Vulnerability Assessment of Shallow Aquifer Hand-Dug Wells in Rural Parts of Northcentral Nigeria using AVI and GOD Methods.

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ABSTRACT

This study focuses on the preliminary vulnerability assessment of shallow aquifer hand–dug wells in the rural area of Northcentral Nigeria. Twenty (20) hand-dug wells were randomly selected. Aquifer Vulnerability Index (AVI) and GOD methods were used based on the geological and subsurface geophysical information generated within the vadose zones which comprises of unconsolidated sediments such as sands and lateritic soils. The results from the data interpretation indicate that the hand-dug wells in the study area are high to extremely high in their vulnerability. AVI method gives values between -0.32 to 1.78 (high to extremely high vulnerability) while GOD method shows values ranges from 0.49 to 0.56 (moderate to high vulnerability).

Aquifer vulnerability maps of the area were generated using ArcGIS software which shows an area of aquifer's inherent possibility of getting contaminated. Recommendations were made that active precautions should be taken in the area against any surfaces activities that could hinder the quality of shallow groundwater of the area.

(Key terms: hand-dug wells, aquifer vulnerability index, AVI, groundwater occurrence, overall lithology, depth to groundwater, GOD, GIS)

INTRODUCTION

In the rural community, shallow aquifer hand-dug wells have been regarded as the most common source of drinking water and for irrigation uses. But due to the inequalities between the rate of recharge and level of groundwater exploitation, there has been a serious decline in the level of groundwater (Pathak, et al., 2009). Water from the shallow aquifer is vulnerable to contamination, because these contaminants infiltrate the vadose materials before reaching groundwater bodies. In most of the rural areas where shallow wells are practiced comprises mostly of alluvial aquifers, which constitute the most important hydrogeological reservoirs and are unprotected from surface contaminants, and they are easily contaminated if no necessary precautions are putting in place. Most of these likely contaminations arise from surface and human activities such as seepage from septic systems, improper disposes of solid and liquid wastes, effluent of untreated sewage systems and applying of manure and fertilizers on the agricultural land.

For the purpose of protecting groundwater resources for any possible contamination in the near future, many attempts and ideas have been sought by the Hydrogeologists, Hydrologists, Water Engineers and Environmentalists in bringing methods for determining which areas are more vulnerable than the others to be contaminated due to several improper surface and human activities (NRC, 1993). Those methods applied in achieving this called groundwater vulnerability methods.

A common method used in groundwater vulnerability investigations include GOD (Foster, 1987), AVI (Van Stempvoort et al., 1993), DRASTIC (Aller et al., 1987), SINTACS (Civita, 2000), COP (Vias, et. al., 2006), EPIK (Doerfliger et al., 1999), VULK (Sinreich et al., 2007) and many more. However, most of these mentioned methods are used for a particular aquifer type such as the karst groundwater vulnerability while other methods applies to the general water resources protection or for a single protection source like water wells. The application of vulnerability mapping helps to show the distribution of those highly vulnerable areas, in which pollution is common and possible to occur possibly now or in the near future because those contaminants can travel to reach the ground within a limited period of time. This research aim at determine the vulnerability of shallow unconfined aquifer in the area to pollution by means of AVI and GOD methods.

LOCATION AND GEOLOGICAL SETTINGS OF THE AREA

The study area is a rural community situated in Ilorin East Area of Kwara State in the North-central part of Nigeria. It is bounded by latitude 8^{0} 32' and 8^{0} 36' and longitude 4^{0} 39' and 4^{0} 43'which falls within the basement complex of Nigeria. This area forms a linear type of settlement where most of available land is used for agriculture. People in the area including the farmers rely on wide and shallow hand - dug wells as their primary source of water for domestic and irrigations uses.

The geology of the area is underlain by crystalline rocks of basement complex. Different types of crystalline rocks are found in various parts of the area, among which are migmatite - gneiss, banded gneiss, granite gneiss, quatzites, older granites and also observed are the intrusions of pegmatitic rocks. The crystalline rocks possess porosities of less than 3% (Bouwer, 1978). Rocks of basement complex, when not weathered are said not to be permeable and produce no storage capacity.

