A Groundwater Quality Study of Lagos State, Nigeria

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Abstract

The paper is aimed at investigating the physico-chemical and microbial quality of water in 30 shallow wells in Lagos State. Results showed that groundwater quality in Lagos is highly variable from one location to the other. Water parameters were found to exceed set local (SON) and international (WHO) standards. Analysis of pH indicated that groundwater in 14 locations are acidic. The 500mg/l WHO limit for TDS was exceeded in 5 locations while EC limit was exceeded in 4. The presence of zinc and Escherichia coli (e.coli) in water samples calls for attention. From the study, there is no sampling point that did not have at least one parameter exceeding set standards. None of the sampling wells can be considered 'pure'. Therefore, groundwater within the Lagos environment cannot be said to be potable. It is a major concern to users, agencies responsible for water provision and governmental bodies. This paper calls for further research.

Keywords: water quality, shallow wells, groundwater, water parameters, water standards, Lagos

1. Introduction

Groundwater is fast becoming an essential resource that cannot be ignored in any part of the world (Llamas, 2005). Prior to this recent development, attention was placed on surface water as a component of the hydrological cycle for water supply, particularly in urban areas. In developing countries like Nigeria, groundwater was considered only as a means of rural water supply. Efforts on water supply development were focussed on surface water. However, the situation is changing even on a global scale. According to Gronwall et al, (2010), an estimated 269 million urban dwellers depend on wells as their principal source of drinking water. In urban Nigeria, it is estimated that almost 60 per cent of the population rely on local wells. This rapidly increasing trend seems to be partly due to people's need to self-supply for lack of alternative sources, and partly due to cheaper well drilling technologies.

Many countries are turning to groundwater as a reliable source of supply. This situation has been aggravated by the large-scale pollution of surface water. Also, factors such as the generally wide availability of groundwater, its low capital development, cost and normally excellent natural quality are leading to rapid development of groundwater resources (Foster and Chilton, 1993). Groundwater has unique natural features which make it suitable for public water supply (Offodile, 1983). It has excellent natural quality, usually free from pathogens, color, turbidity, and can be consumed directly without treatment (Jain et al, 1996). However, it has been observed severally in literature that groundwater is losing its natural purity. For instance, the microbiological and physicochemical analyses of borehole water samples from eastern Obolo LGA of Akwa Ibom State, Nigeria were conducted by Itah and Akpan (2005) to ascertain the potability. Some physicochemical parameters like iron and mercury in some boreholes did not meet the WHO standard for potable water.

According to Harter (2003), groundwater contamination is an undesirable change in groundwater quality resulting from human activities. Urban growth, increased industrial activities, intensive farming, and overuse of fertilizers in agricultural production have been identified as drivers responsible for these changes (Patwardhan, 2003). It is a well-known fact that a polluted environment has a detrimental effect on the health of people, animal life and vegetation (Sujatha and Reddy, 2003). The need to define the quality of water has developed with the increasing demand for water which is suitable for specific uses and conforms to desired quality (Deborah, 1996). Unsatisfactory water supplies and unwholesome sanitary conditions can result in poor human health (Chukwu, 2008). Therefore, the maintenance of water quality at acceptable levels is an essential requirement for successful use of water resources. In order to safeguard the long-term sustainability of the groundwater resources, the quality of the water needs to be continuously monitored (Raihan and Alam, 2008). The overall goal of such assessment is to obtain a comprehensive picture of the spatial distribution of groundwater quality and the changes that occur, either naturally, or under the influence of man (Wilkinson and Edworthy, 1981).

Perhaps of more prominent consequence is the impact of urban developments on water resources. The relationship between land use and hydrology is of interest worldwide. This is due to the fact that water resource (rain, river, sea and ground water) is one of the major components of environmental resources that are under threat either from over exploitation or pollution, exacerbated by human activities on the earth's surface (Efe, 2001). Residential and commercial developments are replacing undeveloped land. Unplanned changes to land use have become a major problem. Most of the land use changes occur without clear and logical planning, paying no attention to their environmental impacts. This is particularly so in the Lagos area which has attained a mega city status. Urban development and the provision of infrastructure are great concerns not only to the government but also to the populace. The provision of potable water appears to be one of the most crucial needs of the residents both now and in future periods. Surface water in the city is unusable because of its polluted state. According to JICA (1999), there are about 2000 industries in Lagos metropolis the majority of which discharge their effluents into Sasa and Odo Iya Alaro streams in the densely populated and heavily industrialized Ikeja suburb. The water quality of the rivers such as shown in the pH, BOD, turbidity, color, total suspended solid, oil and grease, pesticides and heavy metals as well as total coliform exceed the standards of WHO and Federal Environmental Protection Agency. Residents of the city depend on groundwater for regular supply of potable water. Therefore, there is the need for groundwater, to be sustainably used, monitored and protected. This paper examined the groundwater quality of the rapidly expanding city of Lagos and its immediate environs. It focussed on the study of the characteristics of groundwater as depicted by the constituent parameters. Also, the quality of water was measured in this study against set international standards to determine its potability.

