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Research article

Effects of industrialization on groundwater quality in Shagamu and Ota industrial areas of Ogun state, Nigeria

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ABSTRACT

In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by heavy metals on groundwater resources especially in the developing countries. Hence, this study assessed the impacts of industrialization on the quality of groundwater in Shagamu and Ota industrial areas of Ogun State, Nigeria between the period of July and December 2018, covering both wet and dry season. A total of 80 samples was collected from the industrial areas while a total of four control samples was also collected from the residential areas of the study locations across both wet and dry season using a random sampling technique. The water samples were then analyzed in the laboratory for their physico-chemical parameters (using standard procedures) and heavy metals using the Atomic Absorption Spectrophotometer (AAS). The results were evaluated for descriptive and inferential statistics using SPSS for Windows version 20.0. The mean range of values for the measured parameters was: pH (4.35–9.42), EC (18.50–684.0 μScm^{-1}), hardness (3.83–396.06 mg/L), Ca^{2+} (0.18–138.75 mg/L) and that of heavy metals concentrations in the water sample were: Pb (0.003–0.199 mg/L), Cd (0.002–0.013 mg/L), Ni (0.004–0.259 mg/L), Cr (0.002–0.54 mg/L), Mn (0.015–1.940 mg/L), Fe (0.02–2.01 mg/L), Cu (0.012–0.72 mg/L), Zn (0.004–0.500 mg/L). A comparison of the obtained results with the World Health Organization standards (for drinking water) revealed that the levels of pH, Ca, Pb, Ni, Mn, Fe, Cd, and Cr were higher than the prescribed values. It was observed that groundwater sources for the dry season in both Ota and Shagamu have higher heavy metal concentrations that are above the permissible limits than the wet season, implying that more industrial activities were probably conducted during the dry season under the sampling period. The result of the heavy metals was in the magnitude according to the trend Fe > Mn > Cu > Cr > Zn > Ni > Pb > Cd. This study revealed that these industrialized areas contained high concentrations of heavy metals which can cause health disorders and behavioral defects. Thus, the water in the study locations is not suitable for consumption without prior treatment. It is therefore, recommends that the water in the study locations should be treated before were used for various domestic purposes, and the construction of the boreholes and dug wells are proposed here to follow proper siting regulations.

1. Introduction

One of the most important natural resources that provide vital support for the growth of plants and animals is water (Vanloon and Duffy, 2005). This is usually obtained via two major natural sources which are surface water (e.g. the freshwater, lakes, rivers, etc) and groundwater (e.g. borehole and well water) (McMurray and Fay, 2004; Mendie, 2005; Temilola et al., 2011; Boateng et al., 2016). Water is one of our most valued resources, however, freshwater resources are dwindling at an alarming rate. Scarcity of water has become a leading global challenge

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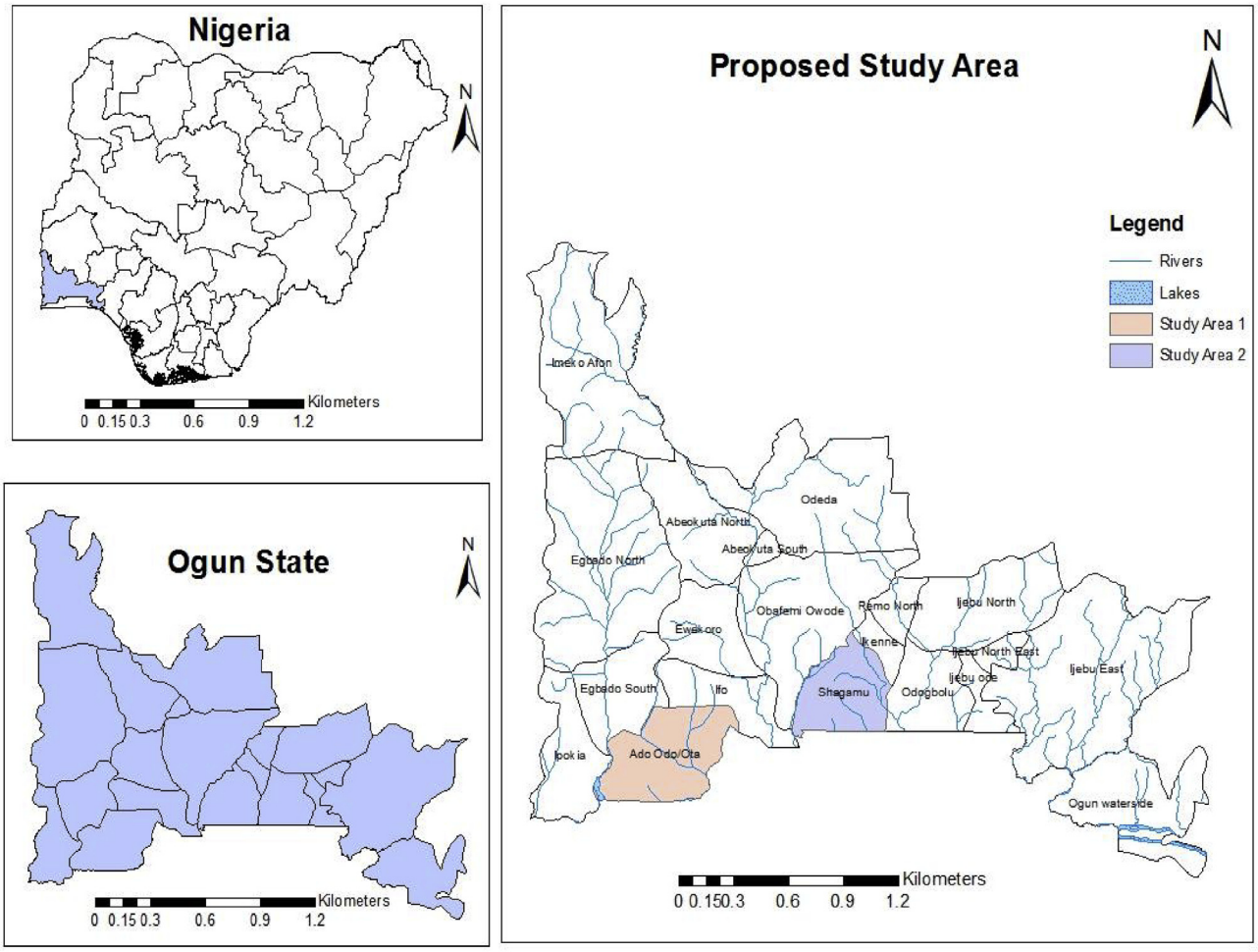

Figure 1. Map showing the study locations of Ota and Shagamu, Ogun State. Arc GIS10.6 (Source: This study).

for sustainable development. This is expected to become more pressing owing to continuous growth in the world's population, which results into, for instance, increase in the standard of living, changes in diet patterns, and the anthropogenic effects on climate change. The rural and urban areas depend largely on groundwater for the provision of potable water supply. Globally, aquifers are experiencing an elevated threat of pollution from industrial development, urbanization, etc. Therefore, this necessitates the need for an extensive study of the quality of groundwater that will result in hands-on campaigns and practical actions; aimed at protecting the natural quality of groundwater (Temilola et al., 2011).

Ecological stability and economic development of many countries depend largely on clean, hygienic and sufficient water. Groundwater remains a vital and precious resource. It is understood not only to be relatively clean but also pollution-free as compared to surface water (Arya et al., 2012; Kaviarasan et al., 2016; Boateng et al., 2016). There has been an increased need for groundwater in recent times as a result of industrial and agricultural growth (Kaviarasan et al., 2016).

The quality of groundwater is influenced by natural sources or various anthropogenic activities (Varol and Davraz, 2015). It is a vital factor for household, agricultural and industrial use (Babiker et al., 2007). Point and non-point pollution contaminate the groundwater and cause various health issues (Rohul-Amin et al., 2012; Nalbantçılar and Pınarkara, 2015). Thus, it is necessary and sustainable to establish frequent monitoring process for water quality parameters that govern the hydrochemical processes. The contamination of groundwater by organic and inorganic compounds of both anthropogenic and natural origins are severe worldwide problems environmentally because groundwater serves as a universal source of drinking water. However, proper identifications and/or characterizations of related human health hazards are vital challenges that deserve keen attention not only by the environmentalists but also by the medical geochemists (Rapant and Krêmová, 2007). Daily, about 25,000 people are recorded dead as a result of water pollution challenges and one-third of urban residents in developing nations have no access to safe drinking water (Yin and Deng, 2006; Li and Ling, 2006).

