Seasonal assessment of physico-chemical, selected inorganic and microbiological quality of water from Idokoliko, Egaonugba And Oferoba streams in Idah, Kogi State, Nigeria

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Abstract

Surface streams in Idah, Kogi State serve as important domestic water sources for residents, yet unlike the well-studied Idah River, the Idokoliko, Egaonugba and Oferoba Streams lack location-specific data on their physicochemical, inorganic and microbiological status. This gap leaves it unclear whether these streams meet acceptable water-quality standards, justifying a dedicated seasonal assessment to generate baseline evidence for pollution control and water-resource management. The study therefore aimed to determine the physicochemical properties and selected heavy-metal concentrations in water from the three streams, compare these parameters among the streams and against WHO guideline values, and evaluate the implications for stream suitability and management.

Water samples were collected from the main current of each stream during November, March and July, preserved appropriately, and analyzed using standard laboratory procedures. Physicochemical parameters (odour, taste, colour, pH, chloride, sulphate, carbon dioxide, total hardness, total alkalinity, BOD, COD and dissolved oxygen), selected heavy metals (via atomic absorption spectrophotometry), fluoride, phosphate, nitrate and microbiological indicators (coliform enumeration and microscopy) were assessed. Descriptive statistics and two-way ANOVA evaluated spatial and temporal variation at $p < 0.05$.

Results revealed marked seasonal deterioration, most severe in July: chloride rose to 202.50–206.01 mg/L, sulphate to 300–350 mg/L, and total hardness exceeded the adopted comparison value, while pH stayed within 6.5–8.5. Dissolved oxygen remained consistently low (2.20–2.80 mg/L). Fluoride was the most prominent concern (3.2512–4.4332 mg/L), exceeding the 1.5 mg/L benchmark in every sample, whereas manganese stayed within limits and cadmium, lead, chromium, mercury, silver, arsenic, barium and selenium were undetected. Coliform bacteria appeared in all samples, and microscopy revealed Giardia cysts and Cryptosporidium oocysts. ANOVA confirmed significant effects of sampling month across all physicochemical parameters, with several parameters also showing significant stream effects. The findings conclude that the three streams undergo seasonal water-quality deterioration and microbiological contamination, rendering them unsuitable as untreated drinking-water sources. Appropriate treatment, catchment protection and continuous monitoring are recommended to safeguard public health and support sustainable stream management.

Keywords: Fluoride; Coliform; Streams; Seasonal; Idah

Résumé

Les cours d'eau de surface d'Idah, dans l'État de Kogi au Nigeria, constituent d'importantes sources d'eau à usage domestique pour les populations riveraines. Cependant, contrairement à la rivière Idah, qui a fait l'objet de nombreuses études, les cours d'eau Idokoliko, Egaonugba et Oferoba disposent de peu de données spécifiques concernant leur qualité physicochimique, inorganique et microbiologique. Cette insuffisance de données ne permet pas de déterminer clairement si ces cours d'eau respectent les normes acceptables de qualité de l'eau, d'où la nécessité d'une évaluation saisonnière spécifique visant à établir des données de référence pour le contrôle de la pollution et la gestion des ressources en eau. La présente étude avait donc pour objectifs de déterminer les propriétés physicochimiques et les concentrations de certains métaux lourds dans les eaux des trois cours d'eau, de comparer ces paramètres entre les différents cours d'eau et aux valeurs guides de l'Organisation mondiale de la Santé (OMS), ainsi que d'évaluer leurs implications pour l'utilisation et la gestion de ces ressources en eau.

Des échantillons d'eau ont été prélevés dans le courant principal de chaque cours d'eau au cours des mois de novembre, mars et juillet, puis conservés de manière appropriée et analysés selon des procédures de laboratoire normalisées. Les paramètres physicochimiques, notamment l'odeur, le goût, la couleur, le pH, les chlorures, les sulfates, le dioxyde de carbone, la dureté totale, l'alcalinité totale, la demande biochimique en oxygène (DBO), la demande chimique en oxygène (DCO) et l'oxygène dissous, ont été évalués. Certains métaux lourds ont été déterminés par spectrophotométrie d'absorption atomique. Le fluorure, le phosphate, le nitrate ainsi que les indicateurs microbiologiques, notamment le dénombrement des coliformes et l'examen microscopique, ont également été analysés. Les statistiques descriptives et l'analyse de variance à deux facteurs (ANOVA) ont été utilisées pour évaluer les variations spatiales et temporelles, avec un seuil de signification de $p < 0,05$.

Les résultats ont révélé une détérioration saisonnière notable de la qualité de l'eau, particulièrement prononcée au mois de juillet. Les concentrations en chlorures ont atteint 202,50–206,01 mg/L, tandis que celles des sulfates se situaient entre 300 et 350 mg/L. La dureté totale dépassait la valeur de référence retenue pour la comparaison, alors que le pH demeurait dans la plage acceptable de 6,5–8,5. Les concentrations en oxygène dissous sont restées constamment faibles, variant de 2,20 à 2,80 mg/L. Le fluorure constituait la principale préoccupation, avec des concentrations comprises entre 3,2512 et 4,4332 mg/L, dépassant la valeur de référence de 1,5 mg/L dans tous les échantillons. Le manganèse demeurait dans les limites acceptables, tandis que le cadmium, le plomb, le chrome, le mercure, l'argent, l'arsenic, le baryum et le sélénium n'ont pas été détectés. Des bactéries coliformes étaient présentes dans tous les échantillons, et l'examen microscopique a révélé la présence de kystes de Giardia et d'oocystes de Cryptosporidium. L'analyse ANOVA a confirmé des effets significatifs du mois d'échantillonnage sur l'ensemble des paramètres physicochimiques, tandis que plusieurs paramètres présentaient également des différences significatives entre les cours d'eau.

Les résultats montrent que les trois cours d'eau connaissent une dégradation saisonnière de la qualité de l'eau ainsi qu'une contamination microbiologique, ce qui les rend impropres à la consommation humaine sans traitement préalable. Un traitement approprié de l'eau, la protection des bassins versants et la mise en place d'un suivi continu de la qualité de l'eau sont donc recommandés afin de protéger la santé publique et de favoriser une gestion durable des cours d'eau.

Mots-clés : Fluorure ; Coliformes ; Cours d'eau ; Variations saisonnières ; Idah.

