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INVESTIGATION OF SEASONAL VARIATION OF GROUNDWATER QUALITY IN JIMETA-YOLA AREA NORTHEASTERN NIGERIA

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ABSTRACT

Seasonal variation of groundwater quality in Jimeta-Yola area was investigated using selected chemical contaminants. The results indicated that pollutant loading occurred in the dry and rainy seasons. The groundwater is fresh and varied from slightly acidic to alkaline in both the dry and rainy seasons. The mean values of BOD, COD and chloride exceeded the recommended standards of drinking water quality in the rainy season from the shallow and deep aquifers (hand-dug wells and boreholes). Nitrate and ammonium ion mean values in both seasons in shallow and deep aquifers exceeded the recommended limit of WHO. The mean coliform number counts exceeded the WHO recommended limit in both seasons in shallow and deep aquifers. The spatial distribution of EC and TDS reveal that the leachates from the dumpsites are significant source of groundwater contamination. The variation in contaminant distribution is influenced by depth to water and well depth. There were increase in COD, BOD, nitrate, phosphate and chloride, and decrease in ammonium ion and coliform with water depth in shallow aquifer in the dry season, and COD, nitrate, ammonium ion, phosphate and chloride increase with water depth, and decrease in BOD and coliform in the rainy season. COD, ammonium ion and chloride increase with well depth, and decrease in COD, BOD, nitrate, phosphate and coliform in deep aquifer in the dry season while COD, BOD, nitrate, ammonium ion, phosphate and chloride decrease in the rainy season. Coliform showed no depth control during the same period. In the dry season in leachate samples, contaminants revealed perfect correlation and nearly perfect correlation in the rainy season. The contaminants in all the aquifers revealed strong positive correlations in both seasons which are an indication of common source. Factor analysis indicates that groundwater chemistry is controlled by anthropogenic activities, salinity, ammonification and natural mineralization. It is recommended that safe waste disposal practice should be encouraged and drilling of boreholes to deeper levels is also suggested.

KEY WORDS: Groundwater quality, Dumpsites, Contaminants, Aquifers,

INTRODUCTION

A study on the seasonal variation in groundwater quality is important in understanding the period of the year when pollution is occurring in groundwater system. Water quality policy can be adopted to ensure sustainable good water supply all year round. Seasonality in physical, chemical or biological characters in groundwater is suggested previously by Zheng and Kelogg (1994); Kelly 919997); Kurosawa (1997). As groundwater has a huge potential to ensure future demand for water, it is important that human activities on the surface do not negatively affect the precious resource (Sarukkalige, 2009). Poor environmental management creates havoc on the water supply, hygiene and exacerbating public health (Okoro et al., 2009). Tay and Kortatsi (2008) emphasize on the importance of groundwater globally important as a source for human consumption and changes in quality with subsequent contamination can, undoubtedly, affect human health. Groundwater quality is mainly controlled by the range and type of human influence as well as geochemical, physical and biological process occurring in the groundwater (Zaporozec, 1981; Carter et al., 1987). Although natural processes may attenuate the concentration of contaminants in groundwater, some contaminants however, persist after entering the subsurface. Longer periods are often required for contaminants to be removed from the contaminated aquifers. Such groundwater contamination may result from domestic, industrial and agricultural activities. Rapid urbanization, especially in developing country like Nigeria, has affected the availability of groundwater due to its exploitation and improper waste disposal practice, especially in urban areas. It is therefore important to regularly monitor the quality of groundwater and to device means to protect it. Significant variations in physic-chemical parameters affect the quality of groundwater. This study is aimed at examining the suitability of groundwater for human consumption, to define period of pollutant loading, identify sources of groundwater pollution, process controlling groundwater chemistry and suggest remediation measures. The study area, Jimeta- Yola; is located within latitudes $9^{o}11'$N to $9^{o}20'$N and longitudes $12^{o}23'$E to $12^{o}33'$E and covers an area of about 305Km2 (Fig. 1). The area has a mean annual rainfall of 918.9mm, and means monthly temperature of 190C and maximum temperature of 37.9^{o}C. The mean monthly temperature is 28.5^{o}C (Ishaku, 2007). The area is characterized by broadly flat topography with gentle undulations and hill ranges (Ishaku, 1995), and is largely drained by the Benue River.

The population of the area is about 325,925(National Population Commission 2005). The major occupation of the people is agriculture and small-scale industries such as Bajabure Nima Foam, polyplastic industry and Adama Beverages occur in the area. Small-scale metallurgical works, numerous water sachet activities and traditional textile factories occur in

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the area. Water supply to the people is from surface water through water treatment plants and groundwater is obtained through boreholes and hand-dug wells. The waste disposal practiced in the area is through open dump for solid wastes, pit latrines, and septic tank for human wastes (Yenike et al., 2003). House hold solid wastes are largely dumped along the flood plains of the Benue River which borders the Yola-Mubi Bye-pass. Other refuse dumps are located in the densely populated areas of the metropolis and close to water sources especially in Luggere area and behind LCCN Church along Ilorin/Bauchi Street. There is also water sources located in Mechanics Work shop and at the edge of the major drainage that empties waste water to the Benue River. The growth in population has affected the land use pattern, which has subsequently affected the quality of the water resource (Adekeye and Ishaku, 2004). The type of waste disposal practiced in the area may have environmental implications in terms of the groundwater quality degradation thus, affecting suitability of the groundwater as a source for human consumption. Consequently, reported cases of waterborne diseases have been on increase in the area.

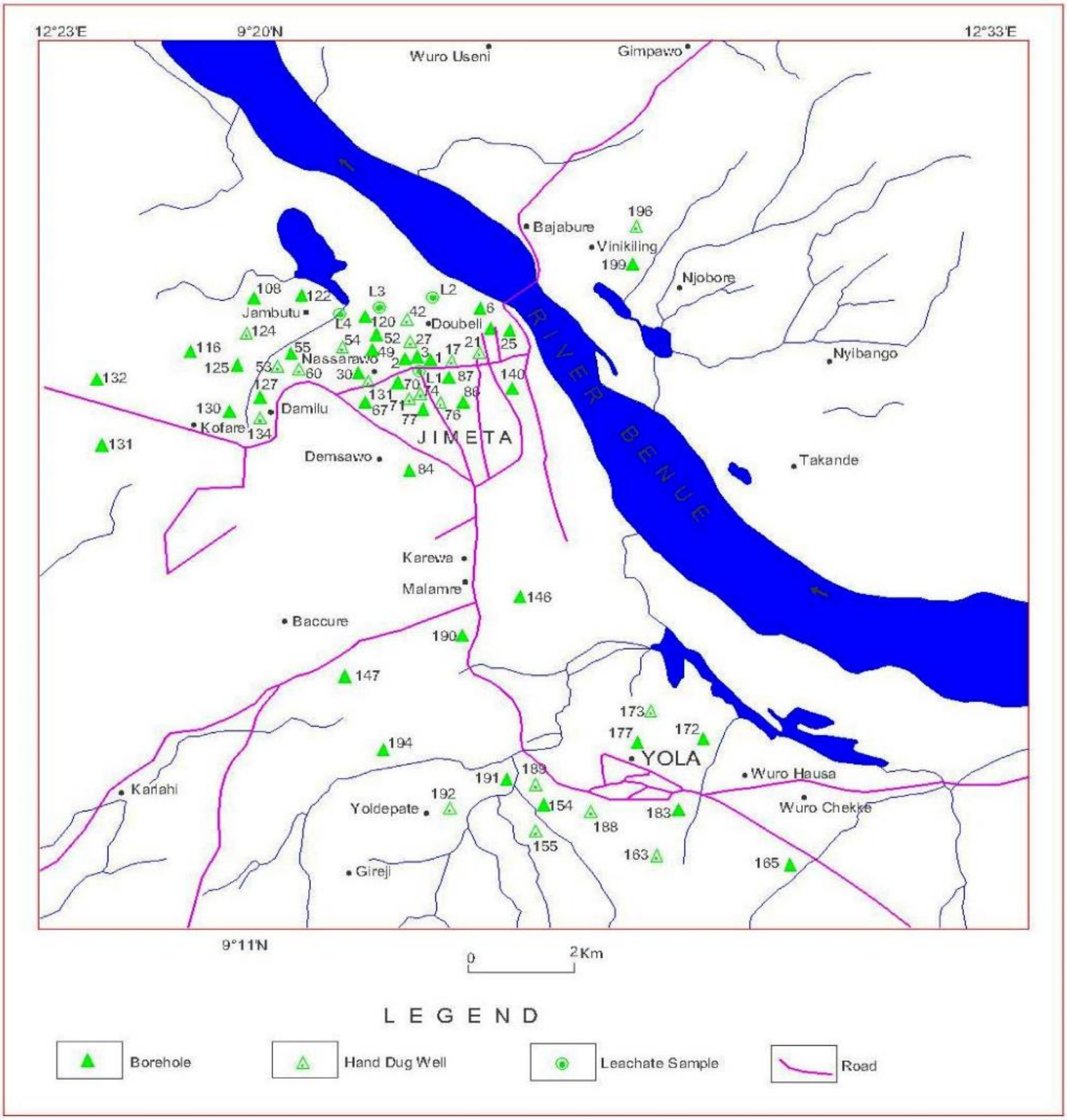

Fig. 1 Map showing access routes and sampling points

(Modified from Ishaku, 2007)

GEOLOGICAL SETTING OF THE AREA

The study area is underlain by the Bima sandstone in the northeast, southeast and southwestern parts of the study area, while the River alluvium covers the northwestern and southern parts of the study area (Fig. 2). The Bima sandstone is found at the base of the sedimentary succession and uncomformably overlies the basement Complex (Offodile, 1989). Lithologically, the Bima sandstone consists of feldsparthic sandstone, grits, pebble bed, clays and shale (Offodile, 1992, 2002; Eduvie, 2000; Ishaku and Ezeigbo, 2000; Yenika et al., 2003).

Based on the analysis of borehole lithologic sections (Fig. 3), two aquifer systems were delineated into unconfined and semi-confined aquifer types. The unconfined aquifer ranges from 7 m to 80 m in saturated thickness with an average of 43.5 m. The semi-confined aquifer has thickness of 4 m and 73 m with an average of 38.6 m (Ishaku and Ezeigbo, 2008). The depths to water between the dry and rainy seasons in the area range from 0.82 m to 12.38 m in the hand-dug wells in the dry season and from 0.05 m to 11.85 m in the rainy season. In boreholes, depths to water range from 3.0m to 40.5 m in the dry season and from 2.7 m to 30.1 m (Ishaku, 2007). Generally, the depths to water increase away from Alluvium aquifers towards the Bima sandstone aquifers. Figs. 4 and 5 show the hydraulic head distribution in the study area. The hydraulic head distribution showed no variation in the direction of groundwater flow between the dry season and rainy season. Regional groundwater flow occurs from the recharge area in the east around Dougirei and 80 housing units, and flows toward the southeast, southwest and northwest, respectively. Another zone occurs around the Federal University of Technology Quarters south of Yola town, and flows toward Wuro Chekke and Gireiji areas. The discharge areas cover Yolde pate and Masakare areas, and some parts of Yola town in the east, and Luggere and Doubeli areas in Jimeta metropolis.