One of the most frequently recommended remedies to the glitches inhibiting growth among the third world countries is the prominence of the industrial enterprises (Afolabi et al., 2012). However, industrialization like every other phenomenon has both its benefits and also its negative effects. Anthropogenic actions including industrial productions and dumping of industrial wastes; reckless discharge of numerous heavy metals into the ecosystem (Sirajudeen et al., 2014; Bhutiani et al., 2017). The issue of water contamination by industrial activities among the located areas are habitually rampant due to the higher concentrations of industries over a minute space (Bhutiani et al., 2017). The percolating wastewater picks up great numbers of heavy metals which get to the aquifer systems and contaminate groundwater (Mohankumar et al., 2016; Bhutiani et al., 2017). Associated health menaces of heavy metals include the reduction of growth and development of cancer (Malassa et al., 2014; Bhutiani et al., 2017). These Heavy metals are familiar environmental pollutants because of their persistence, toxicity in the immediate environment, and bioaccumulative/bioconcentration nature. Their biogenic sources include volcanic eruptions and weathering of metal-bearing rocks, while man-made sources include various industrial, mining and agricultural activities. The applications for industrial, agricultural, and economic developments have led to an increase in the

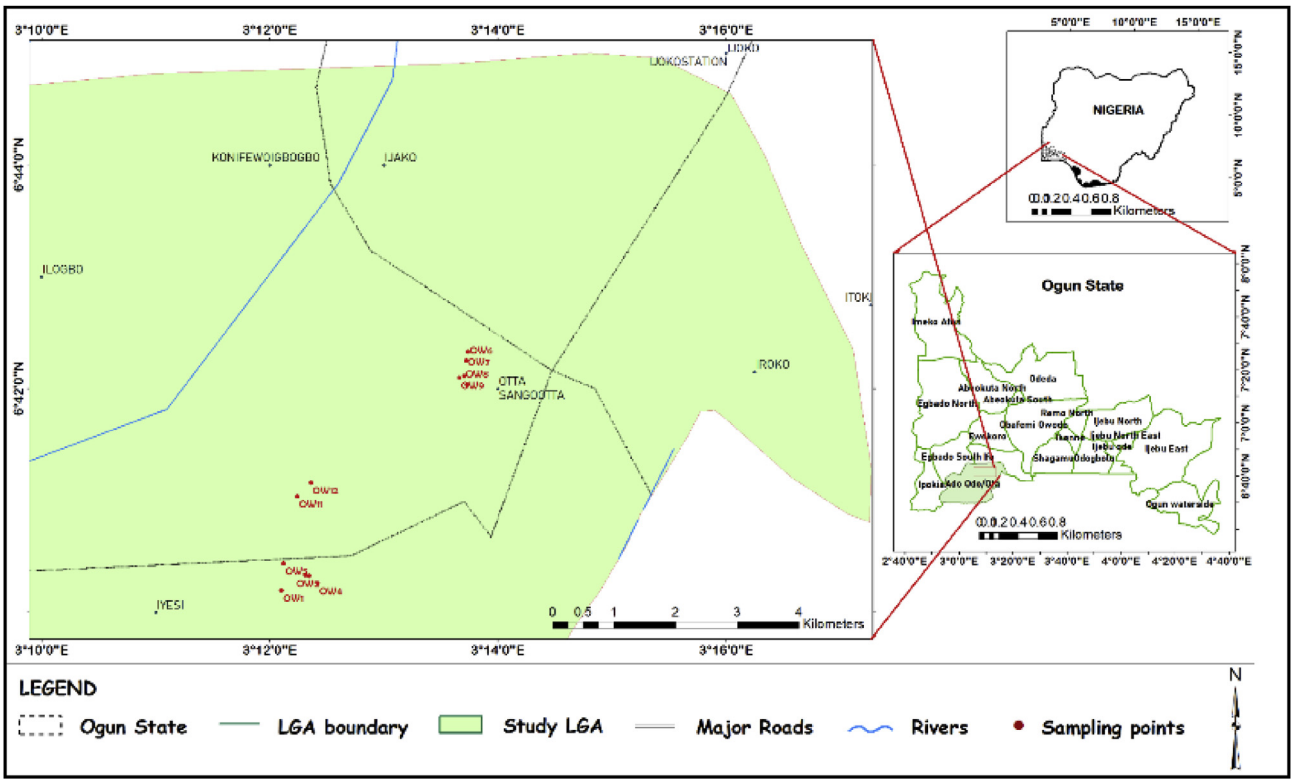

Figure 2. Map of the study area in Ota showing the sampling points.

mobilization and extraction of these elements in the environment and disturbance of their nutrient cycles. This had led to heavy contamination of aquatic and terrestrial ecosystems with heavy metals which are toxic and subsequently poses environmental problem of public health concern. These metals are frequently persistent pollutants and accumulating in the environment and consequently contaminate the food chains including water bodies which therefore necessitate this study.

In Ogun State, Nigeria, a large part of the drinking water supply is by groundwater via boreholes and hand-dug wells. Groundwater is the major source of drinking water in many parts of the rural areas as well

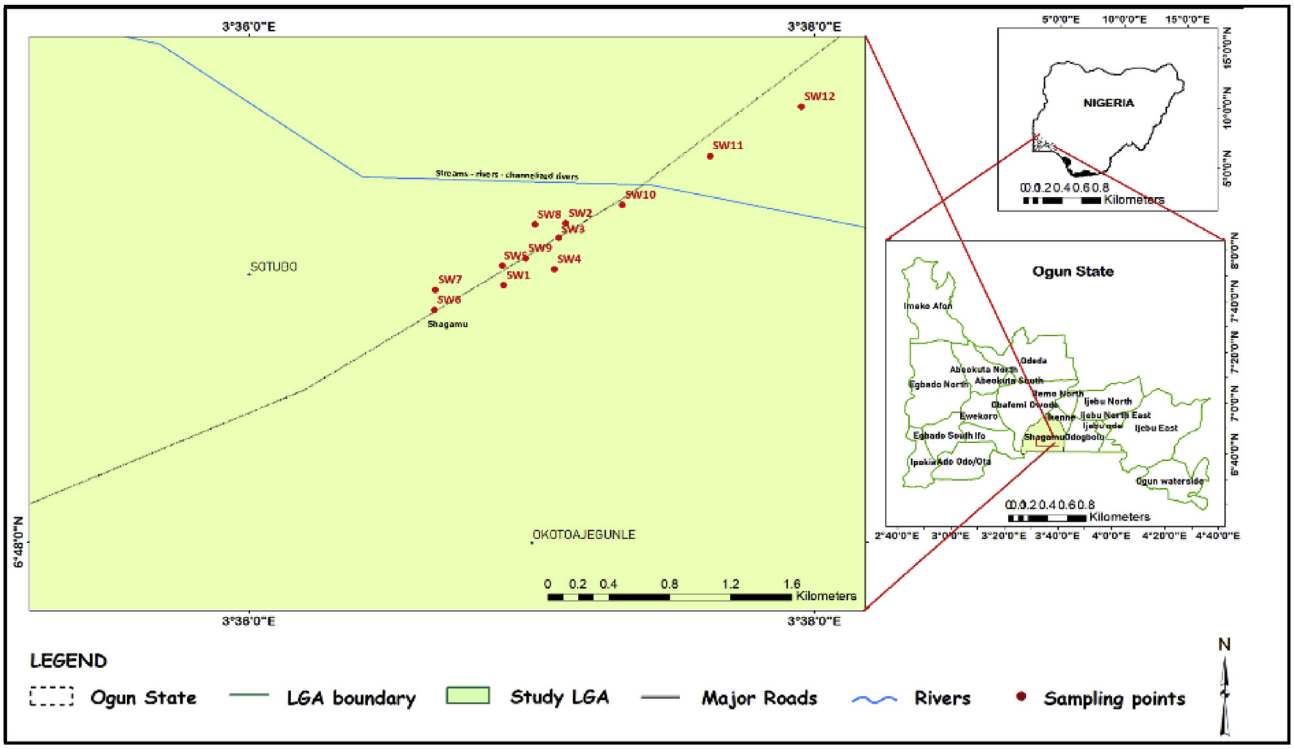

Figure 3. Map of the study area in Shagamu showing the sampling points.

Table 1. Comparison of physicochemical parameters of water samples from Ota and Shagamu in the wet season.