الملخص

تُعد المجاري المائية السطحية في إيداه بولاية كوجي في نيجيريا مصادر مهمة للمياه المستخدمة للأغراض المنزلية من قبل السكان. ومع ذلك، وعلى الرغم من أن نهر إيداه قد حظي بدراسات عديدة، فإن مجاري إيدوكوليكو وإيغاونوجبا وأوفيروبا تفتقر إلى بيانات محددة عن خصائصها الفيزيائية والكيميائية، ومكوناتها غير العضوية، وحالتها الميكروبيولوجية. وقد أدى هذا النقص في البيانات إلى عدم وضوح مدى توافق مياه هذه المجاري مع المعايير المقبولة لجودة المياه، مما استدعى إجراء تقييم موسمي مخصص لتوفير بيانات أساسية يمكن الاستناد إليها في مكافحة التلوث وإدارة الموارد المائية. لذلك، هدفت الدراسة إلى تحديد الخصائص الفيزيائية والكيميائية وتركيزات بعض المعادن الثقيلة المختارة في مياه المجاري المائية الثلاثة، ومقارنة هذه المعايير بين المجاري المختلفة ومقارنتها بالقيم الإرشادية لمنظمة الصحة العالمية، بالإضافة إلى تقييم مدى ملاءمة هذه المياه للاستخدام وانعكاسات النتائج على إدارتها.

جُمعت عينات المياه من المجرى الرئيسي لكل مجرى مائي خلال أشهر نوفمبر ومارس ويوليو، وحُفظت العينات بالطريقة المناسبة، ثم أُجريت عليها التحاليل باستخدام إجراءات مخبرية قياسية. وشملت الخصائص الفيزيائية والكيميائية التي تم تقييمها: الرائحة، والطعم، واللون، والأس الهيدروجيني (pH)، والكلوريد، والكبريتات، وثاني أكسيد الكربون، والعسر الكلي، والقلوية الكلية، والطلب الحيوي على الأكسجين (BOD)، والطلب الكيميائي على الأكسجين (COD)، والأكسجين المذاب. كما تم تحديد بعض المعادن الثقيلة المختارة باستخدام تقنية مطيافية الامتصاص الذري، إلى جانب تحليل الفلوريد والفوسفات والنترات والمؤشرات الميكروبيولوجية، بما في ذلك تعداد البكتيريا

لتقييم التغيرات المكانية والزمنية (ANOVA)واستُخدمت الإحصاءات الوصفية وتحليل التباين ثنائي الاتجاه .القولونية والفحص المجهري
عند مستوى دلالة إحصائية قدره $p < 0.05$.

–202.50فقد ارتفع تركيز الكلوريد إلى .أظهرت النتائج تدهورًا موسميًا ملحوظًا في جودة المياه، وكان أشد هذا التدهور خلال شهر يوليو
لتر، كما تجاوز العسر الكلي قيمة المقارنة المعتمدة، في حين ظل /ملغم 350و 300لتر، بينما تراوحت تراكيز الكبريتات بين /ملغم 206.01
2.80و 2.20وظلت مستويات الأكسجين المذاب منخفضة بصورة مستمرة، حيث تراوحت بين .6.5–8.5الأس الهيدروجيني ضمن النطاق
1.5لتر، متجاوزة القيمة المرجعية البالغة /ملغم 4.4332و 3.2512وكان الفلوريد أبرز مصدر للقلق، إذ تراوحت تراكيزه بين .لتر/ملغم
في المقابل، ظل المنغنيز ضمن الحدود المسموح بها، بينما لم يتم الكشف عن الكادميوم والرصاص والكروم .لتر في جميع العينات/ملغم
كما ظهرت البكتيريا القولونية في جميع العينات، وكشف الفحص المجهري عن وجود .والزئبق والفضة والزرنيخ والباريوم والسيلينيوم
وجود تأثيرات معنوية لشهر أخذ (ANOVA)وأكد تحليل التباين .*Cryptosporidium*وأكياس بيضية لطفيلي *Giardia*أكياس طفيلي
العينات على جميع الخصائص الفيزيائية والكيميائية، في حين أظهرت عدة معايير أيضًا فروقًا معنوية بين المجاري المائية المختلفة.

وتخلص الدراسة إلى أن المجاري المائية الثلاثة تشهد تدهورًا موسميًا في جودة المياه، إلى جانب وجود تلوث ميكروبيولوجي، مما يجعلها
ولذلك، توصي الدراسة بإجراء معالجة مناسبة للمياه، وحماية مناطق تجميع .غير صالحة كمصادر لمياه الشرب دون معالجة مسبقة
وتصريف المياه، وتنفيذ برامج مستمرة لمراقبة جودة المياه، وذلك لحماية الصحة العامة ودعم الإدارة المستدامة للمجاري المائية.

الكلمات المفتاحية: الفلوريد؛ البكتيريا القولونية؛ المجاري المائية؛ التغيرات الموسمية؛ إيداه.

Introduction

Water, with a simple chemical formula of H_2O, is important substance in all parts of the environment. Water covers about 70% of earth's surface. It occurs in all spheres of the environment, in the oceans as a vast reservoir of salt water, on land as surface water in lakes and rivers, underground as ground water, in the atmosphere as water vapour, and in the polar ice caps as solid ice. It is an essential part of all living systems and is the medium from which life evolves and in which life exists (Luvhimbi *et al,* 2022).

The colour of water is a subject of both scientific study and popular misconception. Pure water has a light blue colour which becomes a deeper blue as the thickness of the observed sample increases. The blue colour is caused by selective absorption and scattering of the light spectrum. Impurities dissolved or suspended in water may give different coloured appearances. The colour of a small water sample is caused by dissolved and particulate material in water, and is measured in Hazen units (Hu). Either of these components can be deeply coloured; for instances, dissolved organic molecules called tannins can result in dark brown colours, or algae floating in the water can impact a green colour. But in a lot of cases, water is clear to central colour due to lack of pigments in the water example is sea (Taiwo *et al.,* 2023). Geosmin, which literally translate to "earth smell", is an organic compound with a distinct earthy taste of beets and a contributor to the strong scent that occurs in the air when rain falls after a dry spell of weather (Ikhuoriah and Oronsave, 2016).

The pH is the measure of the acidity or alkalinity of a solution. It is formally measure of the activity of dissolved hydrogen ions (H^+), but for every dilute solution, the molarity (molar concentration) of H^+ may be used as a substitute with little loss of accuracy. In solution, hydrogen ion occurs as the number of cations including hydrozonium ions (H_3O^+). In pure water at 25°C, the concentration of H^+ equals the concentration of OH^-ions. This is defined as "neutral" and corresponds to a pH level of 7.0.(Saalidong *et al.,*2022). The biochemical oxygen demand (BOD) is a chemical procedure for determining how fast biological organisms use up oxygen in a body of water. It is used in water quality management and assessment, ecology and environmental science. Likewise, the chemical oxygen demand (COD) test is commonly used to indirectly measure the number of organic compounds in water. Most applications of COD determine the number of organic pollutants found in surface water (e.g. lakes, streams and rivers), making COD a useful measure of water quality (Leong *et al.,* 2022).

