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Quality Assessment of Ground and Surface Water Resources in Ekori, Yakurr Local Government Area, Cross River State

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Abstract: Water quality is a major concern in many developing regions, where access to safe drinking water is often limited. This study evaluates the physicochemical, bacteriological, and heavy metal characteristics of surface and groundwater resources in Ekori, Yakurr Local Government Area, Cross River State, Nigeria. A total of seven (7) water samples were collected in April 2018 and analyzed for key water quality parameters, including pH, turbidity, total dissolved solids (TDS), hardness, chloride, nitrate, sulfate, phosphate, iron, manganese, lead, chromium, and microbial contamination. The results revealed that pH ranged from 5.10 to 6.63, indicating slightly acidic conditions, particularly in surface water (SW1: 5.10), which falls below the NSDWQ limit of 6.5 – 8.5. Turbidity levels exceeded the recommended 5.0 NTU limit in surface water (SW3: 18.5 NTU, SW2: 13.7 NTU), while hardness was significantly high in groundwater (GW3: 256.3 mg/L, GW1: 222.3 mg/L). Heavy metal analysis showed that iron (SW2: 0.81 mg/L), manganese (SW2: 0.36 mg/L), and chromium (GW2: 0.05 mg/L) exceeded WHO permissible limits, posing potential health risks. Total coliform (TCC) and fecal coliform (FCC) counts were too numerous to count (TNTC) in surface water, indicating severe bacterial contamination. The findings suggest that groundwater is preferable but requires treatment for metal contamination, while surface water is unsuitable for direct consumption. Recommended interventions include pH correction, heavy metal filtration, and disinfection to improve water safety in the region.

Keywords: Water Quality, Heavy Metals, Bacteriological Contamination, Water Treatment, Ekori Community, Groundwater, Surface Water.

I. INTRODUCTION

Water is an essential resource that supports human life, agriculture, and industrial activities. Access to clean and safe drinking water remains a fundamental human right, yet millions of people worldwide continue to suffer from waterborne diseases caused by contaminated water sources [19]. The quality of water resources is influenced by both natural processes and human activities, including industrial discharge, agricultural runoff, and improper waste disposal [1]. In Nigeria, water pollution is a major environmental and public health challenge, especially in rural communities where groundwater and surface water serve as primary drinking water sources [2]. Contaminants such as heavy metals, microbial pathogens, and excessive nutrients pose serious risks to human health and aquatic ecosystems [3]. Studies have shown that uncontrolled agricultural practices, deforestation, and urban expansion contribute significantly to the deterioration of water quality across the country [4].

Ekori community in Yakurr Local Government Area of Cross River State depends on both surface and groundwater resources for domestic, agricultural, and drinking purposes. However, increasing concerns regarding waterborne diseases, heavy metals, and microbial contamination have raised doubts about the safety of these water sources. This study evaluates the physicochemical, bacteriological, and heavy metal characteristics of water in Ekori, comparing all findings with national and international standards to determine potability based on NSDWQ (2008) and WHO guidelines [17], [19].

The availability of potable water is a key driver of public health and socioeconomic development [5]. Contaminated water sources are known to cause cholera, typhoid fever, diarrheal diseases, and long-term exposure risks associated with heavy metal toxicity [6]. Assessing parameters such as pH, turbidity, total dissolved solids (TDS), nutrients, and microbial load is essential for determining water suitability [7]. Surface water bodies—streams, rivers, and lakes—are highly susceptible to pollution due to their open exposure to runoff from agricultural lands and residential settlements [8]. Although groundwater generally undergoes natural filtration, it can still be contaminated through leaching of metals, industrial effluents, and poorly constructed wells [9]. The interaction between geological processes and anthropogenic activities often determines the extent of contamination in groundwater sources [10]. Continuous monitoring of water quality helps identify pollution sources and guides policymakers in implementing sustainable water management strategies. This study contributes to such knowledge by evaluating potential contamination indicators and recommending appropriate treatment methods for Ekori residents.

Physicochemical characteristics such as pH, temperature, turbidity, and dissolved oxygen greatly influence overall water quality [7]. The pH of water affects its corrosivity and solubility of heavy metals, with acidic conditions increasing risks of metal leaching [11]. Conductivity, which measures ionic content, reflects the presence of dissolved salts and minerals and may indicate geological influences or pollution from anthropogenic sources [13]. Elevated turbidity—often resulting from erosion, sewage discharge, or industrial effluent—reduces water clarity and can harbor pathogenic organisms [22].

