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PHYSICOCHEMICAL AND MICROBIAL QUALITY OF SURFACE WATER RESOURCES IN SOME GOLD MINING COMMUNITIES OF OSUN STATE, SOUTHWESTERN NIGERIA

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ABSTRACT

Seasonal and spatial variations in the physicochemical and microbial properties of surface water bodies in some gold-mining communities of Southwestern Nigeria were determined. The physicochemical parameters were analysed using APHA standard methods. Microbial parameters analysed were total heterotrophic bacteria count (THBC), total heterotrophic fungal count (THFC), total coliform count (TCC) and the antibiotic sensitivity test. The mean concentrations of the parameters notably acidity, DO, organic matter, total hardness and nitrate were significantly higher in the rainy than dry seasons ($p < 0.05$). Parameters such as TS, conductivity, acidity, total hardness, TDS, DO and BOD_5 were not impacted in the non-mining stations. However, pH, conductivity and TDS showed significant ($p < 0.05$) difference in the mining and non-mining stations while only turbidity showed very highly significant ($p < 0.001$) difference in the mining stations. THBC ranged from 0 to 8.3×10^6 cfu/ml, THFC ranged from 0 to 7.8×10^5 cfu/ml and TCC ranged from 0 to 2.5×10^6 cfu/ml. The mean microbial counts of THB ($9.1\times10^5 \pm 4.72$ cfu/ml), TC ($1.3\times10^5 \pm 1.25\times10^5$ cfu/ml) and THF ($6.1\times10^4 \pm 3.9\times10^4$ cfu/ml) were higher in the rainy than dry seasons. Also, THB (1.8×10^8 cfu/ml), TC (1.2×10^5 cfu/ml) and THF (2.8×10^5 cfu/ml) mean microbial counts were generally high in surface water sources. Bacterial isolates exhibited resistance to antibiotics in the increasing order fluoroquinolones (44.8%), macrolide (51.7%), aminoglycosides (69.0%), phenicol (71.7%) sulphonamides/trimethoprim (84.5%) and β-lactams 96.6%. This study established that water sources close to gold mining sites was negatively impacted making them unsuitable for domestic uses.

Keywords: Microbial quality, Physicochemical parameters, Mining, Surface water, Seasonal variation, Water quality

INTRODUCTION

Water is a unique and essential natural resource to man. It has significance for the maintenance of an effective supply of food and sustenance of a productive environment to aid human and animal population (Pimentel *et al*., 2004). Increasing human population, rapid urbanization and economic expansion have brought about more demand for good water supply for domestic uses, irrigation, fish production and recreation. This has further put pressure on both the quality and quantity of water resources (Fernandez-Jauregui, 2010). An important requirement for sustainable development must be to ensure the protection of water sources such as rivers, streams and lakes from pollution due to human activities. In Nigeria, surface and groundwater pollution among small towns and rural dwellers is particularly worrisome since they are more dependent than their urban counterparts on untreated water collected from rivers and streams for drinking and other domestic uses. Gold mining refers to human activities involving the mining of ores containing gold and processing them to recover the gold using techniques that vary from being rudimentary to modern. Gold mining contributes significantly to local and national economies (Bermudez-Lugo, 2008), but may impact the environment negatively in terms of water quality, degradation, loss of biodiversity and deforestation, if not controlled (Donkor *et al*., 2006). Mining affects freshwater through heavy use of water in processing ore and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments (Balasubramaniam and Panda, 2014). Besides, considerable amount of solid waste piled in the form of huge overburden dumps, destruction and degradation of forest and agricultural lands, and discharge of effluents from mines into nearby water-bodies are some of the other associated problems that have adverse environmental impact (Tambekar *et al*., 2013).

Moreover, anthropogenic activities such as mining threaten the water sources which are depended on for domestic and other uses by inhabitants of communities around the mining sites. Declining water quantity and quality in surface water of mining communities has become a matter of great concern as mining activities keep increasing, thereby depriving mining communities of access to clean and potable water. Mining by its nature consumes, diverts and can seriously pollute water resources. While there have been improvements in mining practices in recent years, significant environmental risks remain. Negative impacts can vary from the sedimentation caused by poorly built roads during exploration through to the sediment, and disturbance of water during mine construction (Protect Ecuador, 2013). Water can be polluted by chemical or biological contaminants which may be harmful to humans when consumed. Surveillance of physicochemical parameters in water resources helps to assess the suitability of such water for various uses as well as identify deterioration in water quality in order to ensure the protection of public health and the environment (Okoh *et al*., 2007). National and international standards often require the assessment of these parameters in surveillance water quality from different sources (Tebbut, 1983; WHO, 2008). Critical physicochemical parameters assessed in water include pH, temperature, turbidity, odour, total dissolved solids, total suspended solids, nitrate, orthophosphate, electrical conductivity, dissolved oxygen, biochemical oxygen demand, salinity and alkalinity among others (Tebbut, 1992; Joshi *et al*., 2009). Microbial water quality evaluation deals with the microorganisms that may be found in water. Waterborne diseases are associated with presence of pathogenic microorganisms in water and include cholera, typhoid fever and diarrhea (WHO 2011; Schwarzenbach *et al*., 2010). Disease-causing microorganisms associated with waterborne diseases belong to bacteria, viruses, fungi, protozoa and algae which can be present in surface, recreational and groundwater intended for drinking and spread via the faecal oral route (Cabral, 2010; Schwarzenbach *et al*., 2010). The aim of this study was to assess the seasonal and spatial variations in the physicochemical and microbiological qualities of surface water bodies in some gold-mining communities of Southwestern Nigeria.

