Global Journal of Environmental Sciences. Vol. 3, No. 1 & 2, 2004: 33 - 39
ISSN 1596-6194. Copyright Bachudo Science Co. Ltd. Printed in Nigeria by Saesprint (Nig.) Co.

POTABILITY OF SHALLOW GROUNDWATER IN ENUGU TOWN, SOUTHEASTERN NIGERIA.

O. S. ONWUKA, +K. O. UMA, and H. I. EZEIGBO

(Received 13 Feburary 2004; Revision Accepted 16 April 2004)

ABSTRACT

Eighty-eight (88) samples of the groundwater in Enugu have been studied in order to evaluate its potability. The parameters of interest are common waste-derivable chemical constituents such as nitrate (NO_3^-), chloride (Cl^-) and sulphate (SO_4^{2-}), and indicator micro-organisms, like *Escherichia coli*. The study showed that about twenty-two percent (22%) of the samples have concentrations of NO_3^- higher than the WHO permissible level (45mg/l) while eight out of the ten samples analyzed to test the bacteriological quality of the groundwater showed evidence of sewage contamination. The identification of *E.coli* in the water indicates faecal contamination. Improvement in the management of domestic wastes, such as the use of a central sewer, will preserve the aquifer, and consequently improve the quality of the groundwater.

KEYWORDS: Bacteriological examination, Enugu town, groundwater, potability, shallow aquifer

INTRODUCTION

Enugu is underlain by a Campanian-early Maastrichtian shaley bedrock called the Enugu Shale. The lithology of the Enugu Shale comprises mainly soft, grey-blue to dark-grey shales and mudstones, which essentially constitute an aquiclude. The shales have been weathered to a lateritic regolith in most parts of Enugu municipality and its immediate suburbs of Emene, Abakpa and Awkunawnaw. This regolith, however, is porous and permeable, and constitutes the only known aquifer directly underlying the city of Enugu and its immediate suburbs. The aquifer has become an important source of water supply lately. The inhabitants of Enugu exploit the aquifer through hand-dug wells.

Enugu as used in this paper refers to Enugu municipality and its immediate suburbs of Abakpa, Emene, and Awkunawnaw (Figure 1). Pipe-borne water supply in Enugu is inadequate and there are no public/deep boreholes for on-the-spot supplies as in some big towns like Kano and Port Harcourt. Most parts of Enugu are heavily populated, and this makes the problem of inadequate pipe-borne water supply more acute in such areas as Achara Layout, Uwani, and Ogui in the municipality, and also in parts of Abakpa, Emene and Awkunawnaw. The high population also affects the density of domestic waste generated. Thus, areas that are more densely populated generate more waste than areas that are less densely populated.

Enugu is underlain by shaley bedrock that is essentially non-aquiferous, except for a thin lateritized regolith. This thin sole-source aquifer directly underneath Enugu has been grossly exploited by the inhabitants through the use of hand-dug wells to augment the inadequate pipe-borne water supplies from the 9th Mile Corner area. Since the cost of developing dug wells in Enugu is low, there is the tendency for every household to own a well. The problem lies in the quality of the groundwater.

This study was undertaken to examine the physico-chemical and bacteriological quality of groundwater in Enugu in relation to established standards and criteria for water meant for human consumption.

THE STUDY AREA

Enugu is located within latitudes 6°22'N and 6°30'N and longitudes 7°28'30"E and 7°35'30"E (Fig. 1). It covers an area of 390km^2 in the southeastern part of Nigeria. It is a State capital city and has a population of about 564,500 people (National Population Commission, 1994). Enugu is at the eastern foot of a north-south trending cuesta that constitutes a major surface and subsurface water divide for two hydrogeologic (drainage) basins (the Cross River and the Anambra River) that lie to the east and the west of the town respectively.

The area has hot and humid climate and daytime temperature ranges from 27° to 32° C, while night- time temperature ranges from 17° to 28° C. Two main climatic changes occur, namely, the dry season, which lasts from early November to March, with a period of cold weather between December and early February when the Saharan anticlone from the northern hemisphere causes dry and dust-laden air mass to blow from across the desert down into Enugu; and the rainy season which lasts from April to October (Inyang, 1974). The rains are usually heavy, and the annual mean value is over 1500 mm (Federal Department of Water Resources, 1979).