Sample code	Wet Season						Wet Season						
	pH	Temperature (°C)	TDS (mg/L)	EC (μs/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Sample code	pH	Temperature (°C)	TDS (mg/L)	EC (μs/cm)	Alkalinity (mg/L)	Hardness (mg/L)
OW1	8.89	28.25	11.50	23.50	17.25	4.49	SW1	6.11	26.20	36.00	71.50	36.88	97.94
OW2	9.42	27.20	19.00	41.00	24.15	44.21	SW2	6.17	25.90	32.00	66.50	35.78	154.57
OW3	8.85	29.50	11.50	24.50	11.97	4.52	SW3	6.08	25.75	33.00	67.00	18.87	262.26
OW4	8.61	26.80	8.00	18.50	17.90	3.83	SW4	6.40	25.85	30.00	61.00	23.68	77.03
OW5	7.71	30.25	12.50	24.50	18.13	6.74	SW5	6.28	25.85	22.50	45.00	17.25	25.88
OW6	8.05	27.70	13.50	30.50	12.21	7.70	SW6	6.09	25.40	29.00	59.00	17.05	46.40
OW7	7.50	30.00	16.50	32.50	18.18	5.48	SW7	6.09	26.10	31.50	63.50	47.53	147.20
OW8	7.51	28.45	15.50	32.00	11.71	6.63	SW8	6.47	25.45	26.00	57.00	17.98	39.64
OW9	7.74	28.85	14.00	29.50	11.35	4.04	SW9	6.18	25.85	27.00	57.00	18.00	39.98
OW10	6.67	29.60	11.00	23.00	18.68	4.27	SW10	6.01	25.80	31.50	64.00	18.25	70.92
OW11	7.86	27.60	13.00	27.00	29.96	8.86	SW11	6.56	27.00	27.50	56.00	18.18	34.58
OW12	7.77	28.90	11.50	23.50	11.75	6.87	SW12	6.67	25.90	30.50	61.50	11.47	117.20

Note: OW: Ota Wet, **SW**: Shagamu Wet.

as some parts of the urban areas. Therefore, a large population is prone to the risk of drinking contaminated water. Groundwater quality depends on a lot of factors ranging from anthropogenic activities, natural factors such as groundwater velocity, aquifer lithology, and interaction with other types of aquifers, and the environment. The environment acts a vital role in the health and human development (Temilola et al., 2011). Observing time trends in environmental hazard can be useful in understanding the background and changes in environmental contamination.

This work is, therefore; aimed at investigating the effects of industrialization on the quality of groundwater in Shagamu and Ota industrial areas of Ogun State in Nigeria, covering both wet and dry seasons, in terms of their physicochemical parameters and heavy metal concentrations. One of the fundamental reasons for the study is because Ota and Shagamu industrial areas are rated as the fastest growing areas in Ogun State. This growth has, however, taken a toll on the geological resources in the area and groundwater is primarily one of such resource. A good number of industries of different types which have been established in the conurbation of Ota and Shagamu have been loading the environment with ever-increasing levels of different pollutants which are entering the soil/water and degrading the quality of groundwater seriously. This undesirable concentration of chemicals finds their way into the food chain by percolating into the groundwater, thereby resulting in several health challenges including skin problems (such as rashes, boils, itching sensation on their hands and legs) and also severe joint pain in their hips and knees upon the use of the water without prior treatment. This study assessed the degree of pollution in these areas, identified the problematic pollutants and recommended the mitigating measures for the same. This would help to raise awareness so that the health of the residents in these areas are not further impaired due to the lack of continuous assessment of various pollution impact.

2. Materials and methods

2.1. Study area

Ota and Shagamu are located at Ado-odo/Ota and Shagamu Local Government Area respectively in Ogun State, lies between longitude 3° 20′ E and latitude 7° 93′ N. Ota is located between latitude 60° 30′N – 60° 50′N and longitude 30° 02′E – 30° 50′E with an elevation of about 53 m above the sea level while Shagamu is located at about 6°42′N latitude and 3°31′E longitude. Figure 1 presents the map of the study locations of Ota and Shagamu while Figures 2 and 3 show the map of the study areas and the sampling points in Ota Shagamu areas of Ogun State, Nigeria. The population of these areas have increased in the last decades due to the presence of different industries including, for instance,cement manufacturing factories, steel/iron oxide, metallurgical, aluminium rolling mill, pharmaceutical, ink and chemical industries.

2.2. Sampling collection

The processes involved in assessing water quality are numerous and complex. In fact, these processes are closely comparable to a chain of about a dozen links and the failure of any one of them can weaken the whole appraisal. Therefore, designing a unique operation requires critical consideration of the precise objectives of the water quality appraisal (Henry and Deborah, 1996). For this study, groundwater samples were collected from both hand-dug wells and boreholes from the two industrial areas. A total of 80 samples were collected from the industrial zones covering both wet and dry seasons while a total of four control samples was also collected from the residential areas of the study locations.

Samples for physical and chemical analysis were collected with a 2.5 L keg and were preserved accordingly with the use of ice packs. A separate 1 L keg was also used to collect samples for the metals analysis and was fixed *in-situ* with 2 mL concentrated HNO_3. The kegs used were thoroughly washed with distilled water five times before usage. All chemicals used were of analytical grade. Furthermore, the samples for the wet and dry season were collected in July/September and November/December respectively.

2.3. Characterization and water quality parameters

The appearance, pH, temperature, electrical conductivity and total dissolved solids of the water samples were determined *in-situ*. The samples were then labelled appropriately for the laboratory analysis. Prior to samples collection, precaution was taken to ensure that the samples to be collected are free from contaminations. The pH meter was neutralized with distilled water to stabilize its readings. In addendum, sample bottles were firstly rinsed with distilled water and finally with the samples before sample collection.

Generally, the water quality parameters measured include; pH, temperature, electrical conductivity (EC), chloride, total dissolved solids (TDS), hardness, nitrate, sulphate, phosphate, alkalinity, biocarbonate, calcium, magnesium, sodium, potassium and heavy metals such as cadmium, nickel, lead, zinc, copper, iron and manganese. Physical and chemical parameters were determined by conventional instrumental methods following standard analytical method (APHA, 1998). Cation and anion were measured and determined by standard titrimetric and spectrophotometric methods, trace and heavy metals were determined by the Atomic Absorption Spectrophotometer (AAS). The results obtained for

Table 2. Comparison of physicochemical parameters of water samples from Ota and Shagamu in the dry season.

Dry Season							Dry Season						
Sample code	pH	Temperature (°C)	TDS (mg/L)	EC (μs/cm)	Alkalinity (mg/L)	Hardness (mg/L)	Sample code	pH (mg/L)	Temperature (°C)	TDS (mg/L)	EC ((μs/cm))	Alkalinity (mg/L)	Hardness (mg/L)
OD1	4.95	27.80	36.50	73.00	23.75	1.70	SD1	6.30	27.70	153.00	306.00	41.55	299.05
OD2	4.70	30.25	29.50	59.00	18.85	0.97	SD2	6.35	27.65	144.00	285.00	42.90	359.17
OD3	4.75	27.95	17.00	34.00	16.31	1.67	SD3	6.20	25.55	158.50	317.00	42.40	341.53
OD4	4.75	27.95	22.50	45.00	22.08	1.34	SD4	5.85	27.85	170.00	340.00	67.65	396.06
OD5	5.00	30.95	53.00	106.00	17.73	1.65	SD5	5.55	27.80	123.00	246.00	30.95	127.25
OD6	4.35	27.85	66.00	132.00	23.20	11.91	SD6	5.15	27.30	65.50	131.00	24.25	161.00
OD7	4.55	29.20	26.50	53.00	18.18	13.09	SD7	6.25	27.90	61.00	122.00	42.63	169.20
OD8	5.30	28.95	35.50	71.00	11.72	3.09	SD8	6.55	26.85	179.00	358.00	24.35	93.91
OD9	5.70	31.15	44.00	88.00	18.00	2.76	SD9	6.05	27.60	125.50	251.00	23.75	56.53
OD10	5.55	30.95	44.00	88.00	23.75	2.54	SD10	5.75	28.50	342.00	684.00	42.45	81.28
OD11	4.80	29.80	29.50	58.00	31.71	74.71	SD11	4.55	27.70	129.50	309.00	29.98	287.71
OD12	4.95	29.25	45.00	90.00	20.73	67.56	SD12	6.00	30.70	312.00	624.00	54.55	171.61

OD: Ota Dry, **SD**: Shagamu Dry.

the various water quality parameters and that of the heavy metals were later compared with the World Health Organization's (WHO) drinking water quality guidelines.