Microbial contamination remains a major challenge in rural communities where sanitation is poor [4]. The presence of total and fecal coliforms indicates fecal pollution and significantly increases the risk of waterborne disease outbreaks [18]. WHO recommends that safe drinking water contain zero coliform organisms per 100 mL [19].

Heavy metals such as iron (Fe), manganese (Mn), lead (Pb), and chromium (Cr) occur naturally in water due to geological processes but may also enter water bodies through mining activities, agricultural runoff, and industrial discharge [16]. While trace amounts of certain metals are essential, high concentrations can lead to neurological damage, kidney dysfunction, developmental disorders, and carcinogenic effects [14], [21]. In Nigeria, several studies have reported elevated levels of Fe, Mn, and Pb in groundwater, particularly in areas with industrial or automobile-related activities [15], [12]. Effective treatment approaches such as coagulation, activated carbon filtration, and ion exchange are often required to remove heavy metals from drinking water [19].

Previous research across Nigeria highlights common issues including high microbial loads, low pH, excessive turbidity, and metal contamination [23]. Surface water sources in southwestern Nigeria have been reported to contain high coliform levels, indicating pollution from sewage and agricultural runoff [4]. Rivers in North-Central Nigeria have shown turbidity levels exceeding WHO limits [22], while borehole water in mining communities often contains lead concentrations above permissible levels [18]. Iron and manganese contamination has also been documented in groundwater across Cross River State, showing consistency with patterns expected in the present study area [16]. Such findings reinforce the need for ongoing water quality monitoring and improved treatment practices in rural Nigerian communities.

II. METHODOLOGY

Water quality assessment requires a systematic approach that includes the collection, analysis, and comparison of key physicochemical, microbiological, and heavy metal parameters against established standards. This study focuses on evaluating the suitability of surface and groundwater resources in Ekori, Yakurr Local Government Area, Cross River State, Nigeria, for human consumption and domestic use. The research methodology includes sample collection, laboratory analysis, and comparative assessments based on the Nigerian Standard for Drinking Water Quality (NSDWQ, 2008) and World Health Organization guidelines [19].

2.1 Study Area

The study was conducted in Ekori community, located in Yakurr Local Government Area (LGA) of Cross River State, Nigeria. Ekori is situated between latitude 5°58' N and longitude 8°03' E, with a tropical climate characterized by distinct wet and dry seasons. The rainy season typically lasts from April to October, with peak rainfall occurring between July and September, while the dry season extends from November to March. The area is drained by several surface water bodies, including streams and rivers, which serve as major sources of drinking water, irrigation, and domestic use for the residents.

The geology of Ekori consists mainly of sedimentary rock formations rich in lateritic soils, which influence groundwater recharge and mineral content. The primary occupations in the community include farming, fishing, and small-scale trading, with potential anthropogenic impacts on water quality arising from agricultural runoff, improper waste disposal, and deforestation. Many residents rely on shallow wells, boreholes, and streams for their daily water needs, but concerns about pollution from human and industrial activities necessitate a detailed assessment of water quality in the region.

2.2 Materials Used

The study utilized several scientific instruments, reagents, and analytical tools to evaluate the physicochemical, microbiological, and heavy metal characteristics of the water samples. The key materials and equipment used included:

i. Sample Collection Containers: Sterilized 1-liter polyethylene bottles for collecting water samples.
ii. Multiparameter Probe (HACH HQ40d): Used for in-situ measurement of temperature, pH, and electrical conductivity (EC).
iii. Turbidimeter (HACH 2100N): For determining turbidity levels in water samples.
iv. Gravimetric Balance: Used for measuring total dissolved solids (TDS) and total suspended solids (TSS) concentrations.
v. Spectrophotometer (HACH DR 6000): Employed for determining nitrate (NO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), and chloride (Cl^-) concentrations.
vi. Atomic Absorption Spectrophotometer (AAS, Buck Scientific 210 VGP): Used for detecting heavy metals such as iron (Fe), manganese (Mn), lead (Pb), chromium (Cr), and nickel (Ni).
vii. Microbiological Incubator and Culture Media: For detecting total coliform count (TCC) and fecal coliform count (FCC) using MacConkey broth and membrane filtration methods.
viii. Reagents and Chemicals: Included buffer solutions, nitric acid (HNO_3), sodium thiosulfate ($Na_2S_2O_3$), and potassium dichromate ($K_2Cr_2O_7$) for water sample stabilization and microbial growth inhibition.

