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EVALUATION OF MODELS FOR ASSESSING GROUNDWATER VULNERABILITY TO POLLUTION IN NIGERIA

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ABSTRACT
This paper examines, based on a review and synthesis of available material, the presently most applied models for groundwater vulnerability assessment mapping. The appraoches and the pros and cons of each method are evaluated in terms of both the conditions of their implementation and the result obtained. The paper further observed that, with the exception of DRASTIC model, most of other models have not been applied to ground water studies in Nigeria, unlike other parts of world where they are widely used. This review therefore brings to limelight the importance of their applicability in groundwater vulnerability mapping in Nigeria.

Key words: Groundwater, Vulnerability, Pollution, Nigeria

INTRODUCTION

The concept of groundwater vulnerability is derived from the assumption that the physical environment may provide some degree of protection to groundwater against natural and human impacts, especially with regard to pollutants entering the subsurface environment. The term 'vulnerability of groundwater to contamination' was probably first introduced in France in the late 1960s (Albinet and Margat, 1970; Chilton, 2006). The general intention was to show that the protection provided by the natural environment varied from place to place. This was done by describing in map form the degree of vulnerability of groundwater to pollution as a function of the hydrogeological conditions. Thus the fundamental principle of groundwater vulnerability is that some land areas are more vulnerable to pollution than others, and the goal of a vulnerability map is to subdivide an area accordingly. The maps, however, would provide information from which land use and associated human activities could be planned and/or controlled as an integral part of an overall policy of groundwater protection at national, sub-national (province or state) or catchment scale.

Although the general concept has been in use for more than thirty years, there is not really a generally accepted definition of the term. However, Chilton (2006) defined vulnerability as the intrinsic properties of the strata separating a saturated aquifer from the land surface which determine the sensitivity of that aquifer to being adversely affected by pollution loads applied at the land surface.

The historical evolution of the concept of vulnerability was reviewed by Vrba and Zaporozec (1994). Hydrogeologists have debated in particular whether vulnerability should be determined in a general way for all pollutants, or specifically for individual or groups of pollutants. Vrba and Zaporozec (1994) recognized that there could be more than one type of vulnerability: intrinsic (or natural) which was defined purely as a function of hydrogeological factors, and specific for those users who wished to prepare and use maps related to specific pollutants, for example agricultural nitrate, pesticides, or atmospheric deposition. The first vulnerability map at a scale of 1:1 million was prepared in France by Margat (1968). In Germany, Vierhuff *et al.* (1981) made a vulnerability map of the former Federal Republic of Germany before reunification on the same scale. The current international practices in mapping groundwater vulnerability have been reviewed by Vrba and Zaprozec (1994), Magiera (2000), Goldscheider (2002), Heinkele *et al.* (2002) and others. Goldscheider (2002) identified and characterized them according to five groups of methods: (i) Hydrogeologic complex and setting methods, (ii) Index methods and analogical relations, (iii) Parametric system methods, (iv) Mathematical methods and (v) Statistical methods.

Vrba and Zaprozec (1994) and Magiera (2000) have reviewed the use of the different groups of methods, and based on their compilation we can conclude that the parametric system methods are most common today. Examples of this group of methods are the point count system DRASTIC (Aller *et al.*, 1987), the rating system GOD (Foster, 1987) and the EPIK method (Dörflieger 1996). In this paper, an attempt is made to evaluate through review some of the most widely used models for groundwater vulnerability mapping the world over and a recommendation of their applicability to the Nigerian landscape.

MATERIALS AND METHODS

A number of journals, articles, technical reports, institutional records from water resources organizations and virtual output source such as the internet were extensively utilized to acquire data/information for the study. The methodology used for the research work was a qualitative research technique. Thus, secondary data formed the basis for the study.

The qualitative data analysis which involves making an interpretation and sense out of the text and data used in support of the concepts adopted was done based on the premise of establishing evidence in support of the concepts and issues been evaluated and discussed.

