J. ENVIRONMENTAL SYSTEMS, Vol. 31(1) 69-79, 2004-2005

WASTE DISPOSAL AND GROUNDWATER QUALITY IN OWERRI, NIGERIA

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ABSTRACT

Groundwater supply in the city of Owerri is obtained from the semi-confined aquifer occurring at depths of 50 m to 80 m. Common sources of groundwater pollution are leachate from waste dumpsites and sewage from septic tanks. Over seven waste dumpsites exist in Owerri metropolis, and a septic tank is a common feature in every household. Analysis of the groundwater quality shows that the dissolved solid and bacteria exceed the maximum permissible limit allowed for drinking water. The scenario is primarily due to the inability of the underlying rock and the coastal plain sand, to geochemically attenuate the contaminants adequately. Proper treatment of water from both the private and public boreholes should be enforced.

INTRODUCTION

Owerri, a State Capital, is one of the fastest-growing metropolitan towns in Nigeria. It lies within latitudes 5°10'N and 5°57'N, and longitudes 5°35'E, and 7°28'E (see Figure 1). It enjoys a subequatorial climate with an average yearly rainfall of 2500 mm, most of which falls between June and September. A high relative humidity of 70% to 80% is common. The mean temperature over most of the area is 27°C, with a daily range of 6.5°C.

The metropolis occupies about 1019 hectares of land at a population density of 2433 persons per square kilometer. Population was approximately 105,000 in

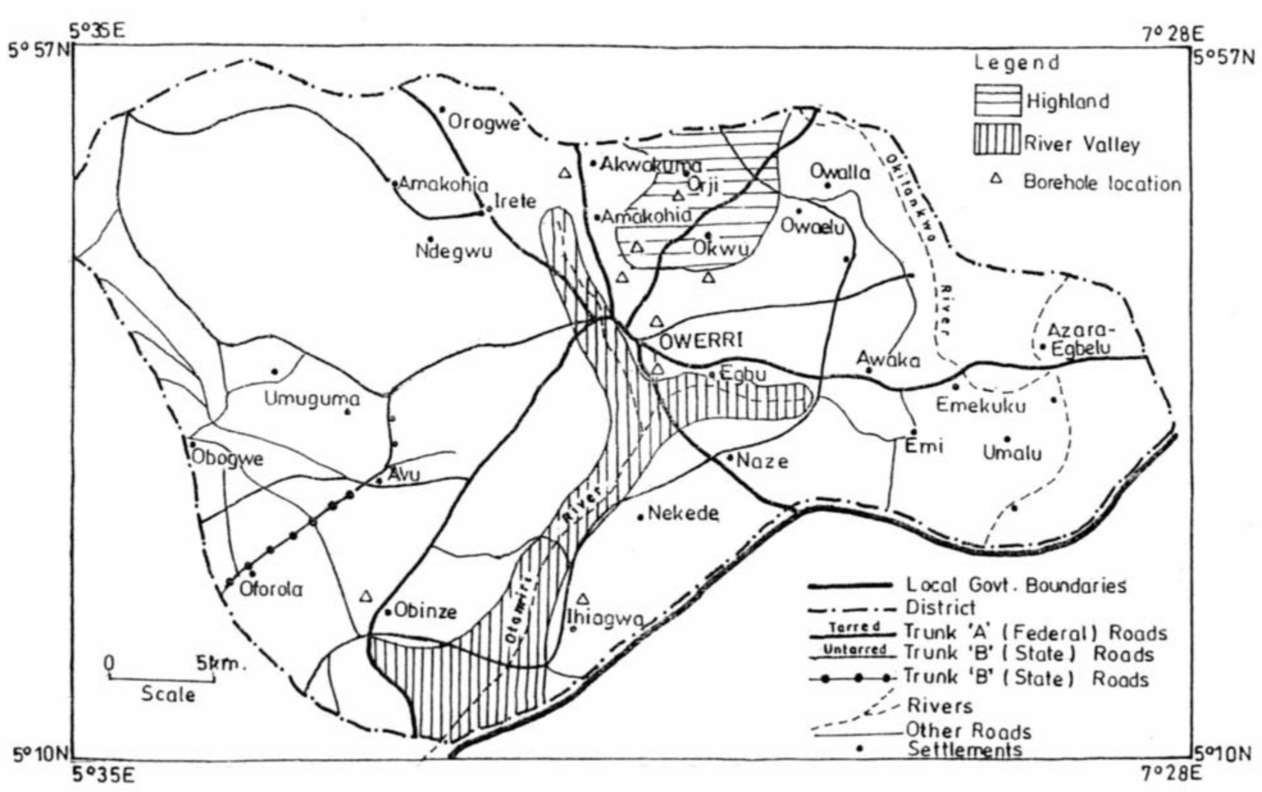

Figure 1. Descriptive map of Owerri metropolis.