2.3 Method and Procedures Followed

A total of seven (7) water samples were collected from three surface water sources (SW1, SW2, SW3) and four groundwater sources (GW1, GW2, GW3, GW4) in April 2018. Surface water samples were taken from rivers and streams, while groundwater samples were obtained from boreholes and hand-dug wells. The samples were collected in the morning between 8:00 AM and 10:00 AM to minimize diurnal variations in water quality.

Each sample was collected in a sterilized 1-liter polyethylene bottle, pre-rinsed with the sample water before collection. For heavy metal analysis, concentrated nitric acid (HNO_3) was added to the samples to maintain a pH below 2, preventing precipitation and adsorption of metals onto the container walls. The samples were immediately transported to the laboratory in an ice-packed cooler (4°C) and analyzed within 24 hours to prevent microbial degradation and chemical alterations.

The pH, temperature, and electrical conductivity of the water samples were measured on-site using a multiparameter probe (HACH HQ40d). Turbidity was determined using a HACH 2100N turbidimeter, while TDS was measured through gravimetric evaporation at 105°C. Hardness was assessed using complexometric titration with EDTA, and anions such as nitrate (NO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), and chloride (Cl^-) were quantified using a UV-visible spectrophotometer (HACH DR 6000).

Heavy metals, including iron (Fe), manganese (Mn), lead (Pb), chromium (Cr), and nickel (Ni), were analyzed using an Atomic Absorption Spectrophotometer (AAS, Buck Scientific 210 VGP). Calibration was performed using standard metal solutions of known concentrations. The detection limits for Fe, Mn, Pb, Cr, and Ni were 0.01 mg/L, 0.005 mg/L, 0.002 mg/L, 0.001 mg/L, and 0.003 mg/L, respectively.

Total coliform count (TCC) and fecal coliform count (FCC) were determined using the membrane filtration technique. A 100 mL water sample was filtered through a 0.45 µm membrane, placed on MacConkey agar, and incubated at 37°C for 24 hours for total coliforms and 44°C for fecal coliforms. The colonies were counted and reported as colony-forming units per 100 mL (CFU/100 mL).

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III. RESULTS AND DISCUSSION

3.1 Result

The results obtained from the physicochemical, bacteriological, and heavy metal analyses of surface and groundwater samples in Ekori, Yakurr Local Government Area, Cross River State, Nigeria, are presented in tables and figures. These findings address the research objectives, which include determining the physicochemical properties of surface and groundwater, assessing the presence of heavy metals, evaluating microbial contamination, and comparing the results with NSDWQ and WHO standards to establish their suitability for consumption.

The results are presented in Table 1, which summarizes the levels of physicochemical, bacteriological, and heavy metal parameters in the water samples. Figures 1, 2, and 3 provide graphical representations, comparing different water sources and highlighting deviations from acceptable standards. These results are analyzed against NSDWQ (2008) and WHO (2011) guidelines, with a focus on identifying contamination hotspots and potential health risks. The discussion interprets the findings, relating them to water pollution sources, hydrogeological conditions, and existing literature on water quality in similar regions.

Table 1: Levels of physicochemical bacteriological parameters, nutrients and some heavy metals in surface and ground water from the seven (7) locations in the study area (Ekori, Yakurr Local Government Area, Cross River State) in April, 2018.

