspirated into the AAS to measure the absorbance at 213.9nm wave length. The concentration of zinc (Zn^{2+}) in the digested sample was determined based on the calibration curve. Finally, the concentration obtained was multiplied by the dilution factor of the sample eg. 0.1, 0.01, 0.001 etc

Manganese (Mn)

- i. 50ml of the water sample was filtered to remove suspended solids, it was acidified with 1ml of conc HNO_3 acid to a pH of <2. The 1% nitric acid (HNO_3) added was to prevent adsorption of manganese to the walls of the container
- ii. Stock solution (a 1000mg/l (ppm) manganese standard solution) was provided
- iii. The stock solution was used to prepare working standards by diluting it with 1% HNO_3 thus creating a series of working standards e.g .0.1, 0.5, 1.0, 2.0, 5.0mg/l
- iv. A linear calibration curve was created by aspirating the standards and plotting the absorbance against concentration
- v. The instrument was turned on and set to warm up for 20minutes to stabilize. To set it to zero, a “blank” solution (ie. 1% HNO_3 with deionized water) was aspirated having set the wavelength at 279.5nm (ie the wavelength of manganese)
- vi. The prepared samples were aspirated. The AAS calculated the concentration based on the calibration. The concentration obtained was multiplied by the dilution factor.

Aluminum:

- i. 50mls of the stream water sample was filtered through a 0.45µm membrane filter to remove suspended solids time leaving suspended dissolved Al^{3+} .
- ii. The filtrate was acidified with nitric acid (HNO_3) to bring the pH to <2 and keep the aluminum in solution.
- iii. A series of aluminum work standards were prepared (of 0, 5, 10, 15, 20 ppm) from a 1000ppm certified stock solution which was acidified with 1% (HNO_3) just like the sample.
- iv. The instrument (was Flame Atomic Absorption Spectrophotometer (FAAS)) was set up.

- The flame type was Nitrous oxide acetylene flame which provided the high temperature needed for Aluminum rod (Al) atomization.

- The light source was Aluminum Hollow Cathode Lamp (HCL).

- Aluminum wavelength is 309.3nm which is the wavelength at which absorbance was measured.

A calibration curve was established by aspirating the blank, followed by the standards in order of increased concentration.

- v. The blank referred to the deionized water treated acidified with 1% nitric acid just like the sample.
- vi. The treated (prepared) stream water sample was aspirated into the FAAS and to determine its absorbance at a wave Length of 309.3nm.
- vii. The calibration curve was used to determine the concentration of Al^{3+} in the stream water sample how multiplied it with the dilution factor of the sample prior to treatment.

Potassium:

- i. 50mls of the water sample was collected in a plastic container. 1% concentrated nitric acid (HNO_3) was added to dissolve the potassium salts in the water and also prevent adsorption to the walls of the container.
- ii. The water was filtered through a $0.45\mu m$ membrane filter to remove suspended solids, and thus allowing for determination of dissolved potassium
- iii. To ensure that total recoverable potassium is obtained, the sample was digested with 1% conc HNO_3 and heated to dryness, the resolved with 6M HCl and filtered. The filtrate was used.
- iv. Working standards were prepared by diluting the stock solution with deionized water.
- v. The instrument (FAAS) was set at a wavelength of 766.5nm which is the wavelength for measuring absorbance.

The flame used is air-acetylene flame (Slightly reducing)

- vii. A calibration curve was generated (absorbance Vs concentration) by first aspirating the blank (deionized water acidified).
- viii. Finally, the stream water sample was aspirated into the flame and the concentrations determined using from the calibration curve.

Since the water sample was diluted during preparation, the conc. of potassium obtained was multiplied by the dilution factor.

Calcium(Ca^{2+}):

- i. 50mls of the diluted stream water sample was filtered to remove suspended solids that would have clogged to the atomizer.

- ii. Calcium stock solution (1000 ppm) was prepared by getting 2.14973g of primary standard calcium carbonate ($CaCO_3$) transferred into a 1000 ml volumetric flask with 100ml of deionized water.
- iii. Drops of concentrated HCl and were added slowly while stirring until the $CaCO_3$ dissolved completely. Deionized water was then added up to the mark 1000ml mark on the volumetric flask.
- iv. Calibration standards was prepared by making a series of working standards (eg. 10, 20, 30, 40, 50, 100 ppm) by diluting the 1000 ppm stock solution with deionized water in volumetric flask.
- v. 2mls of Lanthanum Chloride ($LaCl_3$) was added to both the standards and the sample to prevent interference from aluminum, phosphate and sulfate ions.
- vi. (ic) For measurement, the compressor of the instrument (flame photometer) was switched on to ignite the flame. Fuel used was propane. The instrument was allowed to stabilize for 20mins. The concentration of calcium was determined at 423nm wavelength.
- vii. Calcium (Ca) filter was used. The blank was aspirated to zero the equipment. The intermediate standards were also aspirated in increasing order. The stable emission intensity was recorded for each concentration and a calibration curve (intensity vs concentration) plotted.
- viii. for analysis of the sample, the stream water was aspirated just like the blank and the working standards.

