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MIGRATION OF CONTAMINANTS IN GROUNDWATER AT A LANDFILL SITE, NIGERIA

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The risk of groundwater pollution is regarded as the principal impact of the disposal of waste on land. In examining this problem, geophysical and geochemical studies were carried out at a solid waste disposal site in Owerri, southeastern Nigeria. The disposal system in use is the landfill disposal method. Azimuthal electrical resistivity (ER) soundings were conducted around the site to determine the directions of contaminant transport. Surface and groundwater samples were collected and analyzed to determine some geochemical parameters usually considered to be indicators of pollution from solid waste disposal. Grain size analyses of sediment samples were found to consist of sand particles with high porosity and permeability. A collection of litho-geophysical logs of the study area gives insight about the nature of the porosity and permeability. The grain size analysis results together with the litho-geophysical logs show that contaminated leachates can migrate through the unsaturated zone into groundwater. Results indicate that the landfill and its management pose a threat to human health. Surface and groundwater samples near the landfill are acid at certain spots, while the concentration of PO_4 *and* NO_3 *are well above the guidelines recommended by WHO.*

INTRODUCTION

The groundwater resources of many cities can be rendered unfit as a result of contamination both from point and non-point sources. Point sources such as landfills, septic tanks and oil storage tanks can release high concentrations of pollutants. However, their effects are generally limited to a localized domain within the groundwater system. This is unlike non-point (diffuse) sources such as fertilizers, pesticides and urban runoff, which are unavoidable and very difficult to control.

Most of the wastes generated in Owerri and its environs are dumped at the Avu landfill in Owerri West along the Port Harcourt highway (Figure 1). There has been an immense increase in population, industrial and agricultural growth in Owerri and its environs over the last three decades, and this has contributed to stresses on the groundwater system. The population was 102,800 in 1963, 149,000 in 1976, about 400,000 in 1982, and may exceed 1,000,000 by the year 2000 (Uma and Egboka, 1985). According to the Imo State government development plans, the water need of Owerri is expected to rise to about 1.3 million m^3/day by the year 2000. This volume of water would be supplied by the