MATERIALS AND METHODS

Description of Study Area and Sampling Points

Seven sampling stations were established at different locations of the gold-mining communities. Four sampling points were located at Itagunmodi, two sampling points at Alaba and one sampling point at Aruwa, all comprising of six streams and one river. The description of each of the sampling stations is presented in Table 1.

Sample Collection

Water samples were collected in 2 litre plastic bottles directly from the river and streams, for physicochemical analyses. The water samples for microbiological analyses were collected in sterile bottles which were immediately placed in iced box for storage prior to analysis. Four sets of samples were collected from each sampling station over one annual cycle comprising two sets of samples during the rainy season (August and June) and another two sets during the dry season (December and February) 2015.

Water Analysis

Physicochemical parameters

In-situ hydro-physical parameters such as temperature (ambient and water temperature), water depth, stream/river channel width, flow rate and the grid co-ordinates of each of the sampling stations were determined. Other parameters studied were pH, conductivity, alkalinity, acidity, hardness, turbidity, true colour, total dissolved solids (TDS), total solids (TS) and total suspended solids (TSS). Major ions (calcium, magnesium, sodium, potassium, sulphate and chloride), nutrient compounds (nitrate, phosphate and organic matter), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were analysed according to standard procedures (Golterman *et al*., 1978).

Microbiological quality

The microbiological parameters consired included total heterotrophic bacteria count (THBC), total heterotrophic fungal count (THFC) and total coliform count (TCC), using serial dilution and pour plate techniques. Assessment of antibiotic susceptibility profile of the bacterial isolates were also outlined. The zones of inhibition from the antibiotic susceptibility assay of bacterial isolates were measured, compared and interpreted using standard methods.

Table 1: The geographical location of water sampling stations in study area

S/N	Ref. Code	Type of water body	Name and site description	Grid co-ordinate		Elevation (m)	Distance between stations (m)	Vegetation type	Mining activity
1	ITG A	Stream	Ayo Stream Itagunmodi	N07^{0}31’47.3’’	E004^{0}38’49.1’’	363 ± 5	0	*Costus afer*	Activity ahead of the stream
2	ITG B	Stream	Agunmodi Stream, Itagunmodi	N07^{0}31’43.9’’	E004^{0}38’40.8’’	339 ± 5	105.4	*Costus afer*	No gold mining pit close to the point of sampling
3	ITG C	Stream	Agunmodi downstream, Itagunmodi	N07^{0}31’38.9’’	E004^{0}38’54.0’’	346 ± 8	260.4	*Bambus vulgaris*	Gold mining pits around station and recent mining activities taken place
4	ITG D	Stream	Omi mining, Agunmodi downstream (3) passes through the stream	N07^{0}31’31.7’’	E004^{0}39’04.4’’	339 ± 10	483.6	*Costus afer and Pneumatopteris afra*	Mining activity around the stream. Its course is along a farmland
5	ITG E	River	Owena river, with marginal vegetation on both sides of the stream. Rocky sediment on both sides. Flows through Aruwa village	N07^{0}29’14.0’’	E004^{0}39’02.7’’	288 ± 6	4154	*Citrus afer*	Mining activity upstream. Its course is bat Aruwa
6	ITG F	Stream	Erinla stream. Flowing stream with a wooden bridge across the stream. The water is now the drinking water source for Aruwa people	N07^{0}29’36.4’’	E004038’54.3’’	306 ± 7	4057.9	*Costus afer*	No mining activity around stream
7	ITG G	Stream	Osun stream with a concrete bridge flowing towards Ibo camp which is opposite Alaba village. The stream is used for irrigating farmland that are close to the stream.	N07^{0}29’55.7’’	E004^{0}39’19.9’’	362 ± 6	3459.6	*Costus afer*	Agricultural activity close to the stream

