

## **Groundwater pollution vulnerability and groundwater protection strategy for the Owerri area, southeastern Nigeria**

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**Abstract** The vulnerability to pollution of the Owerri regional water supply in, Nigeria, was assessed as the basis for proposing an appropriate strategy for protecting the groundwater resources. The vulnerability assessment was accomplished using the LeGrand, GOD, SIGA, and DRASTIC computer models. The model techniques generally involve parameter rating and point-count systems, based on evaluation of various hydrogeological parameters in relation to their capacity to influence the flow of contaminants in the groundwater system. The Owerri area is generally flat and groundwater recharge is relatively high. The area is underlain by predominantly sandy strata in the north, which grade into gravelly sequences towards the southwest. The southeastern part of the area is underlain in part by a thick clayey faces that thins and interfingers into the gravelly strata. Effective hydraulic conductivity ranges from  $5.6 \times 10^{-9}$  to  $1.44 \times 10^{-3}$  m s<sup>-1</sup>, the higher value being in the coarse sand and gravel units. The depth to the water table is about 60 m in the north decreasing southward to less than 20 m; the hydraulic-head gradient is 9–22%. The southwestern part of the Owerri area including the Owerri conurbation has a high vulnerability to groundwater pollution and therefore waste disposal sites should not be located there. The northern and southeastern areas have moderate and low vulnerabilities, respectively, and carefully selected and engineered sites within those areas could be considered for future waste disposal. Policies should be instituted to facilitate the closing of pollution sources in the area of high vulnerability such as open disposal pits, leaking petrol stations, effluent discharge from industries, and use of pit latrines, and to locate future disposal site in areas of lower vulnerability.

**Key words** groundwater development; groundwater protection; groundwater vulnerability assessment models; hydraulic head distribution; landfill waste disposal; land-use characteristics; Nigeria

### **INTRODUCTION**

The assessment of the environmental fate and behaviour of substances that have the potential to leach from waste-disposal and other sites is of great interest to environmentalists. Such assessments require knowledge of various environmental, chemical, and hydrogeological parameters. The values of these parameters are very uncertain due to the limited number of observations and the degree of heterogeneity of the geological formations underlying the evaluated area.

The concept of groundwater vulnerability is based on the assumption that the physical environment of an area may provide a degree of protection to the groundwater from anthropogenic and natural contaminants, and that the degree of vulnerability is a function of hydrogeological conditions and prevailing human waste-disposal systems.

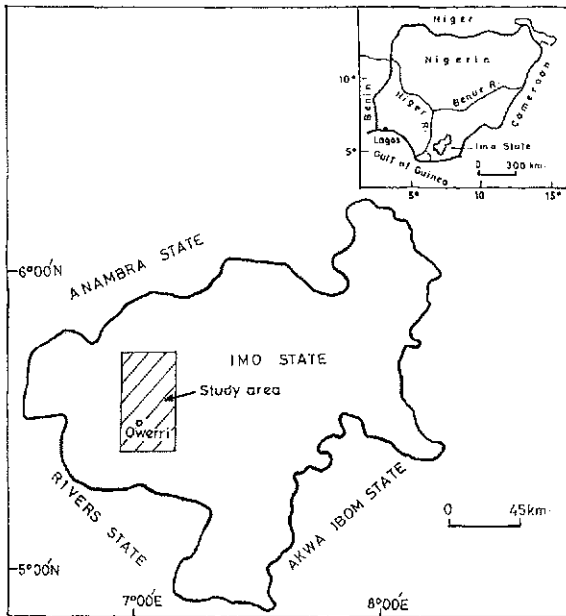


Fig. 1 Location of the study area in Imo State, Nigeria.