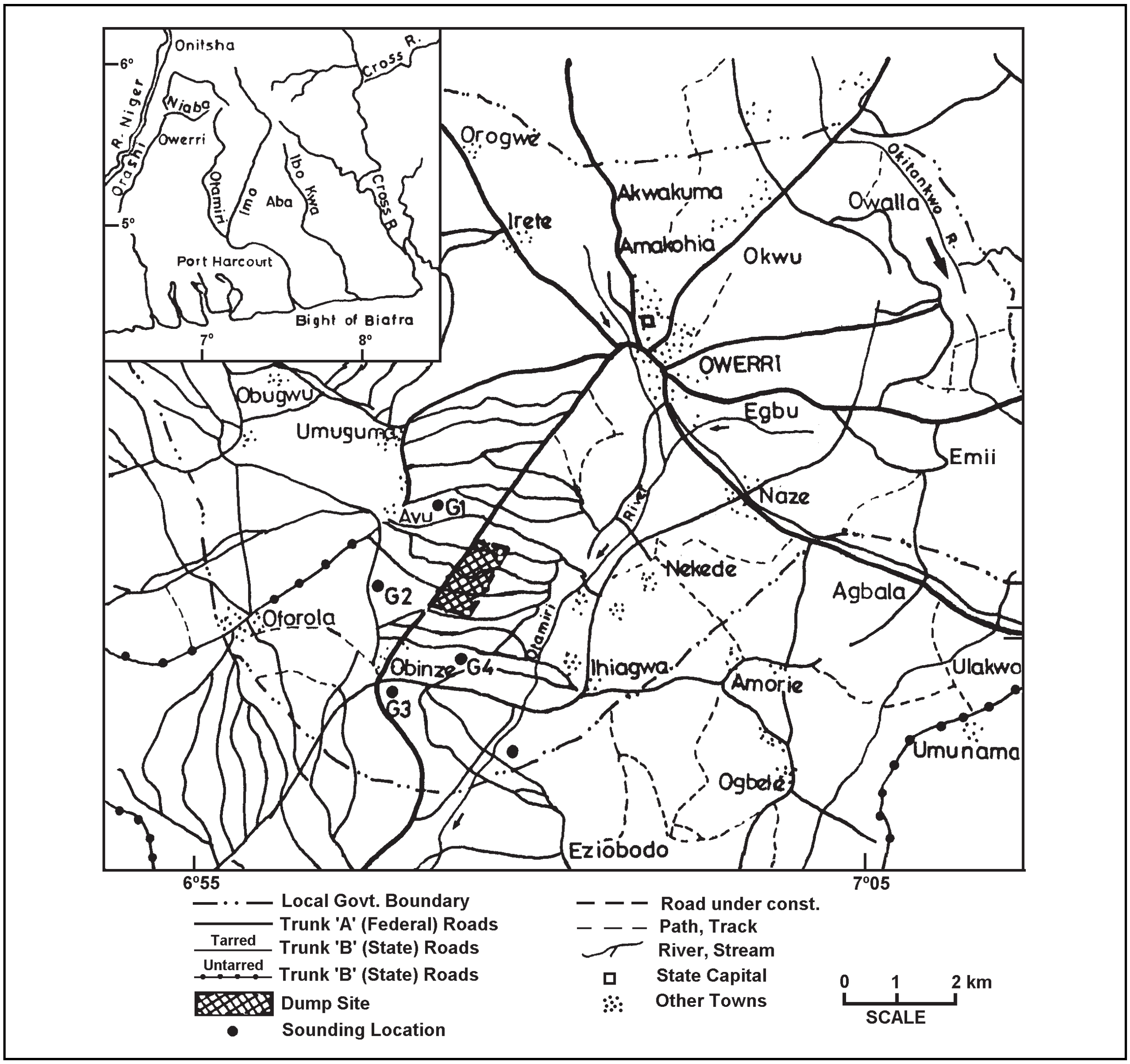

Figure 1. Map of the study area showing access roads and location of electrical resistivity soundings.

surface and groundwater system. It becomes necessary therefore to examine the location of the landfill site at Avu to find out whether there is fault in location as regards contamination of the groundwater system by leachates that are generated in the landfill. It is already possible to cite many examples of groundwater pollution involving the abandonment of production wells or development of the aquifer.

The investigation will involve hydrochemical analysis of water samples and grain size analysis of sediment collected from strategic points in the landfill. The analysis will give insight on the nature of sediments in the study area, the cause of contaminant migration through such sediments, the level of migration of leachates through the unsaturated zone into the saturated zone, and the degree of contamination of groundwater.

GEOLOGY

Owerri is underlain entirely by sedimentary rocks, which belong to the Benin Formation of Miocene to Recent age (Reyment, 1985). Simpson (1954) earlier referred it to as coastal Plain Sands. They consist of thick, very friable sands with minor intercalations of clay beds and lenses. The sands are mostly medium to coarse grained, pebbly, poorly sorted and locally contain lenses and pods of fine-grained sandstone amid sandy clay. Petrographic analysis of the rock (Onyeagocha, 1980) shows that quartz makes up about 95–99 percent of all the grains. The rest consist of 1–2.5 percent of (Na + K) mica, 0.5-1 percent feldspar and 2-3 percent dark minerals (e.g. biotite). The Benin Formation has variable thickness that ranges from about 200 m at the edge of its contact with the older Ogwashi/ Asaba Formation to about 2000 m.

The average thickness of the formation at the study area is about 800 m (Avbovbo, 1973). In many places within the study area the formation is overlain by a considerable thickness of red earth (laterite) composed of iron-stained regolith formed by the weathering and subsequent ferruginization of the weathered materials. The topsoil contains slight to moderate amounts of humus and has an average pH of 4 0.

The intercalations of sandy and clay units give rise to a multi-aquifer system. Boreholes penetrating the upper 200 m of the formation reveal three aquifer systems (Uma, 1984). The upper aquifer is unconfined and exists throughout the study area. The middle aquifer is semiconfined and has a thickness that ranges from about 30 m in the North (around Amaraku and Anara) to about 80 m in the south (around Avu). The aquifer is extensively tapped by boreholes. The separating aquitard between the two aquifers is made up of 3-15 m thick sandy clay. South of Owerri the aquitard becomes more sandy with a very high leakage factor.

METHOD OF STUDY

Geochemical Survey

Water samples were collected from the Otamiri and Nworie rivers at locations shown in Figure 2. The stations were chosen such that water samples reflected the inflowing and outflowing river water with respect to the landfill location. Thus the water samples were considered representative.

Groundwater samples were collected from both hand-dug wells and boreholes fitted with hand pumps within the Otamiri watershed (Figure 2). The water samples were collected during September 1996 and March 1997 to represent the hydrological year.

