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Assessment of Surface and Groundwater Quality of the Akure Metropolis, Southwestern Nigeria.

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Abstract

Hydrochemical analysis was carried out on surface and groundwater samples collected from Akure metropolis with a view to determining their quality. Hydrochemical data on groundwater samples from fifty six (56) boreholes were sourced from the Ondo State Water Corporation. Twenty five (25) surface water samples from streams and rivers in the study area were collected and analyzed using standard analytical techniques. The analyzed physical parameters include colour, odour, turbidity, conductivity and chemical properties such as pH, dissolved solid, hardness, cations, anions and heavy metals. All the groundwater samples were colourless, odourless and tasteless. Some surface water samples were coloured and turbid in appearance while some had objectionable odour. Although the NO_3^- concentration levels in both surface and groundwater samples were generally below the WHO threshold value of 10 mgl^{-1}, relatively high concentration range (2.5-6.0 mgl^{-1}) was recorded within the city centre indicating some level of pollution from cumulative anthropogenetic activities. Only few surface water samples contain Pb while Mn was identified in some surface and groundwater samples. The elevated Pb concentration levels (0.41-3.41 mgl^{-1}) and relatively high Mn concentration levels (up to 2.18 mgl^{-1}) (both much higher than the WHO and NIS thresholds) in some surface water samples was an indication of heavy metal pollution. Conductivity values of the groundwater samples generally ranged from 42.0 – 1400.0 μScm^{-1}. Only surface water sample 17 was moderately saline while other surface water samples were of freshwater type. Based on TDS values, all the groundwater and surface water samples were of freshwater type (TDS < 1000 mgl^{-1}).

Keywords: Physico-chemical Analysis, Surface/Groundwater, Quality, Akure Metropolis.

1. Introduction

The Akure Metropolis has witnessed rapid development in infrastructures (housing and estate development, surface/groundwater development etc), establishment of new industries and expansion of older ones. Population explosion, aggravated by rural-urban migration and infrastructural growth, are accompanied by increase in industrial and domestic wastes. In the metropolis, municipal wastes are dumped in drainage channels, streams, indiscriminately located dump sites and market places. There are evidences of both surface and groundwater pollution from biodegradation of wastes and the resulted leachate (Bayode, 2010; Bayode *et al*., 2011a and Bayode *et al*., 2011b). A significant proportion of the inhabitants of the metropolis depend on surface and groundwater for their domestic use, due to inadequate public water supply.

In recent times, the impact of leachate on groundwater and other water resources has attracted a lot of attention because of its overwhelming environmental significance (Olayinka and Olayiwola, 2001; Ikem *et al.*, 2002; Obase *et al*., 2009; Bayode, 2010; Bayode *et al*., 2011a and Bayode *et al*., 2011b). Combined geoelectric measurements, hydrogeological and chemical analysis of water samples are often used to identify the underground aquifers, estimate porosity and permeability of geologic materials, assess groundwater quality, direction of groundwater flow and spread and possible migration paths of contaminants in a polluted area (Bayode *et al*., 2011b). This study intends to use hydro-chemical analysis of surface and groundwater (well water) samples to assess the quality of the waters (surface and groundwater) within the Akure metropolis.

2. Site Description

The study area (Akure Metropolis) lies within Latitudes 07° 09' and 07° 19'N and Longitudes 05° 07' and 05° 17'E (Northings 790820 – 809277 mN and Eastings 733726 – 752139 mE, UTM Minna Zone 31) (Fig. 1). It covers an areal extent of about 340 km^2. The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs. Topographic elevations vary between 260 and 470 m above sea level (Owoyemi, 1996). The metropolis is drained by several streams and rivers.

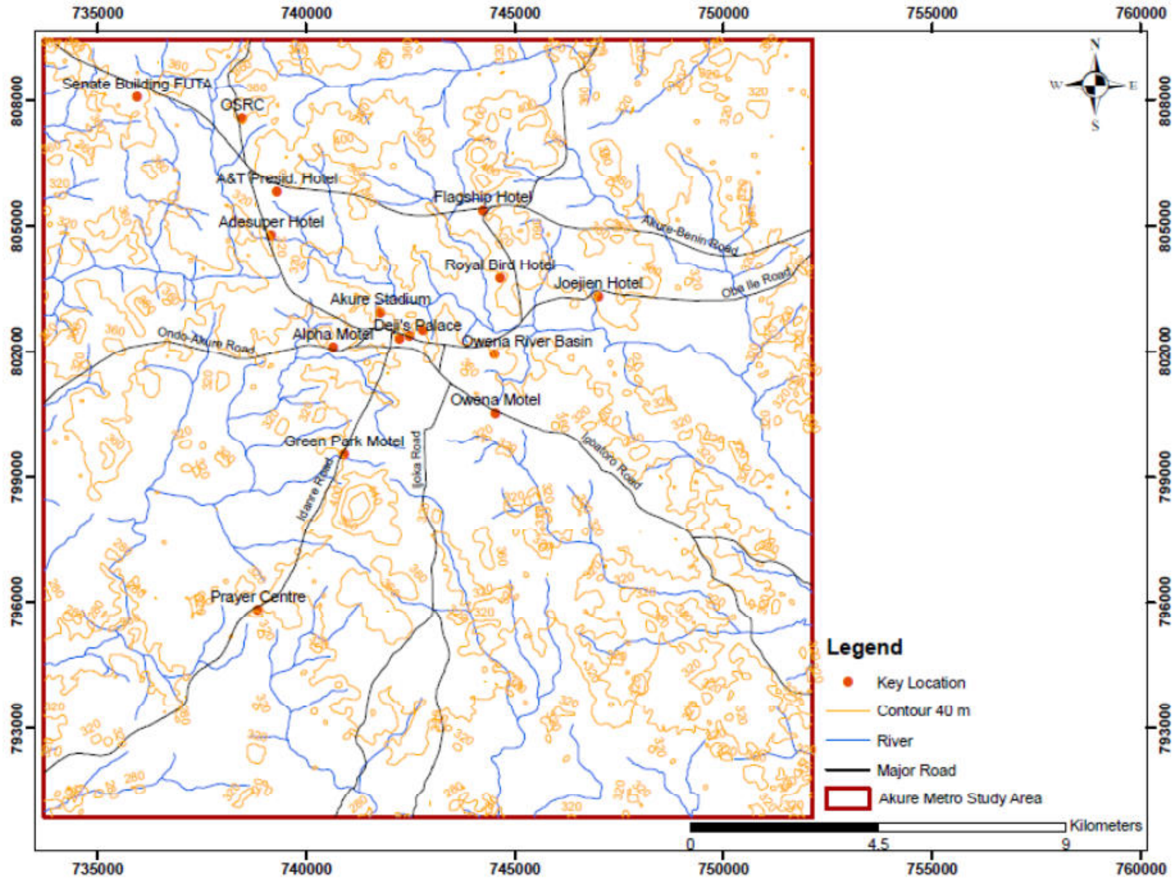

Fig. 1: Map of Akure Metropolis – The Study Area, Showing the Topographic Variations.

3. Geology and Hydrogeology

The geological mapping and other related studies of the area around the Akure Metropolis have been carried out by several workers amongst whom are Olarewaju (1981), Anifowose (1989), Owoyemi, 1996, Odeyemi *et al.* (1999), Aluko (2008) and Sobogun (2008). The area around the Akure Metropolis is underlain by the Basement Complex rocks of Southwestern Nigeria (Fig. 2). The petrological units include Migmatite-Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes (Rahaman,1988).

The study area exhibits varieties of structures such as foliation, schistosity, folds, faults, joints and fractures. Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. These structural trends fall within the principal basement complex fracture direction identified by Oluyide, 1988. The lineament map generated by Owoyemi, 1996 showed high density of lineament and lineament intersections in the eastern, southwestern and north central part of the metropolis underlain by granites and migmatite gneiss while the north central part underlain by charnockites has very low lineament density. The satellite-imagery-delineated lineaments are shown in (Fig. 3). The lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations and subsidiary NW-SE and W-E trends that are typical of the Basement Complex region of Nigeria (Oluyide, 1988, Owoyemi, 1996 and Odeyemi *et al.*, 1999).

The groundwater in a typical basement complex area like the Akure Metropolis, is contained in two major aquifer units, namely weathered and fractured basement aquifers (Ako and Olorunfemi, 1989; Aniya and

Schoeneick, 1992; Olorunfemi and Fasuyi, 1993; and Afolayan *et al*., 2004). The former is derived from chemical alteration processes while the latter is the product of tectonic activities. The weathered layer aquifer may occur singly or in combination with the fractured aquifer (Olorunfemi and Fasuyi 1993; and Bayode *et al*., 2006). The direct exposure of the uppermost part of the vadose zone of the weathered layer aquifer system makes it vulnerable to surface/near surface pollutants such as leachate from waste dump sites and flooding.

