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Groundwater quality of Benin City urban aquifer of the Pleistocene-Oligocene Benin Formation, Nigeria

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ABSTRACT: A general investigation of the groundwater quality of the Benin City Urban Aquifer of Benin Formation for the effects of athropogenic activities shows the following results: lead (Pb) has mean value of 0.044 mg/l from 25 sampled boreholes. Seven of these borehole waters show anomalous Pb values of over 0.050mg/l. For the 25 boreholes, Pb mean value of 0.044mg/l, 0.055mg/l standard deviation and variance of 0.003mg/l are indicative of high Pb concentration compared with 0.05mg/l W.H.O. limit. Although there is low concentration-n of NO_3 with a mean value of 0.7mg/l, nitrate shows a general increase towards the more densely populated city centre. Comparatively, specific site values of nitrate concentrations of 5.65mg/l, 3.19mg/l, 1.74mg/l, 1.12mg/l, although still with safe limits; become significant as they occur within the same target seven of the 25 sampled borehole waters, two of which show 2 and 3 coliform counts (CFU/ML) respectively. These seven boreholes are found to be located near refuse dumps, breweries, cattle and livestock markets, petrol stations, and automobile (motor mechanic) repair grounds; suggesting an impact. Furthermore, a trilinear plot shows a Ca-Mg (HCO_3) water chemistry indicative of a shallow groundwater type and of short-recent geologic history.

Key words: Groundwater quality; Groundwater/Surface water relation; Contamination; Nigeria.

Introduction

Benin City is a growing urban centre with increasing population; 100,694 in 1963, 800,000 in 1991. It is projected to rise to 2,160,000 by 2021, using 5% growth rate. Human activities are on the increase ranging from soil fertility remediation to indiscriminate refuse disposal and increased use of septic tanks and soakaway pits.

These activities are bound to produce leachates into the sandy Benin Formation of Oligo-Pleistocene age. It is the major host of groundwater aquifers that serve as source of water supply to the city. The water supply system in the city, which depends heavily on the Ikpoba River Dam, serves only about 30% of the population. The other 70% derive their water from the numerous boreholes sunk for private, agricultural and industrial purposes. Water sale is now a thriving business in town.

There was a case in 1998 when five men died in an uncompleted uncased shallow dry well in Oko quarters within Benin City urban, cause probably by axifiation from poisonous gases (probably CO_2) produced by decaying organic matter in the soil.

Some research work has been done on many aspects of groundwater related problems in Benin City and the environs. Orubima (1983), reported the case history of the Abudu Pipeline Oil spillage some 35km east of Benin City. Utomivan (1986) worked on groundwater fluctuation in Benin and environs. Ohagi and Akujieze (1989), reported high iron concentration in borehole waters in Benin City. Imeokparia and Offor (1992) observed high levels of Fe, Pb, Ni, Cu in Ogba and Ikpoba rivers of Benin City. Ezeigbo and Aneke (1993) wrote on water resources development of Benin City. Tawari-Fufeyi, P. (1994) identified anomalous Pb concentration in the gills and muscles of Tilapia Marcae (Boulenger) and Chromidotilapia Gientheri (Sauvage) fishes from Ikpoba Dam Reservoir.

Nevertheless, no detailed studies had been done to understand the interaction between the environment (activities) and the underlying groundwater storage systems underlying Benin City urban.

The present study attempts to determine groundwater quality in Benin City urban aquifer and the consequent changes due to certain land use. It will serve as a stepping stone for further studies and future groundwater management.

Materials and Methods

Study area

Benin City urban, the capital of Edo State (Fig. 1) bounded by latitudes (6°06', 6°30') N and longitudes (5°30', 5°45') has an area extent of about 300km^2. The population has been growing. 100,694 in 1963, 352,571 in 1977, 780,976 and using W.H.O., annual growth rate of 5%, the population would be 1,335,734 in 2002, and 2,175,770 in 2012. Human activities include remediation of soil-fertility in agriculture through use of fertilizers, established cattle and livestock pens in markets, cassava mills, timber-wood treatment and saw mill yards, coloured photo tech. laboratories, foam factories, bottling companies and breweries, battery assembly and repair centres, petroleum storage depots and oil pipelines metal works, auto repair, and auto disassembly, butchering yards, and quarrying and indiscriminate refuse dump (at quarry points) increased use of specific tanks and soak-away pits for disposal of human and household wastes.

Benin City is within the Tropical Equatorial Zone dominated by two climatic seasons viz: dry season and wet season. The dry season usually starts in November and ends in April while the wet season usually starts in April and ends in October. Precipitation in mainly by rainfall during the wet season and a mean annual value of 211mm indicating a large volume of water input into the environment.

Geology

Benin City is underlain by the sedimentary formation referred to as Benin Formation (Fig. 1).

The formation was established by well logging of Etete 1 drilled on shore east of the Niger by Shell Nigeria Ltd., and described by Short and Stauble, (1967). The name Benin Formation was used by Rayment (1965) to describe the extensive reddish earth made up of loose ill-sorted sands underlying the Recent-Quaternary Deposits of the Upper fringes of the Niger Delta. Tatam (1947), earlier used the name Coastal Plain Sands to describe the formation of top red earth underlain by sands, clays, exposed in paleocoastal environment now in Owerri, Onitsha and Benin areas with the age Oligocene to Pleistocene. The formation is made up of top reddish clayey sand capping highly porous fresh water bearing loose pebbly sands, sand and sandstone with local thin clays and shale interbeds which are considered to be of braided stream origin. The sands, sandstones and clays vary in colour from reddish brown to pinkish to yellow on weathered surfaces to white in the deeper fresh surfaces. The brown reddish-yellowish colour is due to limonitic coatings.

The formation is poorly bedded and occasionally crossbedded. The Benin Formation locally covered with Quarternary drift (loose brownish sand) varies in thickness but attains a maximum thickness of 6000ft (approx. 1970m) near the sea shore. Under Benin City, it is about 800m thick; almost all of which is water bearing. It is one of the most prolific aquifers in Nigeria. The water level varies from about 20m along Sapele Road to 52m on Ikpoba Hill. Interestingly, the lithological and water quantity contrast sharply with the underlying Ogwashi-Asaba Formation. At NIFOR, for example, the aquilfer is poor and contain high iron.