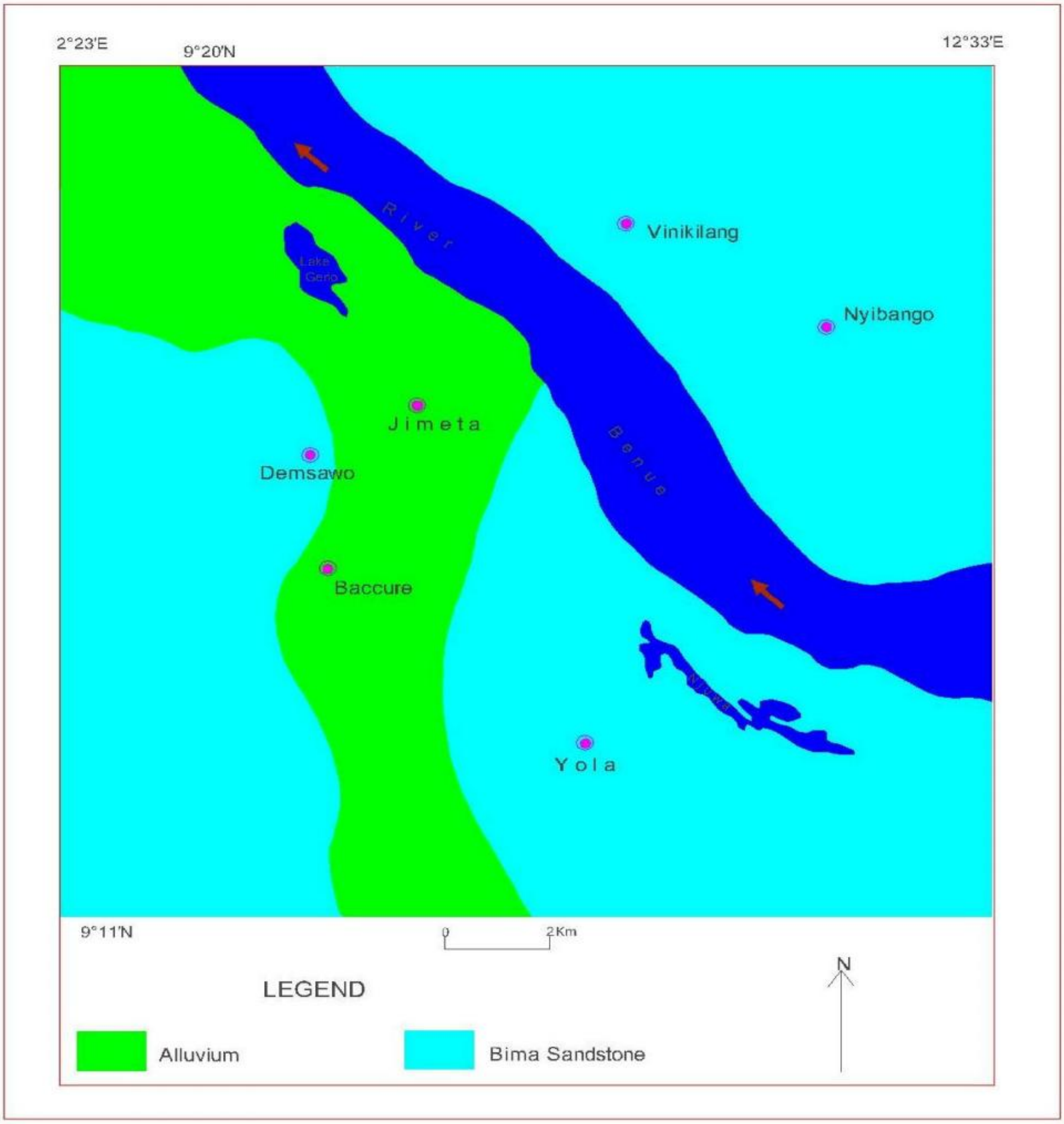

Fig. 2 Geological map of the study area (Nigerian Geological Agency, 2006)

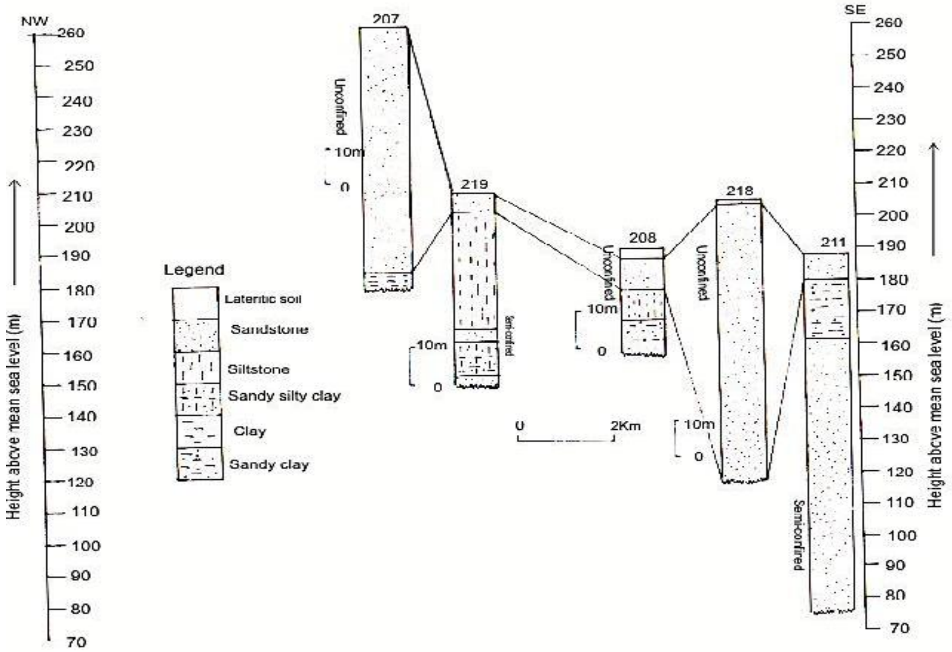

Fig. 3 Borehole lithologic section along NW- SE in the study area

(Ishaku and Ezeigbo, 2008)

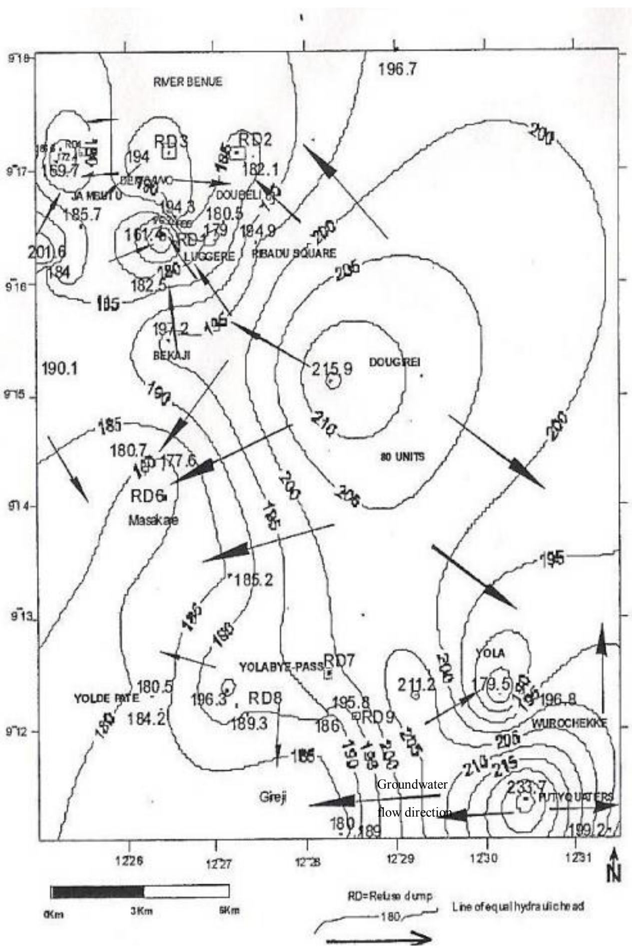

Fig. 4 HYDRAULIC HEAD DISTRIBUTION IN THE WET SEASON THE STUDY AREA

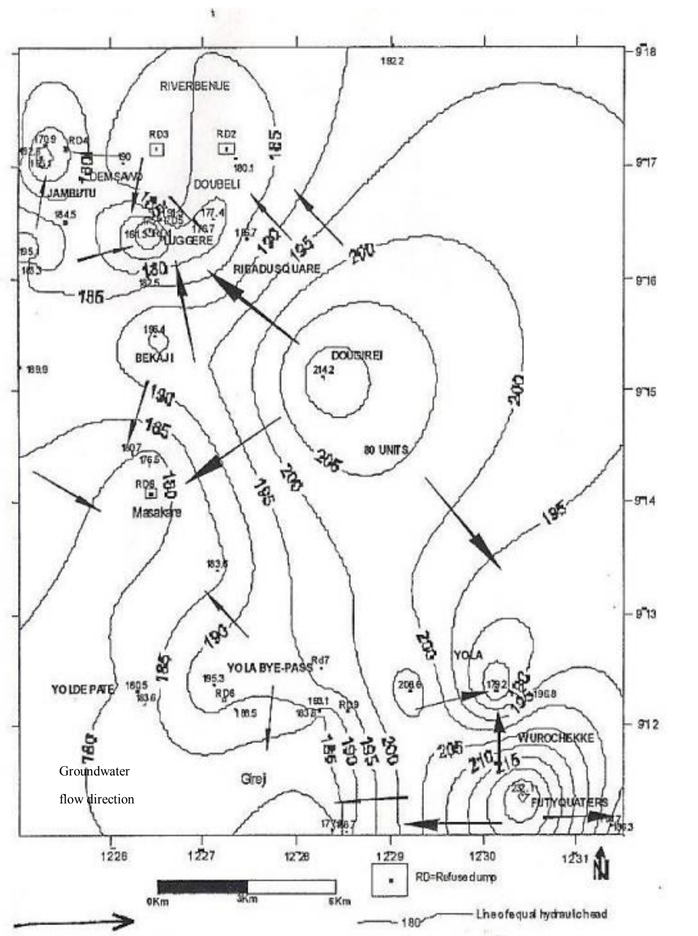

Fig. 5 HYDRAULIC HEAD DISTRIBUTION IN THE DRY SEASON IN THE STUDY IN AREA

MATERIALS AND METHODS

Water samples were collected from the hand-dug wells, boreholes, and leachates beneath refuse dumps in the dry and rainy season periods in the study area. The results were used for the assessment of water quality and to evaluate seasonal variations. Before the collection, the sample containers were rinsed two to three times in the field using the representative groundwater samples according to Rajkumar et al (2010). Water samples were collected from the discharge of existing hand-dug wells and boreholes according to Chilton (1992) method. Locations of the monitoring wells were determined using the Global Positioning System (GPS). The field parameters such as pH, EC and TDS were determined in the field using the potable pH meter HANNA pH meter (Model HI 28129) and TDS/conductivity meter (HACH KIT) (Model 44600-00). The sampling points were strategically located to quantify the impacts of the dumpsites on the water sources close to the dumpsites. Sampling from boreholes located along the drainage networks was also carried out to define the impacts of waste water on groundwater quality degradation. Other samples were collected from densely populated areas where most residents use pit latrines in order to understand the contribution of sewage on groundwater quality. Water samples were also collected in areas where waste disposal is organized to serve as base line water quality. Based on the locations of the sampling points, the type of sampling technique is random sampling. The water samples were analyzed chemically and bacteriologically using spectrophotometer (Model 2010, USA), titrimetric and membrane filtration methods. The chemical parameters analyzed using spectrophotometer were nitrate which was analyzed using cadmium reduction method at wavelength of 500 nm, ammonium ion by Nessler method at wavelength of 425 nm and phosphate by ascorbic acid method at wavelength of 890 nm. Chloride was analyzed using mercuric nitrate employing the use of digital titrator (HACH KIT) (Model 16900). Dissolved oxygen was determined using Winkler titration method (USEPA, 1974; Sexana, 1990). The biochemical oxygen demand (BOD_5) was determined based on Malcolm method (In: Chemical and biological methods of water analysis for aquaculturalist, 1995) while the chemical oxygen demand (COD) was determined according to the standard procedures of APHA (1980). The samples for bacteriological analysis were carried out within 24 hours of collection using the membrane filtration method employing the use of membrane assemblage (Vacuum pump, Asbestos pad, Bukner flask and membrane funnel) and Leica Quebec Dark field colony counter. The bacteriological analysis was carried out according to WHO (1985) method.

RESULTS and DISCUSSION

Results

The results of the physical, chemical and bacteriological parameters are presented in Tables 1, 2, 3 and 4 for the dry and rainy seasons in hand-dug wells and boreholes while Tables 5 and 6 contain the summary of the physical, chemical and bacteriological parameters in both seasons.