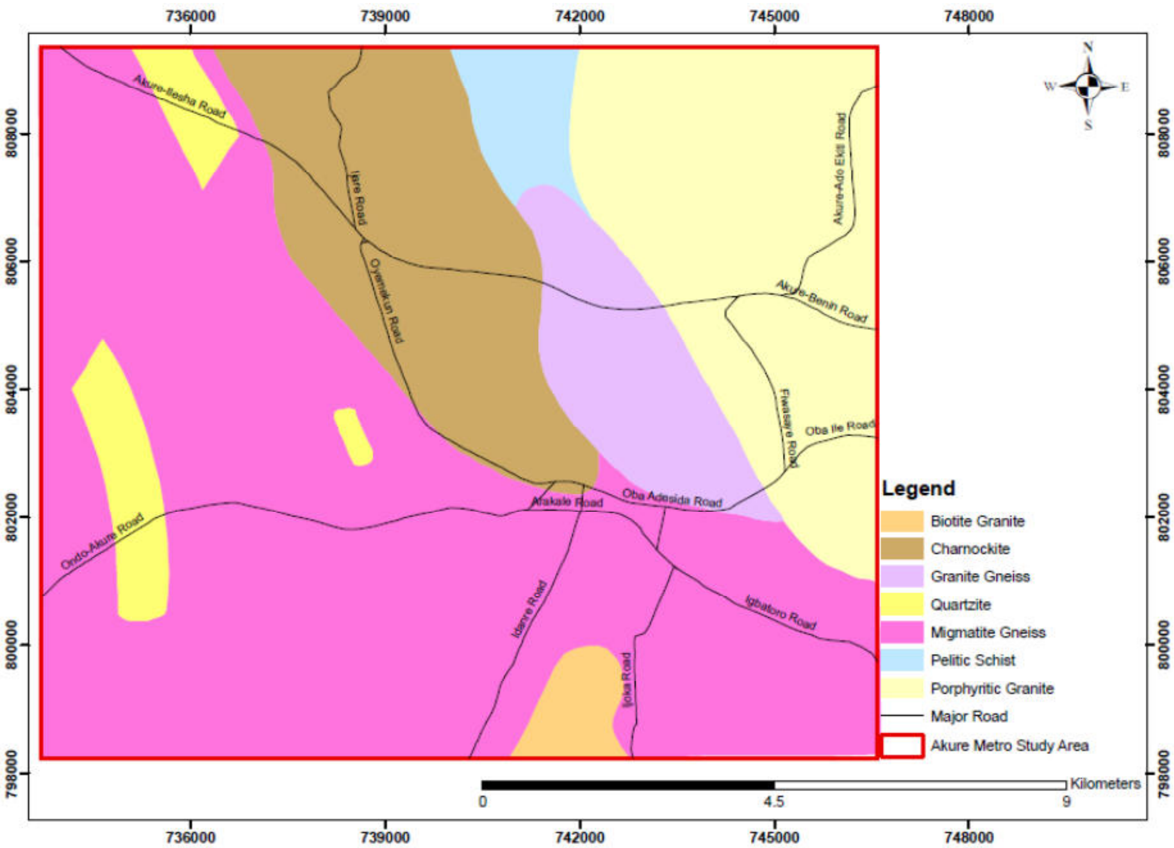

Fig.2: Geological Map of Akure Metropolis (After Owoyemi, 1996).

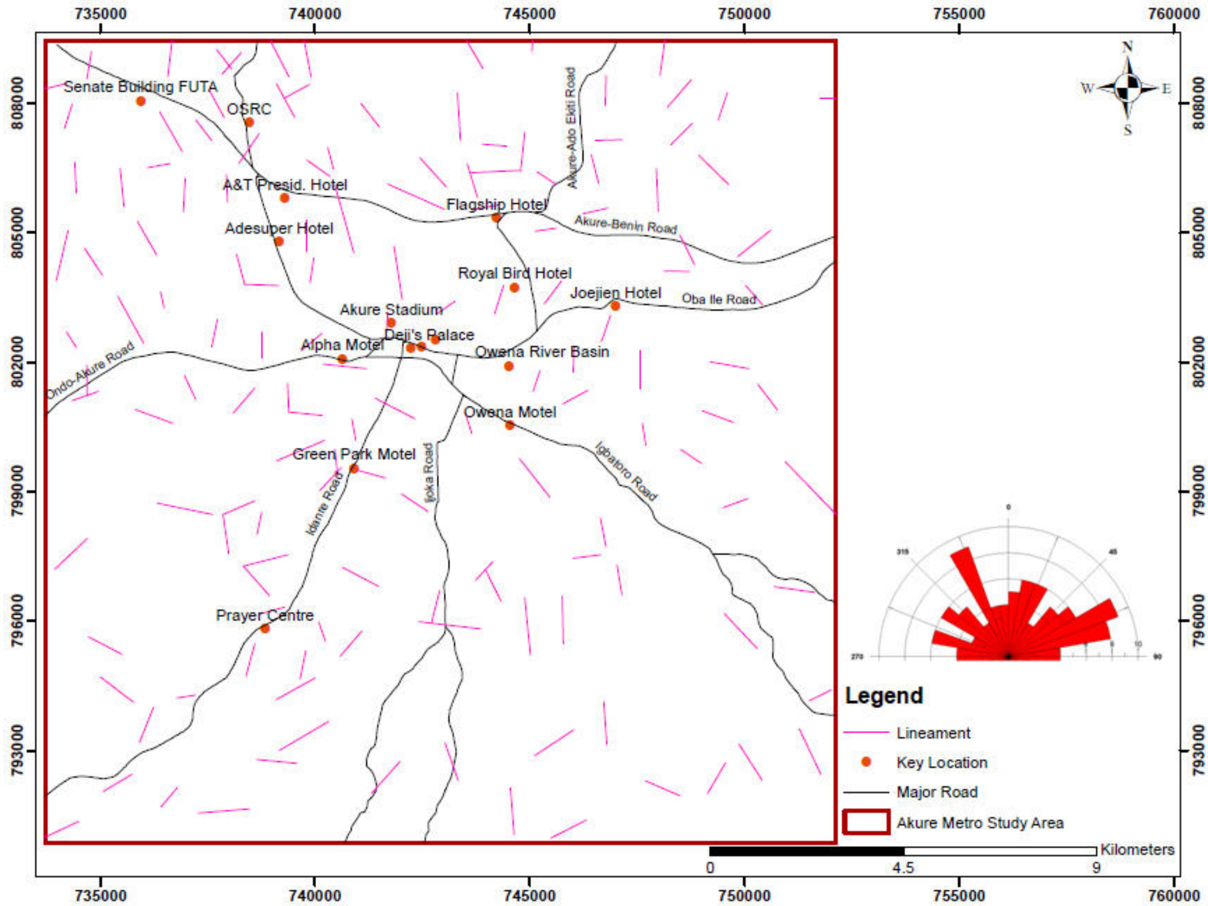

Fig. 3 Lineament Map of Akure Metropolis

4. Methodology

Hydrochemical data on groundwater samples from georeferenced fifty six (56) boreholes were sourced from the Ondo State Water Corporation under the State Water Borehole Water Project. Twenty five (25) water samples from streams and rivers in the study area were collected and their locations georeferenced. The water samples were analyzed for physical (colour, odour, turbidity) and chemical properties (pH, conductivity, dissolved solid, hardness, cations, anions and heavy metals) using standard analytical methods. Figure 4 shows the locations of the surface and borehole water samples.

5. Results and Discussion

5.1 The Physico-chemical Parameters of Water Samples

All the borehole water (groundwater) samples appeared clear, colourless, odourless and tasteless with the exception of samples 5, 6 and 16 which appeared turbid (Table 1). Surface water samples 1, 18 and 24 were clear in appearance while other surface water samples appeared to fall within being slightly coloured, light brown, slightly brownish, brownish, yellowish brown, highly brown, turbid and highly turbid. Surface water samples 1, 3, 5-9, 13, 15-16, 23-24 had unobjectionable odour while the rest of the surface water samples were observed to have objectionable odour (Table 2). Turbidity of the groundwater samples ranged between 0.6 and 12.0 NTU with mean value of 2.28 ± 0.32 NTU (Table 3). The turbidity of most of the groundwater samples were within the limit of WHO and NIS standards for drinking water except Boreholes 5, 6, 16, 45 and 47. The Total Suspended Solids (TSS) of the groundwater samples also ranged from 61.0 – 122.0 mgl^{-1} with mean value of 97.29 ± 8.80 mgl^{-1} while the Total Solids (TS) ranged between 30.8 and 980.0 mgl^{-1} with mean value of 268.88 ± 26.46 mgl^{-1} and were all within the limit of WHO and NIS standards for drinking water (Tables 3 and 5). Surface water samples turbidity values were mostly on the high side compared with the WHO and NIS standards for drinking water ranging from 0.1 - 327.0 NTU with a mean value of 54.12 ± 13.81 NTU (Table 4). Only samples 1 (3.92 NTU) and 18 (0.1 NTU) were within the limit of WHO and NIS standards (Table 6).

5.2 Chemical Parameters of Groundwater and Surface Water Samples

The water bodies from the study area varied from moderately acidic to alkaline with a range of pH values of 6.0 – 8.0. The groundwater samples varied from moderately acidic to neutral (pH 6.0 -7.1) while the surface water samples varied from slightly acidic to alkaline (6.5 – 8.0). On the average the groundwater samples were slightly acidic (average pH 6.55 ± 0.04) while the surface water samples were neutral (average pH 7.00 ± 0.08). The average pH values of both sources of water (i.e. borehole and surface water) were all within the limit of WHO and NIS standards for drinking water (Tables 5 and 6) but groundwater samples: 6, 8-10, 13, 19, 36, 48-49, 51 and 54-55 had pH values lower than that of these standards suggesting that they are acidic.