1963, 160,000 in 1976, and 248,000 in 1991. Given a compound 2.5% growth rate, a population of some 340,000 is expected in 2010.

The growth in population consequently results in a high rate of waste generation. The sewage and leachate contaminants naturally seep into the groundwater aquifer under favorable hydrologic conditions. Groundwater is the major source of water for domestic and industrial uses in the area. One in every thousand households own a private borehole; the proportion is rising.

This article examines the extent to which the groundwater has been polluted by sewage and leachate.

HYDROGEOLOGIC SETTING

Owerri metropolis is underlain in the south and west by coastal plain sand of the Oligocene to Pliocene age. The other portion is occupied by various classifications of shale groups, particularly around the central part, with a narrow strip of false-bedded sandstone [1].

The stratigraphic sequence generally comprises a considerable thickness of red earth (laterite) composed of iron-strained ragolith below which lie thick, very friable sands with minor intercalation of clay beds and lenses. The sands are mostly medium- to coarse-grained, pebbly and poorly sorted. The intercalations of sandy and clay units give rise to a multi-aquifer system within the upper 200 m of the formation. Three aquifer systems have been identified [2]. The upper aquifer is unconfined and extends up to a depth of 40 m. The middle aquifer is semi-confined with thickness varying from 50 m in the south to 80 m toward the north. The separating aquitard is a sandy clay of 3 m–15 m thick. South of the city, the aquitard is more sandy with a very high leakage factor. The semi-confined aquifer is the main source of borehole water supply in the district.

CONTAMINANT SOURCES

Two major types of wastes are generated in Owerri, solid waste and sewage from septic tanks. Solid wastes are generated mainly from homes, offices, and markets. They comprise biodegradable and inert materials. These wastes are commonly disposed in open dumps. Over seven such dumps are sited in the Owerri metropolis. The wastes are often piled as high as possible and then ignited and allowed to burn. Outside aesthetic degradation, pests' breeding and air pollution, the dumps are sources of groundwater pollutants through the migration of the leachate. An analysis of a typical leachate obtained from a representative dump provides the results contained in Table 1 [3].

The other source of groundwater contamination is sewage from septic tanks. All households in the city operate individual soil absorption systems (septic tanks) for sewage disposal. The tank is fundamentally designed to separate solids from the liquid and to digest and store organic matter through a period of detention.

Table 1. Analysis of Representative Leachate (After [3])

Parameter	Data	Parameter	Data
		pH	5.2
Temperature	28.8°C	Turbidity	120 FTU
Appearance	Very cloudy	Salinity	37.95 mg/l
Odor	Very pungent	Nitrate	2.2 mg/l
Sediments	160 (mg/l)	Nitrite	0.6 mg/l
Conductivity	86	Iron	0.5 mg/l
T.D.S.	43 (mg/l)	Calcium	60.0 mg/l
Ca hardness	100 (mg/l)	T.S.S.	117. mg/l
Mg hardness	14.58 (mg/l)	Manganese	4.9 mg/l
Chloride	23 (mg/l)	Phosphates	3.5 mg/ l
CO_2	70 mg/l	Potassium	2.6 mg/l
Bicarbonate	90 mg/l	Total coliform	270/100 mls
Carbonate	0.00 mg/l	Total bacteria count	310/100 mls

Subsequently, the clarified liquids discharge into the absorption field enroute to the groundwater table.

CONTAMINANT MIGRATION

Fluid flow in porous medium follows the fundamental law of Darcy which can be expressed in the form

$$V = Q/A = -K\frac{\delta h}{\delta x} \tag{1}$$

where V is the flux of water (cm/sec), Q is the volumetric flow rate of the fluid, A is the total cross sectional area perpendicular to the direction of flow, K is the hydraulic conductivity, h is the total hydraulic head, and x is the direction of flow. Non-reactive solutes in the flow are transported at an average rate equal to the seepage velocity of the fluid ($\bar{v}$),

$$\bar{V} = \frac{v}{n} \tag{2}$$

where n is the total porosity of the porous material. Contaminant transport processes includes advection, diffusion, mechanical dispersion, and coupled flow [4].