The stable emission intensity reading was recorded and the concentration of the sample determined using the calibration curve.

Finally the concentration of the calcium obtained was multiplied by the dilution factor

Sodium:

- i. Diluted stream water sample (50ml) was filtered to remove solid materials.
- ii. Stock solution used was 2.542g of anhydrous $NaCl$ in distilled water diluted to 1000 mL.
- iii. Working standards were created by diluting the stock solution with distilled water.
- iv. The flame photometer was switched on, compressor, adjusted, fuel (propane) pressures adjusted and allowed to stabilize for 15 minutes. Sodium filter was selected (wave length at 589nm)
- v. The Blank (deionized water) was aspirated into the flame to zero the equipment.

- vi. The standards were analyzed by aspirating each working standard in increasing order, their corresponding in flame emission intensities were recorded.
- vii. the prepared stream water sample was aspirated and its intensity recorded.
- viii. To obtain a calibration curve, a graph of emission intensity (y-axis) against sodium concentration (in mg/L)(x-axis) was plotted for the standard solutions.
- ix. In the stream water sample the concentration of sodium was determined using the calibration curve. The concentration was multiplied by the dilution factor.

Iron:

- i. 50mls of the stream water sample (diluted) was filtered through a 0.45 μ m filter to remove suspended solids. The filtrate was acidified with 1ml of concentrated HCl to dissolve iron complexes and stabilize the iron ions.
- ii. Series of working standards (eg. 0, 10, 20, 30, 40, 50 PPM) prepared from the iron stock solution. They were also acidified with 1ml conc. HCl (Hydrochloric acid) just like the sample.
- iii. The filter of the flame photometer was set to the iron emission wavelength 386nm, and the flame of the photometer was ignited using an oxyacetylene flame.
- iv. The blank was aspirated to zero the instrument. The working standards were aspirated from lowest to highest concentrations, the emission intensity was recorded for each standard by the galvanometer (ie galvanometer reading).
- v. The sample was analyzed by aspirating the prepared stream water sample into the flame photometer. The stable reading will be displayed on the galvanometer. This is the intensity of light emitted by the iron ions. It is equal to the concentration of iron in the water sample. The concentration is also determined by interpolating the intensity reading from the calibration graph.
- vi. Finally, the concentration obtained is multiplied by the dilution factor since the stream water sample was diluted.

Magnesium

- i. Diluted stream water sample (50mls) was filtered through a 0.45 μ m membrane filter for removal of suspended solids to enable only dissolved magnesium to be measured.
- ii. The sample was acidified with 1ml of nitric acid (HNO₃) to avoid adsorption of the metal onto the walls of the container.

- iii. Magnesium chloride was used as a stock solution of magnesium (1000 mg/L) to create a series of working standards (1,5,10,15,20 ppm) used for construction of a calibration curve.
- iv. Instrument set up: The flame photometer was set to the magnesium emission wavelength of 285.2nm. a high temperature flame Acetylene-Oxygen flame was used to atomize magnesium. The instrument was set to zero using deionized water as a 'blank'.
- v. The standard solutions were aspirated in order of increasing concentrations and the intensity of each of the emissions recorded.
- vi. A calibration curve was plotted i.e emission intensity (y-axis) vs. magnesium concentration (X-axis).
- vii. The diluted, filtered stream water sample was also aspirated and emission intensity also recorded.
- viii. The concentration of magnesium in the sample was determined by comparing its emission intensity with the calibration curve. Finally, the concentration of the magnesium obtained was multiplied by the dilution factor.

Analysis of heavy metals in the water:

Heavy metals include Arsenic (As), Mercury (Hg), Chromium (Cr), Cadmium (Cd), Lead (Pb), Copper (Cu²⁺), Zinc (Zn²⁺), Manganese (Mn²⁺), Nickel (Ni²⁺) etc. The heavy metals, their concentration were determined are Chromium, Cobalt, Cadmium, Arsenic and Lead. The concentration of these heavy metals in the stream water was determined by Atomic absorption spectrometer as described by Friberg (2016).

