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Metals' Content and Physicochemical characteristics of Well Waters in Sapele Metropolis, South-Southern Nigeria

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Abstract

Inadequate quantity of good quality water may present potential challenge to human health. This paper present results of metals' content and physicochemical properties of well water samples taken from sixteen (16) different locations in Sapele metropolis and analyzed using standard methods, with view to evaluating the implication for drinking and domestic use. The results obtained showed the following average physicochemical parameters: pH (6.84 ± 0.23), temperature (26.24 ± 0.27°C), TDS (153 ± 95mg/L), TSS (13.13 ± 2.6mg/L), DO (4.43 ± 0.38mg/L), BOD (0.23 ± 0.15mg/L), COD (3.02 ± 1.8mg/L), electrical Conductivity (306 ± 190µS/cm), turbidity (5.53 ± 1.46 NTU), total hardness (6.04 ± 5.90mg $CaCO_3$/L), and O&G (0.27 ± 0.18mg/L). The average anions concentrations were: Cl^- (70.12 ± 45.28mg/L), NO_3^- (8.15 ± 4.11mg/L), NO_2^- (0.45 ± 0.27mg/L), PO_4^{3-} (0.34 ± 0.17mg/L), HCO_3^- (16.70 ± 3.3mg/L), and SO_4^{2-} (7.74 ± 4.4mg/L). The mean concentrations of metals ions were: Ca (1.55 ± 1.4mg/L), Mg (0.52 ± 0.6mg/L), Na (3.88 ± 2.33mg/L), K (2.16± 1.69mg/L), Pb (0.0069 ± 0.0058mg/L), and Zn (0.38 ± 0.28mg/L). Others were: Cr (0.0013 ± 0.0018mg/L), Cu (0.0096 ± 0.0052mg/L), Fe (0.48± 0.28mg/L), Cd (0.00103 ± 0.0017mg/L), and Mn (0.014 ± 0.005mg/L). There were considerable variations in most of the measured properties of the well waters for the different sites however, the results were largely within the established limits set by the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO).

1. Introduction

Water is essential for life on earth; human existence can thus be threatened by inadequate quantity of good quality water. Groundwater accessible as bore holes and dug wells constitutes a major source of domestic water supply in most Nigerian cities where public water supply is in shot fall. Ground water may become contaminated as a result of both natural and anthropogenic factors; salt water encroachment associated with over drafting of aquifers, leaching from geological minerals through which the water travels, as well as radioactive decay of isotopes present in rocks / soils are natural sources of ground water pollution [1-4]. Anthropogenic sources include: leachates from sewage pipes and tanks, seepage from municipal solid wastes, spills and leaks from underground storage tanks and transport of petroleum products and other industrial chemicals [5]. Agricultural activities such as: indiscriminate disposal of animal wastes, unguided use of fertilizers, pesticides, herbicides and even irrigation activities can also lead to contamination of groundwater [6]. Besides, industrial and mining activities as well as deep-well disposal of wastes are major sources of underground water pollution [7]. Indeed, any unwholesome activities on land surfaces – residential, municipal, commercial, industrial or agricultural – will eventually lead to contamination of groundwater resources. This is because, of the strong interconnection between land surfaces / surface waters and the underground waters. Groundwater contamination could result in diminished water quality, shortage of water supply, demeaned surface water systems, elevated cleanup costs, increase costs of alternative water supplies and / or potential challenge to health.

Pollution of water with fecal matters could result in fecal-oral route of infection. This is typical of many waterborne infectious diseases [8]. A wide range of health challenges have been linked to the use and intake of polluted water [9-10]. Diseases such as typhoid, gastroenteritis, diarrhea, skin and kidney problems, immune suppression, methemoglobinemia, cancer, reproductive failure, neurological, respiratory and cardiovascular diseases etc. are associated with the intake of contaminated water [9, 11]. Generally, the signs associated with most heavy metals' toxicity include: gastrointestinal disorders, diarrhea, stomatitis, tremor, hemoglobinuria, ataxia, paralysis, vomiting, convulsion and depression [12, 13]. Specifically, toxicity due to lead accumulation may result decrease in hemoglobin production. Lead being a systemic toxicant, affects several body organs and systems such as: kidneys, liver, central nervous system, hematopoietic system, endocrine system and reproductive system [14-18]. Chronic accumulation of cadmium in body tissues and organs leads to kidney disfunction, hepatic damage and hypertension [19-20]. Copper though essential to normal functioning of the body system, in high doses causes anemia, liver and kidney damage, and stomach and intestinal irritation [21]. Likewise, zinc though an essential element, can results in system dysfunctions with consequent impairment in growth and development when presence in excess amount [12, 13]. Several factors make contamination by chromium a matter of serious concern, particularly, its toxicity, mutagenic, carcinogenic, and teratogenic effects [22-25].

