Determination of the Vulnerability of Water Supply Aquifers in Parts of Imo River Basin, South-Eastern Nigeria: The Case of Benin Formation

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ABSTRACT: *Eight locations in the study area were investigated to obtain data on the depth to water table, net recharge, aquifer media, soil media, topography, impact of the vadose zone and hydraulic conductivity. These parameters are denoted by the acronym, DRASTIC, an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of the area. This was used to develop a vulnerability map for the study area. The vulnerability map shows that areas within Benin Formation have generally moderate vulnerability to pollution.*

***Keywords*:** Aquifer Media, *DRASTIC, Net Recharge, Soil Media, Topography, Vulnerability, Water Table.*

I. INTRODUCTION

The Imo River Basin is based on a bedrock of a sequence of sedimentary rocks of about 5480m thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1986)[1]. It is known to contain several aquiferous units. The proportion of sandstones to shales varies from formation to formation and sometimes from place to place within the same formation. The interlayering of sandy and shaly units form complex aquifer systems that are respectively localized in the formations, such that it is almost impossible for aquifers to cross formation boundaries. This is because the regional stratigraphy and the general trends of the geologic formations feature sharp changes in lithology which prevent hydraulic continuity (Uma, 1989)[2]. The characteristics of these aquifers such as transmissivity, hydraulic conductivity and storage potentials are not clearly understood. Since the mid 1980's, some researchers from the academia have carried out geological/geochemical investigations. Uma (1986) carried out a study on the ground resources of the Imo River Basin using hydro-geological data from existing boreholes. He concluded that three aquifer systems (shallow, middle and deep) exist in the area (Uma, 1989). Geophysical investigations on groundwater resources in the Imo River Basin were also carried out in different sections of the basin. While the contributions made by these workers are remarkable, more work still needs to be done, particularly in the area of vulnerability of the aquifer systems. The present study is aimed at investigating the vulnerability of the hydro-geological character in Ameki and Imo shale Formations to pollution. Vulnerability assessment is more meaningful in areas where water resources are under stress due to industrial or agricultural activities, as it can provide valuable information for planning prevention of further deterioration of the environment ([3]Mendoza et al., 2006; [4]Antonakos et al., 2007).

1.1 The Study Area

Figure 1 show the location map of the Imo River Basin where the study area is situated. The study area (Figure 2) lies between latitudes $5^o05^{'}$N and $5^o37^{'}$ and longitudes $7^o00^{'}$ and $7^o30^{'}$. The Benin Formation (Miocene to Recent) covers more than half of the area of the Imo River Basin. It consists of sands, sandstones, and gravels, with intercalations of clay and sandy clay. The sands are fine-medium-coarse grained and poorly sorted ([5]Whiteman, 1982; and [6]Uma and Egboka, 1985). Petrographic study on several thin sections ([7]Onyeagocha, 1980) show that quartz makes up more than 95% of all grains, but [8]Asseez (1976) and [9]Avbovbo (1978) indicated a possible presence of more percentage of other skeletal materials including feldspar. This formation has very low dip to the south and south-west. The youngest deposits in the basin are alluvium of recent age found mainly at the estuary of the Imo River at the Atlantic Ocean and on the flood plains of the river.

The Imo River Basin has a large amount of recharge; estimated at 2.5 billion m^3 per annum, coming mainly from direct infiltration of precipitation. Average annual rainfall is about 2000mm ([10]Onwuegbuche, 1993). The Benin Formation is by far the most aquiferous unit, consisting mainly of massive continental sands, sandstones, and gravels. It has a very extensive deep unconfined aquifer which covers more than half of the Imo River Basin. The aquifer consists of thick complex interbedded units of fine, medium and coarse-grained quartz sands and gravels (Uma, 1989).

