

Investigation of Aquifer Vulnerability and Pollution Index around Industrial Area in Ilorin, Northcentral Nigeria

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Abstract

Urban pollution due to increased industrialization has become a major concern in recent time. In most cases, hazardous wastes from industries infiltrate groundwater especially in unconfined alluvial aquifer if proper precautions are not taken. This study used GOD model to investigate aquifer vulnerability around industrial area in Ilorin, North-central Nigeria. Heavy metals (Cd, Cr, Zn, Pb, Fe, Ni, Mn, Cu, Co) were also determined from groundwater in study area using metal pollution index (MPI) to validate the GOD model. Three main vulnerability zones were recognized in the study area and these are: low vulnerability zones with GOD index values ranging from 0.22 to 0.26 and moderate vulnerability zones having GOD index value of 0.48 while high vulnerability zones possess GOD index values ranging from 0.56 to 0.64. The pollution index show that the area is highly polluted with respect to (Cd, Cr, Pb, Fe, Ni, Mn, Cu and Co) and lightly polluted with Zn. The sources of pollution in the study area are attributed to industrial effluent discharges. There is urgent need for measures to mitigate further groundwater pollution and protection of aquifer in the study area.

Keywords: Aquifer; Vulnerability; Heavy-Metals; Pollution

Introduction

Groundwater constitutes the freshwater available for domestic, industrial and agricultural use (Mirzavand and Ghazavi, 2015). The adequacy of groundwater resources, both in quality and quantity is important for socio-economic development of an area (Majolagbe et al., 2016). Both groundwater and aquifer are under intense threats from environmental influences and pollutions such as leachates from domestic, industrial wastes (Idowu et al., 2016) and various land use configuration such as application of chemicals that result to groundwater pollution (Adesola et al., 2016; Babarinde and Onyiaocha, 2016) and these pollutants possess some heavy metals that are harmful to the environment with negative impact on water.

The vulnerability of groundwater to pollution could be defined as a tendency of groundwater in an area to be contaminated or polluted (Majolagbe et al., 2016). Study of aquifer vulnerability to pollution assist to understand the distribution of the highly vulnerable areas, in which there are possible pollution occurrences either now or in the near future (Ibrahim et al., 2017). Aquifer vulnerability connotes that different parts of an aquifer may offer different degrees of protection to the groundwater contained in them (Recinos et al., 2014). For instance, in highly porous alluvial soils such as sand and gravels are considered to be very good aquifers with high yield values, but are the most vulnerable and are

unprotected from surface pollution if no proper protection measures are put in place (Ibrahim et al., 2017).

Various methods have been developed for the assessment and evaluation of groundwater vulnerability to contamination from surface pollution. The DRASTIC model (Aller et al., 1987) was first developed for the US Environmental Protection Agency. Following DRASTIC are other methods such as AVI (Van Stempvoort et al., 1993), COP (Vias et al., 2006), EPIK (Doerflinger et al., 1999), GOD (Foster, 1988), SINTACS (Civita, 2000), VULK (Sinreich et al., 2007) and many more.

The aquifer system in the study area is primarily unconfined aquifer, porous and permeable, therefore, there is possibility of contaminants to infiltrate through the soil into the shallow watertable in the study area. This study was carried out to evaluate the performance of GOD model in determining surficial aquifer vulnerability in an industrial area. The GOD model was validated with heavy metals using pollution index.

Location of the Study Area

The study area is situated within latitude 8° 27' 03"N, 8° 29' 02" N and longitude 4° 31' 45" E, 4° 35' 30" E (Ilorin Topographical Sheet 223 N.W) with about 16km. The area is in the intermediate zone between semi-arid in the

north and sub-humid climate in the south distance as shown in Fig. 1, hence characterized by two distinct seasons, that is, the wet season which starts in late march

and ends in the mid of October, while cold and dry weather due to influence of Harmattan is observed in the months of December and January.