The chemical analysis of water samples was carried out in the geotechnical laboratory of the

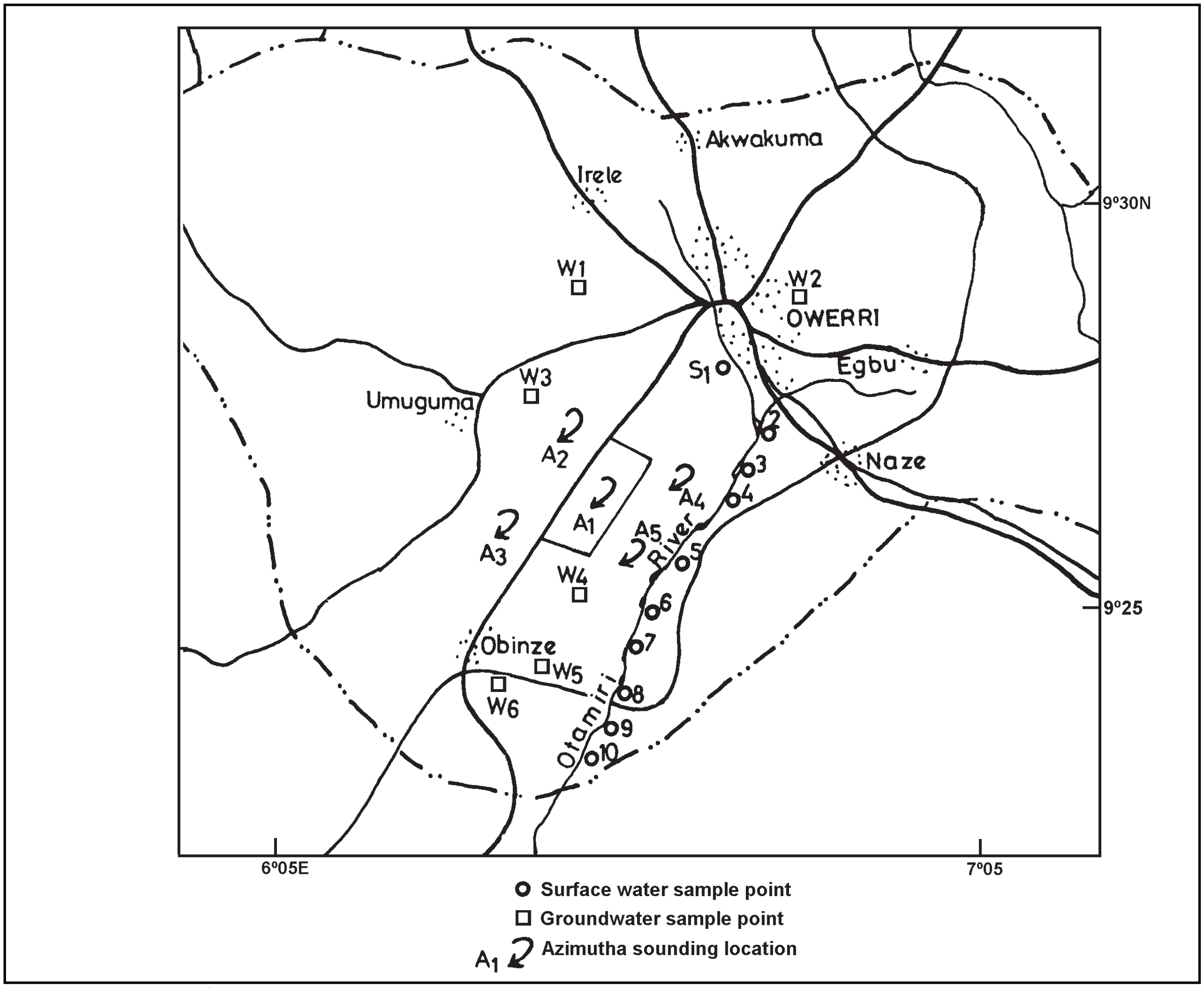

Figure 2. Map of the study area showing sample locations.

Federal University of Technology, Owerri, using the Digital Titrimetric method and the Hach Spectrophotometer, model DREL/5. Analytical results show increases in certain parameters. The grain size analysis was carried out for sediment samples collected at depths of 0.3 and l.7 m at the Avu landfill site.