Sapele is fairly industrialized town with growing population of over 174,273 according to the 2006 census [26]. Most the indigenes of Sapele metropolis have often depended on individually sunk Well for their domestic water supply due shortage in availability of public water. Increased urbanization, industrial and human activities in town perhaps, have affected the quality of the well waters. Many research works have been done on the impact of industrial and human activities on water quality in many parts of the country, but works in the Sapele area are still scanty. This work therefore, seeks to study the qualities of well waters in Sapele metropolis using physical and chemical characteristics as indices; with view to appraising the implications for drinking and domestic use.

2. Material and Methods

2.1. Study area and sampled well waters locations

The study was conducted on well waters samples from Sapele metropolis, Delta State, Nigeria. Sixteen (16) composite samples from different locations in the metropolis were assessed. Viz: Oghene Road (N05°53'44'' E05°41'51''), Olympia (N05°53'25'' E05°40'38''), Commercial avenue (N05°53'34'' E05°40'28''), Ugbeyiyi (N05°52'48'' E05°42'34'') , Ogbodu Estate (N05°53'04'' E05°40'42''), Ojolu Quarters (N05°53'09'' E05°40'03''), Reto (N05°52'52'' E05°40'41''), Mechanic village (N05°52'06'' E05°41'38''), MacPherson (N05°53'55'' E05°40'37''), Okirigwre N05°52'06'' E05°42'36''), Mission Road (N05°54'06'' E05°39'50''), Uraukpa-Gana (N05°53'15'' E05°38'43''), Akintola (N05°53'16'' E05°41'08''), Uko road-Gana (N05°53'28'' E05°39'16''), Amukpe (N05°51'20'' E05°43'11''), and Major Bowen (N05°53'11'' E05°41'20'').

2. 2. Sample Collection

Polyethylene bottles cleansed by acid, washed and rinsed thoroughly with distilled water were used for the sample collection. Thoroughly rinsed Pyrex glass containers were used for the collection of samples in which organic constituents were to be determined. Water samples were collected 3 – 10cm below the surface after thoroughly rinsing the containers with water about to be collected.

2.3. Sample preservation.

Immediately after sample collection, in situ parameters such as pH, temperature and conductivity were determined on site. Those meant for dissolved oxygen determination were fixed on the field by adding manganous sulphate and sodium hydroxide-sodium iodide-sodium azide reagents to the collected samples to form precipitate. The precipitates and the supernatants were taken to the laboratory for subsequent analysis. The rest of the samples were placed in ice-chest and immediately taken to the laboratory. Analyses for anions were soon carried out to prevent changes due to action of micro-organisms. For samples that could not be analyzed promptly, preservations were done after the recommendations of Ademoriti [27], and Radojević and Baskin [28]. Samples for chemical oxygen demand were preserved by acidification with 2ml of concentrated H_2SO_4 per liter. Phosphates were preserved by adding 2.5ml chloroform per 500ml of sample followed by storage at 4^oC. The samples for sodium, potassium, calcium, manganese and trace of heavy metals were preserved by adding 5ml concentrated nitric acid to liter of sample.

2.4. Analyses of Samples

Samples were analyzed using standard methods as described by Ademoriti [27], and Radojević and Baskin [28]: temperature were determined by 100^oC range thermometer, pH with pH meter (model 410A) after standardization of the associated electrodes with buffer 9 and 4 respectively, Dissolved Oxygen (DO) by the azide modification of Winkler's method, five-day Biochemical Oxygen Demand (BOD_5) were determined from depletion in oxygen content after a five-days incubation period, the Chemical Oxygen Demand (COD) were determined by oxidation with potassium dichromate followed by titration of the excess dichromate with ferrous ammonium sulfate, turbidity were measured using turbidity meter after standardization with 0 and 10 NTU polymer standard solutions, conductivity (cond.) were determined with the aid of conductivity meter (model RE387TX), Total Suspended Solids (TSS) were obtained by filtering samples through a weighed standard glass fiber and drying to constant weight, Total Dissolved Solids (TDS) were measured using the same conductivity meter with TDS functional mode selected, the summation of TSS and TDS gives the Total Solids (TS), chlorides were determined by the argentometric (Morh) method, spectrophotometric determinations of nitrates (NO_3^-), nitrites (NO_2^-), and phosphates (PO_4^{3-}) were done using the phenoldisulphonic acid; sulphanilamide; and ascorbic acid methods respectively. Bicarbonates (HCO_3^-) were determined by the acidimetric indicator-end-point method. Sulphates (SO_4^{2-}) were determined by turbidimetric method, while Oil and Grease (O&G) were extracted from aqueous portions into xylene. The absorbance of the extracts was then measured at 420nm on a spectrophotometer using xylene as reference. Ca^{2+} and Mg^{2+} ions were determined by complexometric titrations with sodium salt of EDTA, Na^+ and K^+ were determined by flame photometer, while the other metals (Pb, Zn, Cu, Fe, Cd, & Mn) were determined with Atomic Adsorption Spectrophotometer (AAS) after digestion with concentrated HNO_3.