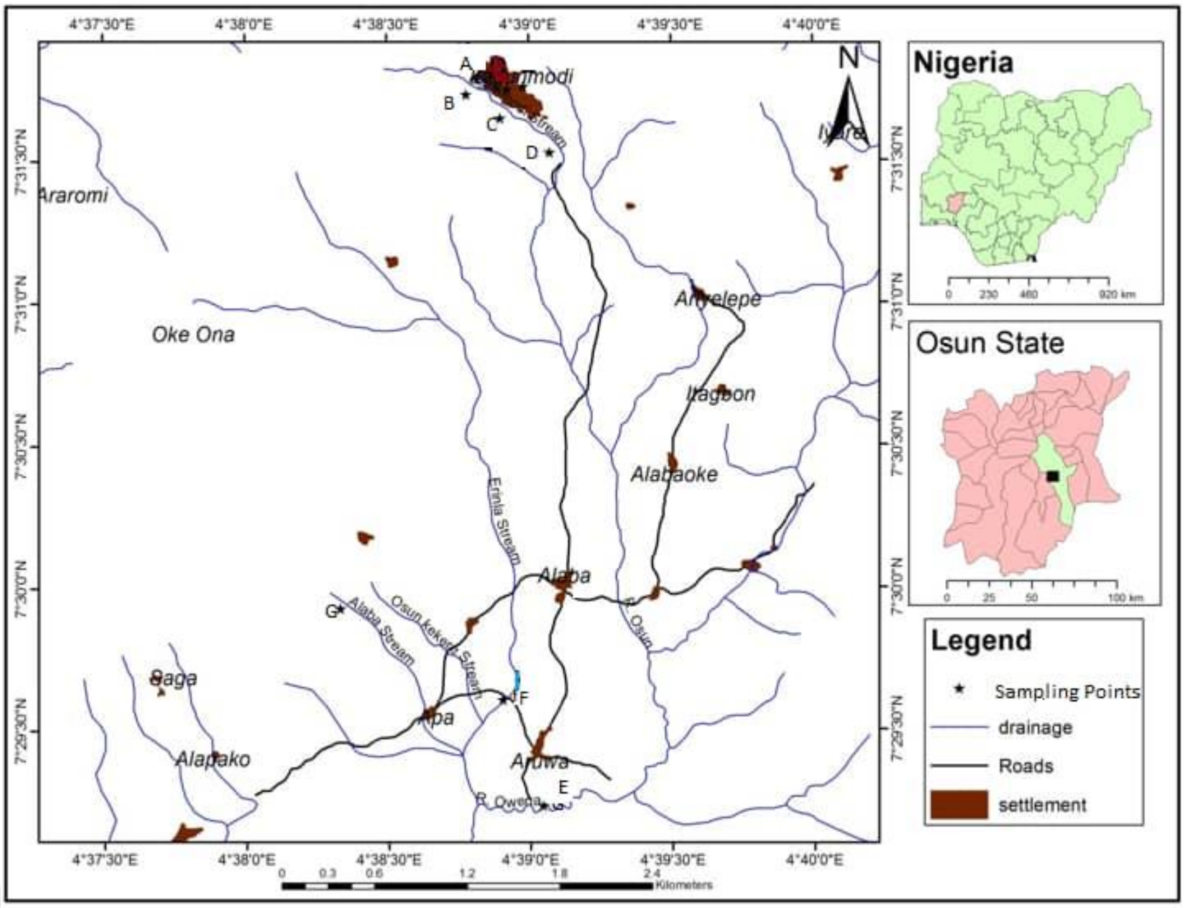

Figure 1: Map of the Study Area showing drainage pattern and Sampling Stations.