S/N	Parameter/Unit	SW1	SW2	SW3	GW1	GW2	GW3	GW4	NSDWQ 2008
1	Temperature (°C)	28.60	28.30	28.40	28.10	28.50	28.50	27.90	Ambient
2	pH	5.10	6.05	6.25	6.25	5.89	6.63	6.15	6.5-8.5
3	Conductivity (µs/cm)	43.00	58.80	45.00	1057.00	740.00	497.00	884.00	1000
4	Turbidity (NTU)	2.79	13.70	18.50	0.32	0.87	0.57	2.24	5.0
5	Hardness (mg/L)	17.10	17.10	17.10	222.30	153.90	256.30	153.90	100
6	BOD (mg/L)	6.29	7.05	6.12	4.80	5.66	4.72	6.19	1.0-5.0
7	Colour (H/U)	<5	<5	15.00	<5	10.00	<5	<5	3.0
8	Taste	Unobj	Obj	Obj	Unobj	Unobj	Unobj	Unobj	Unobj
9	TDS (mg/L)	25.80	35.30	27.00	634.20	444.00	298.20	530.40	500
10	Chloride (mg/L)	29.20	31.00	25.10	16.00	18.00	21.10	20.00	100
11	Fluoride (mg/L)	0.03	0.06	0.06	0.02	0.02	0.03	0.01	1.0
12	Nitrate (mg/L)	6.01	4.33	8.01	5.22	5.18	4.23	5.49	10.0
13	Sulphate (mg/L)	3.46	2.96	2.68	1.27	1.31	1.10	1.21	100
14	Phosphate (mg/L)	0.81	0.77	0.80	0.31	0.38	0.40	0.33	3.5
15	Manganese (mg/L)	0.25	0.36	0.30	0.10	0.06	<0.10	0.08	0.1
16	Iron (mg/L)	0.67	0.81	0.65	0.36	0.29	0.54	0.29	0.3
17	Zinc (mg/L)	0.16	0.13	0.19	0.08	0.12	0.10	0.05	5
18	Copper (mg/L)	0.11	0.10	0.09	0.09	0.09	0.09	0.08	1.0
19	Arsenic (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01
20	Chromium (VI) (mg/L)	0.01	0.01	0.01	0.02	0.05	0.03	0.05	0.01
21	Lead (mg/L)	`0.05	0.08	0.03	<0.01	ND	0.01	0.01	0.1
22	Potassium (mg/L)	3.10	2.90	3.10	1.70	1.90	1.60	1.90	200

23	Cobalt (mg/L)	0.02	0.02	0.02	0.05	0.03	0.00	0.00	-
24	Nickel (mg/L)	0.06	0.08	0.04	0.12	0.10	0.13	0.10	0.01
25	TCC (00/CFU)	TNTC	TNTC	TNTC	108.00	113.00	72.00	TNTC	0
26	FCC (100/CFU)	TNTC	TNTC	TNTC	51.00	65.00	48.00	TNTC	0

