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# GROUNDWATER VULNERABILITY IN PARTS OF ORLU METROPOLIS, SOUTHEASTERN NIGERIA

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## ABSTRACT

*The groundwater vulnerability to pollution in parts of Orlu metropolis, Southeastern Nigeria, was assessed on the basis for proposing an appropriate strategy for protecting the groundwater resources. The vulnerability assessment was accomplished using the LeGrand and GOD 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.*

*Borehole information of five locations was collected within the area. The result show that the unsaturated zone material of these sub areas is composed of sandy-clay facies with low effective hydraulic conductivity (k3) and relatively high sorption properties.*

*The characteristics of the overburden materials indicate that contaminants would not migrate down to the water table with ease, especially areas where the water table is deep. The area generally has extremely low vulnerability and has considerable depth to water table which enhances contaminant attenuation and retardation. Also, the high sorption properties of the overburden materials tend to inhibit advective flow of contaminants down the water table.*

*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.*

***Keywords: Vulnerability, contaminant, pollution, groundwater, water table, aquifer.***

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## 1.0 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.

Water is essential for livelihood as well as socio-economic development of any community. Many communities in Nigeria, especially in the Imo River Basin area where the study area falls rely on surface and groundwater for both domestic and agricultural water supplies. It is estimated that approximately one third of the world's population use groundwater for drinking (Nickson et al., 2005). Groundwater pollution is a growing environmental problem, especially in developing countries. Many major cities and small towns in Nigeria depend on groundwater for water supplies, mainly because of its abundance, stable quality and also because it is inexpensive to exploit. However, the urbanization process threatens the groundwater quality because of the impact of domestic and industrial waste disposal. This results in aquifer deterioration, since some of these waste products, including sewage and cesspool may be discharged directly into the aquifer system. Water soluble wastes and other materials that are dumped, spilled or stored on the surface of the land or in sewage disposal pits can be dissolved by precipitation, irrigation waters or liquid wastes and eventually seep through the soil in the unsaturated zone to pollute the groundwater. Once contaminated, it is difficult, if not impossible, for the water quality to be restored. Thus constant monitoring of groundwater is needed so as to record any potential alteration in the quality and outbreak of health disorders. The degree of vulnerability is expressed by means of maps and analytic models that show that the protection provided by the natural environment varies at different locations.

Orlu and its environs have witnessed a substantial industrial and population growth during the past two decades. The main region of growth is in the Orlu Metropolis which has a population of over four hundred and twenty thousand people according to Wikipedia. Wastes generated in the area are disposed of in open dumps especially abandoned burrow and quarry pits, erosion sites, river banks, septic tanks and pit latrines.

Other potential sources of pollution include oil and gas spills from the numerous petrol stations in and around the metropolis, industrial effluents and waste from agricultural activities.

Open dumps in particular are located indiscriminately in the Owerri area and environs without consideration to the protection of the underlying aquifer and site. The aquifer is largely confined in most locations.

Water table depth prevent direct leachate infiltration into the major pathway for the entry of contaminants from pollution sources into the groundwater system, which is comprised

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generally of an extensive semi-confined to confined sand aquifer and impermeable overburden.

The confined nature of the aquifer, its strategic importance to the supply of portable water to the populace and the fact that polluted aquifer are difficult and expensive to clean up suggest the need for the development and implementation of appropriate protection strategy for the resource. Knowledge of pollution in the area forms the basis for developing such strategy.

**Location and Climate**

The study area is within the Orlu metropolis of Imo State Southeastern Nigeria (Figure 1).

Latitudes 5º47.47N - 5º28N and Longitude 7º02 20E - 7º15E bound it. The prevalent climatic conditions is marked by two main regimes, the wet season lasts from April to October while the dry season commences in November when the dry continental North- Easterly wind blows from the Mediterranean sea, across the Sahara desert and down the Southern part of Nigeria. The wet season is season characterized by double maxima of rainfall. The first peak occurs in July, and the second occurs in September with mean annual rainfall of about 2152mm (Monanu and Inyang, 1975). Violent storms are predominant in months of June, July, September and October. The heavy rainfall and storm result in flooding, soil leaching and erosion.