Table1 Groundwater quality data from the hand-dug wells in the dry season in the study area

Proj. No(Hw)	pH	EC µS/cm	TDS (mg/l)	DO (mg/l)	COD (mg/l)	BOD (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	PO_4^- (mg/l)	Cl^- (mg/l)	Coliform No/100ml	Depth (m)
73	7.7	2140	2140	23.5	3.4	5.1	75.3	1.0	0.8	248.7	6	4.6
74	7.7	2050	2050	26.5	6.5	6.5	90.3	1.3	2.4	530	Nil	3.8
71	7.6	610	300	20.4	4.5	2.3	69.1	0.5	0.9	67.4	6	2.3
17	7.1	1060	530	21.0	9.7	2.9	30.1	1.3	2.8	102.8	Nil	7.3
27	7.6	1760	880	23.4	3.5	6.9	149.7	0.1	2.2	244.6	15	1.1
42	7.8	1640	820	20.8	4.5	5.5	71.3	2.3	4.4	680	Nil	1.4
45	7.5	1490	750	18.1	3.0	6.8	94.3	0.9	0.4	1490	15	2.4
54	7.3	1050	1050	20.4	7.8	3.2	46.5	0.3	2.2	120.5	10	4.8
59	7.4	620	310	18.6	1.3	6.6	25.7	0.3	1.5	46.1	4	2.2
124	7.7	3500	1760	23.4	9.3	13.0	105.4	0.5	3.3	4355	40	7.7
116	8.2	1060	530	105.6	4.5	42.3	98.3	1.1	3.2	750	Nil	7.9
196	7.1	1100	550	20.4	7.5	13.6	34.1	0.5	1.8	705	17	8.0
192	7.1	500	250	21.7	8.0	17.2	57.6	0.3	0.5	325	30	3.1
155	7.5	440	220	17.8	3.3	14.1	18.2	0.5	0.6	180	25	2.0
176	6.5	1300	650	17.8	6.0	7.7	224.1	0.4	1.0	1265	35	5.1
184	5.4	780	390	13.8	6.7	11.0	163.0	0.3	2.3	585	Nil	10.4
163	7.6	1060	540	21.1	0.9	ND	44.7	0.3	1.4	870	ND	4.9
160	7.1	290	150	25.6	7.3	20.5	39.4	0.4	0.4	145	30	4.4
188	7.5	1340	670	13.8	6.9	11.0	93.0	0.5	0.8	1300	Nil	2.6
189	7.1	1010	510	11.8	7.3	9.4	88.6	0.4	4.3	840	10	9.6
173	6.5	1300	470	18.1	3.3	11.2	136.4	0.5	3.6	882.5	20	4.8
134	8.3	350	180	18.0	3.5	5.1	36.3	0.8	0.9	53.2	7	8.6
L1	6.4	1380	1380	20.3	9.5	8.2	16.3	19.2	2.6	590	25	1.6
L2	8.2	1640	820	28.8	0.4	20.4	21.7	Bdl	3.0	ND	95	0.5
L3	7.8	9260	4650	23.5	0.4	13.0	343.7	8.7	4.2	11300	20	0.8
L4	8.2	2490	1250	18.4	8.3	12.8	69.5	0.3	6.3	577.9	105	1.2

Bdl=Below detection limit, ND=Not detected, Hw=Hand-dug well

Table2 Groundwater quality data from the hand-dug wells in the rainy season in the study area

Proj. No(Hw)	pH	EC µS/cm	TDS (mg/l)	DO (mg/l)	COD (mg/l)	BOD (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	PO_4^- (mg/l)	Cl^- (mg/l)	Coliform No/100ml	Depth (m)
73	7.7	2140	2140	23.5	3.4	5.1	75.3	1.0	0.8	248.7	6	4.6
74	7.7	2050	2050	26.5	6.5	6.5	90.3	1.3	2.4	530	Nil	3.8
71	7.6	610	300	20.4	4.5	2.3	69.1	0.5	0.9	67.4	6	2.3
17	7.1	1060	530	21.0	9.7	2.9	30.1	1.3	2.8	102.8	Nil	7.3
27	7.6	1760	880	23.4	3.5	6.9	149.7	0.1	2.2	244.6	15	1.1
42	7.8	1640	820	20.8	4.5	5.5	71.3	2.3	4.4	680	Nil	1.4
45	7.5	1490	750	18.1	3.0	6.8	94.3	0.9	0.4	1490	15	2.4
54	7.3	1050	1050	20.4	7.8	3.2	46.5	0.3	2.2	120.5	10	4.8
59	7.4	620	310	18.6	1.3	6.6	25.7	0.3	1.5	46.1	4	2.2
124	7.7	3500	1760	23.4	9.3	13.0	105.4	0.5	3.3	4355	40	7.7
116	8.2	1060	530	105.6	4.5	42.3	98.3	1.1	3.2	750	Nil	7.9
196	7.1	1100	550	20.4	7.5	13.6	34.1	0.5	1.8	705	17	8.0
192	7.1	500	250	21.7	8.0	17.2	57.6	0.3	0.5	325	30	3.1
155	7.5	440	220	17.8	3.3	14.1	18.2	0.5	0.6	180	25	2.0
176	6.5	1300	650	17.8	6.0	7.7	224.1	0.4	1.0	1265	35	5.1
184	5.4	780	390	13.8	6.7	11.0	163.0	0.3	2.3	585	Nil	10.4
163	7.6	1060	540	21.1	0.9	ND	44.7	0.3	1.4	870	ND	4.9
160	7.1	290	150	25.6	7.3	20.5	39.4	0.4	0.4	145	30	4.4
188	7.5	1340	670	13.8	6.9	11.0	93.0	0.5	0.8	1300	Nil	2.6
189	7.1	1010	510	11.8	7.3	9.4	88.6	0.4	4.3	840	10	9.6
173	6.5	1300	470	18.1	3.3	11.2	136.4	0.5	3.6	882.5	20	4.8
134	8.3	350	180	18.0	3.5	5.1	36.3	0.8	0.9	53.2	7	8.6
L1	6.4	1380	1380	20.3	9.5	8.2	16.3	19.2	2.6	590	25	1.6
L2	8.2	1640	820	28.8	0.4	20.4	21.7	Bdl	3.0	ND	95	0.5
L3	7.8	9260	4650	23.5	0.4	13.0	343.7	8.7	4.2	11300	20	0.8
L4	8.2	2490	1250	18.4	8.3	12.8	69.5	0.3	6.3	577.9	105	1.2

Bdl=Below detection limit, ND=Not detected, Hw=Hand-dug well

Table3 Groundwater quality data from boreholes in the dry season in the study area

Proj. No(BH)	PH	EC µS/cm	TDS (mg/l)	DO (mg/l)	COD (mg/l)	BOD (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	PO_4^- (mg/l)	Cl^- (mg/l)	Coliform No/100ml	Depth (m)
1	6.4	290	150	21.6	0.6	0.2	43.0	0.5	0.3	240	15	54
2	7.3	160	160	19.0	0.5	1.0	26.1	0.4	Bdl	10	Nil	60
87	8.0	380	190	18.0	0.8	0.3	24.4	Bdl	0.01	Bdl	Nil	170
76	6.2	480	240	22.0	2.2	2.8	57.1	ND	ND	ND	ND	40
77	6.5	1230	610	23.4	2.5	5.2	92.1	0.5	0.2	84.8	20	41
86	7.3	380	190	15.2	0.6	1.4	23.9	0.3	2.5	5.2	5	60
3	6.4	1700	80	23.6	2.5	3.6	27.0	0.3	0.2	2.4	5	40
6	7.9	1790	900	18.4	0.3	1.2	101.9	0.4	0.4	129.2	Nil	15
8	6.9	350	180	18.4	3.8	1.2	56.7	0.3	Bdl	23.8	35	42
25	6.7	190	100	20.0	1.1	2.1	62.0	0.4	Bdl	6.0	3	40
49	6.6	420	210	18.0	4.7	0.8	44.3	0.7	2.2	380	Nil	148
52	6.5	100	50	21.8	0.6	2.4	34.1	0.3	Bdl	6.4	65	36
50	6.5	180	90	24.4	1.4	3.2	68.6	0.4	Bdl	4.0	Nil	54
67	6.8	110	50	17.6	Bdl	1.0	18.2	0.4	0.5	4.0	6	45
120	6.8	180	90	19.6	0.3	0.6	22.1	0.4	0.01	8.8	Nil	26
55	6.9	210	110	20.2	4.4	0.6	34.1	0.3	0.1	8.4	10	42
108	6.7	80	40	19.0	1.4	1.2	20.4	0.3	0.02	4.4	3	40
130	6.9	90	90	22.4	0.6	1.4	27.9	0.4	0.3	2.8	20	-
131	6.6	80	40	20.8	1.1	0.2	31.0	0.6	1.8	4.0	30	27
199	6.6	600	300	23.4	4.5	4.2	23.0	0.4	0.1	2.0	3	20
132	6.8	90	50	23.8	0.6	Bdl	44.3	0.4	0.7	60	40	48
140	6.3	150	80	25.2	0.6	2.4	29.2	0.5	6.2	2.8	44	45
84	6.4	90	40	20.6	0.6	0.2	26.6	0.4	0.2	80	ND	94
190	7.7	290	140	27.0	0.3	2.1	12.4	0.6	0.1	130	51	52
147	7.3	410	210	18.3	0.3	1.0	26.1	0.4	0.3	90	15	217
191	6.2	160	80	19.8	3.0	0.6	47.8	0.3	0.1	115	10	48
154	7.0	420	210	19.6	4.0	1.2	46.5	0.5	1.1	120	ND	40
194	6.0	240	120	24.6	2.3	5.8	77.1	0.4	0.1	260	8	35
183	6.2	340	170	19.8	3.4	0.6	44.7	0.4	2.3	16.4	Nil	42
177	6.0	650	650	23.4	4.4	4.4	85.5	0.3	5.4	42.4	Nil	40

172	6.1	200	100	25.6	0.3	7.0	75.3	0.5	0.5	220	Nil	27
178	6.4	710	360	24.6	1.7	4.5	102	0.5	1.1	665	ND	27
165	7.0	530	270	22.6	2.2	3.2	41.2	0.5	0.5	130	14	212
70	ND	ND	ND	Bdl	Bdl	Bdl	43.4	0.3	2.6	Bdl	9	42
125	7.7	540	270	18.6	1.2	1.4	58.0	0.5	0.6	28.4	3	8
146	7.0	260	130	18.0	Bdl	0.4	26.6	0.4	2.5	150	10	40

Bdl=Below detection limit, ND=Not detected, BH=Borehole

Table4 Groundwater quality data from boreholes in the rainy season in the study area

Proj. No(BH)	PH	EC µS/cm	TDS (mg/l)	DO (mg/l)	COD (mg/l)	BOD (mg/l)	NO_3^- (mg/l)	NH_4^+ (mg/l)	PO_4^- (mg/l)	Cl^- (mg/l)	Coliform No/100ml	Depth (m)
1	6.2	270	140	18.6	7.9	5.2	21.7	0.3	1.2	35.5	15	54
2	6.8	220	110	17.8	10.7	4.1	54.0	0.01	0.4	24.8	Nil	60
87	8.0	390	200	20.0	2.0	2.7	12.4	0.14	0.4	17.7	25	170
77	6.4	1510	760	22.4	3.1	6.3	49.6	0.5	1.4	198.6	Nil	41
86	7.8	390	200	18.7	5.7	1.9	28.3	0.6	0.4	35.5	Nil	60
3	6.1	250	130	17.7	7.6	5.6	17.3	0.3	1.0	14.2	Nil	40
6	7.5	1740	880	20.8	9.7	8.7	86.8	0.31	1.1	5375	28	15
8	6.4	420	230	18.6	7.3	6.9	55.8	1.2	0.4	335	Nil	42
25	6.4	240	120	17.6	0.7	6.9	40.3	0.9	1.0	150	20	40
49	6.1	360	180	16.8	0.7	3.9	51.4	0.4	0.6	56.7	Nil	148
52	5.9	100	50	15.5	5.3	6.2	22.1	0.7	0.7	21.3	Nil	36
50	6.0	160	80	17.7	6.0	4.9	24.8	0.4	0.7	24.8	Nil	54
67	6.2	130	70	16.8	4.2	0.7	26.6	0.1	1.1	14.2	Nil	45
120	6.7	160	80	15.9	3.5	4.6	12.4	0.2	0.9	7.1	Nil	26
55	6.6	300	150	17.8	8.7	4.9	44.3	0.02	1.1	24.8	Nil	42
108	6.0	100	50	18.8	4.0	6.8	24.4	0.6	0.5	45	Nil	40
130	7.6	80	80	16.4	6.9	4.3	26.1	1.0	0.4	25	20	-
131	6.7	90	50	15.6	3.7	4.5	15.5	0.9	0.6	25	Nil	27
199	6.8	380	380	18.1	8.0	6.8	43.0	0.3	1.5	35.5	32	20
132	7.5	170	90	16.0	3.4	3.5	27.9	0.6	1.8	14.2	Nil	48
140	6.6	220	110	18.4	6.7	3.7	4.9	0.1	1.1	14.2	1	45
190	7.9	300	150	18.0	3.4	5.1	36.3	0.2	1.8	17.8	Nil	52
147	7.2	500	250	16.9	3.7	0.8	41.6	0.5	1.0	14.2	Nil	217
191	5.7	150	80	17.7	Bdl	14.1	49.2	0.4	0.4	85	Nil	48
194	6.4	310	150	17.7	8.7	14.1	51.4	0.5	0.7	150	38	35
183	6.1	350	170	18.4	8.7	2.3	53.1	0.4	0.5	192.5	40	42
177	5.5	680	340	17.8	9.3	6.1	191.3	0.4	0.4	460	20	40
172	6.8	820	410	16.9	8.7	5.6	109.4	0.3	1.0	670	50	27
178	6.6	1130	560	17.2	8.7	4.3	104.1	0.4	0.6	980	Nil	27
165	7.7	530	270	17.2	7.3	13.6	27.0	0.7	0.5	100	30	212
70	ND	500	250	7.6	2.7	1.5	82.4	0.1	2.1	63.8	Nil	42
125	7.0	570	290	20.4	4.7	8.3	43.8	1.2	0.8	1137.5	35	8
146	6.6	300	150	17.8	5.1	3.7	13.3	1.3	1.3	14.2	2	40

