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RESEARCH ARTICLE

ASSESSMENT OF THE VULNERABILITY OF GROUNDWATER TO POLLUTION IN N'DJAMENA (CHAD) USING THE DRASTIC INDEX METHOD

[1,*]ABDERAMANE Hamit, [1]KENGNI Lucas, [2]IDDO Ernest Sakamou and [2]NJUEYA Kopa Adoua

[1]Department of Geology, Faculty of Exact and Applied Sciences, University of N'djamena, P. O. Box 1027, N'djamena, Chad

[2]Department of Earth Sciences, University of Dschang, Po Box 67, Dschang, Cameroon

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ABSTRACT

N'Djamena, the capital city of Chad has been experiencing a rapid population growth and a fall in water resources for the past years. In order to preserve and protect these resources, this work aims at assessing the vulnerability of aquifer to pollution. The overall objective is to identify areas prone to high risk of contamination, no matter the type of pollutant is. The DRASTIC approach required the inclusion of data from different sources such as field campaigns, borehole data, DEM satellite image, geological and hydro-climatic data. Finally, a map illustrating the water vulnerability was developed based on the seven parameters required by this method. The water table is deeper as one moves away from the banks of the Logone and Chari rivers. The study area is mostly covered with recent deposits of clay and loamy clay. The slopes below 5% cover 98% of the area, indicating a greater potential infiltration of contaminants. While the aquifer consists only of fine-grained sand, almost impermeable surface layers, combined with low slopes, explain that water tends to stagnate on the surface after rainfall. The values of the DRASTIC index vary from 75 to 145 underscoring three vulnerability classes. However, the classes of high to average intrinsic vulnerability cover 61. 39% of the study area, located in the northwest and south-central part of N'Djamena. The level of vulnerability is strongly influenced by the depth values in this sector and the nature of the unsaturated area made up of compact clay materials.

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INTRODUCTION

For a few years, the conservation of the natural environment in general and the protection of water quality in particular, have become major concerns and key objectives in the development programs (El Asslouj *et al.,* 2007). UN (2014) provides that by 2025, close to 5 Billion people will live in regions where it is hard to meet all the fresh water needs. The African countries including Chad suffer too much from issues related to water quality, the reduction of the groundwater resources and the degradation of ecosystems. Indeed, in Chad, one person out of two does not have access to potable water (Doumnang *et al.,* 2006;Kadjangaba, 2007). Half of the children in Chad suffering from malnutrition do not have access to potable water and sanitation, thus ranking Chad at the 6th position of countries in dire need of water across the world. With more than one million inhabitants, N'Djamena has been witnessing a rapid population growth. Drinking water supply is secured by groundwater. Actually, people resort to wells because of their low income and/or the poor water supply network by STE (Water Supply Company). These wells are not hygienic and are exposed to various pollution sources especially in the outskirts of the city where many destitute live (Doumnang *et al.,* 2006; Kadjangaba, 2007). This disastrous situation entails harmful impact on the health, socio-economic and environmental levels and justifies the current activities in the developing countries (Kenmogne *et al.*, 2006). As such, it is necessary to design new strategies in order to have better criteria for the protection of groundwater against pollution threats in urban areas. This depends on the assessment of the vulnerability defined as the specific exposure to changes in the quality and quantity of groundwater due to natural processes and/or human activities (Civita, 1994; Gouaïda, 2008). It is within this framework that this study highlights the cartographic methods (DRASTIC) at the in-situ assessment of potential pollution risks in the city of N'Djamena.

Trial site

N'Djamena which is the administrative and political capital city of the Republic of Chad covers a surface area of close to 41,000 ha (Bichara, 2012). It is located on a marshy site, on the right bank at the junction of the Chari and Logone rivers.

****Corresponding author:*** **ABDERAMANE Hamit,**
Department of Geology, Faculty of Hard and Applied Sciences, University of N'Djamena, N'Djamena, Chad.