Enugu assumed urban status primarily due to the discovery of commercial coal deposits by the British in 1909 (Ugwu, 1984). The present large population of the town has arisen due to the existence of numerous

O. S. ONWUKA, Department of Geology, University of Nigeria, Nsukka - Nigeria
+K. O. UMA, Department of Geology, University of Nigeria, Nsukka - Nigeria (Died 2003)
H. I. EZEIGBO, Department of Geology, University of Nigeria, Nsukka - Nigeria

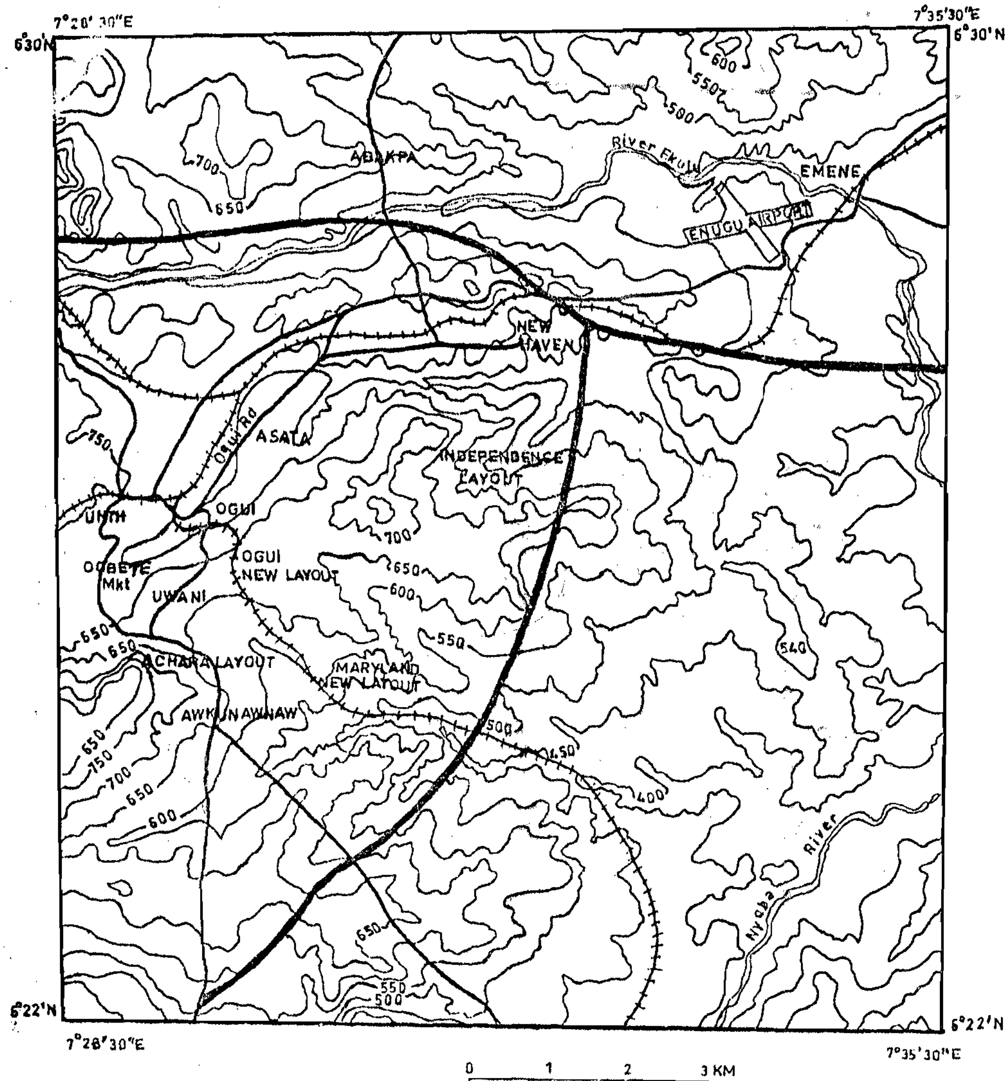

Fig. 1: Map of Enugu showing the study area(s)

industries and government offices as a state capital. The increase in population has led to large structural development in Enugu, which in turn has reduced the landscape available for infiltration; and because Enugu has an undulating and steep topography, the increase in run-off has facilitated erosion and gullying in the outskirts of the town.

The intensity of structural development and population growth is higher in the central areas of Ogui, Achara Layout, Uwani and the suburb areas of Abakpa and Emene than in the estates like Trans-Ekulu and Independence Layout (Figure 2).

Accordingly, more domestic wastes (garbage and sewage) are generated in the areas with higher population densities than in those with lower densities. The problem of waste management in Enugu has persisted over the years, and it is more pronounced in the central areas and the suburbs that are not well planned than in the estates. Farms are absent in the city, except as few scattered gardens; and as a result, there is little or no resultant input by fertilizers and herbicides to the soil and groundwater.

GEOLOGY AND HYDROGEOLOGY

The Enugu Shale underlies Enugu urban and most parts of the suburbs like Emene and Abakpa. It consists of soft grey-blue to dark grey shales and mudstones. Reijers (1996) has reported the occurrence of intercalations of sandstones and sandy shales in the formation. The shales are fractured, and they weather to blackish and greyish lateritized clay cap over the shaley bedrocks. This lateritized overburden is porous and permeable, and varies in thickness up to a maximum of about 20m, depending on topography. It constitutes the only known aquifer directly beneath the city of Enugu, and has become an important source of water supply lately. It is recharged by rainwater. The depth to the water table is controlled by two factors: the local topography and the seasons. Observations at well construction sites suggest that the saturated thickness of the lateritic aquifer varies between 0 and 7 m. The aquifer is thin, and is sometimes intercepted by the fresh bedrocks. Thus the aquifer is regionally discontinuous. Despite the shallow water table and the high possibility

Table 1. Physico-chemical quality of water samples from Enugu.

