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GROUNDWATER POLLUTION NEAR SHALLOW WASTE DUMPS IN SOUTHERN CALABAR, SOUTH-EASTERN NIGERIA.

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ABSTRACT

This article presents results of groundwater quality assessment based on some pollution indicators (total heterotrophic bacteria, THB; total faecal coliform, TFC; nitrate, NO_3^- dissolved oxygen, DO; conductivity, CN) carried out in the vicinity of active and non-active (closed) waste dumps in Calabar South area. The data show that 4% of dissolved oxygen concentration: 58 and 62% of THB and TFC counts respectively recorded exceed the WHO recommended limits for drinking and /or domestic purposes. In addition, good correlation (> 0.70) exists between the pollution indicators on one hand and between THB, TFC and the number of waste dumps on the other. On the basis of a pollution scale developed for this study, the groundwater in the area are classed into 2 (low-moderate) 3 (moderate-high) and 4 (high-very high). Recommendations include periodic groundwater quality monitoring and introduction of modern waste disposal systems.

KEY WORDS: Groundwater quality, Nigeria, pollution, waste dump.

INTRODUCTION

The southern part of Calabar (Fig 1) is characterized by the sitting of waste dumps (pit latrines,septic tanks, household waste dumps etc) near potable water sources without consideration to the hydrogeologic setting of the area and thus, rendering the future groundwater quality at risk. The present study was therefore designed to evaluate the level of groundwater pollution resulting from this activity. The study is also a follow up to the work of Edet (2000) and Edet et. al. (2001) on the appraisal of the effects of indiscriminate waste disposal on potable water sources in Cross River State (Fig 1).

Area setting

Location and climatic characteristics

The study area, Calabar South Local Government Area (CSLGA) referred to here as Calabar South area (CSA, Fig. 1 is situated approximately within latitudes $4^0 55'$-$4^0 56'$ North and longitude $8^0 18'$ - $8^0 21'$ East covering an estimated area of 20 km^2 and more than 80% of the population are low income workers engaged mostly in petty trading, fishing, farming and having a population density of about 4000 per km^2.

The area is characterized by a mean annual temperature and precipitation of 30.1^{0}C and about 2000 mm respectively. Climate data for the period 1990-2000 show that the temperature varies between 23.1 and 28.7^{0}C and the monthly precipitation between 26.7 and 459. 1mm (Edet and Okereke, 2002).

Geohydrological characteristics

The area is drained by two major rives, the Calabar and the Great Kwa River (Fig. 1) Lithologically the area is made up of tidal and lagoonal sediments, gravels, sands, silts and clays with lignite. These materials are associated with the Tertiary Benin Formation and Recent alluvium deposits.

Two major aquiferous units, an upper unconfined unit made up of mostly grayish brownish clayey fine-medium sand and a lower semi-confined unit consisting of mostly grayish white medium-coarse gravelly sand (Fig 1). The mean parameters of the two aquifers are presented in Table 2. The present study is however limited to the upper unconfined unit. For this unit, the estimated change in groundwater storage is 4383.6 m3/d which represents about 1 % of the estimated total amount of extractable water from the aquifer put at $160X10^6 m^3$.

Sampling and analyses

Forty eight (48) groundwater samples were collected during a six month period in 1999 covering parts of the wet and dry seasons (July - December) from eight locations designed as 1-8 (Fig 1). This corresponds to high precipitation and relatively low precipitation period during the study. The localities sampled are characterized by the presence of pit latrines (both active and non active). Location 8 which is about 6 km north of study area is a deep borehole tapping water from the same aquiferous unit (Fig. 1, Table 2) served as a control. The details of site designations, descriptions and characteristics are provided in Table 3. For all the samples, the temperature, pH, Eh, conductivity and dissolved oxygen were determined in the field using standard equipment (WTWLF 91temperature/ conductivity meter, WTW Ph 90 meter and WTW OXI 196 microprocessor oximeter).