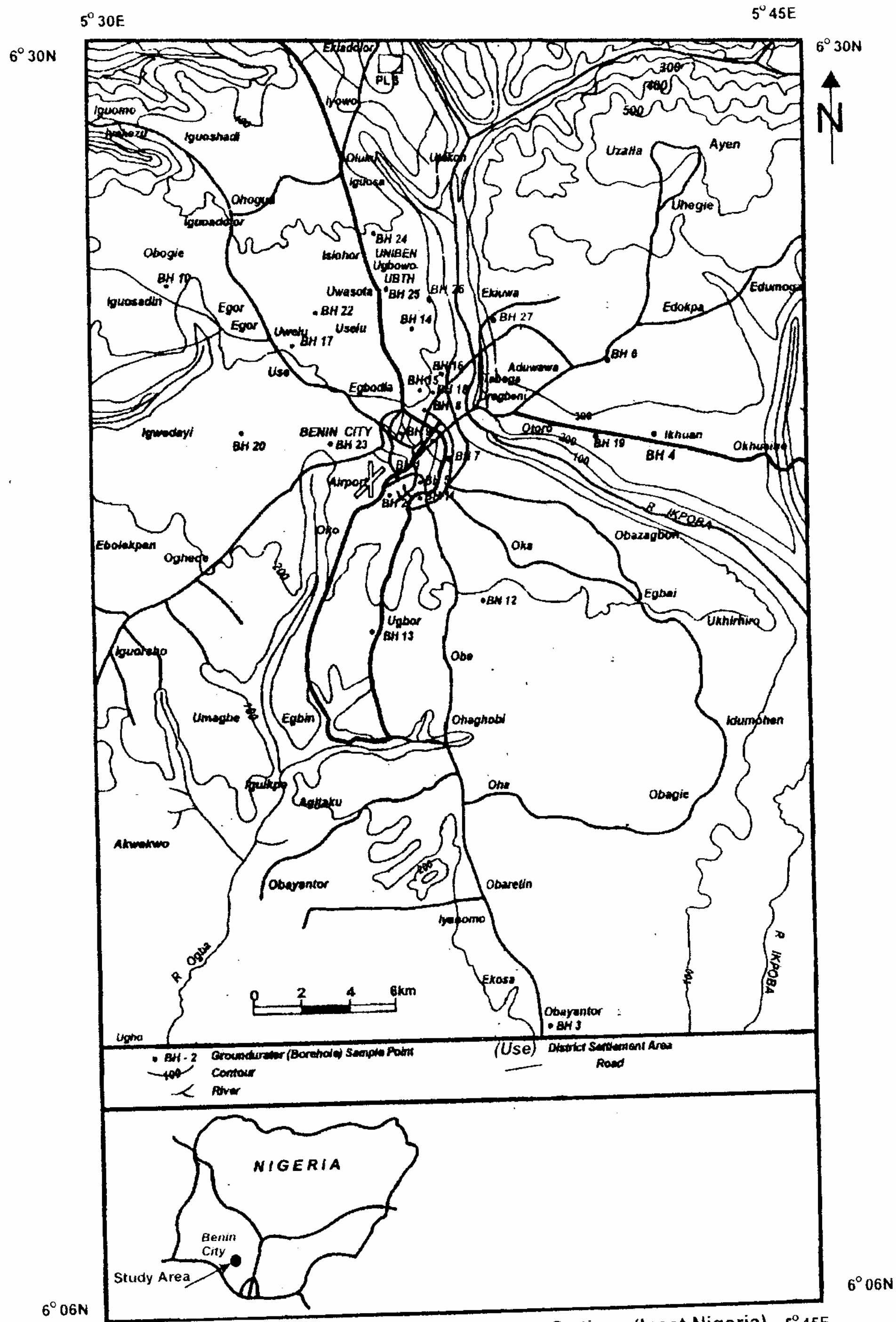


Fig. 1: Map of Study Area and Sampling Stations (Inset Nigeria)

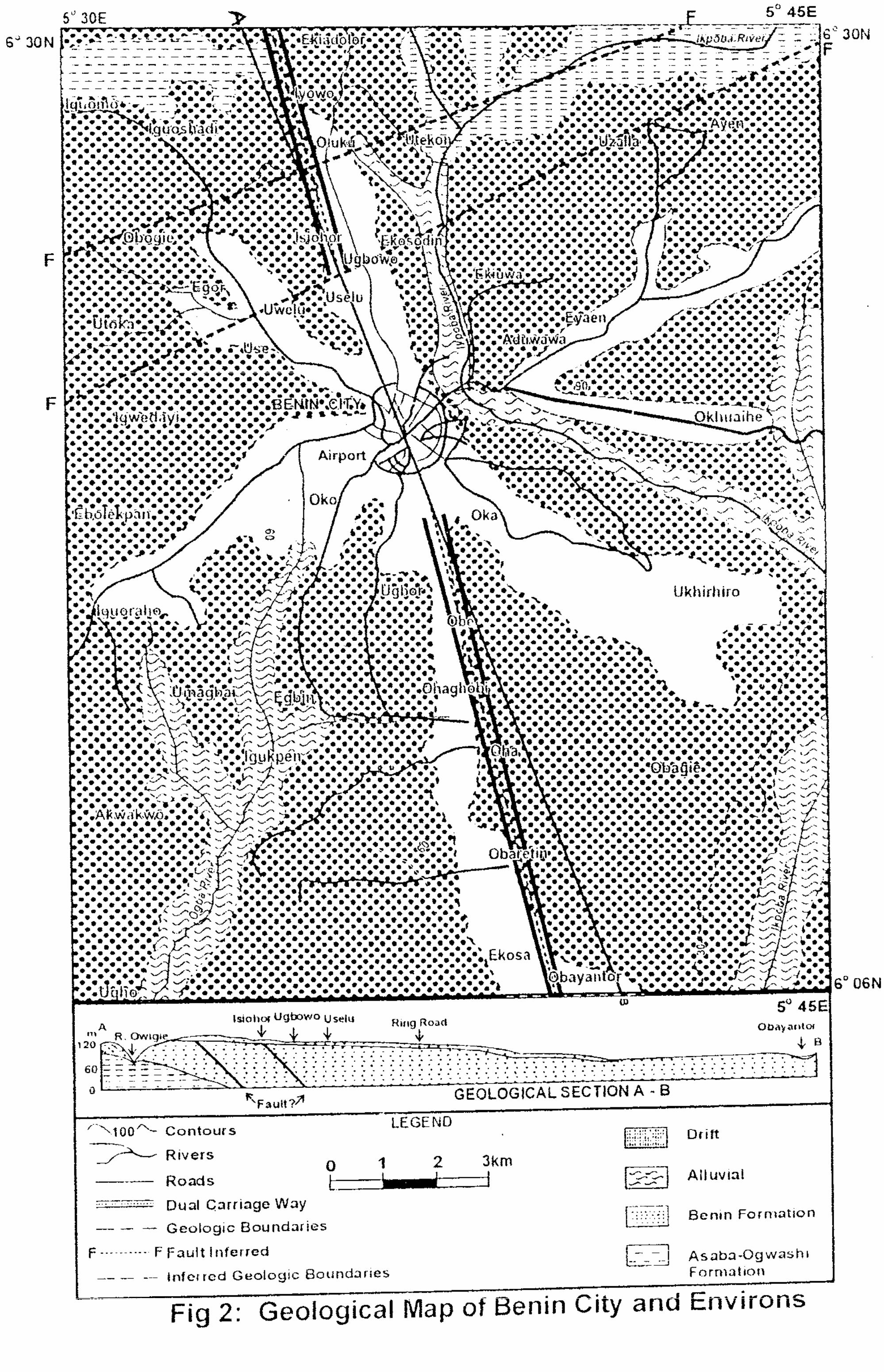


Fig 2: Geological Map of Benin City and Environs

Groundwater/Surface Water Conditions

The aquifer yields range from 28.4m^3 hr^{-1} at Iyanomo to 208m^3 hr^{-1} at Ogbe with draw down ranging down from 4.8m at Iyanomo to 6.7 at Ogba. A draw down of 1.8m and a yield of 125m^3 hr^{-1} had been recorded at Uselu. Generally the aquifer vary from semi confined to confined and may be unconfined in some places. Because of its loose and unconsolidated texture, the formation is generally believed to be highly permeable and porous and prolific in water yield.

Sections across the Ikopa River just South of the Ikpoba Dam Reservoir between boreholes 26/27 and south of the Ikpoba Bridge between boreholes 6 and 7 indicate influent water flow from the river into the aquifer and effluent flow from the aquifer into the river respectively. This is significant in terms of aquifer recharge, aquifer vulnerability and river discharge. See Fig. 3-4.

The area was mapped out geologically and the following features located; borehole points, refuse dump sites, farmlands, livestock pens/markets. At the intereme auto mechanics, auto-disassembling yards, metalwork yards, and their soil characterization/chemistry are yet to be studied. Water samples from dispersed pumping boreholes points all over the city were drawn. 25 borehole water samples were taken and analysed for the concentration of Ca, Mg, Na, K, SIO_2, Fe, Cu, Pb, Zn, PO_4, Cl, NO_3, SO_4 alkalinity (HCO_3), pH, electrical conductivity, turbidity total dissolved solids (T.D.S) and total suspended solids (T.S.S.) microbial analysis and coliform count were also carried out in the laboratory.

Samples were collected in 2-L polythene bottles previously soaked in 10% nitric acid, and rinsed with de-ionised distilled water. Collected samples labelled and stored in iced (0-4°C) coolers in which samples were moved to the laboratory where analyses were done within 24 hours of collection.