2.4. Multivariate statistical analysis

Principal components analysis (PCA) was used to analyse groundwater data using the software package SPSS for windows version 20.0. PCA is a multivariate statistical method that is utilized to decrease the dimensionality of the original data set comprising a large number of interrelated variables while still retaining the conditions existed in the informational index (Jianqin et al., 2010; Ganiyu et al., 2018). PCA extricates factor with eigenvalue >1, which clarified the complete variety in the informational index. Just segment (component) with eigenvalue >1 were held and later exposed to varimax turn (Usman et al., 2014; Ganiyu et al., 2018) before being used for interpretation.

3. Results and discussion

The pH value is a measure of the acidity or alkalinity of water. Tables 1 and 2 show that the pH of the water samples ranges from 4.35 to 9.42 across both the wet and dry season. The pH range obtained in this study was higher when compared to 3.84–7.72 and 5.8–6.9 reported for groundwater in the eastern parts of Niger Delta in Nigeria (Nwankwoala and Udom, 2011) and some parts of Bayelsa State in Nigeria (Okingbo and Douglas, 2013) respectively. However, not all samples were within the WHO permissible limit of 6.5–8.5 (Carrera, 2014). The water sample in OW2 (9.42) was an example, which was alkaline in nature (Table 1). This might have occurred due to the percolation of minerals from mountains and hills. Furthermore, the pH of water samples at Ota was slightly acidic during the dry season and this might have occurred due to effluent discharged from the industries (cement manufacturing factories, steel/iron oxide, metallurgical, aluminium rolling mill, pharmaceutical, ink and chemical industries). The recorded acidic water from the groundwater under consideration can cause corrosion of water pipes and may pose negative effects on the gastrointestinal tracts when consumed, thereby, resulting in diarrhoea (Ayedun et al., 2012). In comparing with the control of locations (Tables 1 and 2), all samples obtained in Ota area are more acidic than the control samples (OW11 and OW12) in the wet season except for samples OW1−OW4 and OW6, whereas for the dry season, only samples OD5, OD8−OD10 are less acidic when compared with the control (OD11 and OD12). However, for the Shagamu area, all the wet season samples are more acidic than the control (SW11 and SW12), while, in the dry season, only samples SD4−SD6 and SD10 are more acidic when compared with control sample SD12. In comparing with control sample SD11, all sample obtained in dry season in Shagamu area are less acidic. Summarily, the samples obtained from both locations are generally acidic for both seasons.

Table 3. Comparison of water-soluble ions of water samples from Ota and Shagamu in the wet season.

Sample code	Wet Season									Wet Season								
	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	PO_4^{2-} (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	Sample code	Ca2+ (mg/L)	Mg^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	PO_4^{2-} (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)
OW1	1.21	0.36	0.18	6.48	34.50	42.22	0.13	ND	0.46	SW1	32.95	3.79	2.46	3.96	73.50	49.40	0.17	0.94	0.94
OW2	16.85	0.51	0.67	3.70	48.30	55.61	0.17	ND	ND	SW2	54.15	4.68	6.31	10.05	71.56	44.46	0.16	0.33	1.43
OW3	1.39	0.26	0.17	4.19	23.93	27.82	0.18	ND	ND	SW3	88.30	10.13	4.79	9.42	37.73	41.60	0.19	0.15	1.58
OW4	1.08	0.28	0.27	2.84	35.80	44.72	0.12	ND	ND	SW4	22.80	4.89	8.82	23.55	47.35	53.90	0.13	0.14	2.75
OW5	1.70	0.61	0.26	2.93	36.25	36.10	0.16	ND	0.17	SW5	7.67	1.64	1.25	10.80	34.50	41.22	0.16	0.02	1.41
OW6	1.84	0.76	1.50	8.06	24.43	57.57	0.13	ND	ND	SW6	15.55	1.84	0.36	9.77	34.10	35.80	0.11	0.02	1.07
OW7	1.61	0.36	0.17	6.93	36.35	41.22	0.22	ND	0.02	SW7	49.95	5.45	4.57	15.20	95.06	56.71	0.19	0.18	0.68
OW8	1.67	0.60	0.22	4.11	23.43	41.22	0.22	ND	0.02	SW8	13.71	1.31	1.52	16.10	35.96	42.26	0.16	0.16	1.09
OW9	1.30	0.20	0.15	2.91	22.70	40.70	0.13	ND	ND	SW9	14.00	1.22	2.91	12.80	36.00	35.83	0.16	0.13	2.29
OW10	1.23	0.30	0.26	5.16	37.35	36.10	0.12	ND	0.00	SW10	20.84	4.59	1.80	20.40	36.50	51.41	0.14	0.07	0.72
OW11	2.40	0.70	0.25	3.32	59.92	49.41	0.13	ND	ND	SW11	11.55	1.39	3.63	21.20	36.35	57.62	0.17	0.03	0.49
OW12	1.80	0.58	0.31	2.82	23.50	52.91	0.13	ND	ND	SW12	25.57	12.10	2.37	42.75	22.93	44.22	0.30	ND	0.56

OW: Ota Wet, **SW**: Shagamu Wet.

Table 4. Comparison of water-soluble ions of water samples from Ota and Shagamu in the dry season.

Dry Season										Dry Season									
Sample code	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	PO_4^{2-} (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	Sample code	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^{+} (mg/L)	Na^{+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	PO_4^{2-} (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)
OD1	0.37	0.19	0.15	7.75	47.50	43.65	0.00	0.03	1.26	SD1	108.10	7.03	5.98	6.01	83.10	51.50	0.02	0.01	0.20
OD2	0.18	0.13	0.25	5.25	37.70	51.50	0.06	0.04	1.89	SD2	131.00	7.73	6.45	6.68	85.80	48.45	0.02	0.01	0.21
OD3	0.35	0.19	0.65	5.55	32.60	41.65	0.00	0.02	0.85	SD3	122.50	8.61	5.70	7.05	84.75	51.30	0.02	0.01	0.14
OD4	0.33	0.13	0.33	5.45	44.15	51.10	0.04	0.02	0.74	SD4	138.75	11.99	7.65	24.50	135.30	50.60	0.02	0.02	0.79
OD5	0.34	0.20	0.58	6.50	35.46	46.60	0.01	0.02	0.98	SD5	35.05	9.67	7.05	29.00	61.90	51.45	0.01	0.02	1.00
OD6	2.09	1.63	1.55	38.50	46.45	77.50	0.01	0.03	0.95	SD6	53.70	6.52	6.85	35.50	48.50	55.90	0.01	0.03	1.19
OD7	2.61	1.60	1.64	36.55	36.35	47.15	0.01	0.22	1.09	SD7	57.55	6.18	5.96	10.00	85.25	53.45	0.01	0.03	1.40
OD8	0.34	0.55	0.17	4.85	23.43	50.30	0.01	0.02	0.90	SD8	31.60	3.64	1.88	8.40	48.70	50.25	0.01	0.03	1.34
OD9	0.38	0.44	0.11	3.85	36.00	46.20	0.00	0.02	0.83	SD9	14.00	5.25	1.70	12.80	47.50	41.90	0.01	0.04	1.01
OD10	0.53	0.30	0.20	3.62	47.50	51.05	0.01	0.01	0.71	SD10	19.25	8.08	14.50	31.50	84.90	78.65	0.01	0.02	0.27
OD11	22.65	4.41	9.50	60.00	63.42	49.41	0.01	0.02	0.48	SD11	99.20	9.69	22.50	33.60	59.95	85.75	0.02	0.04	1.84
OD12	20.21	4.16	9.18	54.90	41.45	115.80	0.01	0.03	0.53	SD12	55.35	8.11	21.05	33.60	109.50	50.30	0.02	0.02	0.24

OD: Ota Dry, **SD**: Shagamu Dry.

The values TDS (Tables 1 and 2) obtained for Ota ranged from 11 mg/L to 19 mg/L and 17 mg/L to 66 mg/L across wet and dry seasons respectively, whereas, for Shagamu, it ranges from 25.4 mg/L to 27 mg/L and 61 mg/L to 312 mg/L for wet and dry seasons respectively. It can be seen here that Shagamu assumed the highest TDS values. The presence of TDS in groundwater may affect its taste. Though no data on health effects related with the ingestion of TDS in drinking-water appear to exist; however, the association between various health effect and hardness, rather than TDS contents, have been investigated in many studies (Dahunsi et al., 2014; Sharma et al., 2016).