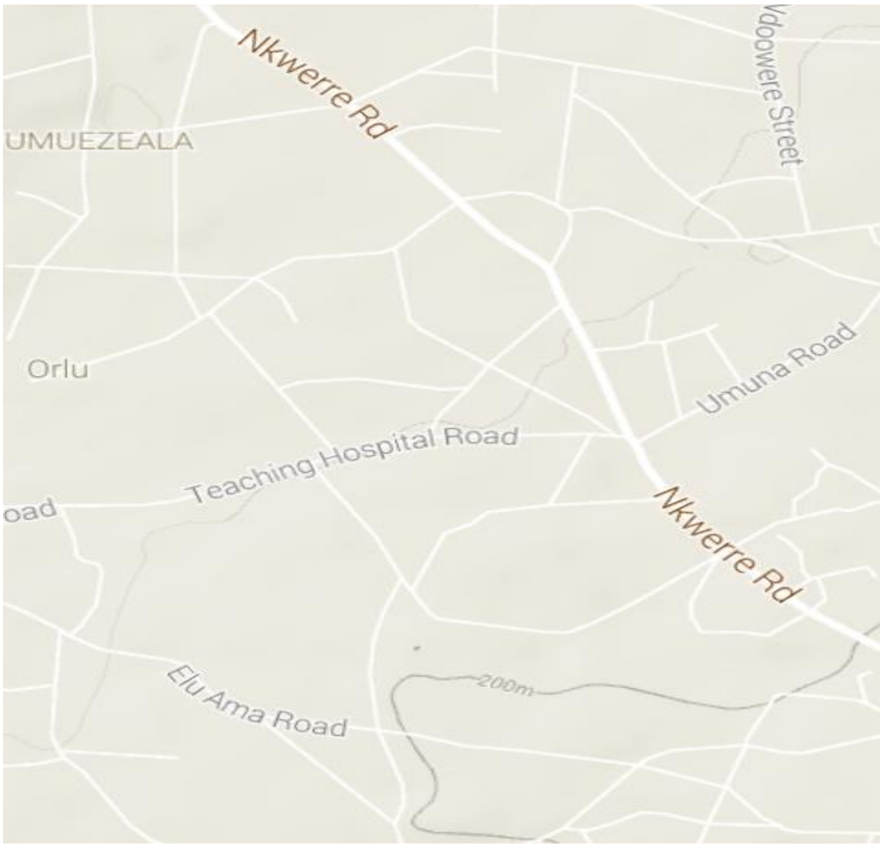


Figure 1. Location/Topographical map of the study area (Source: Google map).

A short spell of dry season referred to as the August break is often felt in August. It is caused by the deflection of the moisture laden westerly trade wind by the cold canary current. Due to vagaries of weather, the August break sometime occurs in July or early September. During the dry season, humidity is low and clouds are absent. The effect of the desiccating North Easterly wind (Harmattan) is felt within the period.

Average monthly temperatures are high throughout the year. A mean annual temperature of 32ºC is observed.

## Physiography

Two types of landforms made up of undulating lowlands and highlands characterize the area. The heliography is dominated by a segment of the Northwest – Southeast trending Awka-Orlu regional escarpment, which stands at an elevation of about 95m above sea level. The elevation of the area is between 60 – 120 meters. The Orlu area occupies a relatively high elevation and is drained by Ozubulu River.

The study area lies within the tropical rain forest belt of Nigeria. The natural vegetation is in the greater part by derived Savannah grassland interspaced with oil palm trees. Generally, the area is underlain by intensely weathered and leach uniform sand, loamy sand and clay.

## Geology

The study area stratigraphically lies within the transition zone of Ogwashi – Asaba Formation and the predominantly Benin Formation (Coastal plain sands) Figure 2, which is an extensive stratigraphic unit in the South-eastern Nigeria sedimentary basin. The formation is of Miocene-recent age and consists of very friable sands with intercalations of shale and clay lenses (Short and Stauble, 1967). The Ogwashi Asaba Formation consists of variable sequence of clay, sandstones and thick seams of lignite.