Heavy metals viz: Chromium (Cr), Manganese (Mn) and Lead (Pb) were determined colorimetrically using the spectronic 21-D spectrophotometer following the procedures outlined in the standard method for water. Analysis for iron (Fe) involved the use of orthophenlphthalen in colour development while 2, 2-Biquinonyl method was used for copper (Cu). This was also used for colour measurement. Sodium (Na) and Potassium (K) values were determined using Technicon Auto Analyser Flame Photometer. Concentration of calcium (Ca) and Magnesium (Mg) were titrimetrically determined using solution of disodium salt Ethylene Diamine Tetra Acetic Acid (EDTA) and using Erichron Black T. and Calcon as indicators.

Results

The results of chemical and bacteriological analysis is as shown in Tables 1 and 2. Results were compared with WHO permissible limits. Furthermore, the concentration values were plotted on graphs and contoured to illustrate distribution pattern amidst the background features of land use, like dump sites borehole locations, cattle – livestock markets – pens to decipher possible impact sources (Figures 6-9). Trilinear plot was done for further study of water chemistry, trend and classification.

Coliform content

The boreholes show the presence of coliforms; boreholes 4 and 6 at Ikpoba Hill and Aduwawa respectively show 2 and 3 coliform count per ml.

Table 1: Chemical analysis of groundwater in Benin City.

H	STATIONS	(A) GLE (m)	(B) SWL (m)	E/C us/cm	TDS mg/l	TSS mg/l	ALK mg/l	Cl mg/l	SO4 mg/l	Ca mg/l	Na mg/l	K mg/l	Mg mg/l	pH	Tutb mg/l	SiO2 mg/l	NO3 mg/l	PO4 mg/l	Zn mg/l	Cu mg/l	Fe mg/	Pb mg/l	Cfu	DTW A-B (m)
	W.H.O Limit			1000	1000		50	250	250	200	200	200	150	6.5/92	5	250	50	15	30	2	0.3	0.05	0	0
1	Central Road	88.4	63.2	230.3	210.75	17.18	75	15.26	15	1.48	6.2	3.65	5.6	6.61	3.75	2.62	0.24	0.4	0.21	0.01	0.03	0.01	0	25.2
2	Pastoral Centre	76.2	44.21	100.9	47.84	14.32	15.02	8	0.27	6	3.8	4.8	7.2	6.76	4.75	4.3	0.02	0.68	0.3	0.03	0.09	0.02	0	32
3	Obayantor	35	33	40	29.04	13.42	10	8	1	8	42	5.12	7.0	6.52	3.75	0.94	2.64	4.27	0.6	0.05	0.03	0.01	0	15
4	Ikpoba Hill	94	66.8	37.6	21.95	12.4	6.08	12.84	0.04	2	12.5	5	2.43	6.8	10	0.6	3.19	0.73	0.33	0.03	0.02	0.28	2	27
5	Palm House	80.2	63	152	138.1	14.14	40.1	2	1.32	4	4.2	5.56	2.4	6.9	5	5.5	0.03	0.63	0.38	0	0.04	0.02	0	23.2
6	Ikpoba Hill	91.5	65	50.71	34.04	18.6	13.51	12.25	0.1	6.8	31	4.6	9.26	7.08	8.75	4.94	5.56	5.45	0.48	0.01	0.05	0.08	3	26.5
7	St. Manel – Isije	79	53.5	66.05	40.32	8.92	20.45	18.14	0.3	12	4	2.1	12.4	6.94	15	5.89	0.77	0.94	0.3	0	0.11	0.09	0	25.5
8	Federal Road	88.4	61	110.2	75	6.1	38.14	15.26	1.24	4	6.2	3.6	5.6	6.6	8.75	6.8	0.22	0.65	0.36	0.05	0.02	0.03	0	27.4
9	Iyaro	87	54.12	35.83	25.68	9.11	15.25	4	1.5	4.6	3	3.65	7.2	6.55	11.3	6	5.24	0.07	0.15	0.01	0.06	0.09	0	32.8
10	Use - Siloko Rd	86	47.3	57.47	50	4.25	25	40	1.24	8	9.1	13.5	14.4	6.68	13.8	1.49	1.74	0.6	1.3	0	0.12	0.06	0	38
11	Exotii	85.4	63	125.5	123.76	12	36.54	14	0.18	4	3.5	5.12	4.6	6.84	7.25	5.4	0.22	0.6	0.26	0.01	0.02	0.03	0	22.4
12	Dumez Road	76.4	48	30	16	10.72	9.1	2	0.05	8.16	4.5	4.2	4.88	7.4	1.25	6.75	0.15	0.01	0.52	0.05	0.04	0	0	28.2
13	Iyayi – Uhor – GRA	58	37	51.3	44.24	18.71	7.84	16	0.25	5.4	3.1	4.6	7.0	6.42	6	3.1	0.03	0.72	0.15	0.03	0.04	0.01	0	21
14	Technical Coll. Rd	91.46	63	62.1	36	8.48	13.52	6.51	0.83	4.2	4.2	8.75	2.4	6.76	25	4.44	0.01	0.05	0.41	0.01	0.1	0.04	0	27.4
15	Medical Road	91.5	67.5	90.6	7.64	14.24	30.75	24	0.8	4	3	5.12	7.0	6.74	10	0.8	0.02	0.1	0.43	0.01	0.4	0.03	0	24
16	Mission Road	54.87	39	60	58.74	21.32	25	28.4	2	4	4.25	5.8	2.4	7.86	15	4.55	0.01	0.1	0.21	0.05	0.15	0.03	0	15
17	Textile Mill Road	85.4	53.4	130	126.1	8.71	7.15	9.09	0.19	4.02	2.06	1.44	2.86	6.88	2.5	6.7	0.01	0.18	0.36	0.06	0.08	0.02	0	31.96
18	Okhoro -- Iyayi	97.5	69.6	45	24.32	14.21	6.8	12.95	0.7	3.4	3	1.92	2	6.68	3.75	9.13	0.23	0.46	0.18	0.06	0.04	0.02	0	27.9
19	Guiness Brewery	75	45.4	82.75	73.4	2.29	50	15.36	1.22	4.02	3.6	2.94	2.4	6.87	2.5	5	0.12	1.26	0.15	0.01	0.02	0.1	0	29.6
20	Evbotubu	58.2	37.5	90.72	68:09	101.7	36.76	20	0.06	5	4	4.2	4:6	7.08	2	0.56	0.55	0.99	0.65	0.06	0.04	0.03	0	20.7
21	Erhunwunse	67.1		70	65.24	29.61	40.14	16	0.09	10	9.27	8.6	14.6	7	3.75	0.75	0.66	0.6	0.7	0.06	0.03	0.04	0	0
22	Uwasota	85.4	56	63	48.3	23.41	6.7	20.9	0.26	8	4.64	7.8	4.8	6.59	6.25	0.38	0.81	0.91	0.45	0.09	0.03	0.03	0	29.4
23	Ekenwan Campus	76.2	49	100.1	69.1	8.41	15.3	12	0.8	4	3.8	5	7.2	6.85	3.75	4.13	0.48	0.1	0.43	0.02	0.02	0.01	0	27.2
24	Universit of Benin	105	64.5	32.13	28.92	5	49	8	1.5	8	3.1	5.14	2.4	6.91	3.75	9	0.33	0.7	0.43	0.02	0.05	0.02	0	40.5
25	UBTH Ugbowo	103	64	51	45.26	5.93	32.64	6.5	1	7.1	286	1.4	3.5	6.8	10	2.15	0.22	0.04	0.35	0.02	0.08	0.01	0	39.6
	Mean			73.11	44.9	16.12	25.43	13.81	1.3	5.6	4.6	5.01	6.72	6.8		4	0.7	0.82	0.4	0.03	0.06	0.04	0	0