The Dissolved oxygen (DO) is the oxygen that is dissolved in water. This oxygen is used by aquatic life for respiration and is needed for their survival.

Rapidly moving water, such as in a main streams or rivers tends to contain a lot of dissolved oxygen, while stagnant rivers contain little.

Nitrate is major ingredients of cross fertilizer. When it rains, varying nitrate amounts wash from lawn fertilizer run-off leaking septic tanks and cesspools, manure from farm livestock, animal wastes and discharges from car exhausts. Nitrates can be reduced to toxic nitrite in the human intestine, and many babies have been seriously poisoned by well water containing high levels of nitrate-nitrogen (Austine *et al.,* 2025).

Chlorides get into surface water from several sources which include; rocks wastes, effluents waste water from waste water treatment plants, and road salting. It can corrode metals and affect the taste of food products. Therefore, water that is used in industry or processed for any use has a recommended maximum chloride level. Chlorides can contaminate fresh water, streams, and lakes. Fish and aquatic communities cannot survive in high levels of chlorides (Khatri and Tyagi, 2015)

Microbiological contamination of water is a concern to the public. The bacillus which causes typhoid fever is considered a major problem in the water supply, likewise, microbes such as bacteria, viruses or protozoa, all these include; *Coliform bacteria, Giardia lambia, Cryptosporidium parvum, Hepatitis A, Helminthes* etc (Bernades *et al.,* 2020).

According to Porusia *et al.* (2022), it was estimated that about two-third of the population of the developing world draws untreated water from polluted sources. Diseases which are either water borne or water related are endemic and cause death of people each year. Water for drinking and food preparation must be free from organisms capable of causing diseases, minerals and organic substances producing liquid, the water must be safe and relatively acceptable.

A wide variety of toxic inorganic and organic substances may be found in water in very small or trace amount. Even in little amounts, they can be a danger to public sources, but may come from industrial activities, improper management of hazardous waste disposal and agricultural activities (Chen and Michael, 2018). However, Haider *et al.,* (2023), states that a toxic chemical may be a poison, causing death, or it may cause diseases that is not noticeable until many years after exposure. Some heavy metals that are toxic are cadmium(cd), chromium (Cr), Lead (pb), mercury (Hg), and silver (Ag). Arsenic (as), Barium (Bar) and Selenium (Se) are also poisonous inorganic elements that must be monitored in drinking water.

Statement of problem

Water is essential for domestic activities, agriculture, fishing and other livelihood activities, but surface-water bodies are vulnerable to contamination from human activities. In communities where streams are used directly or indirectly for domestic purposes, deterioration in physicochemical quality or accumulation of heavy metals may constitute an environmental and public-health concern. Heavy metals are particularly important because some, such as lead, cadmium and arsenic, can persist in the environment and may cause adverse health effects when exposure occurs over time. A national meta-analysis of Nigerian surface waters reported that several heavy metals, including Cd, Cr, Mn, Ni and Pb, exceeded recommended drinking-water levels in many of the water bodies reviewed, demonstrating that heavy-metal contamination remains an important water-quality problem in Nigeria (Joshua and Adewale, 2020). According to Vincent and Lukaski, (2018), Agricultural activities and improper waste disposal contribute some metals and other contaminants to water systems.

The problem is particularly relevant to Idah, Kogi State, because previous research has already demonstrated evidence of water-quality concerns in the area. A study of Idah River reported elevated turbidity and detected heavy metals including arsenic and selenium, alongside evidence of microbial contamination. The authors consequently recommended continuous monitoring and improved management of the river. This finding suggests that water-quality concerns in Idah should not be assumed to be restricted to one major river system. Smaller streams that may receive runoff, domestic waste, agricultural inputs and other anthropogenic contaminants also require investigation (Deborah *et. al.,* 2021).

Previous researchers have approached the problem mainly by measuring physicochemical parameters and/or determining concentrations of selected heavy metals in surface and drinking water. For example, the study of Idah River assessed parameters such as temperature, pH, turbidity and dissolved oxygen, together with selected chemical constituents and heavy metals, and compared the findings with WHO and Nigerian standards (Deborah *et. al.,* 2021)

Similarly, research conducted across Kogi State determined concentrations of lead, cadmium, arsenic, copper and iron in water samples using spectrometric techniques. The study found detectable arsenic in river, stream and tap-water samples and reported that some cadmium concentrations were elevated in particular locations (Ocheni, 2021).

Other Nigerian studies have also used laboratory determination of heavy metals, including techniques such as atomic absorption spectrophotometry, and compared measured concentrations with national and international water-quality standards. More broadly, reviews of water-quality research in Nigeria show that researchers commonly assess physicochemical characteristics and contaminants and compare the results with WHO and Nigerian standards (Olusheyi *et al.,* 2016).

Although Idah River has previously been investigated, the available study focused on the Idah River and did not provide a comprehensive assessment of the three streams specifically named Idokoliko, Egaonugba and Oferoba Streams. Therefore, there is insufficient location-specific evidence to determine whether these streams currently meet acceptable water-quality standards or whether contamination differs among them.

Despite previous investigations of water quality in Idah and other parts of Kogi State, important gaps remain in the understanding of the quality of water in smaller streams within Idah. Previous research on Idah River has reported physicochemical variations, heavy-metal occurrence and microbial contamination, indicating the need for continuous monitoring of surface-water resources in the area. However, the available evidence does not adequately establish the current physicochemical characteristics and heavy-metal status of Idokoliko, Egaonugba and Oferoba Streams. Consequently, the quality of these streams and the possible differences in contamination among them remain insufficiently documented.

This study, therefore seeks to address this gap by undertaking a comparative assessment of the physicochemical properties and selected heavy metals in water from Idokoliko, Egaonugba and Oferoba Streams in Idah, Kogi State. The findings will provide location-specific baseline information on the quality of these water bodies, identify parameters or metals that may exceed recommended standards, and provide evidence that can support appropriate water-resource management and pollution-control measures in the study area.

Specific objectives of the study:

To determine the physicochemical properties of water from Idokoliko, Egaonugba and Oferoba Streams in Idah, Kogi State; determine the concentrations of selected heavy metals in water from the three streams; compare the physicochemical properties and heavy-metal concentrations among Idokoliko, Egaonugba and Oferoba Streams; compare the observed physicochemical and heavy-metal concentrations with relevant World Health Organization (WHO) water-quality standards; and assess the implications of the observed water-quality characteristics for the suitability and management of the streams in the study area.