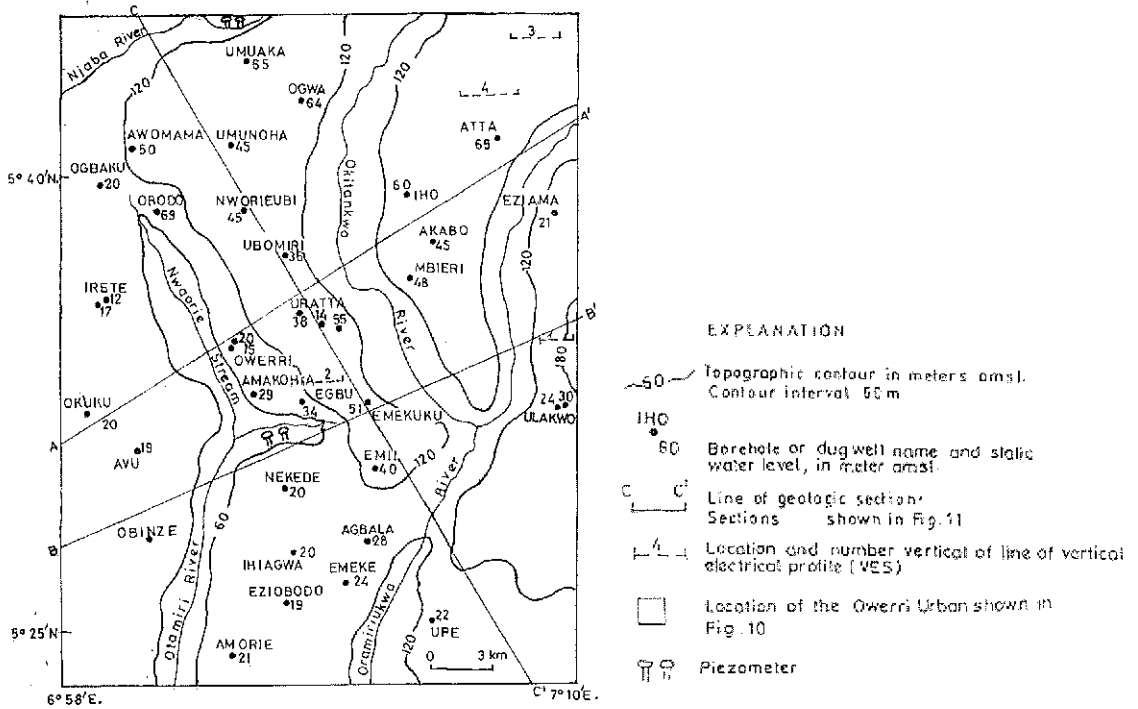


Fig. 2 Generalized map of the Owerri study area showing outline of the Owerri urban area location of the boreholes, depth to the water table, and location of the vertical resistivity profiles. (Data from Table 4).

Maps and analytical models that show that the variability of the protection provided by the natural environment throughout an area can express the degree of vulnerability.

The city of Owerri, Nigeria, and its environs, the object of this study, have undergone substantial industrial and population growth over the past two decades. Most of the growth has been in the Owerri metropolis, reported by Uma (1984) to have a population of about 400 000. Since that date the population has increased considerably. Waste generated in the area is disposed of in open dumps, along river banks, in erosion sites, abandoned borrow and quarry pits, septic tanks, and pit latrines. Other potential sources of pollution include petroleum products from numerous petrol stations, industrial effluents, and agricultural activities. Open dumps, in particular, are sited indiscriminately in the Owerri area without consideration of the protection of the underlying aquifers.

## STUDY AREA

The study area shown in Fig. 1, which includes the Owerri Capital Territory of Imo State in southeastern Nigeria, an area of about 740 km<sup>2</sup>, is bounded by latitudes 5°25' and 5°45'N and longitudes 6°58' and 7°10'E. Figure 2 is a generalized map of the Owerri urban area showing the outline of the Owerri urban area, location of boreholes, depth to the water table, and location of the vertical resistivity profiles (data from Table 4).

The climate is marked by two main seasons: a wet (rainy) season and a dry season. Most of the mean annual rainfall of about 2152 mm (Monanu & Inyang, 1975) occurs during the wet season, April–October, and is associated with moisture-laden maritime southwest trade winds from the Atlantic Ocean. The temperature ranges from 23 to 26°C.

