Assessment of the Vulnerability of the Shallow Aquifer of the City of Sarh in Chad, using the Drastic Approach

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Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final
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ABSTRACT

The demography (3.4%) and the development of anthropic activities in the city of Sarh, constitute a risk of groundwater pollution. That is why a vulnerability map is determined to contribute to the protection of groundwater resources against possible pollution for future decision and allocation of land and activities. The present study interested the city of Sarh and had the objective to elaborate a vulnerability map to pollution by applying the DRASTIC method. The data required for this study are summarized in seven critical factors specific to the model applied (depth of the water table, net recharge, aquifer lithology, soil type, topography (slope), unsaturated zone lithology and hydraulic conductivity). They were acquired from several sources and converted by the GIS into thematic maps. For each critical parameter, a coefficient and a weight were assigned according to its importance in the DRASTIC model. The resulting map shows three classes of vulnerability; 36% of the Sarh region has very low vulnerability, 35% has low vulnerability and 29% has medium vulnerability.

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1. INTRODUCTION

Groundwater is an important resource in the Sahelian zone. However, the qualitý of these waters is a serious environmental problem especially in African cities. Groundwater use increases significantly in areas where the municipaĺ water supply is limited or polluted [1].

The pollution of groundwater resources is a concern that requires universal attention, especially due to increased anthropogenic activities and heavy urbanization. The use of chemicals in daily activities negatively affects the qualitý of groundwater [2]. Contaminants in water can be controlled at the source, before they enter, but once the contaminant has entered, controlling its properties is very difficult and sometimes impossible.

Groundwater protection is essential for effective management of groundwater resources. These protection goals can be achieved through groundwater vulnerability assessment [3]. Therefore, groundwater vulnerability assessment is an indicator of groundwater sensitivity to pollution and an effective planning and decision-making tool for groundwater management strategies [4,5,6].

Many methodologies are available in the literature for estimating the vulnerabilitý of groundwater in an area [7,8]. The DRASTIC method is one of the most well-known and widely used overlay index methods that is applied worldwide for groundwater vulnerability assessment [9]. It was developed by the United States Environmental Protection Agency (USEPA). In DRASTIC, seven hydrogeological parameters are used to assess the groundwater vulnerability of an area, and the method is suitable for porous aquifers [10,11,12].

As a highly urbanized city, Sarh is faced with increased garbage production, domestic wastewater discharges, exposing groundwater to contamination. Also, with the development of agricultural and market gardening, the practice of fishing using chemicals and fertilizers, the pollution could take an important proportion.

The groundwater of the city of Sarh is thus confronted in a recurring way with a risk of pollution related to the anthropic activities. Preventive measures are necessary in order to protect the groundwater of this city in an efficient way for the generations to come. Mapping of pollution-vulnerable areas is one approach to assist in the protection and prevention of groundwater from pollution [13]. At present, no serious study to assess the vulnerability of aquifers to pollution to evaluate the health risk incurred by these populations has yet been carried out in this city. Therefore, there is a lack of tools to help decision making in terms of development to consider the risk of groundwater pollution. The objective of this study is to develop a vulnerability map to the pollution of aquifers in the city of Sarh in a perspective of sustainable management of groundwater using the method DRASTIC. This study will allow to prevent the risks of pollution of these groundwater resources and to protect them against any pollution.

2. PRESENTATION OF THE STUDY AREA

Sarh is the capital of the Moyen Chari province and is in southern Chad between latitudes 9° and 10° North and longitudes 18° and 19° East (Fig. 1). It is bordered to the northwest by the Melfi River, to the southeast by the Maro River, to the east by the Kyabe River, and to the southwest by the Koumra River. Its population is estimated at 97,224 inhabitants [14] with a growth rate of 3.40%.

The climate of the area is characterized by a rainy season from May to October with an annual rainfall of 900 to 1350 mm and a dry season from November to April. The average temperature is 30°C [15]. It belongs to a Sudanese-Guinean climate and its landscape is made up of vast, densely forested red earth plateaus into which rivers flow through deeply incised valleys (Chari valleys).