2. The Study Area

Lagos State is located in the southwestern coast of Nigeria approximately between latitudes $6^0 22'$N and $6^0 52'$N and longitudes $2^0 42'$E and $3^0 42'$E (Odumosu et al., 1999). It is bounded on the west by the Republic of Benin while the southern boundary of the state is formed by the 180km long Atlantic coastline (Figure 1). Its northern and eastern boundaries are shared with Ogun State (Odumosu et al., 1999). It has a total area of 3,577 km^2 about 22 percent of which is water. It is the smallest state in the Federation in terms of land mass.

About a century ago, Lagos was a small port comprising several villages or settlements, developed on the higher ground within the swamp lands that dominated the area (Ajayi, et. al., 1983). Lagos grew from a farming and fishing village of the 15th century to a world class megacity. It has grown spatially from a traditional core settlement of about 3.8 sq. km. to a huge metropolis of over 1,183sq.km. Metropolitan Lagos constitutes about 33% of Lagos State with 455sq.km of the metropolis being water bodies, wetlands and mangrove swamps (George, 2009).

Lagos is characterized by a wet equatorial climate with mean annual rainfall above 1800mm. There are two main seasons, namely; the rainy season and dry season, which usually last from April to October and October to March respectively. It experiences an average temperature of 27^0C. The vegetation cover is dominated by swamp forest, wetlands and tropical swamp forest comprising of fresh waters and mangrove. Generally, the pattern of relief in Lagos reflects the coastal location of the state. Water is the most significant topographical feature in Lagos State. Water and wetlands cover over 40% of the total land area within the state and an additional 12% is subject to seasonal flooding (Iwugo et al., 2003). The geology of Lagos State (Figure 2) is mainly sedimentary of tertiary and quaternary sediments.

Tertiary sediments are unconsolidated sandstones, grits with mudstone band and sand with layers of clay. Quaternary sediments are recent deltaic sands, mangrove swamps and alluvium near the coast. The state is located on sedimentary rock mainly of sand and alluvium. The major soil groups are juvenile, organic- hydromorphic and ferrallitic soils.

The population of the city is expected to grow at the annual rate of 4 per cent, reaching 24 million people by 2015 (UN-HABITAT, 2006). Then it is expected to rank third among the world's cities. According to Kofoworola (2007), approximately 4 million tonnes of municipal solid waste (MSW) are generated annually in Lagos, including approximately 0.5 million of untreated industrial waste. Wastewater treatment in Lagos is almost non-existing. Also, the sewage system of the city is poor, the only conventional sewerage system is in the metropolitan area of Lagos, Victoria Island. Due to inadequate sewerage, much of the excreta and sullage disposed of by the drainage of rainwater through open ditches. During the dry season, when the flushing action of rainfall does not exist, drainage channels become blocked with solids, creating stagnant ponds of contaminated water.

3. Materials and Methods

Water samples were collected randomly from 30 shallow wells within the study area in July, 2010. A purposive random sampling technique was adopted in the selection of sampling locations. As a result, a higher number of sampling wells were selected from the inner metropolis where there is an aggregation of population and higher concentration of wells. The co-ordinates of the sampling points were recorded using the Global Positioning System (GPS) Garmin Channel 72 model. Figure 3 shows the location of the data collection stations. As shown in Table 1, identification numbers were allotted to each of the 30 sampling wells in this study and such numbers were used in the discussions in place of actual names of location. Shallow wells are predominant particularly in the residential areas probably because they are cheaper to construct. Water parameters that are considered to have a significant relationship with man's activities were selected for the study. The parameters include pH, TDS, EC, turbidity, iron, chloride, magnesium, manganese, silica, lead and zinc. The occurrence of e.coli in the water samples was also examined.

For the unstable parameters such as pH, EC and TDS, in situ measurements were taken. This was carried out using a portable digital meter, EXTECH pH-100 and HM digital EC/TDS/Temperature COM-100 respectively. Well water samples were collected in clean 1.5 liter plastic jars with screw caps, and packed in cooler containing ice and transported to a standard laboratory (Chemistry Department, University of Lagos, Nigeria) for further analysis within 24 hours from the time of sample collection. Chloride was determined using titrimetry method. The concentrations of metals (Iron, Zinc, Magnesium and lead) were determined by Atomic Absorption Spectrophotometer (AAS).

Laboratory results of water samples were subjected to statistical analysis. Descriptive analysis covered minimum, maximum, mean, standard deviation of all the parameters in the data sets. Bar charts of parameters were derived in order to assess the potability of the water. The results were then compared with standards set by regulatory bodies such as WHO and Standards Organization of Nigeria (SON).