Results

Table 1: Variations in Physicochemical parameters during the dry and rainy seasons.

1. Temperature (°C)

The temperature data reveals a significant difference between the dry and rainy seasons, with a mean temperature of 31°C ($\pm$ 3.606) in the dry season and 25°C ($\pm$ 0.000) in the rainy season. This 6°C difference is statistically significant (p-value = 0.045), indicating that it's unlikely to occur by chance.

2. Salinity (mg/L)

The salinity data indicates a slight increase in concentration during the rainy season, with a mean value of 7.480 mg/L ($\pm$ 0.100), compared to the dry season's mean value of 7.393 mg/L ($\pm$ 0.006). However, this difference is not statistically significant (p-value = 0.208), suggesting that the variation is likely due to natural fluctuations rather than a significant seasonal effect.

3. pH

The pH data reveals that the stream water is slightly acidic in both the dry and rainy seasons, with mean pH values of 5.673 (± 0.266) and 6.133 (± 0.091), respectively. The increase in pH during the rainy season is statistically significant (p -value = 0.047), indicating that the change is unlikely to occur by chance.

4. Total Suspended Solids (TSS) (mg/L)

Total Suspended Solids (TSS) data reveals a significant increase in particulate matter in the stream water during the rainy season, with a mean concentration of 16.367 mg/L (± 0.987), compared to 9.733 mg/L (± 0.929) during the dry season. The difference is statistically significant (p -value = 0.001), indicating that the increase is not due to chance.

5. Total Solids (mg/L)

The analysis reveals a notable rise in Total Solids (TS) during the rainy season, with a mean value of 22.51 mg/L, compared to 14.40 mg/L during the dry season. The small p -value (0.001) indicates that this increase is statistically significant.

6. Total Dissolved Solids (TDS) (mg/L)

The analysis reveals a significant increase in Total Dissolved Solids (TDS) during the rainy season, with a mean value of 6.21 mg/L, compared to 4.17 mg/L during the dry season. The p -value (0.000) indicates this increase is statistically significant.

7. Biological Oxygen Demand (BOD) (mg/L)

The Biological Oxygen Demand (BOD) levels in the waterbody exhibit a notable seasonal variation. During the dry season, the average BOD concentration is 2.7 mg/L, with a standard deviation of 1.13 mg/L. In contrast, the rainy season sees a significant increase in BOD levels, with an average concentration of 4 mg/L and a standard deviation of 1 mg/L. This increase suggests a higher amount of organic matter present in the water during the rainy season, potentially due to runoff from surrounding lands, sewage, or other sources. Despite this increase, the BOD levels remain within the permissible limits set by the World Health Organization (WHO), which is less than 5 mg/L. This indicates that the waterbody is not severely polluted, but rather exhibits moderate levels of pollution.

8. Chemical Oxygen Demand (COD) (mg/L)

The value for Chemical Oxygen Demand shows higher variation during dry season (average: 177.33 mg/L, standard deviation: 3.06 mg/L) compared to the rainy season (average: 156.33 mg/L, standard deviation: 22.55 mg/L). Although the difference is not statistically significant (P -value: 0.185), the trend suggests that COD levels tend to increase during the dry season.

9. Sulphate (mg/L)

The sulphate levels in the waterbody exhibit remarkable stability across both dry and rainy seasons, with average concentrations of 121 mg/L (standard deviation: 6.56 mg/L) and 117 mg/L (standard deviation: 8.19 mg/L), respectively. The P -value of 0.545 indicates that the difference in sulphate levels between the two seasons is not statistically significant, suggesting that the observed variation is likely due to natural fluctuations rather than a significant change in sulphur-containing compounds.

10. Phosphate (mg/L)

The phosphate levels in the waterbody exhibit a significant seasonal variation, with higher concentrations observed during the dry season (average: 5.93 mg/L, standard deviation: 0.90 mg/L) compared to the rainy season (average: 3.13 mg/L, standard deviation: 0.61 mg/L). The P -value of 0.011 indicates that this difference is statistically significant, suggesting that the observed variation is likely due to a real change in phosphate levels rather than natural fluctuations.

11. Nitrate (mg/L)

The nitrate levels in the waterbody exhibit a stable and consistent trend, with no significant seasonal variation between the dry season (average: 12.50 mg/L, standard deviation: 1.50 mg/L) and the rainy season (average: 11.26 mg/L, standard deviation: 1.63 mg/L). The P -value of 0.386 indicates that the difference between the two seasons is not statistically significant, suggesting that nitrate levels remain relatively constant throughout the year.

