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Research article

Qualitative and quantitative water investigation of Erin-Ijesha (Olumirin) Waterfall, Erin-Ijesha, Nigeria

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ABSTRACT

This study focused on the assessment of water quality in Erin-Ijesha (Olumirin) Waterfall, a prominent natural attraction in southwestern Nigeria. The physiochemical parameters, heavy metal concentrations, and bacteriological characteristics were examined in the upstream, midstream, and downstream sections, to ensure the resource quality and safety from harm. The results revealed notable variations in water quality. The pH, Total Dissolved Solids, Electrical Conductivity, and Temperature were highest in the midstream while Total Hardness, Alkalinity, salinity, Chloride, sulphate, Phosphate, Nitrate, Calcium, and Magnesium were highest in the downstream section. The physicochemical parameters were within the acceptable limits of World Health Organization (WHO), United States Environmental Protection Agency (USEPA), and the Standard Organization of Nigeria (SON) standards, except the pH, temperature, and Total Hardness were higher than the acceptable limits of 6.5–8.5, <25 °C or >50 °C and 50 mg/L in all the sections. Iron was above the WHO, USEPA, and SON permissible limits of 3.0 mg/L in all the sections of the river while there was no indication of copper, lead, and cadmium. Bacterial contamination, particularly the presence of E. coli, exceeded recommended safety thresholds. The Total Bacterial Count (TBC) exceeded safety limits by 0.1 million cfu/mL in the downstream. The mean of the parameters was higher in some instances, and sometimes lower than the values in the various sections of the river. A significant relationship existed between most physical, chemical, and bacteriological parameters at $p < 0.01$. The appraisal of water quality in Olumirin Waterfalls emphasizes the need for proactive measures to ensure water safety, preserve ecosystems, and promote responsible water resource management.

1. Introduction

Waterfalls are natural wonders that attract tourists and serve as sources of freshwater for surrounding communities. Olumirin Waterfall, celebrated for its natural beauty, is a natural wonder located in Nigeria and holds significant local, national, and international importance. The waterfall is not only visually captivating but also recognized for its value as a natural attraction and a potential source of freshwater on a global scale. Maintaining good water quality is a necessity for good health and environmental conservation. Below-standard water quality can hurt human health, harm aquatic life, and have detrimental effects on ecosystems. Monitoring water quality is crucial for ensuring potable water, and preserving natural environmental health.

The Olumirin waterfall is derived from a river system which is important both for its ecological value and contribution to local

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tourism and culture. This waterfall provides a unique opportunity to investigate its physicochemical, bacteriological, and heavy metal parameters, contributing to our understanding of water quality and the potential environmental implications associated with such natural wonders. The water quality at and around the waterfall is vital for the health of the local aquatic ecosystems, including plants and animals that depend on these waters for survival.

However, the increasing contamination of water bodies poses a threat to both human health and the environment. Contaminated water is a breeding ground for pathogens, leading to the spread of water-related diseases including hepatitis, diarrhea, and cholera among others. These diseases result in millions of deaths annually, predominantly affecting vulnerable populations in developing countries with limited access to clean water and sanitation [1]. In addition to microbial contaminants, chemical pollutants including heavy metals, pesticides, and pharmaceuticals can accumulate in water sources and enter the human food chain, causing chronic health issues including organ damage, developmental disorders, and even cancer [2]. The impact of contaminated water extends far beyond human health. Pollutants can disrupt the balance of these ecosystems, leading to the decline of native species and the proliferation of invasive ones [3].

Studies indicate that 3. 7 % of global diseases, and 80 % of all diseases in developing countries result from a lack of potable water and poor sanitation [4]. About 6 to 8 million people die annually from the consequences of disasters and water-related illnesses, inadequate sanitation, and poor hygiene practices [5,6]. The developing countries including Nigeria contributed majorly to the 40 percent of children aged under five global mortalities due to the consumption of unsafe water [7]. Vanguard Newspaper [8] reported that 69 million (35 %) Nigerians lack access to safe water.

The evaluation of the physicochemical, heavy metal, and bacteriological characteristics of waterfall water becomes a necessity, to ensure its safety and suitability for various purposes. Akoto and Adiyah [9] reported that contaminants including heavy metals and nitrate often infiltrate water supplies due to improper treatment, industrial discharge, and waste disposal. Since heavy metals can lead to genetic changes and cancer and can directly harm humans and other living things, they have been studied closely [10,11]. Chemical parameters like salinity, chloride, sulphate, phosphate, nitrate, calcium, and magnesium can be present in surface water due to a combination of natural processes and human activities. The composition of nearby rocks, vegetation decomposition, agricultural runoff, urbanization, industrial discharges, atmospheric deposition, and human interactions such as tourism and geological factors can introduce these parameters.