4. Results and Discussions

The results of the laboratory analysis carried out on water samples are shown in Table 2 while the results of the descriptive data analysis are shown in Table 3. pH was found to range from 5.26 to 7.77 with a mean value of 6.48. In about 16 locations, pH values were higher than 6.5 which is recognized as the minimum limit. The mean of 6.48 observed implies a close to acidity state of groundwater from shallow wells. With a standard deviation of 0.61, there is very little variation in pH.

EC was heterogeneous with a range from 151 μs/cm to 1540 μs/cm. Extremely high EC values were observed in four locations. The mean value of 628 μs/cm is also very high. Ten locations recorded values above the mean namely Wells 3, 4, 5, 15, 17, 19, 20, 22, 23, and 28.

TDS ranged from 77 to 788mg/l. Wells 1 and 9 recorded the lowest values of 77 and 81 mg/l respectively. The mean of 321.87mg/l was exceeded in Wells 3, 4, 5, 15, 19, 20, 22, 23, and 28. This can be attributed to the high values recorded in those 9 locations which tend to overshadow the contributions of the remaining wells. This is further portrayed in the high standard deviation of TDS in the study area.

Turbidity ranged from 0 to 15 NTU. It is worth noting that 7 wells namely 18, 19, 22, 23, 27, 29 and 30 had water samples that were turbid but at different levels. All the remaining 23 locations were not turbid at all. The mean of 1.5NTU was influenced by the large numbers of location with 0 value. However, the standard deviation was 3.49 which is fairly low.

The minimum concentration level of iron was found to be 0.02mg/l while 3.51mg/l was the maximum obtained. Iron concentration in shallow wells was found to be particularly low. The variation in observation was also very low.

The concentration of chloride in the study ranged from 18mg/l to 230 mg/l with a mean of 70.86mg/l. The standard deviation of 43.42 is fairly high indicating the dispersion of the observations.

Nitrate results from shallow wells showed a range of 0.52mg/l to 21.5mg/l. The average value of 4.42mg/l was surpassed in Wells 3, 4, 15, 20, 22, 23 and 28. Extremely high values were observed in Wells 15, 22 and 23. The remaining 27 locations were more closely tied to the mean. This is evident in the standard deviation for nitrate.
Magnesium concentration in the samples ranged from 0 to 204 mg/l with a mean of 25.07mg/l. The standard deviation of 37.31 could have been that high because of the contribution of a seemingly extreme value in one of the locations.

The concentration of zinc in the shallow wells under study ranged from 0 to 38.14mg/l. The metal was detected in all but one location (Well 24). The average reading was 8.62 mg/l and this was surpassed in 8 locations. The observations were varied with a standard deviation of 10.82.

Further comparisons of the estimated values of physico-chemical parameters of water were made with standards set by the World Health Organization (WHO) and the Standard Organization of Nigeria (SON). The results are shown in Figure 4a to Figure 4k. The pH reading as shown in Figure 4a showed that 13 locations fall below the minimum level of 6.5. This implies that water in such locations tends to be acidic. The farther away from the 6.5 minimum limit, the more acidic the water. This indicates poor water quality. The remaining 17 locations were within the acceptable range. No location was above the 8.5 maximum limit. Total dissolved solids affect the taste of drinking water if present at levels above the WHO recommended 500 mg/l level. TDS values were much higher with Wells 3, 4, 15, 20, 22 and 23 exceeding the recommended limit of 500mg/l.

The same trend was observed in the EC chart (Figure 4b) which indicated that Wells 3, 4, 22 and 23 exceeded the set limit. It is important to note that this same set of locations exceeded the TDS limit. Conductivity is a numeric measure of the capacity of an aqueous solution to pass an electric current. Pure water has a conductivity of 1μs/cm and is not expected to conduct electricity.

Turbidity was detected in only Wells 18, 19, 22, 23, 27, 29 and 30. Of these, 3 were above set standard of 5 NTU namely Wells 22, 23 and 29. Nitrate was detected in all water samples in shallow wells. No location exceeded the permissible level of 50mg/l.

The magnesium concentration in shallow wells was observed above the SON limit of 0.2mg/l in 28 sites (Fig.4h). The high concentration of magnesium gives an unpleasant taste to drinking water (WHO,1996).
Manganese on the other hand was well below the limit of 0.2mg/l in all locations. Iron was higher in 12 locations than the WHO standard of 0.3mg/l. Zinc was detected in all but one location (Well 24). It was also observed that the concentration of zinc in groundwater exceeded the maximum limit in 18 locations.

Escherichia coli was detected in 6 locations namely Wells 18, 19, 22, 23, 27 and 29. The mere presence of the bacteria is a great limitation to the potability of the groundwater in such locations. E.coli is regarded as the most sensitive indicator of fecal pollution. Its presence in the borehole water samples is of a major health concern and calls for remedial attention. The presence of this pathogen in the samples was an indication of the likely presence of other enteric pathogens (Petridis et al., 2002).