Conductivity values of the groundwater samples ranged from 42.0 – 1400.0 μScm^{-1} with average value of 374.25 ± 37.11 μScm^{-1} while that of the surface water samples ranged from 40 – 890 μScm^{-1} with average value of 154.80 ± 34.56 μScm^{-1}. Except in groundwater samples 23, 46, 47 and surface water sample 17, the other water samples investigated had their conductivity values within the limit of WHO and NIS standards for drinking water. The Total Dissolved Solid (TDS) values ranged from 30.8 – 870.0 mgl^{-1} with a mean value of 256.72 ± 24.22 mgl^{-1}, and 30 – 620 mgl^{-1} with mean value of 108.00 ± 24.07 mgl^{-1} in borehole and surface water sources respectively. All the TDS values of the groundwater samples were within the WHO standard for drinking water but some did not comply with the NIS standard. The surface water samples TDS values all fell within the limit of WHO and NIS standards for drinking water except in sample 17 with TDS value of 620 mgl^{-1}. The total alkalinity was quite variable in the water sources (range = 2.0 – 260.0 $mgl^{-1}CaCO_3$; mean = 77.71 ± 7.89 $mgl^{-1}CaCO_3$) and (range = 12.0 – 250.0 $mgl^{-1}CaCO_3$; mean = 43.52 ± 9.35 $mgl^{-1}CaCO_3$) for groundwater and surface water samples respectively. Except in well water samples 2, 46-47, 49-51, 55 and surface water sample 17 the total alkalinity values were found to be within the WHO standard for drinking water. Total hardness values ranged from 7.5 – 329.8 $mgl^{-1}CaCO_3$ with an average of 105.52 ± 10.15 $mgl^{-1}CaCO_3$ for groundwater samples as well as 7.2 – 286.6 $mgl^{-1}CaCO_3$ with an average of 43.47 ± 11.31 $mgl^{-1}CaCO_3$ for surface water samples. The total hardness values from both water sources were all within the WHO standard for drinking water except in surface water sample 17 (total hardness = 286.6 $mgl^{-1}CaCO_3$) (Tables 3 and 4).

5.3 Major Ions of Groundwater and Surface Water Samples

Ca^{2+} ranged from 1.2 – 62.4 mgl^{-1} with an average of 23.63 ± 2.33 mgl^{-1}; Mg^{2+} ranged from 0.8 – 42.4 mgl^{-1} with an average of 11.40 ± 1.21 mgl^{-1}; Na^+ varied from 2.0 - 55.0 mgl^{-1} with an average of 20.5 ± 1.81 mgl^{-1}; K^+ ranged from 1.0 – 75.0 mgl^{-1} with an average of 28.19 ± 2.46 mgl^{-1}; Cl^- varied from 1.5 – 145.0 mgl^{-1} with an average of 24.02 ± 3.05 mgl^{-1}; SO_4^{2-} ranged from 0.6 – 72.0 mgl^{-1} with an average of 16.73 ± 2.00 mgl^{-1}; HCO_3^- ranged from 3.6 - 312.0 mgl^{-1} with an average of 93.28 ± 9.46 mgl^{-1}; and NO_3^- varied from 0.6 – 6.0 mgl^{-1} with an average of 2.64 ± 0.34 mgl^{-1} in groundwater samples from the study area. For surface water samples Ca^{2+} (range = 1.6 – 6.2 mgl^{-1}; mean = 10.53 ± 2.55 mgl^{-1}); Mg^{2+} (range = 0.6 – 26.0 mgl^{-1}; mean = 3.94 ± 1.05 mgl^{-1}); Na^+ (range = 2.0 – 23.0 mgl^{-1}; mean = 5.12 ± 0.84 mgl^{-1}); K^+ (range = 0.3 - 25.0 mgl^{-1}; mean = 4.13 ± 1.08 mgl^{-1}); Cl^- (range = 2.0 – 75.0 mgl^{-1}; mean = 12.6 ± 3.58 mgl^{-1});

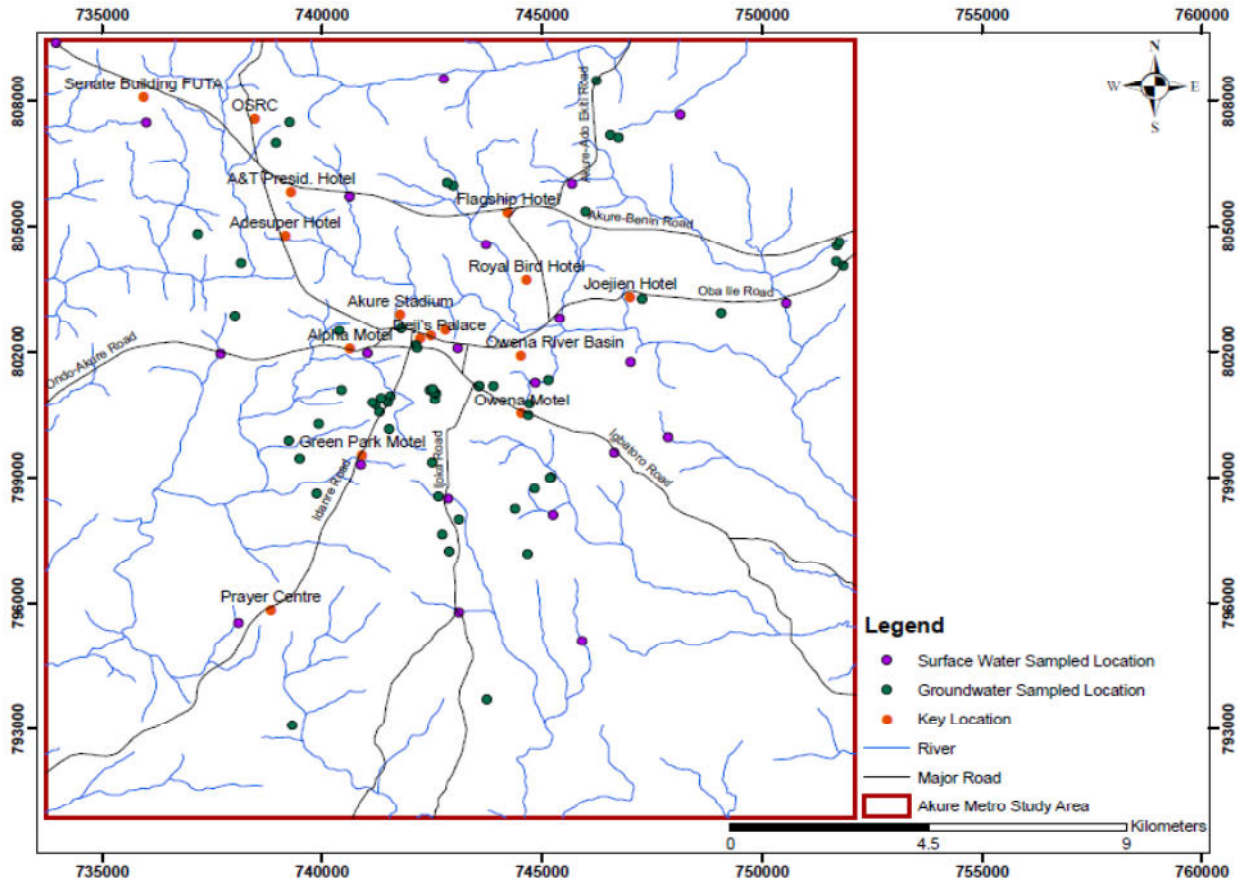

Fig. 4: Surface and Groundwater sample Location Map of the Study Area.

Table 1: Physical Parameter of Groundwater Analysis Results

Well No	Physical Parameter						
		Appearance	Colour ^{o}H	Odour	Taste	Turbidity, NTU	Cond. μScm^{-1}
	WHO Standard	Clear	Colourless	Odourless	Insipid	5	$1.0x10^{3}$
1		Clear	Colourless	Odourless	Insipid	2.5	$6.6x10^{2}$
2		Clear	Colourless	Odourless	Insipid	3	$6.8\ x10^{2}$
3		Clear	Colourless	Odourless	Insipid	1.2	$0.12\ x10^{2}$
4		Clear	Colourless	Odourless	Insipid	4	$7.0\ x10^{2}$
5		Clear	Colourless	Odourless	Insipid	8	$4.0\ x10^{2}$
6		Clear	Colourless	Odourless	Insipid	12	$2.1\ x10^{2}$
7		Clear	Colourless	Odourless	Insipid	2	$4.4\ x10^{1}$
8		Clear	Colourless	Odourless	Insipid	0.8	$2.8\ x10^{2}$
9		Clear	Colourless	Odourless	Insipid	3	$3.0\ x10^{2}$
10		Clear	Colourless	Odourless	Insipid	0.8	$2.4\ x10^{2}$
11		Clear	Colourless	Odourless	Insipid	3	$6.4\ x10^{2}$
12		Clear	Colourless	Odourless	Insipid	2	$0.82\ x10^{2}$
13		Clear	Colourless	Odourless	Insipid	1.88	$3.4\ x10^{2}$
14		Clear	Colourless	Odourless	Insipid	0.6	$4.2\ x10^{1}$
15		Clear	Colourless	Odourless	Insipid	1.5	$3.2\ x10^{2}$
16		Clear	Colourless	Odourless	Insipid	9	$4.0\ x10^{2}$
17		Clear	Colourless	Odourless	Insipid	2.8	$4.4\ x10^{2}$
18		Clear	Colourless	Odourless	Insipid	2	$3.3\ x10^{2}$
19		Clear	Colourless	Odourless	Insipid	1	$7.9\ x10^{2}$
20		Clear	Colourless	Odourless	Insipid	1	$3.7\ x10^{2}$