The advection process involves the transport of solutes in the flowing fluid in response to the hydraulic gradient. During diffusion, the chemical species migrate in response to concentration gradient in accordance with Fick's first law. The governing two dimensional (x,y) partial differential equation describing the advection-dispersion of pollutants in groundwater flow without pollutant source or sink, can be written as,

$$D_{xx}\frac{\delta^2 C}{\delta x^2}+D_{yy}\frac{\delta^2 C}{\delta y^2}+D_{xy}\frac{\delta^2 C}{\delta x\delta y}-V_x\frac{\delta c}{\delta x}=V_y\frac{\delta c}{\delta y}=R\frac{\delta c}{\delta t} \tag{3}$$

where D_{xx}, D_{yy}, D_{xy}, represent hydrodynamic coefficients in x,y and xy directions respectively (L^2/T), C is the solute concentration (M/L^3), V_x, V_y are the pore water velocities in the directions of x and y respectively (M/T), R is the dimensionless retardation coefficient, and t is the time (T). If $R > 1$, the solute is reactive.

The initial condition describing the distribution of solution concentration ($t = t_o$) can be given as

$$C = C_0\ (x,y) \tag{4}$$

The boundary conditions can be described in three components:

1. Boundary of specified concentration, i.e.,

$$C = C_c \tag{5}$$

2. Newman boundary condition (specified concentration gradient normal to the boundary),

$$\frac{\delta c}{\delta n}=C_1 \tag{6}$$

3. Cauchi condition (specified advective – dispersive flux normal to the boundary),

$$V_nC - D_n\frac{\delta c}{\delta n}=\frac{V_0 C_v}{n_e} \tag{7}$$

where V_n is the known flux, C_v is the known solute concentration, and n_e is the dimensionless effective porosity. The partial differential equation (3) describing the advection-dispersion solute transport by groundwater subject to the above initial and boundary conditions has been solved by the Finite Element method (FEM) using quadratic elements [5].

In mechanical dispersion the effects of soil heterogeneity causes macroscopic tortuosity effect on the contaminant flow. Coupled flow processes occur in response to gradients due to chemico-osmosis, electro-osmosis, and thermal-osmosis.

However, if coupled flow is neglected, the total mass flux, J, of the contaminant species is the sum of the advective (J_n), diffusive (J_D), and dispersive (J_m) fluxes such that

$$J = J_A + J_D + J_m \tag{8}$$

For one dimensional transport in saturated medium,

$$J = n_e\bar{v}c - D^*n_e \frac{\delta c}{\delta x} - D_m n_e \frac{\delta c}{\delta c} \tag{9}$$

where D^* is the effective diffusion coefficient and D_m is the mechanical dispersion coefficient.

Beyond the movement of the flux, natural geological materials have the ability to interact geochemically with chemical constituents of the flux. This can lead to partial or total immobilization of the potential groundwater contaminants resulting in geochemical attenuation. A number of naturally occurring geochemical processes are effective in removing groundwater contaminants [6-9]. The processes involve cation and anion exchange with clays, adsorption of cations and anions on hydrous oxides of iron and manganese, sorption on organic matter, direct precipitation of ions from solution and co-precipitation by adsorption. Volatilization and biodegradation are effective mechanisms for attenuating the movement of organic contaminants.

In general geochemical attenuation mechanisms are most active in pH ranges of 5 and 8. The extent of attenuation on leachate contaminants depends upon:

a) the chemical composition of seepage solution;
b) the geochemical and mineralogical properties of the geologic material; and
c) the pH and EH conditions that are established during contact of the water with the geological material.

Sewage or leachate contains pathogenic bacteria and viruses which are carried along the plume. These bacteria are removed by straining, adsorption, or die off. In medium grained sand or fine materials pathogenic and coliform organisms generally do not penetrate more than several meters but in fractured rocks, coarse sand, and gravels bacteria can be transported hundreds of meters along the flow paths. Viruses are relatively immobile in granular geologic materials.

GROUNDWATER ANALYSIS

Thirteen boreholes were randomly selected from within the area under study (Figure 1). They comprise both government-owned boreholes and private-owned boreholes. The depth to which the boreholes were sunk varies between 57 m and 65 m, penetrating the semi-confined aquifer zone.