A further step was taken to isolate water parameter standards that were exceeded in each of the sampling points. The outcome is shown in Table 4. From the table, nine parameters were considered to have exceeded acceptable limits. For instance, pH minimum limit of 6.5 was exceeded in fourteen locations.

In all, there is no sampling point without a default. All the locations have water that exceeds set standards in one parameter or the other. Therefore, it can be concluded that groundwater in the area is not potable. However, it is important to note that some wells are ‘purer’ than others. This is because while some wells have problems in one parameter, others default in many.

For instance, Old Badagry Toll Gate area (1) and Igbosere (30) were found to default in only one parameter which is magnesium. Some others like the sampling well in Epe town (22) and Ikorodu (23) fall short in as many as nine and seven parameters respectively.

5. Conclusions

From the study, water quality varies from one location to the other. Assessment of groundwater quality made in the 30 locations in the study area revealed that there were considerable deviations from set standards. This shows clearly that many of the samples do not satisfy drinking water standards set by the WHO and SON. The results show the level of deterioration of groundwater in different parts of the city. Many people in Lagos environment drink groundwater without treatment with the belief that it is safe. There is the need for public enlightenment on this perceived notion. Government agencies in charge of water resources should embark on regular water quality monitoring with a focus on groundwater. Also, this study calls for further research on underground water quality in the whole of Lagos state as it is pertinent to the health of the people. Since groundwater has a major role to play in water supply schemes, plans for its protection need to be put in place.

Table 1: List of Data Collection Stations

Well No.	Location	Type of Well
1	Old Toll Gate area, Badagry	Hand-dug
2	Badagry town	Hand-dug
3	Oto- Ijanikin	Hand-dug
4	Ojo	Hand-dug
5	Ojodu	Hand-dug
6	Oke- Ira	Hand-dug
7	Ifako Ijaiye	Hand-dug
8	Agege	Hand-dug
9	Ipaja	Hand-dug
10	Capitol Road, Agege	Hand-dug
11	Shogunle	Hand-dug
12	Mafoluku, Oshodi	Hand-dug
13	Palm Avenue	Hand-dug
14	Mushin Olosha	Hand-dug
15	Nathan Str., Surulere	Hand-dug
16	Ajegunle	Hand-dug
17	Ebute metta	Hand-dug
18	Lekki Waterside	Hand-dug
19	Lekki Market	Hand-dug
20	Adijoh	Hand-dug
21	Epe Waterside	Hand-dug
22	Epe town	Hand-dug
23	Ikorodu	Hand-dug
24	Ketu	Hand-dug
25	Bajulaiye, Somolu	Hand-dug
26	Morroco Road	Hand-dug
27	Akerele	Hand-dug
28	Police Barracks, Apapa	Hand-dug
29	Liverpool Road, Apapa	Hand-dug
30	Igbosere	Hand-dug

Table 2: Results of Water Analysis

Well no.	^{0}C	TURB	pH	EC	TDS	NO_3	Cl	Mg	Fe	Mn	Zn	ECOLI
1	29	0	6.55	151	77	0.52	24	4	0.04	0	0.82	0
2	31	0	6.55	232	118	1.36	20	8	0.07	0.03	1.56	0
3	29.5	0	6.54	1442	788	21.5	42	204	3.51	0.09	38.14	0
4	29.1	0	6.62	1148	591	4.72	160	4	2.97	0.05	26.28	0
5	28	0	6.48	815	406	3.95	44	10	2.4	0.07	17.14	0
6	28	0	5.46	564	282	2.73	18	6	1.52	0.03	9.62	0
7	29.8	0	5.26	271	142	1.76	48	8	0.16	0.02	2.225	0
8	28	0	7.44	510	234	2.82	64	14	0.3	0.02	2.77	0
9	28	0	7.77	158	81	0.58	56	4	0.02	0.02	1.05	0
10	28	0	7.59	615	281	3.56	84	2	0.48	0.06	2.84	0
11	30.8	0	5.85	515	261	3.17	52	16	0.34	0.04	2.88	0
12	24.6	0	6.24	581	293	3.52	70	22	0.53	0.06	2.53	0
13	30.2	0	5.62	407	209	2.32	70	0	0.12	0.05	4.88	0
14	29.6	0	6.53	315	158	1.7	48	28	0.08	0.04	3.26	0
15	29.9	0	6.93	988	517	7.56	98	50	0.46	0.09	13.11	0
16	30.3	0	6.33	576	296	4.1	68	22	0.25	0.08	6.29	0
17	31.1	0	6.11	652	314	3.96	100	42	0.51	0.11	6.89	0
18	28.2	5	6.68	431	225	2.55	54	18	0.22	0.07	4.56	11
19	29.4	3	6.87	926	486	3.65	110	58	0.35	0.06	8.2	12
20	30.7	0	7.24	976	504	8.02	130	48	0.41	0.09	10.4	0
21	29.3	0	5.91	506	261	2.68	82	12	0.13	0.04	5.21	0
22	28.6	10	6.06	1540	772	10.35	42	34	0.38	0.05	32.82	215
23	27.2	7	6.84	1447	773	14.72	230	0	0.54	0.09	37.53	30
24	30.1	0	6.35	412	214	2.43	62	2	0.14	0.04	0	0
25	28.5	0	5.87	417	221	3.14	56	14	0.12	0.04	3.53	0
26	28.2	0	5.95	362	189	1.82	56	24	0.08	0.02	2.1	0
27	29.8	3	6.14	433	227	3.09	64	32	0.15	0.03	2.98	11
28	28.7	0	6.84	696	347	4.93	86	22	0.22	0.06	4.08	0
29	29.9	15	6.86	465	236	2.75	55	34	0.17	0.04	3.19	120
30	29.2	2	7.07	306	153	2.56	32	10	0.06	0.02	1.87	0