3. Results and discussion

3.1. Some physico-chemical properties of the well waters.

Some of the physico-chemical characteristics of the well waters are as shown in Tables 1. Table 2 gives the range and mean of the determined parameters in comparison with the Nigerian Standard for Drinking Water Quality (NSDWQ) [29] and the World Health Organization (WHO) guidelines for drinking water quality [30]. The well waters have an average pH value of 6.84 ± 0.27 with a minimum value of 6.22 and maximum of 7.43. These were well within the recommended guideline of 6.5 – 8.5 established by the Nigerian standard for Drinking Water Quality (NSDWQ) [29]. The temperatures of the well waters were slightly constant with a mean of 28.24 ± 0.27^{o}C. The Dissolved Oxygen (DO) for the well waters averaged 4.43 ± 0.38mg/L with the lowest value (3.8mg/L) been recorded at Akintola (AK) while, the highest (5.30mg/L) was obtained at MacPherson (MP). The five-day Biochemical Oxygen Demand (BOD_5) ranged from 0.10 – 0.70mg/L with an average of 0.23 ± 0.15mg/L. These low values are indication that the well waters have less organic load. The average value of COD was 3.02 ±1.8mg/L with a minimum value of 2.00mg/L (for well waters at both Major Bowen and Reto). The highest value of CODs was 8.00mg/L observed for well water at Mechanic Village. The low values of CODs also indicate low contaminations. The total dissolved solids (TDS) for the well waters had values ranging from 46.20 – 355.00mg/L. The highest value (355mg/L) was recorded for water around Olympia while, the lowest (46.20mg/L) was obtained for well water at MacPherson Road. The range of TDS obtained in this study, is comparable to the range of 35 – 274mg/L and 76.00 – 450.00mg/L respectively recorded by Jidauna *et al* [31] and Olubanjo *et al* [32] for wells in Jos, Plateau State and Akungba-Akoko, Ondo State both in Nigeria. The values were however, lower than the 458.01 – 692.00mg/L recorded by Iroha *et al* [33] for well water samples in Abakaliki, in South-Eastern Nigeria.

Table 1: Some Physico-chemical properties of the well waters in Sapele metropolis

						Parameters					
Samples	pH	Temp. (^{o}C)	DO mg/L	BOD mg/L	COD mg/L	TDS mg/L	TSS mg/L	Cond. µS/cm	Turb. (NTU)	O&G mg/L	T.Hardness ($mgCaCO_3$/L)
OG	6.89	25.80	4.90	0.25	2.20	159.0	12.00	318.0	8.5	0.42	3.18
OP	6.96	25.70	4.00	0.28	2.60	355.0	14.00	710.0	3.8	0.20	21.13
CA	6.90	26.70	4.60	0.13	2.40	101.0	18.66	203.0	7.6	0.28	1.24
UB	6.91	26.40	4.20	0.45	2.00	74.0	16.00	149.0	4.1	0.10	1.47
OE	6.92	26.40	4.10	0.12	2.30	290.0	10.00	581.0	3.8	0.23	16.18
OJ	6.93	26.20	4.40	0.20	3.00	109.0	10.00	219.0	7.0	0.25	2.18
RT	6.92	26.20	4.40	0.10	2.00	264.0	16.00	529.0	6.3	0.12	9.52
MV	6.94	26.20	4.30	0.15	8.00	46.20	14.00	91.50	5.4	0.25	1.00
MP	6.35	26.30	5.30	0.20	2.20	200.0	16.00	400.0	6.2	0.12	3.99
OK	6.22	26.40	4.80	0.70	2.60	221.0	14.00	442.0	4.1	0.72	6.25
CM	6.71	26.40	4.10	0.14	2.30	84.0	12.00	168.0	4.4	0.10	2.82
UR	6.78	26.30	4.60	0.15	2.50	105.0	10.00	210.0	6.1	0.12	1.97
AK	7.04	26.00	3.80	0.19	7.00	59.40	13.00	118.8	3.9	0.21	9.00
UG	6.68	26.30	4.40	0.20	2.70	232.0	11.00	464.0	4.8	0.24	10.96
AP	7.43	26.00	4.70	0.13	2.50	76.0	14.00	152.0	4.6	0.63	3.99
MB	6.91	26.00	4.30	0.26	2.00	71.0	10.00	142.0	5.0	0.40	1.76

OG→ Oghene Road, OP→ Olympia, CA→ Commercial Avenue, UB→ Ugbeyiyi, OE→ Ogbodu Estate, OJ→ Ojolu, RT→ Reto, MV→ Mechanic Village, MP→ MacPherson, OK→ Okirigwre, CM→ Catholic Mission Road, UR→ Uraukpa-Gana, AK→Akintola,UG→ UKO road-Gana, AP→ Amukpe, MB→ Major Bowen

The conductivity value took the same trend as TDS since both has direct relationship. Thus, the highest (710.00µS/cm) and lowest (92.50µS/cm) values were also from Olympia, and MacPherson respectively. Both TDS and conductivity (cond.) values were however, within the desirable limits of 500mg/L and 1000 µS/cm respectively as established by [29] (Table 2).