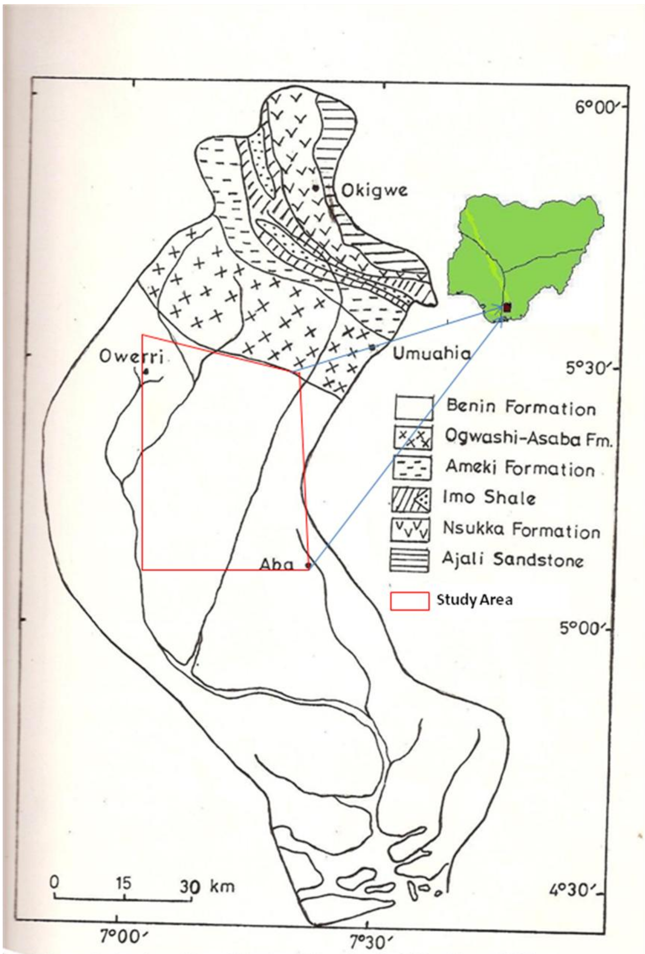

Figure 1: Geology Map of the Imo River Basin (After Uma, 1989)

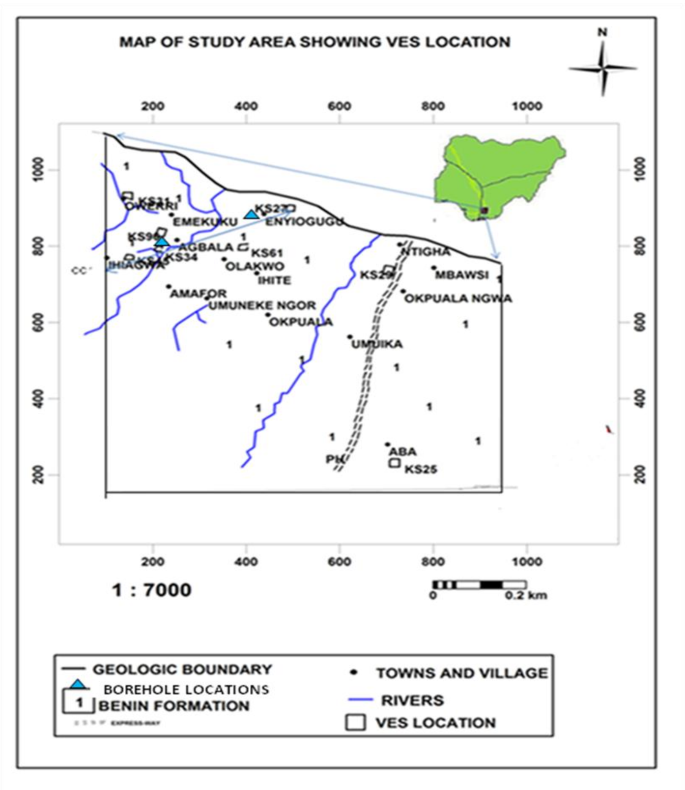

Figure 2: Map of the Study Area showing VES locations

II. METHODOLOGY

The DRASTIC model was developed in USA for the purpose of protecting groundwater resources ([11]Aller et al., 1985; [12]Aller, 1987). DRASTIC is an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydro geological settings of the area. A hydro geological setting is defined as mappable unit with common hydro geological characteristics ([13]Engel et al., 1996). The DRASTIC model was used to develop the groundwater vulnerability map for the study area. The generic model was used to determine the weights and the ratings. The model employs a numerical ranking system that assigns relative weights to various parameters. The acronym DRASTIC is derived from the seven factors considered in the method, which are **D**epth to water table [**D**], net **R**echarge [**R**], **A**quifer media [**A**], **S**oil media [**S**], **T**opography [**T**], **I**mpact of the vadose [**I**] and hydraulic **C**onductivity [**C**]. Each DRASTIC factor is assigned a weight based on its relative significance in affecting pollution potential. The ratings range from 1 – 10 and weights from 1-5. The DRASTIC Index [**DI**], a measure of pollution potential, is computed by summation of the products of ratings and weights of each factor. The final result for each hydrogeological setting is a numerical value, called DRASTIC index. The higher the value is, the more susceptible the area is to groundwater pollution.

Depth to the Water Table

The depth to the water table is the distance from the ground to the water table. This determines the depth of material through which a contaminant must travel before reaching the aquifer. The presence of low permeability layers, which confine aquifers, limits the travel of contaminants into an aquifer. There is a greater chance for attenuation to occur as the depth to water increases because, deeper water levels imply longer travel distances. The depth to the water table was obtained from Table 4.1 and converted to feet to determine the DRASTIC rating.