Table 3: Descriptive Statistics of Water Parameters in Shallow Wells

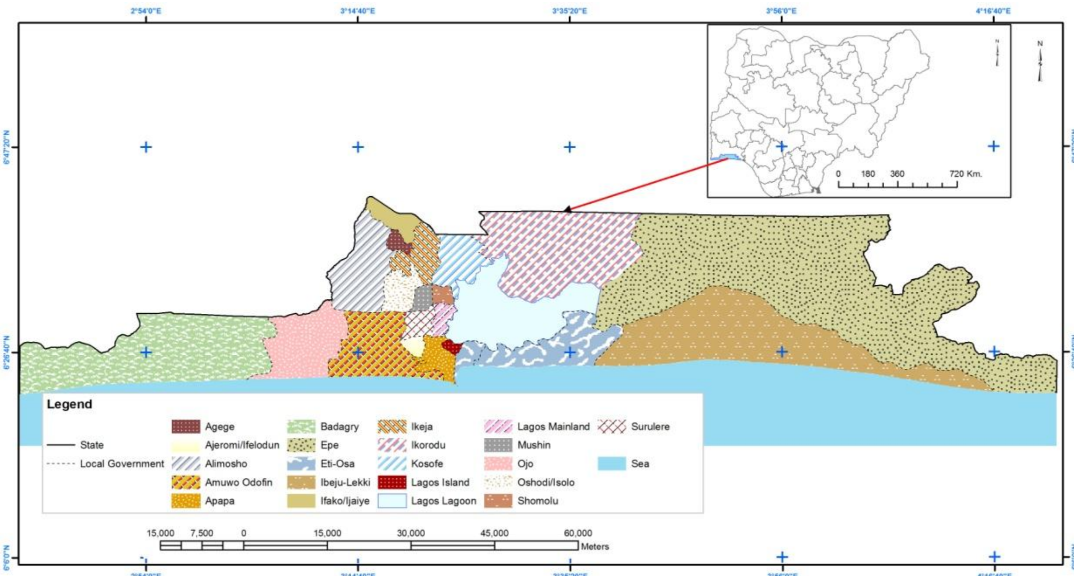
Parameter	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
Turbidity	0.00	15.00	1.50	3.49	232.67
pH	5.26	7.77	6.48	0.61	9.41
EC	151.00	1,540.00	628.57	376.67	59.92
TDS	77.00	788.00	321.87	198.87	61.79
Nitrate	0.52	21.50	4.42	4.36	98.64
Chloride	18.00	230.00	70.83	43.42	61.3
Magnesium	0.00	204.00	25.07	37.31	48.82
Iron	0.02	3.51	0.56	0.87	155.36
Manganese	0.00	0.11	0.05	0.03	60.0
Zinc	0.00	38.14	8.62	10.82	125.52
Ecoli	0.00	215.00	13.30	44.18	332.18