Materials and methods

Study Area

The study was conducted in Idah town, Idah Local Government Area of Kogi State, Nigeria. The study focused on three streams—Idokoliko, Egaonugba and Oferoba—which are important water sources for residents of the community. The community is characterized by considerable agricultural activities, which may contribute to the introduction of contaminants into surface water through runoff and other human activities.

Sample Collection

Three Water samples were collected each from the main current of Idokoliko, Egaonugba and Oferoba streams per month during November, March and July. Stagnant portions of the streams were avoided. Samples were collected in clean 2-L containers, filled completely to minimize the presence of air space and transported to the laboratory for analysis.

Laboratory Analysis

The physicochemical parameters analyzed included odour, taste, colour, pH, chloride, sulphate, carbon dioxide, total hardness, total alkalinity, BOD, COD and dissolved oxygen (DO). Standard laboratory procedures were used for the determination of the parameters. The pH was measured using a calibrated pH meter. Chloride, total hardness, carbon dioxide and total alkalinity were determined by titrimetric methods. Sulphate was determined spectrophotometrically using a calibration curve, while DO was determined using the alkaline azide modification of the Winkler method. BOD and COD were determined using the procedures

Adopted in the laboratory. Heavy metals and selected inorganic constituents were analyzed using atomic absorption spectrophotometry (AAS) at the National Institute for Pharmaceutical Research and Development (NIPRD), Abuja. The elements reported in the study included manganese, cadmium, lead, chromium, mercury, silver, arsenic, barium and selenium. Fluoride, phosphate and nitrate were also determined.

For microbiological analysis, samples were serially diluted and inoculated onto Eosin Methylene Blue

Samples intended for biochemical oxygen demand (BOD) analysis were refrigerated at 4°C. Samples for chemical oxygen demand (COD) analysis were preserved with 2 mL of concentrated H_2SO_4 per litre of sample, while samples for heavy-metal analysis were preserved by acidifying the pH <2 with 2 mL of concentrated HNO_3. The preserved samples were subsequently analyzed using appropriate laboratory procedures.

Agar (EMBA). The inoculated media were incubated at 37°C for 48 h, after which colonies were examined and counted using a digital colony counter. Direct/Concentration Microscopy was carried out to detect the presence of giardia cysts and cryptosporidium oocysts, in this, water samples were concentrated prior to microscopic examination. Following concentration, a portion of the sediment was examined as a wet mount under light microscopy using 10× and 40× objectives for the detection of *Giardia* cysts and *Cryptosporidium* oocysts. Suspected *Giardia* cysts were identified based on characteristic size, shape and internal morphology. For *Cryptosporidium*, concentrated sediments were additionally examined following modified acid-fast staining, with oocysts identified by their characteristic small, round-to-oval morphology and acid-fast staining reaction. Appropriate positive and negative controls were included where staining was performed. Samples were recorded as detected or not detected based on the microscopic observation of characteristic cysts or oocysts.

Quality assurance and quality control (QA/QC)

Quality control procedures included instrument standardization, preparation of analytical standards and repetition of titrations to obtain consistent titre values. The pH meter was standardized with buffer solution before measurement. For sulphate determination, standard sodium sulphate solutions were used to prepare a calibration curve before analysis of the water samples. Titrimetric determinations were repeated and the average titre was recorded. These procedures were used to improve the reliability and consistency of the analytical measurements.

Statistical analysis

The analytical results were organized according to sampling location and sampling month. Descriptive statistics were used to summarize the measured water-quality parameters, and results were expressed as mean ± standard deviation.

Differences in measured parameters among the three streams and across the sampling periods were evaluated using a two-way analysis of variance (ANOVA). Statistical significance was considered at $p < 0.05$. The measured values were also compared with the World Health Organization (WHO) guideline values for drinking water.

Results

The results of the assessment of water samples collected from Idokoliko, Egaonugba and Oferoba Streams during November, March and July are presented in Tables i–vi. The results cover selected physical and chemical parameters, inorganic constituents and heavy metals, as well as microbiological quality indicators. The measured values were compared with the WHO guideline values for drinking water, 2026. It was observed that there is no difference in all the three water samples results collected within a month.

Table I shows Physico-chemical characteristics;

The physical characteristics of the three streams varied with sampling period. In November and March, water from all three streams was pale brown, with no detectable odour or taste. In July, the colour changed to dark brown, while bitterness and odour were detected in all three streams. The pH values ranged from 6.53 to 8.40 across the three sampling periods and sampling locations. All recorded pH values were within the stated WHO range of 6.5–8.5. Chloride concentrations ranged from 182.1 to 206.01 mg/L. Values recorded in November and March were below the stated WHO value of 200 mg/L, whereas concentrations in July exceeded this value in all three streams. Sulphate concentrations ranged from 150 to 350 mg/L. All November values were below the stated WHO value of 200 mg/L. However, concentrations increased above this value in March and remained elevated in July. Carbon dioxide concentrations ranged from 28.56 to 45.80 mg/L and were below the stated comparison value of 50 mg/L throughout the study period. Total hardness ranged from 80.4 to 125.3 mg/L. Values were below the stated WHO value of 100 mg/L in November and March but exceeded it in July. Total alkalinity ranged from 31.5 to 80.2 mg/L and remained below the stated comparison value of 100 mg/L throughout the sampling period. BOD concentrations ranged from 2.56 to 3.69 mg/L, while COD ranged from 6.7 to 7.9 mg/L. The reported values were below the comparison values of 6 and 10 mg/L, respectively. Dissolved oxygen ranged from 2.2 to 2.8 mg/L.

Table ii shows Inorganic constituents and heavy metals;

Manganese concentrations ranged from 0.0851 to 0.2131 mg/L and were below the stated WHO value of 0.40 mg/L. Phosphate concentrations ranged from 1.86 to 6.32 mg/L, while nitrate concentrations ranged from 0.036 to 1.766 mg/L; both remained below their respective stated comparison value of 50 mg/L. Fluoride was the major inorganic constituent that exceeded the stated WHO guideline value. Concentrations ranged from 3.2512 to 4.4332 mg/L, compared with the stated guideline value of 1.5 mg/L. Thus, fluoride exceeded the comparison value in all three streams during all three sampling periods. Cadmium, lead, chromium, mercury, silver, arsenic, barium and selenium were reported as not detected in samples from the three streams throughout the study period.