21		Clear	Colourless	Odourless	Insipid	3.5	4.1 x10^{2}
22		Clear	Colourless	Odourless	Insipid	2	3.0 x10^{2}
23		Clear	Colourless	Odourless	Insipid	1.1	1.4 x10^{2}
24		Clear	Colourless	Odourless	Insipid	2.6	7.4 x10^{2}
25		Clear	Colourless	Odourless	Insipid	1.2	0.3 x10^{2}
26		Clear	Colourless	Odourless	Insipid	0.9	0.72 x10^{2}
27		Clear	Colourless	Odourless	Insipid	1.2	0.38 x10^{3}
28		Clear	Colourless	Odourless	Insipid	1.2	0.24 x10^{3}
29		Clear	Colourless	Odourless	Insipid	1.2	0.24 x10^{3}
30		Clear	Colourless	Odourless	Insipid	1.3	0.28 x10^{3}
31		Clear	Colourless	Odourless	Insipid	1.1	0.24 x10^{3}
32		Clear	Colourless	Odourless	Insipid	1.8	4.6 x10^{2}
33		Clear	Colourless	Odourless	Insipid	1.6	0.38 x10^{3}
34		Clear	Colourless	Odourless	Insipid	1.2	0.86 x10^{2}
35		Clear	Colourless	Odourless	Insipid	1.4	0.84 x10^{2}
36		Clear	Colourless	Odourless	Insipid	2.1	5.92 x10^{2}
37		Clear	Colourless	Odourless	Insipid	1	5.32 x10^{2}
38		Clear	Colourless	Odourless	Insipid	0.8	0.78 x10^{2}
39		Clear	Colourless	Odourless	Insipid	1	0.92 x10^{2}
40		Clear	Colourless	Odourless	Insipid	0.6	0.7 x10^{2}
41		Clear	Colourless	Odourless	Insipid	0.8	0.78 x10^{2}
42		Clear	Colourless	Odourless	Insipid	1.1	0.96 x10^{2}
43		Clear	Colourless	Odourless	Insipid		7.0 x10^{2}
44		Clear	Colourless	Odourless	Insipid	1.5	3.7 x10^{2}
45		Clear	Colourless	Odourless	Insipid	4	7.7 x10^{2}
46		Clear	Colourless	Odourless	Insipid	10.5	1.4 x10^{3}
47		Clear	Colourless	Odourless	Insipid	3.6	1.2 x10^{3}
48		Clear	Colourless	Odourless	Insipid	1.4	3.8 x10^{2}
49		Clear	Colourless	Odourless	Insipid	1.6	3.2 x10^{2}
50		Clear	Colourless	Odourless	Insipid	1.4	0.82 x10^{3}
51		Clear	Colourless	Odourless	Insipid		0.3 x10^{3}
52		Clear	Colourless	Odourless	Insipid	1.8	0.3 x10^{3}
53		Clear	Colourless	Odourless	Insipid	1.2	0.24 x10^{3}
54		Clear	Colourless	Odourless	Insipid	1.2	0.28 x10^{3}
55		Clear	Colourless	Odourless	Insipid	1.3	0.32 x10^{3}
56		Clear	Colourless	Odourless	Insipid	1	0.28 x10^{3}

Table 2: Physical Parameters of Surface Water Analysis Results.

Well No	Physical Parameters					
		Appearance	Colour ^{o}H	Odour	Turbidity, NTU	Cond. µScm^{-1}
	WHO Standard	Clear	3.0 TCU	Unobjectionable	5	1.0x10^{3}
1		Clear	1.5	Unobjectionable	3.92	0.11x10^{3}
2		Slightly Coloured	9	Unobjectionable	49.11	0.11 x10^{3}
3		Light Brownr	14	Unobjectionable	61	0.08 x10^{3}
4		Slightly Coloured	10	Unobjectionable	21.27	0.09 x10^{3}
5		Brownish	18	Unobjectionable	25.3	0.09 x10^{3}
6		Slightly Brownish	10	Unobjectionable	52	0.06 x10^{3}
7		Slightly Brownish	16	Unobjectionable	48.42	0.04 x10^{3}
8		Slightly Brownish	12	Unobjectionable	86	0.10 x10^{3}
9		Slightly Brownish	10	Unobjectionable	23.39	0.10 x10^{3}
10		High Brown	40	Unobjectionable	135	0.21 x10^{3}
11		Slightly Coloured	8	Objectionable	5.73	0.12 x10^{3}
12		Slightly Coloured	6	Objectionable	14.1	0.06 x10^{3}
13		Light Brown	6	Unobjectionable	30.14	0.13 x10^{3}
14		Turbid	20	Objectionable	61	0.8 x10^{2}

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15		Slightly Brownish	20	Unobjectionable	69	0.06×10^3
16		Slightly Coloured	10	Unobjectionable	42.37	0.19×10^3
17		Brownish	26	Objectionable	28.03	0.89×10^3
18		Clear	0.8	Objectionable	0.1	0.30×10^3
19		Hidhly Turbid	25	Objectionable	327	0.26×10^3
20		Yellowish Brown	12	Objectionable	41.34	0.08×10^3
21		Light Brown	9	Objectionable	9.73	0.05×10^3
22		Turbid	27	Objectionable	164	0.11×10^3
23		Slighly Coloured	10	Unobjectionable	20.53	0.08×10^3
24		Clear	3	Unobjectionable	28.85	0.11×10^3
25		Slighly Coloured	7	Objectionable	5.57	0.36×10^3

Table 3: Descriptive Statistics of the Physico-chemical Parameters of Water Quality of Groundwater Samples from Akure, Ondo State

S/N	PARAMETER	STATISTICS					
		N	Min.	Max.	Median	St. Dev.	Mean±S.E.
	Physical						
1	Turbidity (NTU)	54	0.6	12.0	1.4	2.37	2.28 ± 0.32
2	Total Suspended Solids (TSS) (mgl^{-1})	7	61.0	122.0	100.0	23.27	97.29 ± 8.80
3	Total Solids (TS) (mgl^{-1})	56	30.8	980.0	224.0	197.99	268.88 ± 26.46
	General chemical						
4	pH	56	6.0	7.1	6.5	0.28	6.55 ± 0.04
5	Conductivity (μScm^{-1})	56	42.0	1400.0	310.0	277.69	374.25 ± 37.11
6	Total Dissolved Solids (TDS) (mgl^{-1})	56	30.8	870.0	217.0	181.26	256.72 ± 24.22
7	Total Alkalinity ($mgl^{-1}CaCO_3$)	56	2.0	260.0	62.0	59.01	77.71 ± 7.89
8	Total Hardness ($mgl^{-1}CaCO_3$)	56	7.5	329.8	87.6	75.99	105.52 ± 10.15
9	Non Carbonate Hardness ($mgl^{-1}CaCO_3$)	56	0.0	241.2	22.5	42.51	33.64 ± 5.68
	Major ions						
10	Calcium (Ca^{2+}) (mgl^{-1})	56	1.2	62.4	19.6	17.43	23.63 ± 2.33
11	Magnesium (Mg^{2+}) (mgl^{-1})	56	0.8	42.4	9.8	9.07	11.40 ± 1.21
12	Sodium (Na^+) (mgl^{-1})	54	2.0	55.0	20.0	13.33	20.5 ± 1.81
13	Potassium (K^+) (mgl^{-1})	54	1.0	75.0	30.0	18.09	28.19 ± 2.46
14	Chloride (Cl^-) (mgl^{-1})	56	1.5	145.0	18.0	22.80	24.02 ± 3.05
15	Sulphate (SO_4^{2-}) (mgl^{-1})	49	0.6	72.0	15.0	13.99	16.73 ± 2.00
16	Bicarbonate (HCO_3^-) (mgl^{-1})	56	3.6	312.0	74.4	70.79	93.28 ± 9.46
17	Nitrate (NO_3^-) (mgl^{-1})	33	0.6	11.0	2.0	1.93	2.64 ± 0.34
	Heavy Metals						
18	Manganese (Mn) (mgl^{-1})	14	0.01	0.60	0.04	0.15	0.08 ± 0.04
19	Lead (Pb) (mgl^{-1})	N.D	N.D.	N.D.	N.D.	N.D.	N.D.
20	Total Iron (Fe) (mgl^{-1})	51	0.005	2.50	0.10	0.54	0.28 ± 0.08

NOTE: N = Sample number; N.D. = Not detected; Max. = Maximum value;
Min. = Minimum value; St. Dev. = Standard Deviation; S.E. = Standard Error

Table 4: Descriptive Statistics of the Physico-chemical Parameters of Water Quality of Surface Water Samples from Akure, Ondo State

S/N	PARAMETER	STATISTICS					
		N	Min.	Max.	Median	St. Dev.	Mean±S.E.
	Physical						
1	Colour (^0H)	25	0.8	40.0	10.0	9.10	13.21 ± 1.82
2	Turbidity (NTU)	25	0.1	327.0	30.1	69.00	54.12 ± 13.81
	General chemical						
3	pH	25	6.5	8.0	7.0	0.40	7.00 ± 0.08

4	Conductivity (µScm^{-1})	25	40.0	890.0	100.0	172.82	154.80 ± 34.56
5	Total Dissolved Solids (TDS) (mgl^{-1})	25	30.0	620.0	70.0	120.35	108.00 ± 24.07
6	Total Alkalinity (mgl^{-1}$CaCO_3$)	25	12.0	250.0	30.0	9.35	43.52 ± 9.35
7	Total Hardness (mgl^{-1}$CaCO_3$)	25	7.2	286.6	22.7	56.53	43.47 ± 11.31
8	Non Carbonate Hardness (mgl^{-1}$CaCO_3$)	25	0.0	36.6	0.0	9.82	5.31 ± 1.96
	Major ions						
9	Calcium (Ca^{2+}) (mgl^{-1})	25	1.6	62.0	5.4	12.73	10.53 ± 2.55
10	Magnesium (Mg^{2+}) (mgl^{-1})	25	0.6	26.0	2.0	5.27	3.94 ± 1.05
11	Sodium (Na^{+}) (mgl^{-1})	25	2.0	23.0	4.0	4.21	5.12 ± 0.84
12	Potassium (K^{+}) (mgl^{-1})	25	0.3	25.0	2.0	5.39	4.13 ± 1.08
13	Chloride (Cl^{-}) (mgl^{-1})	25	2.0	75.0	5.6	17.88	12.6 ± 3.58
14	Bicarbonate (HCO_3^{-}) (mgl^{-1})	25	14.4	300.0	36.0	56.11	52.22 ± 11.22
15	Nitrate (NO_3^{-}) (mgl^{-1})	25	0.15	4.24	1.5	1.30	1.83 ± 0.26
	Heavy Metals						
16	Manganese (Mn) (mgl^{-1})	10	0.003	2.18	0.39	0.87	0.83 ± 0.27
17	Copper (Cu) (mgl^{-1})	5	0.03	0.84	0.14	0.33	0.26 ± 0.15
18	Chromium (Cr) (mgl^{-1})	5	0.03	1.16	0.62	0.43	0.54 ± 0.19
19	Cadmium (Cd) (mgl^{-1})	2	0.05	0.26	0.16	0.15	0.16 ± 0.11
20	Lead (Pb) (mgl^{-1})	7	0.41	3.41	1.39	1.17	1.63 ± 0.44
21	Total Iron (Fe) (mgl^{-1})	12	0.002	0.20	0.03	0.07	0.06 ± 0.02
22	Zinc (Zn) (mgl^{-1})	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