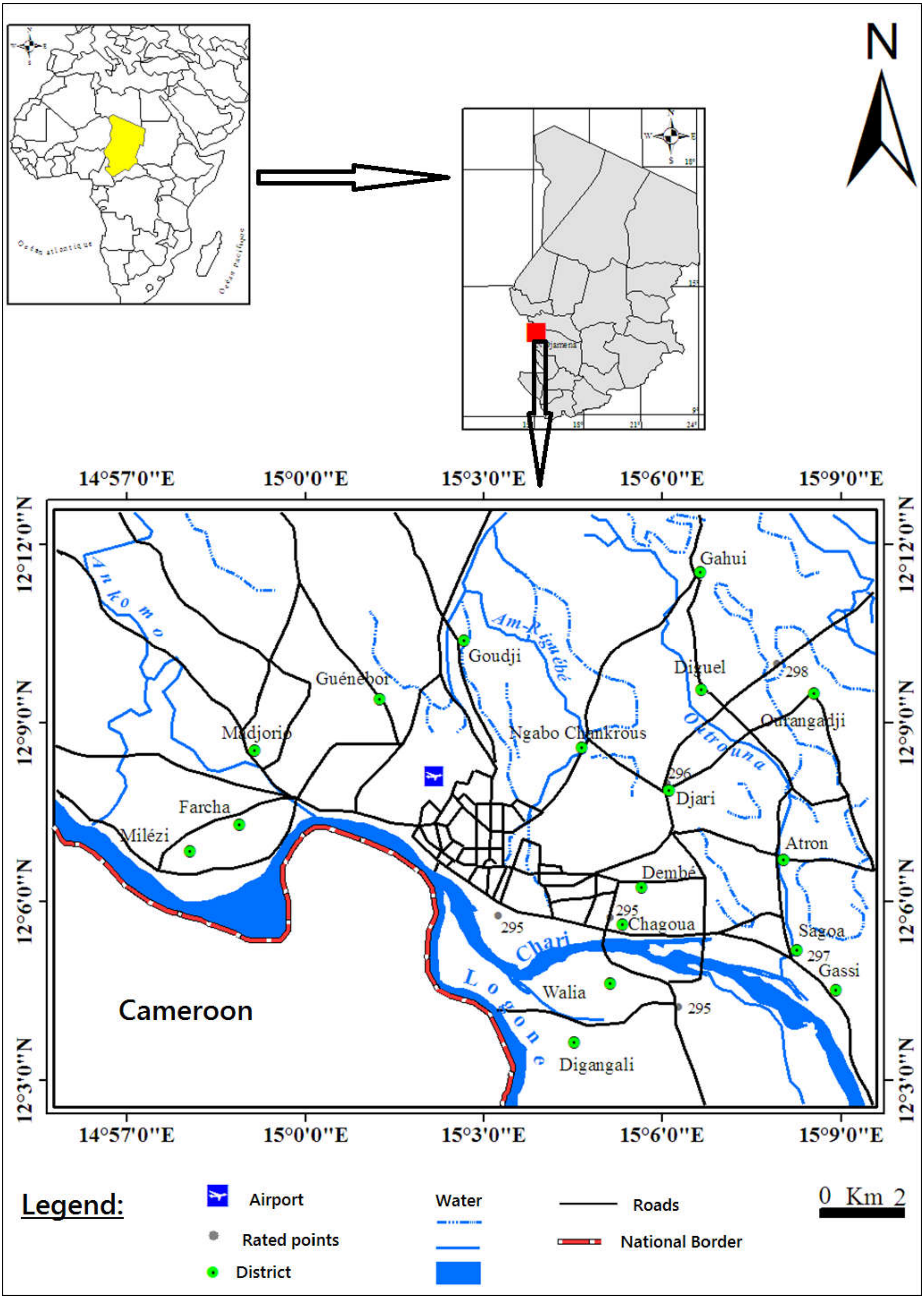

Figure 1. Location and topographic map of N'Djamena

Hydrography is sinuous as Chari and Log one are the major tributaries. Apart from these two rivers, three important seasonal water courses such as Am-Riguébé, Atrouna and Ankomo supplement the hydrographic network of the city (Figure 1). The city has a flat morphology (SDEA, 2003) with altitudes ranging from 290 to 305 meters. The topographic features include low altitude plains which hinder drainage and sanitation and cause floods. The climate is sudanese-sahelian with two seasons: a dry season from October to June and a three-month rainy season from July to September (Figure 2). The annual mean precipitations vary between 400 and 700 mm and are marked by more or less violent downpours. April and May are the hottest months of the year when the highest temperature is 45°C, and the coldest months include December and January when the temperatures go down until 19°C.