Sample Number	Source	Location	Water Table (m)	pH	Ec (µs/cm)	(Mg/l) TDS	$CaCO_3$	Cl^-	HCO^-_3	NO^-_3	SO^{2-}_4	Na^+	K^+	Ca^{2+}	Mg^{2+}
1	Well	* 61 Obioma Street.	6.0	6.2	339	220.35	17.90	70	21.78	40	6.4	42.0	10.96	4.0	1.92
2	,,	* 54 Obioma Street.	-	3.2	510	331.50	14.32	94	17.42	40	45.99	52.24	14.80	4.81	0.56
3	,,	*21 Inyi Street0	2.7	4.7	391	254.15	7.16	66	8.71	60	0.0	43.80	n.d.	8.02	n.d.
4	,,	*21 Umunogo Street	3.2	4.4	445	289.25	14.32	78	17.42	50	15.98	48.96	8.16	9.62	n.d.
5	,,	*13 Igboariam Street	4.8	4.3	502	326.30	58.02	86	82.76	0	n.d.	50.08	8.40	5.61	13.12
6	,,	* 41 Igboariam Street	7.3	4.0	1148	746.20	168.26	132	204.73	30	293.41	208.0	30.4	22	27.57
7	,,	* 45 Igboariam Street.	6.3	3.9	1234	802.1	171.84	116	209.09	70	303.87	204.0	28.0	8.0	36.9
8	,,	* 14 Ekwulobia Street	5.6	6.7	1834	1192.1	358.0	92	435.6	0	428.77	240.0	41.6	14.0	78.49
9	,,	* 15 Akpo Street.	4.6	3.8	383	248.95	14.32	52	17.42	10	22.03	45.36	4.62	2.4	2.02
10	,,	* 4 Osumenyi Street.	6.2	3.5	1029	668.85	96.66	152	117.61	10	218.25	208	55.2	6	19.84
11	,,	* 9 Osumenyi Street.	5.5	4.1	892	579.8	57.28	168	69.7	50	119.19	144	68	7.21	9.54
12	,,	* 17 Osumenyi Street.	6.2	3.6	578	375.7	10.74	120	13.07	40	16.5	68	30.12	4	0.18
13	,,	* 16 Enugu Agidi Street.	6.8	7.2	1623	1054.95	164.68	280	200.38	0	344.15	332.00	24	10.42	33.69
14	,,	* 4 Nwamba Street.	6.9	4.1	553	59.45	75.18	80	91.48	0	17.84	53.08	12.36	6	14.62
15	,,	* 3 Metu Street.	4.8	3.9	1957	1271.4	483.3	176	588.06	10	201.73	196	24	5.61	114.03
16	,,	* 14 Kenneth Road.	7.3	4.7	686	445.90	28.64	128	34.85	70	82.19	80	72	5.61	3.55
17	Well	* 17 Ozalla Street.	4.7	8.1	899	584.35	200.48	24	243.94	10	91.32	140	47.2	34.00	28.06
18	,,	* 28 Ozalla Street.	3.6	6.5	581	377.65	96.66	98	117.61	20	0.23	55.36	13.95	6	19.84
19	,,	* 39 Ozalla/Afikpo Street.	4.2	4.0	300	195.0	14.32	58	17.42	30	157.39	88	42.4	4	1.05
20	,,	* 29 Idodo Street.	73	4.1	588	382.2	28.64	110	34.85	80	18.8	68	20.53	4	4.53
21	Spring	*Along Emeka Ebuna Street	-	3.6	238	154.70	n.d.	6	n.d.	0	n.d.	9.20	2.54	2.40	n.d.
22	Well	* 27 Egbo Nnaji Street.	6.6	3.5	750	487.5	110.98	108	135.09	70	60.36	88	18.4	10	20.89
23	,,	* 13 Egbo Nnaji Street.	5.7	3.6	625	406.25	64.44	96	78.41	20	4.44	55.96	14.22	6.00	12.01
24	,,	• 28 Ikem Street	4.4	3.3	583	378.95	n.d.	78	n.d.	40	77.0	50.00	n.d.	7.21	n.d.
25	,,	• 5 Obinagu Street	4.5	3.5	466	309.90	n.d.	66	n.d.	30	n.d.	42.48	10.18	5.61	n.d.
26	,,	• 17 Udogu Street	5.8	3.2	737	479.05	n.d.	33	n.d.	10	n.d.	63.12	1.20	4.01	n.d.
27	,,	• 8 Ogbonna Street.	6.4	5.4	605	393.25	136.04	96	165.53	20	7.94	58.24	13.04	5.61	29.65