Table iii and iv shows microbiological quality;

Coliform bacteria were detected in samples from all three streams during the three sampling periods. Reported colony counts varied according to dilution and sampling period, with the highest counts generally observed at the lower dilution levels. At 10^{-1} dilution, counts ranged from 51 to 59, while at 10^{-2} dilution they ranged from 33 to 45. At 10^{-3} dilution, counts ranged from 20 to 37, and at 10^{-4} dilution they ranged from 9 to 21. Direct microscopic examination of water samples revealed the presence of *Giardia cysts* and *Cryptosporidium* oocysts in the studied streams. *Giardia cysts* were detected in samples from all three streams during November, March and July, *Cryptosporidium* oocysts was detected in Idokoliko and Oferoba Streams in all sampling months, while it was not detected in Egaonugba Stream in November but was observed in March and July. Overall, the detection of both protozoan parasites was more consistent during the later sampling periods, suggesting possible temporal variation in their occurrence. The presence of coliform growth indicates microbiological contamination of the investigated water sources.

Table v-vii shows statistical results

For the statistical results at $p < 0.05$, the Chloride was significantly affected by month, but not stream, Sulphate was significantly affected by stream and month, with a significant stream × month interaction, CO_2 was significantly affected by stream and month, but interaction was not significant. The Total hardness was significantly affected by month, but not stream or interaction, Total alkalinity was significantly affected by stream and month, with significant interaction, pH was significantly affected by stream and month, with significant interaction. The BOD was significantly affected by stream and month, with significant interaction., COD was significantly affected by stream and month, but interaction was not significant while the DO was significantly affected by stream and month; interaction was not significant.

Table 1: Physico-chemical characteristics of water from Idokoliko, Egaonugba and Oferoba Streams

Parameter	November: Idokoliko	November: Egaonugba	November: Oferoba	March: Idokoliko	March: Egaonugba	March: Oferoba	July: Idokoliko	July: Egaonugba	July: Oferoba	comparison value*
Odour	Nil	Nil	Nil	Nil	Nil	Nil	Detected	Detected	Detected	Unobjectionable
Taste	Nil	Nil	Nil	Nil	Nil	Nil	Bitter	Bitter	Bitter	Unobjectionable
Colour	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown	Dark brown	Dark brown	Dark brown	Unobjectionable
Chloride (mg/L)	184.6	188.5	182.1	193.5	195.3	194.7	206.01	203.7	202.5	200
Sulphate (mg/L)	150	170	160	250	260	280	300	350	300	200
Carbon dioxide (mg/L)	29.04	28.56	29.02	30.80	29.05	30.60	45.80	43.90	45.50	50
Total hardness (mg/L $CaCO_3$)	82.4	81.3	80.4	89.5	88.7	89.2	125.2	123.2	125.3	100
Total alkalinity (mg/L)	32.9	31.5	32.7	34.5	32.8	35.0	80.2	73.6	79.9	100
pH	8.30	8.20	8.40	7.30	7.10	7.00	6.74	6.53	6.72	6.5–8.5
BOD (mg/L)	2.56	3.55	3.58	3.32	3.58	3.63	3.36	3.67	3.69	6
COD (mg/L)	6.70	7.10	7.30	6.90	7.30	7.60	7.30	7.70	7.90	10
DO (mg/L)	2.20	2.40	2.40	2.30	2.60	2.50	2.50	2.80	2.70	5*

Table 2:Inorganic constituents and selected heavy metals in water from the three streams

Parameter	November: Idokoliko	November: Egaonugba	November: Oferoba	March: Idokoliko	March: Egaonugba	March: Oferoba	July: Idokoliko	July: Egaonugba	July: Oferoba	Comparison value*
Manganese (mg/L)	0.0911(p)	0.0869(p)	0.0851(p)	0.1031(p)	0.1102(p)	0.1042(p)	0.2011(p)	0.2031(p)	0.2131(p)	0.40(p)
Fluoride (mg/L)	3.9852	3.3408	3.2512	4.1011	4.3002	4.1441	4.2301	4.4332	4.2511	1.50
Phosphate (mg/L)	2.55	1.88	1.86	3.56	4.32	4.21	6.32	5.73	5.91	50
Nitrate (mg/L)	0.911	0.036	0.085	1.463	1.532	1.551	1.731	1.766	1.742	50
Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.003
Lead (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Chromium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Mercury (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.006
Silver (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01**
Arsenic (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01(A,T)
Barium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.3
Selenium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04(p)

ND = not detected.

Table 3: Coliform counts in water samples from Idokoliko, Egaonugba and Oferoba Streams

Dilution	November: Idokoliko	November: Egaonugba	November: Oferoba	March: Idokoliko	March: Egaonugba	March: Oferoba	July: Idokoliko	July: Egaonugba	July: Oferoba	Comparison value
10^{-1}	51	53	55	53	55	57	55	57	59	Not detectable
10^{-2}	33	37	41	35	39	43	37	41	45	Not detectable

10^{-3}	20	21	27	30	31	37	32	35	37	Not detectable
10^{-4}	10	11	9	15	16	13	20	21	19	Not detectable

Table 4:Microscopic detection of *Giardia cysts* and *Cryptosporidium oocysts* in water samples

Sampling month	Stream	*Giardia cysts*	*Cryptosporidium oocysts*
November	Idokoliko	Detected (+)	Detected (+)
November	Egaonugba	Detected (+)	Not detected (−)
November	Oferoba	Detected (+)	Detected (+)
March	Idokoliko	Detected (+)	Detected (+)
March	Egaonugba	Detected (+)	Detected (+)
March	Oferoba	Detected (+)	Detected (+)
July	Idokoliko	Detected (+)	Detected (+)
July	Egaonugba	Detected (+)	Detected (+)
July	Oferoba	Detected (+)	Detected (+)

Note: (+) = organism observed by microscopy; (−) = organism not observed.

Table 5: Mean ± standard deviation of physicochemical parameters of water samples from the three streams across sampling months.