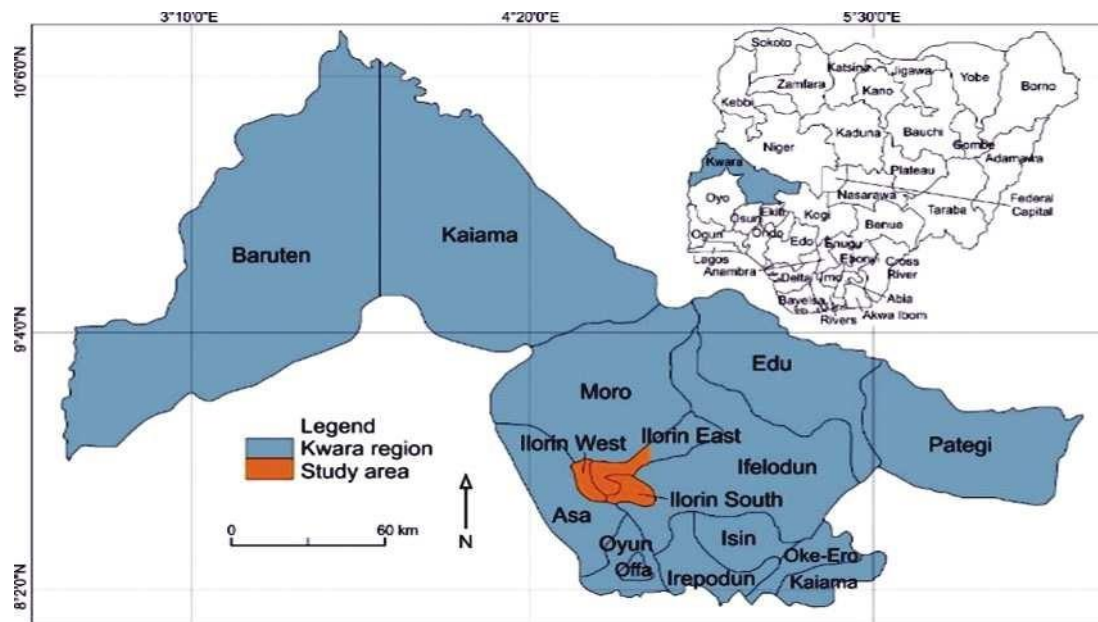


Fig. 1: Map of Kwara state showing study area.

Geology and Hydrogeological Settings of the Study Area

The study area is situated on the Precambrian Basement Complex rocks that include granite, granitic gneiss and migmatite (Alao and Ige, 2003; Omotoso et al., 2011). The rocks form part of regional northwestern Island running northwest – southeast parallel to the River Niger (Annor and Olasehinde, 1996). These represent the deeper fractured aquifers which is partly overlain by a shallow porous aquifer (Alao and Ige, 2003). Moreover, Omotoso et al., 2011 further reported that the gneisses are foliated with light and dark bands and the main minerals are suspected to be quartz, feldspar and mica as observed from the petrographic analysis of rock samples. Quartzite veins cut across one another as observed from the field mapping. Structurally, lineations, foliations, joints, fractures and folds are the main features observed on the rocks. Fig. 2 presents the geological map of Nigeria showing the study area.

The surficial aquifer in the study area is mainly of alluvial deposits which composed primarily of sand and gravel while clayey materials are found in some few places. The depth of these surficial aquifers in the study area ranges between 5.0 m to 11.2m as shown in Table 1.



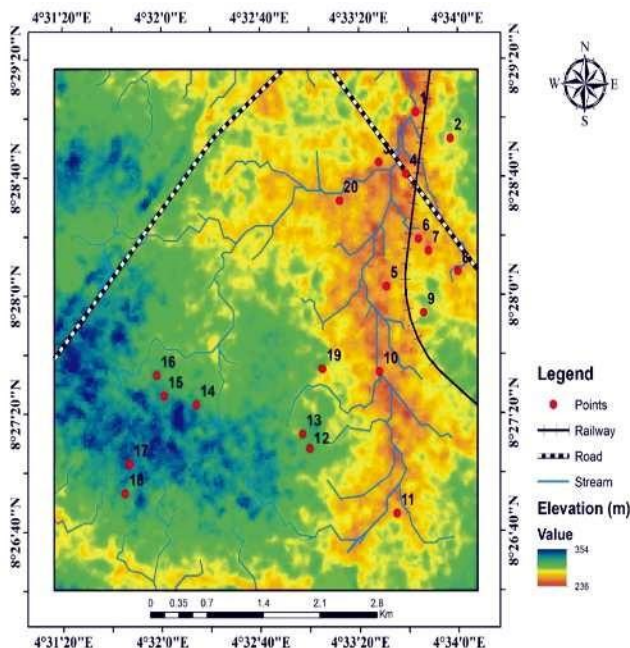
Fig. 2: Geological map of Nigeria showing study area (After Obaje and Abba, 1996)