Its hydrographic network is mainly made up of the Chari River. This flows through the town of Sarh and results from the junction of several rivers coming from the Central African Republic [16]. The flow regime is characterized by a flood that begins in June and reaches its maximum in October-November. The recession is regular from November and the low water level occurs in April-May [15].

The geological history of the study area falls within the Quaternary and terminal continental domains [17]. The formations can be subdivided into three groups: (1) the sandy-clay texture: this

is an ancient fluvio-lacustrine series presenting the clay-sandstone compound with very extensive calcareous nodules (Chari basin); (2) the sandy texture: this is a recent sandy series presenting coarse facies localized in the Chari basin. The series, very diversely sorted, is then sandy with quartz dominating, but with a significant percentage of feldspars and gravels in the deep horizons. The grain size of the sediment is high. The clay fraction is based on kaolinite and montmorillonite in co-dominance, while illite is in smaller quantities. The coarse facies of this series here constitute bulges deposited along the watercourses that ran through marshy areas in the city. These sediments are thought to be derived from the Continental Terminal and Granitic Massifs formations and (3) variable texture: it constitutes the sub-actual fluvial series to the present day, which is, the Chari River bulges. This formation consists of fine sand, silt and clay.

Hydrogeologically, the study area has only one type of aquifer: the free aquifer of the Chari alluvial basin [17]. The groundwater table in this town is shallow, located at a depth of less than 30 m in the dry season. It is generally observed in wells dug on the sandy alignments or mounds that overhang the flooded clay plain by a few meters during the rainy season under 1m to 1.50m of water [17]. The analysis of the worksheets shows that the saturated zone is generally made up of sand of different sizes and clay.

3. METHODOLOGICAL APPROACH

3.1 DRASTIC Approach

In this study, the vulnerability assessment was done by applying a single method, which is DRASTIC. The DRASTIC method is universally used and considers 7 parameters considered important in the vulnerability assessment process.

The DRASTIC method was developed by the US Environmental Protection Agency (EPA) in 1987 [8,18].

It is used to assess the vertical vulnerability of groundwater to pollution by parametric systems; the common principle of these systems is the prior selection of parameters on which the vulnerability assessment is based. Each parameter is subdivided into intervals of significant values and assigned an increasing

numerical rating according to its importance in the vulnerability. The acronym DRASTIC is the initials of the seven factors that determine the value of the vulnerability index: (1) Depth to water (D), (2) Net Recharge (R), (3) Aquifer media (A), (4) Soil media (S), (5) Topography (T), (6) Impact of vadose zone (I) and (7) Hydraulic Conductivity of the aquifer (C). The seven parameters schematically partition a local hydrogeological unit into its main components, which influence contaminant transport and attenuation processes in the soil to different degrees, as well as their transport time [19-26]. A numerical value called parametric weight, ranging from 1 to 5, is assigned to each parameter, reflecting its degree of influence. Each parameter is classified into classes associated with ratings ranging from 1 to 10. The lowest score represents conditions of lowest vulnerability to contamination. A numerical value called the DRASTIC vulnerability index (ID) is determined, which describes the degree of vulnerability of the scores ranging from 1 to 10. The smallest score represents the conditions of lowest vulnerability to contamination. A numerical value called the DRASTIC Vulnerability Index (DI) is determined, which describes the degree of vulnerability of each hydrogeological unit. The DRASTIC vulnerability index is calculated as the sum of the products of the scores and the corresponding parameter weights in equation 1 [27]:

$$ID = Dp * Dc + Rp * Rc + Ap * Ac + Sp * Sc + Tp * Tc + Ip * Ic + Cp * Cc$$

Where D, R, A, S, T, I, and C the seven parameters of the DRASTIC method, p being the weight of the parameter and c, the associated score). The minimum value of the index is "23", while the maximum value is "226". The index (ID) is used to characterize or evaluate the degree of vulnerability of the hydrogeological unit to which it is attached.

There are two versions of the DRASTIC method: the standard DRASTIC version, applied in the case where the contaminants considered are inorganic pollutants and the version DRASTIC pesticides, applied in the case where the contaminants considered are pesticides. The values of the weights of the parameters, in the standard version of the DRASTIC, are presented in Table 1.