Conductivity shows the ability of materials to pass a current and this could be defined as a measure of electrical conduction (Bagherzadeh et al., 2017). From Tables 1 and 2, the EC measurements obtained for this study ranged between 18.50 and 684.0 μS/cm for all the water samples across both seasons and also within the WHO maximum permissible limit of 1250 μS/cm (WHO, 1993, 1996, 2006; Afolabi et al., 2012). The EC obtained for this study is lower compared to the result reported by Afolabi et al. (2012) who obtained 495 μS/cm and 399 μS/cm for Lagos centre and Ikorodu area respectively. The cause of electrical conductivity in water samples is usually as a result of the dissolution of inorganic chemicals in water. These chemicals then break into tiny, electrically charged particles called ions. Ions enhance the water's capability to conduct electricity.

The measure of how much calcium and magnesium is present in water is referred to as hardness (Olajire and Imepeokparia, 2001). The total hardness of the entire water sample across both wet and dry seasons (Tables 1 and 2) ranged between 0.97 to 396.06 mg/L. This range complies with the recommended standard of WHO for hardness which should be within 500 mg/L (WHO, 2006). The range of total hardness obtained in this study was higher compared with values (20.67–33.33 mg/L) obtained in the work of Afolabi et al. (2012). Exposure to hard water was noticed to be a risk factor that could exacerbate eczema (Langan, 2009). The environment plays a vital role in the aetiology of atopic eczema, but precise causes are not known (Langan, 2009).

The calcium content (Tables 3 and 4) of all the water samples ranged from 0.18 mg/L to 138.75 mg/L across both seasons. Some results recorded in this study are not in compliance with the recommended standard of WHO for calcium which is 75 mg/L (WHO, 1993, 1996, 2006), though, some samples have calcium values within the WHO prescribed limit, while most samples have higher values. However, the range of calcium content obtained in this study is higher compared to the result (49.9 mg/L) reported by Ishaku et al. (2011). The high content of calcium may be due to effluents from the industries employing the use of chemicals in their activities.

The magnesium, potassium, alkalinity and sodium values (Tables 3 and 4) were all within WHO (2006) permissible limits, while sulphate, chloride, nitrate and phosphate values (Tables 3 and 4) were also all

Table 5. Comparison of heavy metal concentration in water samples from Ota and Shagamu during the wet season.

Wet Season									Wet Season								
Sample code	Pb (mg/L)	Cd (mg/L)	Ni (mg/L)	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)	Sample code	Pb (mg/L)	Cd (mg/L)	Ni (mg/L)	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)
OW1	0.003	0.003	0.004	0.003	0.025	0.550	0.017	0.045	SW1	0.013	0.017	0.006	0.012	0.050	0.020	0.021	0.190
OW2	0.050	0.007	0.087	0.014	0.050	1.200	0.012	0.051	SW2	0.014	0.020	0.018	0.010	0.030	1.960	0.012	0.190
OW3	0.045	0.010	0.043	<0.04	0.060	1.090	0.015	0.051	SW3	0.011	0.019	0.047	0.022	0.020	1.120	0.013	0.297
OW4	0.036	0.002	0.060	<0.04	0.045	1.150	0.018	0.052	SW4	0.011	0.026	0.183	0.007	0.025	0.760	0.017	0.044
OW5	0.049	0.008	0.024	0.002	0.065	1.270	0.017	0.325	SW5	0.013	0.007	0.241	0.015	0.030	0.760	0.016	0.066
OW6	0.058	<0.01	0.049	0.011	0.040	1.630	0.015	0.101	SW6	0.030	0.029	0.110	0.002	0.040	0.810	0.017	0.014
OW7	0.117	<0.01	0.390	0.004	0.025	1.500	0.014	0.046	SW7	0.026	0.014	0.259	0.003	0.180	1.010	0.017	0.500
OW8	0.113	0.010	0.081	0.002	0.035	2.010	0.012	0.089	SW8	0.014	0.003	0.183	0.002	0.035	0.860	0.018	0.038
OW9	0.120	0.003	0.128	0.004	0.040	0.860	0.013	0.083	SW9	0.060	0.008	0.010	0.006	0.040	0.560	0.015	0.372
OW10	0.149	0.003	0.069	0.002	0.015	0.330	0.016	0.054	SW10	0.014	0.011	0.066	0.005	0.035	1.160	0.016	0.067
OW11	0.199	0.006	0.081	0.002	0.035	0.290	0.018	0.318	SW11	0.009	0.018	0.021	0.025	0.110	0.480	0.014	0.191
OW12	0.188	0.013	0.118	0.022	0.025	0.810	0.014	0.059	SW12	0.011	0.004	0.015	0.003	0.065	0.690	0.015	0.057

OW: Ota Wet, **SW**: Shagamu Wet.

Table 6. Comparison of heavy metal concentration in water samples from Ota and Shagamu during the dry season.

Dry Season `									Dry Season							
Sample code	Pb (mg/L)	Cd (mg/L)	Ni (mg/L)	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)	Sample code	Pb (mg/L)	Cd (mg/L)	Ni (mg/L)	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)
OD1	0.932	0.007	0.039	0.054	0.051	0.294	0.050	0.124	SD1	0.857	0.008	0.066	0.034	0.156	0.507	0.049	0.078
OD2	0.935	0.003	0.083	0.008	0.151	0.282	0.047	0.111	SD2	0.898	0.007	0.047	0.024	0.138	0.487	0.044	0.086
OD3	0.862	0.002	0.091	0.026	0.055	0.355	0.064	0.082	SD3	0.902	0.008	0.064	0.031	0.155	0.473	0.041	0.086
OD4	0.907	0.005	0.084	0.024	0.063	0.316	0.055	0.079	SD4	0.917	0.005	0.221	<0.02	1.940	0.680	0.042	0.124
OD5	0.727	0.003	0.094	0.033	0.056	0.307	0.063	0.085	SD5	0.829	0.007	0.026	0.008	0.167	0.617	0.031	0.110
OD6	0.784	0.005	0.084	0.031	0.203	0.375	0.073	0.362	SD6	0.884	0.011	0.021	0.013	0.191	0.561	0.042	0.092
OD7	0.671	0.006	0.079	0.028	0.191	0.383	0.071	0.355	SD7	0.873	0.011	0.039	0.025	0.178	0.530	0.035	0.086
OD8	0.788	0.004	0.081	0.003	0.140	0.379	0.072	0.059	SD8	0.911	0.005	0.086	0.046	0.104	0.525	0.038	0.106
OD9	0.802	0.004	0.022	<0.01	0.131	0.376	0.053	0.066	SD9	0.923	0.004	0.056	0.043	0.108	0.497	0.042	0.105
OD10	0.813	0.004	0.022	0.004	0.115	0.389	0.047	0.052	SD10	0.865	0.011	0.063	0.004	0.050	0.232	0.055	0.207
OD11	0.834	0.010	0.009	0.011	0.442	0.435	0.042	0.073	SD11	0.865	0.010	0.052	0.011	0.063	0.355	0.058	0.152
OD12	0.826	0.007	0.093	0.013	0.348	0.415	0.042	0.074	SD12	0.834	0.011	0.065	<0.01	0.042	0.251	0.060	0.228

OD: Ota Dry, **SD**: Shagamu Dry.

within WHO permissible limits (WHO, 2008) and pose rare adverse effects to human health (WHO 2008). The concentration of carbonates were higher for the groundwater sample collected during the wet season (Tables 3 and 4) of both study areas (i.e. Ota and Shagamu). By comparing the two locations, Shagamu area showed dominance of carbonate concentrations than Ota area. A close comparison of the concentration of carbonate obtained in this study with WHO permissible limit is difficult since there is no data available on health-related effects associated with carbonate. However, the concentration of the carbonate of this present study obtained for both wet and dry seasons of Ota area ranges from 22.7 mg/L to 63.62 mg/L, while that of Shagamu ranges from 22.93 mg/L to 135.75 mg/L.

