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Research Article

Geochemical and Bacteriological Analyses of Water Resources Prone to Contamination from Solid Waste Dumpsites in Imo State, Southeastern Nigeria

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Abstract

Background and Objective: Geochemical and bacteriological analysis of water resources within some selected dumpsites in Imo State, Southeastern Nigeria was carried out to detect possible leachate contamination from the open dumpsites. The main objective was to determine the quality and potability of the water resources of the study area. **Materials and Methods:** A total of sixteen borehole and stream water samples were used in addition to four leachate samples collected within the dumpsites. Chemical analysis of the samples was carried out using standard procedures with the heavy metals analyzed using the atomic absorption spectroscopy (AAS), while bacterial analysis was carried out using the membrane filter technique. Descriptive statistical techniques including the mean and standard deviation of geochemical and bacteriological parameters were employed for statistical analysis. **Results:** The results of the study revealed that the concentrations in mg L^{-1} of Na^{+2}, Mg^{+2}, Ca^{+2}, CO_3^{-2} and HCO_3^{-} ions for both groundwater and surface samples have mean values of 4.65, 18.1, 87.67, 119 and 83.5 mg L^{-1}, respectively. Iron (Fe^{+2}), potassium (K^{+}), nitrate (NO_3^{-}) and lead (Pb^{+2}) concentrations in the water samples were above the WHO 2010 permissible limits and ranged from 0.05-2.2, 0-23.3, 0.04-343 and 0–7 mg L^{-1}, respectively. Bacteriological analysis revealed average values of 537, 215, 86 and 32 CFU/100 mL for total bacterial count, total coliform count, total faecal count and total *E. coli*, respectively indicating possible bacteriological contamination of the water resources in the vicinity of the dumpsites. Two dominant hydro geochemical facies (water types) were identified in the study area which included the Ca-Mg-Cl and Ca-SO_4 water types. **Conclusion:** It was concluded that the high concentrations of potassium, nitrate, iron, lead and high occurrence of bacteria in the water resources of the study area indicate possible anthropogenic contamination from the nearby dumpsites. It was therefore, recommend that a better waste management approach be adopted for environmental protection and sustainability.

Key words: Solid waste dumpsites, geochemical, bacteriological, atomic absorption spectroscopy, hydrogeochemical facies, anthropogenic factors

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Municipal solid waste disposal is major environmental concern worldwide especially in the developing countries due to the poor and environmentally unsustainable waste disposal techniques used. The poor management of municipal wastes from various cities within the developing countries especially Nigeria has resulted serious degradation of the environment of course with far reaching consequences on the water resources. In most of the situations, the wastes were discarded into open excavations where sands were acquired for construction purposes leading to the infiltration of leachates into the water resources of the surrounding event. Rapid urbanization and industrialization in most of these cities has led to an increase in the number of dumpsites and the common practice in these areas is generally open dumping of solid waste[1]. The continuous growth in population, rapid industrialization and accompanying technology result to increased waste generation and disposal activities[2,3]. Highway constructions as a result of urbanization in developing countries usually have some negative impact on the environment due to numerous abandoned borrow pits prevalent in such locations[4,5]. The road construction companies excavate sand from the earth, thereby creating large pits commonly known as borrow pits. Some of these pits that are very close to or within the municipal areas are often used as unprotected solid waste dumpsites. These pits are most often so deep that areas with shallow water tables are so close to the floor of the ditches where sands have been excavated leading to high susceptibility of the aquifers to anthropogenic contamination. In most cases these pits are later filled up with solid wastes without protecting the aquifer below them while some are abandoned without reclaiming them. In the process of natural recharge of aquifer therefore, leachate from this municipal waste dumps infiltrate into the groundwater and the nearby surface waters. There is therefore an urgent need for monitoring the various water systems (both surface and groundwater) around municipal solid waste dumps for proper water resource management.

The use of physiochemical and biological indices of water analysis for assessment of water quality are very important tools that complement each other in determining the presence of undesirable physical, chemical and biological material ingression into an aquifer unit overlaid by an established contaminant point source like a dumpsite. A detailed knowledge of physical, chemical and biological conditions of water resources in such an environment that be anthropogenically controlled is necessary if public health is not to be compromised[6]. Various environmental studies have shown that the rate of discharge of pollutants into the environment is far higher than the rate of their purification. Many researchers have studied hydrochemical characteristics and contamination of groundwater and surface water in various areas with unprotected dumpsites identified as a major point source of pollution[1,7-9]. Similarly, some researchers have employed the use of surface electrical resistivity techniques to study dumpsites and the possible effects on groundwater and in most cases leachate contamination from the dumpsites are believed to have contaminated the water resources of the areas studied[10-13]. Some of the geophysical methods used for groundwater pollution studies include electrical resistivity, 3-D electrical tomography, induced polarization, ground penetrating radar (GPR), etc. It has become a common practice that each house in the urban centers are having at least a bore hole and overhead tanks as to take care of the rising demand of water resources. Most of these wells are very shallow owing to the fact that they were drilled by local and small scale contractors and as such do not care to drill to deeper aquifer which will definitely cost more. Again most of these privately owned wells were drilled without any geophysical survey as to determine the depth and location of the well to be able assess unpolluted groundwater.

Generally, most studies carried out to assess the impact of solid waste dumpsites on the water resources have mainly focused on the physicochemical characterization and of course the bacteriological indices of the water samples without relating them to the chemical and biological characteristics of the leachate from the dumpsite[1-13]. The bacteriological indices which include the total bacterial counts, the *E. coli* count, the fecal count and so on generally serve as surveillance tools for determining the potability of surface and ground waters[14-16]. This study was aimed at determining the physicochemical and bacteriological indices of the surface and groundwater water resources around three municipal waste dumpsites to investigate possible leachate contamination from a dumpsite. Similarly, effort was made to analyze the leachate samples from the dumpsite and to confirm that the chemical and bacteriological signatures found in the analyzed waters were actually coming from the dumpsites. Finally the presence or absence of these contaminants (both chemical and bacteriological) in the analyzed water samples was used to assess their current quality status, potability and usability.

MATERIALS AND METHODS

Study area: The study area is Imo state and it lies within the Imo River Basin hydrological province of Nigeria. Imo state is located in the Southeastern part of Nigeria with Owerri as its capital. It is located in the tropical, equatorial rain forest belt of

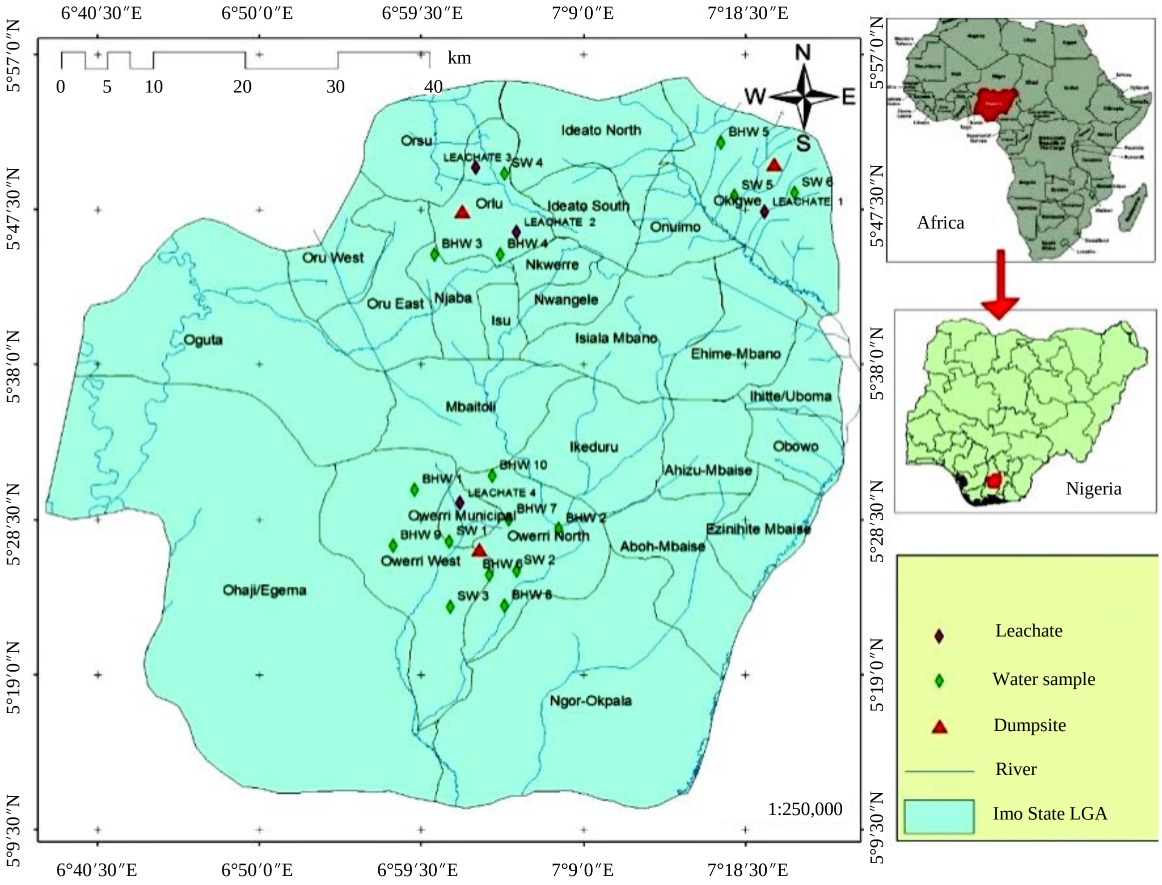

Fig. 1: Location map of the study area showing dumpsites, water and leachate sample locations