RESULTS

Physicochemical parameters

The mean values of the physicochemical parameters of the studied surface water bodies, for the study period, are presented in Table 2. The overall mean value of the turbidity for the rainy season was 25.81 ± 7.52 NTU which was slightly higher than the overall mean value for the dry season which was 23.92 ± 6.7 NTU ($p > 0.05$). Also, the mean value of turbidity of 48.54 ± 11.95 NTU for sampling stations in the mining area was much higher than the mean turbidity value of 13.94 ± 3.13 NTU for stations in the non-mining area, although there was no Significant seasonal difference ($P > 0.01$) between the two mean values. The mean pH value of 7.09 ± 0.14 in the dry season was slightly higher than that in the rainy season which was 7.08 ± 0.12 (Table 2). The mean pH value of 7.36 ± 0.05 for the mining stations was also slightly higher than that in the non-mining stations which was 6.96 ± 0.12 (Table 3). Thus, there was no significant difference ($P > 0.05$) in pH with regard to seasonal variation and between mining and non-mining stations. The seasonal variation in mean conductivity was characterized by a slightly higher value ($p > 0.05$) in the dry season 398.85 ± 69.04 µScm^{-1} than in the rainy season 354.93 ± 65.16 µScm^{-1} with $p > 0.05$ (Table 2). The mean conductivity value of 452.83 ± 63.21 µScm^{-1} for the non-mining stations, was found to be about twice higher than that for the mining stations which was 212.34 ± 14.7 µScm^{-1}. Mean conductivity of stations in the non-mining area was thus significantly higher ($P < 0.05$) than for those in the mining area (Table 3). The mean value of total alkalinity of water bodies in the dry season 96.58 ± 6.45 mgCaC0$_3$L^{-1} was not significantly different from those collected in the rainy season which was 91.56 ± 7.53 mgCaCO$_3$L^{-1} ($p > 0.05$) (Table 2). The mean total alkalinity for the mining stations 104.22 ± 7.47 mgCaCO$_3$L^{-1} was also not significantly different from that of the non-mining stations at 89.38 ± 6.16 mgCaCO$_3$L^{-1} ($P > 0.05$) (Table 3). The mean value of TDS 266.34 ± 46.2 mgL^{-1} was higher in the dry season than in the rainy season 224.41 ± 41.5 mgL^{-1} but there was no significant statistical difference ($P > 0.05$) in seasonal variation (Table 2). The mean value of TDS 294.65 ± 41.5 mgL^{-1} for the non-mining stations was however significantly different ($P < 0.05$) from that of the mining stations at 138.63 ± 10.5 mgL^{-1} (Table 3). The seasonal variation in total hardness was characterized by a higher mean value of 227.14 ± 37.4 mgCaCO$_3$L^{-1} in the rainy season than 115.24 ± 15.26 mgCaCO$_3$L^{-1} in the dry season thus showing highly significant ($P = 0.009$) seasonal variation (Table 2). The mean value of total hardness 187.92 ± 29.28 mgCaCO$_3$L^{-1} for the non-mining stations was however slightly higher than that for the mining stations at 134.95 ± 27.07 mgCaCO$_3$L^{-1} showing no significant difference ($P > 0.05$) (Table 3).

Table 2: Seasonal variation in the physicochemical parameters

Parameter	**Rainy season**	**Dry season**	**ANOVA**	
	Mean±SE	**Mean±SE**	**F**	**P**
P^H	7.08±0.12	7.09±0.14	0.005034	0.9438
CONDUCTIVITY (µS/cm)	354.93±65.16	398.85±69.04	0.214	0.6464
ALKALINITY(mg$CaCO_3$/L)	91.56±7.53	96.58±6.45	0.2564	0.6157
TOTAL HARDNESS(mg$CaCO_3$/L)	227.14±37.40	115.24±15.26	7.674	0.008807**
TDS(mg/L)	224.41±41.49	266.34±46.19	0.4561	0.5038
DO(mg/L)	6.94±0.47	5.38±0.41	6.273	0.01692*
BOD(mg/L)	3.19±0.47	2.25±0.26	3.053	0.08913
COD(mg/L)	6.04±0.46	3.34±0.36	21.41	4.667
Nitrate(mg/L)	1.65±0.09	0.34±0.12	77.85	1.575E-10***
Phosphate(mg/L)	3.07±0.37	3.17±0.37	0.04049	0.8416

P < 0.05 = * Significant Difference

P < 0.001 = *** Very Highly Significant Difference

S.E.M = Standard Error of Mean

Table 3: Gold mining and non-gold mining stations in the physicochemical Parameters

Parameter	**Mining stations**	**Non mining stations**	**ANOVA**	
	Mean±SE	**Mean±SE**	**F**	**P**
pH	7.36±0.05	6.96±0.12	4.649	0.038*
Conductivity(µS/cm)	212.34±14.71	452.83±63.21	6.512	0.015*
Alkalinity (mg$CaCO_3$/L)	104.22±7.47	89.38±6.16	2.028	0.163
Total hardness (mg$CaCO_3$/L)	134.95±27.07	187.92±29.28	1.268	0.268
TDS (mg/L)	138.63±10.46	294.65±41.53	6.338	0.016*
DO (mg/L)	5.73±0.57	6.35±0.41	0.748	0.393
BOD (mg/L)	2.53±0.60	2.82±0.30	0.210	0.650
COD (mg/L)	5.19±0.75	4.46±0.41	0.863	0.359
Nitrate (mg/L)	0.90±0.23	0.97±0.15	0.058	0.811
Phosphate (mg/L)	1.70±0.16	1.98±0.11	2.076	0.158

Order of dominance of major ions

The mean concentrations of the major ions in each station, as expressed in milli-equivalent per litre (meqL^{-1}) were found to be in the dominance order of $Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$ for all of the seven sampling stations. The cationic order for mining stations and non-mining stations were also in the order $Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$. The anionic order of dominance for all sampling stations was in the order $HCO_3^{-} > SO_4^{2-} > Cl^{-}$.