In West Africa, Nigeria stands out as a country with a rich diversity of ecosystems, making water quality research critical for the preservation of natural resources [12]. The effect of natural and human activities on the physiochemical, bacteriological, and heavy metal parameters of waterfalls remains poorly understood. The few existing studies on Olumirin waterfall encountered restricted

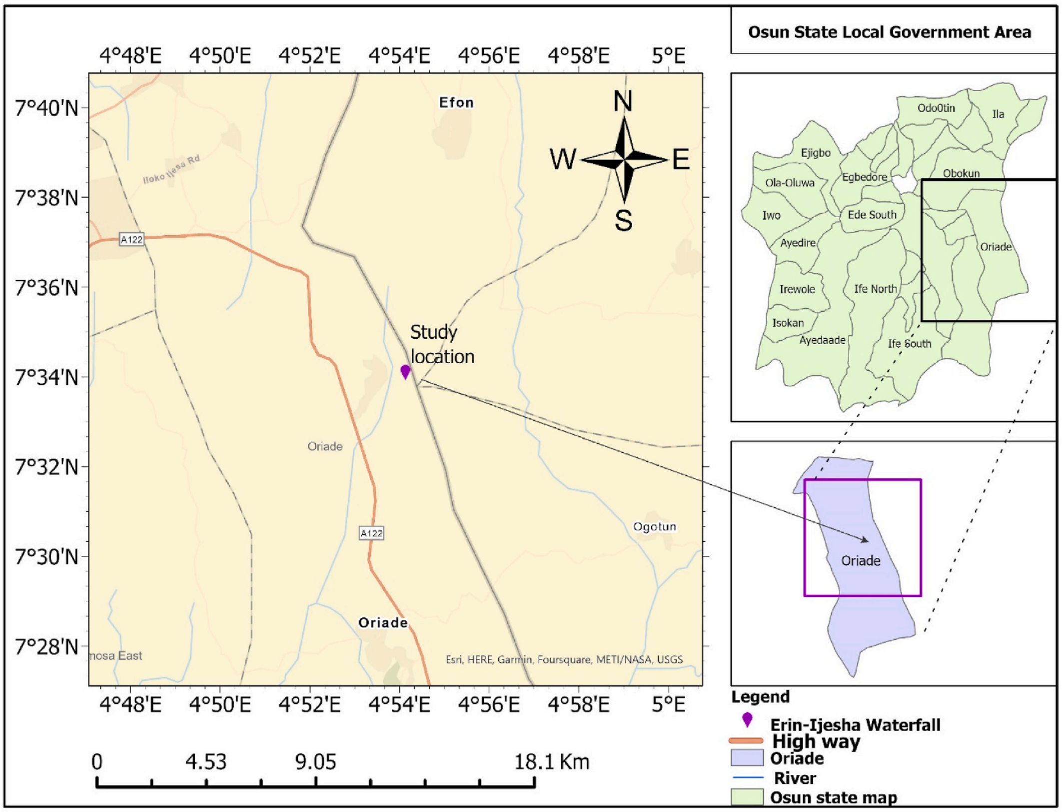

Fig. 1. The location of Erin-Ijesha waterfall in Osun State, Nigeria.

parameters, subject to limited research regarding physicochemical, bacteriological, and heavy metal characteristics, and were limited to a section of the river [13,14]. Oyekanmi et al. [15] examined water quality parameters of Olumirin waterfall concerning the availability of Caridina africana in Erin-Ijesa, Nigeria while Olubunmi-Ojo et al. [16] assessed the perception of tourist and community development of Olumirin Erin Ijesha Waterfall. The inadequate literature and detailed investigation of the parameters in the waterfall create a notable gap in understanding the water quality and identifying potential environmental implications.

The study aims to address these limitations by conducting a thorough assessment of water quality at Olumirin Waterfall at the upstream, midstream, and downstream sections. For detailed analysis, twenty-two (22) parameters including 13 physiochemical parameters, 4 heavy metals, and 5 bacteriological parameters were examined. The study aimed to qualitatively and quantitatively assess the heavy metals, physiochemical characteristics, and bacteriological contamination in Olumirin Waterfall, Erin-Ijesha. The research objectives are to.

i. Determine the physical and chemical parameters of the waterfall in the study area.
ii. Evaluate the level of heavy metals in the study area.
iii. Assess the bacteriological quality of the waterfall in the study area
iv. Examine the relationship between the physical, chemical, and bacteriological parameters in the study area
v. Compare the water quality to both national and international water quality standards.

2. Materials and methods

2.1. Study area

The Erin-Ijesha (Olumirin) Waterfall is located in Erin-Ijesha, Oriade Local Government.

Area, Osun State, Nigeria. The geographical coordinates fall between latitude 7° 27′N and 7°.

37′N and longitude 4° 51′E and 4° 54′E (Fig. 1). The location of Olumirin Waterfall Erin- Ijesha waterfall is an assemblage of seven distinct cascades.

Culturally, it is believed that the waterfalls exude from a big pot located at the top of the ridge and that each step of the waterfall has a flowing fountain that marks the mystical nature of the place [17]. Resources and community conflict are forbidden by Erin-Ijesha residents because any abuse of prescribed social laws prompts personal or communal rituals and sacrifices to pacify spirits that dwell in the physical spaces to maintain social balance and harmony. The Erin-Ijesha residents' strict obedience to conservative rules and veneration of the Erin-Ijesha/Olumirin waterfall deity is mainly obligatory for fear of divine retribution and social imbalance [18]. The waterfall attracts tourists who end up buying local produce and hence boosts the economy by revenue generation for the locals. Fishing can be carried out on waterfalls and the fish sold to get income and improve the living standards of people. The climate of Olumirin Waterfall is tropical, characterized by wet and dry seasons. The wet season, from March to October, brings heavy rainfall and higher humidity [19–22]. In contrast, the dry season, spanning November to February, experiences lower rainfall, higher temperatures, and reduced humidity. The two seasons are controlled by the inter-tropical discontinuity (ITD) that moves in a north-south direction [23–29]. The occurrence of the wet season in a particular geographical area is associated with the inland movement of the ITD and the dominance of the tropical maritime air mass from the Atlantic Ocean while the dry season is

associated with the southward movement of the ITD and tropical continental air mass from the Sahara Desert [30–37].