Methodology

The GOD method was applied to determine aquifer vulnerability in study area. Samples were generated from twenty (20) wells locations based on industrial activities in the area as shown in figure 3. The GOD

Table 1: Database for surficial aquifer vulnerability assessment in study area

Well No.	X	Y	Groundwater occurrence	Overall lithology of aquifer	Depth of groundwater	G	O	D	GOD Index
1	8° 29' 02"	4° 33' 43"	Semi-Confined	Clayey sand	10.2	0.4	0.8	0.7	0.22
2	8° 28' 53"	4° 33' 57"	Unconfined	Sand	5.3	1.0	0.6	0.8	0.48
3	8° 28' 45"	4° 33' 28"	Unconfined	Sandy gravel	5	1.0	0.7	0.9	0.63
4	8° 28' 41"	4° 33' 39"	Unconfined	Sandy clay	6	1.0	0.6	0.9	0.61
5	8° 28' 03"	4° 33' 31"	Semi-Confined	Clayey sand	10.7	0.4	0.8	0.7	0.22
6	8° 28' 19"	4° 33' 44"	Unconfined	Sandy clay	6.3	1.0	0.6	0.9	0.61
7	8° 28' 15"	4° 33' 48"	Semi-Confined	Clayey sand	8.6	0.4	0.8	0.8	0.26
8	8° 28' 08"	4° 33' 60"	Unconfined	Gravel sand	6.7	1.0	0.8	0.8	0.64
9	8° 27' 54"	4° 33' 46"	Unconfined	Sand	5.2	1.0	0.6	0.8	0.48
10	8° 27' 34"	4° 33' 28"	Unconfined	Sandy clay	5.7	1.0	0.6	0.9	0.62
11	8° 26' 46"	4° 33' 35"	Semi-Confined	Clayey sand	11.2	0.4	0.8	0.7	0.22
12	8° 27' 08"	4° 32' 60"	Unconfined	Sandy gravel	7.9	1.0	0.7	0.8	0.56
13	8° 27' 13"	4° 32' 57"	Unconfined	Sand	8.6	1.0	0.6	0.9	0.62
14	8° 27' 23"	4° 32' 14"	Unconfined	Gravel sand	6.9	1.0	0.8	0.8	0.64
15	8° 27' 26"	4° 32' 01"	Semi-Confined	Clayey sand	10.8	0.4	0.8	0.7	0.22
16	8° 27' 33"	4° 31' 58"	Unconfined	Gravel sand	7.2	1.0	0.8	0.8	0.64
17	8° 27' 03"	4° 31' 47"	Semi-Confined	Clayey sand	7.9	0.4	0.8	0.8	0.26
18	8° 26' 53"	4° 31' 45"	Unconfined	Gravel sand	5.3	1.0	0.8	0.8	0.64
19	8° 27' 35"	4° 33' 05"	Unconfined	Sandy gravel	6.6	1.0	0.7	0.8	0.56
20	8° 28' 32"	4° 33' 12"	Unconfined	Gravel sand	5.6	1.0	0.8	0.8	0.64

**Fig. 3:** Map of study area showing sampling points.

model is based on multiplication of three input parameters in the area namely: Mode of groundwater occurrence (G); Overlying lithology (O) and Depth to water table (D).

To validate GOD model, groundwater samples were

collected based on industrial activities locations in the study area which include pharmaceutical, soap and detergent, flour mill amongst others to represent the conditions of groundwater in each location. The water samples were analysed for heavy metals (Cd, Cr, Zn, Pb, Fe, Ni, Mn, Cu and Co) at the Kwara state ministry of water resources in Ilorin, Nigeria.