Water samples were collected from each of the boreholes in the month of June, preserved, and taken to the United Nations International Children's Fund (UNICEF) laboratory in Owerri for physical, chemical, and biological analysis. All the tests were carried out in accordance with the standard methods. Specific parameters of interest tested include pH, total hardness, carbon dioxide, nitrate, total coliform, phosphate, heavy metals, etc. A summary of the results obtained is presented in Table 2.

DISCUSSION

The result of the analysis, comparatively, shows that on the average the pH value and the concentration of carbon dioxide, nitrate, total coliform bacteria, iron, and total dissolved solid (TDS) in the groundwater exceed the permissible limit of WHO drinking water standard, Table 3. The anomalies observed are apparently due to the intrusion of leachate into the groundwater aquifer. Local variations in water quality observed from borehole to borehole (Table 2) are probably due to macro-variations in the geological structure of the area, as well as to proximity to dump site.

A pH value of 6.4 is slightly acidic and is outside the limit recommended by WHO. The relatively high concentrations of carbon dioxide (36 mg/l), nitrite (0.5 mg/l), coliform bacteria (28 count/100 mls), and TDS (31 mg/l) is an indication that the geologic structure, typical of the coastal plain sand, does not completely attenuate the contaminants before they reach the groundwater table, thereby rendering the waters unsafe for human consumption.

A graphic comparison of some reference concentrations is shown in Figure 2. It may be noted that high iron content of the groundwater may not be attributed to the leachate but to the ferrugineous nature of the geologic formation.

To make the water resource from the semi-confined aquifer suitable for drinking purposes, appropriate treatment procedures must be followed. This may include chlorination to raise the level of chloride to an acceptable limit. Filtering systems should also be employed.

It is envisaged that with the growth in population more wastes will be generated and the level of contamination of groundwater will increase. In addition, more private boreholes would be in operation. The private operators hitherto do not treat the water before selling to the public. To safeguard the health of users plans could be put in place to encourage and monitor the use of potable water treatment kits by private operators.

Table 2. Analysis of Borehole Waters from Semi-Confined Aquifer in Owerri Urban

S/NO	Location	BH depth m	pH	Total hardness mg/l	CO_2 mg/l	Nitrate mg/l	Nitrite mg/l	Phosphate mg/l	Coliform No/100ml	Fe^{2+} mg/l	CA mg/l	Cl mg/l	Mn mg/l	T.D.S. mg/l	Total bacteria (count)
1	Obinze*	58	7.1	40	13	0.4	NA	10	0	0.8	12.0	20	NA	NA	NA
2	Shell Camp	65	7.1	34	8	0.13	NA	0	15	0.2	24.0	10.5	NA	NA	NA
3	MOWST*	58	6.4	18	8.4	0.15	NA	0	16	0.13	18.0	11.4	NA	NA	NA
4	Amakohia	67	6.1	18	16	40.5	NA	0.04	0	0.04	28.0	8.2	NA	NA	NA
5	Akwakuma*	60	7.1	36	14.2	0.3	NA	0.9	2	10.7	12.0	0	NA	NA	NA
6	Ugwuorji*	—	6.1	10	50	0.5	0.2	0.5	35	0.2	4.0	0.5	0.02	13.75	100
7	H&E, Qtrs*	—	6.3	20.3	43	4.0	0.5	0.4	40	0.2	8.4	0.5	0.03	19.3	48
8	Prefab	—	6.4	27.6	8	4.6	0.5	1.2	28	0.14	9.0	0.5	0.00	22	100
9	(WAEC)*	—	5.4	19.5	65	0.5	0.2	0.3	54	0.25	6.9	0.8	0.05	23	48
10	Anokwu St.	57	6.0	20	45	0.5	0.2	0.5	55	0.10	8.0	0.5	0.00	35.2	56
11	Oparanozie St.	60	6.3	15	55	7.8	0.9	1.2	62	0.15	9.0	0.5	0.00	37.7	71
12	Egbu	65	6.3	31	28	6.8	0.8	0.9	22	0.12	7.9	0.5	0.15	43.6	24
13	Ihiagwa	59	6.5	25	45	5.7	0.7	0.5	29	0.36	5.0	0.45	0.35	54.3	100
	Range	57-65	5.4-71	10-40	8-65	0.4-7.8	0.2-0.9	0-1.2	0-62	0.04-10.7	40-28	0.45-11.4	0-0.35	13.75-54.3	24-100
	Average	61	6.4	24	36	2.5	0.5	0.5	28	1.03	11.7	4.1	0.08	31.1	68

NA = Not applicable. *Govt. boreholes.