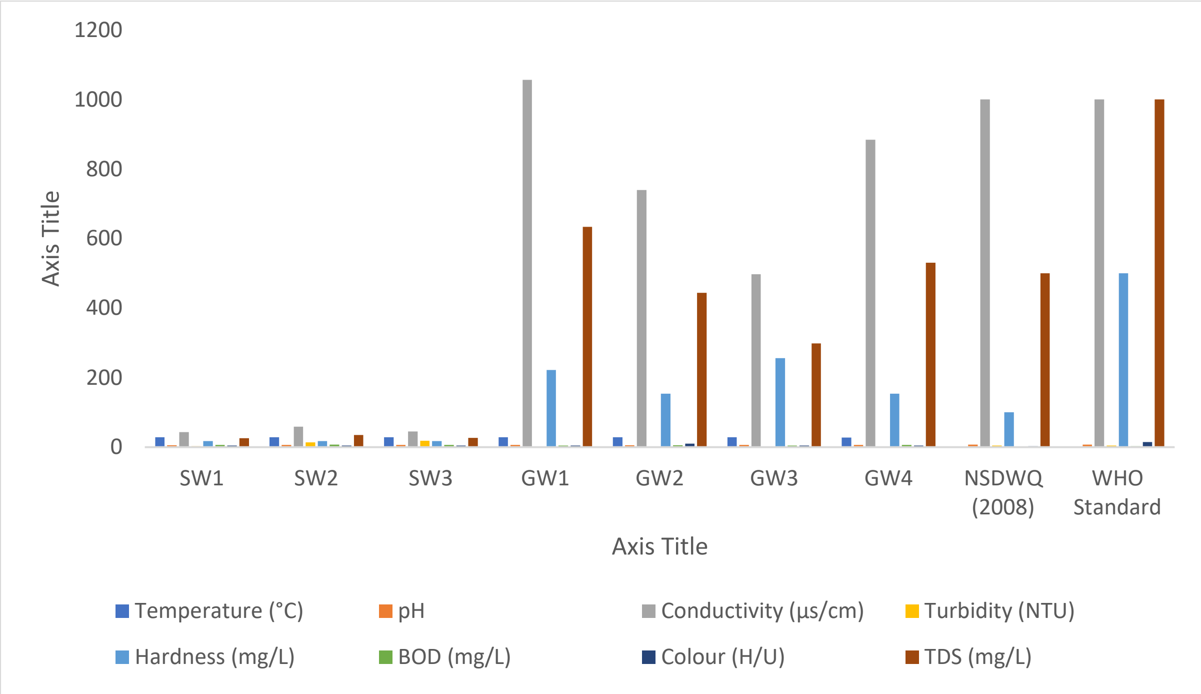

Figure 1: Physical parameters comparations

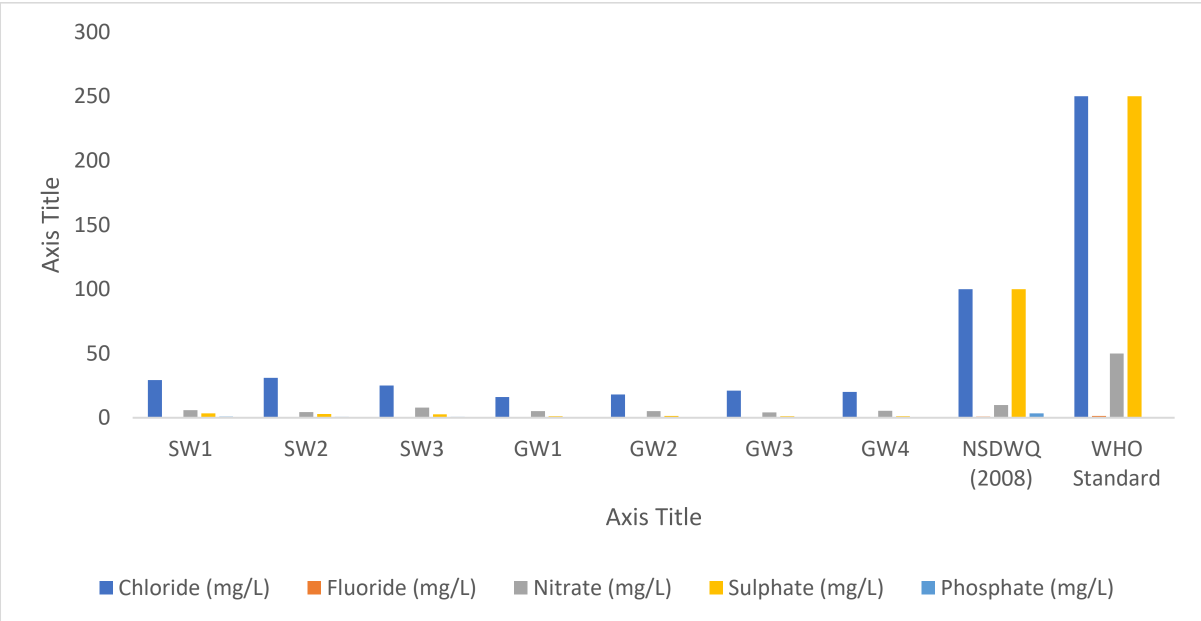

Figure 2: Major Anions and Nutrients parameters comparations

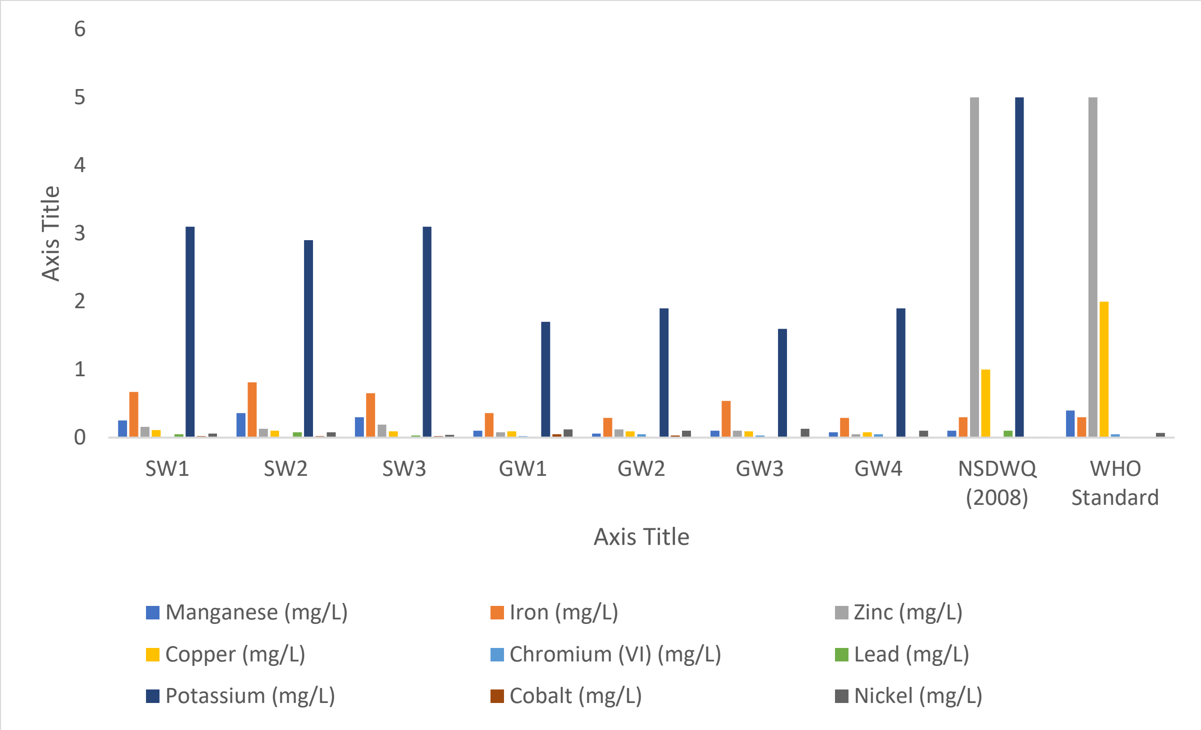

Figure 3: Heavy Metals and Toxic Elements parameters comparation

3.2 Discussion

The physicochemical properties of the water samples play a critical role in determining their potability, suitability for domestic use, and impact on public health. Table 1 presents the measured values for temperature, pH, turbidity, conductivity, TDS, and major anions, along with NSDWQ and WHO limits for comparison.

The temperature of the water samples ranged between 27.9°C and 28.6°C, which is within the expected ambient range for tropical regions. Temperature influences biological activity, chemical reactions, and dissolved oxygen levels, but does not directly affect water quality [7].

The pH values varied from 5.10 to 6.63, with surface water samples (SW1: 5.10) exhibiting more acidic conditions compared to groundwater (GW3: 6.63). These values fall below the NSDWQ standard (6.5–8.5), indicating potential issues with corrosivity and metal leaching [11]. Acidic pH in surface water can be attributed to organic matter decomposition, atmospheric deposition, and soil leaching [4].

Turbidity levels ranged from 0.32 NTU (GW1) to 18.5 NTU (SW3), with surface water samples exceeding the 5.0 NTU limit set by NSDWQ. High turbidity suggests the presence of suspended particles, organic matter, and microbial contaminants, which can reduce disinfection efficiency and increase the risk of pathogen transmission [19].