Samples were then collected and stored in 250

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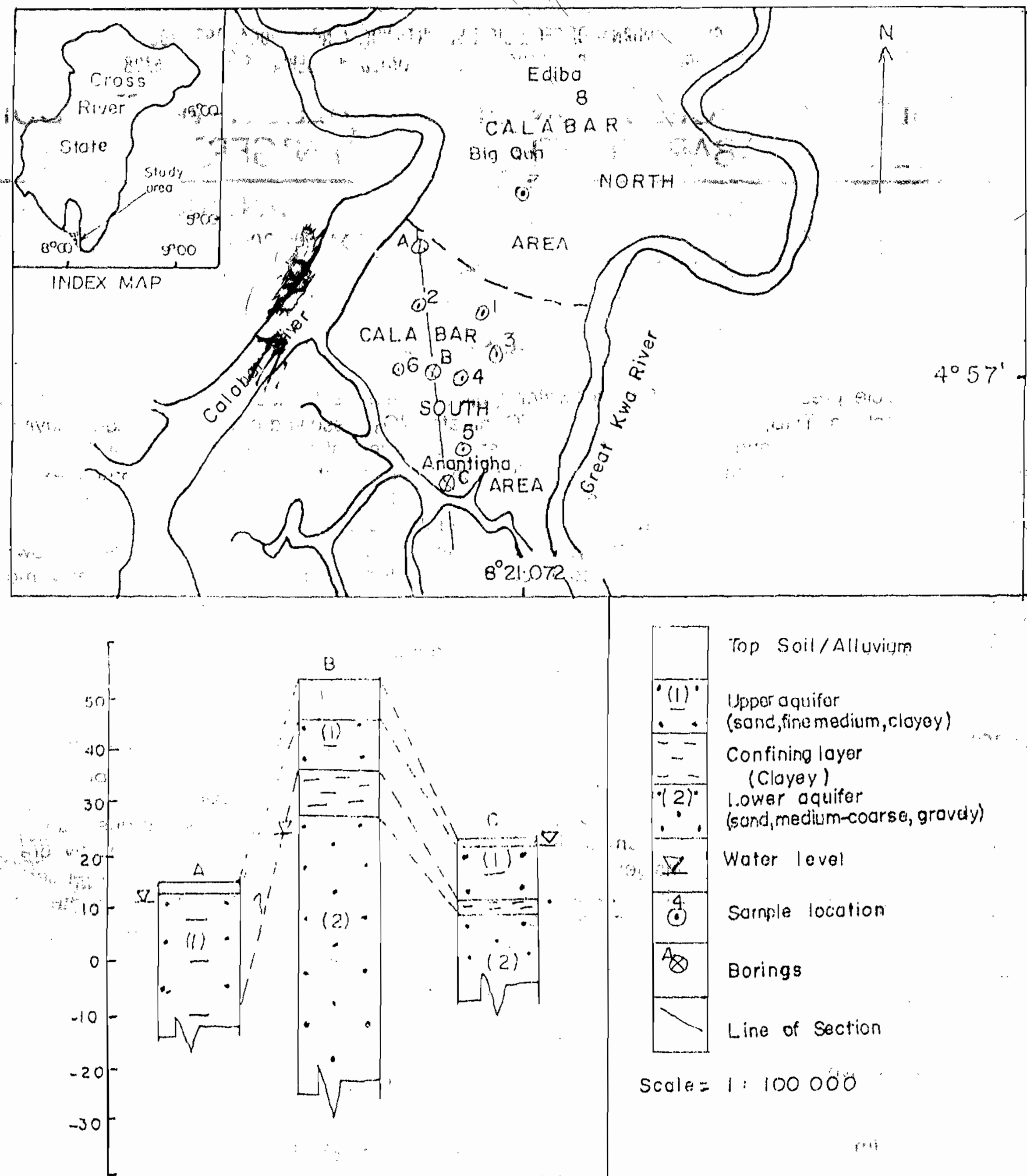

Fig. 1: Map of part of Calabar urban showing sample locations and simplified hydrogeological setting (inset map of Cross River State)

TABLE 1: CLIMATIC DATA FOR THE SAMPLE PERIOD

		Sampling period(s)						
Climatic parameter(s)		1	2	3	4	5	6	mean
Maximum temperature	°C	29.3	29.2	28.7	29.3	30.4	32.3	29.9
Minimum temperature	°C	21.1	21.4	22.6	22.7	22.9	22.6	22.2
Rainfall	MM	349.9	494.5	36.8.3	463.7	207.2	0.3	314.0
Relative humidity	%	88	89	89	89	88	80	87.2