Bdl=Below detection limit, ND=Not detected, BH=Borehole

Table 5 Summary of physico-chemical and biological characteristics of the groundwater in the dry season in the study area

	Hand-dug well			**Borehole**		
Parameters	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
pH	5.9	8.5	7.4	6	8	6.8
EC (áS/cm)	60	4310	1221.4	80	1790	402.4
TDS(mg/1)	30	2160	579.1	40	900	192.4
DO(mg/1)	18.6	52.6	25.9	15.2	27	21.3
COD(mg/1)	0.3	8.9	2.5	0.3	4.7	1.8
BOD(mg/1)	0.1	14.8	3.9	0.2	7	2.1
Nitrate (mg/1)	3.1	238.8	81.2	12.4	102	45.4
Ammonium ion (mg/1)	0.2	16	2.3	0.3	0.7	0.4
Phosphate (mg/1)	0.01	3.6	0.9	0.01	6.2	1
Chloride (mg/1)	41.6	1730	440.6	2	665	92.2
Coliform No/100ml	5	77	35	3	65	20

Table 6: Summary of Physico-chemical and biological characteristics of the groundwater in the rainy season in the study area

Hand-dug well				Borehole		
Parameters	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
pH	5.4	8.3	7.3	5.5	8	6.7
EC (áS/cm)	290	3500	1227.9	80	1740	418.8
TDS(mg/1)	150	2140	745.8	50	880	218.5
DO(mg/1)	11.8	105.6	23.8	7.6	22.4	17.6
COD(mg/1)	0.3	9.7	5.4	0.7	10.7	5.8
BOD(mg/1)	2.3	42.3	10.9	0.7	14.1	5.5
Nitrate (mg/1)	16.3	224.1	76.2	4.9	191.3	45.2
Ammonium ion (mg/1)	0.1	19.2	1.5	0.01	1.3	0.5
Phosphate (mg/1)	0.4	4.4	2	0.4	2.1	0.9
Chloride (mg/1)	46.1	4355	712	7.1	5375	314.5
Coliform No/100ml	4	95	23	1	50	25

Dry season

From Table 5, the pH values range from 5.9- 8.5 with average of 7.4 in the hand-dug wells, pH vary from 6.0-8.0 with an average of 6.8 in boreholes. The leachate samples gave values of 6.9 (L1) and 9.3 (L2) (Table 1) with a mean value of 8.1. Conductivity range from 60 µS/cm-4310 µS/cm in the hand-dug wells, and 80 µS/cm-1790 µS/cm in boreholes with average values of 1221.4 µS/cm and 402.4 µS/cm, respectively. The leachate samples gave values of 2230 µS/cm and 2820 µS/cm with an average 0f 2525 µS/cm. TDS values range from 30 mg/l-2160 mg/l in hand-dug wells with an average of 579.1 mg/l, and from 40 mg/l-900 mg/l with an average of 192.4 mg/l. The leachate samples gave values of 1120 mg/l and 1410 mg/l with an average of 1265 mg/l. DO range from 18.6 mg/l-52.6 mg/l in the hand-dug wells, and 15.2 mg/l-27 mg/l in boreholes with average values of 25.9 mg/l and 21.3 mg/l, respectively. Leachate samples reveal value of DO of 20.6 mg/l representing the only sample collected during the period. COD values range from 0.3 mg/l- 8.9 mg/l in the hand-dug wells, and range from 0.3 mg/l-4.7 mg/l in boreholes with mean values of 2.5 mg/l and 1.8 mg/l, respectively. Leachate sample (L 1) reveals COD value of 6.4 mg/l. The results of BOD reveal that values range from 0.1 mg/l-14.8 mg/l with an average of 3.9 mg/l in hand-dug wells, and reveal values ranging from 0.2 mg/l-7 mg/l with an average of 2.1 mg/l. Leachate sample (L 1) reveal BOD value of 3 mg/l. Nitrate concentrations range from 3.1 mg/l-238.8 mg/l in hand-dug wells, and 12.4 mg/l-102 mg/l in boreholes with mean values of 81.2 mg/l and 45.3 mg/l, respectively. Leachate samples (L 1 and L 2) gave values of 9.3 mg/l and 294.1 mg/l with an average of 151.7 mg/l. In the hand-dug wells, ammonium ion concentrations vary from 0.2 mg/l-16 mg/l, and from 0.3 mg/l-0.7 mg/l in boreholes with mean values of 2.3 mg/l and 1 mg/l, respectively. L 2 gave ammonium ion concentration of 2.6 mg/l. Phosphate concentrations vary from 0.01 mg/l-3.6 mg/l with an average of 0.9 mg/l in hand-dug wells while borehole samples reveal values from 0.01 mg/l-6.3 mg/l with an average of 2.2 mg/l. leachate samples (L 1 and L 2) gave values of 15.9 mg/l and 2.6 mg/l with an average of 9.3 mg/l. Chloride concentrations vary from 41.6 mg/l-1730 mg/l in hand-dug wells, and range from 2 mg/l-665 mg/l in boreholes with averages of 440.6 mg/l and 92.2 mg/l, respectively. Leachate samples (L 1 and L 2) gave chloride values of 165.2 mg/l and 516.8 mg/l with an average of 341 mg/l. Coliform number counts range from 5-77 in hand-dug wells with an average of 35 while it ranges from 3-65 in boreholes with an average of 20 coliform number counts.

Rainy season

Table 6 reveals that pH values range from 5.4-8.3 in hand-dug wells with an average of 7.3. In boreholes, pH values range from 5.5-8.0 with an average of 6.7. Leachate samples gave pH values ranging from 6.4-8.2 with an average of 7.7 (Table 2). Conductivity values vary from 290 µS/cm-3500 µS/cm in hand-dug wells, and values range from 80 µS/cm-1740 µS/cm in boreholes with average of 1227.9µS/cm and 418.8 µS/cm, respectively. The leachate samples reveal values from 1380 µS/cm-9260 µS/cm with an average of 3692.5 µS/cm. TDS values range from 150 mg/l-2140 mg/l in hand-dug wells with an average of 745.8 mg/l while borehole samples reveal values ranging from 50 mg/l-880 mg/l with an average of 218.5 mg/l. in leachate samples, values of TDS range from 820 mg/l-4650 mg/l with mean value of 2025 mg/l. DO values vary from 11.8 mg/l-105.6 mg/l in hand-dug wells, and from 7.6 mg/l-22.4 mg/l in boreholes with mean values of 23.8 mg/l and 17.6 mg/l, respectively. The leachate samples gave DO values ranging from 18.4 mg/l-28.8 mg/l with a mean value of 22.8 mg/l. COD values in hand-dug wells range from 0.4 mg/l-9.7 mg/l, and from 0.7 mg/l-10.7 mg/l in boreholes with mean values of 5.4 mg/l and 5.8 mg/l, respectively. COD values in leachate samples vary from 0.4 mg/l-9.5 mg/l with a mean value of 4.7 mg/l. BOD values vary from 2.3 mg/l-42.3 mg/l in hand-dug wells with a mean value of 10.9 mg/l while in boreholes, values of BOD range from 0.7 mg/l-14.1 mg/l with an average of 5.5 mg/l. leachate sample reveal BOD values of 8.2 mg/l-20.4 mg/lwith an average of 13.6 mg/l. Nitrate concentrations in hand-dug wells vary from 16.3 mg/l-224.1 mg/l, and vary from 4.9 mg/l-191.3 mg/l in boreholes with mean values of 76.2 mg/l and 45.2 mg/l, respectively. Nitrate concentrations in the leachate samples vary from 16.3 mg/l-343.7 mg/l with an average of 112.8 mg/l. The concentrations of ammonium ion ranges from 0.1 mg/l-19.2 mg/l with an average of 1.5 mg/l in hand-dug wells while in boreholes, it ranges from 0.01 mg/l-1.3 mg/l, and a mean value of 0.5 mg/l. Leachate samples recorded values from 0.3 mg/l-19.2 mg/l, and a mean value of 28.2 mg/l. Phosphate concentrations in hand-dug wells range from 0.4 mg/l-4.4 mg/l, and a mean value of 2 mg/l while in boreholes, it ranges from 0.4 mg/l-2.1 mg/l, and a mean value of 0.9 mg/l. Leachate samples recorded values ranging from 2.6 mg/l-6.3 mg/l with an average of 4 mg/l.

Chloride concentrations in hand-dug wells vary from 46.1 mg/l-4355 mg/l while in boreholes, it varies from 7.1 mg/l-5375 mg/l, and a mean value of 712 mg/l and 314.5 mg/l, respectively. Chloride concentrations in leachates vary from 590 mg/l-11300 mg/l with an average of 4156 mg/l. The coliform number counts from hand-dug wells and boreholes vary from 4-95 and 1 to 50 with averages of 23 and 25, respectively. The leachate samples recorded values from 20-105, and mean of 61.

DISCUSSION

The mean values of the physical, chemical and biological parameters between the dry season and rainy season reveal that pH mean values range from slightly acidic to alkaline through out the sampling period. The range of mean pH values of 6.6 to 7.4 between the dry season and rainy season periods is within the WHO (2004) recommended limit for drinking water. The mean values of EC and TDS indicate high mean values in the rainy season from the different water sources. The high values of these parameters are an indication of heavy impacts of human or natural geochemical and biological activities in the area. Conductivity indicates the presence of dissolved solids and contaminants especially electrolytes but does not give information about specific chemical (Adekunle et al., 2007). According to WHO (1998), the recommended conductivity value in drinking water is 1500µS/cm. The mean conductivity values in both seasons exceeded the recommended limit above. The spatial distribution of EC and TDS were mapped using the SURFER software. For example, Fig. 6 reveal high EC value at RD2 dumpsite of 2820 µS/cm and at RD3 with high EC values of 1990 µS/cm, 1740 µS/cm, 1650 µS/cm and 1370 µS/cm occur around the dumpsite, respectively. These high values indicate the heavy impact of the dumpsites on the salinity of groundwater in the surrounding wells. Another example in Luggere area, a leachate sample at RD1reveal EC value of 2230 µS/cm and a plume closer to the dumpsite reveal EC value of 4310 µS/cm. This indicates that the high EC value could be attributed to other sources of pollution such as sewage effluent. An EC plume occurs at Yelwa Pri. Sch. Mosque at EC concentration level of 1400 µS/cm is located closer to the drainage network that empties waste water to the Benue River. Hence the development of the plume is attributed to the impact of waste water on the surrounding wells. In the southern part of the study area (Fig. 6), a plume having EC concentration of 1430 µS/cm occurs around Lamido Sanda area. This plume is located in the discharge as reveal by Figs. 4 and 5 and could be attributed to inflow of contaminated groundwater. At RD9, a plume of EC having concentration of 1230 µS/cm reveals the impact of the dumpsite on the groundwater quality as this concentration decreases to 1500 µS/cm down gradient. In Fig. 7, an EC plume having concentration of 1790 µS/cm occurs at RD2 dumpsite while at RD 1 in the luggere area it occurs at a concentration of 1230 µS/cm and the surrounding areas reveal lower EC values of 480 µS/cm, 380 µS/cm and 180 µS/cm, respectively. This is also an indication that the refuse dumps are responsible for the elevated EC concentrations. In the southern part of the study area (Fig. 7), a plume having EC concentration of 710 µS/cm occurs around the RD9 dumpsite in Bako area of Yola town and other plumes having EC value of 650 µS/cm and 340 µS/cm occur in Garwa and Tibati areas. The plumes at Garwa and Tibati areas occur in the discharge area as reveal by Figs. 4 and 5, and the development of the plumes could be due to inflow of contaminated groundwater.