The DRASTIC index values obtained represent a measure of the hydrogeological vulnerability of the aquifer, ranging from 23 to 226 in the case of the standard version.
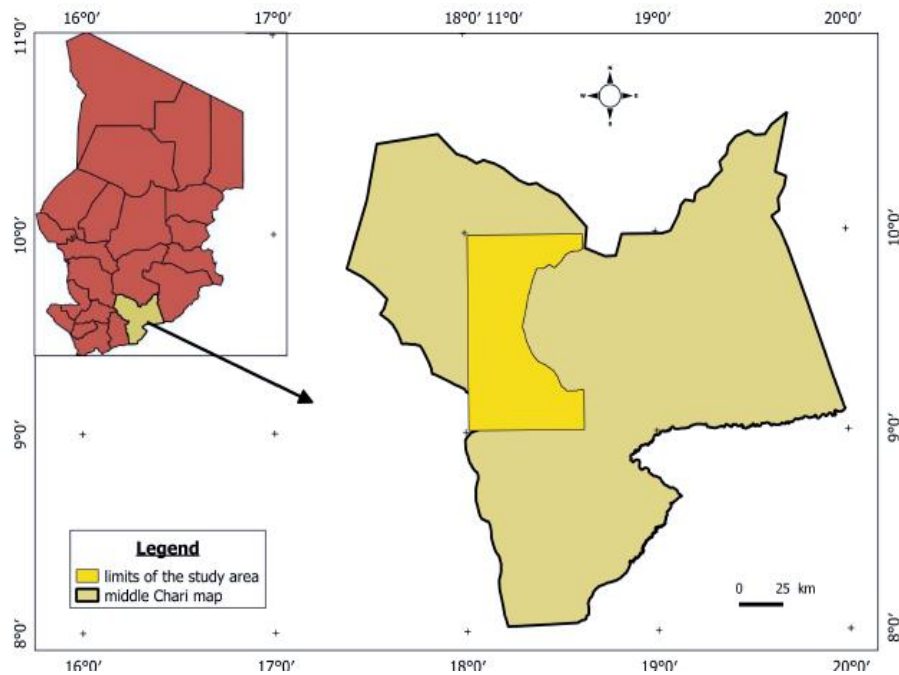
Fig. 1. Map of location of the study area

Table 1. Parameter weights in the standard version of the DRASTIC method

Parameters	DRASTIC standard version
D : Depth to water	5
R : Net Recharge	4
A : aquifer media	3
S : soil media	2
T : Topography	1
I : Impact of vadose zone	5
C : hydraulic Conductivity of the aquifer	3

Table 2. Vulnerability assessment criteria in the DRASTIC method [8,29]

Degree of vulnerability	Vulnerability index [8]	Vulnerability index [29]
Very low	<80 (0 à 30%)	
Low	80 – 120 (31 à 45%)	< 101
Medium	121- 160 (46 à 60%)	101 - 140
High	161- 200 (61 à 75%)	141 - 200
Very high	>200 (76 à 100%)	> 200

The values obtained are grouped, according to [8], into five classes, each of which corresponds to a degree of vulnerability. The higher the calculated ID index, the greater the vulnerability. After the index calculation, vulnerability classes are mapped to the different ranges of calculated DRASTIC indices (Table 2). The equation below (equat 2) is used to convert DRASTIC indices into percentages [28].

$$\textbf{Indice} \ (\%) = \frac{\textbf{ID} - \textbf{23}}{\textbf{20} \ \textbf{3}} \ X \ \textbf{100}$$

3.2 Data

The data used are of several types. They are essentially made up of :

- Shuttle Radar Topographic Mission (SRTM) satellite images of 90 m resolution, downloaded from the website http://srtm.csi.cgiar.org/ covering the study area;

- Geological map of Chad established by [30] at a scale of 1:500,000;

4

- 56 technical data sheets for boreholes drilled in the town of Sarh, covering the period from 1976 to 2015. These data sheets were collected from the center of documentation and geographic information and completed by downloading the data via the site of Siteau of the Ministry of Urban and Rural Hydraulics: http://www.reseau-tchad.org /siteau/coupe_litho/;

- Data of the hydrological parameter (recharge) acquired in the document of [17].