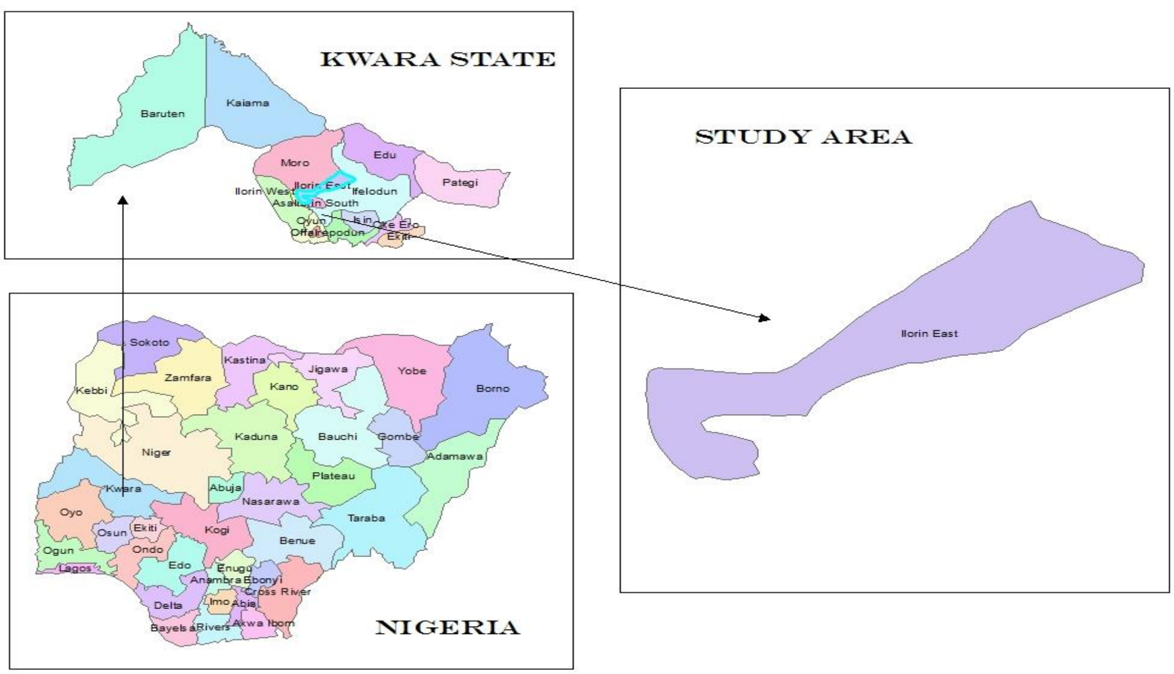

Figure1: Map of Nigeria showing Study Location.

Some appreciable amount of porosity and permeability might be developed in the rocks through fracturing and weathering processes (Davis and De Wiest, 1966), depending on the lithology and textural characteristics of the parent rock. According to Offordile (1983), Jones (1985) and Egboka (1988), they described the units of basement rocks to very productive at the base of the weathered zone where the rocks might have been broken down to sand size and to larger fragments that are not subjected to extensive weathering process. From the geology point of view, it is observed that deep groundwater occurrence in this study area which consist mainly of basement rocks is in the weathered overburden or in the joints and fractures system within unweathered rock units.

The vadose zones based on the geological information, subsurface logging and subsurface geophysical studies comprises mostly of unconsolidated sediments such as sands and lateritic soils as shown in Figure 2 below.

AVI METHOD

Aquifer vulnerability index (AVI) was proposed by (Van Stempvoort et al., 1992) and involved quantifying the vulnerability through hydraulic resistance to vertical flow of water through the protective layers. This method has been approved by the Canadian Prairie Province water board.

The AVI method is based on the characteristics of the protective layers which have been recognized as the most important parameter in describing aquifer vulnerability (McLay et al., 2001, Herbst et al., 2005). This method interprets aquifer vulnerability on the basis of hydraulic resistance (c), as a ratio between the thickness of each sedimentary unit above the uppermost aquifer which is refers to as (d), and the estimated hydraulic conductivity of the protective layer (k).