Net Recharge

Net recharge represents the amount of water per unit area of land, which penetrates the land and reaches the water table. Recharge water is the means by which leaching and contaminants are transported vertically to the water table and horizontally within the aquifer. The greater the recharge rate, the greater the potential for groundwater pollution. The net recharge was taken to be about 12% of the average annual rainfall ([14]Navulur, 1996).

Aquifer Media

An aquifer is defined as a permeable geologic unit that will yield useful quantities of water. The aquifer medium influences the amount of effective surface area of materials with which contaminants may come in contact. The larger the grain size and the more the fractures or openings within the aquifer, the higher the permeability and the lower the attenuation capacity of pollutants in the aquifer media. Only unconfined aquifer was considered, for which the DRASTIC model is valid (Aller et al., 1987). The aquifer media was obtained by taking depths at which water was struck and correlating those depths with the lithological description of the VES result or strata description to identify the aquifer media.

Soil Media

Soil media refers to the uppermost portion of the vadose zone characterized by significant biological activity. It was considered as the upper weathered zone of the earth, which averages a depth of one meter or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of contaminant to move vertically into the vadose zone. The smaller the grain size, the less the pollution potential. Soil media was obtained from the soil map of the study area.

Topography Map

Topography refers to the variability of slope of the land surface. Topography helps control the likelihood that a pollutant will run off or pool and remain on the surface in one area long enough to infiltrate. The study area was found to be relatively flat with topography ranging from 0% **-** 3%. The topography was estimated from a topographic contour map.

Impact of the Vadose Zone

The vadose zone is defined as the zone above the water table which is unsaturated or discontinuously saturated. This zone determines the attenuation characteristics of the material below typical soil horizon and above the water table. The impact of the vadose zone was obtained by using the lithological description or strata description resulting from the VES data analysis.

Hydraulic Conductivity

Hydraulic conductivity refers to the ability of the aquifer material to transmit water, which in turn, controls the rate at which groundwater will flow under a given gradient. The values of the hydraulic conductivity were derived from the Dar Zarrouk parameters (transverse unit resistance and longitudinal conductance in porous media) obtained from the VES data ([15]Niswass and Singhal, 1981).The hydraulic conductivities were converted from m/day to gpd/ft^2 before application in finding the DRASIC Index. 1 gal/day/ft^2 = 0.0408 m/day.

Eight vertical electrical sounding results coupled with the geology of the study area were used to determine such parameters as the depth to the water table, the aquifer media, the soil media and the impact of the vadose zone. The VES sounding locations, as represented by northings and eastings, were used in geo-referencing. The GIS software, ArchView 3.2a, was used to generate the Groundwater Vulnerability Map. Estimates for the vulnerability indices spatial distribution were determined by applying appropriate GIS overlay functions.

III. RESULTS AND DISCUSSIONS

The deduced DRASTIC parameters were used to compute the DRASTIC Index at the various VES points and these are given in Table 1. This was then used to generate the Groundwater Vulnerability Map (GVM) for the study area. Fig. 3 shows the vulnerability map of the study area. The map shows that most of the areas in Benin Formation have moderate vulnerability because the overburden is largely fine, medium and coarse grained sand. Fig. 4 shows the vulnerability map of parts of Imo River Basin covering Imo Shale (4), Ameki Formation (3), Ogwashi-Asaba Formation (2), and Benin Formation (1). This helps to compare the respective degrees of vulnerability of the different formations. Areas of low vulnerability have drastic index of <120; areas of moderate vulnerability have drastic index of 121-140; while high vulnerability is >140. Higher vulnerabilities can be observed around the south east of the study area, around Aba. Low vulnerabilities can be observed at areas around Obibiezena and Naze.

TABLE 1: Calculated DRASTIC Index for the Study Area.

VES #	LOCATION	NORTHINGS	EASTINGS	D_r	D_w	R_r	R_w	A_r	A_w	S_r	S_w	T_r	T_w	I_r	I_w	C_r	C_w	DI
KS25	FAULKS RD, ABA	125638	544503	5	5	9	4	8	3	6	2	10	1	5	5	4	3	144
KS27	OBOKWU NGURU	164201	530389	1	5	9	4	8	3	6	2	8	1	8	5	4	3	137
KS29	UMUIKE LOWA	153926	546313	3	5	9	4	5	3	6	2	9	1	9	5	2	3	138
KS31	100 WORKS L/O OWERRI	168585	510539	5	5	9	4	8	3	6	2	10	1	1	5	8	3	136
KS34	OBIBIEZENA	156051	511975	1	5	9	4	8	3	6	2	10	1	1	5	8	3	116
KS45	UMUOMA	155685	509897	1	5	9	4	3	3	3	2	10	1	3	5	4	3	93
KS61	UMUOHIAGU	157988	523336	1	5	9	4	8	3	6	2	10	1	8	5	2	3	133
KS90	NAZE	159633	512175	5	5	9	4	8	3	6	2	8	1	1	5	6	3	128