The value obtained for lead (Tables 5 and 6) for all water samples (both wet and dry seasons) ranged from 0.003 to 0.935 mg/L, this value, however, is not in compliance with the recommended standard of WHO for lead which is 0.01 mg/L (WHO, 2012). The Pb concentrations of both locations during the wet season varied as some samples were below the WHO permissible limit, some slightly above the permissible limit, while others exceeded the permissible recommendation at an alarming level. Extremely higher concentrations of Pb were detected in all the dry seasons of both Ota and Shagamu locations; which are not in any way complying with WHO permissible limit. This implies that such high level of Pb contaminations in these locations suggested more industrialized areas and more activities performed by the industries during the dry season of both samples' locations when compared with their wet season samples. In comparison with the literature, the range of lead (Pb) content obtained in this study is lower as compared to the values (0–14.8 mg/L) reported by Oyeku and Eludoyin (2010) who carried out an appraisal on heavy metal contamination of groundwater resources in Ojota, Lagos state. Their study areas cover Ikosi Ketu, Oregun industrial estates, the commercial area of Kudirat Abiola way, Ojota residential area and LAWMA dumpsite. Studies on lead contaminations of groundwater are numerous; due to its hazardous effects. Lead is a metal that has no recognized natural advantage to human health. An elevated level of lead can harm numerous systems of the body. In addition, it can harm the nervous and reproductive systems, as well as the kidneys, and it can also result in high blood pressure and anaemia (WHO, 2012). At elevated concentrations, lead can cause convulsions, coma and even death (WHO, 2012). The low-level of Pb below the WHO prescribed limit in some wet samples under this study does not imply that they are completely safe since there is no level of exposure to Pb that is known to be without harmful effects (WHO, 2019). After ingestion of Pb through water or food, it usually accumulates in the skeleton where it causes health disorders including neurological, sub-encephalopathic, and behavioral defects (WHO, 1993; 2006). Its presence in the food chain can result in bioaccumulation, thus becoming harmful to human's health (Owamah, 2013; Dahunsi et al. 2012; WHO, 2019).

The cadmium values (Tables 5 and 6) for all the water samples obtained in this study ranged from 0.002 to 0.029 mg/L, but the WHO permissible limit is 0.003 mg/L (WHO, 1993; 1996, 2006). While in the wet season of the Ota location, some samples (e.g. OW1, OW9, OW10, OD2, OD5) were within the prescribed limit, only OW4 was below the permissible limit. However, for the Shagamu location, all the values obtained in both seasons were above the WHO permissible limit of 0.003 mg/L (WHO, 1993; 1996, 2006). Furthermore, the range of cadmium content in this study is lower, compared to those recorded values (0.05–0.12 mg/L) in work of Aladejana and Talabi (2013) who carried out an assessment on the groundwater quality in Abeokuta with respect to drinking and irrigation uses. Inorganic cadmium is classified as human carcinogens according to the International Agency for Research on Cancer (IARC, 1990). The third most regularly reported heavy metal in drinking water is Cadmium, and it has been known as a public health challenge (Dahunsi et al. 2012; Fernández-Luqueño et al., 2013; USEPA, 2015; ATSDR, 2015). Drinking water contaminated by cadmium is also associated with chronic renal failure (Bawaskar et al., 2010; ATSDR, 2015). Gobe and Crane (2010) reported kidney failure as a result of extensive exposure to cadmium. Chronic exposure to cadmium could result in anaemia, renal problems, cardiovascular diseases, hypertension and osteoporosis (ATSDR, 2015). Cadmium can cause both acute and chronic intoxications (Chakraborti et al., 2004). Bernard (2008) reported that cadmium is very toxicant to the kidney. Upon a longer exposure and low concentrations, it could become deposited in the kidney, eventually leading to kidney diseases, fragile bones and lung damages. A study by Henson and Chedrese (2004) reported the involvement of cadmium exposure during pregnancy with premature birth and reduced birth weights.

From Tables 5 and 6, the nickel values for all water samples ranged from 0.004 to 0.390 mg/L across both the wet and dry seasons. While some values were within the prescribed limit, most of the values obtained were above the recommended standard of WHO of 0.02 mg/L for nickel (WHO, 1993; 1996, 2006). However, the range of nickel content obtained in this study is lower as compared to the values of 0.2–12.9 mg/L reported by Aladejana and Talabi (2013). According to the International Agency for Research on Cancer (IARC, 1990), the undesirable health effects of nickel is largely dependent on the exposure routes (dermal, inhalation, and/or oral). The utmost acquainted harmful health effects of nickel in humans is the allergic skin reactions among those who are sensitive to nickel.

Chromium does not occur freely in nature. Its compounds can be found in waters only in trace amounts. The chromium values (Tables 5

Table 7. Principal component analysis of water parameters in Ota during wet and dry seasons.

	Wet Season (Component)					Dry Season (Component)					
	1	2	3	4	Communalities	1	2	3	4	5	Communalities
pH	-0.18	-0.843	-0.376	0.086	0.911	0.589	-0.402	0.013	0.558	-0.237	0.894
Temp	-0.005	-0.528	-0.228	0.052	0.836	-0.302	0.024	-0.373	-0.31	0.407	0.679
TDS	0.139	-0.295	0.584	0.589	0.963	0.801	0.113	0.117	-0.461	0.134	0.93
EC	0.132	-0.295	0.586	0.588	0.965	0.858	0.125	0.135	-0.413	0.019	0.961
Alkalinity	0.649	0.165	-0.26	0.53	0.927	0.127	-0.176	0.881	0.148	0.309	0.976
Hardness	0.978	0.035	-0.101	-0.115	0.988	0.834	0.069	0.358	0.145	-0.029	0.866
HCO_3^-	0.649	0.165	-0.26	0.531	0.929	0.124	-0.176	0.882	0.15	0.306	0.98
Cl	0.591	0.058	0.264	0.017	0.865	0.355	0.437	0.455	0.027	-0.572	0.867
PO_4^{3-}	-0.193	0.577	-0.394	-0.155	0.741	0.533	-0.173	-0.303	-0.201	0.555	0.761
NO_3^-	-0.003	0.696	-0.071	0.168	0.767	-0.195	-0.611	-0.001	0.042	-0.259	0.865
Ca	-0.587	0.534	-0.067	0.152	0.895	0.474	-0.23	-0.456	0.478	0.375	0.922
Mg	0.968	0.032	-0.153	-0.113	0.983	0.041	0.384	-0.479	0.683	0.227	0.962
K	0.983	0.043	0.067	-0.12	0.992	0.311	-0.161	0.123	0.668	0.115	0.905
Na	0.969	0.066	-0.097	-0.128	0.982	-0.294	0.817	0.052	0.34	0.09	0.892
Pb	0.932	0.188	0.258	-0.067	0.988	-0.268	0.788	0.291	-0.15	0.364	0.937
Cd	-0.122	0.412	-0.722	0.25	0.893	0.162	0.384	-0.189	0.216	0.392	0.84
Ni	0.759	0.101	-0.089	0.226	0.728	0.101	0.836	0.101	0.002	-0.027	0.798
Cr	0.291	0.559	0.259	-0.539	0.791	0.373	0.662	-0.002	0.206	-0.308	0.92
Mn	-0.155	0.549	0.33	0.403	0.799	0.355	-0.344	-0.005	0.063	0.143	0.907
Fe	0.942	0.014	-0.01	-0.128	0.963	0.448	-0.051	-0.453	-0.428	-0.136	0.75
Cu	0.745	-0.477	0.182	-0.268	0.909	-0.515	-0.321	0.364	0.337	0.023	0.676
Zn	-0.426	0.042	0.77	-0.325	0.925	-0.245	-0.126	0.589	-0.317	0.332	0.886
% Variance	37.5	15.4	14.2	9.5	76.6	19.5	17.7	15.6	12.1	8.5	73.4

and 6) for all the water samples ranged from 0.002 to 0.054 mg/L, which shows that majority of the water samples was significantly below the WHO permissible limit of 0.05 mg/L (WHO, 1993; 1996, 2006) except for OD1 which have a value that is above the prescribed standard. The range of chromium content obtained in this study is lower compared to Dahunsi et al. (2014) who appraised the drinking water quality and public health of selected towns in South-West of Nigeria.

Manganese is a chemically active element. It is a hard metal, very brittle, difficult to melt, but easily oxidized. The manganese content (Tables 5 and 6) for all water samples ranged from 0.015 to 1.940 mg/L. All water samples for both locations were below the WHO (2008) permissible limit of 0.4 mg/L except for samples in SD4 which is about 5-fold higher than WHO permissible limit. For this study, the range of manganese content obtained is higher compared to 0.002–1.21 mg/L reported by Aladejana and Talabi (2013) who assessed the groundwater quality in Abeokuta with respect to drinking and irrigation uses. Manganese deficiency in humans seems to be rare because manganese is present in many common foods (USEPA, 1984; Hurley and Keen, 1987). However, many studies have shown that at high concentration, manganese can be toxic, and in extremely low concentration, it causes adverse health effects to humans such as fatness, glucose intolerance, among others. Manganese is an essential element to humans and a moderate amount of it is needed in their intake. Exposure to elevated concentration may, however, result in the syndrome known as *manganism* (Caito and Aschner, 2015).