The hydraulic conductivity of these shallow aquifer wells was determined from laboratory parameter test. This method is regarded as one of the best methods for simulating the original field condition due to the fact that core samples are collected to represent the lithology in its undisturbed state.

Saturated hydraulic conductivity was determined in the laboratory using the below equation:

$$K_{sat} = \frac{QL}{Ath}$$

Figure 2: Subsurface / Vadose Zone Characteristics in the Study Area.

Where: K_{sat} = Coefficient of saturated hydraulic conductivity (cm/s)
Q = Quantity of water discharge in cm
L = Length of sample in cm
t = Total time for discharge in seconds
h = Vertical distance between funnel overflow and chamber outflow port in cm
A = Area of cross section of specimen = 31.65cm^2

The soil samples collected for the parameter test are undisturbed core samples by means of core samplers. Undisturbed samples were collected by slowly pushing thin-walled tubes, and by having sharp cutting ends and tip relief into the soil. Ten centimeters core samples were collected from each observable changes in the lithology, color and texture in which each sample represents a noticeable homogenous layer.

Hydraulic resistance is calculated as:

$$c = \sum_{i=1}^{n} \frac{d_i}{k_i}$$

Where n is number of sedimentary units above the aquifer
d_i = thickness of the vadose zone
k_i = hydraulic conductivity of protective layer
k = unit of length / time (m/s or m/d)
c = has a dimension in day

Log_c would be used for a classification as follows:

When: $Log_c < 1$, it is classify as extremely high vulnerability
Logc = 1 – 2 high vulnerability
Log_c = 2 – 3 moderate vulnerability
Log_c = 3 – 4 = low vulnerability
$Log_c > 4$ extremely low vulnerability

GOD METHOD

This method of vulnerability assessment was first introduced by Foster (1988). The method with acronyms was coined from the first word of its parameters. Groundwater occurrence, Overall lithology, and Depth to groundwater (GOD) as a method of vulnerability determination is rated with a range of 0 and 1 where the overall values in evaluating the rate of vulnerability is determine by multiplying the three factors (groundwater occurrence, overlying lithology and depth to water table) together. For example, the overall values consequently ranges between 0.0 which is negligible and 1.0 which is classify as extreme. Flow chart shown in Figure 3 below illustrates the processes and procedures involves for GOD method.