## General geology

The study area and its environs are underlain by the Benin Formation (coastal-plain sands), an extensive stratigraphic unit in the southeastern Nigerian sedimentary basin. The Miocene-Pleistocene formation consists of very friable sand intercalated with shale and clay lenses (Short & Stauble, 1967). It also contains small isolated units of gravel, conglomerate, very coarse-grained sand, and sandstone in the Owerri area (Ananaba *et al.*, 1993).

The conditions of deposition were partly lagoonal and fluvio-lacustrine/deltaic (Reyment, 1965). The Benin Formation, which dips southwestward, thickens from a thin edge at its contact with the Ogwashi-Asaba Formation and is about 1000 m deep in the Owerri area (Reyment, 1965; Avbovbo, 1978).

## Hydrogeology

The study area is drained by three rivers, the Otamiri, Njaba, and Oramiriukwa, the Nwaorie Stream and the ephemeral Okitankwo Stream (recharge is mainly from surface runoff and groundwater baseflow); peak discharge occurs in September and October (Enuvie *et al.*, 1991).

The porous and permeable sands and interfingering sandy clay and gravels of the Benin Formation form a multi-aquifer system in which aquifer units are separated by semi-permeable sandy clay aquitards. Three aquifer units are recognized in the lower Imo River basin, of which the study area is a part (Uma & Egboka 1986). They are an upper water-table (unconfined) aquifer, a middle semi-confined aquifer, and a lower confined aquifer. The base of the upper water-table aquifer is at a maximum depth of 100 m. The middle semi-confined aquifer has an average thickness of 80 m, and the lower confined aquifer has an estimated thickness of more than 600 m. The aquifers have high storativity and transmissivity. Well yields range from 54.2 to 231.5 m h<sup>-1</sup> (Uma & Egboka, 1986).

## **POLLUTION VULNERABILITY**

The vulnerability of the aquifer to pollution was assessed on the basis of geological, hydrological, and land-use characteristics using appropriate vulnerability models. The data input to the models was derived from interpretation of various thematic maps, hydrostratigraphical analyses, and from determination of the mode of occurrence of the groundwater, aquifer characteristics, and unsaturated-zone and soil-media properties.

Knowledge of the groundwater vulnerability of the area can contribute significantly toward making informed, environmentally sound decisions regarding land-use and groundwater protection, and hence could help to ensure sustainable development of a groundwater resource.

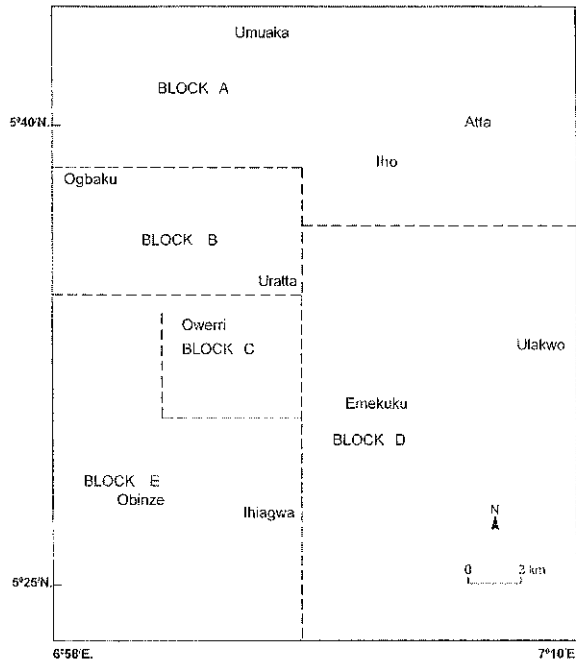
### **Vulnerability–assessment models**

The LeGrand (1964), GOD (Foster, 1987), SIGA (Vrba, 1991), and DRASTIC (Allen *et al.*, 1987) computer models were used for vulnerability analysis of the Owerri study area. They were applied to each of the five sub-areas (Blocks A–E) covering the study area (Fig. 3). Each subdivision was defined by separate geological, hydrostratigraphic, and land-use criteria. These models differ slightly in the types of data formulated, as indicated in Table 1, therefore, the use of multiple models provides the basis for a broad comparative analysis, and checking for convergence of results, thus ensuring a high level of confidence in the predicted vulnerabilities. The model results are presented as numerical points that can then be interpreted to rate the relative degrees of vulnerability to pollution of each block compared to others. These four models were chosen principally because of their general applicability, so including available data, as well as their computational ease.