Table 2: Range and mean of the determined parameters in comparison with standards

Parameters	Range	Mean ± SD	Standard
pH	6.22 – 7.43	6.84 ± 0.27	6.5 – 8.5[a]
Temp (°C)	25.70 – 26.70	26.24 ± 0.27	Ambient[a]
DO (mg/L)	3.80 – 5.30	4.43 ± 0.38	
BOD (mg/L)	0.10 – 0.70	0.23±0.15	
COD (mg/L)	2.00 – 8.00	3.02±1.8	
TDS (mg/L)	46.20 – 355.00	153 ± 95	500[a]
TSS (mg/L)	10.00 – 16.00	13.13 ± 2.6	
Cond. (µS/cm)	92.50 – 710.00	306 ± 190	1000[a]
Turb. (NTU)	3.8 – 8.5	5.35 ± 1.46	5[a]
O&G (mg/L)	0.10 - 0.72	0.27 ± 0.18	
Cl^- (mg/L)	20.00 – 158.32	70.12 ± 45.28	250[a]
NO_3^- (mg/L)	4.07 – 16.10	8.15 ± 4.11	50[ab]
NO_2^- (mg/L)	0.10 – 0.85	0.45 ± 0.27	0.2[a] (3[b])
PO_4^{3-} (mg/L)	0.12 – 0.62	0.34 ± 0.17	
HCO_3^- (mg/L)	12.00 – 22.20	16.70 ± 3.3	
SO_4^{2-} (mg/L)	4.12 – 18.23	7.74 ± 4.4	100
Ca (mg/L)	0.20 – 4.82	1.55 ± 1.4	
Mg (mg/L)	0.10 – 2.18	0.52 ± 0.6	
T. Hardness ($mgCaCO_3$/L)	1.00 – 16.18	6.04 ± 5.90	150[a]
Na (mg/L)	0.80 – 8.50	3.83 ± 2.33	200[a]
K (mg/L)	0.40 – 5.48	2.16 ± 1.69	
Pb (mg/L)	BDL – 0.008	0.0069 ± 0.0058	0.01[ab]
Zn (mg/L)	0.10 – 0.89	0.379 ± 0.28	3a
Cr (mg/L)	BDL - 0.005	0.0013 ± 0.0018	0.05[ab]
Cu (mg/L)	0.003 – 0.020	0.0096 ± 0.0052	1[a] (2[b])
Fe (mg/L)	0.12 – 1.00	0.48 ± 0.28	0.3[a]
Cd (mg/L)	BDL – 0.0068	0.00103 ± 0.0017	0.003[ab]
Mn (mg/L)	0.008 – 0.024	0.014 ± 0.005	0.2[a] (0.4[b])

[a] Nigerian Standard for Drinking Water Quality (NSDWQ) [29], [b] World Health Organization (WHO) guidelines for drinking water quality [30].

The total suspended solids (TSS) for the well waters ranges from 10.00 – 18.00mg/L with the highest been recorded at Commercial Avenue (CA). An average turbidity value of 5.35 ± 1.46 NTU was observed for the well waters, with the highest value of 8.5NTU been recorded for water at Oghene Road while the lowest (3.8NTU) was observed for water at Ogbodu Estate (OE). Most of these values however, were in the neighborhood of the desirable level of 5 units. The average value for oil and grease content of the well water was 0.27 ±0.18mg/L. The lowest value of 0.01mg/L was recorded for well waters at Ugbeyiyi (UB) and Catholic Mission road (CM) while the highest value (0.72mg/L) was found in Okirigwre (OK). Values in some other areas were: Amukpe (0.63mg/L), Major Bowen (0.40 mg/L), Commercial Avenue (0.28 mg/L), Ojolu and Mechanic Village (0.25 mg/L), and Ogbodu Estate (0.23 mg/L).