1 July 2 August 3 September 4 October 5 November 6 December (1999).

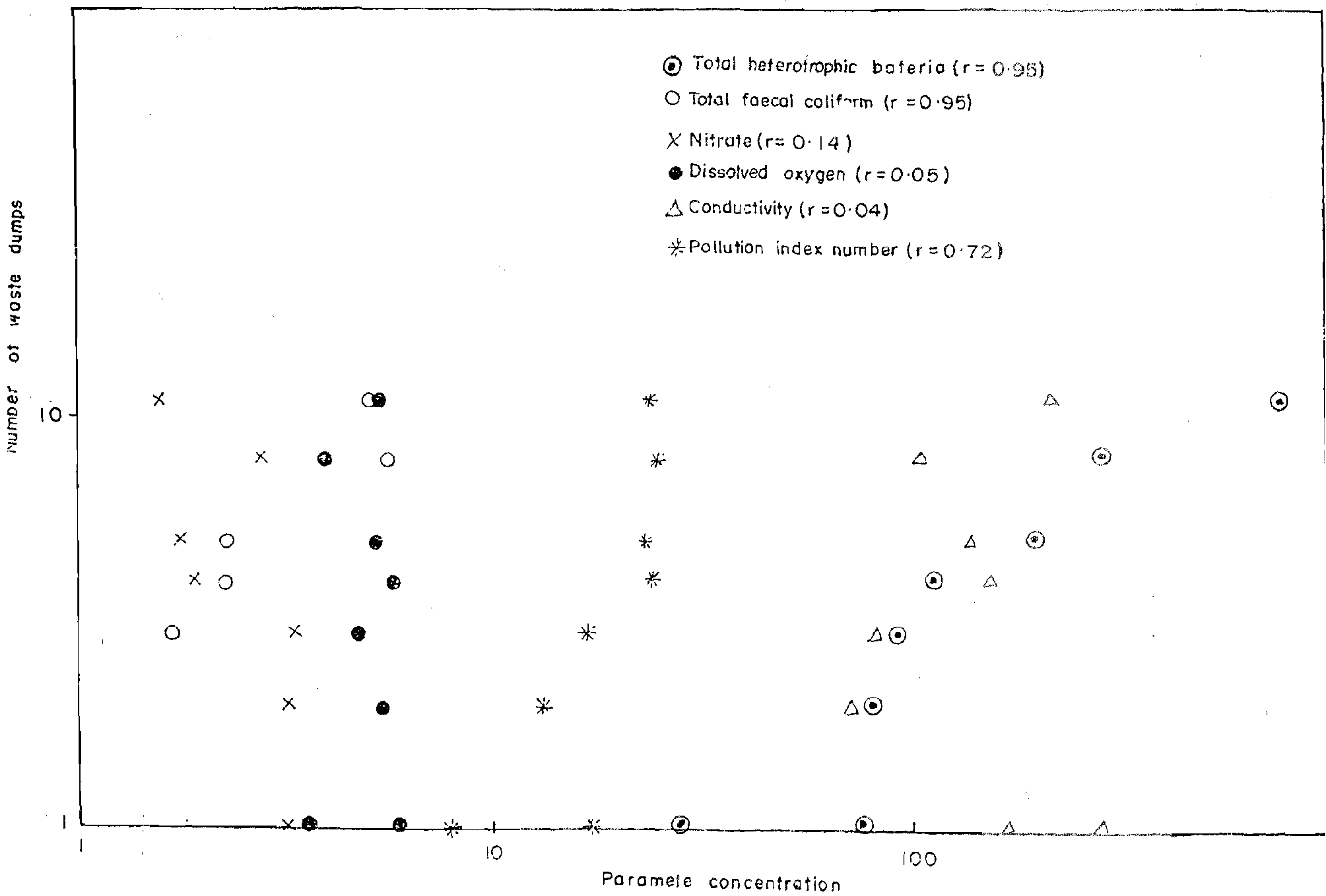

Fig. 2: A 2D correlation matrix between pollution indicators

Table 2: Mean aquifer parameters

Parameters		Aquifer types	
		Upper [1]	Lower
Thickness	M	50.00	23.00
Depth to water level (DWL)	M	34.00	62.20
Discharge	M^3/d	344.40	40.00
Transmissivity	M^2/d	7676.00	1956.00
Hydraulic conductivity	M/d	143.20	78.30
Storage Coefficient		0.5	0.15

[1] Present study consideration

ml polyethene bottles, stored in a cooler and then transferred to a refrigerator at 4^{0}C prior to analysis. The laboratory analysis for nitrate (NO_3^-), nitrite (NO_2^-). ammonium (NH_4^+), sulphate (SO_4^{2-}), chloride (Cl^-) phosphate PO_4^{3-}), total hetertrophic bacteria (THB) and total faecal coliform (TFC) were carried out using standard methods in the Environmental laboratory, Institute of Oceanography, University of Calabar (Nigeria).