Table 4: Summary of Water Parameters Exceeding WHO / SON Standards

WELL NO.	LOCATION	pH	EC	TDS	NITRATE	IRON	ZINC	ECOLI	TURB	MAGNE
1	Old Toll Gate area, Badagry	6.55	151	77	0.52	0.04	0.82	0	0	4**
2	Badagry town	6.55	232	118	1.36	0.07	1.56	0	0	8**
3	Oto- Ijanikin	6.54	1442*	788*	21.5*	3.51*	38.14*	0	0	204**
4	Ojo	6.62	1148*	591*	4.72	2.97*	26.28*	0	0	4**
5	Ojodu	6.48*	815	406	3.95	2.4*	17.14*	0	0	10**
6	Oke- Ira	5.46*	564	282	2.73	1.52*	9.62*	0	0	6**
7	Ifako Ijaiye	5.26*	271	142	1.76	0.16	2.225	0	0	8**
8	Agege	7.44	510	234	2.82	0.3	2.77	0	0	14**
9	Ipaja	7.77	158	81	0.58	0.02	1.05	0	0	4**
10	Capitol Road, Agege	7.59	615	281	3.56	0.48*	2.84	0	0	2**
11	Shogunle	5.85*	515	261	3.17	0.34*	2.88	0	0	16**
12	Mafoluku, Oshodi	6.24*	581	293	3.52	0.53*	2.53	0	0	22**
13	Palm Avenue	5.62*	407	209	2.32	0.12	4.88	0	0	0
14	Mushin Olosha	6.53	315	158	1.7	0.08	3.26	0	0	28**
15	Nathan Str. ,Surulere	6.93	988	517*	7.56	0.46*	13.11*	0	0	50**
16	Ajegunle	6.33*	576	296	4.1	0.25	6.29*	0	0	22**
17	Ebute metta	6.11*	652	314	3.96	0.51*	6.89*	0	0	42**
18	Lekki waterside	6.68	431	225	2.55	0.22	4.56	11*	5	18**
19	Lekki market	6.87	926	486	3.65	0.35*	8.2*	12*	3	58**
20	Adijoh	7.24	976	504*	8.02	0.41*	10.4*	0	0	48**
21	Epe waterside	5.91*	506	261	2.68	0.13	5.21*	0	0	12**
22	Epe town	6.06*	1540*	772*	10.35*	0.38*	32.82*	215*	10**	34**
23	Ikorodu	6.84	1447*	773*	14.72*	0.54*	37.53*	30*	7**	0
24	Ketu	6.35*	412	214	2.43	0.14	0	0	0	2**
25	Bajulaiye, Somolu	5.87*	417	221	3.14	0.12	3.53	0	0	14**
26	Morroco Road	5.95*	362	189	1.82	0.08	2.1	0	0	24**
27	Akerele	6.14*	433	227	3.09	0.15	2.98	11*	3	32**
28	Police Barrack, Apapa	6.84	696	347	4.93	0.22	4.08	0	0	22**
29	Liverpool Road, Apapa	6.86	465	236	2.75	0.17	3.19	120*	15**	34**
30	Igbosere	7.07	306	153	2.56	0.06	1.87	0	2	10**

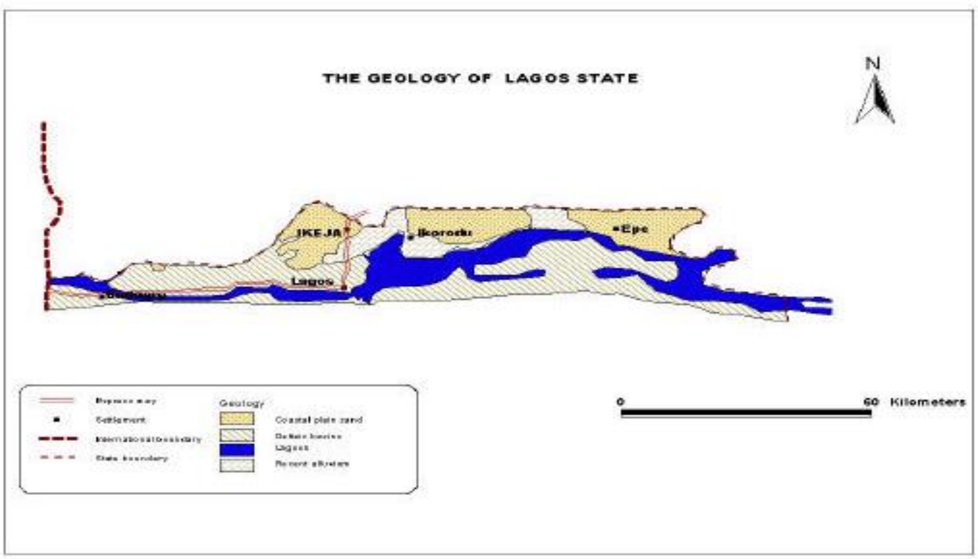
* = beyond WHO limit ** = beyond SON limit