The relief of the study area, Olumirin Waterfall likely consists of topographical features such as hills, valleys, and other landforms that make up the physical landscape [38]. The projecting hills at Erin-Ijesa are within the range of 1200 to 1300 feet above sea level. The specific relief features can significantly influence the area's hydrology, vegetation, and overall environment. The Olumirin Waterfall itself is a notable relief feature, creating a cascading watercourse from elevated areas to lower levels. Additionally, the surrounding region has a gently rolled landscape, as the waterfall is located in the hilly and mountainous southwestern part of Nigeria.

The vegetation at Olumirin Waterfalls is diverse and includes a variety of plant species.

This ecosystem, possibly a tropical rainforest or gallery forest, exhibits changes in plant types-based moisture and elevation. Dominant plant species are abundant and crucial for the local environment. These plants have adapted to the unique conditions around the waterfall, including high humidity and mist. They play important ecological roles, such as maintaining water quality, providing habitat for wildlife, and preventing soil erosion.

2.2. Sample collection

The sample collection was carried out by grabbing methods from three distinct locations (upstream, midstream, and downstream sections) within the study area in May 2023. This method was used because of the advantage of the flexibility in sampling location selection and very little equipment is required for sample collection. The method is also advantageous for parameters that cannot be accurately, or quickly, measured in the field or in situ. A purposive sampling technique was adopted for the sample selection. A total of 9 water samples were collected in 1-liter plastic for assessment of the 22 parameters (13 physiochemical parameters, 4 heavy metals, and 5 bacteriological parameters. The physiochemical parameters assessed include the pH, Temperature (Temp.), Electrical Conductivity (EC), Total Dissolved Solid (TDS), Alkalinity, Salinity, Total Hardness (TH), Chloride (Cl^-), Sulphate (SO_4^{2-}), Phosphate (PO_4^{3-}), Nitrate (NO^3), Calcium ($^{2+}_{Ca}$), and Magnesium (Mg^{2+}) while the heavy metals include Iron (Fe), Cadmium (Cd), Lead (Pb), and Copper (Cu). The bacteriological parameters comprise Total Bacterial Count (TBC), Escherichia coli, Klebsiella spp., Staphylococcus aureus, and Enterobacter spp. The plastic bottles were sterilized and rinsed with distilled water and later with a small quantity of the sample. Gloves were worn to avoid contamination during the sample collection. The samples were stored in an iced cooler for preservation so it will retard the chemical and biological changes at each designated point.

2.3. Data analysis

2.3.1. Physiochemical analysis of water sample

The physical characteristics of the water samples were evaluated using the established

and widely accepted methods outlined by the American Public Health Association. This includes pH, Electrical Conductivity (μS/cm), Total Dissolved Solids (mg/L), and Temperature (°C). They were carried out in situ using a size HANNA COMBO pH/TDS/Conductivity meter, a water sample from each of the distinct points was poured into a beaker, and the probe meter was rinsed with distilled before it was inserted into it to determine the various parameters. It was allowed to stay in the sample till the timer was stabilized for reading, the meter displays the value of pH and temperature first, then when the mode button is pressed its value for electrical conductivity and total dissolved solids shows on the screen. The electrical conductivity (EC) was recorded in us/cm, the temperature in °C while the total dissolved solids (TDS) was in mg/L. The samples collected in 1-liter plastic bottles were transported safely to Apex Laboratory, Ibadan, where the spectrophotometry method was used to analyze the level of nitrate and phosphate while titration was carried out for the total hardness, alkalinity, and chloride.

2.3.2. Heavy metals analysis of water samples

Iron (Fe), Cadmium (Cd), Lead (Pb), and Copper (Cu) are the heavy metals analyzed in this study. As proposed by Kumar et al. [2], these metals were determined after digestion, using an Atomic Absorption Spectrophotometer (Buck Scientific, Model 210). A 100 mL water sample was subjected to a digestion process using 10 mL of nitric acid for 2 h, carried out on a digestion block. The purpose of adding nitric acid was to mineralize the solution. Subsequently, the sample was heated on a hot plate to 150 °C till the volume declined to 20 mL after digestion, the sample was allowed to cool and later diluted to 50 mL using distilled water and a 50 mL volumetric flask. To measure the levels of heavy metals, an Atomic Absorption Spectrophotometer (specifically, the Buck Scientific Model 210 VGP) was employed and it was carried out at Apex Laboratory, Ibadan, Nigeria.