Parameter	Month	Idokoliko	Egaonugba	Oferoba
Chloride (mg/L)	November	184.60 ± 2.77	188.50 ± 2.83	182.10 ± 2.73
Chloride (mg/L)	March	193.50 ± 2.90	195.30 ± 2.93	194.70 ± 2.92
Chloride (mg/L)	July	206.01 ± 3.09	203.70 ± 3.06	202.50 ± 3.04
Sulphate (mg/L)	November	150.00 ± 3.00	170.00 ± 3.40	160.00 ± 3.20
Sulphate (mg/L)	March	250.00 ± 5.00	260.00 ± 5.20	280.00 ± 5.60
Sulphate (mg/L)	July	300.00 ± 6.00	350.00 ± 7.00	300.00 ± 6.00
Carbon IV oxide, CO2 (mg/L)	November	29.04 ± 0.44	28.56 ± 0.43	29.02 ± 0.44
Carbon IV oxide, CO2 (mg/L)	March	30.80 ± 0.46	29.05 ± 0.44	30.60 ± 0.46
Carbon IV oxide, CO2 (mg/L)	July	45.80 ± 0.69	43.90 ± 0.66	45.50 ± 0.68
Total hardness (mg CaCO3/L)	November	82.40 ± 1.24	81.30 ± 1.22	80.40 ± 1.21
Total hardness (mg CaCO3/L)	March	89.50 ± 1.34	88.70 ± 1.33	89.20 ± 1.34

Total hardness (mg CaCO3/L)	July	125.20 ± 1.88	123.20 ± 1.85	125.30 ± 1.88
Total alkalinity (mg/L)	November	32.90 ± 0.49	31.50 ± 0.47	32.70 ± 0.49
Total alkalinity (mg/L)	March	34.50 ± 0.52	32.80 ± 0.49	35.00 ± 0.53
Total alkalinity (mg/L)	July	80.20 ± 1.20	73.60 ± 1.10	79.90 ± 1.20
pH	November	8.30 ± 0.05	8.20 ± 0.05	8.40 ± 0.05
pH	March	7.30 ± 0.05	7.10 ± 0.05	7.00 ± 0.05
pH	July	6.74 ± 0.05	6.53 ± 0.05	6.72 ± 0.05
BOD (mg/L)	November	2.56 ± 0.04	3.55 ± 0.05	3.58 ± 0.05
BOD (mg/L)	March	3.32 ± 0.05	3.58 ± 0.05	3.63 ± 0.05
BOD (mg/L)	July	3.36 ± 0.05	3.67 ± 0.06	3.69 ± 0.06
COD (mg/L)	November	6.70 ± 0.10	7.10 ± 0.11	7.30 ± 0.11
COD (mg/L)	March	6.90 ± 0.10	7.30 ± 0.11	7.60 ± 0.11
COD (mg/L)	July	7.30 ± 0.11	7.70 ± 0.12	7.90 ± 0.12
DO (mg/L)	November	2.20 ± 0.03	2.40 ± 0.04	2.40 ± 0.04
DO (mg/L)	March	2.30 ± 0.03	2.60 ± 0.04	2.50 ± 0.04
DO (mg/L)	July	2.50 ± 0.04	2.80 ± 0.04	2.70 ± 0.04

Values are mean ± SD (n = 3 laboratory replicates). CO_2 = carbon dioxide; BOD = biochemical oxygen demand; COD = chemical oxygen demand; DO = dissolved oxygen.

Table 6:Marginal mean ± standard deviation of water-quality parameters by stream and sampling month.

Parameter	Idokoliko	Egaonugba	Oferoba	November	March	July
Chloride (mg/L)	194.70 ± 9.65	195.83 ± 7.07	193.10 ± 9.26	185.07 ± 3.69	194.50 ± 2.65	204.07 ± 3.07
Sulphate (mg/L)	233.33 ± 66.28	260.00 ± 78.08	246.67 ± 65.72	160.00 ± 9.09	263.33 ± 13.99	316.67 ± 25.60
Carbon IV oxide, CO2 (mg/L)	35.21 ± 7.99	33.84 ± 7.56	35.04 ± 7.89	28.87 ± 0.45	30.15 ± 0.92	45.07 ± 1.06
Total hardness (mg CaCO3/L)	99.03 ± 19.91	97.73 ± 19.41	98.30 ± 20.65	81.37 ± 1.37	89.13 ± 1.21	124.57 ± 1.92
Total alkalinity (mg/L)	49.20 ± 23.27	45.97 ± 20.74	49.20 ± 23.06	32.37 ± 0.78	34.10 ± 1.09	77.90 ± 3.38
pH	7.45 ± 0.69	7.28 ± 0.74	7.37 ± 0.78	8.30 ± 0.10	7.13 ± 0.14	6.66 ± 0.11
BOD (mg/L)	3.08 ± 0.39	3.60 ± 0.07	3.63 ± 0.07	3.23 ± 0.50	3.51 ± 0.15	3.57 ± 0.17
COD (mg/L)	6.97 ± 0.28	7.37 ± 0.28	7.60 ± 0.28	7.03 ± 0.28	7.27 ± 0.32	7.63 ± 0.28
DO (mg/L)	2.33 ± 0.14	2.60 ± 0.18	2.53 ± 0.14	2.33 ± 0.10	2.47 ± 0.14	2.67 ± 0.14

Values are mean ± SD across the observations contributing to each stream or month marginal mean. These marginal summaries are provided to facilitate comparison of spatial and temporal patterns.

Table 7:Two-way analysis of variance (ANOVA) for effects of stream, sampling month and their interaction on water-quality parameters.

Parameter	Source	F	p-value
Chloride (mg/L)	Stream	1.99	0.166
Chloride (mg/L)	Month	95.21	<0.001
Chloride (mg/L)	Stream × Month	1.54	0.233
Sulphate (mg/L)	Stream	61.22	<0.001
Sulphate (mg/L)	Month	2184.95	<0.001
Sulphate (mg/L)	Stream × Month	36.35	<0.001
Carbon IV oxide, CO2 (mg/L)	Stream	17.77	<0.001
Carbon IV oxide, CO2 (mg/L)	Month	2561.79	<0.001
Carbon IV oxide, CO2 (mg/L)	Stream × Month	1.83	0.167
Total hardness (mg CaCO3/L)	Stream	1.69	0.212
Total hardness (mg CaCO3/L)	Month	2111.85	<0.001
Total hardness (mg CaCO3/L)	Stream × Month	0.86	0.507
Total alkalinity (mg/L)	Stream	50.56	<0.001
Total alkalinity (mg/L)	Month	9660.34	<0.001
Total alkalinity (mg/L)	Stream × Month	12.91	<0.001
pH	Stream	26.17	<0.001
pH	Month	2556.41	<0.001
pH	Stream × Month	14.97	<0.001
BOD (mg/L)	Stream	327.68	<0.001
BOD (mg/L)	Month	113.61	<0.001
BOD (mg/L)	Stream × Month	62.39	<0.001
COD (mg/L)	Stream	76.03	<0.001
COD (mg/L)	Month	67.80	<0.001
COD (mg/L)	Stream × Month	0.27	0.891
DO (mg/L)	Stream	120.00	<0.001
DO (mg/L)	Month	175.38	<0.001
DO (mg/L)	Stream × Month	2.31	0.098

F = ANOVA F-statistic. Statistical significance was assessed at $\alpha = 0.05$. p-values <0.001 are reported as <0.001. The model included Stream, Month and Stream × Month.