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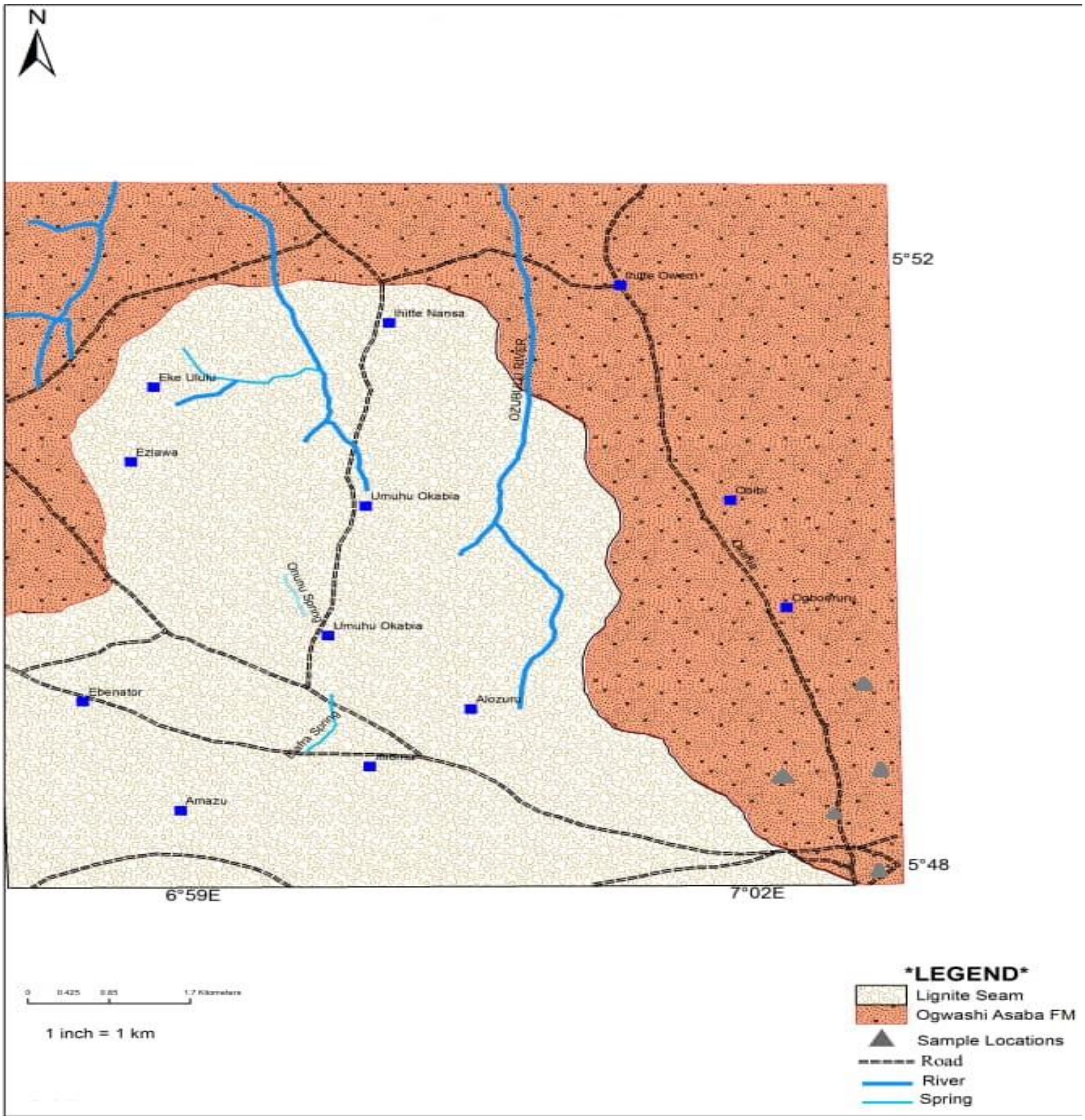


Figure 2. Geological map of the study area(Source: Field work)

The total thickness of the lignite seams is more than 6m(Reyment, 1965). The Ogwashi Asaba Formation is only known from isolated outcrops and in boreholes. It is overlain by the Benin Formation which consists of predominantly sands and gravel and underlain by Ameki Formation.

Minerologically, the sandy units which constitutes over 90% of the rocks is composed of over 95% quartz (Onyeacha 1980). A marked banding of coarse and fine layers with large scale cross-bedding are the major structures of the formation (Ofoegbu, 1988). Recognized in the lower Imo River Basin of which the study area is part (Uma and Egboka, 1986).

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They are the upper water table aquifer, a middle semi-confined and lower confined aquifer units is at a depth of about 100m. The middle semi-confined aquifer has an average thickness of over 600m. Aquifer parameters indicate high storage and transmissive properties. Well yields range from 54.25 to 231.50$m^3$/h (Uma and Egboka, 1986).

Faecal contamination of groundwater appears to pose serious problems in the area (Ezeigbo, 1989) due to probably the shallowness of the water table. This scenario is indicative of the potential case of pollution of the water table aquifer by other categories of contaminants.

## 2.0 MATERIALS AND METHODS

Methods of groundwater vulnerability assessment are based on the evaluation of various natural factors in relation to their capacity for enhancing or attenuating contaminants and application of such parameters to appropriate models. This formation yields an index that can be translated into a degree of susceptibility of the underlying aquifer to contamination.

### DATA COLLECTION

Land use and topographical studies of the area involves a compilation and analysis of existing data, which includes topographical land use and town planning maps. A reconnaissance survey was undertaken to identify major landmarks and to update information from the maps. The land use study was used to determine land use characteristics, which includes the identification of areas under stress and nature conservation zones. The population distribution patterns were also determined, while all active and abandoned waste disposal sites were located. Features like drainage, slope variations and ground surface elevation of the area were noted. The relevant drainage properties include surface water flow trend and discharge/recharge characteristics.