West Africa and lies between latitudes 4°45'-7°15'N and longitudes 6°50'E-7°25'E (Fig. 1). Imo state is bounded on the east by Abia state, on the West by River Niger and across the River Niger is Delta state. It is also bounded on the North and South by Anambra state and Rivers state, respectively. The human population of the state is about 4 million people as recorded during the 2006 national population census. The State comprises of three geopolitical zones, with each zone having a city where the municipal wastes was generated and was deposited at various open dumpsites mostly in borrow pits. Generally, it has been established that the number of dumpsites in an area was a function of population growth[17]. These dumpsites are quickly abandoned as soon they overflow and spillover to the adjoining road without any form of remediation or treatment with this practice most often threatening the quality status of the groundwater system[10,18]. The general populace in the study area depends on groundwater for their daily water needs while very few people especially in the rural areas rely on surface water for their daily needs.

The solid waste dumpsites studied include the Old Aba Road dumpsite in Owerri Metropolis, the Beach Dumpsite in Orlu within and the Ikpa Nkoto Dumpsite in Okigwe. A detailed description of the locations and characteristics of the analyzed water samples is presented in Table 1. The Old Aba Road side is located in an area underlain by the highly porous Benin formation, with the Beach dumpsite underlain by the Ameki formation while the Ikpa Nkoto dumpsite is located in area within the Nsukka formation. In all, the three dumpsites have existed for not less than 40 years and all situated in low lying lands that were highly susceptible to surface contamination. The Aba Road dumpsite, Owerri (Fig. 2) is one of the abandoned pits created during the road construction work within and around Owerri municipality. The pit was later filled up with municipal solid waste and they overflew to the adjoining areas. The major components of these municipal wastes were condemned automobile parts from nearby mechanic villages like car batteries, plastics and iron based materials. Household, industrial, agricultural and of course domestic wastes generated from the municipal markets were also part of the composition of these dumpsites.

Fig. 2: Old Aba Road dumpsite, Owerri showing a typical dumpsites in the study area

Table 1: Locations and descriptions of water samples from the study area

Sample	Location	Longitude (E)	Latitude (N)	Elevation	Description
BHW 1	NO. 2 Otamiri lane, Owerri	007°02' 21.5"	05°28'18.6"	70.0	Borehole sample
BHW 2	Behind the young motors,Egbu Rd. Owerri	007°02' 47.2"	05°28'29.2"	66.0	Borehole sample
SW 1	Otamiri-upstream owerri	007°02' 30.6"	05°28'18.6"	59.0	Surface water
SW 2	Otamiri-midstream Owerri	007°02'29.1"	05°28'17.4"	58.0	Surface water
SW 3	Otamiri-downstream Owerri	007°02' 11.0"	05°28'05.2"	46.0	Surface water
BHW 3	Produce Avenue, Orlu-Mgbee Rd.Orlu	007°02' 30.6"	05°47'54"	186.0	Borehole sample
SW 4	Ogidi River Orlu	007°02'40.6"	05°48'01.4"	114.0	Surface water
BHW 4	Along Bishop Shanahan Rd. Orlu	007°02' 37.0"	05°47'51.11"	185.0	Borehole sample
SW 5	Ogbakwarakwara River Okigwe	007°20'09.4"	05°50'51.2"	133.0	Surface water
BHW 5	Dee Jones Filling station Okigwe	007°02' 34.4"	05°51'28.4"	182.0	Borehole sample
SW 6	Ngene Aajako River Okigwe	007°20'13.5"	05°50'51.25"	140.0	Surface water
BHW 6	Old Aba Road Naze	007°01'3.7"	05°27’ 37.5"	72.0	Borehole sample
BHW 7	Deeper Life Bible Church Njoku Saw Mill Owerri	007°02'38.9"	05°28' 032"	24.68	Borehole sample
BHW 8	Opposite Chybyke Filling Station Aba Road Owerri	007°02.419'	05°27.988'	72.54	Borehole sample
BHW 9	Car Wash Opposite Total Filling Station, Aba Road Owerri	007°02.245'	05°28.277'	69.79	Borehole sample
BHW 10	St. Mulumba Church. Wetheral Rd Owerri	007°02' 395'	05°28.487'	79.86	Borehole sample
L1	Ogidi River bank Orlu	007°02'35.3"	05°47'55.1"	169.0	Leachate sample
L2	Beach dumpsite Orlu	007°02' 40.6"	05°48'01.4	114.0	Leachate sample
L 3	Ikpa Nkoto dumpsite Okigwe	007°02'17.9"	05°51'28.7"	168.0	Leachate sample
L4	Njoku Saw Mill	007°02'29.4"	05°28'05.5"	71.0	Leachate sample

Geology and hydrogeology of the study area: The study area was characterized by the equatorial climate which was generally humid with an average humidity of 75% in the rainy season. The mean annual rainfall lies between 1800 and 2500 mm with mean annual temperature of 20°C.

Generally, geologic formations overlying the aquiferous unit determined the safety and protective capacity of the water available in the aquifer units. The ease with which the contaminants get into the groundwater depends on several factors which include the hydraulic characteristics in addition to the lithology of the overlying formations. The Imo river basin, a sedimentary syncline spanning 140 km North to South, covers six geologic formations in addition to alluvial deposits. The formations in the study area however include the Nsukka, Imo shale, Ameki, Ogwashi, the coastal plain sands of the Benin and Alluvium formations[19]. The three dumpsites studied were however located within different geologic formations of the study area (Fig. 3). The Aba Road dumpsite within Owerri metropolis lies within the Benin formation, with the Beach dumpsite in Orlu lying within the Ameki formation while the Ikpa Nkoto dumpsite in Okigwe lies within the Nsukka formation.

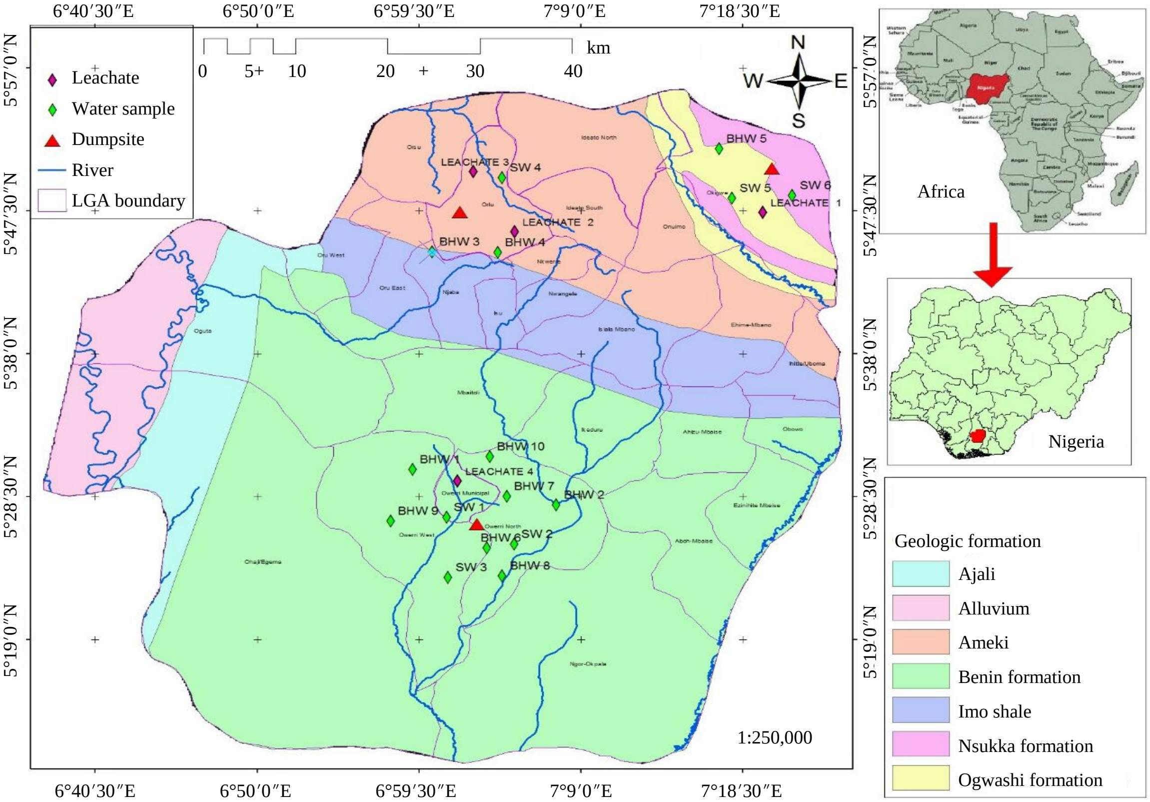

Fig. 3: Geological map of the study area showing the three studied dumpsites

The Benin formation in the Imo River Basin was the youngest formation in the basin with the age as Miocene to Recent and has an average thickness of about 2000 m. Lithologically, the formation was composed of sands and minor intercalation of clays mostly coarse-grained, pebbly, poorly sorted sands and contains pods and lenses of fine-grained sands, sandy clays and clays[20-21]. The Benin formation was very porous and permeable with porosities of about 40% and permeabilities of 1-2 darcy. Confined and unconfined aquifers were present within the Benin formation with the aquifers having very high aquifer hydraulic conductivity and transmissivity values. Thus aquifers in this formation especially the confined aquifers generally have high yields and fairly good protective capacities[22]. The unconfined aquifers in this formation easily gets contaminated from surficial anthropogenic sources due to its high hydraulic conductivity.