28	,,	• 130 Nike Road.	6.8	3.9	362	235.3	10.74	72	13.07	10	4.96	44.76	7.33	3.21	0.16
29	,,	• 33 Ugbene Road	7.4	3.2	443	287.95	35.80	56	43.56	70	7.20	50.00	n.d.	6.00	5.05
30	,,	• 1 Ikegbunam Street.	6.8	6.7	323	209.95	100.24	4	121.97	0	88.12	40.80	6.75	8.02	19.43
31	,,	• 35 Ugwunwani Street.	8.5	6.0	990	643.5	232.7	112	283.14	10	161.49	120	50.4	4	54.12
32	,,	• 6 Ikegbunam Street.	9.1	7.1	615	399.75	164.68	30	200.38	0	79.08	48.64	14.42	8.82	34.66
33	,,	• 6 Umuaga Street.	4.2	4.4	659	428.35	39.38	80	47.92	60	74.47	72	13.2	7.21	5.19
34	,,	• 7 Umuaga Street	3.5	3.5	509	330.85	n.d.	78	n.d.	50	n.d.	72.00	77.80	4.81	n.d.
35	,,	• 30 Umuaga Street	6.0	3.4	501		7.16	86	8.71	40	n.d.	36.00	26.40	4.81	n.d.
36	,,	• 15 Ngwo Street	5.9	3.4	412	267.80	n.d.	66	n.d.	40	n.d.	42.26	12.73	3.21	n.d.
37	,,	• 39 Nike Road	4.3	3.6	389	252.85	n.d.	74	n.d.	30	n.d.	40.80	7.39	3.21	n.d.
38	,,	• 16A Mbosi Street	4.9	5.8	1299	844.35	n.d.	244	n.d.	60	n.d.	332.00	48.96	12.83	n.d.
39	,,	• Last Bus stop/Nike Road:	4.7	6.2	161	104.65	10.74	26	13.07	30	20	23.36	5.22	4.00	0.18
40	,,	• 12 Chukwueme Street	5.7	5.6	325	211.25	28.64	78	34.85	20	13	43	23.44	8	2.1
41	,,	+ Christ Apostolic Church	2.2	7.1	669	434.85	239.86	42	291.85	20	62.19	44.0	40	68	16.98
42	,,	+ 15 Nwabueze Street.	3.2	7.1	1453	944.45	193.32	236	235.22	110	77	148	70.97	37.68	24.09
43	,,	+ Veg. Garden, Nwabueze Str.	-	7.8	773	502.45	239.86	44	291.85	40	58.66	20	66.4	66	18.19
44	,,	+ 7 Ani Lane	1.9	6.0	102	66.3	17.9	14	21.78	0	9.93	12.36	2.58	4	1.92
45	,,	+ 9B Nwabueze Street.	3.4	7.1	1091	709.15	358.00	80	435.6	10	81.11	88	4	44.09	60.21
45	,,	+ 22A Nwabueze Street.	3.0	5.7	103	66.95	25.06	14	30.49	10	5.4	10.10	2.62	4	3.66
47	,,	+ 22A Nwabueze Street.	5.7	6.5	291	189.15	53.70	32	65.34	30	23.51	26.08	10.02	14	4.54
48	,,	+ 17 Nzekwe Street.	7.0	6.0	122	79.3	28.64	6	34.85	20	28.86	13.36	7.38	10	0.88
49	,,	+ 1 M.C. Ani Lane	3.7	6.1	251	163.15	50.12	24	60.98	10	46.21	24	23.2	12	4.89
50	,,	+ 6 Chukwuejim Street.	2.3	6.2	269	174.85	32.22	30	39.20	40	57.23	36.0	18.4	7.21	3.45
51	,,	+ 13 Umuowa Street.	5.2	5.5	156	101.4	10.74	38	13.07	10	48.36	36	18.4	1.6	1.64
52	,,	+ 72/74 Abakaliki Road.	9.1	4.6	231	150.15	10.74	46	13.07	30	7.88	30.32	5.58	2.40	1.15
53	,,	+ 9 Godwin Ede Street.	5.8	5.4	434	282.1	32.22	78	39.2	30	6.94	49.76	7	4.01	5.39
54	,,	+ 11 St. Jude Street.	5.0	3.7	280	182	7.16	60	8.71	30	0.9	35.44	6.62	1.60	0.77
55	,,	+ 15 St. Jude Street.	5.4	6.1	298	193.7	25.06	72	30.49	20	0.95	39.96	12.18	4.0	3.66