- The processing of all these data was carried out using the techniques of digitization and interpolation (IDW) using the software MAPINFO 11.0, Surfer 8 and QGIS 2.16.

4. RESULTS AND DISCUSSION

In order to elaborate the vulnerability map, several thematic maps, related to the above-mentioned parameters, have been drawn up:

4.1 Depths of the Groundwater Table

The depth map of the groundwater table represents the parameter D and is one of the most important parameters of the DRASTIC method. This parameter gives an idea of the distance the pollutant must travel before reaching the water table. Thus, the map was established from the piezometric map. This map (Fig. 2) shows shallow levels (less than 13 m) in the southern part, medium depths in the center (up to 23 m). The greatest depth can be seen in the extreme north of the study area (over 33m). This parameter alone can provide information on the vulnerability of the water table.

4.2 Recharge

The aquifer is recharged mainly by direct infiltration at an average of 0.54 - 0.65 mm of effective rainfall. Considering the overall surface area of the study area, the amount of infiltrated water is estimated at 5.2 million m^3 per year, which is divided into low, medium and high infiltration respectively in the north, center and south of the study area.

4.3 Soils

The soils in the study area are made up of soils with overall hydromorphy or temporary shallow depths such as the family on sandy material and recent fluvial alluvium and ferruginous soils such as the family on beige or ochre material, sandy to sandy clay (Fig. 3a).

4.4 Topography of the Study Site

Topography is expressed as slope in DRASTIC. Areas with low slopes tend to hold water longer. This allows for greater infiltration of recharge water and greater potential for contaminant migration [31]. The slope was developed from the DTM of the study area. The general observation shows that all the terrain is not very hilly (Fig. 3b), however the slope can exceed in some cases (in the left bank floodplain) 10%.

4.5 Vadose Zone

The vadose zone is the layer above the water table and is completely unsaturated. Many processes that affect the pollution potential of the aquifer system take place in the vadose zone. The character of this zone determines the attenuation characteristics of the environment above the water table. In addition, this zone controls the path of contaminant particles to the aquifer system. The lithology of this zone shows us that the unsaturated zone is generally formed from top to bottom by: (1) sub-actual to present fluvial series which is, constituted by fine sand, silt and clay and (2) recent sandy series very diversely sorted; quartz sand dominant, but with a significant percentage of feldspars and gravels in the deep horizons. Sediment grain size is high.

4.6 Hydraulic Conductivity

Hydraulic conductivity expresses the ability of geological formations to transmit water with possible pollutants under a hydraulic gradient to the saturated zone. This factor governs the path of groundwater flow in the aquifer. If the permeability is high, the attenuation capacity is low and vice versa [31]. It is a function of the rock and the fluid (water) flowing through it. Based on data from existing boreholes in the region, it appears that the areas with the highest permeability (0.01 m/s) are located on the NNW-SSE diagonal axis that coincides with the direction of the Chari River and its banks.

4.7 Pollution Vulnerability Map of the Sarh Aquifer

The final DRASTIC vulnerabilitý map was produced based on a synthesis of the seven DRASTIC parameters after multiplyinǵ each parameter by its appropriate score and weight. The scores evaluated by the DRASTIC method ranged from 22 to 122. This vulnerabilitý map

was classified into three classes according to the DRASTIC index values. The indices obtained are:

- ID < 30%: very low vulnerability;
- 31 < ID < 45%: low vulnerability;
- 46 < ID < 60%: medium vulnerability.

Such a classification takes into account the standard classes defined by [8] and allowed to obtain the vulnerability map to pollution of alluvial aquifer of the Sarh region.