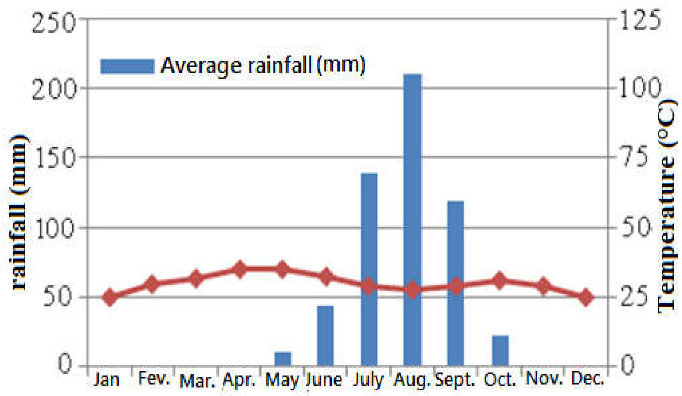

Figure 2. Ombrothermic diagram of N'Djamena (2010-2013)

According to Pias (1999), the major types of soil are hydromorphic and vertisols formed in the plains of piedmont on a series of Quaternary age. According to the second general census of the population and housing (INSEED, 2012), the city of N'Djamena has approximately 2 Million inhabitants, or nearly 17% of the Chadian population. This represents nearly 40% of the urban population of Chad. As an administrative and political capital city, N'Djamena is the most cosmopolitan city of Chad. Its economic activity is heterogeneous. The water resources are currently facing an increasing degradation due to numerous and different causes, which include, inter alia, the discharge of waste waters from households and industries (Doumnang *et al.,* 2006; Kadjangaba, 2007). These waste waters are usually poured in the environment (grounds, rivers, ponds) without preliminary treatment. In 2012, Chad counted 1,941,366 polluting structures including 19% in N'Djamena. The region of N'Djamena has close to 80 % of potential polluting structures (CBLT, 2014). During the wet period, there is a significant increase in the enrichment of the medium caused by the interflow of urban areas. This increase is about +84% and +144% as compared to the dry season. . The contaminations of wells and boreholes can be attributed to runoff and infiltrations in the water table (human and animal faeces, contact with waste water through runoff and/or infiltration, telluric germs brought by the winds).

MATERIALS AND METHODS

Description of the DRASTIC method\

The DRASTIC Method developed by EPA (Environmental Protection Agency) in the United States in 1985 and defined by Aller *et al.* (1987) is one of the most common and used methods around the world for the mapping of the specific vulnerability of an aquifer, applicable to both surface and ground water tables (Lallemand and Bars, 1994; Schnebelen *et al.,* 2002; Hamza *et al.,* 2008; AïtSliman *et al.,* 2009; Ake *et al.,* 2009). It is mainly used for the small-scale cartography (Lyakhloufi *et al.,* 1999; Dumoulin, 2010). "DRASTIC" is the Anglo-Saxon acronym including the initial hydrogeological parameters which influence the vulnerability of a water table, namely D: depth of the water table; R: net recharge; A: nature of the aquifer; S: nature of the soil; T: topographic slope of the ground; I: impact of the unsaturated area; C: permeability of the aquifer. These are physical features which play a role in the migration and mitigation of a contaminant within the complex soil-ventilated area-aquifer (Lallemand and Bars, 1994; BRGM, 1996; Sinan *et al.,* 2003; Fofana, 2005). This model rests on a traditional space analysis which is widespread in the GIS. The appropriate use of this methodology is supplemented by the setting up of a Geographic Information System which will be used not only for the digitalization but also for the superposition of the maps which will result from it (Figure 3). In the GIS, each parameter is noted on a layer by affecting it a coefficient corresponding to the weight of the parameter, i. e. its influence on the vulnerability of the water table. Then, these layers are superposed on a result layer where the DRASTIC index will be computed. The generated DRASTIC index (DI) is the sum of products of the weights and the scores allocated to the various layers which constitute the parameters taken into account in this methodology. It is defined by the following formula:

$$ID = \sum_{i=1}^{7} n_i p_i = n_D p_D + n_R p_R + n_A p_A + n_S p_S + n_T p_T + n_I p_I + n_C p_C$$

Where n and pare the scores and weights allocated respectively to each parameter (D, R, A, S, T, I, C).