## **STUDY METHODS**

### **Land-use pollution vulnerability study**

The land-use map of the Owerri urban area shown in Fig. 4, indicates industrial, residential, and agricultural areas, the general population density, and features that can have environmental consequence, such as gullies waste-disposal sites, quarries, and



**Fig. 3** Block subdivision of the study area.

**Table 1** Main parameters and models for assessing intrinsic vulnerability of groundwater (from Civita, 1993).

Parameter	Model name:			
	GOD	LeGrand	SIGA	DRASTIC
Precipitation rate and chemical composition			X	
Topographic surface, slope variability				X
Soil thickness, texture, and mineralogy				X
Soil permeability		X	X	
Character of unsaturated zone	X	X	X	X
Depth to water table	X	X	X	X
Hydrogeologic features				X
Aquifer hydraulic conductivity				X
Net recharge				X

**Table 2** Land use in the Owerri urban area (from Ibe *et al.*, 1992) (location of the sub areas as in Fig. 5).

Land use	Sub-area:		
	Northern	Southern	Central
Farm/land/fallow	65%	55%	5%
Industrial, educational	1%	5%	10%
Residential	25%	35%	80%
Nature conservation zones	8%	2%	1%
Erosion areas	0.1%	0.2%	0.3%
Others	0.9%	3.8%	4.7%
Relative population distribution	Moderate	Moderate	Dense

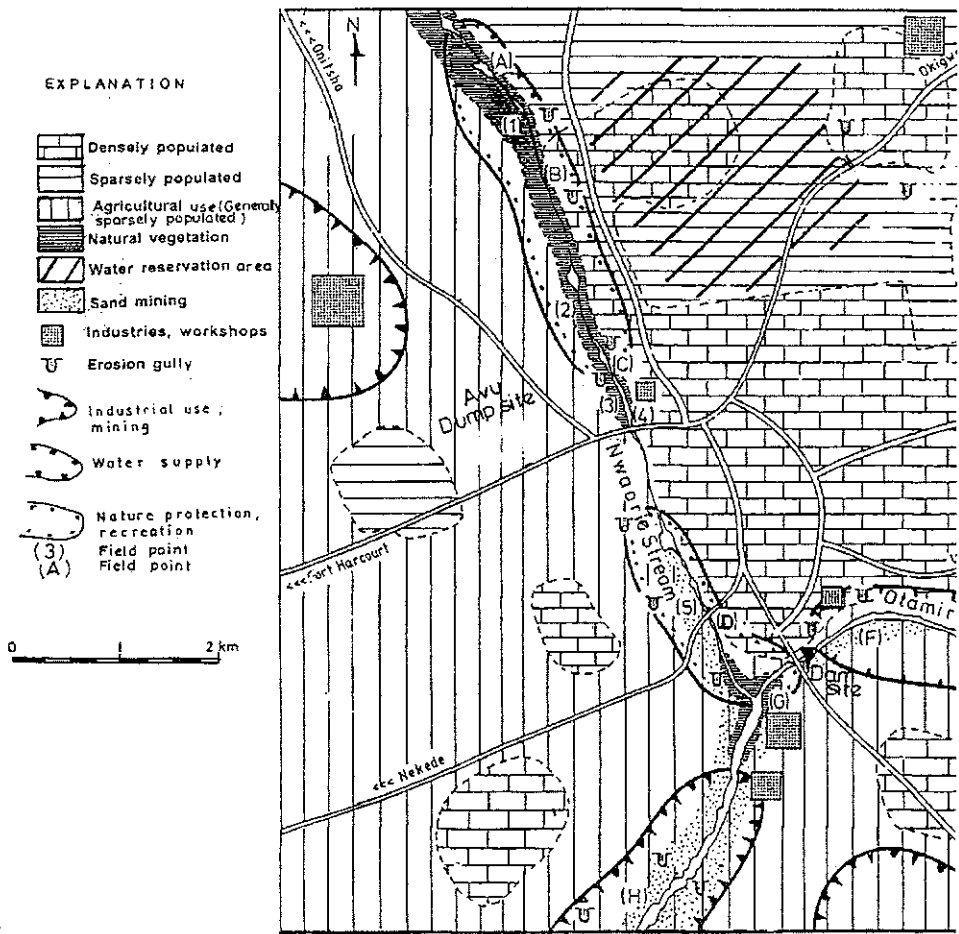
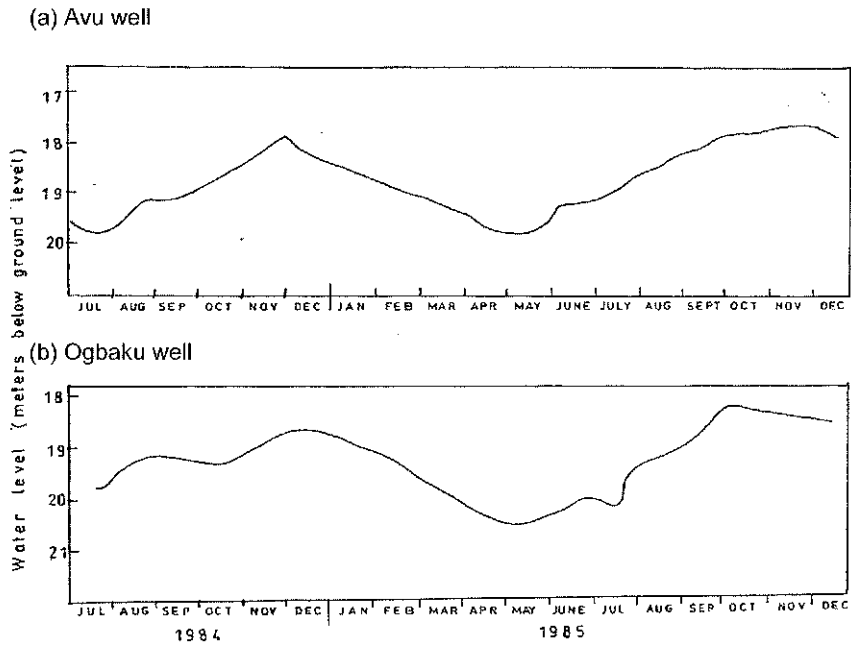