The highest DRASTIC index exists in the southern part of the area (Fig. 4). The layer in this area consists of sand and to the greatest amount of recharge. This may explain why it is moderately vulnerable (Fig.4). In this zone, the piezometric level is close to the ground surface and there is a density of streams. The next area with low vulnerability is the one indicated in the middle of Fig. 4. This area has a vulnerability index between 31 and 45%. The geological formation consists of sand and clay, fluvial - alluvial deposits. The lowest vulnerability index (<30%) was found in the northern part. The northeastern part has a clay layer and quite high-water depths. This explains why this area has a very low vulnerability index.
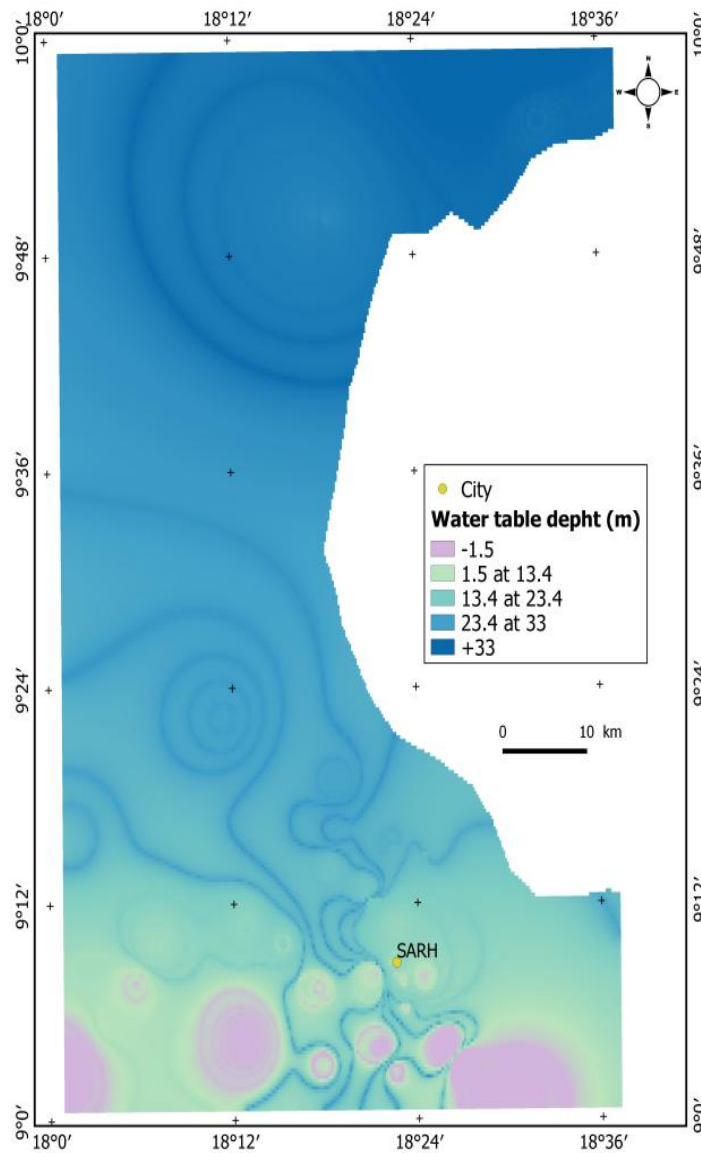