DISCUSSION

The following variables are generally used to assess natural groundwater vulnerability: net recharge, soil properties, unsaturated zone lithology and thickness, groundwater level below ground, aquifer media and aquifer hydraulic conductivity. Topography (slope of the land) is often applied too. Parameter weighting and rating methods are usually implemented to express relationships between the variables and to reflect their importance for groundwater vulnerability assessment. A selection of the presently most applied methods for groundwater vulnerability mapping is presented and evaluated in this paper. They are:

- The DRASTIC method, used mainly in the USA,
- The GLA-Method and its recent modification, the PI-Method, used by the German authorities,
- The EPIK-Method used by the Swiss authorities and the
- COP-Method which may become the method to be used by all European authorities for vulnerability mapping in karst areas.

1.0 DRASTIC Method

The DRASTIC methodology was developed in the United States under cooperative agreement between the National Water Well Association (NWWA) and the USA Environmental Protection Agency (EPA) for detailed hydro-geologic of evaluation pollution potential and is a model used to spatially and comparatively display high vulnerability areas in contrast to low vulnerability areas with respect to the potential to pollute groundwater (Dixon, 2005). DRASTIC is an acronym for :

D	-	**D**epth to water table
R	-	net **R**echarge
A	-	**A**quifer media
S	-	**S**oil media
T	-	**T**opography
I	-	**I**mpact of the vadose zone
C	-	hydraulic **C**onductivity of the aquifer

The overall 'pollution potential' or DRASTIC index is established by applying the formula:

DRASTIC Index: Di= $D_R*D_W + R_R*R_W + A_R*A_W + S_R*S_W + T_R*T_W + I_R*I_W + C_R*C_W$

Where, r = Rating W = Weight

D- Depth to Water

Depth to Water affects the time available for a contaminant to undergo chemical and biological reactions such as dispersion, oxidation, natural attenuation, sorption etc. A low depth to water parameter will lead to a higher vulnerability rating.

R- Net Recharge

Net Recharge is the amount of water which enters the aquifer. This value can be calculated on an annual or monthly basis with data available. Although recharge will dilute the contaminant which enters the aquifer, recharge is also the largest pathway for contaminant transport. Therefore, the amount of recharge is positively correlated with the vulnerability rating. Net Recharge can be calculated using climate data by applying a mass balance on the water.

Net Recharge = Precipitation – Evaporation – Runoff

A - Aquifer Media

Aquifer Media is used to produce a rating based on the permeability of each layer of media. High permeability allows more water and therefore more contaminants to enter the aquifer. Therefore a high permeability will yield a high vulnerability rating.

S - Soil Media

Soil media is affects the transport of the contaminant and water from the soil surface to the aquifer. Some of the interactions with soil have already been stated, but for review, the soil media can affect the types of reactions which can take place. Sorption phenomena, for example, can be affected by the structure of the soil surface. Additionally, different soils will provide better habitats for microorganisms which can potentially biodegrade the contaminant. The rating system that is proposed by Aller et. al., (1987) follows. This rating system seems to be based on the hydrological transport of the contaminant to the aquifer, rather than on other characteristics(see table 1).

T- Topography

The topography of the land affects groundwater vulnerability because the slope of the land is an important factor in determining whether the contaminant released will become run-off or infiltrate the aquifer. With a low slope, the contaminant is less likely to become run-off and therefore more likely to infiltrate the aquifer. Digital Elevation Data (DEM) may be used to calculate and project the slope using GIS.

I - Impact of Vadose Zone

The vadose zone is the typical soil horizon above and below the water table, which is unsaturated or discontinuously saturated. If the vadose zone is highly permeable then this will lead to a high vulnerability rating.

C-Hydraulic Conductivity

The hydraulic conductivity relates the factures, bedding planes and intergranular voids in the aquifer. These components become pathways for fluid movement, and likewise pathways for contaminant movement once a contaminant enters the aquifer. The hydraulic conductivity is positively correlated with the vulnerability rating.

From these parameters a DRASTIC index or vulnerability rating can be obtained. The higher the value for the DRASTIC index, the greater the vulnerability of that location of an aquifer. The ratings are assigned values between 1 and 10, while the weight has a fixed value as listed in Table 2 below. It should be understood that DRASTIC is of two types. There is the normal DRASTIC and the agricultural DRASTIC. The latter is mainly used when assessing groundwater vulnerability in areas that are mainly affected by agricultural usage of herbicides and pesticides.