NOTE: N = Sample number; N.D. = Not detected; Max. = Maximum value;
Min. = Minimum value; St. Dev. = Standard Deviation; S.E. = Standard Error

Table 5: Comparison of the Values of the Current Study with Approved Standard Water Quality Guides (Groundwater Sample)

S/N	PARAMETER	CURRENT STUDY		STANDARD		HEALTH IMPACT (NIS, 2007)
		Range	Mean±S.E.	(WHO, 2004)	(NIS, 2007)	
	Physical					
1	Colour (^{0}H)	Colourless	Colourless	Colourless	15 (TCU)	None
2	Turbidity (NTU)	0.6 -12.0	2.28 ± 0.32	5.0	5.0	None
3	Total Suspended Solids (TSS) (mgl^{-1})	61.0 – 122.0	97.29 ± 8.80	No Value	No Value	None
4	Total Solids (TS) (mgl^{-1})	30.8 – 980.0	268.88 ± 26.46	1000	No Value	None
	General chemical					
5	pH	6.0 -7.1	6.55 ± 0.04	6.5 - 8.5	6.5 - 8.5	None
6	Conductivity (µScm^{-1})	42.0 – 1400.0	374.25 ± 37.11	1000	1000	None
7	Total Dissolved Solids (TDS) (mgl^{-1})	30.8 – 870.0	256.72 ± 24.22	1000	500	None
8	Total Alkalinity (mgl^{-1}$CaCO_3$)	2.0 – 260.0	77.71 ± 7.89	200	No Value	None
9	Total Hardness (mgl^{-1}$CaCO_3$)	7.5 – 329.8	105.52 ± 10.15	400	No Value	None
10	Non Carbonate Hardness (mgl^{-1}$CaCO_3$)	0.0 241.2	33.64 ± 5.68	No Value	No Value	None
	Major ions					
11	Calcium (Ca^{2+}) (mgl^{-1})	1.2 – 62.4	23.63 ± 2.33	75	No Value	None
12	Magnesium (Mg^{2+}) (mgl^{-1})	0.8 – 42.4	11.40 ± 1.21	30	0.20	Consumer acceptability
13	Sodium (Na^{+}) (mgl^{-1})	2.0 - 55.0	20.5 ± 1.81	No Value	200	None
14	Potassium (K^{+}) (mgl^{-1})	1.0 – 75.0	28.19 ± 2.46	No Value	No Value	None
15	Chloride (Cl^{-}) (mgl^{-1})	1.5 – 145.0	24.02 ± 3.05	250	250	None

16	Sulphate (SO_4^{2-}) (mgl^{-1})	0.6 – 72.0	16.73 ± 2.00	200	100	None
17	Bicarbonate (HCO_3^-) (mgl^{-1})	3.6 - 312.0	93.28 ± 9.46	No Value	No Value	None
18	Nitrate (NO_3^-) (mgl^{-1})	0.6 – 11.0	2.64 ± 0.34	50	50	Cyanosis, and asphyxia (blue-baby syndrome) in infants under 3 months
	Heavy Metals					
19	Manganese (Mn) (mgl^{-1})	0.01 – 0.60	0.08 ± 0.04	0.10	0.20	Neurological disorder
20	Total Iron (Fe) (mgl^{-1})	0.005 – 2.50	0.28 ± 0.08	0.01	0.30	None

S.E. = Standard Error; WHO = World Health Organisation; NIS = Nigerian Industrial Standard

Table 6: Comparison of the Values of the Current Study with Approved Standard Water Quality Guides (Surface Water Sample)

S/N	PARAMETER	CURRENT STUDY		STANDARD		HEALTH IMPACT (NIS, 2007)
		Range	Mean±S.E.	(WHO, 2004)	(NIS, 2007)	
	Physical					
1	Colour (^{0}H)	0.8 - 40.0	13.21 ± 1.82	3.0 TCU)	15 (TCU)	None
2	Turbidity (NTU)	0.1 - 327.0	54.12 ± 13.81	5.0	5.0	None
	General chemical					
3	pH	6.5 – 8.0	7.00 ± 0.08	6.5 - 8.5	6.5 - 8.5	None
4	Conductivity (μScm^{-1})	40 - 890	154.80 ± 34.56	1000	1000	None
5	Total Dissolved Solids (TDS) (mgl^{-1})	30 - 620	108.00 ± 24.07	500	500	None
6	Total Alkalinity ($mgl^{-1}CaCO_3$)	12.0 – 250.0	43.52 ± 9.35	100	No Value	None
7	Total Hardness ($mgl^{-1}CaCO_3$)	7.2 – 286.6	43.47 ± 11.31	100	No Value	None
8	Non Carbonate Hardness ($mgl^{-1}CaCO_3$)	0.0 – 36.6	5.31 ± 1.96	No Value	No Value	None
	Major ions					
9	Calcium (Ca^{2+}) (mgl^{-1})	1.6 – 6.2	10.53 ± 2.55	75	No Value	None
10	Magnesium (Mg^{2+}) (mgl^{-1})	0.6 – 26.0	3.94 ± 1.05	30	0.20	Consumer acceptability
11	Sodium (Na^+) (mgl^{-1})	2.0 – 23.0	5.12 ± 0.84	200	200	None
12	Potassium (K^+) (mgl^{-1})	0.3 - 25.0	4.13 ± 1.08	10	No Value	None
13	Chloride (Cl^-) (mgl^{-1})	2.0 – 75.0	12.6 ± 3.58	100	250	None
14	Bicarbonate (HCO_3^-) (mgl^{-1})	14.4 – 300.0	52.22 ± 11.22	No Value	No Value	None
15	Nitrate (NO_3^-) (mgl^{-1})	0.15 – 4.24	1.83 ± 0.26	10	50	Cyanosis, and asphyxia (blue-baby syndrome) in infants under 3 months
	Heavy Metals					
16	Manganese (Mn)	0.003 – 2.28	0.83 ± 0.27	0.05	0.20	Neurological

	(mgl^{-1})					disorder
17	Total Iron (Fe) (mgl^{-1})	0.002 – 0.20	0.06 ± 0.02	0.3	0.30	None
18	Copper (Cu) (mgl^{-1})	0.03 – 0.84	0.26 ± 0.15	1.0	1.0	Gastrointestinal disorder
19	Chromium (Cr) (mgl^{-1})	0.03 -1.16	0.54 ± 0.19	0.05	0.05	Cancer
20	Cadmium (Cd) (mgl^{-1})	0.05 – 0.26	0.16 ± 0.11	0.003	0.003	Toxic to the kidney
21	Lead (Pb) (mgl^{-1})	0.002 – 0.20	1.63 ± 0.44	0.01	0.01	Cancer, interference with Vitamin D metabolism, Affect mental development in infants, Toxic to the Central and Peripheral Nervous Systems

S.E. = Standard Error; WHO = World Health Organisation; NIS = Nigerian Industrial Standard

HCO_3^- (range = 14.4 – 300.0 mgl^{-1}; mean = 52.22 ± 11.22 mgl^{-1}); NO_3^- (range = 0.15 – 4.24 mgl^{-1}; mean = 1.83 ± 0.26 mgl^{-1}). All the major ions analyzed from most of the water sources from the study area (borehole and surface water) were within the limit of WHO and NIS standards for drinking water except Mg^{2+} in groundwater samples 33 (32 mgl^{-1}) and 46 (42.4 mgl^{-1}) (Tables 3, 4, 5 and 6).

The ranking orders of the mass concentrations ($meql^{-1}$) of the major ions analyzed were: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ for the cations in both water sources (borehole and surface water) from the study area; $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ and $HCO_3^- > Cl^- > NO_3^-$ for the anions in borehole and surface water respectively. This hierarchy is in line with that of the world's average for standard freshwaters (Hutchinson, 1957; Akinbuwa, 1999). Nwankwoala and Udom (2011) also recorded this similar trend from groundwater sources from Port Harcourt city. The HCO_3^- was the most dominant anions from all
the water samples investigated suggesting that the waters were all of the bicarbonate type

5.4 Heavy Metal Content of Groundwater and Surface Water Samples

Three metals were analysed from the groundwater samples namely: Iron (Fe), Manganese (Mn) and Lead (Pb). Pb was not detected in any of the water samples while the concentration of Mn ranged from 0.01 – 0.60 mgl^{-1} with average value of 0.08 ± 0.04 mgl^{-1} and the concentration of Fe ranged from 0.005 – 2.50 mgl^{-1} with average value of 0.28 ± 0.08 mgl^{-1}. Most of the samples had concentration of Fe higher than the limit of the WHO and NIS standard for drinking water. Mn concentrations in most of the sample were within the WHO and NIS standard for drinking water except in groundwater sample 46 (0.6 mgl^{-1}). The mean values of both metals Mn and Fe detected from all the groundwater samples comply with these standards. Based on the mean values of the metal concentrations they can be ranked as: Fe > Mn > Pb (Tables 1 and 3).