TABLE 2: CONCENTRATION IN Mg/WATER SAMPLES FROM BENIN CITY 1993 & 1999 A COMPARATIVE STUDY

Station/Year	Mg	Ca	Na	Fe	Cl	NO_3	PO_3	SO_4	S_iO_2	pH
IYARO 93	0.89	2.90	3.00	0.00	3.40	0.00	0.00	4.60	5.00	5.00
IYARO 99	7.20	4.60	3.00	0.10	4.00	5.24	0.07	1.50	6.00	6.55
UBTH 93	2.50	7.00	2.00	0.10	3.40	0.10	0.07	2.50	5.00	5.00
UBTH 99	3.50	7.10	2.86	0.10	6.40	0.22	0.04	1.00	2.15	6.80
UNIBEN 93	1.70	4.70	3.00	0.00	2.50	0.00	0.00	3.50	2.70	6.91
UNIBEN 99	2.40	8.00	3.10	0.10	8.00	0.33	0.07	1.50	9.00	6.00
ST EMMANUEL 99	0.50	5.6	4.40	0.00	1.30	0.10	006	0.68	5.00	6.94
ST EMMANUEL 99	12.40	12.00	4.00	0.11	18.14	0.77	0.94	0.30	5.89	6.00
IKOBA 93	0.6	2.97	3.5	0.10	4.5	0.0	0.30	5.7	2.5	5.8
IKOBA 99	9.26	6.80	3.10	0.05	12.25	5.65	5.45	0.10	4.94	7.08
PLAM HOUSE 93	2.7	7.3	4.5	0.0	3.0	0.0	0.64	2.50	5.00	6.00
PLAM HOUSE 93	2.0	4.0	4.20	0.04	2.00	0.33	0.63	1.32	5.50	6.90
OBAYANTOR 67	0.0	0.0	0.0	0.04	16.00	0.15	0.0	0.0	1.0	6.0
OBAYANTOR 99	7.0	8.0	4.2	0.09	8.0	2.65	2.47	1.0	0.94	

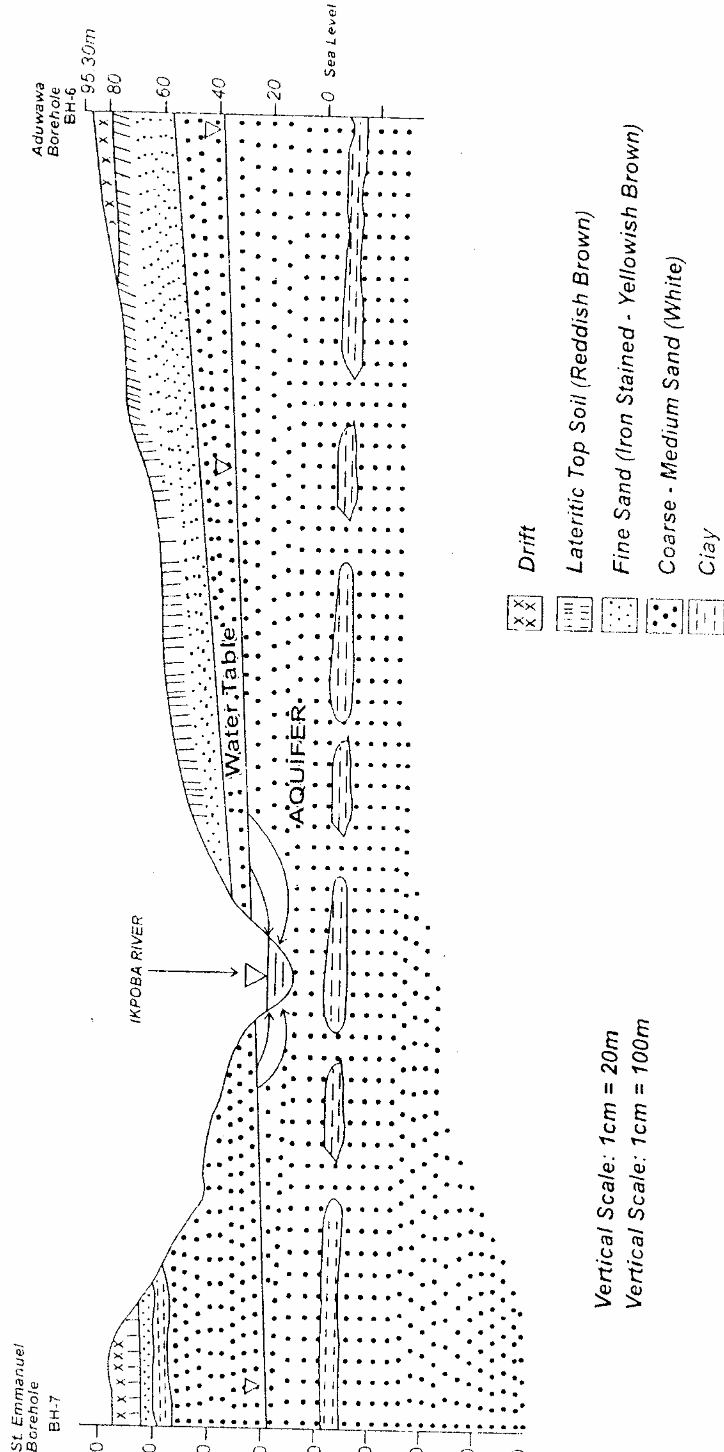


Fig. 3: Section showing Aquifer Disposition and Ikpoba River (between ST. Emmanuel Borehole and Aduwawa Borehole) Illustrating Effluent flow from the Aquifer South wards of Benin City.

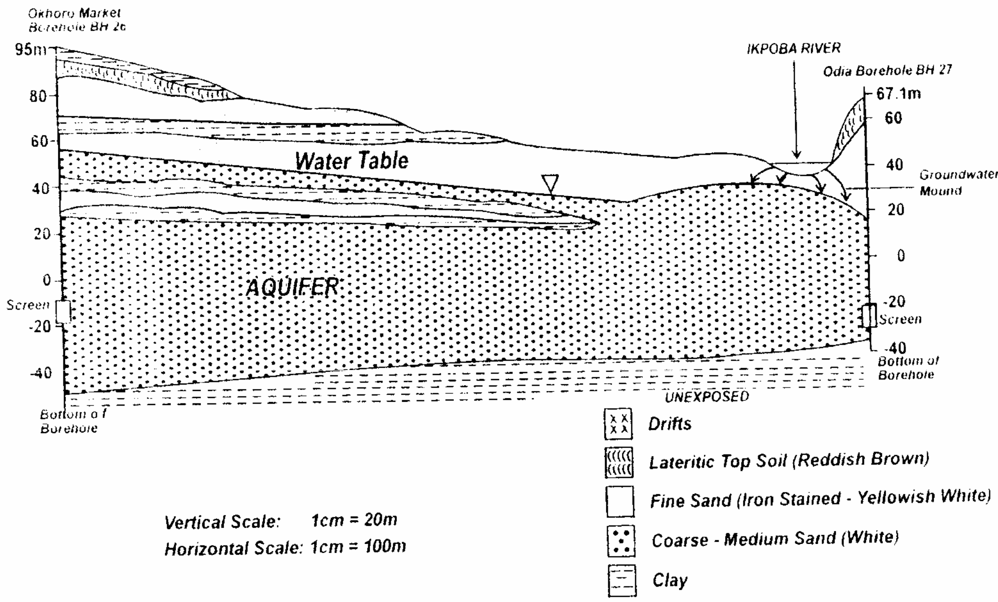


Figure 4: Section showing Ikpoba River Aquifer Relationship. (Influence flow is Illustrated)