* Achara Layout + Emene • Abakpa

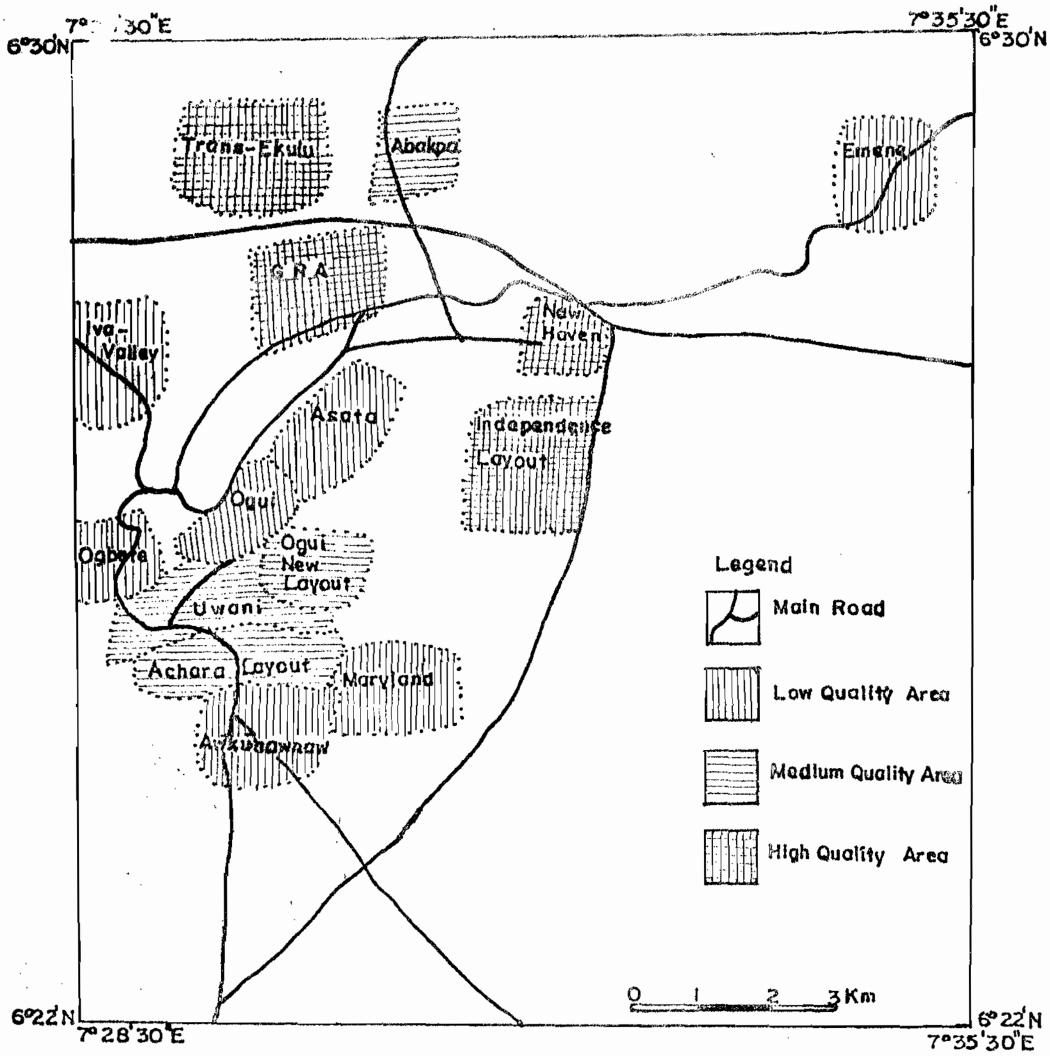

FIG. 2 : ENUGU: QUALITY OF RESIDENTIAL AREAS
Source: Ministry of Lands & Survey, Enugu

of the water table intercepting the valleys, many valleys are dry. At the peak of the rainy season when the water table is raised and the discharge volume is higher, springs do frequently occur.

MATERIALS AND METHODS

Eighty-eight (88) water samples, taken from fifty-four (54) dug-wells and one (1) spring, were analyzed for this study. Fifty-five (55) samples were chemically analyzed in the dry season (February 1997). Twenty-three (23) wells were resampled in the rainy season (September). Results of the analysis of these later samples were compared with those of the former. All the samples were collected with sterilized one-litre white plastic cans, and analyzed at the Soil Science Laboratory, Department of Soil Science, University of Nigeria, Nsukka. Ten (10) samples collected from seven (7) dug-wells in April, 1997, were analyzed to assess the bacteriological quality of the groundwater. The first seven samples were collected early in the morning before wells were opened for general use. The next three samples (duplicates from three of the wells) were collected after wells had been opened for use in the day. All the samples were collected with sterilized standard-size specimen bottles tied at the necks with clean twine rope; and preserved in buckets of ice blocks while on transit to the laboratory. When analysis was not immediately carried out, the samples were carefully preserved in refrigerators in the laboratory. They were analyzed at the Department of Microbiology, University of Nigeria, Nsukka.