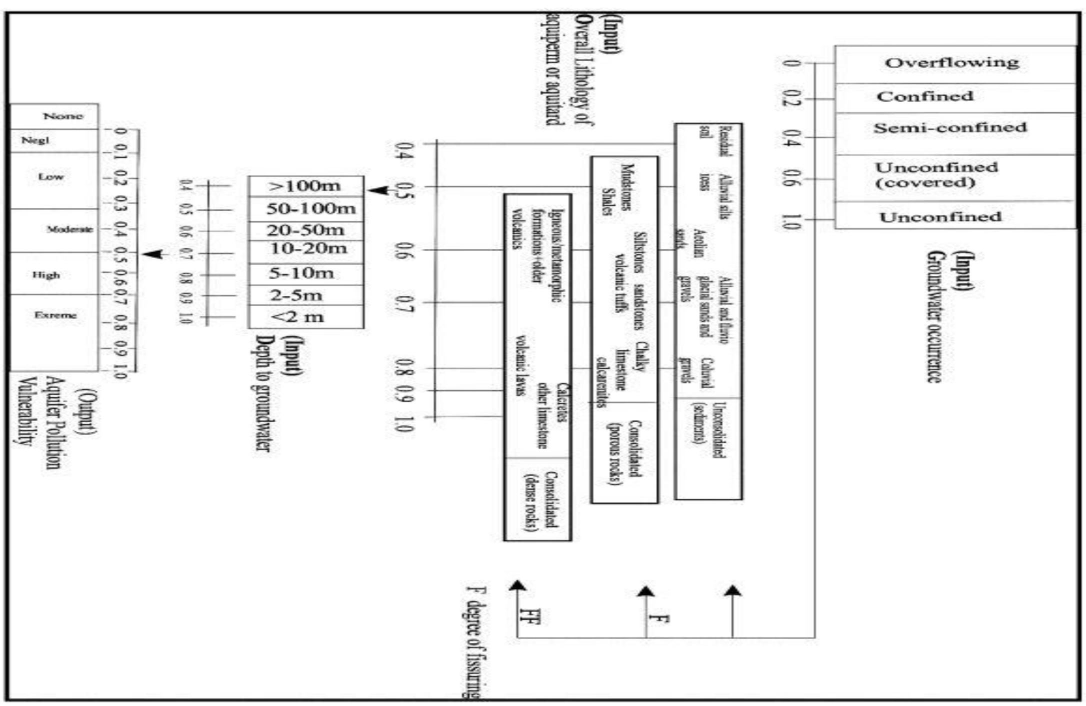

Figure 3: GOD Model for Aquifer Vulnerability Assessment (Source: Forster, 1988).

One of the most usefulness of GOD method is that it could be apply to any kind of aquifer system except in the karst regions. However, one of the disadvantages of this method is that factor D is over rated. Also, most of different lithologies are given similar vulnerability values.

RESULTS AND DISCUSSION

The results from the two methods applied in this study shows that majority of the wells in this area is high to extremely high vulnerable to pollution based on the lithological characteristics, nature of groundwater occurrence and depth of the shallow wells as showed in (Table 1 and Table 2) below.

The aquifer vulnerability maps of the area have been produced using ArcGIS software which reflects an aquifer's inherent susceptibility of becoming contaminated. However, an extremely high and high pollution potential index of the area shows the possibility of the hydro-geologic environment and the landscape factors of the area to be readily more waterborne contaminants towards the shallow groundwater. The aquifer vulnerability maps of the surficial aquifer is shown in Figure 3 below which indicates high, extremely high and moderate vulnerability zones that were generated from twenty (20) selected hand - dug wells from the area. The vadose zones of the aquifers comprises mostly of sands and lateritic soils. GOD index values based on the calculation ranges from 0.49 to 0.56 while values from AVI method found between -0.32 to 1.78.