2.3.3. Bacteriological analysis of water sample

The water bacteria coliform count was analyzed using the plate count method, as proposed by Gorsuch et al. [39] following ASTM D5465 standards. In the laboratory procedure, the sample was serially diluted in sterile water and then cultured on nutrient agar. Different incubation conditions were used, with one set of plates incubated at 22 °C for 24 h and another set at 37 °C for the same duration. The nutrient medium often included substances that inhibited the growth of non-target organisms and enabled easy identification of the target bacterium, usually through a change in the medium's color. After the incubation period, colony counting was done by eye, which was a quick process and did not require a microscope, as the colonies were typically a few millimeters in size. The analysis was carried out at Apex Laboratory, Ibadan, Nigeria.

2.4. The mean and correlation analysis of the water sample parameters

The physiochemical, bacteriological, and heavy metal parameters were subjected to descriptive and inferential statistics. The mean and bivariate correlation were employed to determine the proper description of the sample and correlation between each of the parameters tested to the water quality of both the National and International water quality standards.

Table 1
Physicochemical parameters, the mean, and acceptable International and National water quality standards of WHO [41,42], USEPA [43] and SON [44].

Parameters	Upstream	Midstream	Downstream	Unit	Mean	WHO (mg/L) [41,42]	USEPA [43]	SON (mg/L) [44]
Ph	8.88	9.18	8.81	–	8.96	6.5–8.5	6.5–8.5	6.5–8.5
TDS	8	12	10	mg/L	10	500	500	500
EC	14	24	20	μS/cm	19.33	1000	>1000	1000
Temperature	26.5	27.6	26.4	°C	26.83	<25 °C (Cold) or >50 °C (Hot)	–	–
Total hardness	96.81	102.71	116.28	mg/L	105.27	200	–	50
Alkalinity	145.38	161.43	185.12	mg/L	163.97	100	–	100
Salinity	0.006	0.010	0.012	mg/L	0.009	<600	–	–
Magnesium	0.73	0.78	0.83	mg/L	0.78	30	35	20
Chloride	48.3	54.1	68.2	mg/L	56.87	250	250	250
Sulphate	0.22	0.29	0.31	mg/L	0.27	200	250	200
Phosphate	0.98	1.09	1.16	mg/L	1.08	12	10	–
Nitrate	1.93	2.81	4.261	mg/L	3.02	10	10	50
Calcium	0.83	0.98	2.21	–	1.34	75	–	75

3. Results and discussion

3.1. The physicochemical parameters of water samples in Olumirin waterfalls

The physicochemical parameters of water samples in Olumirin waterfalls, Erin-Ijesha, Osun State are shown in Table 1. The pH measures water acidity or alkalinity logarithmically on a scale from 0 to 14. Seven (7) shows neutrality while the values below and above 7 indicate acidity and alkalinity respectively [40]. The pH significantly impacts aquatic ecosystems by influencing the survival and growth of aquatic organisms, chemical reactions, corrosion, drinking

water, agriculture, and industries. The pH values at different sampling points vary slightly. The values ranged from 8.81 to 9.18, and the highest pH value of 9.18 was recorded in the midstream while the lowest (8.81) was recorded in the downstream section. Both the upstream and midstream values were higher than the 6.5–8.5 permissible limits of WHO and SON. Based on the provided pH values, this can have several implications, including potential health concerns, the risk of corrosion or scaling in plumbing systems, impacts on aquatic life and ecosystems, and potential effects on the palatability of water. The causes of elevated pH levels could be a result of geological formations, and human activities, such as industrial discharges and tourism-related contaminants.

Total hardness (TH) in water relates to the concentration of certain minerals, mainly magnesium, and calcium, which can make water " hard" [45–47]. The value of TH ranged from 8 mg/L to 12 mg/L. It was highest in the midstream (12 mg/L) and lowest in the upstream section (8 mg/L) and these fall in the moderately hard water level. It is within the typical range (200 mg/L of WHO and 50 mg/L of SON) for most drinking water and should not pose health concerns. Total hardness measurements offer insights into the water's capacity for forming precipitates, which can affect plumbing systems and equipment [48].

The TDS also varied from 8 mg/L in the upstream section to 12 mg/L in the midstream. These values are within the 500 mg/L permissible limits of both national standard limits [44] and international standards [41–43]. The TDS in water represents the total concentration of dissolved substances including minerals, salts, metals, and organic compounds [49,50], and it is an indicator, offering insights into water composition, salinity, hardness, and potential contaminants. TDS measurements offer useful information concerning nutrient levels, corrosion potential, and the suitability of water for various applications, including drinking, industrial processes, and aquatic ecosystems [51].

Electrical conductivity quantifies the ability of water to conduct electrical current, reflecting the presence of dissolved ions and salts, serves as an indicator of salinity levels, aiding in the understanding of water composition, and conductivity, indirectly offers insights into nutrient concentrations, serving as a substitute for potential contamination from pollutants [50]. EC levels can vary depending on the specific region and its natural geological conditions. However, a general guideline for EC in drinking water is that it should be below 800 μS/cm, but this can vary [52]. The result of electrical conductivity was 14 μS/cm in the upstream, 24 μS/cm in the midstream, and 20 μS/cm in the downstream. The EC is within the acceptable limits (1000 μS/cm) of WHO [41,42], USEPA (43), and SON [44].