The computed index represents a measurement level of the contamination risk of the hydrogeological unit to which it is attached. DRASTIC generates an index for the pollution potential of the groundwater resources. According to the DI, the specific vulnerability map enables to distinguish the classes according to the vulnerability level corresponding to the selected proportions. This index is spread out over intervals from 23 to 226 in the case of the standard version. It is higher when the water table is exposed to a potential contamination or pollution. Tables 1 and 2 define the number of classes and qualify their respective vulnerability levels according to the numerical value of the DRASTIC index according to various authors (Aller *et al.,* 1987).

Data used

A piezometric campaign carried out in May 2014 (Figure 4) and supplemented by data provided by the Directorate of Hydraulics of the Ministry of Livestocks and Hydraulics enabled to have real values of the depth of water. The recharge values issued by Kadjangaba (2007) state that the recharge of the water table in the city of N'Djamena ranges between 4 and 17mm/year. Based on the lithological profile of different boreholes developed in the study area, the nature of the aquifer was identified. The data collected from the profile of boreholes, wells and the soil map of Chad on the 1/1. 000. 000 scale enabled to define the nature of the soil. Thanks to the DEM satellite images provided by the Management of the project PADUR, the values of slopes were computed. As concerns the hydraulic conductivity, the aquifer of the study area is made up of mean sands.