Iron (Fe), Manganese (Mn), Copper (Cu), Chromium (Cr), Cadmium (Cd), Lead (Pb) and Zinc (Zn) were analyzed from surface water samples from the study area. Zn was not detected in any of the surface water samples with Fe (range = 0.002 – 0.20 mgl^{-1}; mean = 0.06 ± 0.02 mgl^{-1}), Mn (range = 0.003 – 2.28 mgl^{-1}; mean = 0.83 ± 0.27 mgl^{-1}), Cu (range = 0.03 – 0.84 mgl^{-1} mean = 0.26 ± 0.15 mgl^{-1}), Cr (range = 0.03 -1.16 mgl^{-1} mean = 0.54 ± 0.19 mgl^{-1}), Cd (range = 0.05 – 0.26 mgl^{-1}; mean = 0.16 ± 0.11 mgl^{-1}), and Pb (range = 0.002 – 0.20 mgl^{-1}; mean = 1.63 ± 0.44 mgl^{-1}). Most of the surface water investigated had metal concentrations higher than the standards where they were detected except Cu that had concentrations within the limit of the standards in all the surface water samples investigated. Based on the mean concentrations of the metals, most of the mean values of the metal concentrations were higher than the limit of the WHO and NIS standard for drinking water except Fe (0.06 ± 0.02 mgl^{-1}) and Cu (0.26 ± 0.15 mgl^{-1}). The metals can be ranked as: Pb > Mn > Cr > Cu > Cd > Fe > Zn based on the mean concentrations of metals from the surface water samples from the study area (Tables 4 and 6).

5.5 Variation in Some Physico-chemical Parameters of Water Quality of Surface and Groundwater Water Samples

Table 7 is the results of ANOVA statistics comparing some of the investigated water quality parameters from both the borehole and surface water samples from the study area. It was observed from the results that most of the parameters investigated had higher mean values in groundwater samples than in surface water samples except that of Turbidity: groundwater (2.28 ± 0.32 NTU); surface water (54.12 ± 13.81 NTU), pH: groundwater (6.55 ± 0.04); surface water (7.00 ± 0.08) and Manganese: groundwater (0.08 ± 0.04 mgl^{-1}); surface water (0.83 ± 0.27 mgl^{-1}) with higher mean values for the surface water samples than in the groundwater samples. ANOVA statistics also revealed that all the parameters compared from both water sources (i.e. borehole and surface water) were significantly different ($p < 0.05$) except for Nitrate (NO_3^-) ($p = 0.0767$) and Total iron (Fe) ($p = 0.167$) (Table 7).

5.6 Physico-chemical Parameters of Water Quality Indicating Pollution

In this study, the parameters analyzed that are indices of pollution of the water sources investigated include: NO_3^- and the heavy metals (Fe, Mn, Cr, Cu, Cd, Zn and Pb). Their corresponding effects on human health are also indicated in (Tables 5 and 6). Obviously in samples where the concentrations of these parameters were observed to be higher than the expected values based on the standards of comparisons as highlighted above could be said to be polluted by these parameters. Most of the surface water bodies had high metal concentrations and this should be noted for further investigations on the likely sources of these elements and how to reduce/mitigate their likely effects on human health in order to enhance the portability of these water sources.

5.7 Classification of the Water bodies/Samples

Based on the Conductivity values according to the Talling and Talling (1965) scheme groundwater samples 3, 5-10, 12-18, 20-23, 25-42, 44, 48-49, 51-56 fell into the category of freshwater; Conductivity values < 600 (µScm^{-1}) while others were moderately saline (Conductivity values between 600-6000 µScm^{-1}). Only surface water sample 17 was moderately saline while other surface water samples were of freshwater type (Table 8). Based on TDS values all the water samples from both borehole and surface water samples were of freshwater type (TDS < 1000 mgl^{-1}) (Table 9). Groundwater samples: 3, 6, 7-9, 12, 14, 18, 22-23, 25-26, 28, 34-35, 38-42, 44, 48, 52-53, 56 were soft (Total Hardness <75 $mgl^{-1}CaCO_3$), groundwater samples: 1, 5, 13, 16, 20, 21, 24, 27, 29, 30, 31, 36, 49, 51, 54, 55 were moderately hard (Total Hardness between 75 – 150 $mgl^{-1}CaCO_3$), groundwater samples: 4, 10, 11, 15, 17, 19, 32, 33, 37, 43, 45, 47, 50 were hard (Total Hardness between 150 – 300 $mgl^{-1}CaCO_3$) and groundwater samples: 2, 46 were very hard (Total Hardness >300 $mgl^{-1}CaCO_3$) based on the total hardness values. Surface water sample: 17 was hard, samples: 18, 25 were moderately hard and the other surface water samples were soft based on the total hardness values (Table 10). Table 11 presents the classification of the water bodies/samples based on the predominant chemical elements/parameters that were carried out but none of the investigated water samples from both borehole and surface water samples fell within the category of the classification suggested by the scheme. Based on the fact that bicarbonate is the predominant anion from all the water sources, the water from the area can be said to be of the bicarbonate type.

5.8 Surface/Groundwater Quality Index Map

In this study, thematic maps of electrical conductivity and NO_3^- concentration levels in both surface and groundwater samples were used to generate water quality index maps. The concentration levels of Mn and Pb were overlay on the NO_3^- map to investigate possible correlation with NO_3^- and further validate possible pollution.

Figure 5 shows the surface/groundwater electrical conductivity (EC) map for the study area. The water conductivity values ranged from 6 - 1400 µScm^{-1}. In most parts (99.4%) of the metropolis, the conductivity values were less than 500 µScm^{-1} and between 500 and 999 µScm^{-1} within a small portion (around the State Hospital) of the city centre which constituted a tiny 0.6% of the study area. Water samples from two borehole sites within the small portion had conductivity values of 1200 µScm^{-1}. and 1400 µScm^{-1} respectively and may be deemed to have been polluted in view of the WHO threshold of 1000 µScm^{-1} for potable water. Based on electrical conductivity, the surface and groundwater

can be adjudged to be significantly unpolluted.

The NO_3^- concentration levels in both surface and groundwater samples ranged from 0.6-6.0 mgl^{-1} (Fig. 6). These values are generally less than the WHO threshold value of 10 mgl^{-1} and are hence indicative of potable water. The NO_3^- map however shows that the highest concentration range (2.5 – 6.0 mgl^{-1}) was recorded within

Akure city centre – the ancient Akure settlement. The concentration levels decreased away from the city centre into the recently developed and developing areas. The elevated NO_3^- concentration levels within the city centre (including Aule, Ilesha Garage, Oba Nla, Oke-Ijebu, School of Agriculture, State Hospital area, Oshinle, Ijoka) indicate some level of pollution, possibly from cumulative anthropogenetic activities.

Figures 7 and 8 contain an overlay of the concentration levels of Mn and Pb respectively on the NO_3^- map. Only few surface water samples contain Pb while Mn was identified in some surface and groundwater samples. The overlay was to check if any correlation existed between NO_3^- and the heavy metals. The Mn concentration levels did not show any correlation with the NO_3^- (Fig. 7) with Mn concentration levels relatively lower (< 0.1 mgl^{-1}) within the city centre where NO_3^- concentration levels were highest. Higher concentration levels (1.61 and 2.01 mgl^{-1}) were recorded outside the city centre and within areas with lower NO_3^- concentration levels. This could imply that the point sources of NO_3^- and Mn were different.

However some of the surface water samples within the city centre showed elevated concentration levels of Pb (2.18 - 3.41 mgl^{-1}) both within and outside the city centre (see Fig. 8) also indicating non-correlation between the sources of NO_3^- and Pb. The sources of Pb could be independent, just like Mn. The WHO permissible concentration levels for Mn and Pb in water (surface and groundwater) are 0.1 mgl^{-1} and 0.01mgl^{-1} respectively. Figures 7 and 8 show that some of the surface water samples are heavy metal polluted. The groundwater (borehole water) analyzed gave heavy metal concentration levels that are generally less than the WHO permissible levels and hence not heavy metal polluted.

6. Conclusions

The groundwaters were colourless, odourless and tasteless with the exception of samples 5, 6 and 16 which were turbid. Surface water samples 1, 18 and 24 were clear while others fall within being slightly coloured, light brown, slightly brownish, brownish, yellowish brown, highly brown, turbid and highly turbid in appearance. Surface water samples 1, 3, 5-9, 13, 15-16, 23-24 had unobjectionable odour while the rest surface water samples were observed to have objectionable odour. Surface water samples turbidity values were mostly on the high side compared with the WHO and NIS standards for drinking water ranging from 0.1 - 327.0 NTU with mean values of 54.12 ± 13.81 NTU. Only samples 1 (3.92 NTU) and 18 (0.1 NTU) were within the limit of these standards.

ANOVA statistics results comparing some of the investigated water quality parameters from borehole and surface water samples showed higher mean values in groundwater samples than in surface water samples except that of Turbidity: Groundwater (2.28 ± 0.32 NTU); surface water (54.12 ± 13.81 NTU), pH: Groundwater (6.55 ± 0.04); surface water (7.00 ± 0.08) and Manganese: Groundwater (0.08 ± 0.04 mgl^{-1}); surface water (0.83 ± 0.27 mgl^{-1}) with higher mean values for the surface water samples than in the groundwater samples. ANOVA statistics also revealed that all the parameters compared from both water sources (i.e. borehole and surface water) were significantly different ($p < 0.05$) except for Nitrate (NO_3^-) ($p = 0.0767$) and Total iron (Fe) ($p = 0.167$).