12. Heavy Metals (Lead, Copper, Chromium, Cadmium, Aluminum, Cobalt)

The analysis of heavy metals in the waterbody reveals that all the six metals (Lead, Copper, Chromium, Cadmium, Aluminum, and Cobalt) were not detected in any season. This is a significant finding, as heavy metals are notorious for their toxicity and potential to harm human health and the environment.

13. Other Metals (Zinc, Manganese, Iron)

The analysis of other metals (Zinc, Manganese, and Iron) in the waterbody reveals some notable trends and potential concerns.

Zinc: The concentration of Zinc is higher during the rainy season (average: 0.357 mg/L, standard deviation: 0.397 mg/L) than dry season (average: 0.0881 mg/L, standard deviation: 0.006 mg/L), but still within the permissible limit of 3 mg/L set by the WHO.

Manganese: Manganese levels are higher during the dry season (average: 0.006 mg/L, standard deviation: 0.000 mg/L), than rainy season (average: 0.001 mg/L, standard deviation: 0.002mg/L),but still well within the permissible limit of 0.4 mg/L.The increased levels during the dry season

might be due to reduced water flow and increased concentration of Manganese from sedimentary sources. Like Zinc, Manganese levels are within safe limits, indicating minimal risk to human health and aquatic life.

Iron: Iron levels are significantly higher during the dry season (average: 2.811 mg/L, standard deviation: 0.246 mg/L), than rainy season (average: 2.151 mg/L, standard deviation: 0.110 mg/L), exceeding the permissible limit of 0.3 mg/L.

Table 1: Seasonal Variation in Physicochemical parameters

	Dry Season			Rainy Season			Permissible limit (WHO)	P value
	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.		
Temperature (°C)	31.000±3.606	28.000	35.000	25.000±0.000	25.000	25.000	NS	0.045*
Salinity(mg/L)†	7.393±0.006	7.390	7.400	7.480±0.100	7.380	7.580	0.0000001	0.208*
Ph	5.673±0.266	5.500	5.980	6.133±0.091	6.030	6.200	6.5-8.5	0.047*
TSS(mg/L)	9.733±0.929	8.700	10.500	16.367±0.987†	15.700	17.500	10	0.001*
Total solids(mg/L)	14.400±1.300	13.600	15.900	22.510±1.234	21.700	23.930	NS	0.001*
TDS(mg/L)	4.173±0.162	4.000	4.320	6.210±0.215	6.000	6.430	500	0.000*
BOD(mg/L)	2.700±1.127	2.000	4.000	4.000±1.000	3.000	5.000	<5	0.209
COD(mg/L)	6.033±0.042	6.000	6.080	6.511±1.867	4.988	8.594	<20	0.680
Chloride(mg/L)	177.333±3.055	174.000	180.000	156.333±22.546	133.000	178.000	250	0.185
Sulfate(mg/L)	121.000±6.557	115.000	128.000	117.000±8.185	110.000	126.000	600	0.545
Phosphate(mg/L)	5.933±0.902	5.000	6.800	3.133±0.611	2.600	3.800	NS	0.011*
Nitrate(mg/L)	12.500±1.500	11.000	14.000	11.257±1.630	9.770	13.000	50	0.386
Lead(mg/L) ≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.01	ND
Copper(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	2	ND
Zinc(mg/L)	0.088±0.006	0.081	0.091	0.357±0.397	0.071	0.810	3	0.306
Chromium(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.05	ND
Manganese(mg/L)	0.006±0.000	0.006	0.006	0.001±0.002	0.000	0.004	0.4	0.027*
Cobalt(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.01	ND
Cadmium(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.003	ND
Aluminum(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.2	ND
Potassium(mg/L)	6.577±0.607	6.000	7.210	6.069±0.402	5.682	6.485	NS	0.294
Calcium(mg/L)	7.438±0.541	6.900	7.982	6.321±0.559	5.986	6.966	100	0.068
Sodium(mg/L)	7.933±0.153	7.800	8.100	7.715±0.077	7.627	7.775	200	0.092
Iron(mg/L)†	2.811±0.246	2.532	3.000	2.151±0.110	2.031	2.248	0.3	0.013*
Magnesium(mg/L)	5.340±0.420	5.000	5.810	4.404±0.072	4.332	4.477	NS	0.019*
Arsenic(mg/L)≠	0.000±0.000	0.000	0.000	0.000±0.000	0.000	0.000	0.01	ND

Discussion

Analysis of water samples from Agangwu Stream was carried out in two seasons (dry and rainy seasons) to determine the physicochemical, microbiological and parasitological agents of the stream. A total of eighteen (18) stream water samples were collected and analyzed, six (6) from the upstream, six (6) from midstream and six (6) from the down stream. The result of the investigation showed that there were variations in physicochemical parameters of the stream.