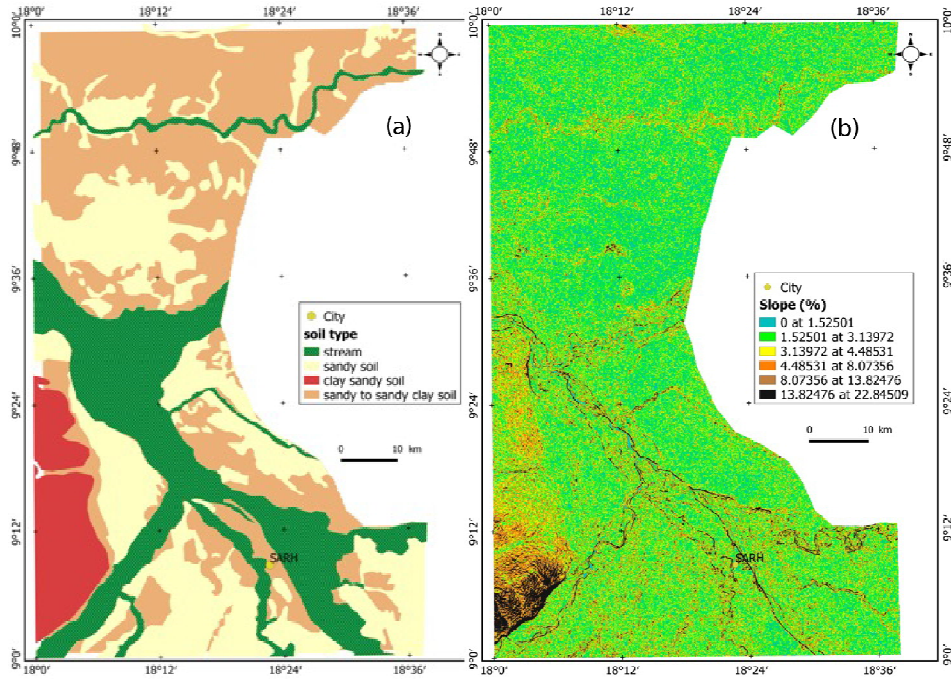**Fig. 2. Map showing depth of captured groundwater**

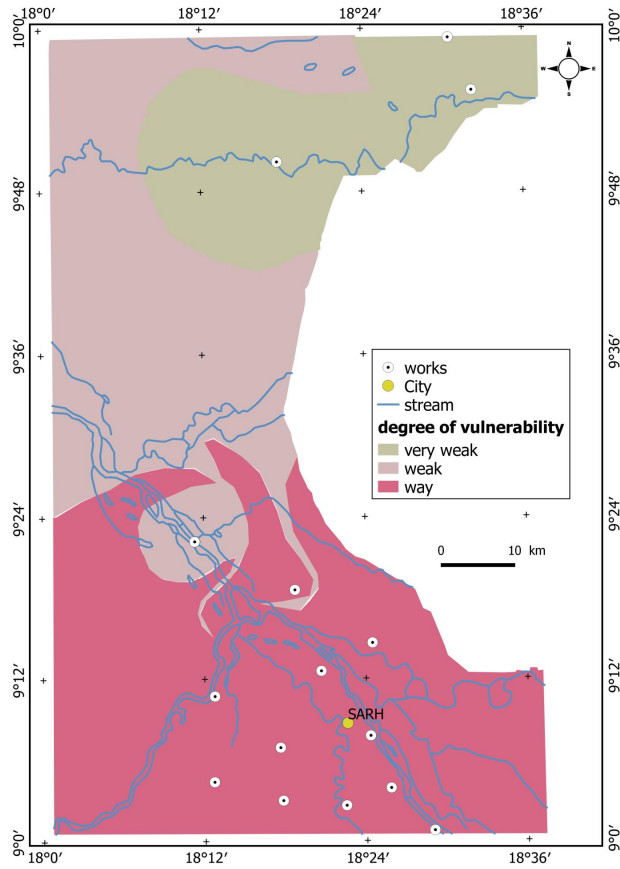**Fig. 3. Maps showing soil type (a) and topographic (b)**

Fig. 4. Vulnerability map of the study area

5. CONCLUSION

The vulnerability mapping study of the Sarh aquifer allowed the identification of areas sensitive to a contaminant or a group of contaminants. The final map produced by the DRASTIC method; highlights three classes of vulnerability whose distribution is as follows: 36% of the study area have very low vulnerability; 35% of the study area have low vulnerability; 29% of the study area have medium vulnerability.

This study demonstrates that DRASTIC is a good approach for assessing groundwater vulnerability in Sarh City. Although DRASTIC analysis requires a large amount of data, the results obtained are realistic and representative of the actual field situation.

The use of the DRASTIC approach deserves further study, as this combined approach can incorporate other factors, such as pollutant movement, pollution sources, etc., that are important in accessing the vulnerability of the area. As such, it would be wise for the communal authorities to take strong decisions to prohibit the development of uncontrolled sceptic tanks without authorization and to make the population aware of the need to preserve the resource.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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