Information obtained from literature was analyzed to establish the general geology. The local geology was studied from field observations of outcrops and in particular boreholes records. Lithologic units were identified in the available borehole records and were correlated over the area in order to ascertain their lateral continuity.

Information from borehole lithologic log only provides widely spaced point data on lithology, thickness, stratigraphy and other characteristics of the geologic materials. The mode of groundwater occurrence was deduced from geologic studies, static water level data and from observation of surface features influenced by groundwater seepage. Aquifer recharge pattern was estimated from the records of ground fluctuations as established by Okogbue and Agbo (1989). Recharge values for the area were estimated as 25% of the annual rainfall.

Hydraulic conductivity values and sorption properties were determined from grain size data of sufficient sediments and aquifer materials. In areas where actual borehole samples are not available, hydraulic conductivity values were estimated from the descriptive logs. Porosity values were estimated from the grain size distribution data using the graphical techniques of Nwankwo (1995), while sorption characteristics was estimated as the amount of clay and clay size fraction in the samples.

### CHOICE AND ATTRIBUTES OF PARAMETERS

Nine parameters have been used in various combinations by various assessment models. The principal attributes and characteristics are discussed as follows;

## UNSATURATED ZONE CHARACTERISTICS

The layer below the soil and above the water table represents the unsaturated zone. Relevant characteristics of the unsaturated zone include its sorption properties and hydraulic conductivity. If the unsaturated zone is composed of low permeability geolologic materials, flux velocity will be low and the residence time of contaminants in the zone is increased. This may result in enhanced sorption and removal of contaminants from the infiltrating leachate/water and hence reduces vulnerability.

## DEPTH TO WATER TABLE

The depth to water table represents the travel distance over which contaminants have to migrate to contaminate an aquifer. Over a great depth, considerable contaminant attenuation and retardation could occur depending on lithology. Cumulative attenuation effect in sandy zones can be significant if the depth to water table is considerable.

## GROUNDWATER OCCURRENCE

Groundwater occurrence is related to aquifer type determined by depth and aquifer lithology. Shallow unconfined aquifers are more prone to pollution than deep unconfined aquifer while confined aquifers are least prone.

Lithological character of aquifer in terms of consolidation and stratification also plays a major role in pollution attenuation and retardation by inhibiting spreading of contaminants.

## AQUIFER MEDIA CHARACTERISTICS

This parameter defines the hydraulic properties of materials composing the aquifer in terms of permeability and porosity. The lateral spreading of contaminants in groundwater is controlled by aquifer material hydraulic conductivity. Less permeable aquifer shows a certain degree of self-protection against contaminant spreading.

## WATER TABLE GRADIENT

The hydraulic gradient is a major determinant of both direction and magnitude of darcy velocity and hence the pattern of contaminant spreading in the saturated zone gradient directed towards pollution target (e.g. water supply wells) are considered to be in the adverse direction and hence of higher vulnerability rating.

## RECHARGE

Recharge is the amount of water passing the unsaturated zone into the aquifer systems during a specified period. It is usually expressed as annual net charge. The amount and quality of recharge significantly affects the physical and chemical processes in the soil-rock groundwater system.

Recharge provides a means of flushing contaminants from ground surface down to the water table. The flushing mechanism is very effective during frequent and intense rainfall events of wet season. Recharge can also be useful in contaminant attenuation by considerably reducing contaminant concentration in groundwater through dilution and dispersion. Recharge is considered an important parameter within the climate setting of the study area.

## TOPOGRAPHY

Ground surface has some control on infiltration rates. On steeper ground, the portion of precipitation available for infiltration is less important because surface run-off is more active.

## SOIL MEDIA PROPERTIES

This refers to the zone above the unsaturated zone and is regarded as one of the principal natural factors in assessing ground water vulnerability. The main soil parameterincludestexture, biological activity; structure, thickness, contents of organic matter and clay (Vrba and Zaporex,1994).The soil has an important attenuation function and is a critical attribute when groundwater vulnerability to diffused contaminant source is assessed.

## HORIZONTAL DISTANCE

The horizontal distance is used to show the significance of distance from a pollution source to a pollution target. The parameter is important when plumes emanating from landfills and other pollution sources migrate to the potential pollution targets. Examples are borehole, rivers and streams.