3.2. The concentrations of some anions in the well waters.

The average chloride concentration for the well waters was 70.12 ± 45.28mg/L, with the highest value (158.32mg/L) been recorded for water at Olympia. While the lowest (20.00 mg/L) was noted for well water at Akintola (Table 2 and 3). None of these values however, exceeded the recommended desirable limit of 250mg/L established by the Nigerian Standard for Drinking Water Quality [29]. The average value of nitrates for the well waters was 8.15 ±4.11mg/L drawn from a range of 4.09 – 16.10mg/L. The relatively high values of 16.10 and 15.70mg/L found for well at Reto (RT) road and Uku road-Gana (UG) might be due to closeness of these wells to septic tanks, and leachates from agricultural farms, which nitrates fertilizers have been applied. These areas are characterized by the presence of large farmlands. The values were however within the established limit of 50mg/L set by both the Nigerian Standard for Drinking Water Quality (NSDWQ) [29] and the World Health Organization (WHO) guidelines for drinking water quality [30]

Table 3: Concentrations of some anions in the well waters of Sapele metropolis

Samples	**Parameters (mg/L)**					
	Cl^-	NO_3^-	NO_2^-	PO_4^{3-}	HCO_3^-	SO_4^{2-}
OG	84.71	6.00	0.12	0.30	12.00	8.20
OP	158.32	4.78	0.32	0.20	18.50	10.23
CA	50.72	4.07	0.48	0.12	12.10	4.12
UB	22.72	6.32	0.25	0.25	20.00	5.46
OE	142.70	5.13	0.10	0.50	15.00	8.52
OJ	48.18	13.90	0.85	0.20	18.00	5.12
RT	120.34	16.10	0.80	0.59	22.20	5.28
MV	20.18	6.00	0.42	0.23	16.00	5.14
MP	98.72	12.00	0.80	0.30	12.00	5.46
OK	98.89	8.70	0.72	0.62	14.00	18.23
CM	23.62	6.02	0.27	0.23	14.00	6.30
UR	50.92	4.70	0.41	0.13	13.00	18.50
AK	20.00	5.12	0.21	0.22	20.00	6.10
UG	100.05	15.70	0.80	0.60	19.00	5.18
AP	34.00	5.80	0.14	0.50	17.00	5.22
MB	48.00	10.10	0.45	0.39	18.50	6.70

OG→ Oghene Road, OP→ Olympia, CA→ Commercial Avenue, UB→ Ugbeyiyi, OE→ Ogbodu Estate, OJ→ Ojolu, RT→ Reto, MV→ Mechanic Village, MP→ MacPherson, OK→ Okirigwre, CM→ Catholic Mission Road, UR→ Uraukpa-Gana, AK→ Akintola, UG→ UKO road-Gana, AP→ Amukpe, MB→ Major Bowen.

The mean concentration for nitrites in the water was 0.45±0.27mg/L with a range of 0.10 – 0.85mg/L. There was very strong correlation between NO_3^- and NO_2^- at 0.01 probability. The nitrites concentrations for most of the sampled waters were higher than 0.2mg/L NO_2^- recommended by NSDWQ [29] but all were lower than the 3mg/L NO_2^- established by WHO [30] for drinking water quality. For all samples examined, the sum of the ratios of the concentrations of each [nitrates (NO_3^-) and nitrites (NO_2^-)] to its guidelines value were also much lower than the specified value of one (1) stipulated by WHO [30]. This indicates that the water is not polluted with respect to these ions [30]. Excess nitrates and nitrites in water have been implicated as a cause of methemoglobinemia (blue baby syndrome) in infants [30, 36]. The average value of phosphate for the well water was 0.34 ± 0.17mg/L. The highest value of phosphates was at Okirigwre with value of 0.62mg/L. This was followed by Uko Road –Gana, and Reto with values of 0.60mg/L and 0.59mg/L respectively. This could be due to the use of phosphate fertilizers in adjoining farms since these areas have vast agricultural lands. The range of values for nitrates (4.07 – 16.10mg/L), phosphates (0.12 – 0.62mg/L), and chlorides (20.00 – 158.32mg/L) obtained in this study, are similar to the 0.30 – 4.60mg/L NO_3^-, 0.70 – 7.60mg/L PO_4^{3-}, and 14.20 – 61.60mg/L Cl^- reported by Igwemmar *et al* [34] for borehole water in Gwagwalada, Nigeria. Oko *et al* [35] reported mean values of 2.05, 1.93, and 70.91mg/L for nitrates, phosphates and chlorides respectively for well water in Wukari, Taraba State, Nigeria. The mean value for nitrates (8.15mg/L) observed in this study was much higher, while that for phosphates (0.34mg/L) was lower than that reported by Oko *et al* [35]. The mean chloride values for both studies were about the same. The mean of sulphates in the sampled well waters was 7.74 ± 4.4mg/L drawn from a range of 4.12 – 18.23mg/L. Drinking water with high concentrations of sulphates, produces laxative effect which is typically enhanced in the presence of magnesium [30]. There was slight correlation between sulphates and nitrates ($P < 0.05$ probability). The mean of bicarbonates for the well waters was 16.70 ± 3.3mg/L with a range of 12.00 – 22.00mg/L. The relatively high values of 16.00 and 20.00mg/L obtained for wells at mechanic village (MV) and Uruakpa (UR) could be adduced to the closeness of these wells to gas-flaring site. Carbon (IV) oxide evolved in combustion process may be pick up by rainwater to form carbonic acid which on dissociation yield bicarbonates. Calcium and magnesium ions majorly responsible for water hardness, had average values of 1.55±1.4mg/L Ca and 0.52±0.65mg/L Mg in the water samples. The total hardness ranged from 1.00 – 16.80mg$CaCO_3$/L with a mean of 6.04 ± 5.90mg$CaCO_3$/L. These values are quite low and the water generally, can be described as soft [37].