Geophysical Survey

One of the primary problems in the investigation of groundwater pollution is locating the contaminant plume. Because of the analogy between the Darcy's law and Ohm's law for electric current flow, it is possible to determine the direction of contaminant flow from electrical resistivities measured as functions of azimuth. Since the potential for groundwater resources as well as for contaminant transport are governed by the fractures of the rock formation, the electric current flow has different magnitudes in different directions. When apparent resistivities in different directions are plotted as radii, they generate anisotropy figures, which is an ellipse in the simple case of parallel fractures with the long axis parallel to the strike of the fracture (Skjernaa and Jorgensen, 1994). Taylor and Fleming (1988) describe azimuthal resistivity surveys.

Azimuthal electrical resistivity soundings were conducted at 5 locations The instrument used was the ABFM terrameter 300 with stainless steel electrodes. Electrode spacing (a) and constant potential

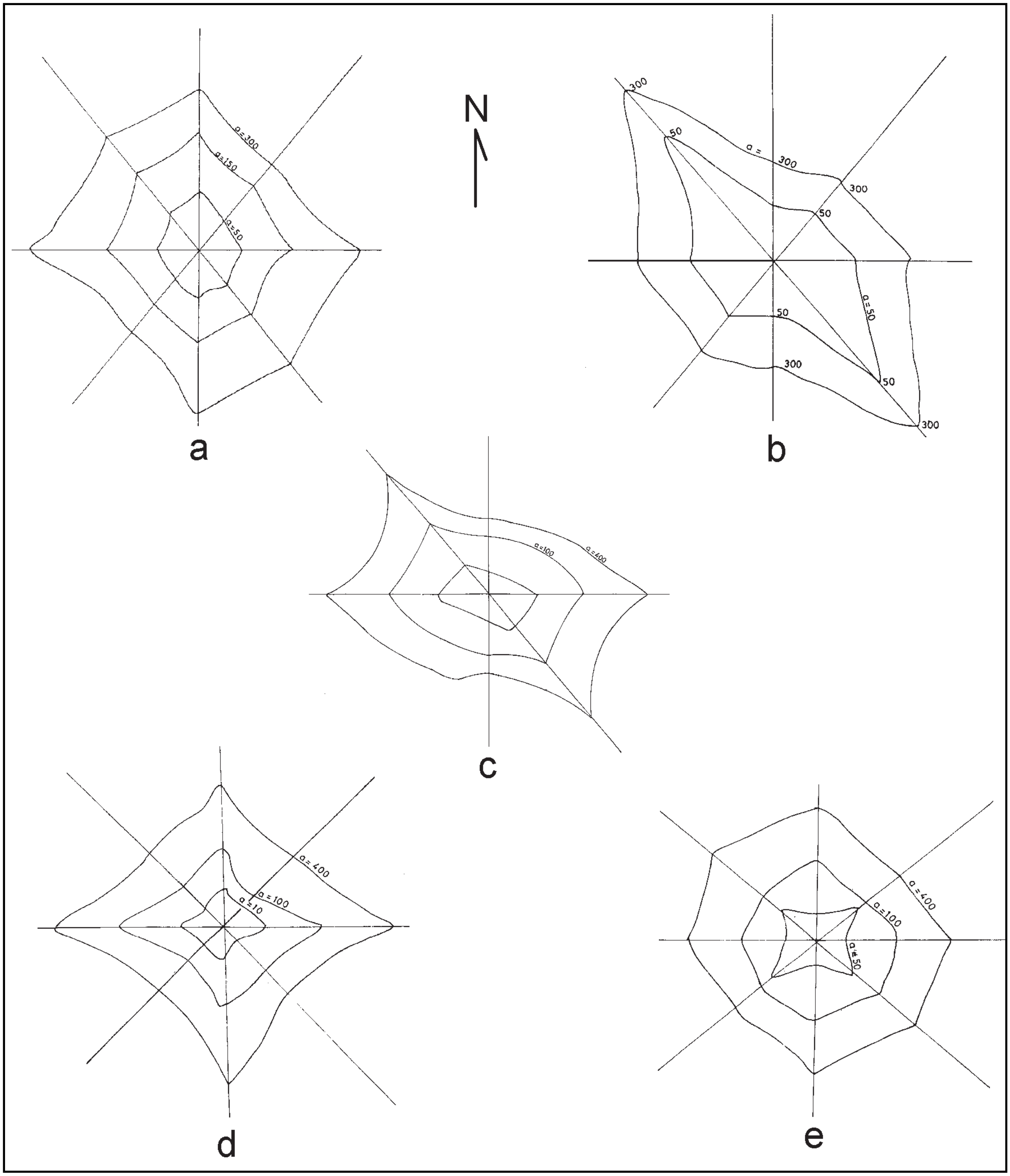

Figure 3. Anisotropy figure for locations AS1 (a), AS2 (b), AS3 (c), AS4 (d), and AS5 (e).

electrode spacing (b) were rotated about the center point and measurements were made in 45^{o} increments (i.e. 0^{o}, 45^{o}, 90^{o}) and N-S, NE-SW, E-W, and SE-NW directions. The measured values are multiplied by the geometric factor to give the apparent resistivity, which was used to construct the anisotropy figures.