The iron values (as presented in Tables 5 and 6) for all water samples ranged from 0.02 to 2.01 mg/L, these values were above the WHO (1998) permissible limit of 0.1 mg/L except for SW01 which have a value of 0.020 mg/L. The range of iron contents obtained in the present study is about 11-fold lower compared to the value (0–21.4 mg/L) obtained by Oyeku and Eludoyin (2010) who carried out an appraisal on heavy metal contamination of groundwater resources in Ojota, Lagos state. Their study areas cover Ikosi Ketu, Oregun industrial estates, the commercial area of Kudirat Abiola way, Ojota residential area and LAWMA dumpsite. Iron is an important element in human nutrition. It has a minute concern as a health hazard and it is not fit for processing of foods, and beverages (Prakash and Somasshekar, 2006). The elevated concentration of iron might be due to corrosion of casting pipes, percolations of iron contaminants through spaces between borehole, among others (Prakash and Somasshekar, 2006).

The copper content (Tables 5 and 6) obtained in this study is below the recommended standard of the WHO of 1.0 mg/L (WHO, 1984; Fitzgerald, 1998). However, its presence can on the long run bio-accumulate which can later result in various adverse health issues (WHO, 1984; Fitzgerald, 1998). The effects of copper deficiency can include anaemia, osteoporosis in infants and children (WHO, 1984; Fitzgerald, 1998; Dahunsi et al., 2014). The zinc values across both wet and dry seasons range from 0.14 to 0.500 mg/L and were within the WHO (2008) permissible threshold but greater than the range (0.05–0.28 mg/L) reported by Dahunsi et al. (2014).

In general, heavy metal concentrations in this study varies, as some are within the permissible limits, while others significantly exceeded the prescribed limits. Majority of groundwater sources for the dry season in both Ota and Shagamu have higher heavy metal concentrations that are above the permissible limits than the wet season, implying that more industrial activities were probably conducted during the dry season under the sampling period. It should be noted that, the first major reason for choosing these locations (i. e. Ota and Shagamu) is based on the industrialization activities; dominated by cement manufacturing factories, steel/iron oxide, metallurgical, aluminium rolling mill, pharmaceutical, ink and chemical industries. Secondly, the health concerns among some residents who live in proximal to these companies/industries, which could be as a result of the release/discharge of heavy metal and ions into the groundwater during the course of their various activities. It can be observed that the presence of industries in these two locations contributed heavily to the contamination of groundwater. Although, some metals and trace elements are required to be present in water for its consumption suitability, however, in the studied locations, nearly all of these constituents were higher than the standard limits that

Table 8. Principal component analysis of water parameters in Shagamu during wet and dry seasons.

	Wet Season (Component)						Dry Season (Component)				
	1	2	3	4	5	Communalities	1	2	3	4	Communalities
pH	-0.562	0.497	-0.237	0.203	0.14	0.836	-0.377	0.41	-0.775	0.064	0.916
Temp	0.148	0.733	-0.087	0.152	0.05	0.885	0.628	-0.157	-0.201	0.086	0.675
TDS	0.754	0.033	-0.044	0.302	-0.501	0.942	0.716	-0.048	-0.561	0.336	0.955
EC	0.767	-0.037	-0.098	0.269	-0.479	0.947	0.751	-0.079	-0.508	0.326	0.957
Hardness	0.874	0.125	0.22	-0.145	0.298	0.953	0.566	0.77	-0.09	0.09	0.949
Alkalinity	0.635	-0.046	-0.437	0.156	-0.169	0.86	0.167	0.783	0.309	-0.316	0.952
HCO_3	0.874	0.125	0.22	-0.145	0.298	0.953	0.567	0.768	-0.091	0.09	0.948
Cl	0.38	0.692	0.041	0.064	0.213	0.857	0.564	-0.415	0.39	-0.049	0.794
PO_4^{3-}	-0.032	0.478	-0.279	0.101	-0.234	0.805	0.52	0.519	0.103	-0.493	0.796
SO_4^{2-}	0.751	-0.279	-0.297	-0.058	0.225	0.901	-0.186	-0.554	0.548	0.455	0.863
Ca	0.378	-0.321	-0.35	0.449	0.498	0.964	-0.303	-0.462	0.696	0.231	0.846
Mg	-0.444	0.11	0.406	0.643	0.289	0.933	0.127	0.779	0.284	-0.326	0.943
K	-0.07	-0.507	0.523	0.533	0.016	0.902	0.592	0.511	0.487	-0.052	0.862
Na	0.441	-0.17	0.762	0.123	-0.191	0.937	0.895	-0.272	0.225	-0.086	0.948
Pb	-0.011	-0.364	0.179	-0.607	-0.15	0.956	0.628	-0.441	0.591	0.125	0.959
Cd	0.374	-0.307	0.218	0.378	-0.071	0.746	-0.534	0.324	0.02	0.465	0.815
Ni	-0.074	0.014	0.448	-0.353	0.564	0.883	0.484	-0.313	0.015	-0.54	0.656
Cr	-0.01	0.353	-0.425	0.214	-0.005	0.784	0.179	0.709	0.151	0.618	0.943
Mn	0.362	0.649	0.41	-0.101	0.21	0.895	-0.79	-0.097	-0.341	-0.052	0.873
Fe	0.333	-0.455	-0.298	0.3	0.503	0.848	0.087	0.753	0.385	0.474	0.974
Cu	0.066	0.138	0.597	-0.04	-0.317	0.693	-0.681	0.481	0.396	0.069	0.968
Zn	0.639	0.245	-0.093	-0.498	0.026	0.836	0.787	-0.215	-0.111	0.029	0.916
% Variance	23.8	14.6	12.5	10.7	8.6	70.2	32.9	24.9	15.1	9.6	82.5

are considered safe for human consumption, therefore, they were considered as toxic/poisonous (Tchounwou et al., 2014; De Meyer et al., 2017; Samantara et al., 2017). The persistency and bioaccumulation nature of these heavy metals and trace elements have significant characteristics of posing health risks to mankind. These toxicants possess harmful effects on human health, aquatic life, animals and plants. The high level of Pb, Cd, Cr, Mn, Ni, etc, and other ions noticed in these locations are not completely safe; because of the possibility that residents may consume them beyond the prescribed/recommended quantities. Their consumption beyond the permission limit can result into different health challenges and chronic diseases including high blood pressure, kidney problem, liver cirrhosis, skin irritation, etc. (USEPA, 2001; 2006; WHO, 2011).

3.1. Principal component analysis in Ota and Shagamu (source identification of pollution in groundwater)

The results of principal components analysis (PCA) of water parameters in Ota industrial area during the wet and dry seasons are presented in Table 7. The varimax rotated analysis during the wet season revealed five factors/components. The percentage of variability of data set varied between 8.5 and 19.5 %; while 73.4 % of the total variance of the data set is explained by the five factors leaving less than 26 % attributable to other unclarified parameters. Factor 3 has strong significant positive and negative loadings for Alkalinity, HCO_3^-, Zn, Ca, Mg and Cl and it's suspected to be a hardness source. Factor 4 has been a positive loading for K, Mg, Ca, pH with negative loading for TDS, EC and Fe. This factor represents industrial pollution sources. Ayedun et al. (2012) and Taiwo (2012) had reported that confined aquifers of a sedimentary basin are vulnerable to the building up of dissolved iron. Negative loading for Fe may perhaps suggest the presence of Fe in the groundwater maybe natural rather than anthropogenic (Taiwo, 2012). Factor 5 is loaded for TDS, Cl^-, and PO_4^{3-} which is probably due to pollution by industrial sources. This source could be designated industrial effluents, sewage and surface run-offs.

Furthermore, groundwater parameters from Ota industrial area during the dry season have been separated into four components by PCA with 76.6 % variability of data set varying from 9.5 to 37.5 (Table 7). Factor 1 has a high loading for Zn, Cu, Fe, Ni, Pb, Na, K, Mg, Cl, HCO_3^-, hardness and alkalinity with negative loading for Ca are markers for industrial pollution. Therefore, this source could be seen as an industrial source. Sango-Ota is one of the industrial bases in Ogun State. Effluents or discharges from the industries could have raised the concentrations of these elements (Taiwo, 2012). The loadings for factor 2 are pH, temperature, PO_4^{3-}, NO_3^{2-}, Ca, Cd, Cr, Mn and Cu, this factor could be a designated leachate source. Leaching of septic tanks, sewage and wastes into the groundwater resource may lead to nitrate pollution. Leachate from septic tanks and open dumps could have infiltrated into the groundwater resource, thereby polluting it (Taiwo, 2012). Factor 3 is loaded for TDS, EC, Cd and Zn, this source could be attributed to leachate source. Factor 4 represent a positive loading for TDS, EC, alkalinity, HCO_3^- and Mn with a negative loading for Cr. This source could be seen as an industrial source.