## LEGRAND MODEL DESCRIPTION

The Legrand model is a rating system where fixed range of values is assigned to parameters that are judged necessary adequate for vulnerability assessment. Parameters of the model include depth to water table, sorption above the water table, hydraulic conductivity water table gradient and horizontal distance to a pollution target.

The rating chart illustrates the evaluation procedure for these factors. A numerical value is read above the line for each of the parameters based on the corresponding data below the line; for example, depth to water table of 30m gives a vulnerability rating of 7.9, a coarse gravel lithology provides a sorption above water table rating of 0.0. A vulnerability index is obtained as the sum of the numerical rating of the five parameters in the study area. The index is then expressed in words in terms of possibility of pollution. The model is applicable to the pollution of groundwater from waste disposal sites.

**Table 1: LEGRAND'S MEASURE OF VULNERABILITY**

| **Total piont** | **Possibilty of pollution** |
|---|---|
| 0 – 4 | Imminent |
| 4 – 8 | Probable / Possible |
| 8 – 12 | Possible but not likely |
| 12 – 25 | Very improbable |
| 25 – 35 | Virtually impossible |

## GOD MODEL DESCRIPTION

The GOD model is also a rating system similar in some aspects to the LeGrand model. The vulnerability assessment is based on three parameters, which include mode of groundwater occurrence, overlaying lithology and depth of water table. The flow chart is used to illustrate the evaluation procedure of the GOD model. The operation is divided into three input steps that would generate three rating values. For example, a semi-confined aquifer in input step 1

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has a rating of 0.3; alluvial sand/gravel 0.7 (input step II); depth of water table of 20-50m, 0.6m (input step III). The product of these rating values gives a vulnerability index ranging from 0.0 to 1.0 (Extreme vulnerability).

INPUT STEP 1

| one | Artesan Confined | Confined | Semi Confined | Semi Confined (covered) | Unconfined |
|---|---|---|---|---|---|
| 0 | 0.1 | 0.2 | 0.3 | 0.5 | 1.0 |

INPUT STEP 2

| | | | | | |
|---|---|---|---|---|---|
| Residual Soils | Alluvial Silts Loess | Sand | Alluvial Fluvid Glacial Sand Gravel | Alluvial Gravels | Unconsolidated sediments |

| | | | | |
|---|---|---|---|---|
| Mid-stone Shale | Silt stone | Sandstone | Chalky limestone Cacarenites | Consolidated porous rocks |
| | Volcanic Tuffs | | | |

| | | | |
|---|---|---|---|
| Igneous/metamorphic formation & older volcanoes | Recent volcanic lava | Calcavorous & older limestone | Consolidated Igneous Rocks |

INPUT STEP 3

X 0.4 0.5 0.6 0.7 0.8 0.9 1.0

| >100M | 50-100M | 20-50M | 10-20M | 5-10M | 0 – 2.5M | <2M |
|---|---|---|---|---|---|---|

| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|---|---|---|---|---|---|---|---|---|---|
| Extremely Low | Low | | Moderate | | High | | Extremely High | | |

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## 3.0 RESULTS AND DISCUSSIONS

The vulnerability assessment models used in this study are the LeGrand and GOD models of vulnerability, which are based on rating of certain parameters such as depth, sorption, water table gradient, groundwater type, overlying sediments etc. Tables 2, 3, 4 and 5.

**Table 2: Vulnerability assessment based on LeGrand model.**

| **Parameter** | **Locations** | | | | |
|---|---|---|---|---|---|
| | **Saint Mary's** | **Umuna** | **Orlu Hotel** | **Nwamkpi** | **IMTH** |
| Coordinates | **N $5^{0}$ 47.874$^{\prime}$ E $7^{0}$ 1.505$^{\prime}$** | **N $5^{0}$ 47.218$^{\prime}$ E $7^{0}$ 1.879$^{\prime}$** | **N $5^{0}$ 49.914$^{\prime}$ E $7^{0}$ 2.210$^{\prime}$** | **N $5^{0}$ 47.769$^{\prime}$ E $7^{0}$ 2.192$^{\prime}$** | **N $5^{0}$ 46.720$^{\prime}$ E $7^{0}$ 2.582$^{\prime}$** |
| Elevation (m) | 204.96 | 182.39 | 180 | 175.37 | 177.51 |
| Depth to water table (m) | 80 | 50 | 70 | 75 | 55 |
| Sorption | 4.5 | 2.5 | 4.5 | 4.5 | 2.5 |
| Permeability | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Water table gradient | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Horizontal distance(km) | 0.1 | 1.0 | 1.5 | 1.2 | 1.0 |
| Total point | 86.6 | 56.5 | 78 | 82.7 | 60.5 |