The Ameki formation was often divided into the upper and lower beds. The upper beds of the Ameki formation consists of coarse-grained, cross-bedded sandstone, bands of fine, grey to green sandstone and sandy clay while the lower beds consists of massive dark grey to brownish sandy mudstone, fine to coarse-grained sandstones, intercalations of calcareous shale and thin shelly limestone. Shales were more prominent in the lower Ameki section thereby increasing the aquifer protective capacity in the area. The Ameki formation was associated with both confined and unconfined aquifers with fair to good yield.

The Nsukka formation lithologically consists of alternating sequences of sandstone, dark shale, sand and thin coal seams. The wells in this formation were usually deep with fresh groundwater[23]. Aquifers within the formation were generally confined with occasional presence of artisan wells resulting from combination of the effects of stratigraphy and structure. This implies that underground water within this formation was more protected from surficial contaminants as they were associated with very high aquifer protective capacity.

Sample collection and analysis: Leachate and water samples (from both surface and groundwater resources) around the three dumpsites were collected and stored in sterilized bottles and cellophane bags, respectively using standard methods (Fig. 1). They were kept at constant ambient temperature in a chest before they were sent to the laboratory for analysis. Physicochemical parameters, trace metals and bacteriological parameters were analyzed using standard methods. A total of sixteen water samples from boreholes and rivers and four leachate samples within the vicinity of the dumpsites were collected and analyzed. The samples were analyzed for the presence of using a combination of titrimetrics, colorimetric and atomic absorption spectroscopy (AAS), while the bacteriological samples were analyzed using the membrane filter technique. Electrical conductivity of the water samples was determined using a hand held conductivity meter model H198302 (HANNA). The conductivity meter was calibrated using conductivity solution at 25°C after which it was switched on and inserted into the 50 mL water sample and the conductivity values were then read and recorded in μs cm^{-1}. Salinity was determined with a hand held Refractometer Model e-line refractometer. ATC Range Order code 44 -803, range 0-320 Brix ATC, scale division 0.2. A drop of the digested water sample was placed on the refractive surface of the refractometer and the refractive index was read and recorded. The refractive index has been scaled as the salinity values recorded in mg L^{-1}. The refractive index was recalibrated using distilled water has been scaled as the salinity values were recorded for each water sample recorded in mg L^{-1}. Similarly, the alkalinity was determined using a combination of colorimetric and titrimetrics methods with the aid of the H183200 multi-parameter bench photometer of wavelength 575 nm. The heavy metals were determined using atomic absorption spectrometer. The digested water samples were aspirated into the oxidizing air acetylene flame and the sensitivity for 1% absorption was observed. The amount of energy of the characteristic wavelength absorbed in the flame was recorded and was proportional to the concentration of the metal in the aspirated water samples. Finally, membrane filtrate technique was applied in the bacteriological analysis of the water samples. The filtrates from the water samples were incubated at temperature range of 37-41.5°C for 100 h. The growth of the colonies was then counted with a colony counter of 13x magnification, the colony count was later confirmed and recorded.

Graphical analytical techniques: The result of the chemical parameters were generally analyzed and better understood using graphical techniques like Stiff diagram, Schoeller semi-logarithmic diagram, Piper diagram, Durov, Ion balance and so on. Sadashivaiah *et al.*[17] in their study used, Piper diagram to present the result of hydrogeochemical characteristics of Tumkur Taluk ground waters. The cation and anion diagrams were most often plotted in milliequivalent (mEq L^{-1}) rather than in milligram per liter (mg L^{-1}). An equivalent was the amount of an anion or cation species needed to add or remove one mole of electrons from a system. A mill equivalent is defined as 1/1000 of an equivalent of a chemical element, radical or compound. In general, conversion of the concentrations of chemical pollutants in milligram per litre are converted to milliequivalent per litre using Eq. 1 and subsequently used to construct the graphical diagrams:

$$\text{Concentration (mEq L}^{-1}) = \frac{\text{Concentration (mEq L}^{-1}) \times \text{valency}}{\text{Molecular mass}} \quad (1)$$

The fundamental aim of the graphical techniques were to identify the chemical relationships between the water samples and to identify samples with similar chemical characteristics since they often have similar hydrologic histories, recharge areas, infiltration pathways and flow paths in terms of climate, mineralogy and residence time. Most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species. Piper diagram is a graphical representation of the chemistry of a water sample with the cations and anions shown by separate ternary plots. The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations while the apexes of the anion plot are sulfate, chloride and carbonate plus bicarbonate anions. The two ternary plots were then projected up onto a diamond. Piper diagram which is the plot of cations and anions on the three sides of two equilateral triangles and a diamond in between the two equilateral triangles was used to classify the water samples into various water types. Stiff diagram is plotted for individual samples as a method of graphically comparing the concentration of selected anions and cations for several individual samples. The shape formed by the Stiff diagrams will quickly identify samples that have similar compositions and were particularly useful when used as map symbols to show the geographic location of different water facies. The Schoeller diagram which is a semi-logarithmic diagram allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated.

Determination of the agricultural and domestic potentials of the water samples: To determine the suitability of the analyzed samples for use for domestic and agricultural purposes, sodium adsorption ratio (SAR), magnesium adsorption (MAR) and kelley ratio (KR) were calculated from the results of the geochemical analysis. SAR was an expression pertaining to the cation make up of water and solution and was therefore used for characterizing the sodium hazard of irrigation water. The SAR value was used to calculate the degree to which irrigation water tends to enter into cation exchange section in the soil. The main problem with high sodium concentration was its effect on soil permeability. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops such as fruit trees. Similarly, in natural waters, Mg in equilibrium state will adversely affect crop yields. Magnesium content of water was considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Sodium adsorption ratio (SAR), magnesium adsorption (MAR) and kelley ratio (KR) were applied on the field data to make further assessment of the water quality from the study using Eq. 2-4:

$$\text{SAR} = \frac{\text{Na}^{2+}}{\sqrt{\dfrac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \tag{2}$$

Sodium adsorption ratio (SAR) lying between 0 and 10 was permissible for all soil types, values between 10 and 18 are generally good for coarse textured soils while water samples with SAR above 18 may have harmful effect on most types of soil[24]:

$$\text{MAR} = \frac{\text{Mg}^{2+} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+}} \tag{3}$$

Magnesium adsorption ratio (MAR) is generally calculated using Eq. 3. Magnesium absorption ratio (MAR) of water less than 50 is generally suitable for irrigation while MAR values greater than 50 the will be unsuitable for irrigation purposes[25]:

$$\text{KR} = \frac{\text{N}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}} \tag{4}$$

Similarly, kelly ratio (KR) is generally estimated in water using equation 4 above. Kelley ratio (KR) values of water greater than one, generally shows that the water may be suitable for irrigation purposes while for KR >1, the water may not be suitable for irrigation purposes[26].

Statistical analysis: Descriptive statistical techniques including the mean and standard deviation of geochemical and bacteriological parameters were employed to find out the variations and relationship of the water samples within the locations.

RESULTS

Physical characteristics of the water samples: The result of the chemical and bacteriological analyses of the water samples (surface and groundwater) from the study area are presented in Table 2. The pH values of the water samples were within the permissible ranges as specified by WHO[6] and varies from 5.2 at borehole BHW 10-7.39 at BHW 1 indicating slightly acidic to slightly alkaline waters. However, the pH values of the leachate samples were all acidic and varies between 4.2-5.3. Since the maximum permissible limit (MPL) of pH values in drinking water as stipulated by the World Health Organization (WHO) and the standards organization of Nigeria (SON) was between 6.5-8.5, it therefore means that water samples outside this range may not be permissible. Results of the chemical analysis therefore revealed that the acidity levels of the analyzed water samples were all within the permissible range except for boreholes BHW 6, BHW 7, BHW 8, BHW 9, BHW 10 and SW 5. In addition, the electrical conductivity (EC) of the samples varies from 3 µS in sample SW1 to 219 µS at BHW 9 while the electrical conductivity of the leachate samples varies between 133-192 µS. Since the MPL of the electrical conductivity of drinking water as recommended by SON and WHO and 250 µS cm^{-1}, respectively, therefore the EC of boreholes BHW 8 (149 µS) and BHW 9 (219Us) were above the recommended limits of WHO. The higher values of EC of BHW 8 and BHW 9 were indicative of higher levels of ionic concentrations probably due to leachate contamination. Similarly, the concentration of the total dissolved solids (TDS) of the water samples across the study area varies from 484.9 mg L^{-1} as high as 2354 mg L^{-1}. Some of the water samples therefore have TDS values higher than the permissible limits of 1500 mg L^{-1} as prescribed by WHO[6]. Comparing these values with the concentration levels of the leachates revealed that the concentration levels of the leachate samples were exceedingly high.