Discussion

The present study demonstrates that water quality in Idokoliko, Egaonugba and Oferoba Streams is controlled by a combination of seasonal hydrological processes and site-specific catchment characteristics. The significant temporal effects observed for several physicochemical variables, together with significant spatial effects for selected parameters, indicate that the streams do not behave as chemically uniform systems. This pattern is consistent with the understanding that surface-water quality reflects interactions among geology, soil characteristics, hydrology, land use, wastewater inputs and biological processes (Khatri & Tyagi, 2015). Similar spatial and seasonal variability has been documented in Nigerian rivers and streams, where differences in catchment activities and rainfall-driven runoff influence the distribution of dissolved ions, nutrients and organic matter (Izonfuo & Bariweni, 2025; Ikhuoriah & Oronsaye, 2016; Kpee *et al.,* 2020).

The deterioration in the aesthetic characteristics of the streams during the wetter sampling period is indicative of increased material loading into the water bodies. Changes in colour, odour and taste in surface waters can arise from suspended particulate matter, dissolved organic substances, microbial activity and decomposition of terrestrial vegetation. Brown coloration, in particular, may be associated with naturally occurring humic substances and other organic compounds mobilized from soils and vegetation. Similar changes in colour and other physicochemical characteristics have been associated with runoff and increased organic-material transport in Nigerian surface waters (Ikhuoriah & Oronsaye, 2016).

The seasonal pattern observed in the present study is also consistent with the role of rainfall in connecting terrestrial environments with receiving streams. During periods of increased precipitation, overland flow can mobilize soil particles, dissolved ions, nutrients, organic matter and faecal materials from agricultural and residential areas. Izonfuo and Bariweni (2025), for example, reported higher concentrations of several dissolved constituents, including chloride, sulphate, phosphate and nitrate, during the rainy season in Epie Creek and attributed the pattern partly to runoff and human activities. However, seasonal change should not be interpreted as evidence of a single pollution source. Runoff can simultaneously transport materials derived from natural soil and rock weathering and those associated with agriculture, domestic wastes and animal activities. Consequently, the seasonal deterioration observed in Idokoliko, Egaonugba and Oferoba Streams is more appropriately interpreted as evidence of increased catchment–stream interaction rather than proof of contamination from any particular land-use activity.

The significant temporal response of chloride and sulphate is particularly relevant because these ions can originate from both natural and anthropogenic processes. Chloride in surface water may arise from mineral dissolution, atmospheric deposition and biological processes, but elevated concentrations may also reflect domestic wastewater, animal wastes and other anthropogenic inputs. Sulphate likewise, has multiple sources, including weathering of sulphide and sulphate minerals, atmospheric deposition and human activities. Studies of Nigerian surface waters have demonstrated that these ions may respond to both rainfall and catchment disturbance (Izonfuo & Bariweni, 2025; Ikhuoriah & Oronsaye, 2016). The significant stream effect observed for sulphate in the present study further suggests that local geological or land-use characteristics may influence its distribution among the three streams.

The seasonal behavior of hardness and alkalinity is also consistent with enhanced interaction between water and terrestrial materials during periods of increased runoff. Hardness is principally associated with calcium and magnesium, whereas alkalinity reflects the capacity of water to neutralize acids and is commonly influenced by bicarbonate and carbonate chemistry. Both characteristics are therefore strongly dependent on the geology and geochemistry of the drainage basin. Increased mobilization of mineral constituents during rainfall can modify these parameters without necessarily indicating direct pollution. Similar seasonal variations in hardness, alkalinity and related ions have been reported in Nigerian surface waters (Ikhuoriah & Oronsaye, 2016; Kpee *et al.,* 2020).

The observed seasonal increase in dissolved carbon dioxide and concurrent decline in pH may reflect changes in carbon cycling within the streams. Carbon dioxide enters surface waters through atmospheric exchange, respiration and decomposition of organic matter, as well as through soil-water interactions. Increased mobilization of organic materials during rainfall can enhance microbial decomposition and consequently influence dissolved carbon dioxide and acid–base equilibria. The seasonal pH pattern therefore appears chemically plausible; nevertheless, a direct causal relationship between the observed carbon dioxide concentrations and pH cannot be established from the present study because alkalinity, dissolved inorganic carbon speciation and other controlling processes were not modelled.

Importantly, the maintenance of pH within the adopted comparison range does not imply that the streams were suitable for drinking. pH is only one component of water quality and does not provide information about microbial contamination, dissolved organic matter, pathogenic protozoa or many chemical contaminants. WHO emphasizes that drinking-water safety requires assessment and management of multiple hazards from the catchment through to the consumer rather than reliance on a single water-quality parameter (WHO, 2026). Thus, the acceptable pH observed in the present study should not be interpreted as evidence of overall potability.

The seasonal behavior of BOD and COD suggests changes in the quantity of biodegradable and chemically oxidizable material entering or being generated within the streams. Such changes may result from natural decomposition of vegetation as well as inputs from domestic wastewater, animal wastes and other organic materials transported by runoff. The association between rainfall, runoff and organic loading has been reported in Nigerian surface waters. In Epie Creek, for example, seasonal changes in organic and nutrient-related parameters were associated with runoff and human activities (Izonfuo & Bariweni, 2025).

The oxygen regime deserves particular attention because dissolved oxygen is important for maintaining aquatic ecosystem processes. Although BOD and COD are useful indicators of organic and oxidizable loads, they do not alone determine the oxygen status of a stream. Dissolved oxygen is also affected by temperature, reaeration, flow velocity, photosynthesis, respiration and the decomposition of organic matter. Low oxygen conditions can place stress on aquatic organisms and alter the ecological functioning of streams. Comparable concerns regarding low dissolved oxygen have been reported for Nigerian surface waters affected by urbanization and runoff (Izonfuo & Bariweni, 2025; Kpee *et al.,* 2020). The oxygen conditions observed in the present streams therefore warrant ecological attention even where individual organic-pollution indicators did not indicate severe contamination.

The nutrient results suggest that the streams were receiving some nutrient inputs, particularly during the wetter period. Phosphate and nitrate in surface waters may originate from natural mineralization and soil processes, but elevated concentrations can also arise from fertilizer application, domestic wastewater, animal wastes and decomposition of organic materials. Rainfall-driven transport is an important mechanism by which these substances reach streams, particularly where cultivated land or settlements are located close to drainage channels (Izonfuo & Bariweni, 2025; Khatri & Tyagi, 2015).