100m - Unacceptable range

1.0km - Acceptable range

1.5km - Acceptable range

1.2km - Acceptable range

1.0km - Acceptable range

**Table 3: Groundwater Vulnerability assessment results based on the GOD model.**

| **S/N** | **LOCATION** | **GROUNDWATER TYPE** | **OVERLYING SEDIMENTS** | **DEPTH TO WATER LEVEL (m)** |
|---|---|---|---|---|
| **1.** | Saint Mary's | Confined Aquifer | Sand | 80 |
| **2.** | Umuna | Confined Aquifer | Clay | 50 |
| **3.** | Orlu Hotel | Confined Aquifer | Clay | 70 |
| **4.** | Nwankpi | Confined Aquifer | Sandyclay | 75 |
| **5.** | IMTH | Confined Aquifer | Sand | 55 |

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**Table 4: Groundwater Vulnerability assessment rating based on the GOD model.**

| S/N | Coordinates | Elevation | Borehole Location | Parameter | | | Ratings | | | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | G | O | D | G | O | D | |
| **1.** | **N 5$^{0}$ 47.874$^{\prime}$ E 7$^{0}$ 1.505$^{\prime}$** | 204.96 | Saint Mary's | Confined Aquifer | Sand | 80 | 0.2 | 0.6 | 0.5 | 0.06 |
| **2.** | **N 5$^{0}$ 47.218$^{\prime}$ E 7$^{0}$ 1.879$^{\prime}$** | 182.39 | Umuna | Confined Aquifer | Clay | 50 | 0.2 | 0.5 | 0.6 | 0.06 |
| **3.** | **N 5$^{0}$ 49.914$^{\prime}$ E 7$^{0}$ 2.210$^{\prime}$** | 180 | Orlu Hotel | Confined Aquifer | Clay | 70 | 0.2 | 0.5 | 0.5 | 0.05 |
| **4.** | **N 5$^{0}$ 47.769$^{\prime}$ E 7$^{0}$ 2.192$^{\prime}$** | 175.37 | nwankpi | Confined Aquifer | Sandyclay | 75 | 0.2 | 0.5 | 0.5 | 0.05 |
| **5.** | **N 5$^{0}$ 46.720$^{\prime}$ E 7$^{0}$ 2.582$^{\prime}$** | 177.51 | IMTH | Confined Aquifer | Sand | 55 | 0.2 | 0.6 | 0.5 | 0.06 |

**Table 5: Vulnerability Assessment**

| **Location** | Vulnerability Assessment |
|---|---|
| Saint Mary's | Extremely Low |
| Umuna | Extremely Low |
| Orlu Hotel | Extremely Low |
| nwankpi | Extremely Low |
| IMTH | Extremely Low |

Based on the rating score (Table 4), vulnerability to pollution is lower at Orlu hotel and Nwankpi than Saint Mary's, Umuna and IMTH. However, all the locations fall under the same extremely low vulnerable area (Table 5).

From the lithologs of boreholes in the area, the general lithology in the area is sandy-clay formation which thus increases the sorption properties of the overburden, thereby reducing the vulnerability of groundwater in the area, Figure 3.