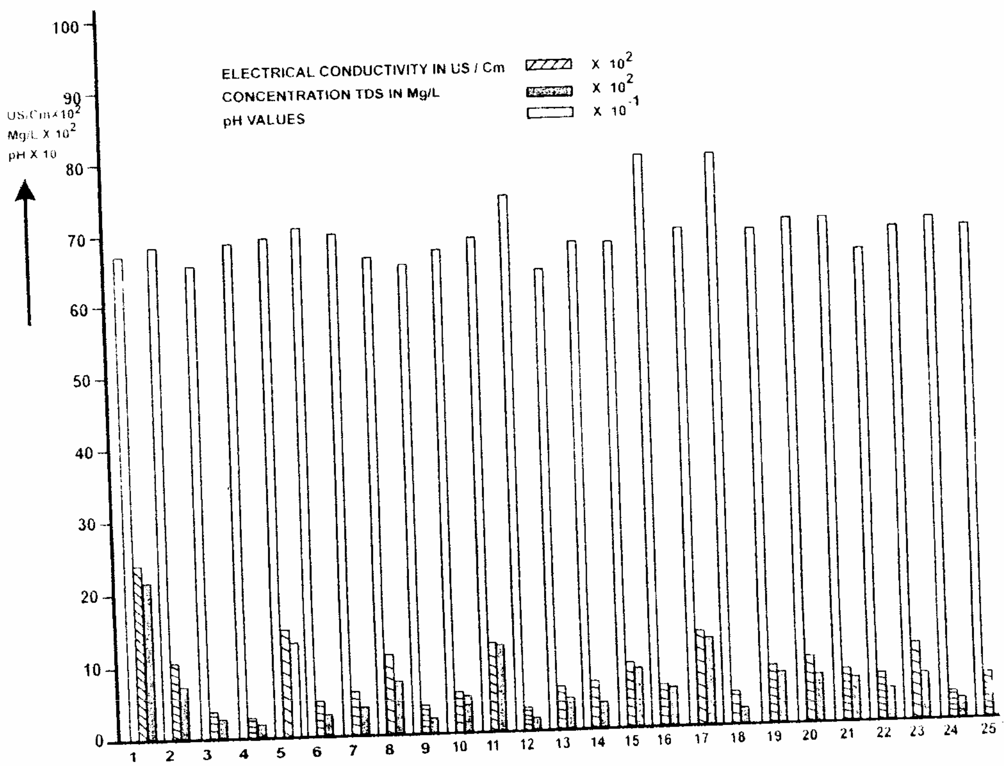


Figure 5: Variation of pH, Total Dissolved Solids (T.D.S), and Electrical Conductivity (EC)