Water levels were measured before laboratory samples were collected, using the UVIC electrical water level indicator. The electric conductivity (EC) and the pH were measured using the Wissenchaftlich Technische Werkstaetion (WTW) LF91 EC meter and Pye Unican 290MK pH meter, respectively. Calcium was determined by titration with ethylenediaminetetraacetate ("Versenate") solution, using the procedure described by Vogel (1961). Sulphate determination was by turbidimetric method, as described by the APHA (American Public Health Association), AWWA (American Water Works Association) and WPCF (Water Pollution Control Federation) (1971). In this method, sample was treated with conditioning reagent and barium sulphate solution, and the absorbance of resultant turbidity due to the presence of sulphate was recorded, using the

Table 2: Bacteriological Quality of Well-water samples from Enugu

Sample No.	Location	Presumptive Coliform Count/100 ml (MPN) Index	Confirmed E.coli count/100 ml
1	21 Inyi Street, Achara Layout	140	01
2	17 Osumenyi Str., Achara Layout	130	8
*2	17 Osumenyi Str., Achara Layout	1600	35
3	29 Idodo Str., Achara Layout	1800+	11
4	28 Ikem Str., Abakpa	1800+	13
*4	28 Ikem Str., Abakpa	550	9
5	33 Ugbene Rd., Abakpa	1800+	45
6	15 Nwabueze Str., Emene	3	0
*6	15 Nwabueze Str., Emene	3	0
7	22A Nwabueze Str., Emene	550	130

Bausch and Lomb Spectronic 20 spectrophotometer. Sodium and potassium were determined by flame photometric method, using the Gallenkamp Flame Analyzer, Model FGA 330C, as described by APHA *et al.* (1971). Chloride, nitrate, bicarbonate, and hardness in the form of calcium carbonate were determined by simple titration, using the Merk field chemical kits.

Presumptive coliform count test was performed using the multiple tube technique (MTT) in MacConkey broth medium. *Escherichia coli* was confirmed using Eijkman method in which the presumptive positive tubes were sub-cultured on 2% brilliant-green bile broth, and incubated at 44°C for 24 – 28 hours (Tebbutt, 1992).

RESULTS

The results of the analyses are presented in Tables 1 and 2, and in Figure 3. Table-1 shows that the samples vary from very acidic to fairly alkaline water (pH value of 3.2 – 8.1). They also have varying degrees of hardness from very soft water (< 15mg/l $CaCO_3$) to very hard water (> 180mg/l $CaCO_3$) (Linsley, Franzini, Freyberg, and Tchobanoglous, 1992). (Figure-3) is a comparison of the chemistry of the groundwater in dry and wet seasons.

DISCUSSION

Apart from nitrate (NO_3^-), the levels of the major ions, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^- and HCO_3^- (Table 1) are within the acceptable limits (WHO, 1984[1]). Nitrate introduction in the soil usually arises from farming practices and/or domestic waste disposal; and a concentration in excess of 10mg/l is often regarded as a probable indicator of contamination from these sources (Hounslow, 1995; Mueller and Helsel, 1996). Excess nitrate results in methaemoglobinaemia or "blue water baby" in children (O'neill, 1993). Nitrates contamination from agricultural sources is very unlikely in Enugu. There are few or no gardens where fertilisers, which are the main sources of agricultural input of nitrates to groundwater systems. Apparently,