Oxygen parameters and nutrient compounds in surface water bodies

The seasonal mean concentration of DO 6.94 ± 0.47 mgL^{-1} was discovered to be significantly higher during the rainy season than in the dry season 5.38 ± 0.41 mgL^{-1} (Table 2). The overall mean concentration of DO 6.35 ± 0.41 mgL^{-1} in the non-mining stations was not significantly different (p>0.05) from that in the mining stations which was 5.73 ± 0.57 mgL^{-1} (Table 3). The overall mean concentration of BOD_5 recorded during the rainy season 3.19 ± 0.47 mgL^{-1} was higher but not significantly different from that recorded during the dry season 2.25 ± 0.26 mgL^{-1} (P>0.05) (Table 2). Also, the overall mean BOD_5 for the non-mining stations 2.81 ± 0.30 mgL^{-1} was slightly higher but not significantly different from that of the mining stations 2.53 ± 0.60 mgL^{-1} (Table 3). The concentration of COD of 6.04 ± 0.46 mgL^{-1} was about twice higher in the rainy season than during the dry season 3.34 ± 0.36 mgL^{-1} but there was no significant difference (P> 0.05) between the two seasonal mean values (Table 2). The overall mean concentration of COD in the mining stations 5.19 ± 0.75 mgL^{-1} was also slightly higher than that in non-mining stations 4.46 ± 0.41 mgL^{-1} (Table 3). The overall concentration of NO_3^{-} 1.56 ± 0.10 mgL^{-1} was higher in the rainy season than in the dry season 0.33 ± 0.12 mgL^{-1}, showing significant seasonal variation (P=0.000) (Table 2). However, the overall mean concentration of NO_3^{-} 0.97 ± 0.15 mgL^{-1} was slightly higher in the non-mining stations than in mining stations 0.90 ± 0.23 mgL^{-1} (p>0.05) (Table 3). The overall mean concentration of PO_4^{3-} 3.17 ± 0.37 mgL^{-1} recorded in the rainy season, was higher than in the dry season 3.07 ± 0.37 mgL^{-1}, but there was no significant seasonal variation (P= 0.91) (Table 2). The overall mean concentration of PO_4^{3-} 1.98 ± 0.11 mgL^{-1} in the non-mining stations was found to be higher than in the mining stations 1.70 ± 0.16 mgL^{-1}, but they were not significantly different (P= 0.16) (Table 3).

Microbiological parameters

THBC ranged from 0 to 8.3×10^6 cfu/ml with a total mean± s.e.m of $4.9\times10^5\pm2.43\times10^5$ cfumL^{-1}. The mean value of THB in the mining stations (7.5×10^5cfumL^{-1}) was found to be higher than that of the non-mining stations ($3.9\times10^5\pm1.95\times10^5$cfumL^{-1}) but there was no significant difference (P > 0.05) between the two mean values (Table 4).

THFC ranged from 0 to 7.8×10^5 cfu/ml with a total mean±s.e.m value of $5.0\times10^5\pm2.43\times10^5$cfumL^{-1}. The mean concentration of THF count was higher in the non-mining stations ($6.4\times10^4\pm3.0\times10^4$cfumL^{-1}) than in the mining stations ($4.09\times10^4\pm11793.33$cfumL^{-1}) but there was no significant difference (P > 0.05) between the two values (Table 4.b). TCC ranged from 0 to 2.5×10^6 cfu/ml with an overall mean±s.e.m value of $1.0\times10^5\pm6.60$E+04cfu/100mL^{-1}. Seasonal mean value of TC was higher in the dry season ($1.3\times10^5\pm1.25$E5cfu/100mL^{-1}) than in the rainy season ($7.4\times10^4\pm47733.25$cfu/100mL^{-1}) but the two values were not significantly different from each other (Table 5). The mean value of TC count was slightly higher (p > 0.05) in mining stations ($3.2\times10^5\pm2.13$ E 5cfu/100mL^{-1}) than in non-mining stations ($1.2\times10^4\pm5893.12$cfu/100mL^{-1}) (Table 5). The mean microbial counts of THB ($9.1\times10^5 \pm 4.72$ cfu/ml) and THF ($6.1\times10^4 \pm 3.9\times10^4$ cfu/ml) were higher in the rainy than the dry seasons with no statistical difference between the two seasons (P > 0.05) (Table 4).

Table 4: Microbial load (population) (cfu/ml) in the water bodies

S/N	Microbial abundance (Cfu/ml.)	Rainy Season Mean ±SE	Dry Season Mean ±SE	ANOVA	
				F	P
1	THB	$9.09\times10^5 \pm 4.72\times10^5$	$8.9\times10^4 \pm 3.9\times10^4$	2.992	0.092
2	THF	$6.07\times10^4 \pm 3.9\times10^4$	$5.37\times10^4 \pm 1.7\times10^4$	0.027	0.871
3	TC	$7.35\times10^4 \pm 4.8\times10^4$	$1.35\times10^5 \pm 1.25$ E5	0.210	0.650

Table 5: Microbial load (or population) (cfu/ml) of mining and non-mining stations of all water bodies