RESULTS

Table 4 contains the range of results for all the locations while table 5 gives a summary of all the results for the entire locations and period.

Temperature, conductivity and pH

On locational basis, the mean temperature appear uniform ranging from a minimum of 27.4 to a maximum of 28.0^{0}C. For the entire study period, temperature varied from 26.5 to 29.0^{0}C (mean 27.5^{0}C). These values are consistent with the air temperature for the period (Table 1)

The conductivity values range between 51.9-321μs/cm at locations 4 and 8 respectively (Table 4). These values are far below the WHO maximum allowable limit of 1400 μs/cm for drinking and domestic purposes. The pH values varied from 3.11 (location 3) to 7.99 (location 8) and a mean of 5.89 for the period (Table 5) which is also below WHO range of 6.5-8.5.

Nitrate, nitrite and ammonium

The concentration of nitrate (NO_3^-) for the entire period varied from 0.23-10.63 mg/L (mean 2.30 mg/L), Table 5. Spatially the mean value were lowest at the control point (location 8), 0.51 mg/L and highest at location 5 (3.33 mg/L) Table 4 Generally, more than 95% of the NO_3^- concentrations were lower than the WHO maximum limit value of 10 mg/L.

Nitrite (NO_2^-) varied from 0.001-0.027 mg/L (mean 0.008 mg/L) for the entire period. For the study locations, the mean lowest value of 0.002 mg/L was obtained at location 1 and highest mean value of 0.011 mg/L at location 8. the concentration of ammonium

Table 3
Sample locations, description and characteristics

Description and characteristic parameters	Locations[a]							
	1	2	3	4	5	6	7	8
Location name (street/road)	Atamunu	Ezekiel	Adam Duke	Efioanwan	Ekeya	Spat	Old Marian	Marian
No of active pit laterines (PT)	3	8	3	1	1	-	-	-
No of inactive pit laterines	1	3	2	1	2	-	-	-
No of shallow dumps	-	-	-	-	-	1	-	-
No of septic tanks/cesspools	-	-	-	-	-	-	8	1
Distance of PTs from well (m)	15	10	8	20	12	30	5	-
Direction of PT from well	SE	NW	SW	E	NE	NW	S	-
Remarks	-	-	-	-	-	-	-	Control

(NH_4^+) for the period varied between 0.00 (location 8) to 5.18 mg/L (location 5). The mean values for the locations varied between 0.48 mg/L at sample location 8 and 0.95 at location 2 (Table 4).

Sulphate, chloride and phosphrate

The concentration of sulphate (SO_4^{2-}) varied from 0.29 at sample location 4 to 8.70 mg/L at sample location 2 for the entire period (Table 5). The mean concentration for the locations varied between 0.69-3. 74 mg/L. These values are very low compared to the WHO limit of 400 mg/L. Low SO_4^{2-} concentrations are related to the reduction of sulphate in the presence of bacteria and organic matter (Offiong and Edet, 1998). This can be represented by the equation below.

$$SO_4^{2-} + 2CH_2O = H_2S + 2HCO_3 \qquad (1)$$

Chloride concentration varied from 5.68-71. 0 mg/L at locations 7 and 2 respectively for the entire period (Table 5). Mean values for the different localities ranged between 12.04 (Location 8) to 50.77 mg/L (location 2). These values are consistent with concentrations of Cl^- (0.03-0.42 meq /L) in nearby surface waters (Offiong and Edet 1998) and precipitation (<1.40 meq / L) thus indicating that the rivers and rainfall are the primary source of recharge for the aquifer. The concentrations of phosphate for the sample period and all the locations (< 0. 15 mg/l) were below the WHO limit of 5.0 mg/L.