Figure 1: Map of Lagos State Showing Location and Administrative Setting



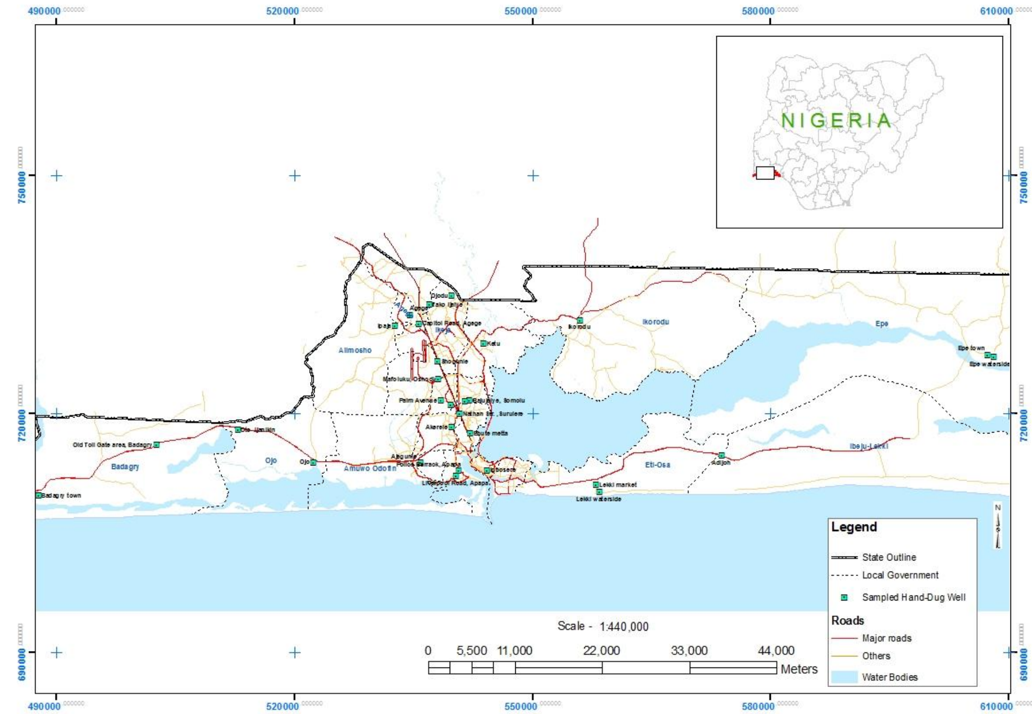
Source: Lagos State Ministry of Physical Planning

Figure 2: Geology of Lagos State



Source: Lagos State Ministry of Physical Planning

Figure 3: Map of Lagos State Showing Data Collection Stations



Source: Authors' Fieldwork

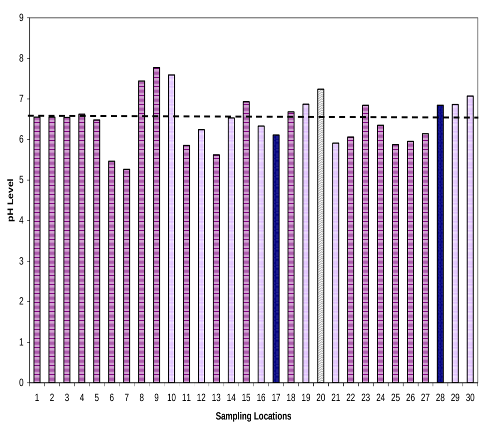


Fig.4a (pH)

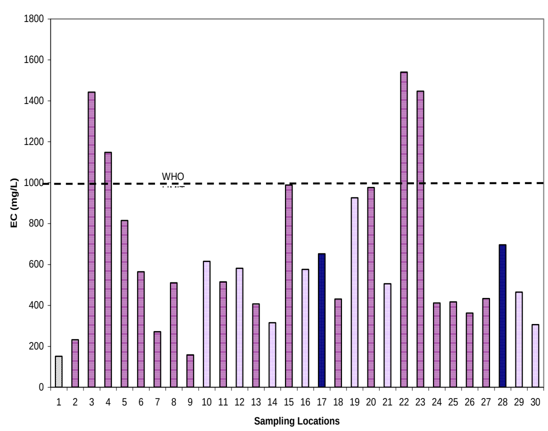


Fig.4b (EC)

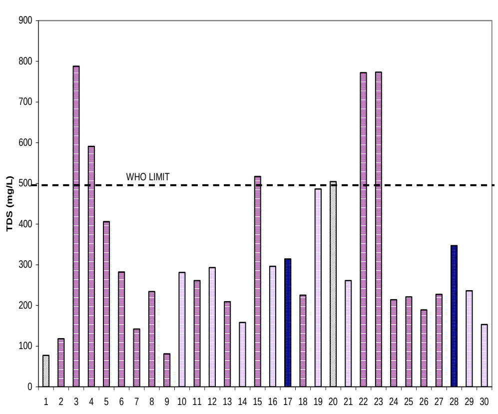


Fig. 4c (TDS)

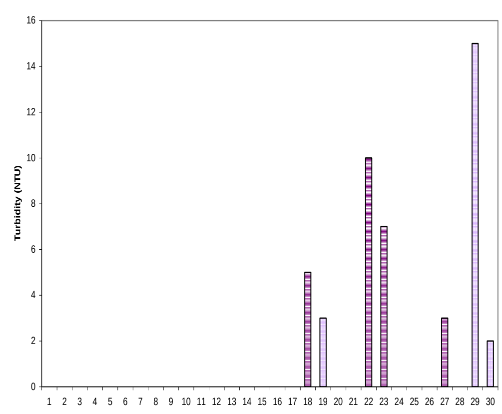


Fig.4d (Turbidity)