S/N	Microbial abundance	Mining stations Mean ±SE	Non-mining stations Mean ±SE	ANOVA	
				F	P
1	THB	$7.5\times10^5 \pm 6.87$ E5	$3.90\times10^5 \pm 1.95$ E5	0.465	0.499
2	THF	$4.09\times10^4 \pm 1.2\times10^4$	$6.43\times10^4 \pm 3.0\times10^4$	0.262	0.612
3	TC	$3.18\times10^5 \pm 2.13$ E5	$1.24\times10^4 \pm 5.9\times10^4$	4.955	0.032*

P<0.05 = * Significant difference

Antibiotic sensitivity profile of bacteria isolates

The antibiotic resistance profile of Gram's positive and negative bacteria isolates are presented in Tables 4a and 4b, respectively. Fluoroquinolones (PEF, RH and CPX) was the most potent class of antibiotics against the isolated bacteria with the overall value of 44.8% but pefloxacin 5.17% was the most potent of all the fluoroquinolone group of antibiotics. The antibiotic potency decreased in the order of macrolide (E) 51.7%, aminoglycoside (GEN and STR) 69.0%, sulphonamides/trimethoprim (SXT) 84.5%, β-lactams (Z and AMX) and penicillin (APX) 96.6% (Table 6). Fluoroquinolones (PEF, RH and CPX) class of antibiotic was also most effective against the Gram's negative bacteria with the overall value of 22.1% while pefloxacin was also recorded as the most potent among the group with the value of 6.7% (Table 6). Other isolated bacteria showed resistance to the antibiotics in the following decreasing order aminoglycosides (GEN and STR) 46.7%, sulphonamides/trimethoprim (SXT) 53.3%, phenicol (CHL) 71.7% and β-lactams (AMX and AUG) 90.9%.

Table 6: Antibiotic Resistant Profile of Gram's Positive Bacterial Isolates.

Gram's positive					
Bacterial Isolates	**Classes of Antibiotics**	**Specific Antibiotics**	**Number of Isolates That Showed Resistance Phenotype**	**% Resistance**	**Overall Resistance (R)**
Corynebacterium kutscheri	Fluoroquinolones	PEF	03	5.17	44.8
		RH	47	81.0	
		CPX	28	48.3	
Corynebacterium xerosis	Aminoglycoside	GEN	35	60.3	69.0
		STR	45	77.6	
Bacillus alvei	Penicillin	APX	56	96.6	96.6
Bacillus pantothenticus	β- Lactams	Z	53	91.4	95.7
		AMX	58	100	
Lactobacillus fermenti	Sulphonamides/ Trimethoprim	SXT	48	84.5	84.5
Yersinia pseudotuberculosis	Macrolides	E	31	51.7	51.7

Table 7: Antibiotic Resistance Profile of Gram's Negative Bacterial Isolate

Gram's negative					
Bacterial Isolates	**Classes of antibiotics**	**Specific Antibiotics**	**Number of isolates that showed resistance phenotype**	**% Resistance (R)**	**Overall Resistance (R)**
Enterobacter intermedius	Sulphonamides /Trimethoprim	SXT	32	53.3	53.3
Citrobacter diversus	Phenicol	CHL	43	71.7	71.7
Salmonella enteric	Fluoroquinolones	SP	26	43.3	22.1
		CPX	13	21.7	
		PEF	4	6.7	
		OFX	10	16.7	

Vibrio	β-Lactams	AMX	55	91.7	
orientalis		AUG	54	90	90.9
Serratia	Aminoglycosides	GEN	25	41.7	
fonticola		STR	31	51.7	46.7

Table 8: Mining Impacts on the Physico-chemical Parametersand Microbial Parameters of Itagunmodi Water bodies