Dissolved oxygen, total heterotrophic bacteria and faecal coliform

The concentration of dissolved oxygen (DO) for the period ranged between 2.2-6.0 mg/L. the mean values between 3.57-5.87 mg/L for the locations. High DO are probably due to shallow water level (Cisse et. al 2000). The count of total heterotrophic bacteria for all the 48 samples varied b/w 22-1021 per ml (mean 200.5 per ml). The mean counts ranged between 27.8 at sample location 8 to 764. 8 per mL at sample location 2

The total faecal coliform counts for the same number of samples varied from 0 at locations 3, 4, 6, 8 to 7 per/100 mL at location 2. Spatially, the mean values varied between 0 (locations 4, 6, 8) and 5.5 per 100 mL at location 7 (Table 4).

DISCUSSION OF DATA

In evaluating the quality of groundwater and determining the level of pollution in the area, some parameters considered as pollution indicators were used. These include total heterotrophic bacteria (THB), total faecal coliform (TFC), nitrate (NO_3^-) dissolved oxygen (DO), conductivity (CN) and /0r chloride ($C1^-$) (Barrett et. al 2000; Cisse et. al 2000; Edet 2000).

From the data, the concentrations of THB, TFC, DO and CN are higher in the recharge area against the values in the discharge area (Table 6). The pattern is due to the high number of waste dumps in the recharge area (n= 28) compared to the discharge area (n =6). In addition an east-west regional groundwater divide characterizes the area.

Secondly, the concentrations of these parameters are higher for the wet (rainy) season (Table 6) with percentage difference in the range 3-64. This aspect is attributed to high contaminant transport due to high infilration rate (~1.0x10^4 cm/S) of the top soil layer and high permeability (~118.3 m/d) of the aquiferous layer. Also according to Robins (1998), the greater the

Table 4
Physical, chemical and biological parameters for all locations (range)

Parameters		Locations								WHO
		1	2	3	4	5	6	7	8	
Temperature	°C	26.3-29.2	25.9-28.9	26-29	26-29	26.3-29.3	26.1-29.1	26.3-29.2	26.9-29.9	
Conductivity	μS/cm	153.4-156.4	228.3-231.3	141.6-144.6	70.5-74.5	79.2-82.2	170.2-173.2	101.4-104.4	288.8-291.8	1400
pH		4.27-7.27	3.71-6.71	3.11-6.11	3.32-6.32	3.66-6.66	3.84-6.84	4.39-7.39	4.99-7.99	6.5-8.5
Eh	mV	78-81	105.83-108.83	139.61-142.61	126.38-129.38	110.83-113.83	88.5-91.5	69.33-72.33	20.75-23.75	
Dissolved oxygen	mg/L	4.2-7.2	3.63-6.63	3.72-6.72	3.87-6.87	3.2-6.2	2.07-5.07	2.45-5.45	4.37-7.37	5.0min
Nitrate (NO_3^-)	mg/L	0.4-3.4	0.14-3.14	0.31-3.31	1.7-4.7	1.83-4.83	1.66-4.66	1.31-4.31	0.00-2.01	10
Nitrite (NO_2^-)	mg/L	0.00-1.5	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.1
Ammonium (NH_4^+)	mg/L	0.00-2.08	0.00-2.45	0.00-2.01	0.00-2.21	0.00-2.38	0.00-2.08	0.00-2.39	0.00-1.98	0.50
Sulphate (SO_4^{2-})	mg/L	1.92-4.92	5.03-8.03	0.72-2.28	0.81-2.19	0.7-2.3	1.01-4.01	2.24-5.24	0.00-2.64	400
Chloride (Cl^-)	mg/L	28.74-31.74	49.27-52.27	25.19-28.19	10.99-13.99	14.19-17.19	33.53-36.53	14.24-17.24	10.57-13.57	250
Phosphate (PO_4^{3-})	mg/L	0.00-1.50	0.00-1.50	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	0.00-1.51	5
Total heterotrophic bacteria (THB)	per ml	112-115	763.3-766.3	199-202	78.2-81.2	89.8-92.8	75.3-78.3	393.2-396.2	26.3-29.3	100
Total faecal coliform (TFC)	per 100ml	0.00-5.3	0.00-8.0	0.00-5.3	0.00-0.01	0.00-4.7	0.00-0.01	0.00-8.5	0.00-0.001	1

Table 5
Summary of parameter concentrations for the entire sampling period (n=48)