Conductivity, an indicator of dissolved ions, showed significantly higher values in groundwater (GW1: 1057.0 µS/cm) than surface water (SW1: 43.0 µS/cm), suggesting greater mineral dissolution and ionic content in groundwater sources. The total dissolved solids (TDS) followed a similar trend, with groundwater samples exceeding 500 mg/L, indicating possible leaching of geological minerals or anthropogenic contamination [9].

The concentrations of major anions—including chloride, nitrate, sulfate, and phosphate—were within acceptable limits. However, nitrate levels in surface water (SW3: 8.01 mg/L) approached the NSDWQ limit (10.0 mg/L), suggesting potential agricultural or sewage contamination [13].

The presence of heavy metals in water is a major public health concern, as long-term exposure can lead to neurological damage, organ failure, and carcinogenic effects [21]. The heavy metal concentrations detected in the study are presented in Table 1, with comparisons against NSDWQ and WHO permissible limits.

Iron (Fe) concentrations exceeded the 0.3 mg/L limit in surface water samples SW2 (0.81 mg/L) and SW3 (0.67 mg/L). Elevated iron levels are common in tropical regions with lateritic soils, leading to rust-coloured staining, metallic taste, and potential pipe clogging [16].

Manganese (Mn) was detected at levels above 0.1 mg/L in SW2 (0.36 mg/L) and GW1 (0.10 mg/L), which may pose neurological risks if consumed over prolonged periods [20].

Lead (Pb) was present in surface water at SW2 (0.08 mg/L) and SW1 (0.05 mg/L), exceeding the WHO limit (0.01 mg/L). Lead contamination can result from industrial discharge, corroded pipes, and atmospheric deposition, with severe effects on cognitive function and blood toxicity [18].

Chromium (Cr) was detected above permissible limits in GW2 (0.05 mg/L) and GW3 (0.03 mg/L). Chromium (VI) is a known carcinogen linked to liver and kidney damage [20].