Temperature, the degree of heat or coldness present in a water sample influences the behavior and growth of aquatic organisms, impact dissolved oxygen levels, and contribute to thermal stratification [53]. The temperature influences biological activity and the solubility of chemical compounds. The temperature of the river ranged from 26.4 °C in the downstream section to 27. 6 °C in the midstream section. The WHO recommended that water temperatures should be kept outside the range of 25–50 °C and preferably outside the range of 20–50 °C to prevent the growth of Legionella [41]. The temperature should be less than 25 °C for cold water and above 50 °C for hot water.

Alkalinity denotes the water's capacity to resist changes in pH when acids are introduced, helping to stabilize pH changes [54]. It allows for the understanding of the balance in water chemistry and its impact on the health of ecosystems and human activities [55]. Alkalinity ranged from 145.38 mg/L to 185.12 mg/L. The value was lowest in the upstream section and increased as it flowed through the midstream to the downstream section where it was highest. It is relatively high and suggests that the water in the downstream has a strong capacity to resist pH. The alkalinity in the three sections was above the 100 mg/L allowable standard limits of WHO, and SON. Alkalinity in water measures its capacity to neutralize acids and maintain a stable pH [56].

Salinity measures sodium and chloride ions (dissolved salts) in water [57]. Salinity allows an understanding of the complex interplay between water quality, ecological dynamics, and human activities. The salinity ranged from 0.006 mg/L to 0.012 mg/L which implies the samples contain low salinity and are within acceptable limit of >600 mg/L of WHO for drinking water.

Sulphate is a chemical compound that can be found in water. Sulphate measures the sulphate ions concentration in the water including discharges from the industries and geological processes, and influences the water's acidity and alkalinity. Sulphate levels in water are an important parameter in assessing water quality [58]. The sulphate level ranged from 0.216 mg/L in the upstream section to 0.314 mg/L in the downstream and is within the 200 mg/L acceptable limits of WHO, and SON, as well as the 250 mg/L standard limits of USEPA.

The phosphate levels at the different sampling points are relatively moderate ranging from 0.982 mg/L to 1.162 mg/L, and fall within the 12 mg/L and 10 mg/L permissible limits of WHO, and USEPA respectively for potable water. Phosphate concentration assessment assists in identifying any shifts in water quality due to anthropogenic influences [59].

Chloride measures the concentration of chloride ions present in water and derived from salts, pollutants, and industrial processes. It influences pH and nutrient availability in water. Chloride varied from 48.3 mg/L to 68.2 mg/L. Chloride increased in the river as it flowed from upstream (48.3 mg/L) to downstream (68.2 mg/L). The values are within the standard limit of 250 mg/L for both National and International drinking water standards of SON, WHO, and USEPA. Chlorides are present in all-natural water and are major anions in water. Sedimentary rocks are a major source of chloride in water [60] and this could have been the underline source of chlorine in the waterfall.

The nitrate concentrations in the samples ranged from 1.934 mg/L to 4.261 mg/L, indicating that the water is suitable for drinking, and meets the regulatory guidelines of 10 mg/L for WHO, and USEPA, and 50 mg/L for SON. The low concentration of nitrate could be due to low dissolved oxygen concentration in the river, human and animal sewage, fertilizer, and so on [60,61]. These findings suggest that the nitrate content in the water samples poses no significant health risks based on the established water quality standards. However, high nitrate concentration

results in cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months.

Calcium in water is generally not harmful and is, in fact, an essential mineral for human health. It is a key component of water hardness and can contribute to the taste and quality of potable water [62]. The calcium levels in the water samples were assessed, and their concentrations ranged from 0.83 mg/L to 2.21 mg/L. The values were low and within the permissible limits of 75 mg/L for drinking water quality for WHO and SON standards. The possible cause of higher values in the midstream is due to more anthropogenic activities in that particular layer by tourists.

Magnesium levels can originate from geological sources and human activities such as agriculture and runoff. Magnesium varied from 0.73 in the upstream to 0.83 mg/L in the downstream in the study area. The highest value was recorded in the downstream while the lowest was recorded in the upstream section of the river. Magnesium is very low and within the 20 mg/L, 30 mg/L, and 35 mg/L permissible standard limits of SON, WHO, and USEPA respectively. Khan et al. [63] and Iyer [64] reported that dolomite in sedimentary rocks and serpentines and tremolites in metamorphic rocks are major sources of magnesium in water. The low level of magnesium could have been because of the less underlying sedimentary and metamorphic rocks in the study area. The advantages of magnesium within the allowable limits of portable water standards include adjustment of blood glucose levels, steady heartbeat, strong bones, and blood pressure regulation, among others [47]. A very low or very high level of magnesium results in diarrhea, nausea, Alzheimer's disease, bronchial asthma, and migraine while elevated magnesium results in hypertension, cardiovascular disease, and so on [65–67].

3.2. *The heavy metals of water samples in Olumirin waterfall, Erin-Ijesa*

Iron results from natural sources and anthropogenic sources including the weathering of rocks, sediments, industrial discharges, agricultural runoff, and so on [68]. The presence of iron (Fe) in water samples, with measured values of 0.410 mg/L, 0.301 mg/L, and 0.382 mg/L in the downstream, midstream, and upstream (Fig. 2). The highest iron concentration was recorded downstream and the lowest in the midstream. Iron was above the 0.3 mg/L permissible limit of WHO, USEPA, and SON in all sampling points. Excessive iron in drinking water can result in undesirable taste, staining of plumbing fixtures, and potential health concerns [69].