Figs. 8 and 9 show TDS distribution during the dry season period. Fig. 8 reveals a TDS plume having concentration of 1410 mg/l at RD2. At RD3 it occurs at a concentration of 690 mg/l and the surrounding wells reveal concentrations of 870 mg/l and 830 mg/l, respectively. A TDS plume having concentration of 1000 mg/l occurs between RD3 and RD4. The high concentration could be attributed to inflow of contaminated groundwater from the surrounding areas. In Luggere area, RD1 reveal a TDS value of 1120 mg/l, and a plume having concentration of 2160 mg/l also occurs. This indicates other sources of groundwater contamination such as sewage effluent. In southern part of the study area (Fig.8), a plume having TDS of 750 mg/l occurs around RD9 and another occurs at Lamido Sanda area having TDS of 720 mg/l. This reveals that higher TDS was recorded at RD9 which is attributed to the contribution of the leachates from the dumpsite. The plume occurring at the Lamido Sanda area is due to the inflow of contaminated groundwater as the plume occurs in the discharge area Figs. 4 and 5. Fig.9 reveals a plume having TDS of 900 mg/l at RD2 while in Luggere area, a plume having TDS value of 610 mg/l occurs. The high concentration of TDS at the dumpsites is an indication of the contributions of the dumps to the elevated TDS concentrations in the surrounding areas. In the southern part of the study area (Fig.9), a plume having concentration of 650 mg/l occurs another plume of less concentration (360 mg/l) occurs between RD7 and RD9. The high TDS concentrations around the dumpsites suggest the contributions of the dumpsites to the elevated TDS concentrations in the surrounding areas of the dumpsites.

Figs. 10 and 11 reveal EC distribution in the rainy season period in hand-dug wells and boreholes. Fig. 10 reveals a major EC plume having a value of 9260µS/cm at RD3 and this decrease to 2490 µS/cm at RD4 along flow direction as indicated by Figs. 4 and 5. The surrounding wells around RD3 reveal concentrations of 1760 µS/cm, 1640 µS/cm, 1490 µS/cm and 1050 µS/cm, respectively. This shows that the high EC values are due to leachate salts from RD3. Another plume having EC of 3500 µS/cm occurs in Jambutu area, and the high EC value is attributed to the uncontrolled waste disposal practice in the area. In the southern part of the study area (Fig. 10), high EC values were recorded between RD7 and RD9 at Bako and Lamido Sanda areas. These high EC values could be attributed to the leachates from the dumpsites and inflow of contaminated groundwater. In Fig. 11, an EC plume having EC value of 1740 µS/cm occurs around RD2 and another at RD1 in Luggere area having EC value of 1510 µS/cm. These high values are indications of the contribution of leachable salts into groundwater from the dumpsites. In the southern part of the study area (Fig.11), an EC plume having a value of 1130 µS/cm occurs between RD7 and RD9. This also shows the contribution of leachable salts from the dumpsite into groundwater in the surrounding areas.

Figs. 12 and 13 show the distribution of TDS in hand-dug wells and boreholes in the rainy season.

Fig.12 shows a major TDS plume having concentration of 4650 mg/l at RD3 dumpsite and the surrounding wells reveal lower concentrations of 1050 mg/l, 880 mg/l, 820 mg/l, 750 mg/l and 1250 mg/l at RD4, respectively. This is a clear indication of the contribution of leachates from the dumpsites into groundwater in the surrounding areas. At RD1 in Luggere area, the leachate sample from the dumpsite reveal TDS concentration of 1380 mg/l and the surrounding wells reveal higher TDS concentrations of 2140 mg/l and 2050 mg/l. This is a clear indication of the contribution of contaminants into groundwater from other sources such as sewage effluent following the use of pit latrines by most residents in the area. In the southern part of the study area (Fig.12), the dumps RD7, RD8 and RD9 and the surrounding wells reveal lower TDS values which could be attributed to dilution effect by precipitation. In Fig.13, TDS plume occurs at RD1 and RD2 at concentrations of 760 mg/l in Luggere area and 880 mg/l around the Doubeli dumpsite. The dumpsites reveal higher TDS concentrations than the surrounding wells which is a clear indication of the dumpsites contribution to the degradation of groundwater quality. In the southern part of the study area (Fig.13), a plume of TDS having concentration of 560 mg/l occurs between RD7 and RD9 and the hand pump borehole at the cemetery reveal TDS concentration of 410 mg/l. This is also a clear contribution of waste in the degradation of groundwater quality. The surrounding wells reveal lower TDS values below the values obtained from RD9 and the cemetery.

From the spatial distribution of seasonal concentrations of EC and TDS, higher concentrations were observed at and around the dumpsites, this suggest the increase in concentrations of EC and TDS in groundwater due to leachable salts from the dumpsites. This clearly shows that leachable salts from the dumpsites are a significant source of pollutants. For EC and TDS concentrations are highest in the leachates from the dumpsites. As per TDS classification (Fetter, 1990), the groundwater samples collected in both seasons belong to fresh water type (TDS<1000 mg/l). The mean values of TDS in both seasons are within the maximum permissible limit (1500 mg/l) of WHO's drinking water guide line.

From the mean values of dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) show that DO reveal high concentration in the dry season and low concentration in the rainy season. The low concentration in the rainy season is an indication of high biological activities. Thresh hold of dissolved oxygen in drinking water is 5.0 mg/l (Cruise and Miller, 1994). Based on the above standard, the groundwater contains high concentration of dissolved oxygen. However, the concentration of dissolved oxygen is not low to cause anaerobic conditions in groundwater that can cause odours. According to Adekunle et al (2007), very lowDO may result in anaerobic conditions that can cause bad odours. COD and BOD are indices of organic pollution (Adekunle et al., 2007). The author further stated that a COD of less than 1 mg/l is assumed not to be caused by anthropogenic influence. From the mean values of COD in both seasons reveal anthropogenic influence on groundwater as the mean COD values in both seasons exceeded 1 mg/l with the highest mean values recorded in the rainy season. According to Esa (1983), COD in drinking water supply should not exceed 2.5 mg/l and potable water of COD content greater than 7.5 mg/l is regarded as poor. The mean values of COD in the rainy season from the different water sources are above 2.5 mg/l and therefore may not be suitable for human consumption but that the water quality is not poor. The BOD mean values from the different water sources are higher in the rainy season. According to Environment Canada (1979), BOD of less than 4 mg/l is of good quality and levels greater than 10 mg/l are polluted. Based on the above standards, the water from the different sources exceeded 4 mg/l but is below 10 mg/l except BOD mean value from the hand-dug wells in the rainy season exceeded 10 mg/l, and therefore suggest polluted water which is not suitable for human consumption. Okeke and Oyebande (2009) in an investigation on water resources challenges in Nigeria discovered that high BOD and COD in water samples suggest high oxidizing organic components, and thus, are likely pollution sources. Therefore, the high COD and BOD mean values in the rainy season is an indication that the leachates from the dumpsites contain high level of oxidizing materials that could constitute groundwater pollution problems. According to Jones-Lee and Lee (1993), high BOD and COD can cause taste problems and oxygen depletion in water. Nitrate concentrations reveal high concentrations in both dry season and rainy season periods. In hand-dug wells, the mean values did not show significant difference. The mean value in the dry season is higher by 1.1 mg/l, and in both cases, the mean values are above the desirable limit of WHO (2004) of 50 mg/l. This shows that the water from hand-dug wells is contaminated with respect to nitrate. The leachate samples gave mean value of 151.7 mg/l during the dry season and 112.8 mg/l in the rainy season. Nitrate concentration exceeding 2 mg/l in groundwater indicate anthropogenic source of nitrate (Mueller and Helsel, 1996). Consequently, the high nitrate mean values above 2 mg/l in both seasons are an indication of anthropogenic activities in the area. Excessive nitrate in drinking water can cause a number of health disorders, such as methemoglobinemia, gastric cancer, goiter, birth malformations and hypertension (Majumdar and Gupta, 2000). The high nitrate values are of health-concern especially to growing infants as it causes methemoglobinemia. The symptoms of methemoglobinemia are paleness, bluish mucous membranes, digestive and respiratory problems (McCasland et al., 2007). Ammonium ion reveals high mean value during the dry season in hand-dug wells and low mean value in the rainy season. In boreholes, the mean value is high in the rainy season with a difference of 0.1 mg/l higher than the mean value in the dry season. The mean values in hand-dug wells in both seasons exceeded the WHO (1996) recommended limit of 1.5 mg/l. The mean values in both seasons from the borehole samples are within WHO recommended limit. The low mean value in the hand-dug wells in the rainy season could be explained by the fact that at shallow depth, the sources of nitrogen are prevalent, and chemical reduction of nitrate takes place under anaerobic condition resulting in the formation of ammonia through the following equation:

$CH_2O\ (NH_3) + O_2 = NH_4^+ + HCO_3$...............................(1)
(Ammonification)

On dissolution in water, ammonia forms the ammonium cation. At shallow depth, ammonia is stored and is released under favourable condition to yield nitrate by aerobic bacteria through the following equation:

$NH_4 + 2O_2 = NO_3^- + 2H^+ + H_2O$..................................(2)

(Nitrification)

Natural levels of ammonia in groundwater are usually 0.2 mg/l (Dieter, 1991). The presence of ammonia at higher level than geologic levels is an important indicator of faecal pollution (IOS, 1984, 1986). In the presence of chloride, ammonium chloride influences metabolism by shifting the acid-base equilibrium, disturbing the glucose tolerance, and reducing the tissues sensitivity to insulin (USEPA, 1989). The mean phosphate concentrations reveal high mean value in the hand-dug wells and boreholes in the rainy season. The high mean values are associated with the dissolution of waste materials and sewage effluents. High mean values from the different water sources are within WHO (1998) recommended limit of 10 mg/l. The mean chloride concentrations in the dry and rainy seasons indicate high mean values in the rainy season from the different water sources. This suggests the release of sources of salts from anthropogenic activities into groundwater during the rainy season. The mean values from the different water sources exceeded the highest desirable limit of WHO (2004) of 200 mg/l in the rainy season.The dumpsites in the rainy season reveal mean chloride value of 389.3 mg/l with leachate sample (L3) having value of 11300 mg/l (Table 2). This clearly shows that the leachates from the dumpsites are a significant source of pollutants contributing to groundwater degradation. Elevated concentration of chloride is an indication of anthropogenic impacts on groundwater in the area. Ifabiyi (2008) stated that excessive consumption of chloride may lead to various health problems particularly when it contains undissolved metal ions such as copper, zinc, mercury, silver etc, in excess concentration can result to cancer. He went further to state that when chloride contains other form of salts such as calcium, magnesium, sodium and potassium its excess concentration can lead to other problems such as hypertension, high blood pressure, corrosion, and water hardness. The mean coliform number counts from the different water sources are extremely high in both seasons. WHO (1998) recommended 10 coliform number counts in drinking water. The coliform number counts from the different water sources is bacteriologically contaminated, and is unfit for human consumption without treatment. The presence of bacteria and total coliform in well water indicate contamination by human or animal wastes (Orebiyi et al., 2010). Bacteriologically contaminated water could be the source of out breaks of water diseases such as cholera, dysentery, typhoid fever, diarrhea, hepatitis and cryptosporidiosis (Okeke and Oyebande, 2007).

Figs.14 and 15 show the plots of well depths versus contaminants in dry and rainy seasons in hand-dug wells (shallow aquifer) while Figs.16 and 17 show the plots of well depths versus contaminants in dry and rainy seasons in boreholes (deep aquifer). Fig.14 reveals increase in COD, BOD, nitrate, phosphate and chloride, and decrease in ammonium ion and coliform with water depth. The decrease in ammonium ion concentration with water depth implies that denitrification is active at shallow water depth due to anaerobic bacteria. In Fig.15, COD, nitrate, phosphate, ammonium ion and chloride reveal increase in concentration with water depth. BOD and coliform show decrease in concentrations in the rainy season which also suggest the action of denitrification process by anaerobic bacteria. In Fig.16, there was decrease in the concentrations of COD, BOD, nitrate, phosphate and coliform, and increase in ammonium ion and chloride with well depth. The decrease in the concentrations of these contaminants is an indication that the anthropogenic sources of the contaminants occur at shallow depth. The decrease in the concentration of nitrate is attributed to denitrification process. At deeper level, nitrate concentration decreases due to absence of oxygen. When nitrates reach groundwater, they are usually in high concentrations only in the top meter. This is the aerobically active zone; microorganisms degrade organic carbon as the terminal electron acceptor. Below this depth, oxygen is usually not replenish quickly enough and the environment becomes anaerobic with no oxygen present, nitrates are used as electron acceptors and are denitrified quickly (Bittner, 2000). According to Bittner (2000), nitrate contamination is present at shallow depth due to anthropogenic sources such as septic systems, agricultural fertilizers, and inadequate treatment and disposal of sewage wastes. In the study area the anthropogenic sources of pollution include indiscriminate waste disposal practice inform of house hold solid wastes, sewage effluents following the use of pit latrines by most residents and waste water discharge in drainage networks that empties such water to the Benue River. The increases in chloride in the dry season in deep aquifer could be attributed to its conservative nature. In Fig.17, COD, BOD, nitrate, ammonium ion and chloride decrease with well depth while coliform reveal no depth control. This decrease in the concentrations of the contaminants is attributed to dilution effect due to recharging groundwater by precipitation. In Fig.16, most of the sample points plotted between the depth range of 8 m to 60 m, and few samples plotted between the depths of 90 m to 220 m. Ammonium ion and coliform plotted between the depth ranges of 150 m to 220 m. Fig.17 also indicated that most sample points plotted between 8 m to 60 m, and few points also plotted between the depth of 90 m to 220 m, and ammonium ion and coliform plotted between the depths of 150 m to 220 m. The detection of COD and BOD at deeper levels is an indication of organic pollution which must have originated from the surface. It can be observed from Table 3 that most boreholes in the area are less than 50 m and tap from the unconfined aquifer, hence, the chances of contamination is high for boreholes that fall within the range of 8 m to 60 m.