Parameter	Unimpacted Mean±s.e.m	Impacted Mean±s.e.m	ANOVA		% Impact
			F	P	
Air temp	26.87±0.64	26.29±0.44	0.469	0.498	2.16
Water temp	27.81±0.34	25.09±0.24	37.020	0.000***	9.78
Depth	8.61±1.40	0.33±0.08	126.382	0.000***	96.17
Turbidity	3.96±1.33	32.33±6.19	7.335	0.010*	-7.16
TSS	614.30±171.08	398.75±70.64	1.924	0.174	35.09
TS	1162.10±153.92	536.18±72.66	16.971	0.000***	53.86
True colour	79.16±16.82	152.50±18.93	4.816	0.035*	-0.93
Apparent colour	75.84±12.90	126.11±116.92	22.240	0.000***	-66.28
pH	6.21±0.10	7.40±0.02	275.092	0.000***	-19.16
Conductivity	843.10±34.51	210.39±7.57	705.657	0.000***	75.05
Alkalinity	63.20±10.75	105.09±3.73	22.240	0.000***	-66.28
Acidity	43.40±6.12	17.13±1.57	34.947	0.000***	60.53
Hardness	227.39±31.67	151.12±26.82	2.433	0.128	33.54
TDS	547.80±27.95	137.37±5.59	475.768	0.000***	74.9
Calcium	73.99±10.97	27.39±1.41	46.771	0.000***	62.98
Magnesium	21.05±3.81	35.64±7.74	1.213	0.278	-69.31
Sodium	18.51±2.13	9.46±0.56	33.640	0.000***	48.89
Potassium	26.16±8.41	5.22±0.93	16.582	0.000***	80.045
Sulphate	56.02±7.65	41.81±4.60	2.521	0.121	25.37
Chloride	63.14±3.86	4.25±0.29	656.141	0.000***	33.78
Nitrate	1.36±0.26	0.87±0.14	2.863	0.099	36.03
Phosphate	3.06±0.60	3.12±0.29	0.010	0.921	-1.96
Organic matter	2.16±0.54	4.10±1.23	0.851	0.362	-89.81
DO	6.02±0.85	6.21±0.34	0.060	0.808	-3.16
BOD	3.15±0.63	2.57±0.30	0.863	0.359	18.41
COD	3.66±0.72	5.06±0.41	3.038	0.090	-38.25
THB (Cfu/ml)	$7.3\times10^5\pm5.2\times10^5$	$4.5\times10^5\pm2.9\times10^5$	0.231	0.634	
THF(Cfu/ml)	$8.4\times10^4\pm7.7\times10^4$	$5.2\times10^4\pm1.3\times10^4$	0.409	0.526	38.36
TC(Cfu/ml)	$3.2\times10^3\pm1.8\times10^3$	$1.5\times10^5\pm9.4\times10^4$	0.834	0.367	-4587.5

P < 0.05 = * Significant Difference
P < 0.001 = *** Very Highly Significant Difference

DISCUSSION

Turbidity value of 25 NTU was seen to be within the maximum permitted level of the Nigerian standard for drinking water quality (NSDWQ, 2007). The pH was recorded to be higher in mining stations in the dry season than in the rainy season with ($p < 0.05$) hence, mining activities seemed to make the water pH more acidic leading to pollution of streams that are close to these mining stations or drain such stations. The slight seasonal difference in the mean pH value that was observed in this study was similar to what had been recorded for many African rivers such as Osun River (Egborge, 1971), Ogun River (Adebisi, 1981) and Cross river (Akpan and Offem, 1993). This observed trend can be attributed to influx of decayed leaf litters and debris from the covering vegetation. The pH values noted in this study was similar with that recorded in previous study by Adetunde *et al.*, 2014 recorded pH range of 5.11 and 7.73 and suggested that it might be as a result of mining activities and some chemicals used which had drained and percolated down the soil and water resource. The pH range obtained in the study is within the recommended level of 6.5-8.5 hence, the water sources are considered safe for domestic purposes with regard to pH values. Conductivity value was established to be statistically significantly higher ($p<0.05$) in the non-mining stations (452.83±63.21μScm^{-1}) than in mining stations (212.34±14.71μScm^{-1}) in the dry season. However, both mean values can be regarded as medium. Higher conductivity during the dry season had been noted by many authors, Allan, 2001; Essien-Ibok *et al*., 2010; Akpan and Offem, 1993; Abowei and George, 2009 which they attributed to increased level of evapo-transpiration rates resulting in higher level of ions (dissolved solids) in the water. The conductivity values recorded for this study are within the permitted level of NSDWQ standard. The higher mean value of total alkalinity in the mining stations during the dry season observed in this study is in corroborates the report of Aguigwo (1998), and Izonfuo and Bariwen (2001). This is probably due to the increased evaporation experienced during the dry season which tends to concentrate the level of bicarbonate in the water bodies which is largely responsible for the alkalinity of the water bodies. The lower value in the rainy season suggests that runoff water contributed to the dilution of this parameter. Aguigwo (1998) reported that total alkalinity above 40mgL^{-1}CaCO$_3$ is indicative of high productivity. Higher significant difference ($p < 0.05$) in TDS value which was observed in non-mining station during the dry season could be due to sedimentation as a result of reduced water levels, implying reduced floods. It may also have resulted from evapocrystallization process and low rainfall resulting to low dilution of the river water. Therefore, large amount of dissolved oxygen would have been depleted since TDS comprises mainly of inorganic salts and small amounts of organic matter (Bhat *et al*., 2009) Total hardness showed a higher mean±s.e.m value in the rainy season (227.1±37.4mgL^{-1}) than in the dry season (115.24±15.26mgL^{-1}) with a statistically significant difference ($p < 0.01$).

The overall cationic order of dominance observed in this study was in the order of $Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$ all expressed in milli equivalent per liter (meq/L). This slightly contrasts the order for the world's standard fresh water which is $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ (Rhode, 1949; Ekpenyong, 1982; Welcomme, 1985). This same cationic order was observed both in the mining and non-mining stations of the water bodies. The overall cationic order for this study has revealed the dominance of Mg^{2+} over other cations thus suggesting a common geology and similar weathering influence among the water bodies. The anionic order of dominance of study area water bodies ($HCO_3^{-} > SO_4^{2-} > Cl^{-}$) expressed in (meq/L) showed it to be a carbonate type of water just like the world's average standard fresh water (Hutchinson, 1957).