3.3. The concentrations of some metals' ions in the well waters.

The concentrations of metal ions in the sampled well waters are as shown in Table 4. The concentration of sodium for the well waters ranged from 0.80 – 8.50mg/L with an average of 3.83 ± 2.33mg/L (Table 2).

Table 4: Concentrations of some metals ions in the well water samples of Sapele metropolis

Samples	Parameters (mg/L)									
	Ca	**Mg**	**Na**	**K**	**Pb**	**Zn**	**Cr**	**Cu**	**Fe**	**Cd**	**Mn**
OG	0.94	0.20	2.17	1.10	0.005	0.89	0.004	0.013	0.25	0.0017	0.010
OP	4.82	2.18	8.5	5.48	0.013	0.86	0.004	0.006	0.48	0.0017	0.014
CA	0.23	0.16	1.89	0.40	0.004	0.25	BDL	0.003	0.59	BDL	0.016
UB	0.42	0.10	1.20	0.88	BDL	0.21	BDL	0.003	0.12	BDL	0.008
OE	3.72	1.65	6.85	4.28	0.004	0.10	BDL	0.013	0.20	BDL	0.010
OJ	0.64	0.14	1.80	0.82	0.005	0.32	BDL	0.012	0.42	0.0068	0.014
RT	2.84	0.58	6.18	4.12	0.008	0.25	BDL	0.020	0.85	BDL	0.018
MV	0.20	0.12	0.80	0.40	0.020	0.20	0.005	0.010	1.00	0.0017	0.024
MP	1.18	0.25	4.26	3.18	0.015	0.63	BDL	0.016	0.83	0.0017	0.024
OK	1.80	0.42	4.40	3.53	0.010	0.25	BDL	0.012	0.46	BDL	0.014
CM	0.91	0.13	5.50	2.40	0.002	0.82	0.001	0.005	0.82	0.0011	0.009
UR	0.62	0.10	4.90	1.87	0.008	0.23	BDL	0.009	0.14	BDL	0.015
AK	3.10	0.30	1.35	0.70	BDL	0.10	BDL	0.003	0.20	BDL	0.010
UG	2.30	1.25	6.10	4.00	0.012	0.64	0.004	0.014	0.65	0.0017	0.021
AP	0.58	0.61	2.62	0.55	BDL	0.10	BDL	0.004	0.41	BDL	0.012
MB	0.47	0.14	2.90	0.82	0.004	0.21	0.002	0.010	0.22	BDL	0.010

OG→ Oghene Road, OP→ Olympia, CA→ Commercial Avenue, UB→ Ugbeyiyi, OE→ Ogbodu Estate, OJ→ Ojolu, RT→ Reto, MV→ Mechanic Village, MP→ MacPherson, OK→ Okirigwre, CM→ Catholic Mission Road, UR→ Uraukpa-Gana, AK→ Akintola, UG→ UKO road-Gana, AP→ Amukpe, MB→ Major Bowen.

The relatively high value of 8.50mg/L noted for well water around Olympia might be due to pollution from vehicular exhaust systems since this area is always subject to traffic jam. The potassium content of the well water varies from 0.40 – 5.48mg/L. The highest value for potassium was also found on wells around Olympia, possibly for the same reason stated for sodium above. Other high values of 4.12 and 4.00mg/L were observed for well waters at Reto and Uko Road-Gana. This could have resulted from leachates from NPK fertilizers used in these areas. The range of values however were within the 200mg/L specified by [29].