Fig. 4 Map showing land use in the Owerri urban area (from Ibe *et al.*, 1992).

nature-conservation sites. The Owerri urban area is divided into three sub-areas northern, southern, and central, and their land use is given in Table 2.

In the central sub-areas, 90% of the land is residential and industrial. Population in the central sub-area is dense, consequently there is high production of waste, both industrial and domestic. In the southern and northern sub-area, areas under agricultural production occupy the greater percentage of the land (55% and 65%, respectively). Population in these sub-areas is moderate to sparse and waste is mainly of domestic origin. Most of the waste sites are located in these sub-areas. Sand quarrying occurs along the major streams, and gully erosion is common along streams in all three sub-areas.

The mode of groundwater occurrence was deduced from geological studies of the area, static water-level data from boreholes, and observation of surface features influenced by groundwater seepage. The aquifer-recharge pattern was estimated from the record of water-level fluctuation in the Ogbaku and Avu boreholes by Okogbue & Agbo (1989) (Fig. 4). An estimate of aquifer recharge was also incorporated using the water-level data and porosity measurements of the aquifer material in adjacent



**Fig. 4** Hydrographs of: (a) Avu well in the northwestern part of the study area, and (b) Ogbaku well in the southwestern part, July 1984–December 1985 (from Okogbue & Agbo, 1989). Location of wells shown in Fig. 2.

**Table 3** Slope, soil type, and recharge at selected localities in the study area (data as Table 4).

Location	Slope, $S$ (%)	Soil type	Estimated recharge ( $\text{mm year}^{-1}$ )
Umuaka	0.31	Loamy sand	669
Emekuku	0.86	Clayey loam	669
Ogbaku	0.20	Sandy loam	540
Owerri	0.39	Clayey loam	446
Ihiagwa	0.80	Clayey loam	600

Anambra State (Nwankwor & Etche, 1990). Recharge for the Owerri metropolis, where water-level data are not available, was estimated at 25% of the annual rainfall.