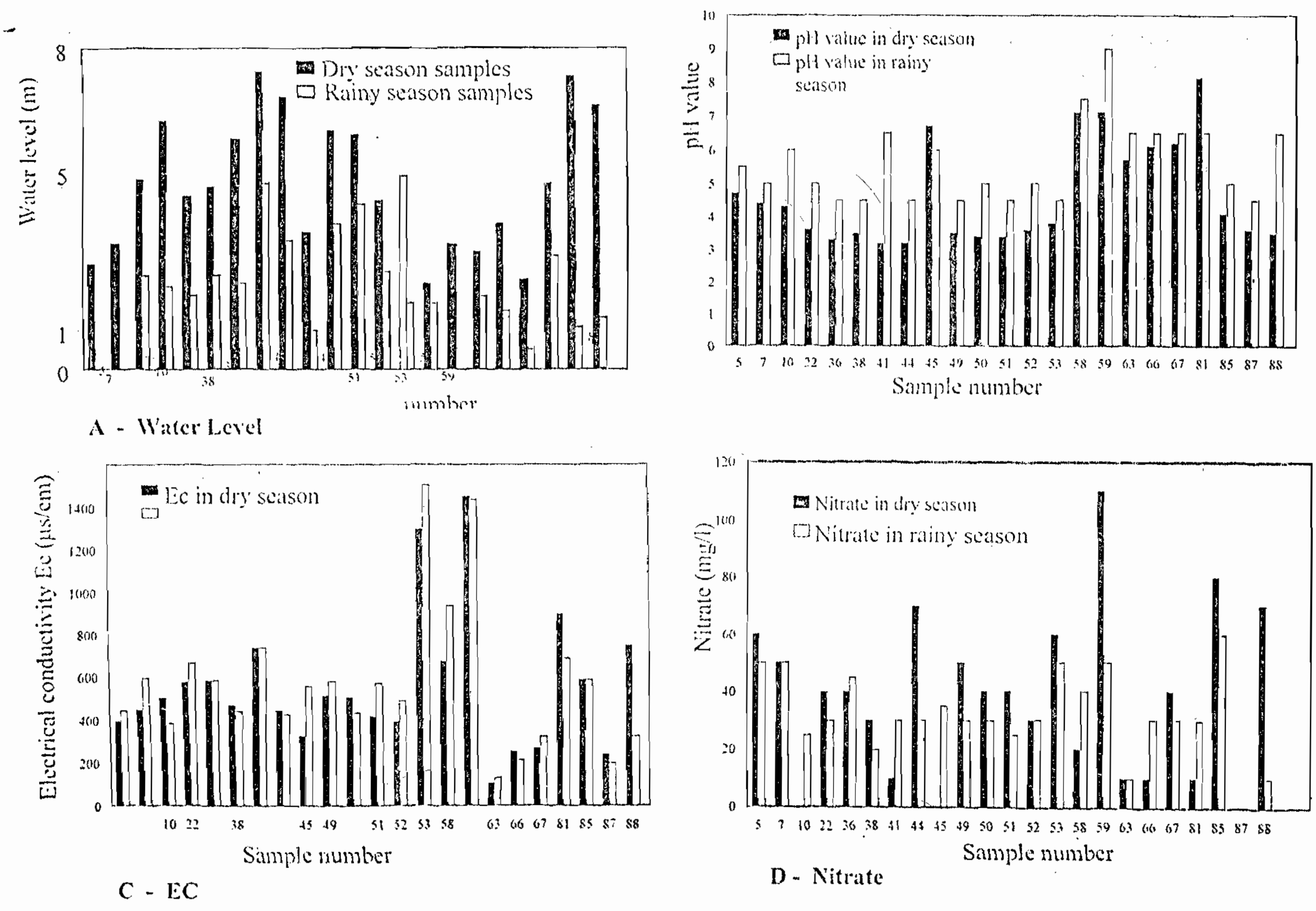

Fig. 3. Effects of the seasons on groundwater in Enugu and its environs.

therefore, nitrate contamination in the study area could be attributed to the impact of sewage contamination of the groundwater. The occurrence of irregular concentration values suggests localized point sources, which arise from careless dumping of garbage and siting of septic tanks and cesspools in and around homes. For example, at location 6, NO_3^- concentration is 30mg/l, whereas the value at location 7 is 70mg/l. Also the values at locations 42 and 43 are 110mg/l and 40mg/l, respectively. The comparisons are equally true for their Cl^- and SO_4^{2-} concentrations. Distances less than 30m in each case separate these pairs of locations. Other factors that affect the concentration of contaminants in the study area include the local topography which affects the groundwater flow pattern, the settlement pattern and the population densities of the different parts of the town which affect the level of hygiene and volume of waste generated. Also, the location patterns of wells and waste receptacles may result in easy movement of contaminants from a waste point to a water point.

Figure-3 is a comparison of the chemistry of the groundwater in wet and dry seasons. The significant rise in the water table in the rainy season is explicable. The mean annual rainfall is high, and infiltration is high, in spite of the undulating topography that facilitates runoff. The aquifer material is very porous. These factors enhance the introduction of dissolved materials to the groundwater, as indicated by increase in the electric conductivity (EC).

In some locations, the water table may rise to the ground surface in the rainy season. Examples include locations 3, 4, and 42. During this period, such elevated water table may rise above the septic tanks, resulting in sewage dilution. This is indicated by a general decrease in NO_3^- concentrations. Unless the flow path and the tracking of contaminants from a source (e.g., a septic tank) to a sink (e.g., a dug-well) proved otherwise, it would be safe, then, to conclude that there would be greater contamination of the groundwater in the rainy season than in the dry season.

The coliform count (Table 2) is a measure of the health hazard arising from the consumption of faecally contaminated polluted water. Thus, coliform count is used to assess the sanitary quality of water meant for human consumption (McCaull and Crossland, 1974; Hutton, 1983). The existence of the coliform group as a whole and the confirmation of *Escherichia coli* are indicative of faecal contamination of the groundwater and the possible presence of pathogenic bacteria like *salmonella typhi, shigella* sp., etc. (Chanlett, 1979; Lorch, 1981; Fish, 1992). All the samples, except No. 42, are unacceptable for drinking (Lorch, 1981). Further investigation (through the isolation of the *E. coli*) indicates that only sample No. 42 meets the WHO acceptable limit of zero *E. coli* counts in 100 ml of drinking water (WHO, 1984[2]).

Considering the environment of well No. 42, however, it was surprising that the water was bacteriologically acceptable. The well is located beside a dirty gutter, and it is open. Apparently, however, some materials, such as detergent or oil, may have inhibited the growth of bacteria on incubation. In addition, there could have been some technical defects in handling the sample in the course of the analysis. Sobsey (1977) observed that heat, temperature changes, and water treatment processes could damage coliform bacteria. The damaged bacteria escape the coliform enumeration and these do not grow satisfactorily in the routine procedures. The result is that the bacteriological quality of the water is over-estimated.