Parameter		Summary			WHO
		Minimum	Maximum	Mean	
Temperature	°C	26.5(2)	29.0(8)	27.5	
Conductivity	μS/cm	51.9(4)	321.0(7)	149.0	1400
pH		3.00(3)	7.36(7)	5.89	6.5-8.5
Eh	mV	15(8)	201(3)	141.17	
Dissolved oxygen	mg/L	2.2(7)	6.0(8)	4.7	5.0min
Nitrate (NO_3^-)	mg/L	0.23(8)	10.63(6)	2.30	10
Nitrite (NO_2^-)	mg/L	0.001(4)	0.027(7)	0.008	0.1
Ammonium (NH_4^+)	mg/L	0.00(8)	5.18(5)	0.88	0.5
Sulphate (SO_4^{2-})	mg/L	0.29(4)	8.70(2)	6.53	400
Chloride (Cl^-)	mg/L	5.68(7)	71.00(2)	50.77	250
Phosphate (PO_4^{3-})	mg/L	0.007(8)	0.122(3)	0.012	5
Total heterotrophic bacteria (THB)	per ml	22(8)	1021(2)	200.5	100
Total faecal coliform (TFC)	per 100ml	0(3,4,6,8)	7(2)	2.1	1

Number in brackets represents locations (See Table 1)

rechange the greater the potential for dilution, but the more efficient the transport of pollutant from surface to water-table. This is true for the study area since precipitation is the major source of recharge. This is supported by the fairly good relation (γ) between the amount of precipitation and the concentration of nitrate (γ = 0.43), total heterotrophic bacteria (γ = 0.58) and total faecal coliform (γ = 0.68).

DO	1.00				
NO_3	-0.53	1.00			
CN	-0.15	0.69	1.00		
THB	0.16	-0.65	0.75	1.00	
TFC	0.38	-0.82	0.67	0.88	1.00
	DO	NO_3	CN	THB	TFC