The salinity values across the study area vary from 62.7 mg L^{-1} at borehole location BHW 10 to as high as 3555 mg L^{-1} in the water sample of borehole BHW 5. Generally, since water samples with dissolved salt content less than 1000 mg L^{-1} were generally fresh, it therefore means that some of the analyzed water samples having salinity concentrations greater 1000 mg L^{-1} may therefore be brackish to moderately saline. A close look at the salinity values of the leachate samples across the study area shows that they were saline to hypersaline. The dissolved oxygen (DO) concentrations of the analyzed water samples varies from 4.0 mg L^{-1} in surface water sample SW 3 to 4.8 mg L^{-1} in the groundwater sample of BHW 1. Generally, since the normal DO

Table 2: Results of the physico chemical analysis of the water samples from the selected dumpsites

Parameters	BHW 1	BHW 2	SW 1	SW 2	SW 3	BHW 3	SW 4	BHW 4	SW 5	BHW 5	SW 6	BHW 6	BHW 7	BHW 8	BHW 9	BHW 10	L1	L 2	L3	L 4
pH	7.39	6.92	7.22	7.5	7.14	6.7	6.65	6.62	6.57	6.66	6.91	6.1	5.9	6.1	6.3	5.2	4.2	4.7	5.1	6.4
Conductivity (µS cm^{-1})	81	40	3	79	39	42	55	48	56	37	10	70	68	149	219	40	133	192	156	4310
Dissolved oxygen (mg L^{-1})	4.8	4.3	4.1	4.2	4.3	4.1	4.1	4.5	4	4.4	4.4	4.3	4.5	4.2	4.4	4.3	1	0.8	1.2	1
BOD (mg L^{-1})	1.28	0.48	2.08	1.6	1.6	0.32	0.43	0.48	0.3	0.2	0.3	1.2	0.1	0.4	1.2	1.4	4.5	3.26	3.1	3.2
Total dissolved solids (mg L^{-1})	2354	1836	1000	897	1353	923	1285	949.3	1012	2822	1375	485.1	738.6	563	608.2	484.9	1471	6692	5260	11923
COD (mg L^{-1})	2.05	0.77	3.33	2.56	2.56	0.51	0.77	0.77	0.48	0.32	0.48	1.92	0.16	0.64	1.92	2.24	7.2	5.22	4.96	5.64
Salinity (mg L^{-1})	2936	1738	823	428	988	461	856	527	263	3555	1580	304	220	209	97.3	62.7	3555	8328	4214	3643
Alkalinity ($CaCO_3$), (mg L^{-1})	252	358	178	156	392	204	174	356	270	200	204	5	10	60	5	50	330	772	578	1900
Carbonate (mg L^{-1})	132	280	88	72	268	116	96	146	134	96	110	127	76	70	47	49	220	640	420	2125
Bicarbonate (mg L^{-1})	120	78	90	84	124	88	78	210	136	104	94	42	32	24	16	16	110	132	158	215
Nitrate (NO^{-}_3)(mg L^{-1})	83.3	11.9	47.5	68.4	55.6	15.3	25.8	0.04	7.8	90.3	13.7	137	343	257	322	243	24.5	115	1280	7192
Nitrate-nitrogen (NO_3^- N) (mg L^{-1})	18.8	2.7	8.2	15.7	10.4	3.5	5.8	0.01	1.8	204	3.2	29.5	73.8	57	71.4	54.1	28.4	26	29	1600
Phosphorus (P) (mg L^{-1})	1.1	0.4	1.4	0.1	0	0.3	0.3	0.2	0.2	0.5	0.4	0	0.4	1.4	0	6.4	0.5	1	1.1	25
Sulphate (SO_4^{-2}) (mg L^{-1})	165	288	82.3	206	124	329	534	41.2	453	165	124	55	0	0	5	5	570	782	605	125
Chloride (mg L^{-1})	1625	962	456	237	547	255	474	292	146	1968	875	0.43	184	134	127	59	138	4610	2332	115
Sodium (mg L^{-1})	12.6	10.2	4.14	2.45	6.22	3.17	4.21	3.36	2.2	11.3	7.12	3.02	2	1.64	0.03	0	12.6	14.6	13.5	9.33
Potassium (mg L^{-1})	20	30	25	60	30	10	40	80	30	40	20	0.06	0.11	0.03	0	0.02	190	117	160	10.2
Calcium (mg L^{-1})	140	145	160	120	185	80	10	100	90	120	100	80	24.4	10	19.4	18	70	110	30	235
Magnesium (mg L^{-1})	30	25	30	30	0	20	15	75	10	20	25	10	0	0	0	0	100	135	220	85
Iron (mg L^{-1})	0.12	0.18	0.11	0.05	2.2	1.12	0.26	0.12	0.23	0.33	0.18	0.55	0.4	0.31	0.19	0.2	2.14	2.16	3.41	32.5
Copper (mg L^{-1})	0.1	0.06	0.13	0.17	0.08	0.2	0.18	0.1	0.13	0.04	0.16	0.2	0.05	0.05	0	0.08	1.62	1.02	1.8	4
Lead (mg L^{-1})	0.06	0.08	0.12	0.46	0.02	0	0.14	0.06	0	0	0	0.15	0.13	0.03	0	0.01	0.34	0.16	0.48	5.24
Total Bacterial Count (CFU/100 mL)	14	39	1700	1600	3400	59	54	1200	42	52	29	76	210	54	39	21	15200	17200	24300	2125
Tot *E. coli* count (CFU/100 mL)	3	14	870	520	920	8	7	850	12	14	7	30	143	17	11	14	3200	1050	4600	378
Total faecal count (CFU/100 mL)	0	4	80	60	210	0	1	780	2	3	2						600	2700	70	

range of clean water was between 0-18 mg L^{-1}, therefore water samples with DO concentrations less than 2 mg L^{-1} are described as been hypoxia. Since DO concentrations of 5-6 mg L^{-1} were often needed to support a diverse population, it therefore means that the surface water samples with DO values of 4.1-4.3 mg L^{-1} may not be able to support the growth of aquatic organisms. Similarly, the alkalinity of the water samples varies from 5 mg L^{-1} in the water samples of borehole sample BHW 9 to 392 mg L^{-1} (SW3). The descriptive statistics of the various water samples from the different dumpsites at Owerri, Orlu and Okigwe is presented in Table 3. Similarly, the mean values of the concentrations of the different parameters were compared with the World Health Organization (WHO) and standard organization of Nigeria (SON) water standards.

Carbonate (CO_3^{-2}) concentrations in the groundwater ranged from 47-280 mg L^{-1} with average value of 128 mg L^{-1} (Tables 1, 4). The concentrations of carbonate in the surface water, ranged from 72-268 mg L^{-1} with an average value of 229 mg L^{-1}. The carbonate concentrations in the groundwater and surface water are within the WHO standard limit (Table 4). Carbonate and bicarbonate concentration values of the water samples of the study area obtained are highly positively correlated with the alkalinity values of the respective samples (Table 4). Generally, the presence of carbonates and bicarbonates in water samples contribute significantly to the alkalinity of the samples. Consequently, the Owerri leachate sample with the highest alkalinity value of 1894 mg L^{-1} has the highest carbonate and bicarbonate concentrations of 2124.50-217 mg L^{-1}, respectively. Similarly, Orlu borehole and surface water samples have nitrate concentration values of 7.67-26.90 mg L^{-1}, respectively, while Okigwe surface water samples has a value of 10.75 mg L^{-1}. These values are all below the permissible limit of 50 mg L^{-1} stipulated by WHO and SON standards. The water samples from Owerri dumpsite and environs however have nitrate concentration values higher than the standard WHO prescribed values (Table 4). The excess nitrate seen in the groundwater around the Owerri dumpsite was believed to have originated from the dumpsite as the geology of the area aided the leaching of the nitrate into the shallow aquifer of the area. Phosphates do not pose a serious human or health risk except in very high concentrations. None of the samples across the study area had high concentrations of phosphorus in its various forms. The average sulphate concentration levels of water samples of Owerri dumpsite and environs of 74.00 mg L^{-1} was below the SON standard of 100 mg L^{-1} while concentration levels of Orlu surface water of 567.50 mg L^{-1} are all above the WHO standard value of 400 mg L^{-1} (Table 4).