Recharge estimates at five locations in the study area (Table 3) show that the pattern of groundwater recharge is fairly uniform, although the Owerri metropolis has a relatively low rate of groundwater recharge.

### Vulnerability assessment

The groundwater-vulnerability assessments of the various blocks covering the study area (Fig. 3) computed by the LeGrand, GOD, SIGA and DRASTIC models are summarized in Fig. 6. There is general agreement on the vulnerability predicted by the four models, although there were slight differences in the model parameters used. The

**Table 4** Depth to the water table in boreholes and hydraulic head in the block of the study area.

Borehole names	Depth to static water level (m)	Head gradient (%) per block	Block
Awomama	50	22	A
Umuaka	65		
Ogwa	64		
Atta	65		
Eziama	21		
Iho	60		
Orodo	63		
Umunoha	45		
Mbieri	48		
Akabo	45		
Nworicubi	45	15	B
Ogbaku	20		
Ubomiri	36		
Orogwe	19		
Amakohia	29		
Uratta I	38		
Egbeada	20	12	C
Uratta ii	14		
Owerri i	20		
Owerri ii	15		
Egbu	34	10	D
Uratta iii	55		
Emekuku	51		
Agbala	28		
Upe	22		
Emeke	24		
Ulakwo i	24		
Ulakwo ii	30		
Emii	40		
Irete i	12		
Irete ii	17		
Ihiagwa	20		
Okuku	20		
Nekede	20		
Obinze	19		
Avu	19		
Eziobodo	19		
Amorie	21		

pollution predicted vulnerability is low in Block D and high in Blocks C and E. Block B has moderately high vulnerability, whereas vulnerability of Block A is moderate.

The low vulnerability to pollution of block D in the southeast part of the area, is due to the presence of a semi-confining clay layer, 10–20 m thick, overlying the aquifer and the substantial depth to water table in part of that block. The high vulnerability to pollution of blocks C and E (Owerri metropolis and southwest part of the area respectively), is due to the porous and permeable sediments in the vadose zone

Computer assessment model	Block					EXPLANATION Degree of Vulnerability
	A	B	C	D	E	
LeGrand						High
GOD						Moderately high
DRASTIC						Moderate
SIGA						Low
RESULT						Low

Fig. 6 Comparison of the vulnerability assessments of the various computer models of the blocks of the study area.

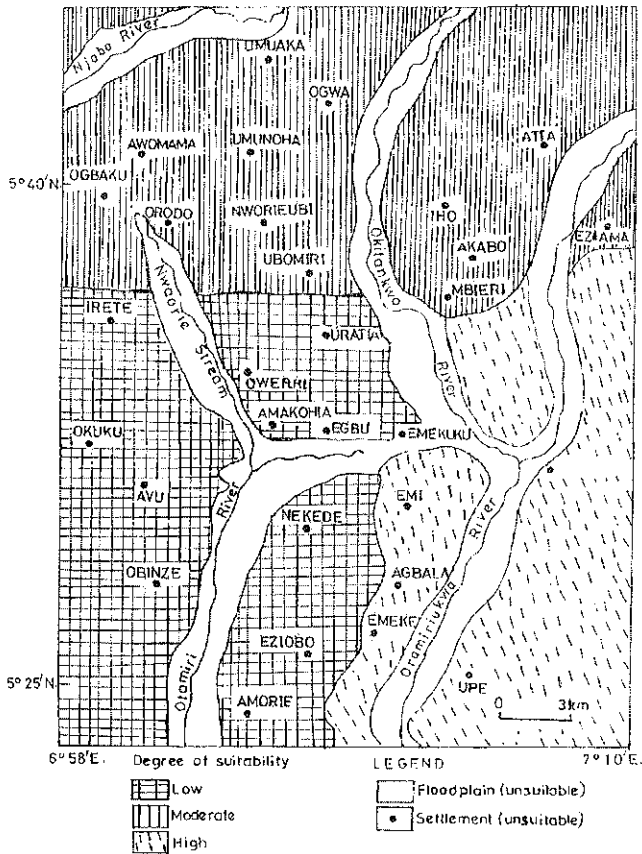


Fig. 7 Map showing the degree of suitability for waste disposal of various part of the study area.