The anisotropy figure for each location is shown in Figure 3. Vertical electrical soundings were performed at 12 other locations to determine the depth to water table.

RESULTS AND DISCUSSION

Geophysical Investigation

With regard to overall orientation and form, the anisotropy figures obtained at the same location but with different (a) values are often almost identical. Figures 3a and 3e are triple peaked indicating that electrical anisotropy is in three directions. These are the NW-SE, N-S and the E-W directions. Figures 3b and 3c are double peaked with electrical anisotropy in the NW-SE and the E-W directions. Figure 3d shows electrical anisotropy in the N-S and E-W directions. The multiple structural trends observed in the anisotropy figures may be a result of intersection of joints, anisotropy figures allow a three directional classification of electrical anisotropy, namely NW-SE. N-S, and E-W directions.

The major peaks are in the NW-SW and N-S direction while the E-W trends form shoulders. The NW-SE trends seem to emphasize the regional trend patterns, while the N-S trend appears to have been influenced by the ancient Otamiri river channel that, according to Ananaba et al. (1993), is fault controlled. The inferred directions served as a guide in the selection of groundwater samples for analysis.

The sieve analysis results and the litho/geophysical logs indicate that the contaminants present in the water samples may have migrated through the porous and permeable sand body into the groundwater. This is probably enhanced by the heavy rainfall in the study area. High rainfall occurred in the months of June, July and September, with a mean annual rainfall of about 2290 mm (Garnier, 1967). The rain water facilitates microbial degradation of organic matter and at the same time aids in the dissolution of certain substances like nitrate, phosphates, sulfate iron and other cations and anions. Rainwater also provides a medium of transport for the leachate into groundwater.

Geochemical Investigation

Table 1 shows the geochemical analysis of data for some hand-dug wells by Uma, 1984. Table 2 shows the geochemical analysis of Otamiri river water samples, and groundwater samples from boreholes within Owerri and around the landfill, which are all within the Otamiri river watershed. A comparison shows increases in certain substances in groundwater, which are likely to be due to the landfill at Avu which started receiving solid waste in 1987.

Table 2 shows an increase in the nitrate content of groundwater at Avu compared to the data from Uma which showed no nitrate in the water sample. Recent analysis shows a nitrate content of 8.4 mg/l. Although the level is still lower than the recommended limit of 50 mg/l of nitrate, the increase from no nitrate in 1984 to 8.4 mg/l in 1997 would continue in the near future and might exceed the recommended limit.

The high concentration of iron in groundwater in this area is probably due to the leaching of iron from iron scraps, which constitute a reasonable part of the wastes in the Avu landfill. The high concentration of iron may also be attributed to leaching from ferruginized sandstone units of the Benin Formation and the lateritic overburden in these places. The presence of iron above the recommended limit of 0.03 mg/l causes an unpleasant taste and stains.

The presence of a high concentration of manganese in groundwater comes from the soils as sediments. Just like iron, the presence of manganese in water poses more of economic problem than a health hazard since its impacts are undesirable tastes, deposits and dark stains.

There is a general increase in turbidity in almost all the samples analyzed, compared to that

Table 1. Geochemical Analysis Data for Some Boreholes and Hand-dug Wells in Owerri and its Environs (After Uma, 1984)