Table 1: Rating system for DRASTIC

Range	Rating
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy Loam	4
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and nonaggregated clay	1

Aller *et al.,* (1987)

Table 2: Assigned weights for DRASTIC parameters

Parameters	DRASTIC	Agricultural DRASTIC
Depth to Water Table	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil Media	2	5
Topography	1	3
Impact of the vadose Zone	5	4
Hydraulic Conductivity	3	2

2.0 GLA-Method and PI- Method

The GLA-Method which was first proposed by Hoelting et al., (1995) is based on a point count system just like the DRASTIC model. Goldscheider (2002) further developed GLA-method into the PI-method in the framework of the European COST 620. Unlike the DRASTIC, the GLA-method only takes the unsaturated zone into consideration. Attenuation processes in the saturated zone are not included in the vulnerability concept. The degree of vulnerability is specified according to the **protective effectiveness** of the soil cover and the unsaturated zone. The parameters considered for the assessment of the overall protective effectiveness are as follows:

Parameter 1: S- effective field capacity of the soil (rating for eFC in mm down to 1m depth)
Parameter 2: W- percolation rate
Parameter 3: R- rock type
Parameter 4: T- thickness of soil and rock cover above the aquifer
Parameter 5: Q- bonus points for perched aquifer systems
Parameter 6: HP- bonus points for hydraulic pressure conditions (artesian conditions)

The protective effectiveness (P_T) is calculated using the formula:

$P_T = p_1 + P_2 + Q + HP$

Where

P_1 - protective effectiveness of the soil cover: $P_1 = S*W$

P_2 - protective effectiveness of the unsaturated zone (sediments or hard rocks):

$$P_2 = W^* (R_1 {*} T_1 + R_2 {*} T_2 + \ldots\ldots.. + R_n {*} T_n).$$

Based on the German mapping approach, the highest value assigned for factor W, is 1.75 for a groundwater recharge of less than 100mm/a (Hoelting et al., 1995). A modified scale for the factor W was introduced which reflects the low amounts of groundwater recharge in many areas (see Table 3).

Table 3: Modification of factor W (percolation rate)

Groundwater Recharge {mm/a}	Factor W
>400	0.75
>300 – 400	1
>200 – 300	1.25
>100 – 200	1.5
>50 – 100	1.75
>25 – 50	2
≤ 25	2.25

The PI-method which is a modification of the GLA-method integrates the protective cover (P) and the infiltration factor (I). In PI-method, the protective cover and the infiltration factor are separately mapped as individual maps and then combined to the groundwater vulnerability map.

3.0 The EPIK Method

This method was elaborated in the framework of the COST activities of the European Commission by the University of Neuchatel, Centre of Hydrogeology, for groundwater vulnerability mapping in karst areas. It was later developed by the Swiss Agency for the Environment, Forests and Landscape into a standard tool for groundwater Protection zone delineation in karst areas (Saefl, 2000). EPIK takes the following parameters into account:

- ✓ Development of the **E**pikarst,
- ✓ Effectiveness of the **P**rotective cover,

- ✓ Conditions of **I**nfiltration and
- ✓ Development of the **K**arst network.

For each parameter a standard weighting coefficient is used. The classification for each parameter and area is obtained by systematic mapping for these parameters. The standard values for the EPIK parameters are shown in table 4, while table 5 illustrated the standard weighing coefficients for the EPIK parameters.

Table 4: Standard values for the EPIK parameters

E_1	E_2	E_3	P_1	P_2	P_3	P_4	I_1	I_2	I_3	I_4	K_1	K_2	K_3
1	3	4	1	2	3	4	1	2	3	4	1	2	3

Table 5: Standard weighing coefficients for the EPIK parameters

Parameter	Epikarst	Protective cover	Infiltration	Karst network
Weighing coefficient			γ	
Relative weight	3	1	3	2

The overall protection index **F** is calculated based on the following equation:

$F = aE + \quad P + \gamma I + \quad K$

F can obtain values between 9 and 34.

4.0 COP- Method

COP- Method is an European approach for aquifer study in karst regions. The method was introduced by the Group of Hydrogeology in the University of Malaga/Spain (Ghuma) in the framework of the COST 620 programme as a standard method for groundwater vulnerability mapping in karst aquifers (Vias et al., 2002). As outlined by Daly et al. (2002) COP –Method may become the European approach for groundwater vulnerability mapping in the karst areas, provided its application proves to be succeessful in the coming few years. This method uses the parameters

- C – Concentration of flow
- O – Overlying layers and
- P - Precipitation.