Similarly, sodium ion was one of the essential ions for osmoregulation and body fluid maintenance and as such should not be very low or totally absent in drinking water. The Sodium and Calcium content of the water and leachate samples were all below the SON standard value of 200 mg L^{-1}, respectively (Table 5). The source of sodium in the groundwater may be due the presence of feldspar or sodalite in the soil around the study area sodium ion concentrations in the groundwater samples across the study area ranged from 0-12.63 mg L^{-1} with a mean concentration value of 5.08 mg L^{-1}, while the surface water sodium concentrations ranged from 2.20-7.12 mg L^{-1} with a mean concentration value of 3.39 mg L^{-1}. Generally, in the study area, the concentrations of sodium in the surface water samples were lower than the concentration in the ground water samples. In general, the sodium ion concentrations in the water samples from the study area were very low as compared with WHO water standard. Though the magnesium content of the water samples were all higher than the Standard Organization of Nigeria permissible limit of 0.2 mg L^{-1} for drinking water, only the concentration of magnesium in borehole water from Orlu with a mean concentration of 47.50 mg L^{-1} was above the WHO standard of 30 mg L^{-1}. The leachate concentrations were also far above the permissible limits as prescribed by SON and WHO.

Trace metal concentrations of the water samples: The trace metal concentrations of the analyzed water samples within the dumpsites showed that iron concentration in the area varies from 0.12 mg L^{-1} at borehole location BHW 1 to 2.2 mg L^{-1} for surface water sample SW 3 (Table 1). The leachate samples across the study area have high levels of iron concentrations reaching an extremely high concentration of 32.5 mg L^{-1} in leachate sample (L 4). Some of the water samples have iron concentration values lower than prescribed permissible limits of 0.3 mg L^{-1} prescribed by SON and WHO. Copper concentrations in the analyzed water samples as shown in Table 1 revealed that copper concentrations varies from 0.0 mg L^{-1} in borehole sample BHW 9 to about 0.2 mg L^{-1} BHW 6. Though the copper concentrations of the leachate samples exceeded the SON and WHO standard values of 1.0-2.0 mg L^{-1}, respectively, the copper concentrations in the rest of the samples were generally within the permissible limits. The lead concentrations of the water resources of the study area varies from about 0.0 mg L^{-1} in most of the borehole sample (BHW 5, 6,3 and 9) to about 0.46 mg L^{-1} in the surface water samples of SW 2. It should be noted that no significant traces of lead was detected in Okigwe borehole water samples whereas, significant traces of lead

Table 3: Descriptive statistics of physiochemical parameters of the various dumpsite locations

Sample locations	pH	Conductivity (µS cm^{-1})	Dissolved oxygen (mg L^{-1})	BOD (mg L^{-1})	Total dissolved solids (mg L^{-1})	COD (mg L^{-1})	Salinity (mg L^{-1})	Alkalinity ($CaCO_3$) (mg L^{-1})
Owerri borehole water	6.27	95.28	4.40	0.87	1009.97	1.39	795.29	105.71
	0.71	65.69	0.20	0.52	761.01	0.83	1111.40	141.24
Owerri surface water	7.29	40.33	4.20	1.76	1083.33	2.82	746.33	242.00
	0.19	38.02	0.10	0.28	239.15	0.44	287.76	130.37
Owerri leachate	6.41	4315.00	1.10	3.11	11927.50	5.57	3646.50	1894.00
	0.01	7.07	0.14	0.13	6.36	0.11	4.95	8.49
Okigwe bore hole water	6.67	37.05	4.45	0.21	2821.00	0.32	3555.00	199.00
	0.01	0.07	0.07	0.01	1.41	0.00	0.00	1.41
Okigwe surface water	6.74	33.00	4.20	0.30	1193.50	0.48	921.50	237.00
	0.24	32.53	0.28	0.00	256.68	0.00	931.26	46.67
Okigwe leachate	5.11	156.10	1.25	3.45	5266.00	4.74	4215.50	580.00
	0.01	0.14	0.07	0.49	8.48	0.32	2.12	2.82
Orlu bore hole water	6.66	45.00	4.30	0.40	936.15	0.64	494.00	280.00
	0.06	4.24	0.28	0.11	18.59	0.18	46.66	107.48
Orlu surface water	6.65	54.50	4.15	0.44	1317.50	0.81	878.00	212.00
	0.01	0.71	0.07	0.01	45.96	0.05	31.11	53.74
Orlu leachate	4.45	162.50	0.90	3.88	4081.50	6.21	5941.50	551.00
	0.35	41.71	0.14	0.87	3691.80	1.40	3375.02	312.54
SON	6.5-8.5	1000.0			500.00			
WHO	6.5-8.5	250.0		No guideline	1500.00	No guideline		500.00

All values are represented as Mean standard deviation

Table 4: Descriptive statistics of some geochemical parameters (anion)

Sample locations	Carbonate (mg L^{-1})	Bi-carbonate (mg L^{-1})	Nitrate (NO_3^-) (mg L^{-1})	Nitrate-nitrogen (NO_3-N) (mg L^{-1})	Phosphate (PO_3^{-4}) (mg L^{-1})	Phosphate (mg L^{-1})	Phosphorus (P) (P_2O_5) (mg L^{-1})	Sulphate (SO_2^{-4})	Chloride (mg L^{-1})
Owerri bore hole water	111.60	46.85	199.60	43.90	4.28	1.38	3.20	74.0	441.60
	81.75	38.71	124.80	27.26	6.89	2.27	5.16	112.0	615.40
Owerri surface water	142.70	99.33	57.16	11.43	1.46	0.50	1.10	137.0	413.30
	108.80	21.57	10.53	3.85	2.36	0.78	1.81	63.0	159.30
Owerri leachate	2125.00	217.50	7190.00	1586.20	83.50	24.00	59.00	123.0	116.50
	0.70	3.53	2.82	19.58	2.12	1.41	1.41	3.5	2.12
Okigwe bore hole water	95.00	104.50	91.20	203.00	1.70	0.55	1.30	164.0	1968.00
	1.41	0.70	1.27	1.41	0.14	0.071	0.14	2.1	0.70
Okigwe surface water	115.00	10.75	2.50	0.85	0.30	0.65	289.00	510.5	
	16.97	29.69	4.17	0.98	0.49	0.14	0.35	233.0	515.50
Okigwe leachate	422.50	160.00	1283.00	28.55	3.20	1.10	2.30	603.0	2331.00
	3.53	2.82	3.53	0.63	0.14	0.00	0.28	2.8	1.41
Orlu bore hole water	131.00	149.00	7.67	1.75	0.85	0.25	0.65	185.0	273.50
	21.21	86.26	10.79	2.46	0.21	0.07	0.21	204.0	26.16
Orlu surface water	103.00	79.00	26.90	6.10	1.10	0.45	0.80	568.0	479.00
	9.89	1.41	1.55	0.42	0.14	0.21	0.14	47.0	7.07
Orlu leachate	430.00	121.00	69.75	27.20	2.30	0.75	1.70	676.0	2374.00
	297.00	15.55	63.99	1.69	1.27	0.35	0.98	150.0	3162.00
SON			50.00	50.00				100.0	250.00
WHO			50.00	50.00				250.0	250.00

All values are represented as Mean standard deviation

Table 5: Descriptive statistics of geochemical parameters (cation and trace metals)

Sample locations	Sodium (mg L^{-1})	Potassium (mg L^{-1})	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (mg L^{-1})	Copper (mg L^{-1})	Lead (mg L^{-1})
Owerri bore hole water	4.21	7.17	62.40	9.28	0.27	0.07	0.06
	5.07	12.51	59.39	13.04	0.15	0.06	0.05
Owerri surface water	4.27	38.33	155.00	20.00	0.78	0.12	0.20
	1.88	18.92	32.78	17.32	1.22	0.04	0.23
Owerri leachate	9.39	10.10	234.00	86.50	31.75	4.03	5.14
	0.08	0.13	1.41	2.12	1.05	0.04	0.14
Okigwe bore hole water	11.32	40.01	120.50	20.50	0.32	0.04	0.00
	0.03	0.01	0.70	0.70	0.01	0.01	0.00
Okigwe surface water	4.66	25.00	95.00	17.50	0.20	0.14	0.00
	3.47	7.07	7.07	10.60	0.03	0.02	0.00
Okigwe leachate	13.58	158.54	31.00	222.50	3.45	1.80	0.50
	0.11	2.05	1.41	3.53	0.06	0.00	0.02
Orlu bore hole water	3.26	45.00	90.00	47.50	0.62	0.15	0.03
	0.13	49.49	14.14	38.89	0.70	0.07	0.04
Orlu surface water	4.21	42.50	10.00	16.60	0.27	0.19	0.12
	0.01	3.53	0.00	2.26	0.01	0.02	0.02
Orlu leachate	13.60	153.50	90.00	117.50	2.15	1.32	0.25
	1.41	51.61	28.28	24.74	0.01	0.42	0.12
SON	200.00			0.20	0.30	1.00	0.01
WHO	200.00		200.00	30.00	0.30	2.00	0.01