Sampling points	Okuku HW	Amafor HW	Avu HW	Umuokanne BH	Obinze BH	Otamiri River 1983
Parameters Ca	3.2	3.6	12	8	4.4	2.4
Mg	2.4	0.98	1.46	4.88	1.34	3.41
Na	2.27	2.3	4.6	3.28	4.33	6.5
Fe Total	0.02	0.75	0.40	0.08	0.04	0.09
Nitrate	2.2	6.16	0	3	5.28	8.8
$CO_3 + HCO_3$	10.78	7.78	21.56	23.95	9.88	11.98
SO_4	3.0	1	3	3	100	3
Cl	3.5	3.5	3.5	5	0.02	10
Nitrite	0.026	0.05	0	--	0.02	--
pH	5.8	5.85	5.5	4.9	5.3	5.3
Total Hardness	18	13	36	40	16.5	20
Ca Hardness	8	9	30	20	11	6
Mg Hardness	10	4	6	20	5.5	14
Turbidity (FTU)	12	3	5	30	1	--
Color (Hazen)	--	5	1	100	10	--
Alkalinity	--	--	--	5.0	--	--
Phosphate	0.04	0.15	--	0.35	0	--
Mn	0.1	0.1	0.03	--	0.05	--
NO_3 as Nitrate N_2	--	--	0.2	3.0	--	-
TDS	33.5	20.1	56.95	20.0	32.0	50.0

obtained in the analyses carried out by Uma. Turbidity occurs due to suspended finely divided organic matter and also inorganic matter, plankton and other micro-organisms in water. Suspended clay and silt also increase turbidity. The general increase in color of the water samples is a result of the enormous organic matter loads which are deposited at the landfill.

Although phosphate concentrations are within the recommended acceptable limit of 5mg/l, there is a general increase in concentrations compared to the results of Uma. Just like nitrates, the presence of phosphates in groundwater is due to biological wastes and residue, which are common at the landfill.

CONCLUSIONS AND RECOMMENDATIONS

The present mismanagement of the landfill, which involves crude dumping, should be discontinued. The landfill in its present condition creates a nuisance of odor, destroys the aesthetic nature of the environment and imperils water resources. By far the most significant result of his investigation is the high concentration of phosphate and nitrate in water bodies. Safe disposal of solid waste is an important social program.

Government intervention is required to avoid the outbreak of epidemics. Satisfactory management of solid waste is largely dependent on efficient planning and operation. These in turn must be

Table 2. Chemical Analysis of Water Sample from Few Hand-Dug Wells, Boreholes and Surface Water in Owerri and Environs (1997)

Sampling points	Okuku HW	Amafor HW	Avu HW	Umuokanne BH	Obinze BH	Otamiri River 1983	Obosima HW2	Obogwe HW3	Ororola HW5
Parameters Ca	2.8	3.57	7.6	7.82	4.15	2.88	2.88	2.89	8.34
Mg	1.02	1.26	1.11	3.44	1.23	2.13	1.05	1.05	1.28
Na	4.59	5.35	3.95	3.32	4.36	5.68	4.27	4.21	7.6
Fe Total	0.38	0.49	0.59	0.17	0.13	0.001	0.39	0.34	0.37
Nitrate	5.68	6.04	8.4	3.16	5.01	3.79	0.27	0.09	0.13
$CO_3 + HCO_3$	17.5	18	20.77	22.75	9.64	-	18.5	18.5	18
SO_4	12	15	15	4.8	0.84	5.07	12.5	10	10
Cl	1.4	1.7	2.54	5.08	0.04	1.6	1.65	1.6	1
Nitrite	0	0.03	0.03	0.04	0.02	-	0.03	0	0.01
pH	5.2	5.7	5.32	5.2	6.2	-	4.36	4.9	6.1
Total Hardness	11.2	12.8	12.16	31	4.62	-	11.52	11.52	12.8
Ca Hardness	7	7.6	7.6	15	9.22	-	2.88	7.2	7.8
Mg Hardness	4.2	5.2	4.56	16	5.4	-	4.32	4.32	5
Turbidity (FTU)	20	11	25	40	1	-	18	11	10
Color (Hazen)	60	60	25	100	10	-	70	70	40
Alkalinity	17.5	18	18.5	19.24	17	-	18.5	18.5	18
Phosphate	1.1	0.85	2	1.74	0	1.42	1.9	2	2
Mn	0	0.25	0.25	0	0	-	0	0.1	0
NO_3 as Nitrate N_2	0.08	0.07	0.09	3.06	4.06	-	0.06	0.02	0.03
TDS	36.88	24.7	64.1	21.27	20	52.1	32.1	38.17	39.76

supported by adequate legislation and financing. A WHO expert committee on solid waste disposal and control (1971) recommended that international, bilateral, and private agencies should assist government in planning programs through the provision of professional expertise as well as providing direct financial assistance.

It must be pointed out that only a few of the parameters of the geochemical regime were measured in this study. Measurements were made only at a few stations and only twice a year. The results obtained so far point to a potential pollution level in our water resources arising from improper waste management. A more detailed investigation is required to better evaluate pollution levels.

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