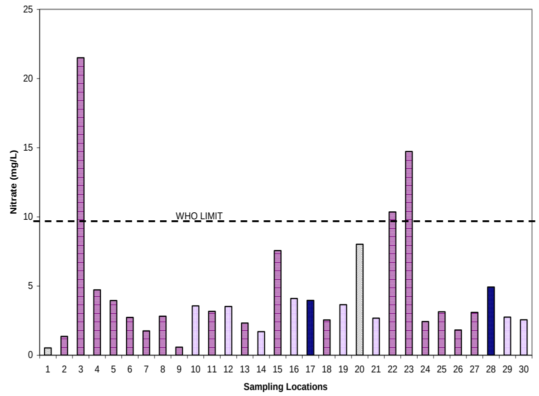


Fig.4e (Nitrate)

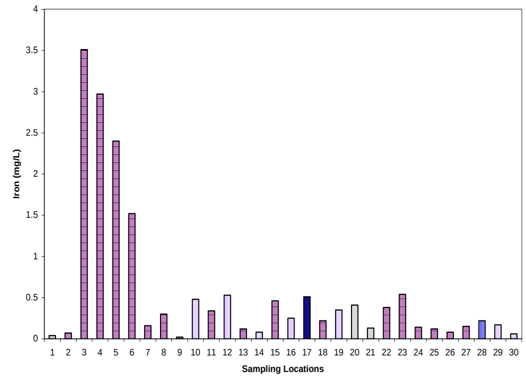


Fig.4f (Iron)

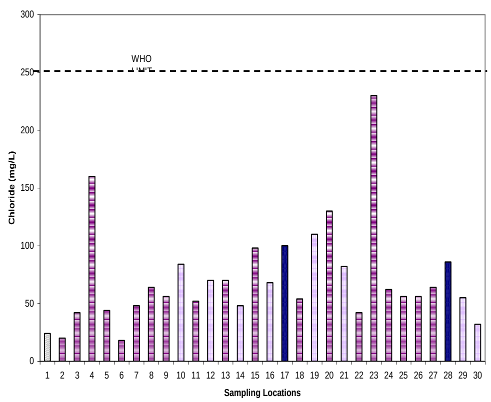


Fig. 4g (Chloride)

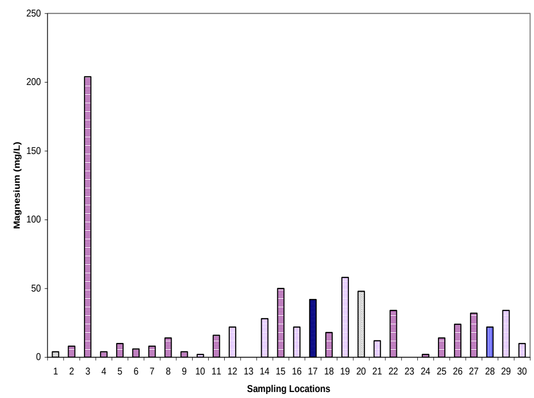


Fig.4h (Magnesium)

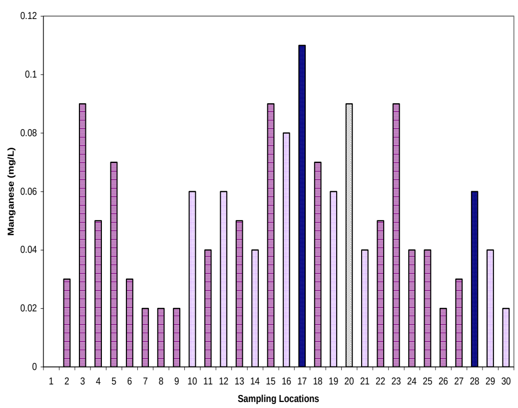


Fig.4i (Manganese)

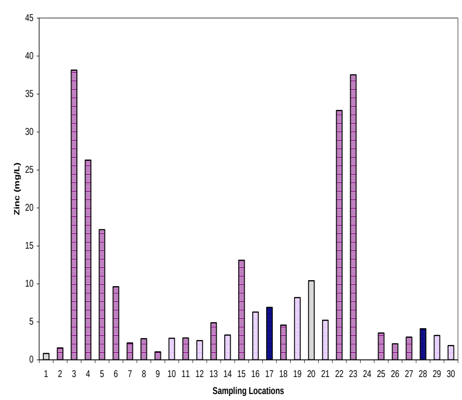


Fig.4j (Zinc)

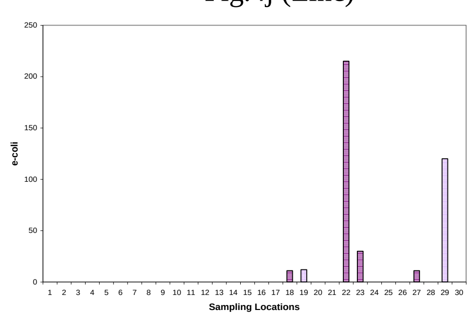


Fig.4k (e-coli)

Figures 4 (A – K): Graphs Showing Variation in Water Parameters in Different Locations

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