The value of copper, cadmium, and lead in the study area is 0.00. Copper in water results from natural geological processes and human activities such as industrial runoff and agricultural practices [70,71]. Though essential in trace amounts for some biological functioning, elevated levels of copper are harmful to the ecosystem and humans. Too much copper can be fatal. It is essential to ensure that copper levels remain within regulatory standards to maintain safe drinking water quality. Lead results from industrial emissions, urban runoff, and aging infrastructure [72]. The sources of cadmium include fossil fuels (coal and oil), smelters, and incineration of urban municipal waste (plastics and nickel-cadmium batteries). Lead and cadmium are toxic heavy metals that can contaminate water sources and can harm the ecosystem and man, particularly children. The 0.000, 0.000, and 0.000 values of copper, cadmium, and lead

at the various sampling points indicate the absence of the metals in the water. This is an indication that the water resource is free from these heavy metals and falls within the WHO, USEPA, and SON 1.3 mg/L, 0.005 mg/L, and 0 mg/L permissible limits for drinking

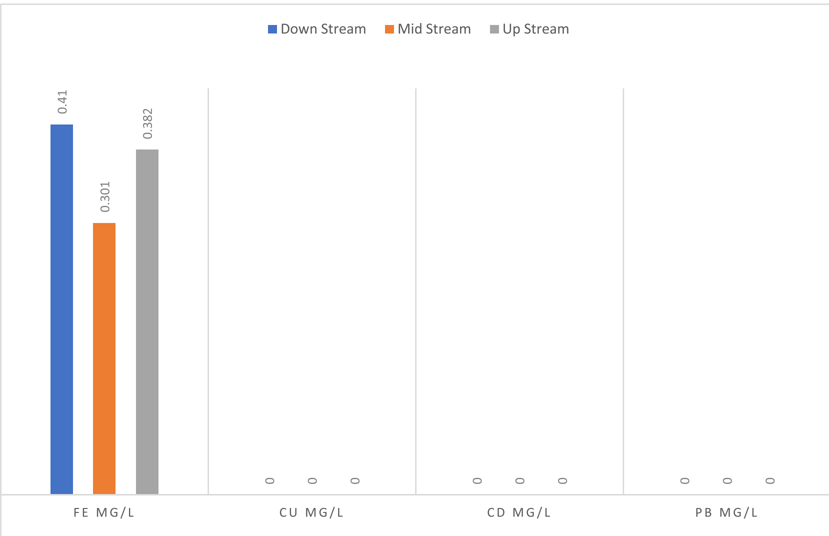

Fig. 2. The heavy metals across the sampling points in Olumirin Waterfall, Erin Ijesa.

water standards.

3.3. Bacteriological characteristics of water samples in Olumirin Waterfalls

Bacteriological parameters are crucial indicators of microbial contamination and the potential risks associated with waterborne pathogens. Microorganisms, such as total coliforms

and E. coli, reveal fecal contamination and serve as proxies for the presence of harmful bacteria, viruses, and other pathogens [73]. In the assessment of water quality, several bacterial coliform counts were analyzed across the sampling points. These counts included Total Bacterial Count (TBC), Escherichia coli, Klebsiella spp., Staphylococcus aureus, and Enterobacter spp. (Fig. 3).

TBC serves as a comprehensive measure of overall bacterial contamination which is the total number of bacteria (both living and dead) in the sample [74]. The Total Bacterial Count exceeds the established threshold for safe water quality by 0.1 million colony-forming units per milliliter (cfu/mL) downstream. The water sample contains a higher concentration of bacteria than the recommended limit of drinking water standard for total coliform bacteria, which is typically set at zero (0) or below 1 colony-forming unit per 100 mL (cfu/100 mL) for safe water use. This means total coliform bacteria should be absent in potable water. The effect of this exceedance may include increased health risks, potential waterborne illnesses, and the need for water safety measures. Furthermore, environmental impacts and regulatory compliance issues may arise due to the elevated bacterial counts. Lower bacterial counts are generally preferred for drinking water, as higher bacterial counts may indicate potential contamination and pose a risk to human health [75].

The presence of E. coli in water can suggest that the water may be contaminated with fecal matter, and this can pose a health risk if the water is used for drinking or recreational purposes. The coliform bacteria in human feces, especially adults are about 2,000,000,000 each

day, on an average basis [4]. The E. coli is low in the river but increases gradually as the river flows from 0.4 cfu/mL in the upstream to 0.8 cfu/mL in the downstream section (Fig. 3). WHO stablished that the Maximum Contaminant Level (MCL) for bacteria in drinking water is zero total coliform colonies per 100 mL of water. *Escherichia coli* (*E. coli*) or thermotolerant coliform bacteria must not be detectable in any 100 mL sample [39,40]. In other words, a zero count of E. coli per 100 mL of water is considered safe for drinking. Also, a count of 1–10 MPN/100 mL is regarded as low risk while a count of 11–100 MPN/100 mL is medium risk. E. Coli causes urinary tract infections, bacteremia, meningitis, diarrhea, (one of the main causes of morbidity and mortality among children), acute renal failure, and hemolytic anemia [76].