Fig. 3: A 3D correlation matrix for pollution indicators

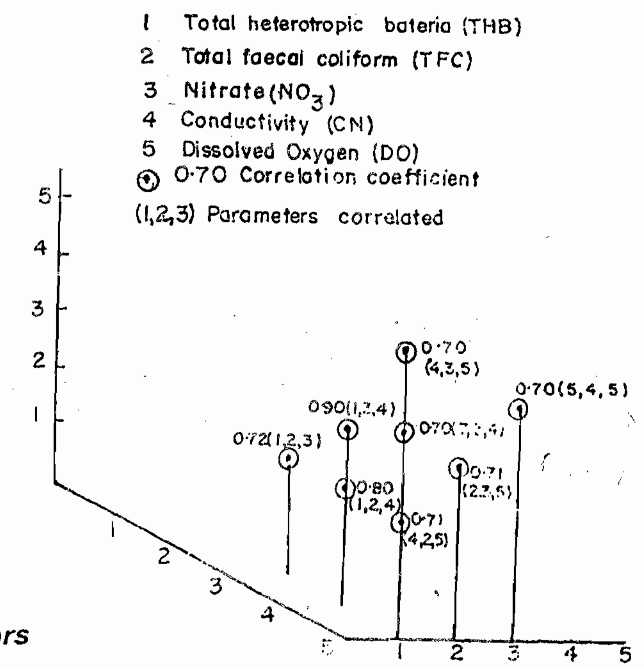

Fig. 4: Degree of groundwater pollution at each locality

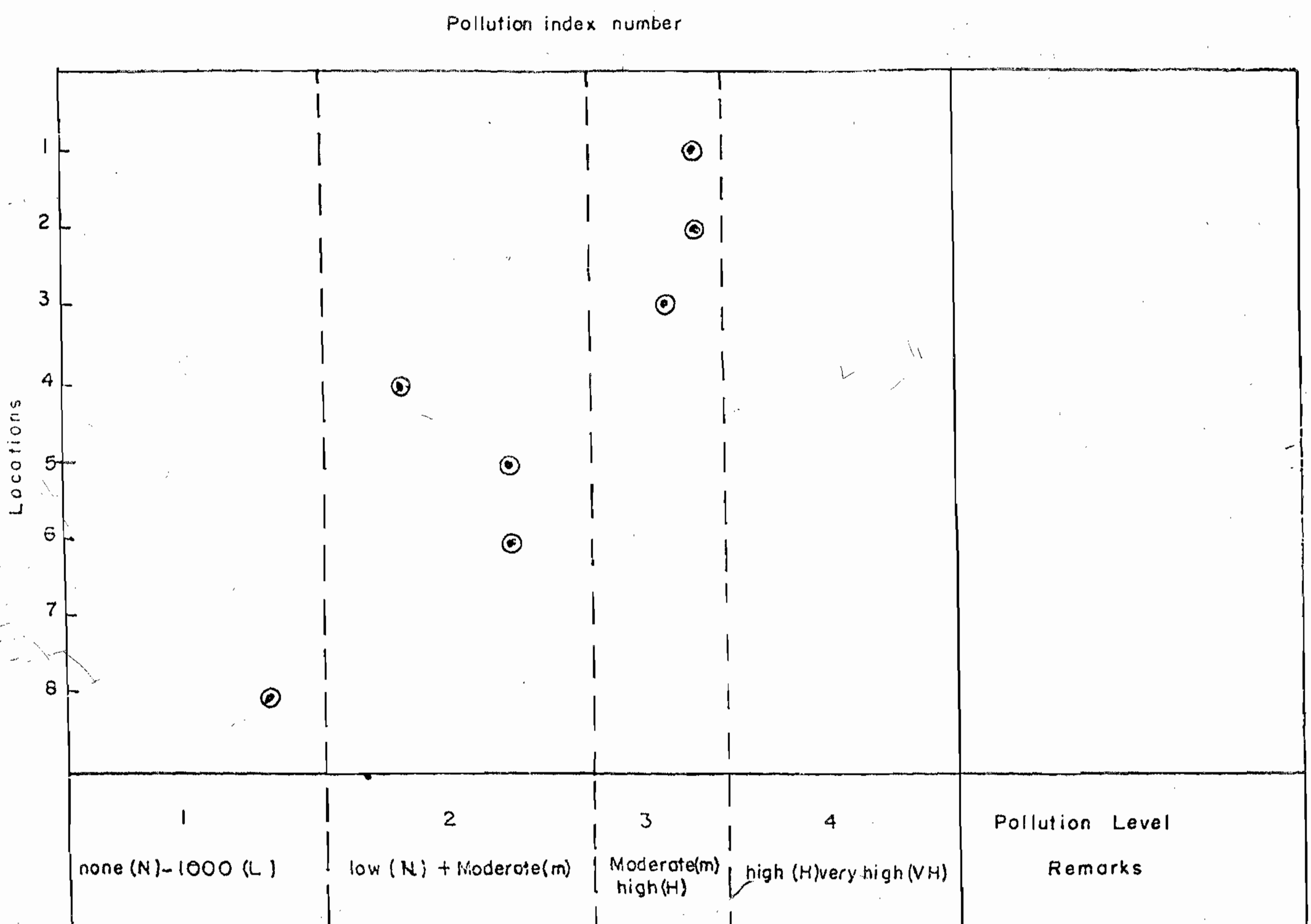

Fig. 5: Relation between number of waste dumps and some parameters

The values of the parameters are higher in sample locations 1, 2, 3, and 7 (Table 4.). This is attributed to the fact that, these localities (1, 2, 3, 7) are very close to the waste dumps (mean distance 10 m) as against locations 4, 5 and 6 with a mean distance of 21 m between the waste dumps and the potable water sources (Table 3). In sample localities 2 and 7, with the highest count of THB and TFC, 11 and 8 numbers of active/non active pit latrines and septic tanks/cesspool were documented (Table 3). The low number of waste dumps (n =6) at locations 4, 5 and 6 coupled with the distances between the dumps and water sources (12-30m, Table 3) are responsible for the low THB and TFC counts (Table 4).

Generally, on the basis of correlation coefficient (γ) values, the total number of waste dumps show good correlation ($\gamma > 0.70$) with THB and TFC and poor correlation ($-0.14 \geq \gamma \leq 0.04$) with DO, NO_3^- and CN (Fig 2). In addition, correlation coefficient values between the parameters indicate good ($\gamma \geq 0.70$); fairly good ($> 0.50\gamma < 0.70$) and poor ($\gamma < 0.50$) relations (Fig. 4). However, multiple correlation analysis for all the parameters indicate good relation ($\gamma \geq 0.70$) (Fig 4). High correlations are related to high organic matter related to human faeces, number and distance(s) of waste dumps from potable water sources, seasonal variations and permeability of the aquiferous layer. On the other hand, fairly good-poor relations are attributed to local groundwater table variations, and flow direction, depth of waste dumps and shallow boreholes/hand dug well and the type and quantity of waste.