The COP – Index is obtained by

COP – Index = (C score) * (O score) * (P score)

The **C** Factor represents the degree of concentration of the flow water towards karstic conduits that are directly connected with the saturated zone and thus indicate how the protection capacity is reudced. This factor has two scenarios. For scenario 1 the factor C is calculated based on the parameters distance to the swallow hole (d_h), distance to the sinking stream (d_s) and the combined effects of slope and vegetation (SV):

$C = d_h * d_s * sv$

Scenario 2 occurs in areas where the aquifer is not recharged through a swallow hole. Here the C factor is calculated based on the parameters surface features (sf) and slope (s) and the combined effects of slope and vegetation (sv):

$C = sf * sv$

The **O** factor takes into account the protective function of the unsaturated zone and the properties of the layers soil (O_S – soil subfactor) and unsaturated zone (O_L- lithology subfactor). Both are separately calculated and then added to obtain the O fator:

$O = O_S + O_L$

The **P** factor represnts the total quantity, frequency, duration of precipitation as well as the intensity of extreme events, which are considererd to be the chief influencing factors for the quantity and rate of infiltration. This factor is obtained by a summation of the subfactors quantity of precipitation (P_Q) and intensity of precipitation (P_I):

$P = P_Q + P_I$

The calculation of the subfactor PI is based on the assumption that a higher rainfall intensity results in an increased recharge and thus a reduced protection of the groundwater resource. The "mean annual intensity" or PI is calculated from:

$$\text{Mean annual intensity} = \frac{\text{mean annual precipitation (mm)}}{\text{Mean number of rainy days}}$$

Comparison of Methods and Recommendation for Application

DRASTIC is a popular model for groundwater vulnerability assessments as it is relatiely inexpensive, straightforward, and uses data that are commonly available or estimated, and produces an end product that is easily interpreted and incorporated into the decision-making process (Margane, 2003). As observed by Foster (1998), the shortcoming of DRASTIC is that it underestimates the vulnerability of fractured aquifers and that its weighting system is not scientifically based. As for the GLA-method, one of its basic advantage is that it can be use for resource protection and land use planning for all types of aquifers. It however, does not sufficiently take into account the special properties of karst.

Goldscheider (2002) made the following critical remarks concerning the EPIK Model:

- Some important factors are missing: the recharge and the thickness of the unsaturated zone (depth to water table) are not taken into account.
- The EPIK is not defined for all hydrogeological settings
- The transformation of the vulnerability classes into source protection zones is disputable.

The basic advantage of the COP-method is that the parameters needed for analysis are relatively easy to acquire and the method is straightforward. However, due to the large number of calculation processes, the map compilation is time consuming.

The choice of the most appropriate method for groundwater vulnerability mapping to be used in any area or country depends on data availability. In Nigeria, except for a study by Ibe et al., (2001) that utilized the GOD and DRASTIC models for the assessment of groundwater vulnerability in Owerri, southeastern Nigeria, much work has not beeen done using these models in assessing aquifers vulnerability to pollution. Even the Nigerian Federal Ministry of Water Resources and Agriculture has not developed nor adopted/adapted any of the available models for groundwater vulnerability mapping. This review thus reveals the potential needs and at the same time unveils and recommends the use of some of these models in groundwater mapping in Nigeria

Although various studies have been undertaken in Nigeria to assess groundwater quality in different parts of the country, little have been done in areas of vulnerability mapping. It should be understand that maps produced from the use of any of the models will aid land use planners and water resources decision makers to determine areas of low, moderate and high vulnerability to pollution potentials.

The fact that Nigerian aquifers are threatened by intensive use of agricultural chemical (fertilizers and pesticides), uncontrolled solid waste disposal and significant untreated wastewater discharge into or near surface waters (that recharge the alluvial reservoirs), urbanization and industrialization calls for a method for groundwater vulnerability assessment mapping.

CONCLUSION

The choice of the most appropriate method for groundwater vulnerability mapping to be used in any area depends on the data availability, spatial data distribution, the scale of mapping, the purpose of the map and hydrogeological setting. However, the better the data availability, the more detailed the map. In areas where data availability is low but the general hydrogeological setup is known, DRASTIC would be a suitable method of choice. For countries like Nigeria, where dearth of data exists, the DRASTIC model will be the suggested method for now.

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