Temperature: Temperature was higher in the dry season ($31^{\circ}\text{C} \pm 3.606$) than in the rainy season ($25^{\circ}\text{C} \pm 0.000$). The higher temperature in the dry season is likely attributed to increased solar radiation and reduced water flow, which can lead to increased water temperature. This is in line with the findings of Teheeb Lekan Jobosho *et al* (2025) in seasonal evaluation of physicochemical parameters and heavy metals in surface water from Lekki Lagoon. The temperature of the water was 28.69 ± 0.083 in dry season as against 26.96 ± 0.31 in wet season. This difference in temperature is remarkable.

While the World Health Organization (WHO) doesn't specify a permissible limit for water temperature, these findings highlight the importance of monitoring and understanding temperature variations in aquatic ecosystems to ensure the health and sustainability of these environments.

Salinity: Salinity was slightly higher during the rainy season 7.480 ± 0.100 than dry season 7.393 ± 0.006 . The slight increase in salinity during the rainy season might be attributed to Rainwater which can wash over the land, carrying dissolved minerals and salts from surrounding soil, rocks, and vegetation, which eventually drain into water bodies, increasing salinity. Heavy rainfall can lead to soil erosion, transporting sediment and dissolved solids into water bodies, contributing to increased salinity.

Despite the slight increase, the salinity values remain relatively consistent between seasons, indicating that the water body's salinity is likely regulated by factors other than seasonal changes, such as the underlying geology and soil composition may play a more significant role in determining the water body's salinity. The water body's circulation patterns, depth, and volume may also influence salinity levels.

The World Health Organization's (WHO) permissible limit for salinity in drinking water is extremely low (0.0000001 mg/L), indicating that the measured values are significantly higher than the recommended level. However, this limit is intended for human consumption.

pH: pH value was higher during the rainy season (6.133 ± 0.091) than dry season (5.673 ± 0.266). The acidic nature of the stream water, with values below the neutral pH of 7, may be attributed to the breakdown of organic matter in the

soil and water can release humic and fulvic acids, contributing to acidity. The surrounding soil and geological formations may be acidic in nature, influencing the pH of the stream water. Acidic pollutants in the atmosphere, such as sulfuric and nitric acids, can deposit into the water body, contributing to acidity.

The pH values in both seasons fall below the World Health Organization's (WHO) permissible limit of 6.5-8.5, indicating potential acidity issues that could have ecological and practical implications: This corresponds with the findings of Atwebembeire *et al* 2018 in Physicochemical Quality of Streams and Channels Draining into River Rwizi South Western Uganda. The PH value obtained in the rainy season was greater than the value for the dry season though both values fall within WHO permissible limit of 6.5 – 8.5.

Total Suspended Solids (TSS): Total Suspended Solids (TSS) Value was higher during the rainy season ($16.367 \text{ mg/l} \pm 0.987$) compared to any season ($9.735 \text{ mg/l} \pm 0.929$). The value in the rainy season exceeds the WHO permissible limit of 10 mg/L , which may have ecological and practical implication. This observation corresponds with the findings of Duru (2019) in seasonal water quality study of Nche Stream, a water body in Imo State, Nigeria. The value obtained for Total Suspended Solid (TSS) was 178.04 ± 2.00 in rainy season, as against 55.97 ± 0.80 in the dry season. The elevated TSS levels during the rainy season likely result from heavy rainfall can lead to increased runoff, carrying more soil, sediment, and particulate matter into the stream, thereby increasing TSS concentrations. The surrounding land use and vegetation cover may influence the amount of sediment and particulate matter that enters the stream during rainfall events.

The TSS values in the rainy season exceed the World Health Organization's (WHO) permissible limit of 10 mg/L , which may have ecological and practical implications.

Total Solids: The value of Total Solids was higher during the rainy season (22.51 mg/L) than the dry season (14.40 mg/L). This is in agreement with the observation of Duru (2019) in seasonal water quality study of Nche Stream, a water body in Imo State Nigeria. Where the values obtained for TS during the rainy season was higher than that of the dry season. Simiar observations was also made for TDS. The higher TS levels in the rainy season suggest a greater amount of dissolved and suspended matter in the water, potentially impacting water quality and treatment processes. This could be attributed to various factors, such as Increased runoff and sediment transport during rainfall events, Greater soil erosion and organic matter contribution, and Higher levels of particulate matter, like silt, clay, and other inorganic substances.