Most of the well waters contain traces of lead; the range was from 0.002 – 0.020mg/L. Some wells however, had undetectable levels of Pb. These values are comparable to the range (ND – 0.07mg/L Pb) and mean of 0.01mg/L Pb obtained for groundwater in the coaster aquifer of Owerri, Nigeria by Amadi *et al* [38]. The highest value of 0.020mg/L was observed for the well at Mechanic Village (MV) which also share boundary with a gas-flaring site. The gas flare and lead from automobile engines systems perhaps, were responsible for this relatively large figure. Ugbeyiyi – a relatively unpolluted zone - had undetectable lead content in its wells. All these values, however, are well below the maximum permissible standard of 0.01mg/L stipulated by the Nigerian Standard for Drinking Water Quality (NSDWQ) [29] (Table 2). The well waters had zinc concentration averaging 0.38 ± 0.28mg/L which was well within the limit of 3mg/L established by NSDWQ [29]. Most of the Well waters had undetectable levels of chromium. However, values of 0.004mg/L was recorded for samples at Oghene Road, Olympia, and Uko Road- Gana, while values of 0.005, 0.002, and 0.001mg/L were recorded for samples from mechanic Village (MV), Major Bowen (MB), Catholic Mission Road (CM) respectively (Table 4). The comparatively high value of 0.005mg/L for mechanic village Wells could be ascribed to the nearness of these Wells to a gas-flaring site and auto-mechanic repair station. The high value at Olympia could be adduced to high vehicular activities at this location. The average concentration of Cu in the Wells was 0.0096 ± 0.0052mg/L which was within the limits of 1mg/L and 2mg/L recommended by NSDWQ [29] and WHO [30] respectively. The range of values (0.003 – 0.020mg/L) obtained in this report were also much lower than the 0.032 – 0.040mg/L and the 0.07 – 1.00mg/L recorded by Ngele *et al* [39] and Amadi *et al* [38] respectively for groundwater samples at Amike, Ebonyi State and Owerri, Imo State, both in South-Eastern Nigeria. The iron concentrations for the Well waters had an average value of 0.48±0.28mg/L. This value was higher than the mean value of 0.240 and 0.21mg/L obtained by Ngele *et al* [39] and Amadi et al [38] respectively for groundwater samples from Amike, Ebonyi State and Owerri, Imo State, in South-Eastern Nigeria. The highest value of 1.00mg/L was found at mechanic village. This could be due to leachates from rusted scraps of motor parts which are predominant in this site. High values of 0.85 and 0.83mg/L were also observed for well waters at Reto and MacPherson road respectively. Leaching of Fe ions from soil minerals might have contributed to these large values. The average concentration of cadmium for the well waters was 0.00103 ± 0.00017mg/L. This value is low and encouraging as it shows a relatively low level of cadmium pollution. Most wells had undetectable levels. The highest value of 0.0068mg/L was recorded at Ojolu quarter (OJ). This perhaps is due to seepage from open dump containing cadmium in this area. Wells at Oghene Road, Olympia, Mechanic Village, MacPherson and Uko-Gana had same concentrations of 0.0017mg/L while, that at Catholic Mission road had a concentration of 0.0011mg/L Cd. The other wells had undetectable level of Cd in their waters. The manganese concentrations of well waters were quite low, with a mean of 0.014mg/L ± 0.005mg/L drawn from a range of 0.009 – 0.018mg/l. These values were within the highest desirable level of 0.2mg/L recommended by NSDWQ [29].

3.4. Correlation analysis.

Results of Pearson's correlation coefficients and P-values calculated for all possible variables pairs (Appendix A & B), indicated very strong correlation ($P < 0.01$) between the physicochemical parameters: Conductivity; Cl^-; Total hardness; Ca; Mg; Na; K and TDS. Chlorides (Cl^-) was highly correlated ($P< 0.01$) with Ca, Mg, Na, and K content. Very significant positive correlations were also present between: NO_3^- and NO_2^-; NO_2^- and Cu; NO_2^- and Mn. Among the heavy metals, very significant relationships ($P < 0.01$) were observed between: Pb and Cr; Pb and Mn; Cr and Cd; Cr and Mn; Fe and Mn. Significant negative correlation ($P < 0.05$) were found between: TSS and Cd; Turbidity and Total hardness. The pH was also negatively correlated with BOD and NO_2^-. Significant positive correlations ($P <0.05$) were also present between: DO and Turbidity; BOD and SO_4^{2-}; COD and Cr^-, TDS and Cu; TSS and Cr; Conductivity and Cu; NO_3^- and PO_4^{3-}; NO_3^- and Cd; NO_2^- and Cu; NO_2^- and Cd; NO_2^- and Fe; PO_4^{3-} and Cu; K and Cu; Pb and Fe; Cu and Mn. These positive correlations may imply that: one parameter is associated with the other for instance the correlation of chlorides with Na, K, Mg, and Ca implied that chlorides in the water exist mainly in these forms. It may also indicate same source(s) as seen in the correlations among heavy metals. Significant positive or negative correlations may also imply that one variable has direct or indirect impact on the values of the others. Temperature and pH usually exhibit a lot of effects on the values of other physicochemical properties. However, the fairly constant values for temperature and pH in the sampled waters explained the lack of much correlations with other physicochemical properties in this report. The lack of significant positive or negative correlations suggest that the presence of high value for a particular measured parameter, does not necessarily indicate high (or low) value for the other.