All values are represented as Mean standard deviation

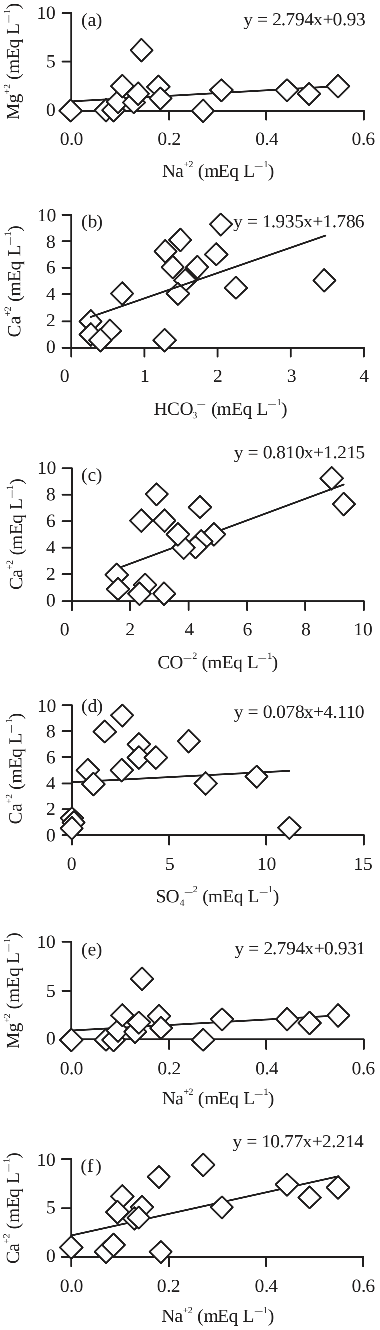

Fig. 4(a-f): Scatter plots of cations versus anions and cation versus cation, (a) Mg^{+2} vs. Na^{+2}, (b) Ca^{+2} vs. HCO^-_3, (c) Ca^{+2} vs. CO_3^{-2}, (d) Ca^{+2} vs. SO_4^{-2}, (e) Mg^{+2} vs. Na^{+2} and (f) Ca^{+2} vs. Na^{+2}

concentrations were found in borehole water samples within the Owerri and Orlu dumpsites with values of 0.06-0.03 mg L^{-1}, respectively. These values were higher than the 0.01mg L^{-1}, standard limit for drinking water as prescribed by SON and WHO 2010 indicating possible leachate contamination. The mean concentrations of iron, copper and lead concentrations in the ground and surface water across the area were (0.35, 0.088, 0.052 mg L^{-1}) and (0.505, 0.14, 0.123 mg L^{-1}), respectively. Similarly, the high concentration of lead in water samples within the Owerri dumpsite was believed to be related to contamination from anthropogenic sources from surficial materials in the dumpsite. In addition since Owerri dumpsite was situated very close to the Nekede Mechanic Village (a distance of about 800 m), it was suspected that the source of lead contamination in the water samples may be the several bad car batteries which were common components of the wastes in Owerri dumpsite.

Analysis of the relative abundance of ions in the water samples: Generally, scatter plots of cations and anions (Fig. 4a-f) naturally helps to reveal the proportional relationship between the cations and anions as they occur in water. Sodium and magnesium plot (Fig. 4a) shows that greater percentage of the water samples was richer in sodium than magnesium, confirming the presence of halite dissolution. Magnesium ion was also an essential element for good health especially in lowering anxiety and stress. Its concentration in ground water ranged from 0-75 mg L^{-1} and mean concentration value of 20 mg L^{-1} while the concentration in surface water ranged from 0-30 mg L^{-1} and average value of 17 mg L^{-1}. It was obvious that there was sodium and magnesium ionic exchanges in the surface water giving rise to decrease concentrations of magnesium as sodium concentration increased. However, there was a week positive relationship between the two cations. Calcium ion concentration in groundwater ranged between 18-145 mg L^{-1} with average value of 80.8 mg L^{-1} and the concentration in surface water ranged from 10-185 mg L^{-1} with average value of 113 mg L^{-1} (Table 2). Calcium ion concentration in the water samples studied was normal as it was within the WHO acceptable limit. Similarly, calcium versus carbonate and bicarbonate revealed a strong positive related (Fig. 4c). The abundance of bicarbonate and carbonate ions over calcium (Fig. 4b, c) which was one of the dominant cations in the groundwater was as a result of the dissolution of carbonate minerals by the carbonic acid that percolates through the heaps of the solid waste during the rainy season. The calcium versus carbonate and bicarbonate are positively related (Fig. 4c).

Determination of the domestic and irrigation uses of water samples of the study area: The continuous use of poor quality water without drainage and soil management may lead to saline and sodic soil, particularly in clayey soils. The quality of irrigation water depends primarily on the presence of dissolved salts and their concentrations. Sodium absorption

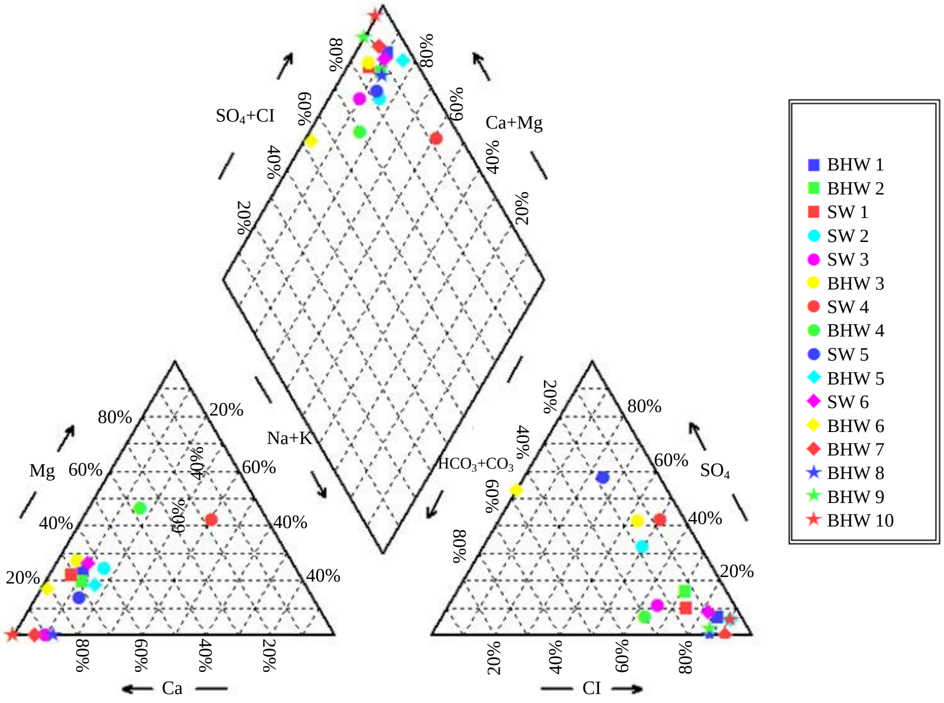

Fig. 5: Piper diagram of both groundwater and surface water samples of the study area

ratio, magnesium ratio and Kelly's ratio were estimated for the analyzed water samples to assess the possible application of the water resources for both domestic and agricultural purposes. The result of the study revealed that the sodium adsorption ratio (SAR) of the water samples across the study area varies from 0 to 0.253 with a regional mean of 0.132 (Table 6). Magnesium content of water was considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. The MAR across the study area varies between 0 to 92.4 while the Kelly's ratio lies between 0 to 0.149, respectively (Table 6). Kelly's ratio was an important parameter that helps to evaluate irrigation water quality based on the level of Na measured against Ca and Mg. Generally, water samples with Kelly's Ratio less than one were suitable for irrigation. Water samples BHW 4 and SW 4 with MAR values of 71 and 55, respectively were generally not suitable for agricultural purposes. Since over 75% of the analyzed water samples across the area have KR<1, MAR<50 and SAR lying between 0 and 18, therefore the water resources of the study area were good for agricultural purposes. The sodium absorption ratio obtained in this study was generally less than 18 indicating low to fair alkali hazard and therefore, excellent irrigation water.

Graphical interpretation of the hydro geochemical facies: To further analyze the water samples with the main objectives of determining the hydrogeochemical facies, graphical techniques which include piper's trilinear, stiff and schoeller diagrams were used. The piper's trilinear plot (Fig. 5) revealed that the dominant water type in the study area is Ca-SO$_4$water type. Ca-SO$_4$waters were typical of gypsum ground waters and mine drainage. This water type was believed to be strongly influenced by ion exchange between the water resources and the abundant ions emanating from the huge metallic materials deposited in the dumpsite especially from several artisans and vehicle mechanics. Similarly, the slightly high value of sulphate concentration in the water samples may also have been contributed from the decomposition of organic materials in the dumpsites. However, schoeller diagrams presented in Fig. 6 revealed the dominance of the Ca-Mg-Cl waters. The interpretation of stiff diagrams (Fig. 7) diverse water types which include Mg-Cl, Ca-Mg-Cl, Ca-Na+K-Cl, Ca-SO$_4$, Ca-Cl and Ca-HCO$_3$. The presence of diverse water types are further buttressed with the different shapes of the stiff diagrams as presented in Fig. 7. Generally, samples with similar chemical characteristics often have similar hydrologic histories, similar recharge areas, infiltration pathways and flow paths. Therefore, the shapes of the stiff diagrams clearly