The chart in figure 4 shows the evaluation procedure using GOD model. The interpretation of GOD model classified aquifer vulnerability into neglect, low, moderate, high and extreme high vulnerability to contamination. The GIS integration of the collected field data was carried out using ArcView platform by Environmental Systems Research Institute (ESRI, 1999) to generate a vulnerability map for the study area.

Results and Discussions

The data generated from GOD model are presented in Table 1 and Table 2. These data include groundwater occurrence (G); aquifer lithology (O) and depth of groundwater (D). The surficial aquifer vulnerability of the study area is classified into three (3) zones: low vulnerability zone, moderate vulnerability zone and high vulnerability zone (figure 5). The low vulnerability zones have GOD index values ranging from 0.22 to 0.26

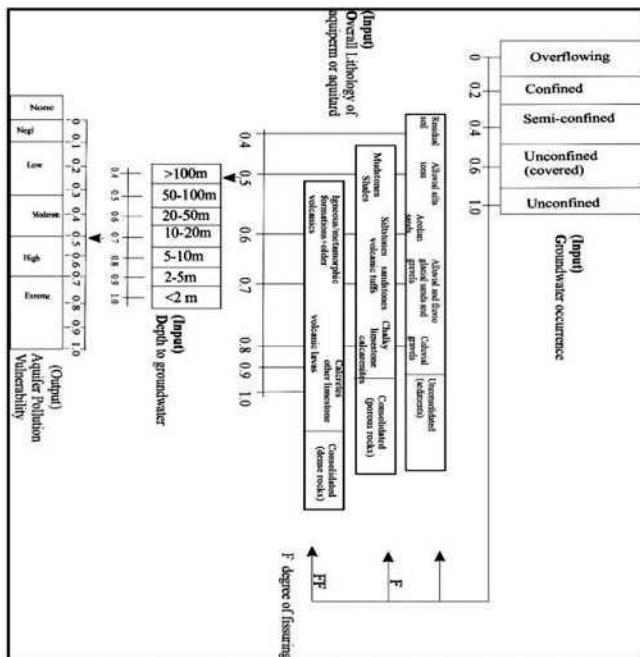


Fig. 4: GOD Model for evaluation of aquifer vulnerability index (Foster, 1988)

Table 2: Classification of aquifer vulnerability in study area

Well No.	X	Y	Aquifer Vulnerability
1	8° 29' 02"	4° 33' 43"	Low
2	8° 28' 53"	4° 33' 57"	Moderate
3	8° 28' 45"	4° 33' 28"	High
4	8° 28' 41"	4° 33' 39"	High
5	8° 28' 03"	4° 33' 31"	Low
6	8° 28' 19"	4° 33' 44"	High
7	8° 28' 15"	4° 33' 48"	Low
8	8° 28' 08"	4° 33' 60"	High
9	8° 27' 54"	4° 33' 46"	Moderate
10	8° 27' 34"	4° 33' 28"	High
11	8° 26' 46"	4° 33' 35"	Low
12	8° 27' 08"	4° 32' 60"	High
13	8° 27' 13"	4° 32' 57"	High
14	8° 27' 23"	4° 32' 14"	High
15	8° 27' 26"	4° 32' 01"	Low
16	8° 27' 33"	4° 32' 58"	High
17	8° 27' 03"	4° 32' 47"	Low
18	8° 27' 43"	4° 33' 35"	High
19	8° 27' 35"	4° 33' 05"	High
20	8° 28' 32"	4° 33' 12"	High

and consists predominantly of clayey sand. The moderate vulnerability zones possess GOD index value of 0.48 which compose of sands and sandy - clay while high vulnerability zones have GOD index values ranging from 0.56 to 0.64 with mainly of sandy-gravel and gravel-sand. The vulnerability map of the surficial aquifer in the study is presented in Figure 4.