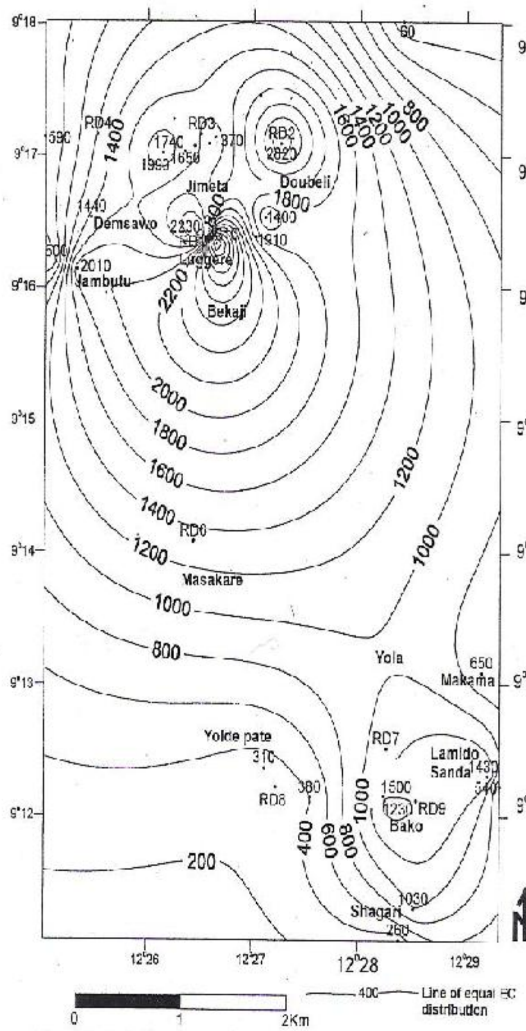

Fig. 6 Distribution of EC in hand-dug wells in the dry season

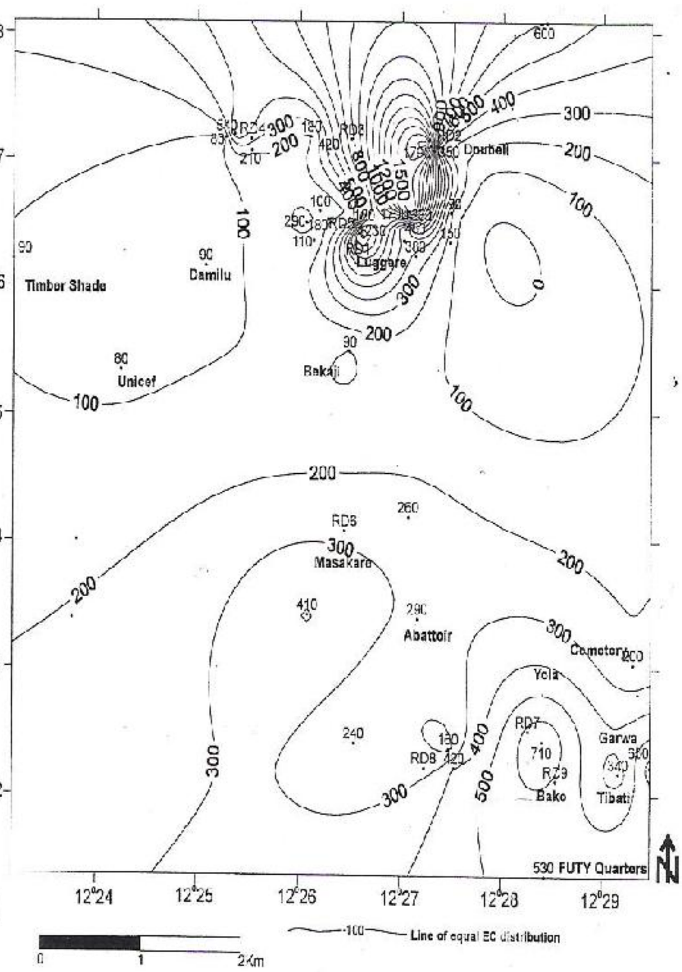

Fig. 7 Distribution of EC in boreholes in the dry season

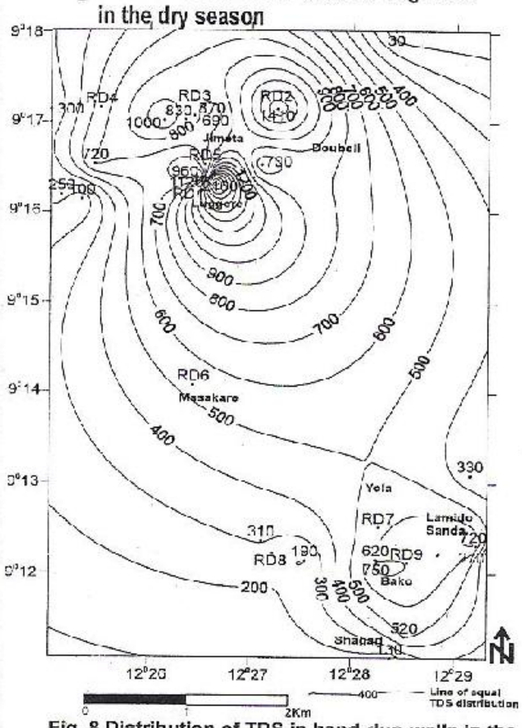

Fig. 8 Distribution of TDS in hand-dug wells in the dry season

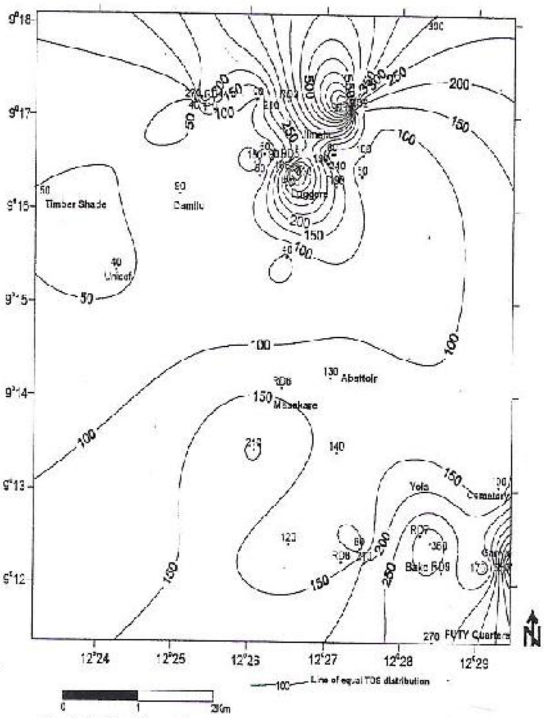

Fig. 9 Distribution of TDS in boreholes in the dry season

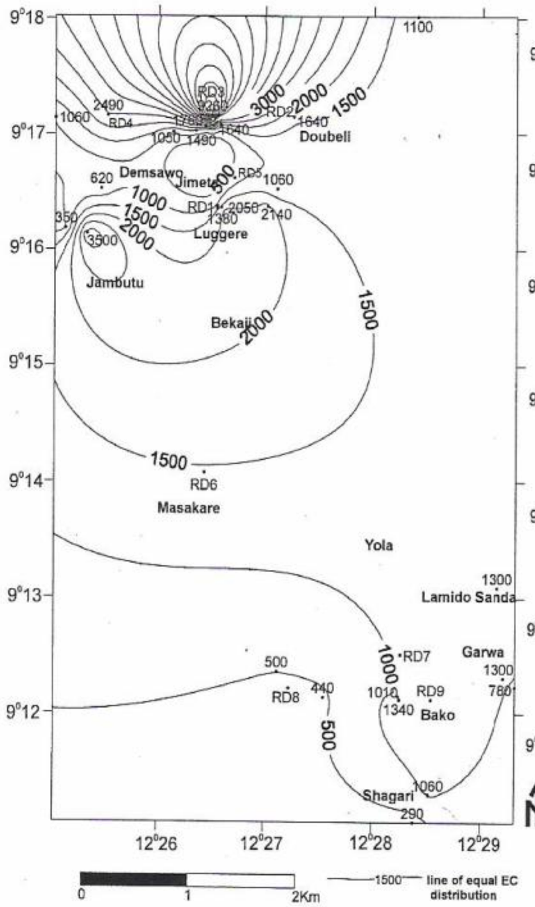

Fig. 10 Distribution of EC in hand-dug wells in the rainy season

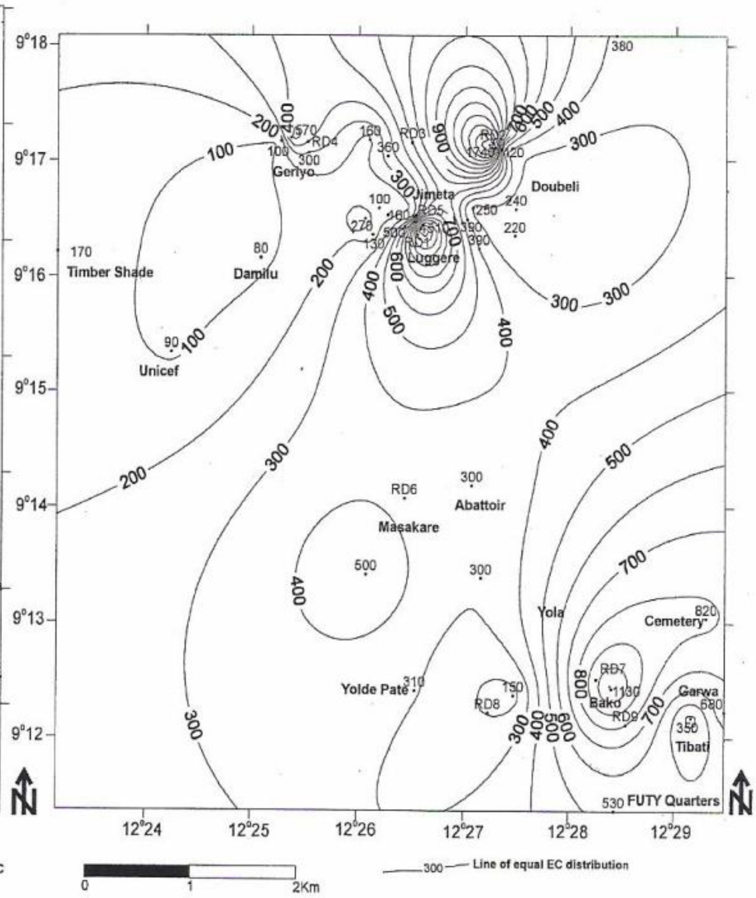

Fig. 11 Distribution of EC in boreholes in the rainy season

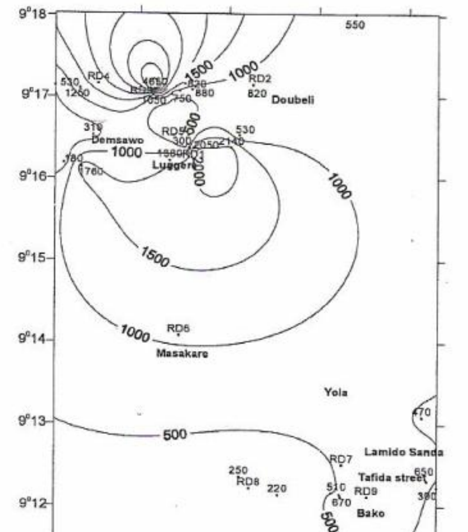

Fig. 12 Distribution of TDS in hand-dug wells in the rainy season

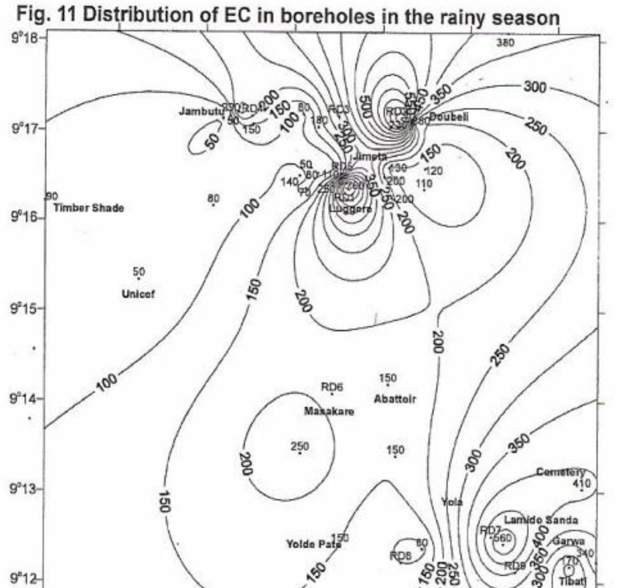

Fig. 13 Distribution of TDS in boreholes in the rainy season

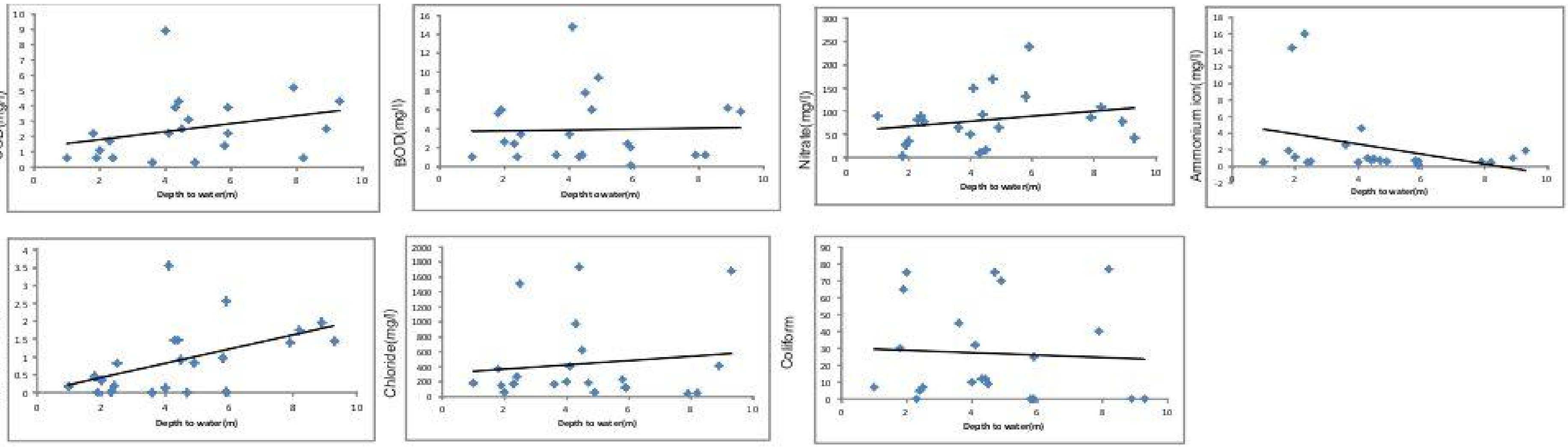

Fig. 14 Plot of depth to water versus chemical parameters in hand-dug wells in the dry season

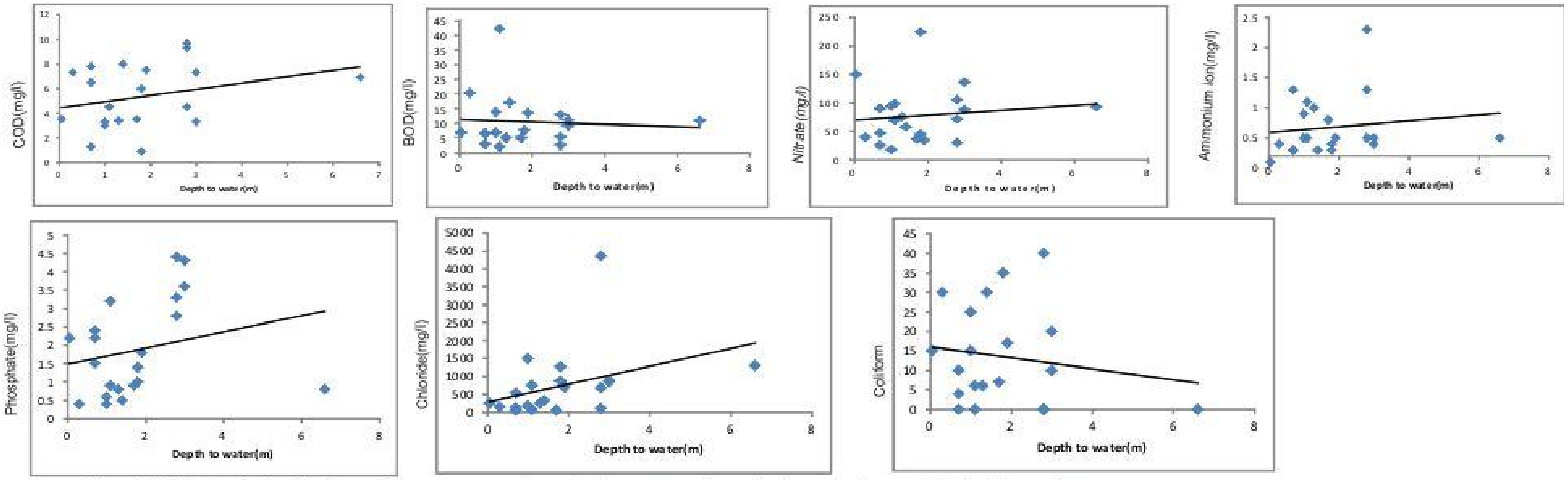

Fig. 15 Plot of depth to water versus chemical parameters in hand-dug wells in the rainy season

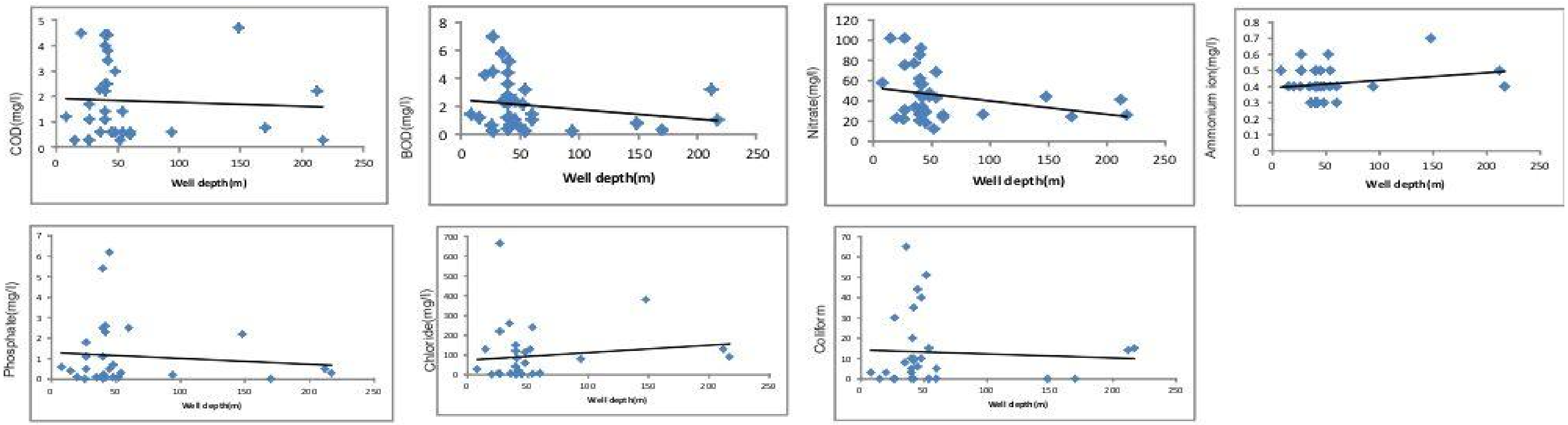

Fig. 16 Plot of well depth versus chemical parameters in boreholes in the dry season

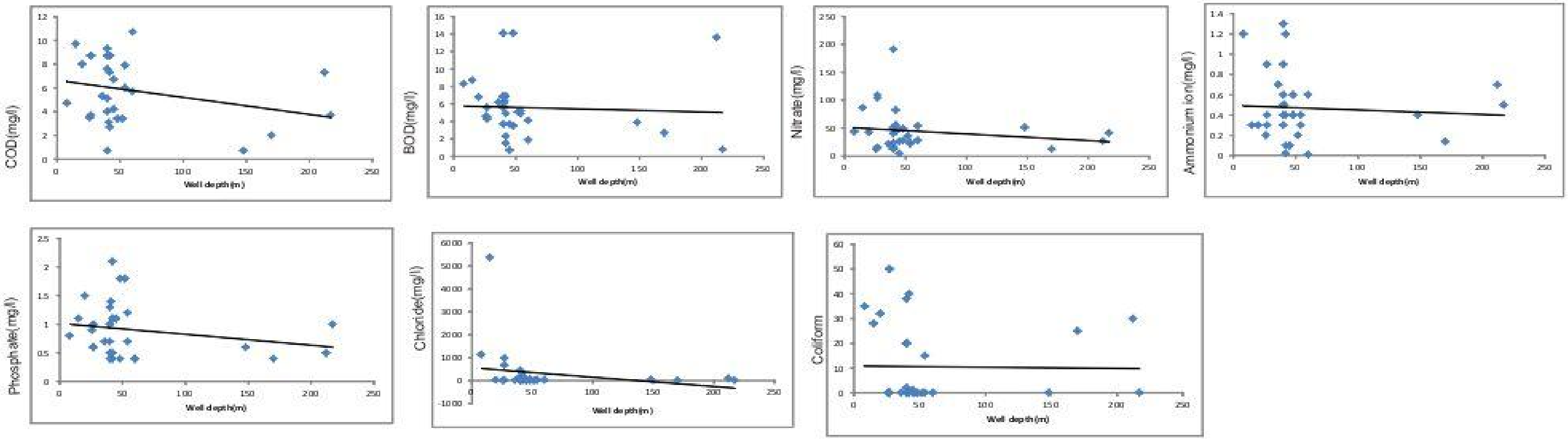

Fig. 17 Plot of well depth versus chemical parameters in boreholes in the rainy season

Correlation analysis

The importance of linear correlations between variables is determined by coefficients in the -1, 1interval. The relationship between the two (2) parameters is more significant when the coefficient approaches the extreme values of -1 and 1. A positive correlation suggests a commnality between the correlated elements, such as similar evolutionary patterns. A negative coefficient indicates that the variables in question are evolving in opposite direction (Hamzaoui-Azaza et al., 2009). According to Adams et al (2001), samples showing r>0.7 are considered to be strongly correlated whereas r>0.5-0.7 shows moderate correlation at a significant level (p) of 0.05