However, the results of principal components analysis of water parameters in Shagamu industrial area during the wet and dry seasons are presented in Table 8. In the varimax rotated PCA done on the groundwater quality during the wet season, revealed five factors/components. The percentage of variability of data set varied between 8.6 and 23.8 %; while 70.2 % of the total variance of the data set is explained by the five factors leaving less than 30 % unidentified. Factor 3 has positive loading for Mg, K, Na, Ni, Mn and Cu with a negative loading for Cr and alkalinity and it was suspected to be a geologic and industrial source. Factor 4 has been positive loading for K, Mg, Ca with negative loading for NO_3^-, Pb and Zn. This factor could be best described as a solid source. Factor 5 is loaded for TDS, EC, Ca, Ni and Fe which is probably due to pollution by industrial sources. This source could be the designated industrial effluents, sewage and surface run-offs.

Furthermore, groundwater samples from Shagamu during the dry season undergone a varimax rotation by PCA, four major components were identified (Table 8). Only 82.5 % of the total data set was identified

Table 9. Comparison of the concentration of heavy metals of the studied locations with the previous works and WHO standard.

G (including W, B and other sources) (mg/L)	W (mg/L)	B (mg/L)	References
Pb			
	0.001–0.019	0.001–0.024	Momodu and Anyakora. (2010).
0.135–0.305			Aremu et al. (2002).
0.060–0.960			Peter and Funmilayo (2016).
0.00–0.02			Laniyan et al. (2015).
	0.40–6.60	0.21–6.60	Yusuf et al. (2018).
0.04–0.29			Dahunsi et al. (2014)
0.10–0.43			Adeyemi et al. (2017)
1.2–26.9			Haileslassie and Gebremedhin (2015)
	0.01		WHO standard
	0.003–0.935		This study
Cd			
	0.001–0.091	0.002–0.098	Momodu and Anyakora. (2010)
0.76–4.09			Dahunsi et al. (2014)
	0.07–0.16	0.05–0.09	Yusuf et al. (2018)
0.009–0.446			Casimir et al. (2015)
0.09–1.59			Haileslassie and Gebremedhin (2015)
0.002–0.042			Oluyemi et al. (2009)
	0.003		WHO standard
	0.002–0.029		This study
Ni			
	0.61–1.53	0.66–1.28	Yusuf et al. (2018).
0.44–1.27			Dahunsi et al. (2014)
0.07–0.18			Winifred et al. (2014)
0.09–0.031			Alabi et al. (2013)
	0.02		WHO standard
	0.004–0.390		This study
Cr			
	0.05–0.11	0.01–0.03	Yusuf et al. (2018)
0.24–2.59			Dahunsi et al. (2014).
0.001–0.014			Alabi et al. (2013).
0.5–5.2			Haileslassie and Gebremedhin (2015)
0.20–0.71			Longe and Balogun (2010)
	0.05		WHO standard
	0.002–0.054		This study
Mn			
0.01–0.05			Ayedun et al. (2012)
0.00–1.27			Laniyan et al. (2015)
	0.25–0.63	0.29–0.64	Yusuf et al. (2018)
0.046–1.850			Gimba et al. (2015)
0.02–0.08			Alabi et al. (2013).
6.96–184.75			Haileslassie and Gebremedhin (2015)
	0.4		WHO standard
	0.015–1.94		This study
Fe			
0.01–10.01			Laniyan et al. (2015)
0.395–22.912			Gimba et al. (2015)
0.41–1.41			Winifred et al. (2014)
0.089–2.466			Alabi et al. (2013).
11–2167			Haileslassie and Gebremedhin (2015)
0-460 (μg/L)			Yerima et al. (2019)
	0.1		WHO standard
	0.02–2.01		This study

G: Groundwater, **W**: Well water, **B**: Borehole water.

leaving up to 17.5 % unidentified as four major factors allotted. Factor 1 is having high loadings for temperature, TDS, EC, alkalinity, HCO_3^-, Cl, PO_4^{3-}, K, Na, Pb, Cd, Ni, Mn, Cu and Zn. Additionally, the loadings for factor 2 are pH, alkalinity, hardness, HCO_3^-, Cl, PO_4^{3-}, NO_3^-, Ca, Mg, K, Pb, Cr, Fe and Cu. The source of factor 1 and 2 could be probably resulted from industrial pollution sources as the two factor dominates the whole data set with 32.9 % and 24.9 % respectively of the 82.5 % variability.

The loadings for factor 3 are pH, TDS, EC, NO_3^{2-}, Ca, K and Pb, this factor could be a designated leachate source. Leaching of septic tanks, sewage and wastes into the groundwater resource may lead to nitrate

pollution. Factor 4 was loaded for PO_4^{3-}, NO_3^-, Cd, Ni, Cr and Fe, this source could be attributed to industrial pollution sources.

3.2. Comparison of the heavy metal in the present study with the previous works and WHO standard

In order to establish the concentrations of the heavy metals (Pb, Ni, Cd, Fe, Mn, and Cr) obtained in the study locations, this study compared the obtained data with the previous works found in the literature and also, the WHO standard, as shown in Table 9. Generally, this study reveals abnormalities of the heavy metals in the study location than the WHO standard. This is in close agreement with other previous works which also show prevalence or diminution of heavy metals. This implies that there exist higher concentrations of heavy metal pollutants at the studied sample points of Shagamu and Ota industrial areas and they all showed discrepancies in comparison with the permissible limit.

4. Conclusion

The indiscriminate discharge of untreated industrial effluents as observed in this study is the major source of groundwater pollution which results in serious contamination. This is evident via the high concentrations of pH, calcium, Pb, Cd, Fe, Ni, and Cr along some sampling points as a result of the heavy discharge of effluents from various industrial activities. Most of the companies in the study locations are within residential areas. Some residents live proximal to these companies. As such, the effluents discharged by these industries are deposited into the outer drainage/culvert of the industries without being treated. This, in turn, gets into the land and sinks in. It eventually gets into the residential boreholes and shallow well-waters that have depth below the standard level. This problem is exasperated due to the unavailability of stringent water and environmental laws and law enforcement of the existing ones. Furthermore, the unregulated siting of boreholes close to the industries by the residents is also a cause for concern as the groundwater can easily be contaminated by various industrial activities which involved the use of chemicals. This can thus, render the water unsuitable for consumption without prior treatment.

With the exception of pH and calcium at some sampling points, the results obtained from this study showed that all physicochemical parameters were in compliance with the WHO (2006) standard. The obtained concentration of heavy metals such as Pb, Ni, Cd, Fe, Mg, and Cr indicated that there exists a significant concentration of pollutants at different sampling points. The findings from the analysis of heavy metals indicated that the groundwater is alarmingly getting contaminated by heavy metals, and this is due to the industrial activities in the study areas. The concentration of heavy metals in the water samples was discovered to be significantly higher than the permissible limits of WHO with the exception of zinc and copper. The result obtained from the analysis showed the order of concentration of the heavy metals detected in all water samples analyzed to be in the sequence of Fe > Mn > Cu > Cr > Zn > Ni > Pb > Cd. The trend of heavy metals calls for concern, as most of the analyzed parameters were above the recommended standards. This could cause adverse health effects on man and the environment at large. Peradventure nothing is done to curb this disturbing act, in no distant time, residents will begin to experience severe consequences of indiscriminate discharges of industrial effluents proximal to their neighborhoods. This study, therefore, recommends treatment of water in the study locations prior to its use for domestic purposes since the proximity of the boreholes and wells to these industries are the principal cause of the heavy metals contaminations. The appropriate agencies should be involved in providing potable water for these communities, and the residents should be oriented through public workshops and outreaches about the impending danger of drinking the water of the study locations or its usage in their domestic activities. Therefore, the construction of boreholes and dug wells is proposed here to follow the proper siting regulations under the close supervision of water engineers.

Declarations

Author contribution statement

Ojekunle Olusheyi Zacchaeus: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Mujeeb Balogun Adeyemi, Adeyemi Azeem Adedeji: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Abdulraheem Okehi Anumah, Kayode Adesina Adegoke: Analyzed and interpreted the data; Wrote the paper.

Taiwo Adewale Matthew, Ganiyu Saheed Adekunle: Contributed reagents, materials, analysis tools or data.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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