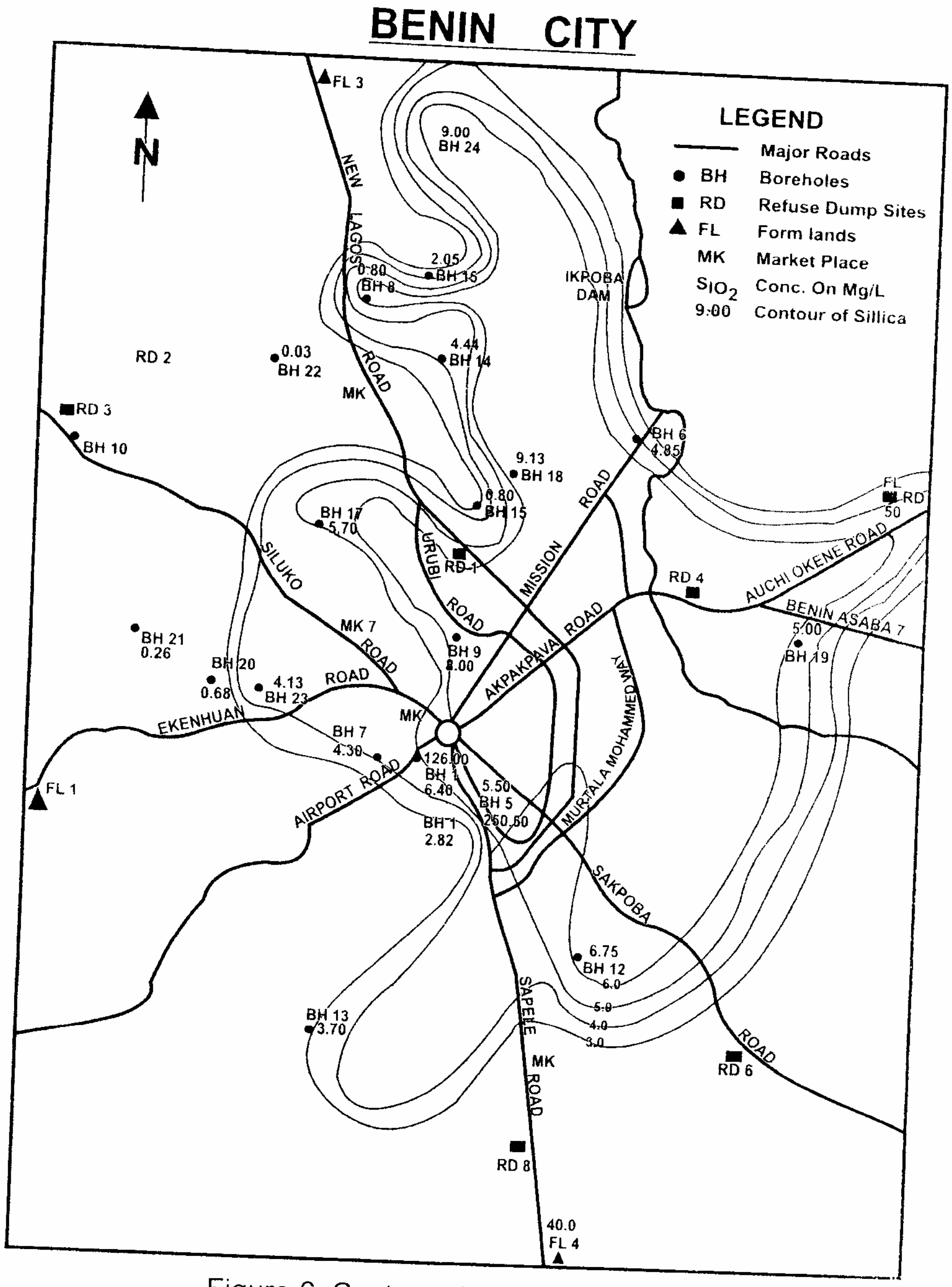


Figure 6: Contoured Isopleths of Silica

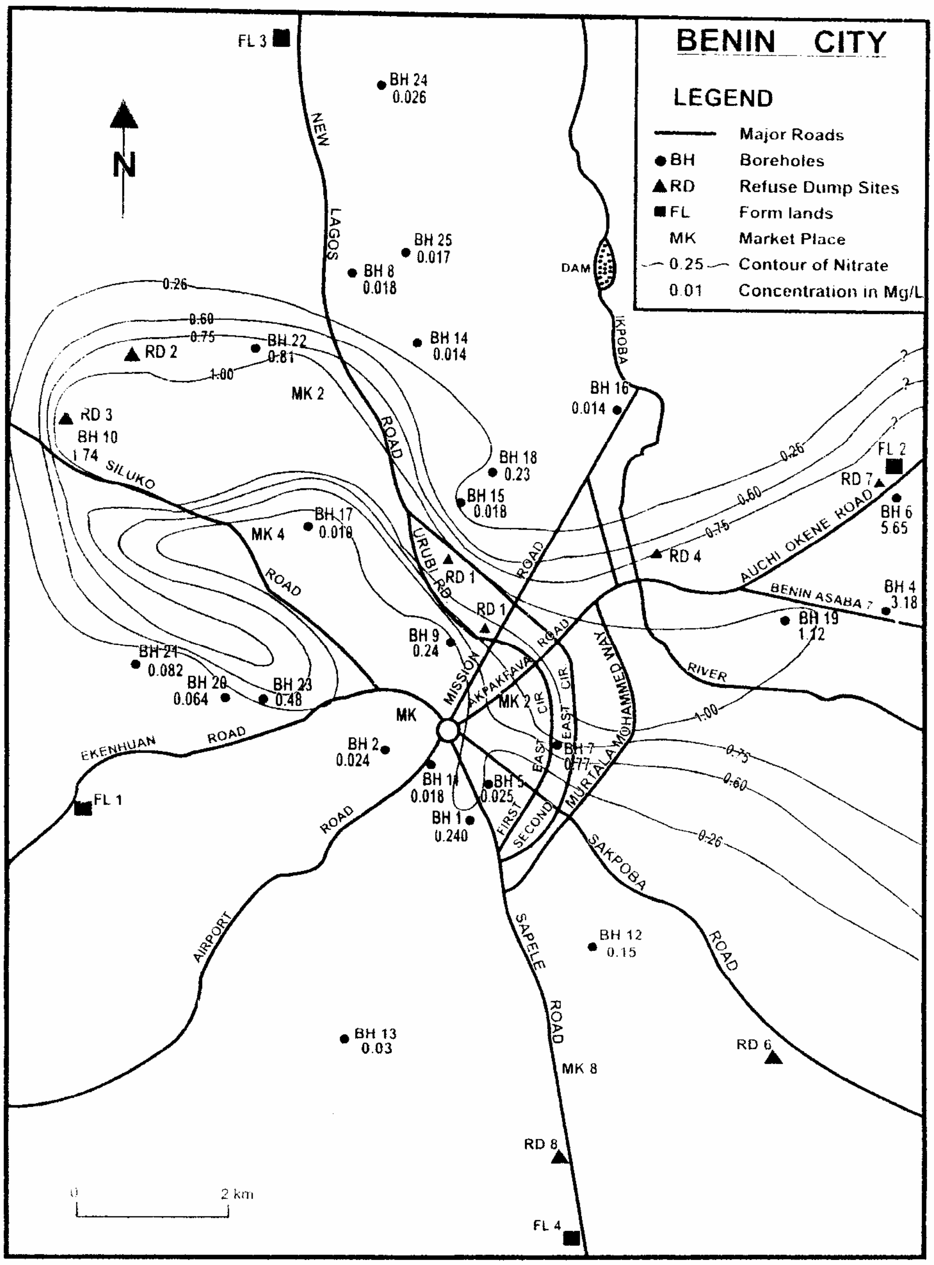


Figure 7: Contoured Variation of Nitrate Isopleth

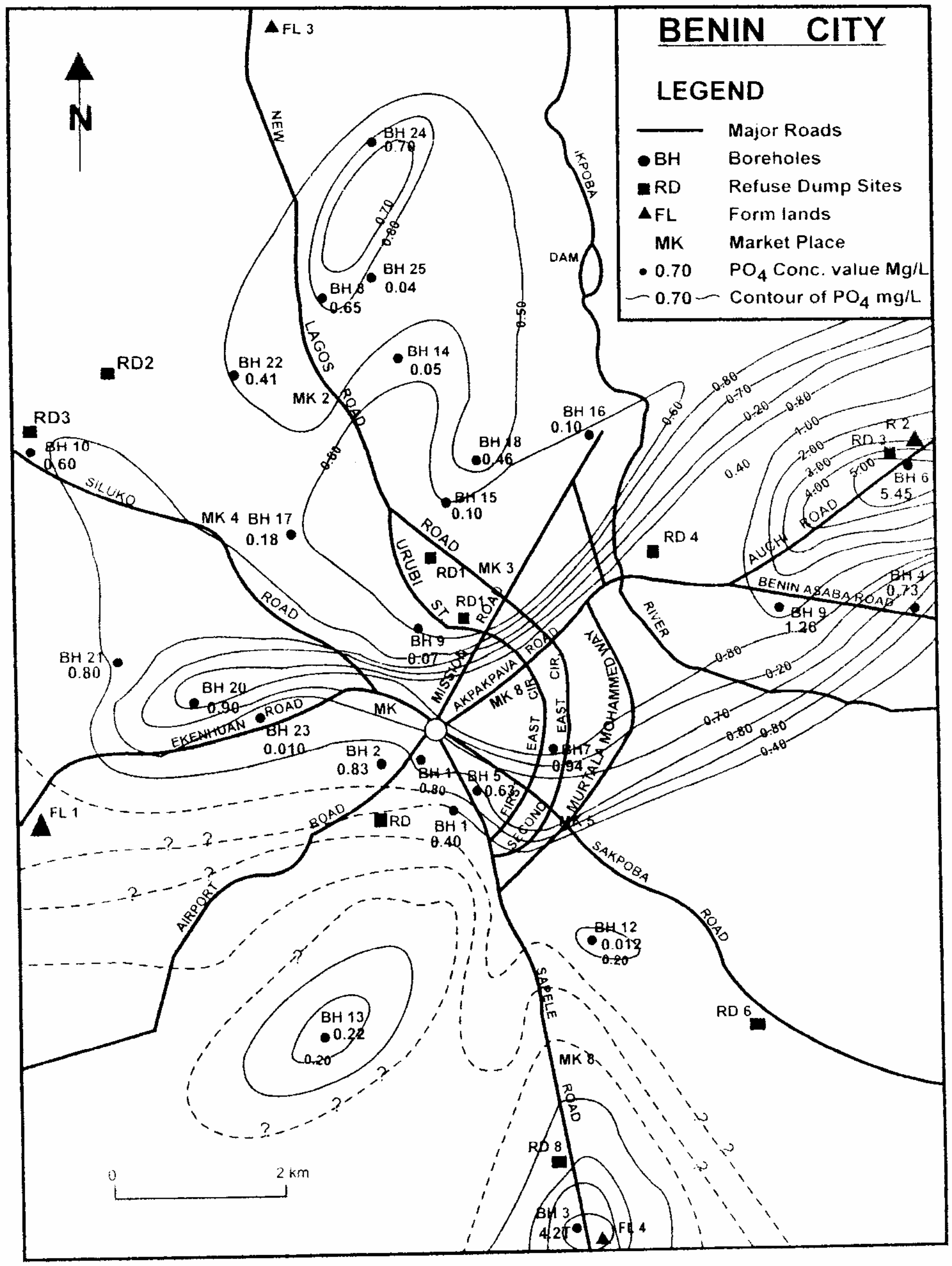


Figure 8: Contoured Variation of PO_4 Isopleth

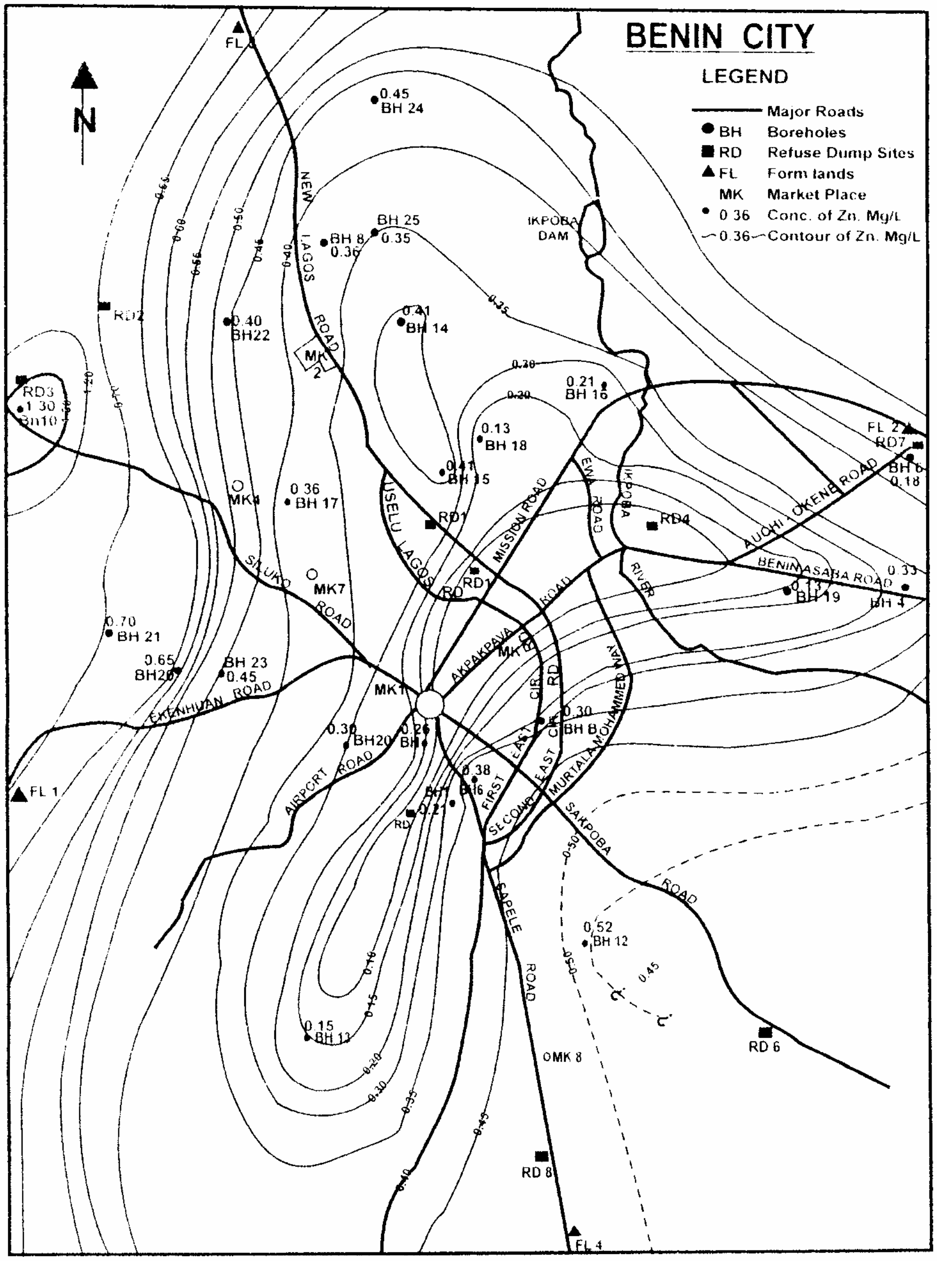


Figure 9: Contoured Isopleths of Zinc

Discussion

The pH of an environment is determined by the ionic interactions that produce or consume hydrogen ions in the system and so it is important as an index of trend and mobility of the metallic ions. The lowest pH value recorded at the study is 6.42 in the vicinity of major dump site to the South of the City at Ugbor. This value is objectionable because it falls out of the W.H.O. permissible range of 6.5-9.2. Land fills, dump sites and urban refuse dumps are made up various wastes ranging from biodegradable organics, urea, faeces, metal scraps, vegetable etc.

$CH_2O + O_2(g) \rightarrow \frac{1}{2} CO_2(g) + H_2O$ ………………………(2) Biodegradation)

In the presence of urea and other nitrogenous wastes, etc. the reaction could follow as shown:

$5CH_2O + 4NO_3 \rightarrow 2N_2(g) + 5HCO_3 + H^1 + 2H_2O$ ……….(3) (Detnitrification)

Thus the biodegradation processes produce CO_2. The CO_2 produced in addition to that from the atmosphere and soil water, would give low pH values. Domenico and Schwartz (1990).

Further influence of the pH and the bicarbonate species is seen from (3) de-nitrification given by Rivers *et al* (1996). The pH value of 7.86 taken at BH – 16 (near Ikpoba River bank) suggests hydraulic continuity between Ikpoba River and underlying aquifer system.

It is observed that Electrical conductivity (EC), Total Dissolved Solid (T.D.S), silicate (SiO_2), nitrate (NO_2), phosphate (PO_4), lead (Pb) increase towards the urban centre i.e. with population increase and activities.