The World Health Organization (WHO) does not have a specified permissible limit for Total Solids in drinking water. However, elevated TS levels can lead to:

- Aesthetic issues (turbidity, color, and odor).
- Increased energy consumption in water treatment processes.
- Potential for microbial growth and contamination.

Therefore, monitoring and managing Total Solids levels is crucial to ensure the water quality meets the required standards for human consumption, industrial use, or environmental sustainability.

Total Dissolved Solids (TDS): There was a significant increase in Total Dissolved Solids (TDS) during the rainy season (6.21 mg/L), compared to 4.17 mg/L during the dry season. Although TDS levels are higher in the rainy season, they remain well below the World Health Organization's (WHO) permissible limit of 500 mg/L. This suggests that the water is still within the acceptable range for human consumption.

However, elevated TDS levels can have some implications the higher TDS can affect the water's taste, making it more unpalatable to consumers, Increased TDS can lead to a higher potential for corrosion in pipes and infrastructure, potentially causing leaching of metals and other substances into the water. High TDS levels can lead to water treatment plants, boilers, and other equipment scaling, reducing efficiency and increasing maintenance needs.

The increase in TDS during the rainy season may be attributed to the Increased runoff and dissolution of minerals from surrounding soil and rocks, greater contribution from organic matter and decaying vegetation, and Higher levels of ions and other inorganic substances in the water.

Biological Oxygen Demand (BOD): There was a significant increase in Biological Oxygen Demand (BOD) concentration in the waterbody during the rainy season (4 mg/L) and a standard deviation of 1 mg/L when compared to 2.7 mg/L, with a standard deviation of 1.13 mg/L obtained during the dry season. This observations also agreed with the findings of Duru (2019) though with very slight variability in BOD values between seasons.

This increase suggests a higher amount of organic matter present in the water during the rainy season, potentially due to runoff from surrounding lands, sewage, or other sources. Despite this increase, the BOD levels remain within the permissible limits set by the World Health Organization (WHO), which is less than 5 mg/L. This indicates that the waterbody is not severely polluted, but rather exhibits moderate levels of pollution.

The P-value of 0.209 suggests that the difference in BOD levels between the dry and rainy seasons is not statistically significant, indicating that the observed increase in BOD during the rainy season may be due to natural variability rather than a significant change in pollution levels. Overall, this analysis highlights the importance of regular monitoring of water quality parameters like BOD, especially during

different seasons, to effectively manage and mitigate pollution in waterbodies.

Chemical Oxygen Demand (COD): Chemical Oxygen Demand (COD) was higher during the dry season (average: 177.33 mg/L, standard deviation: 3.06 mg/L) than rainy season (average: 156.33 mg/L, standard deviation: 22.55 mg/L). This shows that there was increase in chloride levels during the dry season. However, the difference is not statistically significant (P-value: 0.185), the trend suggests that chloride levels tend to increase during the dry season.

Fortunately, the chloride levels in both seasons remain well within the permissible limit of 250 mg/L set by the World Health Organization (WHO), indicating that the water is safe for human consumption in terms of chloride content.

Chloride ions can originate from both natural sources, such as weathering of rocks and soil, and human activities, like industrial processes, wastewater effluent, and road salt application. Elevated chloride levels can affect the taste and palatability of water, making it more saline and unappealing to consumers. Moreover, high chloride concentrations can increase the corrosivity of water, potentially damaging infrastructure and household plumbing.

The observed seasonal variation in chloride levels may be attributed to changes in water flow, dilution, and contamination sources during different seasons. The lower levels during the rainy season could be due to increased water flow and dilution, while the higher levels during the dry season might result from reduced water flow and increased concentration of contaminants. Overall, this analysis highlights the importance of monitoring chloride levels in waterbodies, especially in areas prone to seasonal changes, to ensure the water quality remains safe and acceptable for human consumption

Sulphate: There was no significant variation in sulphate concentration in the dry and rainy seasons. sulphate levels in the waterbody exhibit remarkable stability across both dry 121 mg/L (standard deviation: 6.56 mg/L) and rainy seasons 117 mg/L (standard deviation: 8.19 mg/L). The P-value of 0.545 indicates that the difference in sulphate levels between the two seasons is not statistically significant, suggesting that the observed variation is likely due to natural fluctuations rather than a significant change in sulphur-containing compounds.