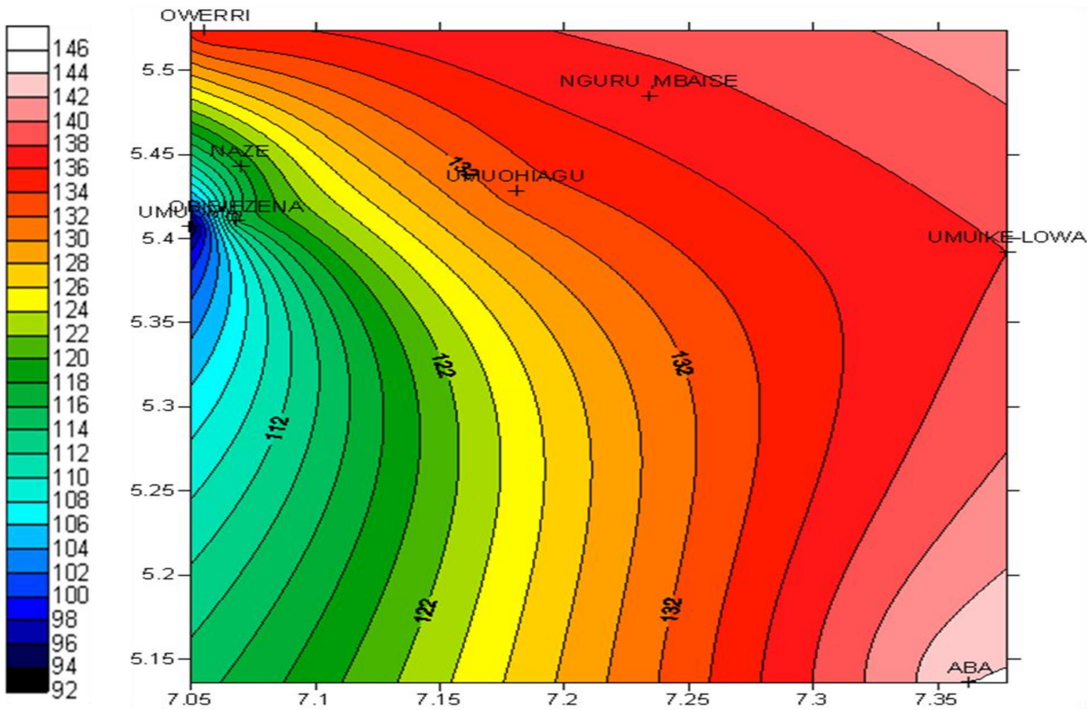

Figure 3 :Vulnerability Map of Benin Formation

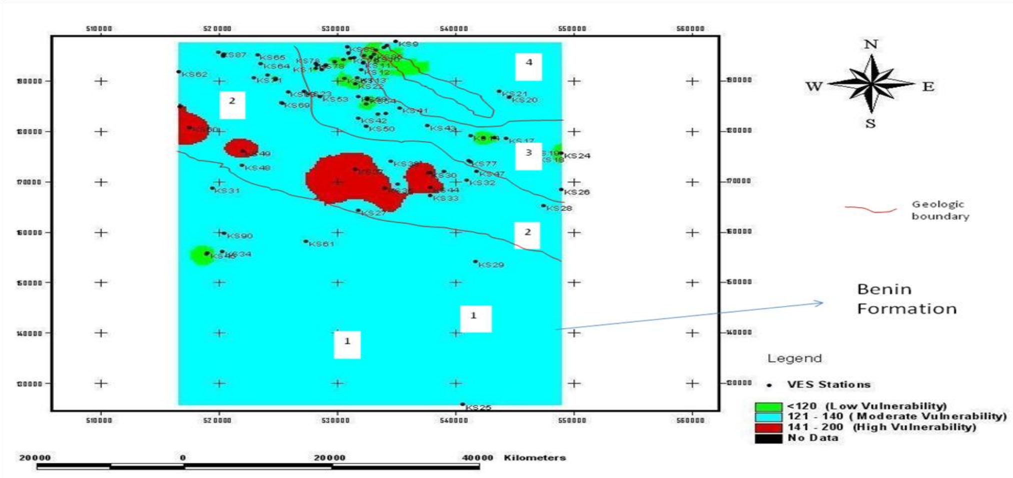

Figure 4: The Vulnerability Map of Parts of Imo River Basin

IV. CONCLUSION

The study area consists of coastal plain sands with relatively high permeability, so most of the area is moderately vulnerable. The DRASTIC model proved to be useful in the assessment of the vulnerability of the formation studied.

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