Microbiological analysis is crucial in assessing the potability of water sources. Total coliform count (TCC) and fecal coliform count (FCC) were too numerous to count (TNTC) in all surface water samples, confirming severe fecal contamination from human and animal waste and making these water sources unsafe for consumption without disinfection [19].

Groundwater samples also exhibited microbial contamination, with TCC ranging from 72 CFU/100 mL (GW3) to 113 CFU/100 mL (GW2). The presence of fecal coliforms suggests leakage from latrines, septic tanks, or sewage infiltration into groundwater sources [10].

These results emphasize the need for chlorination, UV disinfection, and improved sanitation practices to reduce health risks associated with microbial contamination.

IV. CONCLUSION

This study evaluated the physicochemical, bacteriological, and heavy metal characteristics of surface and groundwater resources in Ekori, Yakurr Local Government Area, Cross River State, Nigeria. The findings revealed varying degrees of contamination across the sampled locations, with some parameters exceeding the Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) permissible limits. The assessment of physicochemical properties showed that pH levels in most surface water samples were below the acceptable range of 6.5 – 8.5, indicating acidity that could lead to increased metal leaching and corrosivity. Surface water sources exhibited high turbidity levels, particularly at SW3 (18.5 NTU) and SW2 (13.7 NTU), both of which exceeded the NSDWQ limit of 5.0 NTU, suggesting the presence of suspended solids and organic matter. Groundwater samples, on the other hand, displayed significantly higher conductivity and total dissolved solids, with values reaching 1057.0 µS/cm and 634.2 mg/L, respectively, indicating elevated mineral content likely from natural geological formations and anthropogenic activities.

Heavy metal analysis confirmed the presence of iron, manganese, lead, and chromium at concentrations exceeding permissible limits, raising concerns about potential health risks. Iron levels were highest in surface water, with SW2 recording 0.81 mg/L, well above the NSDWQ threshold of 0.3 mg/L. Manganese exceeded the 0.1 mg/L limit in SW2 (0.36 mg/L) and GW1 (0.10 mg/L), potentially affecting neurological functions with prolonged exposure. Lead concentrations reached 0.08 mg/L at SW2, exceeding the WHO limit of 0.01 mg/L, while chromium was detected at concerning levels in groundwater, with GW2 containing 0.05 mg/L. The presence of these toxic metals suggests possible contamination from both natural and human-induced sources, including leaching from lateritic soil, industrial emissions, and improper waste disposal.

Microbiological analysis provided further evidence of contamination, with total coliform count (TCC) and fecal coliform count (FCC) being too numerous to count (TNTC) in all surface water samples. This indicates severe fecal pollution, likely from human and animal waste, making these sources highly unsuitable for consumption without treatment. Groundwater, though relatively less contaminated, also exhibited microbial pollution, with coliform counts ranging from 72 CFU/100 mL to 113 CFU/100 mL, surpassing the NSDWQ guideline of 0 CFU/100 mL. The presence of fecal coliforms in groundwater suggests possible infiltration from latrines, septic tanks, or surface runoff, further emphasizing the need for proper sanitation measures.

The overall findings of this study indicate that while groundwater sources exhibit better quality compared to surface water, both require treatment before consumption. Surface water, in particular, is heavily contaminated and poses serious health risks due to its high turbidity, microbial presence, and heavy metal content. Groundwater, though safer, requires interventions to address elevated total dissolved solids and heavy metal contamination. Comparing the results with NSDWQ and WHO standards highlights the urgent need for water treatment and pollution control strategies to ensure the safety of drinking water in Ekori.

REFERNECE

[1] S. O. Adefemi and E. E. Awokunmi, "Determination of physicochemical parameters and heavy metals in water samples from Itaogbolu area of Ondo State, Nigeria," *African Journal of Environmental Science and Technology*, vol. 4, no. 3, pp. 145–148, 2010.

[2] H. O. Nwankwoala, "Groundwater resources of Nigeria: Quality, sustainability, and management," *Journal of Environmental Management*, vol. 10, no. 2, pp. 78–92, 2016.

[3] S. I. Efe, P. I. Aruegodore, and V. N. Ojeh, "Heavy metal contamination of water resources in the Niger Delta Region, Nigeria," *Environmental Research Journal*, vol. 14, no. 2, pp. 45–58, 2020.