Because there is low population towards the outskirts of the city, this increase could only be explained by increase in population activities. The peaks of silicate at Ugbowo and Uselu areas indicate point source impact. However its source cannot be fully explained by this study. Nevertheless, the peaks of nitrates coinciding with that of phosphate (PO_4) at Aduwawa and Ikpoba Hill BH – 6 and BH – 4 localities surrounded by farmlands, refuse dumps and cattle markets strongly suggest impact from animal wastes, dung and fertilizers. Stumm and Morgan (1981) explained nitrate generation from mineralization of organic nitrogen as follows:

$CH_2O(NH_3) + O_2 \rightarrow NH_4 + HCO_3$ ……………………….(4)
$NH^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ ………………………(5)

Lead level had exceeded the permissible 0.05mg/l at several locations. Source of lead could be through the water conveyor, pipes or mains. But polyvinylchloride (PVC) replaced lead pipes, casing and mains.

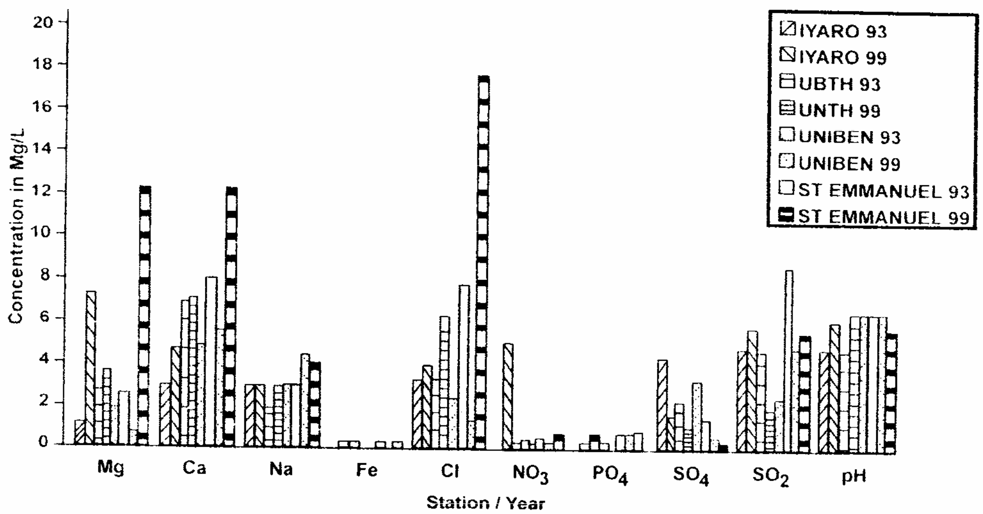
If the water mains are the culprit for lead then low pH could be precursor for generating lead in the borehole water. If pH is low, hydrogen ions would be made available to produce the reaction below:

$\frac{1}{2}PbO_2 + 2H^+ \rightarrow \frac{1}{2} Pb^2 + H_2O$ ………………………….(6)

But areas with low pH at Ugbor, Obayantor have low lead levels. This rules out water mains.

The fact that several workers, Imeolparia and Ofor (1992) had indicated high level of metals Fe, Ni, Pb, Cu etc. in Ikpoba – Ogba rivers and Tawari-Fufeyi (1994) indicated anomalous levels of Pb in fish tissues from Ikpoba Dam reservoir suggest that water pipes may not necessarily be the source of the anomalous concentration of lead in groundwater of Benin Formation Aquifer.

Other sources of lead could be traced to auto combustion of gasoline made of organo-metallic compounds such as Tetera-Ethyl-lead and tetra Methyl Lead. Bryce-Smith (1975) reported 1.0% lead (10,000 ppm) in ground dust in some English cities. Mathis and kevern (1975) and Mombeshora *et al* (1983) had shown that lead (Pb) is deposited in surrounding soils, and washed into the aquatic environment by run off. Tawari-Fufeyin (1994) suggested that high pH, high total organic matter (TOM) resulted in organic molecules that were capable of complexing metal (TOM) resulted in organic molecules that were capable of complexing metal including Pb in Ikpoba River Dam sediments.