and relatively shallow depths to the water table (10–35 m). There are some differences in the predicted vulnerability for blocks A and B in the northern half of the area. The SIGA model predicts high vulnerability for the two blocks, whereas the LeGrand and

GOD models predict moderate vulnerability. The DRASTIC model, however, rates the vulnerability as high in block B and moderate in block A. The high to moderate degree of vulnerability of the groundwater to pollution in the blocks is the result of porous and permeable overburden materials and the depths to water table of 30–65 m.

Based on the relative scores of the respective parameters and within the limits of the quality of the available data on these parameters, the most important parameters in groundwater vulnerability in the study area are depths to water table (or overburden thickness) and the presence or absence of a confining layer above the aquifer.

The degree of vulnerability to pollution determined by the models were defined by parameter for each block covering the study area, and no land-use practices were taken into account. However, such practice may control the choice of waste-disposal sites within a block, even where groundwater vulnerability is low. For example, health, aesthetic and nuisance factors would preclude waste disposal sites in the immediate vicinity of residential areas. Also, areas of steep terrain and flood plains (areas of high vulnerability), are unsuitable as disposal sites. Hence, to identify such areas, the spatial variation of vulnerability was superimposed over land use and topographical maps to develop a functional vulnerability map, shown in Fig. 7. The degree of aquifer sensitivity to human impact delimits the zones that could in practice be used for waste disposal. In general, suitability and vulnerability are inversely related.

## CONCLUSIONS

The vulnerability to pollution of the Owerri regional aquifers evaluated using the LeGrand, GOD, SIGA, and DRASTIC computed models, is high in Owerri metropolis and areas to the southwest, i.e. where the unsaturated zone is composed of sand and gravel with high effective hydraulic conductivity and low absorption properties, characteristics that facilitate the migration of contaminants down to the rather shallow water table. Areas north of Owerri have moderate vulnerability for predominantly sandy sediments underlie them but the water table is fairly deep, which enhances contaminant attenuation. However, because of their low absorption capacity, the overburden material would tend not serve to retard advective flow of contaminants down to the water table.

The areas southeast of Owerri of low vulnerability, are underlain by sandy clay and clay with low effective hydraulic conductivity, high absorption capacities, and a deep water table; all conditions that would retard contaminant flow. The groundwater occurs under mostly unconfined conditions but locally is semi-confined. However, a greater part of the sandy area would be prone to pollution from surface waste disposal sites through direct rainwater infiltration. The hydraulic-head gradients throughout the area are directed toward the streams and rivers, which suggests considerable groundwater baseflow. Hence, surface-water bodies are at risk in the event of pollution of the groundwater system.

Open-dump waste disposal, leaks from petrol stations, and effluents from industry are common in those areas of moderate to high vulnerability in and around Owerri. These contaminant sources probably adversely effect groundwater quality. Thus, existing waste-disposal sites in these areas should be relocated and future waste-disposal activities eliminated, to forestall further groundwater degradation. A con-

taminant-impact assessment should be undertaken to assess the degree of contamination of the groundwater system from existing waste-disposal sites. Such an assessment would also indicate the extent of rehabilitation required at each site.

Should areas of low pollution vulnerability in the northern and southeastern parts of the study area be considered as potential waste-disposal sites, and properly engineered sanitary landfills would be required to ensure adequate protection of the groundwater regime. Site-specific monitoring schemes should also be emplaced to detect any movement of contaminants into the groundwater or to surface-water bodies, in the event of contaminant and landfill design failure at the sites.

Groundwater quality could be improved overtime by educating residents, particularly on the health implications of water pollution from human waste, and by maintaining strict government control on land use and groundwater development.

The development of a hydrogeologically based vulnerability analysis provides a basis for developing appropriate protection strategies for the groundwater resources and also helps to explain water-quality problems in Owerri and its environs.

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