[4] E. O. Orebiyi et al., "Assessment of pollution hazards of shallow well water in Abeokuta and environs, southwest Nigeria," *African Journal of Environmental Science and Technology*, vol. 4, no. 3, pp. 134–140, 2010.

[5] UNESCO, *The United Nations World Water Development Report 2019: Leaving No One Behind*. Paris: UNESCO Publishing, 2019.

[6] N. J. Ashbolt, "Microbial contamination of drinking water and disease outcomes in developing regions," *Tropical Medicine and International Health*, vol. 20, no. 4, pp. 419–426, 2015.

[7] D. V. Chapman, *Water Quality Assessments: A Guide to the Use of Biota, Sediments, and Water in Environmental Monitoring*, 2nd ed. London: UNESCO/WHO/UNEP, 1996.

[8] I. O. Akpan and J. O. Offem, "Assessment of seasonal variation in the physicochemical properties of surface water in Cross River, Nigeria," *Environmental Monitoring and Assessment*, vol. 189, no. 9, pp. 1–15, 2017.

[9] M. N. Tijani, "Hydrogeochemical assessment of groundwater in parts of southwestern Nigeria," *Environmental Geology*, vol. 45, no. 6, pp. 768–777, 2006.

[10] O. T. Oyeku and A. O. Eludoyin, "Heavy metal contamination of groundwater resources in a Nigerian urban settlement," *African Journal of Environmental Science and Technology*, vol. 4, no. 4, pp. 201–214, 2010.

[11] A. I. Ezeribe, K. C. Oshieke, and A. Jauro, "Physicochemical properties of well water samples from some villages in Nigeria with cases of fluorosis," *Science World Journal*, vol. 7, no. 1, pp. 1–4, 2012.

[12] I. M. Adekunle, M. T. Adetunji, A. M. Gbadebo, and O. B. Banjoko, "Assessment of groundwater quality in a typical rural settlement in Southwest Nigeria," *International Journal of Environmental Research and Public Health*, vol. 4, no. 4, pp. 307–318, 2007.

[13] H. O. Nwankwoala, G. J. Udom, and S. A. Ugwu, "Assessment of groundwater quality in Yenagoa and its environs, Bayelsa State, Nigeria," *Journal of Water Resource and Protection*, vol. 6, no. 5, pp. 423–432, 2014.

[14] H. O. Nwankwoala and G. J. Udom, "Hydrochemical evaluation of groundwater in parts of eastern Niger Delta, Nigeria," *Journal of African Earth Sciences*, vol. 2, no. 3, pp. 65–74, 2011.

[15] A. F. Aiyesanmi, K. O. Ipinmoroti, and I. I. Oguntimehin, "Impact of automobile workshop on groundwater quality in Akure Metropolis," *Journal of Environmental Science and Health*, vol. 41, no. 2, pp. 211–220, 2006.

[16] J. C. Akan, F. I. Abdulrahman, and V. O. Ogugbuaja, "Impact of tannery and textile effluent on the chemical characteristics of Challawa River, Kano State, Nigeria," *Australian Journal of Basic and Applied Sciences*, vol. 4, no. 11, pp. 3307–3317, 2010.

[17] APHA, *Standard Methods for the Examination of Water and Wastewater*, 22nd ed. Washington, DC: American Water Works Association, 2012.

[18] J. N. Edokpayi, J. O. Odiyo, O. S. Durowoju, and A. Mavhungu, "Impact of wastewater effluent on water quality of receiving rivers in developing

countries: A case study of South Africa," *Water*, vol. 10, no. 10, p. 1231, 2018.

[19] WHO, *Microbial Aspects of Drinking-water Quality*. Geneva: WHO Press, 2017.

[20] A. T. S. D. R. (ATSDR), *Toxicological Profile for Manganese*. Atlanta: U.S. Department of Health and Human Services, 2012.

[21] L. Patrick, "Lead toxicity, a review of the literature," *Alternative Medicine Review*, vol. 11, no. 2, pp. 114–127, 2006.

[22] I. M. Ishaku, M. R. Majid, and R. Ibrahim, "Water quality and sanitation conditions in Jalingo, North-eastern Nigeria," *International Journal of Environmental Sciences*, vol. 1, no. 5, pp. 852–862, 2011.

[23] P. A. Akpan, N. K. Udoakah, and E. B. Essien, "Groundwater quality assessment in parts of Akwa Ibom State, Nigeria," *Journal of Water Resource and Protection*, vol. 11, no. 4, pp. 454–468, 2019.