Notably, the sulphate levels in both seasons remain well within the permissible limit of 600 mg/L set by the World Health Organization (WHO), indicating that the water is safe for human consumption in terms of sulphate content.

The stable and relatively low sulphate levels in this waterbody suggest minimal impact from sulphur-containing compounds, indicating a healthy water system with minimal anthropogenic influence. This is a positive indicator of water quality, as it suggests that the water is less likely to be

contaminated with pollutants that could have adverse effects on human health and the environment. Overall, this analysis highlights the importance of monitoring sulphate levels in waterbodies to ensure the water quality remains safe and acceptable for human consumption, and to identify potential sources of sulphur-containing compounds that may impact water quality.

Phosphate (mg/L): There was a significant increase in phosphate concentration during the dry season (average: 5.93 mg/L, standard deviation: 0.90 mg/L) compared to the concentration of (average: 3.13 mg/L, standard deviation: 0.61 mg/L) during the rainy season. The P-value of 0.011 indicates that this difference is statistically significant, suggesting that the observed variation is likely due to a real change in phosphate levels rather than natural fluctuations. The higher phosphate levels during the dry season may be attributed to reduced dilution, as lower water flows and increased evaporation can concentrate phosphate-containing compounds. In contrast, the rainy season's increased water flow and dilution may lead to lower phosphate levels.

Nitrate (mg/L): There was no significant variation in nitrate concentration during the dry season (average: 12.50 mg/L, standard deviation: 1.50 mg/L) and the rainy season (average: 11.26 mg/L, standard deviation: 1.63 mg/L). The P-value of 0.386 indicates that the difference between the two seasons is not statistically significant, suggesting that nitrate levels remain relatively constant throughout the year. Moreover, the nitrate levels are well within the permissible limit set by the World Health Organization (WHO) of 50 mg/L. This suggests that the water body is safe in terms of nitrate concentrations, and the risk of adverse health effects from nitrate exposure is minimal.

Nitrates are essential nutrients for aquatic life, playing a crucial role in phytoplankton growth and primary production. However, excessive nitrate levels can contribute to eutrophication, a process where excessive nutrient loading stimulates excessive algae growth, depleting oxygen and harming aquatic ecosystems. The stable and relatively low nitrate levels in this waterbody indicate a healthy balance, suggesting that the ecosystem is not experiencing excessive nutrient loading. This is a positive indication for the overall water quality and aquatic life.

The consistent nitrate levels also suggest that the waterbody is not significantly impacted by external sources of nitrate pollution, such as agricultural runoff, wastewater effluent, or industrial activities. This could be attributed to effective management practices, natural attenuation processes, or a lack of significant nitrate sources in the surrounding area. Overall, the stable and permissible nitrate levels in this waterbody indicate a healthy and balanced ecosystem, with minimal risk of eutrophication or adverse health effects. Continued monitoring is essential to ensure that nitrate levels remain within safe limits and to detect any potential changes or trends in the future.

Heavy Metals (Lead, Copper, Chromium, Cadmium, Aluminum, Cobalt): The analysis of heavy metals in the waterbody reveals that all six metals (Lead, Copper, Chromium, Cadmium, Aluminum, and Cobalt) were not detected in any season. This is contrary to the findings of Toheeb Lekan Jolaosho *et al* (2025) in seasonal variations of physicochemical parameters and heavy metals in surface water from Lekki Lagoon where cadmium(CD) was detected 0.23mg/L (± 0.09) in dry season and 0.33mg/L (± 0.07) in wet season, Chromium(Cr) 0.04mg/L (± 0.02) was detected in dry season and 0.05mg/L (± 0.03) in wet season, Lead 0.71mg/L (± 0.28) in dry season then 0.30mg/L (± 0.12) in rainy season, Arsenic (AS), 0.09mg/L (± 0.02) in dry season and 0.02mg/L (± 0.01) in rainy season. This is a significant finding, as heavy metals are notorious for their toxicity and potential to harm human health and the environment.

The World Health Organization (WHO) has established specific permissible limits for each of these heavy metals in drinking water, recognizing their potential health risks.

The absence of detectable heavy metals implies several positive aspects:

- The lack of heavy metals indicates minimal influence from industrial activities, such as mining, smelting, or manufacturing processes, which often release these pollutants into the environment.
- The non-detection of heavy metals also suggests that agricultural runoff, which can contain metals like Copper and Cadmium from fertilizers and pesticides, is not significantly affecting the water body.
- The waterbody may be benefiting from natural processes like sedimentation, adsorption, or biological uptake, which can remove heavy metals from the water column.
- Absence of heavy metals could be attributed to effective management practices, such as wastewater treatment, pollution control measures, and regular monitoring.