Conclusion

The examinations of metals' content and physicochemical properties of well waters in Sapele metropolis revealed that they were largely in conformity to the stipulated standards established by Nigerian Standard for Drinking water and the World Health Organization. However, high concentration of cadmium (above the NSDWQ and WHO standards) was observed for well at Ojolu. Similarly, high values of lead concentrations (though within NSDWQ and WHO standards) were noted for wells at Mechanic Village and Uraukpa-Gana area. Based on the physico-chemical characteristics, the well waters can be judge satisfactory for drinking and domestic purpose. However, the bacteriological and microbiological characteristics need to be considered. Also, because of the possibility of metals' accumulation in human bodies, periodic testing of the levels of some metals such as lead and cadmium content accompanied with other key parameters should be encouraged to ascertain the potability of the waters.

Appendix A: Correlation coefficients of relations between the various measured parameters

	pH	DO	BOD	COD	TDS	TSS	Cond	Turb	T.Hard	Cl	NO_3^-	NO_2^-	PO_4^{3-}	Ca	Mg	Na
BOD	-0.54*	0.15														
Cond	-0.29	0.04	0.18	-0.39	0.99**	0.01										
Turb	-0.02	0.59*	-0.29	-0.16	-0.16	0.14	-0.16									
T.Had	0.09	-0.41	-0.02	-0.07	0.84**	-0.11	0.84**	-0.48*								
Cl^-	-0.28	0.12	0.09	-0.41	0.98**	-0.02	0.98**	0.07	0.80**							
$NO2^-$	-0.56*	0.37	0.15	-0.13	0.22	0.12	0.22	0.26	-0.10	0.21	0.83**					
PO_4^{3-}	-0.18	0.16	0.25	-0.26	0.44	-0.19	0.44	-0.29	0.31	0.44	0.53*	0.26				
HCO_3^-	0.41	-0.61*	-0.01	-0.16	0.08	-0.03	0.08	-0.42	0.32	0.01	0.42	0.13	0.29			
SO_4^{2-}	-0.44	0.16	0.51*	-0.15	0.24	-0.03	0.24	-0.16	0.12	0.25	-0.25	-0.01	0.06			
Ca	-0.01	-0.44	0.00	0.01	0.80**	-0.09	0.80**	-0.47	0.97**	0.75**	0.04	-0.06	0.29			
Mg	0.11	-0.33	-0.05	-0.16	0.82**	-0.13	0.82**	-0.46	0.95**	0.79**	-0.01	-0.12	0.32	0.85**		
Na	-0.25	-0.12	-0.07	-0.45	0.84**	-0.19	0.84**	-0.33	0.77**	0.80**	0.18	0.13	0.36	0.72**	0.77**	
K	-0.41	-0.06	0.12	-0.35	0.94**	-0.06	0.94**	-0.35	0.81**	0.89**	0.29	0.26	0.46	0.79**	0.78**	0.94**

**significant at the 1% level, *significant at the 5% level. Parameters that showed no significant correlation with any others were not shown

Appendix B: Correlation coefficients of relations between the various measured parameters

	Pb	Cr	Cu	Fe	Cd	Mn
pH	-0.24	0.42	-0.43	-0.26	0.31	-0.34
DO	0.20	0.31	0.42	0.20	-0.04	0.43
BOD	0.13	0.14	-0.05	-0.26	0.04	-0.20
COD	0.67**	0.59*	-0.31	0.22	-0.03	0.28
TDS	0.15	0.32	0.52*	0.11	-0.21	0.18
TSS	0.29	0.55*	-0.18	0.40	-0.55*	0.29
Cond.	0.15	0.32	0.52*	0.11	-0.20	0.18
Turb.	-0.19	0.28	0.32	0.11	0.38	0.26
T.hard.	0.13	0.27	0.16	-0.15	-0.23	-0.03
Cl-	0.12	0.36	0.57*	0.07	-0.19	0.19
NO3-	0.12	0.00	0.74**	0.38	0.48	0.45
NO2-	0.31	0.17	0.60*	0.49*	0.53*	0.65**
PO_4^{3-}	0.05	0.05	0.55*	0.11	-0.26	0.09
Ca	0.11	0.23	0.19	-0.06	-0.23	-0.06
Mg	0.16	0.33	0.11	-0.04	-0.22	0.02
Na	-0.01	-0.19	0.36	0.14	-0.39	0.08
K	0.19	0.07	0.84**	0.21	-0.38	0.20
Pb		0.84**	0.23	0.53*	-0.29	0.84**
Zn		0.11	0.15	0.29	-0.52*	0.08
Cr			0.60*	0.16	0.96**	0.74**
Cu				0.34	0.19	0.50*
Fe					-0.38	0.73*

**significant at the 1% level, *significant at the 5% level. Parameters that showed no significant correlation with any others were not shown.

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