When the values of NO_3^-, EC and Cl^- (Table 1) were related to *E. coli* populations of the samples, all the samples, apart from no. 46, showed high values of these sewage-derivable chemical parameters. The bacteriological result is therefore a confirmation of faecal contamination of the groundwater.

The relationship between *E. coli* count and the concentration of NO^-_3 in the samples can be explained discriminately. The human intestine is the primary host for *E. coli*, and the bacteria are excreted in large numbers with faeces. Nitrate (NO^-_3) is usually produced from the decomposition of complex nitrogenous matter in faeces. The correlation between *E. coli* and NO^-_3 in the groundwater, therefore, is that both may have come from a common source, sewage.

CONCLUSION

The lateritic aquifer underneath Enugu, southeastern Nigeria, has become an important source of water supply for the people. Many households have resorted to the use of well water to augment inadequate supplies of pipe-borne water. But the aquifer is contaminated through anthropogenic sources, especially through sewage from septic/absorption tanks and solid wastes. Improvement in the waste management and well construction patterns will safeguard the aquifer. The change in waste management pattern may involve quick evacuation of waste collection centres before the refuse begins to decay and produce leachates. It will also mean the change of use of septic tanks/pit latrines by every compound to the use of a central sewer where sewage could be treated and made less harmful.

Simple water treatment practices, such as boiling and filtration, would make the groundwater potable.

ACKNOWLEDGEMENT

The Volkswagen Stiftung, Hanover, Germany provided the field hydrochemical kits used. The Merck kits for nitrates and chlorides and the pH strip are donations from Prof. W. Kinzelbach of ETH, Zurich, Switzerland. Mr. Charles Ugbor of the Shell Chair office, University of Nigeria, Nsukka, assisted the typing of this work. These forms of assistance are gratefully acknowledged.

REFERENCES

APHA (American Public Health Association), AWWA (American Water Works Association) and WPCF (Water Pollution Control Federation), 1971. Standard methods for the examination of water and wastewater (13 ed.), pp. 317-334.

Chanlett, E.T., 1979. *Environmental protection*, 2 ed. McGraw-Hill Book Company 585 p.

Federal Department of Water Resources, 1979. *Hydrogeological investigations in the sedimentary basins, v. 2.* BRGM (Nig.) Ltd Lagos.

Fish, G., 1992. Freshwaters. *In* Harrison, R.M. (ed.), *understanding our environment; An introduction to environmental chemistry and pollution.* The Royal Society of Chemistry, London, 326 p.

Hounslow, A.W., 1995. *Water quality data: Analysis and interpretation.* Lewis Publishers, N. Y., 397 p.

Hutton, L.G., 1983. *Field testing of water in developing countries.* Water Research Centre, Medmenham Laboratory, England, 125 p.

Inyang, P.E.B., 1974.Climatic regions. *In* Ofomata, G.E.K.(ed.), *Nigeria in maps; Eastern States.* Ethiope Publishing House, Benin, pp.27-29.

Linsley, R.K., Franzini, J.B., Freyberg, D.L. and Tchobanoglous, G., 1992. *Water resources engineering*, 4 ed. McGraw-Hill Book Company, pp. 506-515.

Lorch, W., 1981. Water quality. *In* Lorch, W (ed.), *Handbook of water purification.* McGraw-Hill Book Company, London, 715 p.

McCaull, J. C. and Crossland, J., 1974. *Water pollution* (Commoner, B., ed.). Harcourt Brace Jovanovich Inc., N.Y., 206 p.

Mueller, D.K. and Helsel, D.R., 1996. Nutrients in the nation's waters – Too much of a good thing? U.S. Geol. Surv. Circ. 1136: 24 p.

National Population Commission, 1994. 1991 *National census summary,* NPC Headquarters, Abuja, p.26.

O'neill, P., 1993. *Environmental chemistry.* Chapman & Hall, London, 268p.

Reijers, T.J.A., 1996. *Selected chapters on geology.* SPDC, Nigeria, 195 p.

Sobsey, M.S., 1977. Current microbiological concerns in drinking water. Conf. On water supply engineering: quality treatment and management. University of North Carolina, Chapel Hill, N.C.

Tebbutt, T.H.Y., 1992. *Principles of water quality control* (4ed.). Pergamon Press, New York, 251p.

Ugwu, F. N., 1984. Development of coal mining in Nigeria. Proc. Nigerian Mining and Geosciences Society, University of Nigeria, Nsukka, 13pp.

Vogel, A.I., 1961.*Elementary practical organic chemistry: small scale preparations, qualitative organic analysis, quantitative organic analysis.* Longmans, 870p.

WHO, 1984[1]. *Guidelines for drinking water quality,* vol. 1: Recommendations. World Health Organisation (WHO), Geneva, 100p.

WHO, 1984[2]. *Guidelines for drinking water quality,* vol. 2: Health Criteria, and Other Supporting Information. World Health Organisation (WHO), Geneva.