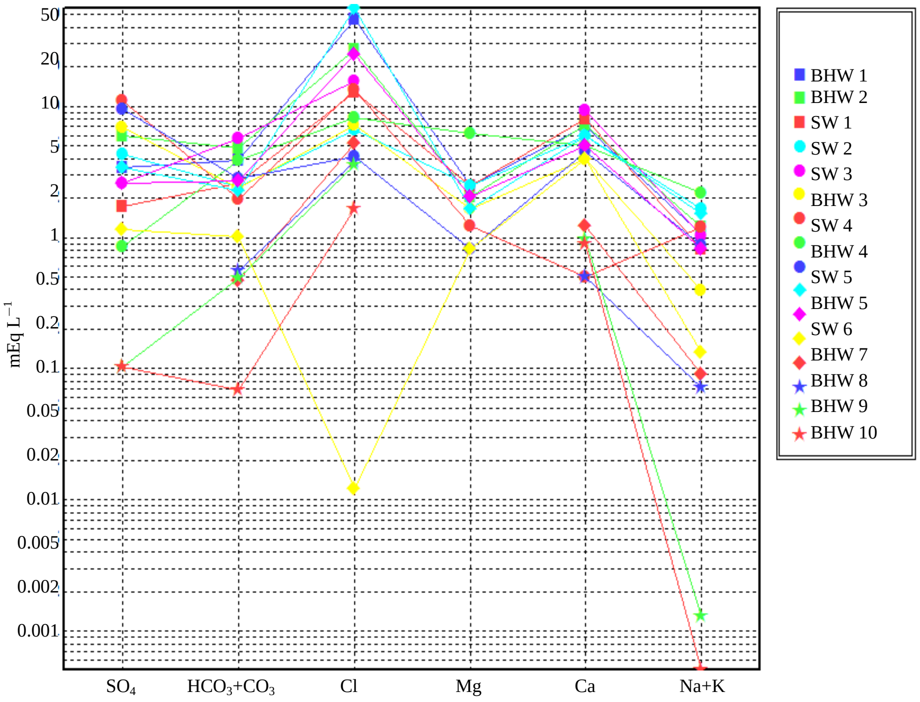

Fig. 6: Schoeller diagram of the groundwater and surface water samples of the study area

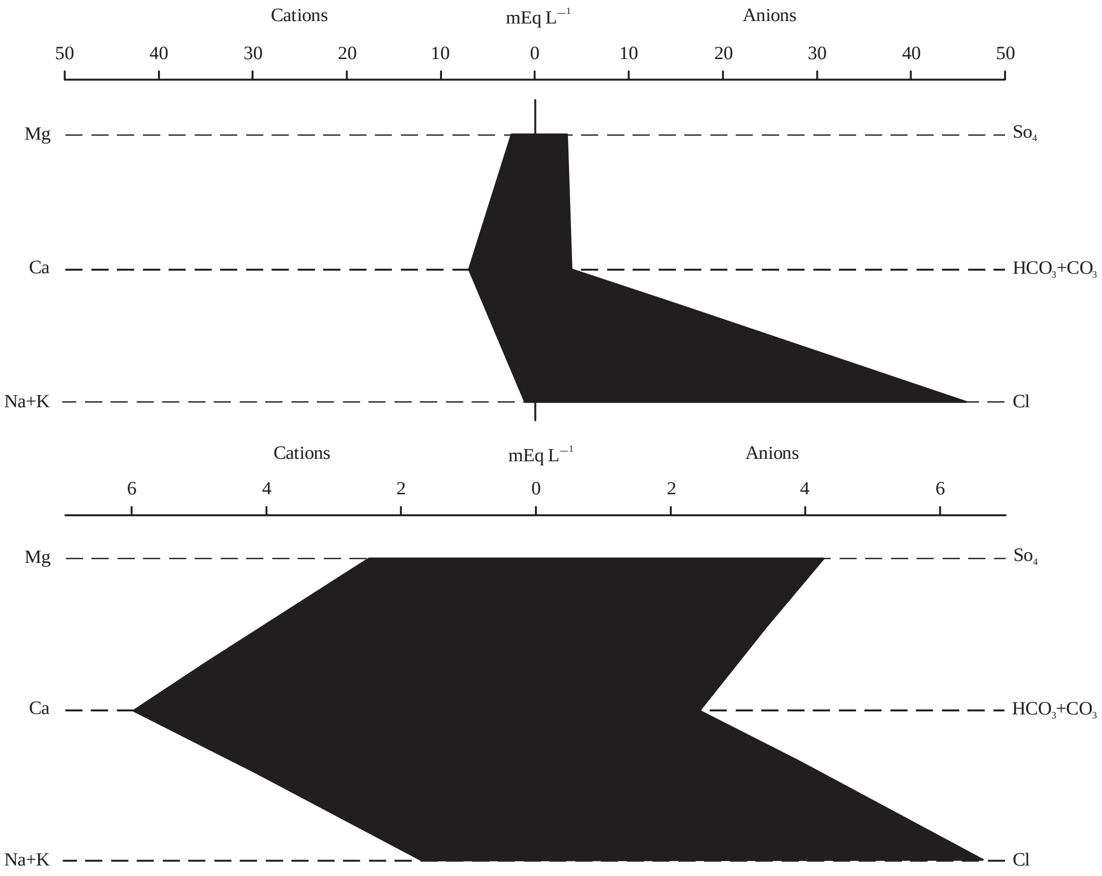

Fig. 7: Typical stiff diagrams of water samples plotted in the study area (a) Stiff diagram BHW 1 and (b) Stiff diagram SW 2

Table 6: Calculated values of SAR, MAR and KR

Samples ID	Na^+	Mg^{+2}	Ca^{+2}	K^+	HCO^-_3	CO_3^{-2}	SAR	MAR	KR
BHW 1	12.63	30	140	20.0	120	132	0.2526	26.098	0.06
BHW 2	10.211	25	145	30.0	78	280	0.206	22.127	0.05
SW 1	4.136	30	160	25.0	90	88	0.0787	23.606	0.02
SW 2	2.452	30	120	60.0	84	72	0.0518	29.179	0.01
SW 3	6.22	0	185	30.0	124	268	0.1259	0.00	0.03
BHW 3	3.165	20	80	10.0	88	116	0.082	29.179	0.02
SW 4	4.21	15	10	40.0	78	96	0.1967	71.199	0.11
BHW 4	3.362	75	100	80.0	210	146	0.0619	55.278	0.01
SW 5	2.201	10	90	30.0	136	134	0.0587	15.477	0.02
BHW 5	11.28	20	120	40.0	104	96	0.251	21.548	0.06
SW 6	7.12	25	100	20.0	94	110	0.1649	29.179	0.04
BHW 6	3.02	10	80	0.1	42	127	0.0846	17.082	0.03
BHW 7	2.00	0	24	0.1	32	76	0.1114	0.00	0.07
BHW 8	1.64	0	10	0.0	24	70	0.1428	0.00	0.14
BHW 9	0.03	0	19	0.0	16	47	0.0019	0.00	0.00
BHW 10	0.00	0	18	0.0	16	49	0.000	0.00	0.00
Leachate 1	12.562	100	70	190.0	110	220	0.2257	70.188	0.05
Leachate 2	14.613	135	110	117.0	132	640	0.2206	66.916	0.04
Leachate 3	13.473	220	30	160.0	158	420	0.1872	92.358	0.03
Leachate 4	9.33	85	235	10.0	215	2125	0.1326	37.347	0.02

revealed that sixty three percent (63%) of the water samples were rich in calcium and chloride ions indicating similar recharge areas and infiltration pathways. Similarly, most samples from the study area have a long tail at the chlorine vertex indicating that chlorine was the dominant anion. In conclusion therefore, two major or dominant hydrogeochemical facies (water types) were identified in the study area which includes the Ca-Mg-Cl and Ca-SO_4 water types.

Bacteriological analysis of water samples: The bacteriological quality of most water resources within the dumpsites were generally very poor mainly due to surficial contamination that may possibly arise from two main sources. Firstly, the widespread and indiscriminate defaecation by animals including humans and cows that freely roam the study area. Secondly, another reason may be due to poor refuse disposal methods as most biological wastes including used adult and baby diapers were generally dumped in the open waste dumps. The average faecal coliform bacteria in Orlu borehole water is 390 CFU/100 mL. This was a high risk case and unfit for drinking. The result of bacteriological analysis confirms the chemical signature suggesting the presence of pollutants in the water resources studied. The BHW 4 in the Northern part of the study area has the highest levels of total bacteria count, followed by BHW 7 in the Southern part of the study area. BHW 4 is exceedingly contaminated having total coliform count of 850 cfu, total feacal count of 780 CFU and total E coli of 240 CFU which were all above the WHO drinking water standard. The WHO 2010 standards on faecal coliform bacteria, grouped the occurrence of feacal coliform bacteria into the following risk categories: 0 CFU/100 mL (conformity), 1-10 CFU/100 mL (low risk), 10-100 CFU/100 mL (intermediate risk), 100-1000 CFU/100 mL (high risk) and 41000 CFU/100 mL (very high risk). Due to the poor bacteriological quality of most of the surface water samples which were generally used for domestic purposes including drinking in the rural areas, several water borne diseases like typhoid, diarrhea, cholera, etc were prevalent in some part of the study area. Drinking water contaminated with E. coli was known to cause stomach and intestinal illness including diarrhoea and nausea and can even lead to death.