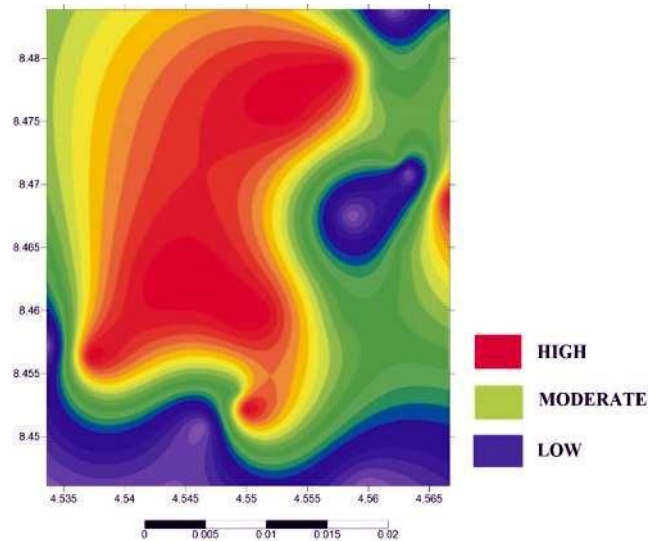


Fig. 5: A produced vulnerability map for study area

The statistical summary of heavy metals concentrations in groundwater in the study area is presented in Table 3.

Table 3: A statistical summary of heavy metals concentrations (mg/l) in the study area

S/N	Parameters	Min.	Max.	Average mean
1	Cd	0.03	2.31	0.45
2	Cr	0.10	3.10	1.06
3	Zn	0.04	5.70	1.07
4	Pb	0.10	50.5	13.3
5	Fe	11.0	79.0	40.2
6	Ni	0.03	5.10	1.28
7	Mn	2.00	88.0	25.0
8	Cu	5.30	105	51.7
9	Co	0.11	10.4	4.08

The groundwater pollution index in study area was determined using metal pollution index (MPI) method as shown in Table 4 which used to indicate the impact of metallic parameters on the overall quality of the water (Udoh and Amadi, 2020). MPI values also indicates the relative impact of heavy metals on the quality of water in the study area. The higher the concentration of a metal when compared to its maximum permissible level, the poorer the quality of the water (Taylor and McLennan, 1995).

Equations

The MPI formula is expressed as follows:

$$MPI = \sum_{i=1}^n \left(\frac{C_i}{(MAC)_i} \right) \dots \dots \dots (1)$$

Where C_i is the mean concentration

MAC is the maximum allowable concentration

There are generally five (5) groups of MPI namely as:

MPI < 0.01 = Very lightly polluted

0.01– 1.0 = Lightly polluted

1.0 – 5.0 = Moderately polluted

5.0 – 10.0 = Highly polluted

> 10.0 = Very highly polluted

The computed metal pollution index for the groundwater in the area as presented in Table 4 ranked the degree of metallic pollution from very highly polluted (Cd, Cr, Pb, Fe, Ni, Mn, Cu and Co) to lightly polluted (Zn) and the possible sources of the pollution in the area are from industrial effluent of soap and detergent, pharmaceuticals, bottling companies among others.

Conclusion

This study shows that most of the locations in the study area are prone to pollution. The validation of GOD method using a metal pollution index classified the study area to be very highly polluted to lightly polluted. Possible sources of groundwater pollution in the study area include industrial effluent of soap and detergent, pharmaceuticals and bottling companies which are

Table 4: Computed metal pollution index (MPI) for groundwater in study area

Parameter (Mg/l)	C_i	MAC NSDWQ (2017)	MP I Val ue	Rating
Cd	0.45	0.003	150	Very-highpolluted
Cr	1.06	0.05	21.0	Very-high polluted
Zn	1.07	3.00	0.36	Lightly polluted
Pb	13.3	0.01	133	Very-highly polluted
Fe	40.2	0.30	134	Very-high polluted
Ni	1.28	0.02	64	Very-highly polluted
Mn	25.0	0.20	125	Very-highly polluted
Cu	51.7	1.00	51.7	Very-high polluted
Co	4.08	0.02	204	Very-high polluted

located in the study area. Continuous monitoring of groundwater pollution in the study area is recommended to reduce future pollution.

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