Although the NO_3^- concentration levels in both surface and groundwater samples were generally less than the WHO threshold value of 10 mgl^{-1}, relatively high concentration range (2.5-6.0 mgl^{-1}) was recorded within the city centre

Table 7: ANOVA Statistics of the Variation in Some Physico-chemical Parameters of Water Quality of Surface and Groundwater Samples from Akure, Ondo State .

S/N	PARAMETER	STATISTICS					
		GROUNDWATER		SURFACE WATER		ANOVA	
		N	Mean±S.E.	N	Mean±S.E.	F	P
	Physical						
1	Turbidity (NTU)	54	2.28 ± 0.32	25	54.12 ± 13.81	30.82	3.85×10^{-7}
	General chemical						
2	pH	56	6.55 ± 0.04	25	7.00 ± 0.08	35.13	7.69×10^{-8}
3	Conductivity (μScm^{-1})	56	374.25 ± 37.11	25	154.80 ± 34.56	13.26	5.00×10^{-4}
4	Total Dissolved Solids (TDS) (mgl^{-1})	56	256.72 ± 24.22	25	108.00 ± 24.07	14.02	3.43×10^{-4}
5	Total Alkalinity ($mgl^{-1}CaCO_3$)	56	77.71 ± 7.89	25	43.52 ± 9.35	6.54	1.24×10^{-2}
6	Total Hardness ($mgl^{-1}CaCO_3$)	56	105.52 ± 10.15	25	43.47 ± 11.31	13.33	4.67×10^{-4}
7	Non Carbonate Hardness ($mgl^{-1}CaCO_3$)	56	33.64 ± 5.68	25	5.31 ± 1.96	10.78	1.53×10^{-3}
	Major ions						
8	Calcium (Ca^{2+}) (mgl^{-1})	56	23.63 ± 2.33	25	10.53 ± 2.55	11.38	1.15×10^{-3}
9	Magnesium (Mg^{2+}) (mgl^{-1})	56	11.40 ± 1.21	25	3.94 ± 1.05	14.62	2.61×10^{-4}
10	Sodium (Na^{+}) (mgl^{-1})	54	20.5 ± 1.81	25	5.12 ± 0.84	31.64	2.87×10^{-7}
11	Potassium (K^{+}) (mgl^{-1})	54	28.19 ± 2.46	25	4.13 ± 1.08	42.20	7.36×10^{-9}
12	Chloride (Cl^{-}) (mgl^{-1})	56	24.02 ± 3.05	25	12.6 ± 3.58	4.91	2.96×10^{-2}
13	Bicarbonate (HCO_3^{-}) (mgl^{-1})	56	93.28 ± 9.46	25	52.22 ± 11.22	6.55	1.24×10^{-2}
14	Nitrate (NO_3^{-}) (mgl^{-1})	33	2.64 ± 0.34	25	1.83 ± 0.26	3.25	7.67×10^{-2}
	Heavy Metals						
15	Manganese (Mn) (mgl^{-1})	14	0.08 ± 0.04	10	0.83 ± 0.27	10.12	4.31×10^{-3}
16	Total Iron (Fe) (mgl^{-1})	51	0.28 ± 0.08	12	0.06 ± 0.02	1.96	1.67×10^{-1}

NOTE: N = Sample number; S.E. = Standard Error

Table 8: Classification of the Water Bodies/Samples Based on their Conductivity Values (Talling and Talling, 1965)

S/N	Conductivity (μScm^{-1})	Nature of Water	Groundwater	Surface-Water
1	<600	Freshwater	3, 5-10, 12-18, 20-23, 25-42, 44, 48-49, 51-56	1-16, 18-25
2	600-6000	Moderately saline	1, 2, 4, 11, 19, 24, 43, 45, 46, 47, 50	17
3	>6000	Saline	Nil	

Table 9: Classification of the Water Bodies/Samples Based on their Total Dissolved Solid (TDS) values (Okiongbo
and Douglas, 2013)

S/N	Total Dissolved Solids (TDS) (mgl^{-1})	Nature of Water	Groundwater	Surface-Water
1	<1000	Fresh water	1 – 56	1 -25
2	1000 – 10000	Brackish water	Nil	Nil
3	10000 – 100000	Saline water	Nil	Nil
4	>100000	Brine water	Nil	Nil

Table 10: Classification of the Water Bodies/Samples Based on their Total Hardness Values (Okiongbo and Douglas, 2013)

S/N	Total Hardness (mgl^{-1}CaCO$_3$)	Nature of Water	Groundwater	Surface-Water
1	<75	Soft	3, 6, 7-9, 12, 14, 18, 22-23, 25-26, 28, 34-35, 38-42, 44, 48, 52-53, 56	1 – 16, 19-24
2	75 – 150	Moderately Hard	1, 5, 13, 16, 20, 21, 24, 27, 29, 30, 31, 36, 49, 51, 54, 55	18, 25
3	150 – 300	Hard	4, 10, 11, 15, 17, 19, 32, 33, 37, 43, 45, 47, 50	17
4	> 300	Very Hard	2, 46	Nil

Table 11: Classification of the Water Bodies/Samples Based on Predominant Chemical Elements/Parameters (Petraccia *et al.*, 2006)

S/N	Parameter	Nature of Water	Groundwater	Surface-Water
1	Calcium (Ca^{2+}) >150 (mgl^{-1})	Calcium water	Nil	Nil
2	Magnesium (Mg^{2+}) >50 (mgl^{-1})	Magnesium water	Nil	Nil
3	Sodium (Na^{+}) >200 (mgl^{-1})	Sodium water	Nil	Nil
4	Bicarbonate (HCO_3^-) >600 (mgl^{-1})	Bicarbonate water	Nil	Nil
5	Sulphate (SO_4^{2-}) >200 (mgl^{-1})	Sulphate water	Nil	Nil
6	Chloride (Cl^-) >200 (mgl^{-1})	Chlorinated water	Nil	Nil
7	Bivalent iron (Fe^{2+}) >1 (mgl^{-1})	Ferrous water	Nil	Nil

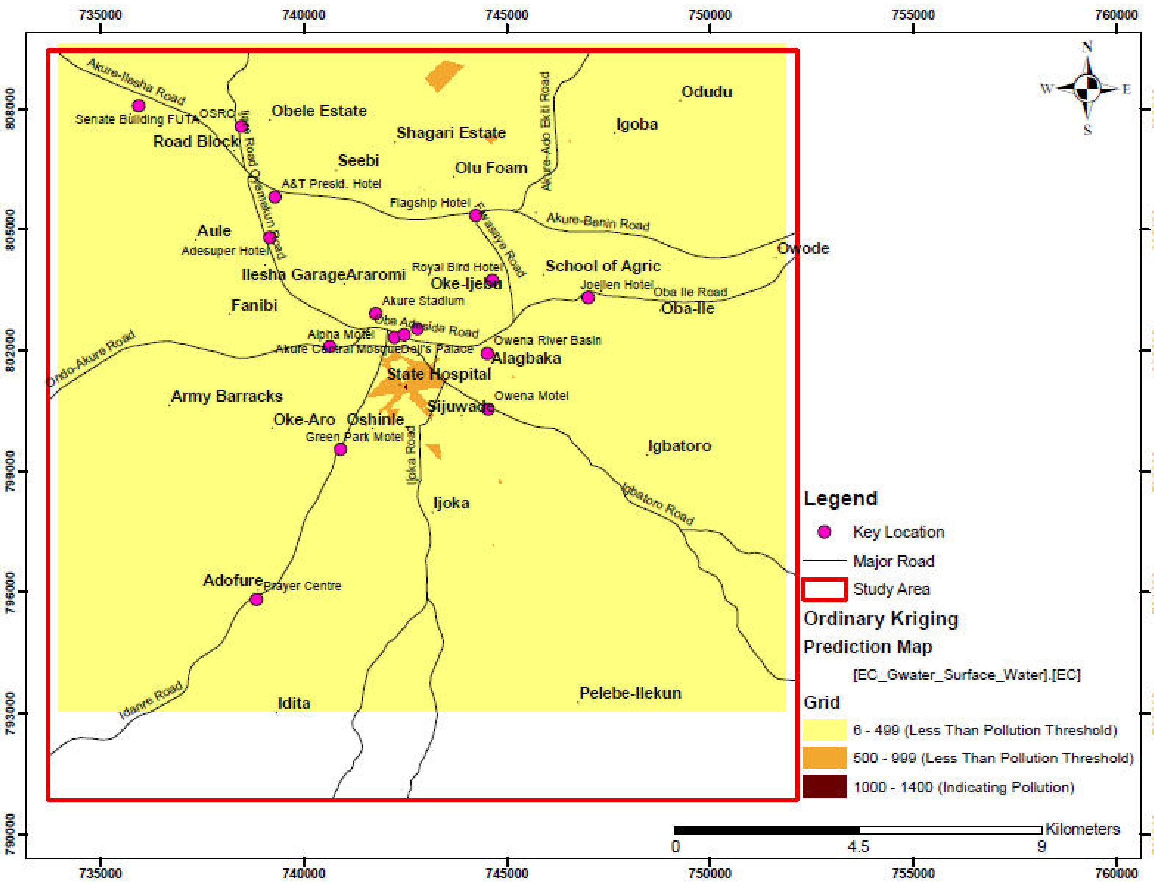

Fig. 5: Surface/Groundwater Pollution Index Map – Variation in Electrical Conductivity