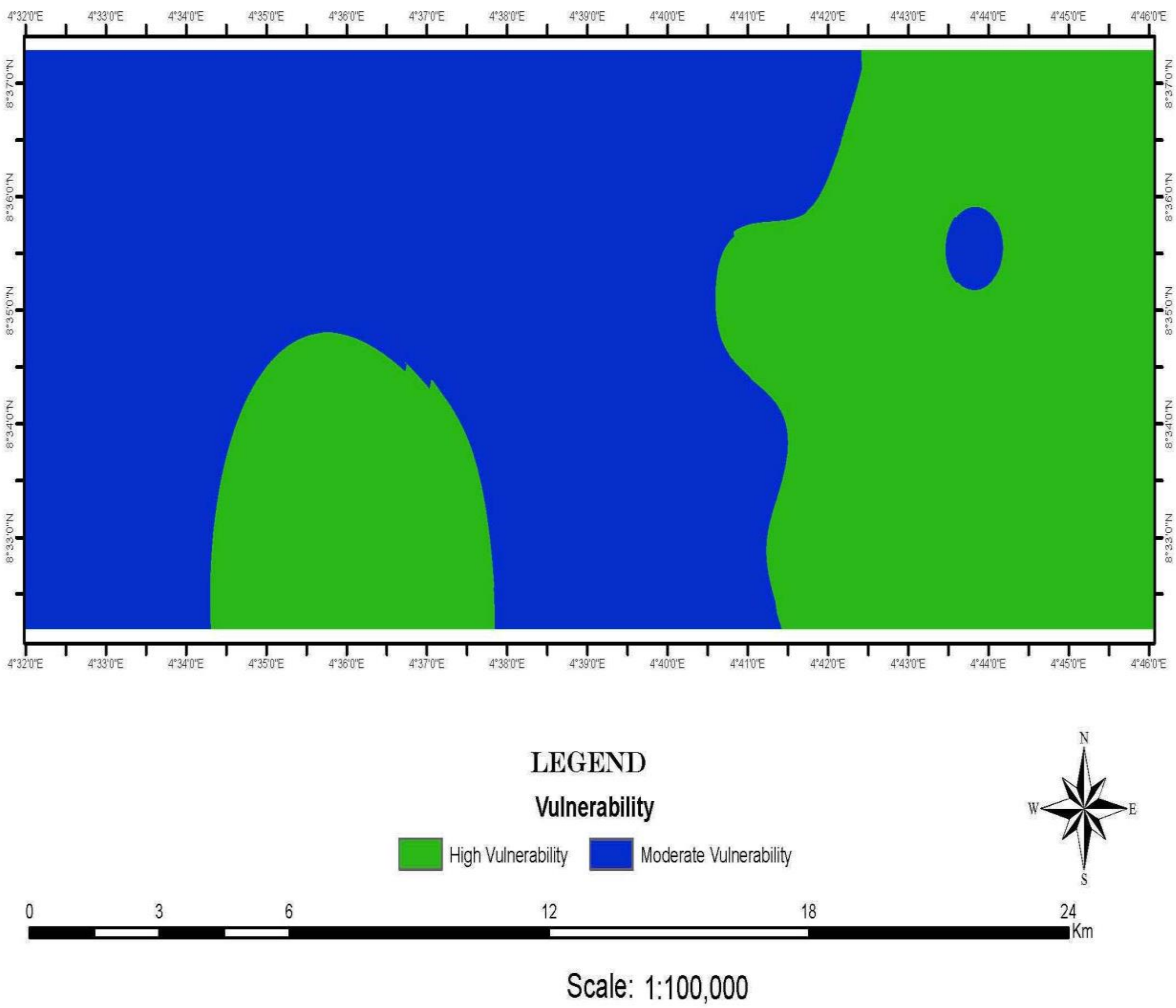

Figure 4: Vulnerability Map of the Study Area.

Table 1: Results of Aquifer Vulnerability Assessment using AVI Method.

Location No.	Coordinate	Thickness, d (m)	Hydraulic conductivity K (m/d)	Hydraulic resistance c = d/k	Log_c	Vulnerability Assessment
1	8⁰ 32' 57" 4⁰ 39' 56"	4.93	15.6	0.32	0.50	Extremely High
2	8⁰ 33' 09" 4⁰ 40' 11"	20.6	19.79	1.04	0.12	Extremely High
3	8⁰ 33' 19" 4⁰ 40' 27"	18.7	0.74	25.27	1.40	High
4	8⁰ 33' 27" 4⁰ 40' 33"	52.0	0.95	54.74	1.74	Extremely High
5	8⁰ 33' 36" 4⁰ 40' 42"	9.11	9.24	0.99	0.00	Extremely High
6	8⁰ 33' 47" 4⁰ 40' 51"	7.54	5.25	1.44	0.16	Extremely High
7	8⁰ 33' 57" 4⁰ 40' 59"	11.9	24.80	0.48	-0.32	Extremely High
8	8⁰ 34' 03" 4⁰ 41' 13"	16.7	13.74	1.22	0.08	Extremely High
9	8⁰ 34' 11" 4⁰ 41' 21"	15.0	0.25	60.0	1.78	High
10	8⁰ 34' 18" 4⁰ 41' 29"	5.12	0.39	13.13	1.12	High
11	8⁰ 34' 27" 4⁰ 41' 37"	8.58	4.22	2.03	0.31	Extremely High
12	8⁰ 34' 32" 4⁰ 41' 48"	23.7	6.74	3.52	0.54	Extremely High
13	8⁰ 34' 39" 4⁰ 42' 05"	15.7	0.68	23.09	1.36	High
14	8⁰ 34' 47" 4⁰ 42' 37"	6.13	1.56	3.93	0.59	Extremely High
15	8⁰ 34' 57" 4⁰ 42' 49"	3.37	0.16	21.06	1.32	High
16	8⁰ 35' 11" 4⁰ 43' 06"	8.73	0.39	22.38	1.35	High
17	8⁰ 35' 20" 4⁰ 43' 29"	16.5	0.31	53.23	1.73	High
18	8⁰ 35' 31" 4⁰ 43' 39"	3.1	0.47	6.60	0.82	Extremely High
19	8⁰ 35' 41" 4⁰ 43' 47"	7.4	0.21	35.23	1.55	High
20	8⁰ 35' 52" 4⁰ 43' 58"	17.3	1.09	15.87	1.20	High

However, awareness should be given to the people in the area as to avoid dumping of refuse or waste products or any surface activities that could affect the shallow groundwater due to limited or shallow depth of the wells in the area.