DISCUSSION

The analysis of the relative abundance of ions in water samples is a very important process in hydrogeochemistry as it most often gives an idea of the history of the groundwater and the several chemical reactions that takes place in time between the water and the host rock[27]. It is well known that among the cations, Ca and Mg are the dominant ions in groundwater which were influenced by the dissolution of carbonate minerals. This concept has been used by several scholars which include Datta and Tyagi[28] and Dehnavi *et al.*[29] which provide a clear and lucid picture of the processes of carbonate weathering which was often caused by rainwater impregnated with CO_2 and thus became rich in carbonic acid[30]. The acidic water influences the dissolution of carbonate minerals (calcite and dolomite) in the aquifer system. Similarly, sodium was one of the important naturally occurring cation and its concentration in fresh water was generally lower than Ca and Mg[31]. Generally, when halite dissolution was the dominant process, a cross plot of sodium versus chloride may be of help. The SAR revealed that the water resources of the study area were good for agricultural purposes like irrigation and fish farming. In natural waters, Mg in equilibrium state will adversely affect crop yields[32]. Sodium percent was an important factor for studying sodium hazard. High percentage sodium water for irrigation purpose may stunt the plant growth and reduces soil permeability[33]. The main problem with high sodium concentration is its effect on soil permeability. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops such as fruit trees.

Several key papers have previously reported anthropogenic contamination of some water bodies across the Nigeria due to discharge of industrial effluents, sewage, agricultural wastes, etc[22,34-36]. The concentration of trace metals in water bodies was of utmost importance because the persist in the environment and were not easily biodegraded[37]. The discharge or leaching of metallic pollutants into water bodies generally affects their quality and potability by rendering water bodies unsuitable thereby posing a serious health threat to the food web and the immediate population. The pH values of the water samples varied from 5.2-7.39 indicating slightly acidic to slightly alkaline waters. The relatively high acidic concentrations of some of the water samples were probably due to the leaching of organic acids from decaying materials in the dumpsites. Similarly, the high acidity may be due to the hydrolysis of iron compounds in the lateritic soils within the study area[1]. Similar results have also been reported by other scholars[1,38]. High pH values may affect metabolic activities of aquatic organisms since they were pH dependent[39-40]. In addition, pH values also affects biological and chemical reaction in water bodies and it is a factor that determines water suitability for various purposes including toxicity to animals and plants[41]. The concentration of the total dissolved solids (TDS) of the water samples across the study area varies from 484.9-2354 mg L^{-1}. The notable increase of TDS is similar to that recorded by Ghannam *et al.*[42]. These high values may be due to stagnation and concentration of salts in the water bodies. Excessive TDS can reduce water clarity, hinder photosynthesis and lead to increased water temperatures[43]. Similarly, the electrical conductivity (EC) of the samples varies from 3-219 µS .These high values of electrical conductivity were similar to the values earlier reported by Ezzat *et al.*[44] and Ghannam *et al.*[42]. In addition, the salinity values of the water samples across the study area varied from 62.7-3555 mg L^{-1}. Since water samples with dissolved salt content less than 1000 mg L^{-1} are generally fresh, it therefore means that some of the analyzed water samples having salinity concentrations greater 1000 mg L^{-1} may therefore be brackish to moderately saline.

The trace metal concentrations of the analyzed water samples within the dumpsites showed that iron concentration in the area varies from 0.12-2.2 mg L^{-1}. Similarly, result of high iron concentrations in water resources was previously reported around Avu dumpsite Southwards of the three dumpsites studied[22]. These high concentrations of iron in both the surface and groundwater were suspected to be coming from the metallic materials that may have been buried in the dumpsites for so many years. The high concentration of iron may also be attributed to leaching from the ferruginous laterite sandstone units of the Benin formation. The presence of iron above the WHO recommended limit causes unpleasant taste and of course stains on cloths and containers that come in contact with the water. In addition, cases of high lead concentration was previously reported in water resources of sand mine ponds around Otamiri River within the Imo river basin which were associated with the accumulation of contaminants from its various sources which were anthropogenically controlled[29]. The high concentrations of iron and lead in both ground water and surface water were an indication that the heavy metals may have infiltrated into the ground water from the dumpsites. Similarly, the copper concentrations in the analyzed water samples varies from 0.0-0.2 mg L^{-1}. Copper forms a number of complexes in natural waters with inorganic and organic ligands[45]. This property also makes it potentially toxic because the transitions between Cu (II) and Cu(I) generally results in the generation of superoxide and hydroxyl radicals[46-47]. In addition, excessive exposure to copper has been linked to cellular damage leading to Wilson disease in humans[47]. Finally, the lead (Pb) concentrations of the water resources of the study area varies from 0.0-0.46 mg L^{-1} with most of the samples exceeding the permissible concentrations of 0.1 mg L^{-1} stipulated by WHO[6]. The high level of Pb might be attributed to runoff from the dumpsites, agrochemicals and effluents discharges[48-49]. Bioaccumulation of Pb in animals especially humans induces brain damage, kidney damage and gastrointestinal diseases, while chronic exposure may cause adverse effects on the blood, central nervous system, blood pressure, kidneys and vitamin D metabolism[50-51] .

The dissolved oxygen (DO) concentrations of the analyzed water samples varies from 4.0-4.8 mg L^{-1}. Depletion of dissolved oxygen was an indication of high organic matter and nutrients load which may lead to high rate of microbial decomposition in water bodies as reported by Sabae *et al*.[41]. Generally in rivers and streams, DO levels less than 3 mg L^{-1} are stressful to most aquatic organisms. Most fishes die at 1-2 mg L^{-1}. However fish can move away from low DO areas. Water with low DO from 0.2-0.5 mg L^{-1} were considered hypoxic, waters with less than 0.5 mg L^{-1} were anoxic. The standard for sustaining aquatic life is stipulated at 5 mg L^{-1}, a concentration below 2 mg L^{-1} may lead to death for most fishes[52]. Bacterial contamination of borehole and surface waters in most part of the study area were observed to be very high especially in areas around the dumpsites. Similarly, microbial contamination of water samples around the study area has been previously reported by Ezeigbo[1]. Bacteria and other micro organisms were known to travel great distances in fine textured soils but can migrate much greater distances in coarse textured materials[1]. However, for shallow aquifers, especially, around Owerri, surficial contamination from micro organisms is very possible. Due to the poor bacteriological quality of most of the stream water samples generally used for domestic purposes especially in the rural areas, several water borne diseases like typhoid, diarrhea, cholera, etc are prevalent in most part of the study area.

CONCLUSION

The results of this study demonstrated that the water resources in the Northern and Southern parts of the study area contain both undesirable chemical and biological species. These contaminants were traced to the nearby dumpsites whose leachate samples contain the identified pollutants in greater proportions. The geologic formations underlying these locations also played a major role of assisting the easy transportation of the contaminants from the dumpsites into the surface and groundwater bodies in the area. Iron concentration in the study area varied from 0.12-2.2mg L^{-1} while copper concentrations in the analyzed water samples ranged from 0.0-0.2 mg L^{-1}. In addition, the lead concentration varied from about 0.0-0.46 mg L^{-1}. Similarly, two dominant hydrogeochemical facies (water types) were identified in the study area which includes the Ca-Mg-Cl and $Ca\text{-}SO_4$ water types. The high concentrations of nitrates, iron and lead in the water resources of the study area are indeed very worrisome. These results therefore call for urgent water resources management strategy in the area in order to circumvent the fast deteriorating quality of water resources, which may pose associated health and environmental risks. Relocation of the dumpsite at Old Aba Road from the areas within the Benin formation to places within Imo shale formation and Nsukka formation which have better aquifer protective cover such as shale and clay is recommended. Geologic formations like the Benin formation that are predominantly sandy with high porosity and permeability should not be used as dumpsites if the water resources are to be protected. The high concentrations of potassium, nitrate, iron, lead and high occurrence of bacteria in the water resources of the study area indicate possible anthropogenic contamination from the nearby dumpsites. It was therefore suggested that a better waste management approach be adopted for environmental protection and sustainability.

SIGNIFICANCE STATEMENTS

This study explained the effect contamination from unprotected dumpsite on the water resources of the surrounding areas. It is an attempt to explain the processes of anthropogenic contamination of surface and groundwater systems from leachate contamination. The domestic, agricultural and industrial uses of the affected water samples were also assessed to further x-ray the possible effects of the leachate contamination from the dumpsite. Using graphical methods like the piper's diagram, the dominant hydrogeochemical facies were established as the Ca-Mg-Cl and $Ca\text{-}SO_4$ water types. High concentration levels of potassium, nitrate, iron, lead and bacteria in the water resources of the study area which were above the established permissible limits indicate possible anthropogenic contamination from the nearby dumpsites. This study therefore help researchers in environmental studies to further uncover the critical area of groundwater contamination from a point source. The implication of the presence of elevated levels of pollutants in water resources on plant growth, human health and industrialization were made clearer.

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