Dumpsites

The correlations between the contaminants in the leachate samples in the dry season indicate perfect correlation between EC and pH, TDS and pH, TDS and EC, NO_3 and pH, NO_3 and EC, Cl and pH, Cl and EC, Cl and TDS, PO_4 and NH_4, and Cl and NO_3. These correlations suggest that the salinity of the dumpsites is controlled by NO_3, pH and Cl while pH is influenced by NO_3 and Cl while PO_4 and NH_4 have common origin. In the rainy season, nearly perfect correlation exists between TDS and EC (r=0.98), NO_3 and EC (r=0.999), NO_3 and TDS (r=0.98), and Cl and TDS (r=0.999). These correlations indicate that the salinity of the dumpsites is controlled by NO_3 and Cl.

Hand-dug wells (shallow aquifer)

Correlations between the contaminants are presented in Table 7 for the shallow aquifer. Strong positive correlation exists between TDS and EC (r=0.92), and BOD and DO (r=0.91) in the dry season. This suggests that BOD and DO are from the same source. In the rainy season, strong positive correlation exists between Cl and EC (r=0.95), TDS and EC (r=0.94), Cl and TDS (r=0.83), BOD and DO (r=0.81), Cl and NO_3 (r=0.76), NO_3 and EC (r=0.74). The correlation between Cl and TDS, and NO_3 and EC indicates that the salinity of the groundwater is controlled by Cl and NO_3. The correlation between BOD and DO indicates that the parameters are from the same source. The correlation between Cl and NO_3 indicates the influence of municipal wastes at shallow depth in the rainy season. Correlation between Cl and NO_3 with coefficient greater than 0.35, suggests the effect of municipal wastes (Piskin, 1973); Ritter and Chimside (1984). The strong positive correlation between TDS and EC is an approximate relationship for most natural groundwater (Richard, 1954).