But since the area is well known for agricultural activities, all necessary precautions should be taken to avoid shallow groundwater contamination of the area.

Table2: Results of Aquifer Vulnerability Assessment using GOD Method.

Well Number	Coordinate	Groundwater occurrence	Lithology protective layer	Depth	G O D	GOD Index	Vulnerability Assessment
HDW 1	8^0 32' 57" 4^0 39' 56"	Unconfined	Sand / Lateritic soil	8.7	1.0 0.7 0.8	0.56	High
HDW 2	8^0 33' 09" 4^0 40' 11"	Unconfined	Sand/lateritic soil	8.2	1.0 0.7 0.8	0.56	High
HDW 3	8^0 33' 19" 4^0 40' 27"	Unconfined	Sand/lateritic soil	8.9	1.0 0.7 0.8	0.56	High
HDW 4	8^0 33' 27" 4^0 40' 33"	Unconfined	Sand/lateritic soil	7.6	1.0 0.7 0.8	0.56	High
HDW 5	8^0 33' 36" 4^0 40' 42"	Unconfined	Lateritic soil	8.1	1.0 0.7 0.8	0.56	High
HDW 6	8^0 33' 47" 4^0 40' 51"	Unconfined	Sand/lateritic soil	7.4	1.0 0.7 0.8	0.56	High
HDW 7	8^0 33' 57" 4^0 40' 59"	Unconfined	Ferruginized sand stone	9.2	1.0 0.7 0.8	0.56	High
HDW 8	8^0 34' 03" 4^0 41' 13"	Unconfined	Lateritic soil	8.3	1.0 0.7 0.8	0.56	High
HDW 9	8^0 34' 11" 4^0 41' 21"	Unconfined	Lateritic soil	8.7	1.0 0.7 0.8	0.56	High
HDW 10	8^0 34' 18" 4^0 41' 29"	Unconfined	Sand/lateritic soil	7.6	1.0 0.7 0.8	0.56	High
HDW 11	8^0 34' 27" 4^0 41' 37"	Unconfined	Lateritic soil	10.2	1.0 0.7 0.7	0.49	Moderate
HDW 12	8^0 34' 32" 4^0 41' 48"	Unconfined	Lateritic soil	8.6	1.0 0.7 0.8	0.56	High
HDW 13	8^0 34' 39" 4^0 42' 05"	Unconfined	Lateritic soil	7.6	1.0 0.7 0.8	0.56	High
HDW 14	8^0 34' 47" 4^0 42' 37"	Unconfined	Lateritic soil	7.8	1.0 0.7 0.8	0.56	High
HDW 15	8^0 34' 57" 4^0 42' 49"	Unconfined	Lateritic soil	9.6	1.0 0.7 0.8	0.56	High
HDW 16	8^0 35' 11" 4^0 43' 06"	Unconfined	Lateritic soil	8.4	1.0 0.7 0.8	0.56	High
HDW 17	8^0 35' 20" 4^0 43' 29"	Unconfined	Ferruginized sand stone	6.8	1.0 0.7 0.8	0.56	High
HDW 18	8^0 35' 31" 4^0 43' 39"	Unconfined	Ferruginized sand stone	8.6	1.0 0.7 0.8	0.56	High
HDW 19	8^0 35' 41" 4^0 43' 47"	Unconfined	Ferruginized sand stone	8.9	1.0 0.7 0.8	0.56	High
HDW 20	8^0 35' 52" 4^0 43' 58"	Unconfined	Ferruginized sand stone	7.8	1.0 0.7 0.8	0.56	High

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