Table 3. Comparative Evaluation of Groundwater Quality

Parameters	Leachate	GW quality	WHO standard (drinking)
pH	5.2	6.4	6.5-8.5
Total hardness (mg/l)	100	24	150
CO_2 (mg/l)	70	36	10
Nitrate (mg/l	2.2	2.5	45
Nitrite (mg/l)	0.6	0.5	0.1
Coliform (count/100 ml)	270	28	10
Phosphate (mg/l)	3.5	0.5	3.0
Iron (mg/l)	0.5	1.0	0.3
Chloride (mg/l)	23	4.1	250
Calcium (mg/l)	60	11.7	150
Manganese (mg/l)	4.9	0.08	0.05
T.D.S.	43	31	3

SUMMARY AND CONCLUSION

The capital city of Owerri is underlain by, mainly, medium to coarse sand with intercalation of clay lenses, especially at the central region of the metropolis. Wastes in the form of leachate and septic tank sewage migrate into the semi-confined groundwater aquifer occurring at depths of over 50 m. Although geochemical attenuation of the contaminants takes place, a good proportion of some pollutants such as carbon dioxide, nitrite, total dissolved solids, and bacteria find their way into the groundwater. With concentrations exceeding the maximum level acceptable by WHO for drinking water, the borehole waters are generally unsafe.

Most of the boreholes in the city are privately owned and no effort is made by the operators to treat the water before selling to the public. It is of concern that water be treated before distribution to customers. Ownership of potable water treatment kits should be a condition for approval of private boreholes as sources of water supply. The water may be chlorinated before use, to raise the chloride concentration to the minimum permissible level of 250 mg/l.

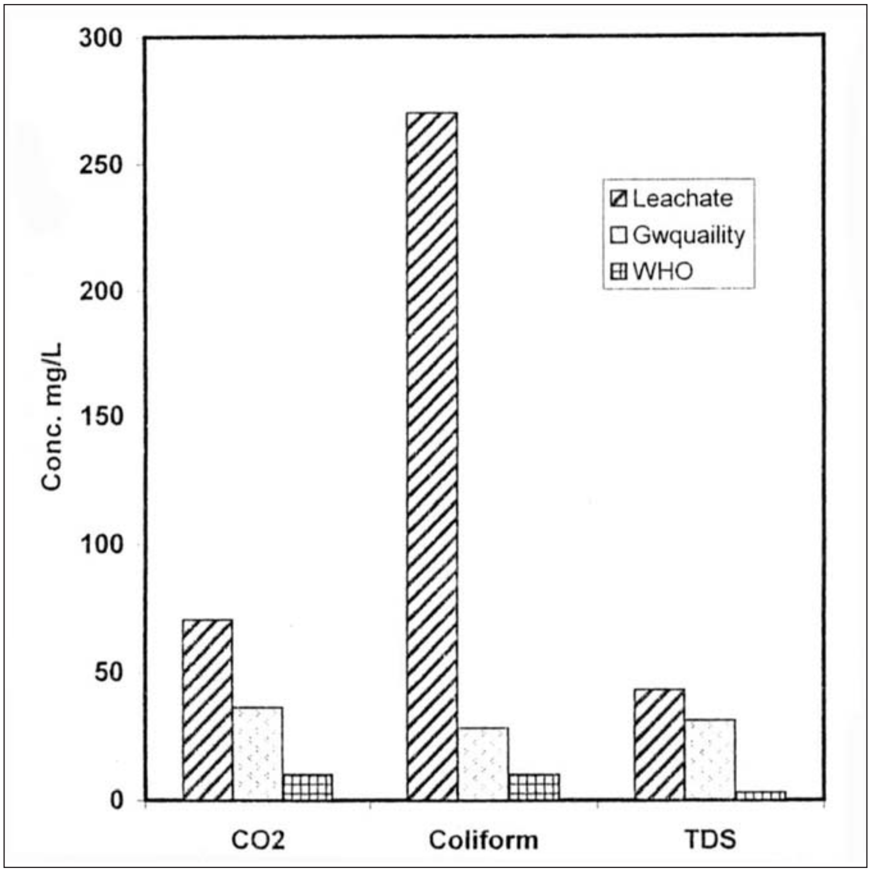

Figure 2. Comparison of some reference concentrations.

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