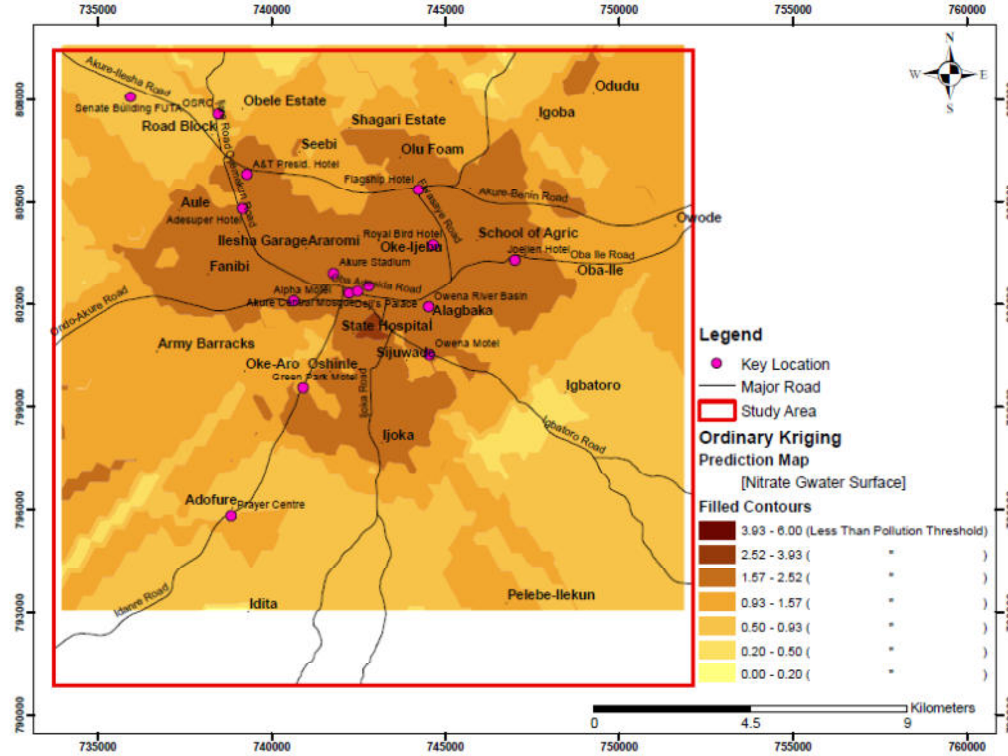

Fig. 6: Surface/Groundwater Pollution Index Map – Variations in Nitrate Concentration Levels

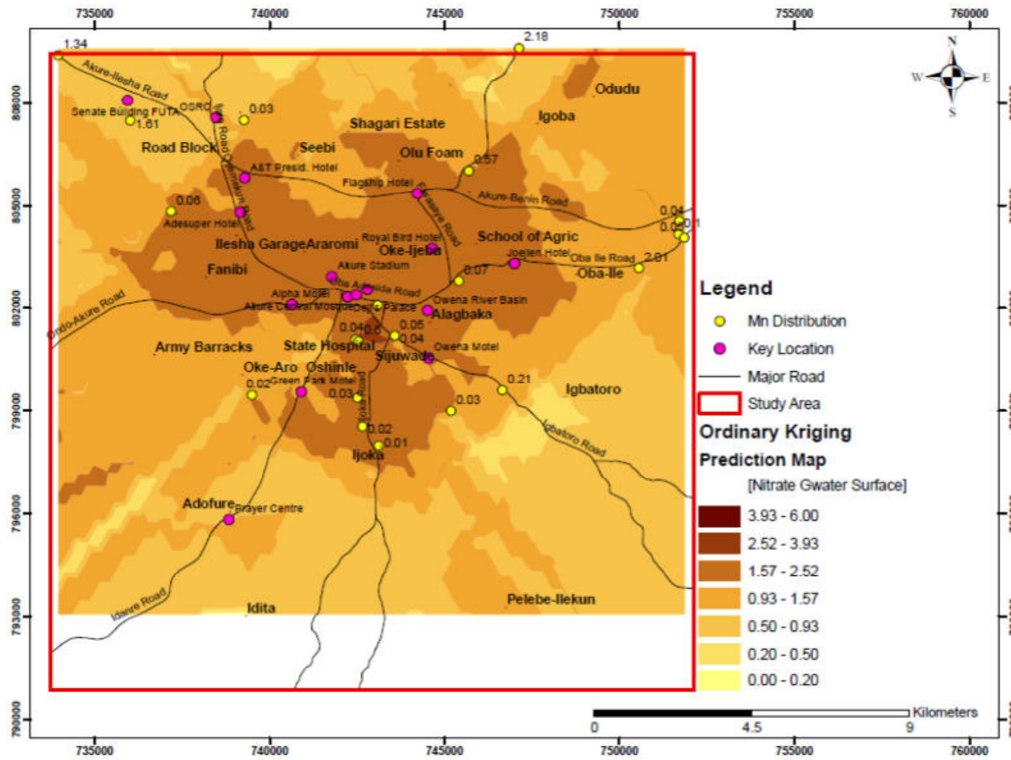

Fig. 7: Surface/Groundwater Pollution Index Map – Variations in Nitrate Concentration Levels with Mn Distribution

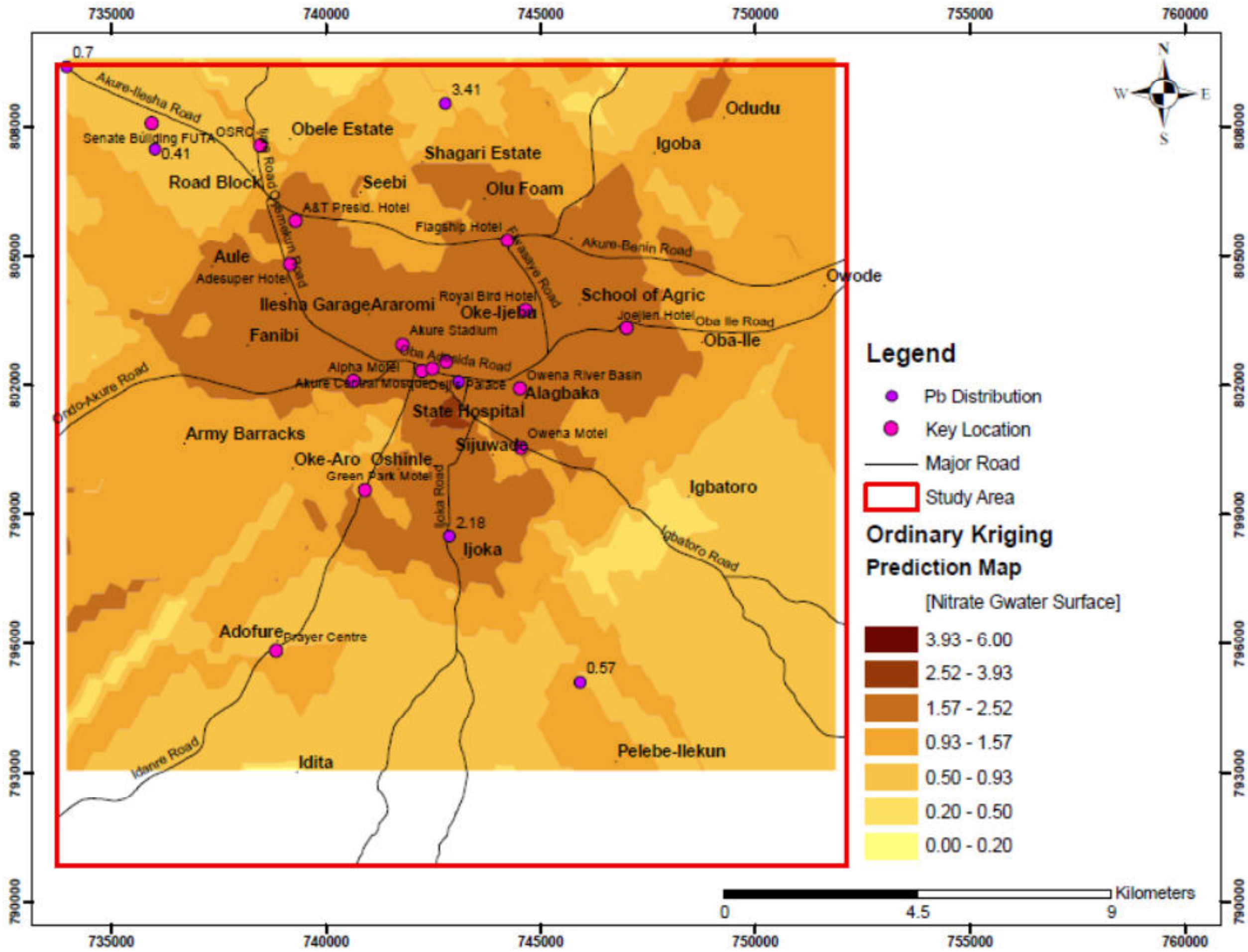

Fig. 8: Surface/Groundwater Pollution Index Map – Variations in Nitrate Concentration Levels with Pb Distribution

indicating some level of pollution from cumulative anthropogenetic activities. Only few surface water samples contain Pb while Mn was identified in some surface and groundwater samples. The elevated Pb concentration levels (0.41-3.41 mgl^{-1}) and relatively high Mn concentration levels (up to 2.18 mgl^{-1}) (both higher higher than the WHO and NIS thresholds) in some surface water samples was an indication of heavy metal pollution.

Conductivity values of the well water samples generally ranged from 42.0 – 1400.0 µScm^{-1}. Only surface water sample 17 was moderately saline while other surface water samples were of freshwater type. Based on TDS values, all the groundwater and surface water samples were of freshwater type (TDS < 1000 mgl^{-1}). The Total Hardness of values for both groundwater and surface water were well within the WHO threshold for potable water except surface water sample 17. Based on the fact that bicarbonate is the predominant anion from all the water sources. It can be concluded that the water from the area can be said to be the bicarbonate type.

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