The low DO mean value that was recorded in the dry season could be due to increase in temperature and duration of bright sunlight which has influence on the percentage of soluble gases. During the dry season, the long days of intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO_2 and giving off oxygen. This probably accounts for the qualities of oxygen noted during harmattan (Krishnamurthy, 1990). The overall DO value of the water bodies ranged from 2.8 to 9.6mgL^{-1} with a mean value of 6.16±0.33mgL^{-1} which compares well with the result of the work by Etim and Adie (2012) who recorded the highest average DO value of 6.68mgL^{-1} for Ogunpa river. Cold water can hold more dissolved oxygen than warmer water, this probably could have accounted for the significantly higher ($p < 0.05$) value of DO recorded in the rainy season than in the dry season.

Fluoroquinolones class of Gram's positive antibiotics was found to be more effective 44.8% against the isolated bacteria having pefloxacin as the most potent among the group Table 6.

Also, other antibiotics decreased in the order of macrolide (E) 51.7%, aminoglycoside (GEN and STR) 69.0%, sulphonamides/trimethoprim (SXT) 84.5%, β-lactams (Z and AMX) and penicillin (APX) 96.6%. Meanwhile, Gram's positive bacteria isolated showed 100% resistance to amoxicillin (Table 6). This was similar to the high resistance profile that was reported in other African countries such as in Kenya, where bacteria showed 100% resistance to amoxicillin, ampicillin and gentamycin (63.6%), (maina *et al*., 2013) but recorded 90.6% sulphonamides/trimethoprim, 94.4% ciprofloxacin which differ from the result obtained in this study which was 84.5% sulphonamides / trimethoprim and 48.3% ciprofloxacin. This study also conforms with the study reported by Odewade *et al*. (2021) where amoxicillin showed 100% resistance to organisms tested. The less potency of penicillin, β-lactams, sulphonamides and aminoglycosides to Gram's positive bacteria isolated in this study could be due to the antibiotics being used for a long period and must have been abused and as a result, the organisms must have developed mechanisms to circumvent their mode of action (Kolawole *et al*., 2009). Gram's negative bacteria isolated from the study water bodies that was susceptible to class of antibiotic were in the order fluoroquinolones (pefloxacin 6.7%, ofloxacin 16.7%, ciprofloxacin 21.7% and sparfloxacin 43.3%) with the overall value of 22.1%, followed by the aminoglycosides (gentamycin 41.7% and streptomycin 51.7%) with the overall value of 46.7%, sulphonamides/trimethoprim (septrin 53.3%), phenicol (chloranphenicol 71.7%) and β-lactams (amoxacillin 91.7% and augmentin 90%) with the overall resistance of 90.9% (Table 7). However, the result of this study contradicts the result that was recorded from a study that was carried out in Abuja, Nigeria where 17.8% ofloxacin and 22.2% gentamycin were recorded (Amaeze *et al*., 2013). The less potent of the above-mentioned antibiotics may also be as a result of drug abuse and indiscriminate misuse of antibiotics among the general population which has enhanced the emergence of resistance strains just as it could be the case in other organisms in any particular region or community in Nigeria which has led to the emergence of bacterial strains that are resistant to these relatively safe antibiotics (Bockstael *et al*., 2009).

Impact of the Gold mining on the physicochemical parameters and Microbial Quality in Water bodies Studied

In the course of this study, a number of parameters were recorded to have been significantly impacted probably due to the mining activity within the environment of the water bodies based on the comparism between non-mining stations and mining stations in the study area. The parameters include Turbidity, Total suspended solids (TSS), Apparent colour, True colour, pH, Alkalinity,Organic matter, and Chemical oxygen demand (COD) (Table 8). Also, water temperature, pH, conductivity and TDS showed statistically significant differences between mining and non-mining stations while turbidity showed very highly significant difference statistically between the two set of stations.

More species of bacteria occurred in Stations A,B,E and F in the rainy seasons of the study while higher number of bacterial species occurred in Stations C, D and G in the dry season but more species of fungal occurred in Station A in the rainy season while it occurred more in Stations B, and F in the dry season. On the overall, bacteria species happened to occur more than the fungal species in both seasons of the year and this is because the recorded bacterial species tend to thrive more in alkaline or close to neutral pH as most of the water are slightly alkaline, meanwhile, fungal species strive more in acidic condition leading to higher occurrence of fungal species in Stations D, and E.

CONCLUSION

The mined gold washed in the streams that are close to the mining sites have not been impacted negatively on most of the physico-chemical parameters but the microbial quality of the surface water was established to be impacted negatively therefore rendering it unsuitable for drinking without prior treatment.

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