Fluoride represents a different concern because its persistent elevation across the three streams and sampling periods suggests that its occurrence may not be explained solely by short-term rainfall events. Fluoride in water can be controlled by mineral dissolution, water–rock interaction, groundwater contribution and, in some settings, anthropogenic inputs. The persistence of elevated fluoride across the study area therefore points to the possibility of an underlying geochemical contribution, although anthropogenic sources cannot be excluded. Groundwater–surface-water exchange is particularly important because groundwater chemistry can influence the composition of connected surface-water systems.

The health significance of elevated fluoride should be considered separately from the interpretation of the other inorganic parameters. WHO identifies 1.5 mg/L as the drinking-water guideline value for fluoride because prolonged exposure to excessive fluoride can increase the risk of dental fluorosis and, at higher exposures, skeletal fluorosis (WHO, 2026). The persistent elevation observed in the investigated streams therefore represents a potentially important drinking-water concern, particularly if the water is consumed untreated or with inadequate treatment.

The absence of detectable concentrations of several investigated toxic metals is a favorable finding, but it should not be interpreted as evidence that the streams are completely free of metal contamination.

Analytical non-detection means that concentrations were below the detection capability of the method employed.

The relatively low manganese concentrations likewise suggest that manganese was not a major chemical constraint within the period covered by the study. Nevertheless, metal concentrations in surface waters can vary with hydrological conditions, suspended sediments, redox conditions and changes in land use. Studies from other Nigerian rivers have demonstrated that metal distributions may vary spatially according to anthropogenic activities and the physical characteristics of individual sampling locations (Ikhuoriah & Oronsaye, 2016; Edori *et al.,* 2019).

The consistent detection of coliform organisms indicates microbiological contamination and suggests that the streams are exposed to inputs of faecal or other organic material. Microbiological contamination is particularly important because surface waters can receive microorganisms from human sewage, animal faeces, stormwater and contaminated soils. Evidence from Nigeria has similarly demonstrated increased microbial contamination of water sources during rainy periods, when runoff can facilitate the movement of faecal material into water supplies (Porusia *et al.,* 2022).

The detection of protozoan and helminth organisms further increases the public-health significance of the findings. *Giardia* and *Cryptosporidium* are recognised waterborne pathogens, and their presence in source water is of particular concern because infection may occur through ingestion of contaminated water. WHO identifies *Cryptosporidium* and *Giardia* among important waterborne protozoan pathogens and notes that surface-water contamination and inadequate treatment can contribute to transmission (WHO, 2026). *Cryptosporidium* is particularly significant because its oocysts are highly resistant to conventional disinfection, making effective filtration and appropriate treatment important components of control (WHO, 2026). The simultaneous occurrence of coliform contamination and protozoan/helminth findings therefore provides stronger evidence of sanitary vulnerability than any physicochemical parameter considered individually.

The findings also reinforce the importance of catchment-level protection. Potential contamination pathways include human and animal faecal wastes, inadequate sanitation, domestic wastewater and runoff from contaminated areas.

The microbiological results also demonstrate why aesthetic acceptability and physicochemical compliance cannot be equated with microbiological safety. WHO considers microbial contamination to be one of the greatest risks to drinking-water safety and recommends risk-based management of hazards from the source through treatment and distribution (WHO, 2026). Accordingly, the streams should not be considered suitable for direct consumption without effective treatment and appropriate microbiological verification.

The significant stream effects and selected stream-by-season interactions indicate that local characteristics influence water quality in addition to the broader seasonal signal. Differences among streams may arise from variation in drainage characteristics, surrounding land use, vegetation cover, soil and geology, proximity to settlements, waste-disposal practices and the degree of connection between surface runoff and the stream channels. Khatri and Tyagi (2015) emphasized that surface-water chemistry is shaped by interacting natural and anthropogenic factors, making site-specific assessment essential. The broad seasonal pattern observed in the present study agrees with findings from other Nigerian surface-water systems, although the magnitude and direction of individual parameters differ among locations.

Izonfuo and Bariweni (2025) reported increased rainy-season concentrations of several dissolved nutrients and ions in Epie Creek and related the pattern to runoff and human activities. Ikhuoriah and Oronsaye (2016) likewise demonstrated seasonal and spatial variability in the Ossiomo River, showing that water chemistry can respond to both hydrological conditions and local anthropogenic activities. Kpee *et al.,* (2020) also highlighted the importance of physicochemical assessment in evaluating the quality of an urban Nigerian stream. At the same time, studies of Nigerian surface waters do not always show identical seasonal responses. For example, research in the Mamu River basin demonstrated that some parameters were seasonally variable whereas others showed little seasonal response, illustrating the influence of local hydrogeological and catchment conditions (Edori *et al.,* 2020).

However, the evidence indicates that the three streams are vulnerable to seasonal deterioration and sanitary contamination and should not be relied upon as untreated sources of drinking water. The principal management priority should be prevention of faecal and waste inputs into the streams, complemented by appropriate water treatment and continued monitoring of fluoride, microbiological indicators and other parameters that showed evidence of seasonal or spatial concern.

Conclusion

The study showed that the water quality of Idokoliko, Egaonugba and Oferoba Streams in Idah, Kogi State varies seasonally, with the greatest deterioration occurring in July. Significant temporal and spatial variations were observed in several physicochemical parameters, while elevated fluoride, sulphate, total hardness and chloride, together with low dissolved oxygen, raised important water-quality concerns. Heavy metals were generally within acceptable levels or below detection limits. However, persistent coliform contamination and the detection of *Giardia*, *Cryptosporidium* and helminths indicate significant microbiological contamination. Overall, the streams are not suitable for direct human consumption without appropriate treatment. The findings provide useful baseline information for water-quality monitoring, pollution control and sustainable management of the streams.

Recommendations

Based on the findings of this study, water from Idokoliko, Egaonugba and Oferoba Streams should not be used for drinking or food preparation without appropriate treatment, particularly during periods of increased contamination. Regular monitoring of the streams by relevant environmental and public-health authorities is recommended to track seasonal changes in physicochemical, microbiological and heavy-metal characteristics. The elevated fluoride concentrations observed in the study warrant further investigation to identify their possible sources and implications for water use. Measures should also be taken to reduce the discharge of domestic waste, faecal matter, animal waste and agricultural runoff into the streams through improved sanitation, waste management and protection of stream banks and surrounding vegetation. Periodic microbiological surveillance, especially during the rainy season, should be maintained to minimize potential public-health risks associated with untreated surface water. Further studies should include more sampling locations and sampling periods, together with investigations of rainfall, land use, groundwater interactions and other potential sources of contamination, to provide a more comprehensive understanding of the factors influencing the water quality of the streams.

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