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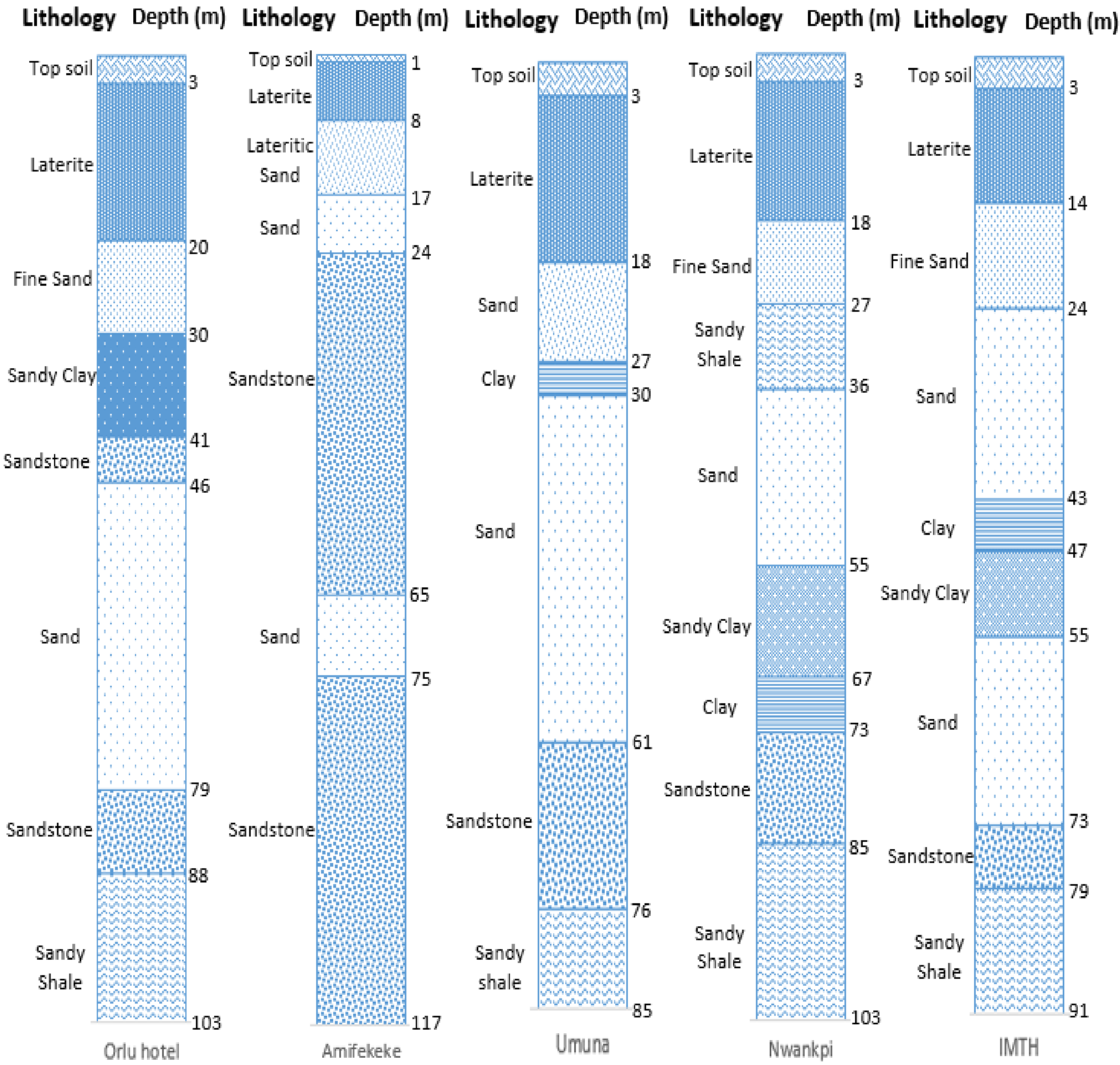


Figure 3. Lithologs of boreholes in the study area.

## DISCUSSION

## VULNERABILITY PATTERNS

There is a general agreement on the vulnerability predicted by the models despite slight differences in the combinations of the model's parameters. The GOD model of vulnerability predicts extremely low vulnerability rating. The areas under study are characterized by

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confined aquifer, overlying sand and depth of water table of about 50-80 meters (over burden thickness). The LeGrand model of vulnerability also indicates that the areas under consideration are not susceptible to ground water pollution.

Based on the relative scores of the relative parameters and within the limit of the quality of available data on theses parameters, the most important parameters in ground water vulnerability in the area are depth to water table (or over burden thickness) and the confining layer.

Vulnerability as determined by the models showed non-susceptibilities defined with respect to the entire area. It does not take into account land use practices that may have overriding effects on the choice of wastes disposal sites within each area. For example; health, aesthetic and nuisance factor would preclude the use of the immediate vicinity of residential areas as waste disposal sites even where groundwater vulnerability is very low. Also, features related to topography including slope differences and flood plain area with high vulnerability influence the siting of potential disposal sites.

## GROUND WATER MANAGEMENT STRATEGIES

The different models of vulnerability assessment show area of moderate ratings. It is required therefore that appropriate management programmes be developed and implemented to minimize the adverse impacts of man's activities on ground water quality particularly in areas of moderate to high vulnerability.

The existing land use activities have shown the prevalence of open dump disposal, leaks from petrol stations and effluents from industries in areas of high vulnerability. These contaminant sources are expected to have adverse effects on the groundwater quality. Consequently, the existing waste disposal sites (unplanned) should be closed down and waste disposal discontinued.

The abandoned sites should also be rehabilitated to forestall further ground water quality degradation. It has been observed from ground water flow modeling that chemically conservative chemicals have impact on the groundwater/surface water quality (Witkowski, 2016). However, actual impacts of petrol stations would require detailed studies to ascertain the extent to which groundwater quality has been impaired. In practice, however, contaminant mass is poor indication of potential environmental damage. A better representation of the potential problem is given by the degree of environmental degradation revealed from groundwater quality studies- (Villumen et al 1983). Therefore, groundwater quality monitoring should be adapted in the area.