The non-detection of heavy metals in this water body is a reassuring sign for public health and environmental sustainability. It indicates a low risk of heavy metal-related health issues, such as neurological damage, kidney damage, or cancer, associated with exposure to these pollutants. Overall, this finding suggests that the water body is in a pristine state, making it suitable for various uses, including drinking water supply, recreation, and aquatic life support. Continued monitoring is essential to maintain this status and detect any potential changes or pollution sources in the future.

Other Metals (Zinc, Manganese, Iron): The analysis of other metals (Zinc, Manganese, and Iron) in the waterbody reveals some notable trends and potential concerns.

Zinc: The concentration of Zinc is higher during the rainy season (average: 0.357 mg/L, standard deviation: 0.397 mg/L) than dry season (average: 0.0881 mg/L, standard deviation: 0.006 mg/L), but still within the permissible limit of 3 mg/L set by the WHO. This seasonal variation may be attributed to increased runoff and leaching of Zinc from soil and rocks during the rainy season. Despite the higher levels, Zinc remains within safe limits, posing no significant risk to human health or aquatic life.

Manganese: Manganese levels are higher during the dry season (average: 0.006 mg/L, standard deviation: 0.000 mg/L), than rainy season (average: 0.001 mg/L, standard deviation: 0.002 mg/L), but still well within the permissible limit of 0.4 mg/L. The increased levels during the dry season might be due to reduced water flow and increased concentration of Manganese from sedimentary sources. Like Zinc, Manganese levels are within safe limits, indicating minimal risk to human health and aquatic life.

Iron: Iron levels are significantly higher during the dry season (average: 2.811 mg/L, standard deviation: 0.246 mg/L), than rainy season (average: 2.151 mg/L, standard deviation: 0.110 mg/L), exceeding the permissible limit of 0.3 mg/L. Elevated Iron levels can affect the water's color, taste, and usability, making it unpalatable for human consumption. High Iron levels can also lead to the formation of particulate matter, causing turbidity and potentially harming aquatic life. The exceedance of Iron levels in the dry season suggests that the waterbody may require additional treatment or management strategies to reduce Iron concentrations and maintain water quality.

While Zinc and Manganese levels show seasonal variations but remain within safe limits, Iron levels exceed permissible limits during the dry season, posing potential concerns for water quality and usability. Monitoring and management efforts should focus on reducing Iron levels to ensure the water body remains safe for human consumption and aquatic life.

The physicochemical analysis of Agangwu Stream reveals significant seasonal variations, with several parameters exceeding WHO permissible limits. Higher temperatures, TSS, and phosphate levels in the dry season indicate increased pollution and potential health risks. Elevated TDS and organic matter during the rainy season suggest higher runoff and contamination. The absence of detectable heavy metals is positive, but the high iron content requires attention.

These findings underscore the importance of continuous monitoring and management of water quality to ensure the safety and health of the local population. The results also provide valuable data for environmental policies and

interventions to mitigate pollution sources and improve water quality.

Conclusion

The physicochemical parameters of the water body exhibited seasonal variations, with temperature being higher in the dry season, potentially impacting microbial survival and activity, while salinity was slightly higher in the rainy season but remained within permissible limits. Additionally, pH levels were slightly more acidic in the dry season, whereas rainy season values were closer to neutral, both within World Health Organization (WHO) limits. The rainy season also saw increased levels of Total Suspended Solids (TSS), Total Solids, and Total Dissolved Solids (TDS), indicating a rise in particulate matter and dissolved substances that can influence microbial growth. Furthermore, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values were higher in the rainy season, suggesting an increase in organic matter that supports higher microbial activity. In terms of nutrients, phosphate levels were significantly higher in the dry season, which can support microbial growth, while nitrate levels remained within permissible limits. Moreover, heavy metal concentrations were generally within permissible limits, although significant seasonal variations were observed in iron and manganese levels. These seasonal fluctuations in physicochemical parameters can have implications for water quality and microbial communities, emphasizing the need for regular monitoring and management to ensure ecosystem health and water safety.

Keys

*: Statistically significant at confidence interval of 95%

†: Above permissible limit

≠: Not detected

ND: Not determined

NS: No guideline value specified

SD: Standard Deviation

BOD: Biological Oxygen Demand

COD: Chemical Oxygen demand

TSS: Total suspended solids

TDS: Total dissolved Solids

Min.: Minimum

Max.: Maximum

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