Table 6
Relation between concentrations of some parameters with respect to the recharge-discharge area and seasons

Parameter(s)		Period(s)		Area(s)	
		Wet	Dry	Recharge	Discharge
Rainfall amount	mm	404.2/1212.7	223.7/671.2	-	-
Depth to water level (DWL)	m	2.15	3.75	-	-
Total heterotrophic bacteria	per ml	260.39	197.71	359.60	82.60
Total faecal coliform	per 100ml	2.62	1.84	3.20	0.57
Nitrate	mg/L	3.57	1.27	1.78	3.23
Dissolved oxygen	mg/L	5.12	4.97	5.35	4.55
Conductivity	µS/cm	180.61	126.21	175.9	108.5

Table 7
Proposed ratings to each class interval of pollution indicator (present study)

Parameter(s)	Ratings (class)		
	1 (Good)	2 (Moderate)	3 (Poor)
Total heterotrophic bacteria (THB)	< 50	50-100	> 100
Total faecal coliform (TFC)	< 1	1-2	> 2
Nitrate (NO_3^-)	< 5	5-10	> 10
Dissolved oxygen (DO)	> 5	4-5	< 4
Conductivity (CN)	< 100	100-150	> 150

Table 8
Proposed groundwater pollution scale for the are:

Pollution level	Pollution index number	Remarks
1	< 10	None (N) - low (L)
2	10-20	Low (L) - moderate (M)
3	20-25	Moderate (M) - high (H)
4	> 25	High (H) - very high (VH)

Determination of pollution levels

In order to determine and quantify the level of pollution in the area, a scale (Groundwater Pollution Scale) was developed during the study using the pollution indicators (THB, TFC, NO_3^-, DO, CN). A weight is assigned to each indicator depending on importance and concentration level during study period. The parameters of greatest importance (THB, TFC) are assigned 3 since they strongly and consistently indicated pollution (Figs 2, 3, 4) NO_3^- is assigned a weight of 2 since it is a potential indicator of pollution (Edet 2000) despite the low values (< 10.63 mg/L), Table 5) and poor correlations (γ = 0.14) with number of waste dumps. NO_3^- however, show good-fairly good correlation with THB, TFC, DO, CN (Fig 3). The CN and DO are rated low as indicators of pollution due to low values coupled with high variability in correlation with other parameters ($-0.15 > \gamma < 0.75$, Fig 3). Because prolonged and gradual pollution of groundwater will affect their concentrations in future, these parameters are assigned weights of 1.

The parameters are divided into classes and a rating representing the magnitude of pollution assigned to each class (Table 7). A combination of the weights and rating is then used to compute the pollution index number (PIN) as a sum of the products of weights and rating for each indicator (THB, FTC, NO_3^-, DO and CN). The PIN is then used to develop a Groundwater Pollution scale (GPS) which gives a semi- quantitative assessment of the level of groundwater pollution (Table 8).

For each sample location, the PIN is computed and presented in Fig. 5 to show the overall groundwater pollution levels in the area. From the figure, the PIN for sample locations 1, 2, 3 and 7 range between 23-25 and 13-17 for locations 4, 5, and 6 while the value for the control point (location 8) is 8.

This clearly shows that the groundwater at location 8 is not polluted while that at locations 4, 5, 6 are low-moderately polluted and moderately-very highly polluted at locations 1, 2, 3 and 7. Generally, there is a good (> 0.70) correlation between the PIN and the number of waste dumps (Fig. 2).

CONCLUSIONS AND RECOMMENDATIONS

Groundwater in shallow aquifers in areas of high concentrations waste dumps are moderately-very highly polluted (e.g. locations 1, 2, 3, 7) compared to area with low number of dumps (e.g. locations 4, 5, 6) which are lowly-moderately polluted. Area characterized by deep aquifers and very low number of shallow dumps are not affected (e.g. location 8).

Total heterotrophic bacteria (THB) and total faecal coliform (TFC) counts are more indicative of pollution with higher concentrations in the rainy (wet) season.

High correlation exists between the number of waste dumps; the distance of dumps from potable water sources and the level of pollution.

It is recommended that for areas (e.g. Calabar South area) with high population density and low level of sanitation, a groundwater quality monitoring programme should be put in place and use of modern or semi modern facilities for waste disposal encouraged by International Organizations (e.g. UNICEF) in collaboration with the Federal, State and Local authorities.

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