Table 7: Correlation between chemical contaminants in shallow aquifer

Dry season		**Rainy Season**	
Parameters	Correlation coefficients	Parameters	Correlation coefficient
TDS and EC	0.92	TDS and EC	0.94
BOD and DO	0.91	BOD and DO	0.81
DO and TDS	0.52	Coliform and BOD	0.59
Nitrate and EC	0.48	Nitrate and EC	0.74
TDS and pH	0.45	Nitrate and pH	0.47
BOD and TDS	0.42	Ammonium ion and TDS	0.44
BOD and EC	0.42	Phosphate and EC	0.45
Phosphate and DO	0.42	Chloride and EC	0.95
Coliform and chloride	-0.54	Chloride and TDS	0.83
		Chloride and Nitrate	0.76
		Coliform and Phosphate	0.53

Boreholes (deep aquifer)

In the dry season (Table 8), strong positive correlation exists between TDS and EC (r=0.73), and BOD and DO (r=0.70). In the rainy season, strong positive correlationexists between TDS and EC (r=0.99), Cl and EC (r=0.72), and Cl and TDS (r=0.71). These correlations indicate that the salinity of the groundwater is controlled by Cl while BOD and DO were derived from same source. The correlation among the contaminants from the leachate samples and the different water sources is an indication of common origin.

Table8: Correlation between chemical contaminants in deep aquifer

Dry season		**Rainy Season**	
Parameters	Correlation coefficients	Parameters	Correlation coefficient
TDS and EC	0.73	TDS and EC	0.99
BOD and DO	0.70	Chloride and EC	0.72
Nitrate and TDS	0.66	Chloride and TDS	0.71
Nitrate and BOD	0.56	Nitrate and EC	0.53
Chloride and Nitrate	0.51	Nitrate andTDS	0.52
Chloride and Ammonium ion	0.49	Nitrate and COD	0.40
DO and pH	-0.42		
BOD and Ph	-0.45		

Multivariate Statistical Analysis

The multivariate statistical technique relates variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes (Nton et al., 2007). The application of the analysis has proved useful in the interpretation of hydrogeological dataas revealed by many workers such as Bakaloviez, (1994); Aruga et al (1995); Elueze et al (2001). Furthermore, factor analysis is a tool used to rearrange data to present it in a manner that better explains the structure of the underlying system that produced the data (Dawdy and Feth, 1967). The multivariate analysis was carried out using the statistical package for Social Sciences Software (SPSS). The results from this study employing the use of factor analysis classify the data into dry season and rainy season.

Dry season

From Table 9, three factors were identified in the dry season in shallow aquifer which accounts for 72% of the variance. Factor 1 explains 38.7% of the total variance and has strong positive loadings for EC, TDS, DO, BOD and pH. These positive loadings are confirmed by the strong positive correlations between EC and TDS (r=0.92), BOD and DO (r=0.91) while TDS and pH indicated moderate correlation (r=0.49) (Table 7). Factor 1 therefore indicates level of organic pollution which resulted from anthropogenic sources such as house hold solid wastes and sewage effluent. Factor 2 explains 20.2% of the total variance and has strong positive loadings with respect to chloride. Table 7 did not reveal any correlation between chloride and other contaminants. Factor 2 indicates salinity of groundwater due to the release of chloride-rich salts from anthropogenic sources. Factor 3 explains 13.1% of total variance and consists of high positive loading with respect to nitrate. Nitrate indicated moderate correlation with EC (Table 7). Factor 3 can be interpreted to represent nitrate contamination. In deep aquifer in the dry season (Table 10), three factors were identified which accounts for 67.1% of the variance. Factor 1 explains 30% of the total variance and has high positive loadings for BOD and nitrate. Nitrate and BOD indicate moderate correlation (Table 8). Factor 1 therefore suggests level of organic pollution. Factor 2 explains 24.4% of the total variance and has high positive loadings with respect to DO and ammonium ion, moderate loading with respect to coliform and COD. DO and ammonium ion did not show any form of correlation with each other. Factor 2 therefore suggests that ammonification process is active. Factor 3 explains 12.6% of the total variance and has moderate loadings with respect to pH, EC and TDS, and negative loading with respect to chloride. The high positive loading between EC and TDS is confirmed by their strong positive correlation (r=0.73). Chloride did not show any form of correlation with TDS and EC, however, chloride coorelates only with nitrate and ammonium ion at moderate levels. Factor 3 therefore explains the extent of mineralization, which is dependent on pH, and therefore suggestive of heavy impacts of human or natural geochemical and biochemical activities in the area.

Table 9: Eigen Values, percentage of Variance Explained and cumulative variance of principal component (PCs) in the dry season in shallow aquifer

	Component		
Parameters	1	2	3
pH	.734	-467	-191
EC	.888	.238	.257
TDS	.884	.243	.265
DO	.843	.197	-.345
COD	-.357	.598	-.059
BOD	.804	.145	-.405
Nitrate	.347	-.046	.839
Ammonium	.432	-.241	-.512
Phosphate	.498	.561	-.079
Chloride	-.106	.745	-.007
Coliform	.314	-.735	-.122
% variance Explained	38.7	20.2	13.1
% cumulative	38.7	58.9	72

Table 10: Eigen values, percentage of variance explained cumulative variance of principal components (PCs) in the dry season in deep aquifer

	Component		
Parameters	1	2	3
pH	.513	.018	.574
EC	.628	-.018	.559
TDS	.638	.239	.439
DO	.291	.753	.046
COD	.620	-.408	.068
BOD	.798	.035	.189
Nitrate	.782	.234	-.332

Ammonium	-.151	.893	.039
Phosphate	-.423	.324	.029
Chloride	.345	.378	-.624
Coliform	-.447	.838	.110
% variance Explained	30	24.4	12.6
% cumulative	30	54.5	67.1

Rainy season

In shallow aquifer in the rainy season period (Table 11), indicates three factors that accounts for 66.9% of the variance. Factor 1 explains 31.5% of the total variance and has high positive loadings with respect to chloride, EC and coliform. This is buttressed by strong positive correlations between chloride and EC (r=0.95) (Table 7). Coliform however, did not show any form of correlation between EC and chloride. Factor 1 indicates salinity of the groundwater derived from anthropogenic sources. Factor 2 explains 19.8% of the total variance and has moderate loadings with respect to EC, TDS and pH. This factor also showed strong negative loading with respect to BOD, and negative loading with respect to coliform. From the correlations in Table 7, TDS and EC reveal strong positive correlation (r=0.94), and coliform and BOD (r=0.59). Factor 2 therefore explains organic matter decomposition by bacterial action. Factor 3 explains 15.6% of the total variance and has strong positive loading with respect to DO and moderate loading with respect to pH, and negative loadings for ammonium ion and phosphate. These contaminants did not show any form of correlation with each other (Table 7). Factor 3 can be explained as groundwater oxygenation. Oxygenation of groundwater encourages nitrification process, thus converting the stored ammonium ion into nitrate. In deep aquifer in the rainy season, Table 12 indicates three factors that accounts for 67.6% of the variance. Factor 1 explains 36% of the total variance and has high positive loadings for EC, TDS and chloride. This is confirmed by the nearly perfect correlation between TDS and EC (r=0.99), strong positive correlation between chloride and EC (r=0.72), and chloride and TDS (r=0.71) (Table 8). Factor 1 explains the salinity of the groundwater derived from anthropogenic sources. Factor 2 explains 18.1% of the total variance and has moderate loadings for DO and pH, and negative loadings with respect to nitrate and COD. DO and pH did not show any form of correlation, nitrate and COD indicated moderate correlation 9Table 8). Factor 2 indicates oxidation of organic matter. Factor 3 explains 13.5% of the total variance and has moderate loadings with respect to BOD, pH and coliform. There was no any form of correlation between these parameters. Their association could be related to organic pollution.

From the above discussion, it can be observed that in the dry season, factor 1 reveals organic pollution, factor 2 salinity and factor 3 indicated nitrate contamination in shallow aquifer. In deep aquifer during the same period, factor 1 reveals organic pollution, factor 2 ammonification and factor 3 indicated natural mineralization. According to Bittner (2000), high ammonia concentrations can be found at great depths whereas high nitrate concentrations are usually only found near the aquifer surface. Consequently, the process of ammonification is associated with the deep aquifer. At deeper level, oxygen is deficient, and is not replenish quickly, and nitrate is denitrified by anaerobic bacteria. In the rainy season in shallow aquifer, factor 1 indicates salinity, factor 2 organic decomposition and factor 3 oxygenation of groundwater. In deep aquifer, factor 1 indicated salinity, factor 2 oxidation of organic matter and factor 3 organic pollution. Factor 1 generally indicated organic pollution in both seasons with respect to shallow and deep aquifers in the dry season. Factor 2 indicated salinity and ammonification in shallow and deep aquifers while factor 3 indicated nitrate contamination and natural mineralization in shallow and deep aquifers in the dry season. In the rainy season, factor 1 indicated salinity with respect to shallow and deep aquifers, factor 2 indicated organic decomposition in shallow aquifer and oxidation of organic matter in deep aquifer while factor 3 indicated oxygenation of groundwater in shallow aquifer and organic pollution in deep aquifer. It can be concluded that groundwater chemistry is controlled by anthropogenic pollution and natural mineralization in the dry season while the groundwater is controlled by anthropogenic pollution in the rainy season due to dissolution of wastes materials by precipitation.

Table 10: Eigen values, percentage of variance explained cumulative variance of principal components (PCs) in the rainy season in shallow aquifer

	Component		
Parameters	1	2	3
pH	-.372	.512	.567
EC	.813	.541	.152
TDS	.640	.535	.082
DO	.268	-.100	.740
COD	.661	-.438	-.121
BOD	.275	-.784	.324
Nitrate	.384	.297	-.061
Ammonium	.297	-.226	-.469
Phosphate	.494	.214	-.626
Chloride	.824	.207	.157

Coliform	.715	-.538	.237
% variance Explained	31.5	19.8	.15.6
% cumulative	315	51.3	66.9

Table 10: Eigen values, percentage of variance explained cumulative variance of principal components (PCs) in the rainy season in deep aquifer

	Component		
Parameters	1	2	3
pH	.130	.660	.555
EC	.968	.129	-.017
TDS	.967	.134	-.050
DO	.510	.602	-.164
COD	.543	-.585	-.139
BOD	.311	-.152	.586
Nitrate	.549	-.661	-.086
Ammonium	-.346	.215	.331
Phosphate	.095	.282	-.614
Chloride	.893	.319	-.049
Coliform	.439	-.358	.533
% variance Explained	36	18.1	13.5
% cumulative	35.996	54.099	67.567

CONCLUSION

The following conclusions can be drawn from this study:

1. The groundwater of the study area is fresh and ranges from slightly acidic to alkaline.
2. Pollutant loading occurred in both dry and rainy seasons.
3. The mean values of BOD, COD and chloride exceeded the recommended standards of drinking water quality in the rainy season from the shallow and deep aquifers (hand-dug wells and boreholes).
4. Nitrate and ammonium ion mean values exceeded the recommended limit of WHO in both seasons in hand-dug wells (shallow aquifer).
5. The mean coliform number counts exceeded the WHO recommended limit in both seasons from both the shallow and deep aquifers.
6. The spatial distribution of EC and TDS reveal that the leachates from the dumpsites are significant source of groundwater contamination.
7. The variation in contaminant distribution is influenced by water depth. There was increase in COD, BOD, nitrate, phosphate and chloride, and decrease in ammonium ion and coliform with water depth in shallow aquifer in the dry season, and COD, nitrate, ammonium ion, phosphate and chloride increase with water depth while BOD and coliform decrease with water depth in the rainy season.
8. COD, ammonium ion and chloride increase with well depth in deep aquifer in the dry season while COD, BOD, nitrate, ammonium ion, phosphate and chloride decrease with well depth. Coliform show no well depth control in the rainy season.
9. In the dry season in leachate samples, EC, pH, TDS, nitrate, chloride, phosphate and ammonium ion show perfect correlation. In the rainy season, TDS and EC show nearly perfect correlation.
10. In shallow aquifer in the dry season, strong positive correlation exists between TDS, EC, BOD and DO. In the rainy season, strong positive correlation exists between TDS, EC, chloride, nitrate, BOD and DO.
11. In deep aquifer in the dry season, strong positive correlation exists between TDS, EC, BOD and DO. In the rainy season, there was strong positive correlation between TDS, EC and chloride.
12. Factor analysis indicates that groundwater chemistry is controlled by anthropogenic pollution and natural mineralization.
13. It is recommended that safe waste disposal practice should be encouraged and drilling of boreholes to deeper levels is also suggested.

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