## LANDFILL DESIGN OPTIONS FOR GROUNDWATER PROTECTION

An area within extremely low vulnerability is indicative of the relative low sensitivity of the groundwater system to human impact such as would arise from waste disposal activities. The lower sensitivity could further be supplemented by the use of properly engineered sanitary landfills as may be dictated by detailed site-specific characteristics. The choice of a suitable landfill for the zones depends on the geographical, hydrological and environmental setting of the sites.

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The groundwater system in confined conditions with depth to water table ranging from 50-80m, the unsaturated zones is composed of high permeability sand with hydraulic conductivity values ranging from 1.44×10**

A suitable landfill type would have to incorporate the multiple barrier concepts to prevent defective contaminant flow into the aquifer and leachate collection system to control mounding. The primary leachate collection system is separated from the secondary leachate collection system by a compacted clay liner would help in attenuating such contaminants.

Hydraulic confinement (or hydraulic trap) concept is considered suitable for landfill site development in such hydrogeological settings of low to moderate hydraulic conductivity (Novakoric and Tagger, 1992). The concept is aimed at creating and maintaining an inward groundwater flow into the landfill so that the amount of contaminants leaving the site would be minimal. The hydraulic confinement design depends on the following three principles: Inward hydraulic gradient and groundwater flow, leachate collection system and leachate attenuation by the natural environment.

## 4.0 CONCLUSION AND RECOMMENDATIONS

The vulnerability of parts of Orlu was evaluated using the LeGrand and GOD models. The unsaturated zone material of these sub areas is composed of sandyclay facies with low effective hydraulic conductivity (k3) and relatively high sorption properties.

The characteristics of the overburden materials indicate that contaminants would not migrate down to the water table with ease, especially areas where the water table is deep. The Areas generally has low vulnerability and predominantly underlain by sandyclay facies and have considerable depth to water table which enhance contaminant attenuation and retardation. Also, the high sorption properties of the overburden materials tendto inhibitadvective flow of contaminants down the water table.

Aquifer materials are highly permeable which enhances lateral spreading of contaminants in the ground water system. The observed hydraulic gradients are directed towards streams and rivers, which suggest considerable groundwater inflow into them, and hence indicating the surface water bodies are at risk in the event of pollution of the groundwater system.

Open dump waste disposal, potential leaks from filling stations and effluents from industries are common in areas of moderate vulnerability. These contaminated sources are expected to have adverse effects on groundwater quality, it is therefore required that the existing waste disposal sites in such areas should be closed down and waste disposal activities discontinued to forestall further groundwater degradation. A contaminant impact assessment should be undertaken in the areas to assess the degree of contamination of the groundwater system such as might have arisen from existing waste disposal sites. It is expected that such assessment would determine the extent of rehabilitation required for each site.

In the event of choice of site in sub-areas with lower disposal site, a properly engineered sanitary landfill is required to ensure adequate protection for ground water regime. Site specific monitoring schemes should be also evolved in these sub-areas depending on the

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ground water flow direction, nearness to surface water bodies, potential pollution target and landfill design.

Groundwater quality could be managed by relocating residents particularly on health implications of water pollution and by maintaining strict governmental control on land use and groundwater development.

To induce inward gradient, the landfill base contour have to be below the aquifer potentiometric surface. A comprehensive study of the potentiometric surface in the site would therefore have to be taken as part of the hydraulic trap construction and development.

The leachate collection system controls mounding and allows the development of the hydraulic trap by reducing the leachate head on the land fill to a level below the potentiometric surfaces, thus inducing flow from the aquifer into the landfill. An additional clay liner is required to be placed on the natural aquifer to prevent the inflow of contaminants in cases of accidental breakdown of the hydraulic trap due to hydrogeological factors and/or the engineered systems.

## RECOMMENDATIONS

Indiscriminate dumping of waste along roads, riverbanks and unplanned refuse dumps should be discontinued so as to forestall the contamination of ground water.

- Boreholes should be properly grouted (at least 10cm) down hole to stop the infiltration of contaminants into the underlying aquifer.
- Sanitary landfill should be employed in solid waste disposal so as to protect the groundwater in the area.
- Pit latrines and septic tanks should be well planned and properly built to reduce the risk of groundwater contamination.
- Industries should treat their waste before dumping or channeling it into the surrounding water bodies.
- Filling stations should exercise discipline when fueling vehicle and should ensure that their storage tanks are constructed to standards to minimize the risk of groundwater pollution.
- Metal waste should not be dumped indiscriminately, they should be recycled.
- A steady assessment and monitoring levels of pollution/ contamination due to environmental and other anthropogenic impacts.

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