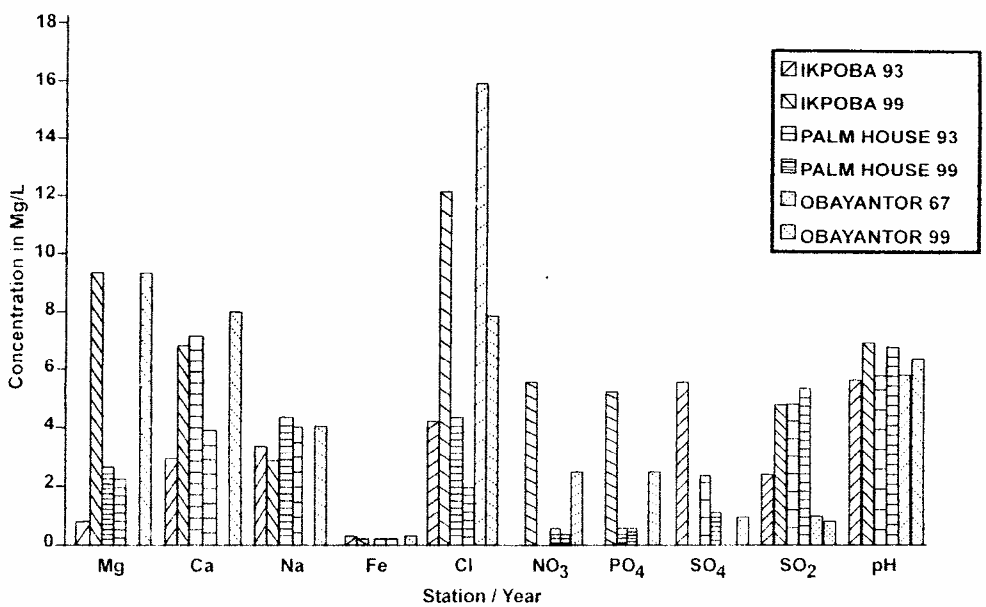


Figure 10: Variation of Constituents with years: A Comparative out lay

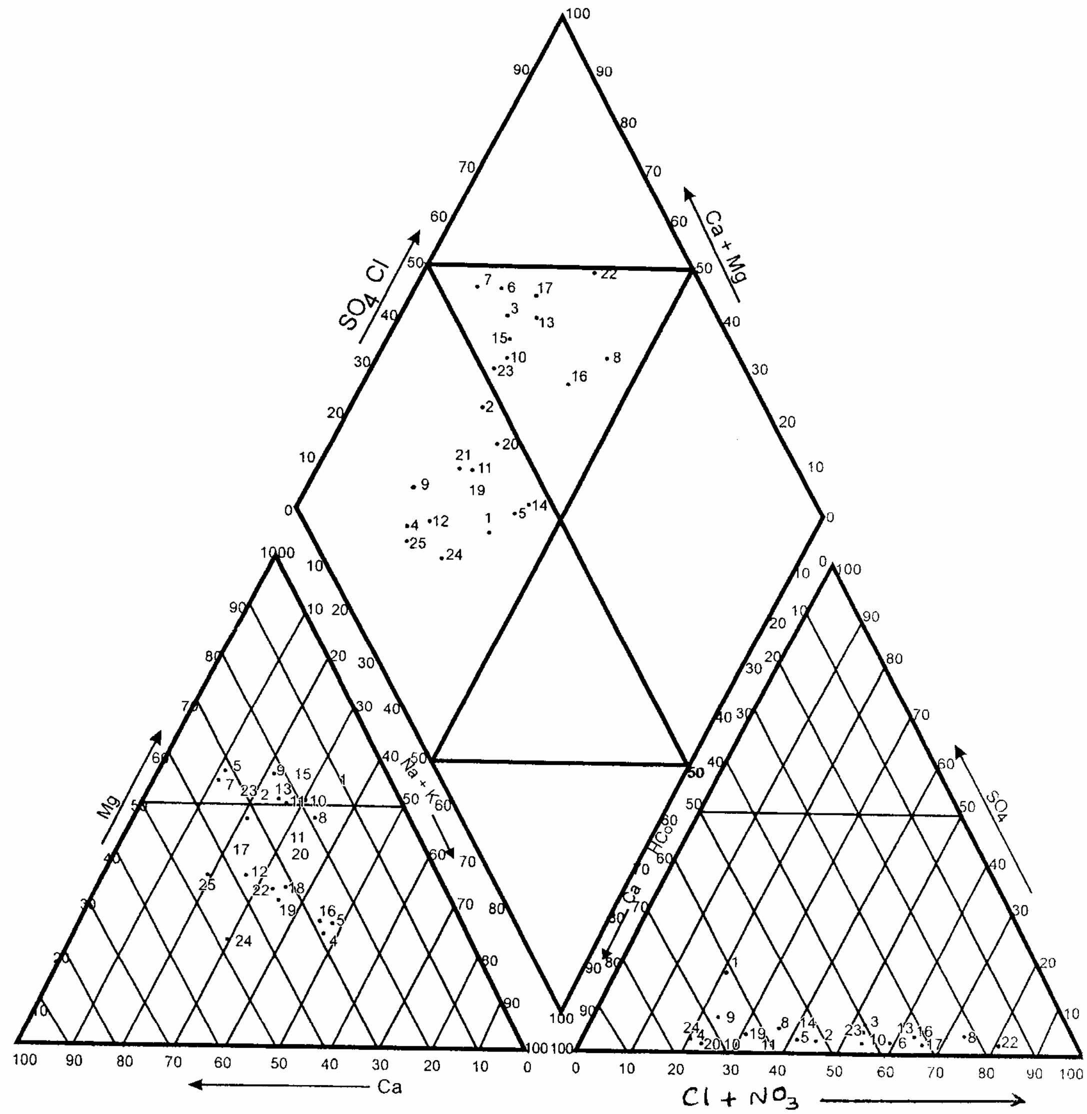


Fig. 11: Trilinear Plot of Ionic Species

The source of lead from this study confirms auto exhaust, combustion of leaded petroleum and auto mechanics workshops as major source of pollution because of the main artery roads; Benin-Auchi, Benin-Onitsha road carry the densiest traffics and has higher concentration of auto-mechanic workshops with an abandoned mechanic village off Benin-Agbor-Onitsha highway. A section across from south of the Ikpoba Dam beyond the Ikpoba bridge reveals effluent flow from aquifer to the river. But north of the dam site influent flow is the case. Thus any contamination or pollution of the surface water would affect the aquifer water. While in the effluent areas, the river is gaining water from the aquifer, indicating why there is little or no variation in Ikpoba River levels throughout the year (See Fig. 3 and 4).

The trillinear plot in Fig. 11 shows about 56% of the water samples fall within the HCO_3 classification 44% fall within no dominant group, the water could be said to be of Ca-Mg (HCO_3) type. The availability of the bicarbonate species could be explained from reactions in equation 1, 3 and 4.

Conclusion

The pattern of increase of NO_3, PO_4 T.D.S., with population density and the particularly peak sources of both at the same vicinity of cattle markets, farmlands at Aduwawa – Ikpoba Hill areas suggest an impact traceable to such activities as use of fertilizers and cattle penning. Although NO_3 and PO_4 have not reached a pollution level at the time of investigation, further exposure to impact would endanger the groundwater quality. It has been established that nitrites formed by bacterial conversion/ingested nitrates levels in groundwater have also been linked with gastric cancer in humans, W.H.O. (1996). The anomalous level of lead (Pb) calls for a more cautious search for source, mobility and remediation for the concentration of the metal that have been noted to cause serious toxicity in human. Comparing the ionic concentrations in the groundwater from the same sources in 1993 and 1999, (Figure 11). Tables 1 and 2 indicate a gradual increase of Mg, Ca, Na, Cl, NO_3, PO_4).

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