Klebsiella species in water is an indicator of bacterial contamination, it underscores the need for water quality assessment and treatment, particularly when the water is intended for human use [77]. Klebsiella Spp reduced from 0.3 cfu/mL in the upstream to 0.2 cfu/mL in the midstream and was not detectable downstream. The occurrence of these bacteria in water is an indication of

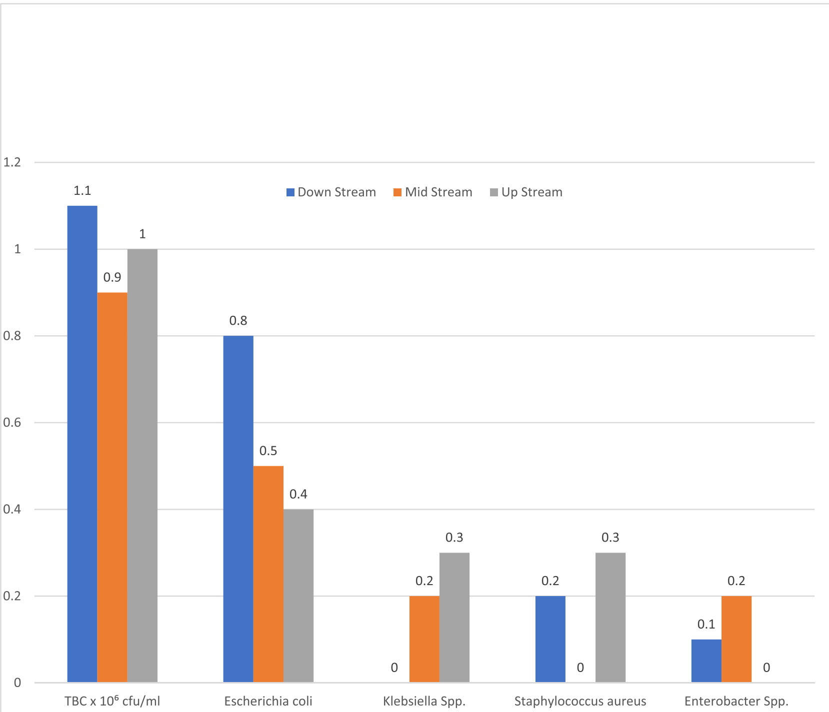

Fig. 3. Bacteria count across the sampling points in the study area. **NOTE:** TBC x 10^6 cfu/mL = Number of viable bacteria x serial dilution ratio/ volume of inoculum.

Table 2
Correlation of physical and chemical parameters in Olumirin Waterfall.

	Ph	TDS	EC	Temp.	Total HardNess	Alkalinity	*Sali nity*	*Chlo ride*	Sulphate	Phosphate^{-}	Nitrate	*Cal cium*	Magnesium
pH	1												
TDS	0.763[b]	1											
EC	0.684[b]	0.993[b]	1										
Temp.	0.995[b]	0.826[b]	0.756[b]	1									
Total Hardness	−0.392[a]	0.295	0.403[a]	−0.294	1								
Alkalinity	−0.286	0.401[a]	0.504[b]	−0.185	0.994[b]	1							
Salinity	0.011	0.655[b]	0.737[b]	0.115	0.916[b]	0.955[b]	1						
Chloride	−0.403[a]	0.283	0.391[a]	−0.306	0.994[b]	0.992[b]	0.910[b]	1					
Sulphate	0.086	0.709[b]	0.785[b]	0.188	0.883[b]	0.930[b]	0.997[b]	0.877[b]	1				
Phosphate	−0.083	0.581[b]	0.670[b]	0.021	0.949[b]	0.979[b]	0.996[b]	0.945[b]	0.986[b]	1			
Nitrate	−0.315	0.373[a]	0.477[b]	−0.215	0.997[b]	0.983[b]	0.946[b]	0.995[b]	0.919[b]	0.972[b]	1		
Calcium	−0.566[b]	0.101	0.214	−0.478[b]	0.980[b]	0.952[b]	0.818[b]	0.983[b]	0.773[b]	0.868[b]	0.961[b]	1	
Magnesium	−0.100	0.567[b]	0.657	0.004	0.955[b]	0.982[b]	0.994[b]	0.951[b]	0.983[b]	0.997[b]	0.976[b]	0.877[b]	1

[a] R is significant at 0.05 level ([a]$\alpha \leq 0.05$).
[b] R is significant at 0.01 level ([a]$\alpha \leq 0.01$).

contamination with human or animal waste or other potential sources of bacteria [78].

The downstream and upstream alone contained Staphylococcus aureus with counts of 0.3 and 0.2 cfu/mL at the upstream and downstream sections of the waterfall, raising concerns about potential bacterial contamination. The reason for the disappearance in the midstream is unknown. Monitoring and testing for Enterobacter in water are essential for assessing water quality and ensuring it meets safety standards [75].

The presence of Enterobacter started from the midstream section (0.2) and reduced to 0.1 at the downstream section. This shows that the pathogen responsible for these bacteria was introduced to the river in the midstream, and could have been as a result of human interaction. Odeyemi et al. [13] reported that the bacteria strains showed high levels of resistance to some antibiotics such as ampicillin (76 %), cotrimoxazole (60 %), gentamicin (19 %), nalidixic acid (31 %), nitrofurantoin (24 %), colistin (48 %), streptomycin (34 %), and tetracycline (52 %).

3.4. The mean and correlation analysis of water samples in Olumirin Waterfall

The mean values of the physicochemical parameters of EC, and Magnesium were higher than the upstream values but lower than the values of the midstream and downstream sections (Table 1). The mean values of TDS, pH, and Temperature were lower than in the midstream section but higher than in the other 2 sections. The TH, alkalinity, salinity, Cl, sulphate, phosphate, nitrate, and calcium values were higher than the mean in the downstream section but less in the upstream and midstream section.

The presence of the heavy metal of iron in the upstream and downstream sections of the

river is higher than the mean of 0.36 mg/L. However, copper, cadmium, and lead were not detected in the river. Both the values of iron in each of the sections and the mean value were higher than the acceptable standard limits for potable water.

The values of TBC and E. Coli were higher in the downstream section than the mean of 1.0 million cfu/mL and 0.57 cfu/mL respectively. Klebsiella Species in the downstream, Staphylococcus aureus in the midstream, and Enterobacter Species in the downstream were not detectable. The 0.25 mean of Klebsiella species and Staphylococcus aureus value was lower than

the upstream values. Enterobacter species value is higher than the mean in the midstream.

Correlation shows a significant relationship between the physicochemical parameters. All the physicochemical parameters related to one another, mostly at $p > 0.01$, and on very few occasions at $p > 0.05$ (Table 2). Temperature is significantly related to other physical parameters of pH, TDS, and EC, and only calcium as a chemical parameter at $p > 0.01$. All the chemical parameters are related to one another at a 99 % confidence level. In like manner, all the physical parameters are related to one another at $p > 0.05$. However, the physical parameters are significantly related to the chemical parameters at $p > 0.01$ in some instances, and $p > 0.05$ on a few occasions. For instance, pH is significantly related to total hardness, chloride at $p > 0.05$, and calcium at $p > 0.01$ but not with the other chemical parameters. Also, the pH is significantly related to other physical parameters of temperature, TDS, and EC.

Significant relationships existed among the various bacteria in the water. TBS is significantly related to *E. coli,* Klebsiella species, and Staphylococcus aureus at $p > 0.01$ (Table 3). Klebsiella species is significantly related to E. coli while Enterobacter spp. and Staphylococcus aureus were significantly related at $p > 0.01$.

4. Conclusion

The study has examined the physiochemical parameters, heavy metal concentrations, and bacteriological characteristics of the waterfall in the upstream, midstream, and downstream sections. The water quality varied in the various sections and among various parameters. The physical parameters were higher in the midstream while chemical parameters were higher in the downstream section. Most of the physicochemical parameters were within the national and international potable water standards hence, suitable for human consumption. Iron was the only heavy metal present in the water and could cause harm because it was above water standards.

Bacterial contamination, particularly the E. coli and the Total Bacterial Count (TBC) exceeded safety limits and could be injurious to human health, especially in the downstream section of the river.

The geological formations, dissolved substances (minerals, salts, etc.), human activities

including agricultural runoff, and tourism-related contaminants such as chemical use of products, bathing and swimming by tourists, and poor waste management techniques resulting in fecal contamination are the factors responsible for the variation of the parameters across the different locations where samples were collected. The solution to these problems lies in the shielding of water sources from potential pollution and contamination. The government should build septic tank toilets and engage in community

Table 3
Correlation of bacteriological parameters in Olumirin Waterfa
ll.

	TBC	Escherichia coli	Klebsiella Spp.	Staphylococcus aureus	Enterobacter Spp.
TBC	1				
Escherichia coli	0.721[b]	1			
Klebsiella spp.	−0.655[b]	−0.996[b]	1		
Staphylococcus aureus	0.655[b]	−0.052	0.143	1	
Enterobacter spp.	−0.500	0.240	−0.327	−0.982[b]	1

[a] R is significant at 0.05 level ([a]$\alpha \leq 0.05$).
[b] R is significant at 0.01 level ([a]$\alpha \leq 0.01$).

partnerships for water resource protection. Farmers in the vicinity of the waterfall should use fertilizers and pesticides sparingly, while tourists should invest in a travel-friendly refillable water bottle, maintain proper waste disposal, and stop smoking in the vicinity of the resource because cigarette butts are a huge source of pollution.

5. Data availability statement

Data is available in the journal article.

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Ethics Declarations

Review and/or approval by an ethics committee was not needed for this study because it is a required project in the Department of Water Resources Management and Agrometeorology.

Declaration of conflict of interest for qualitative and quantitative water analysis of Erin-Ijesha (Olumirin) Waterfall, Erin-Ijesha, Nigeria

The author declares that there is no conflict of interest regarding the publication of the article titled 'The qualitative and quantitative water analysis of Erin-Ijesha (Olumirin) Waterfall, Erin-Ijesha, Nigeria.

CRediT authorship contribution statement

Joseph O. Adejuwon: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Faith I. George:** Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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