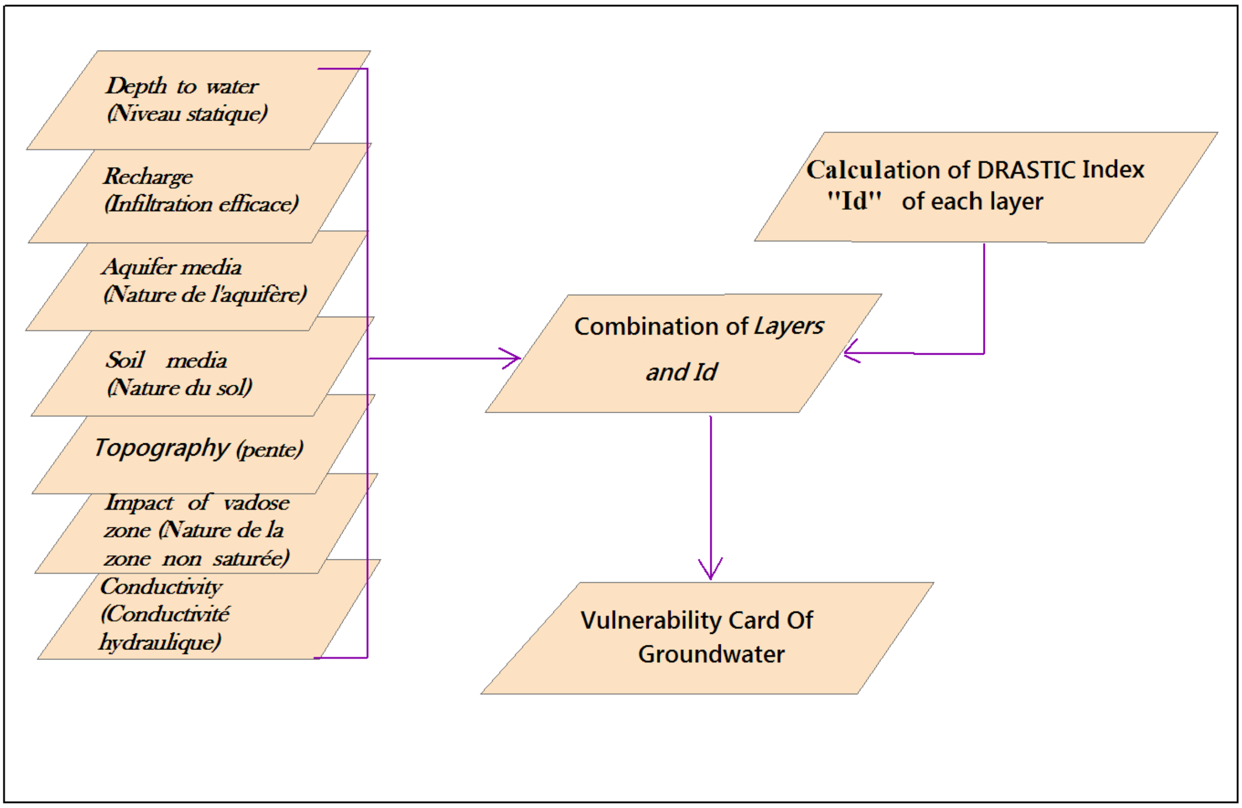

Figure 3. Methodology of the design of the vulnerability map of ground waters

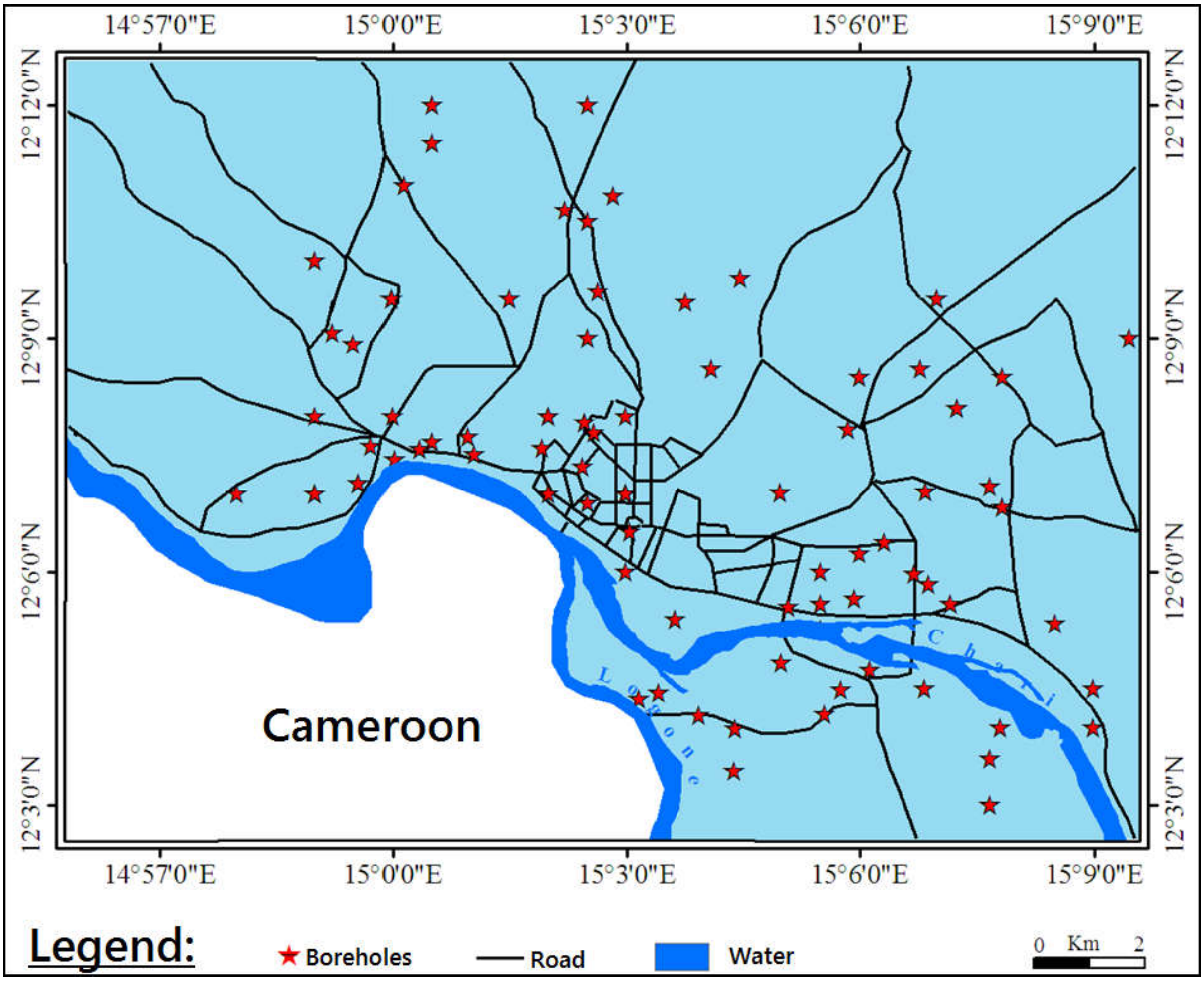

Figure 4. Distribution map of boreholes

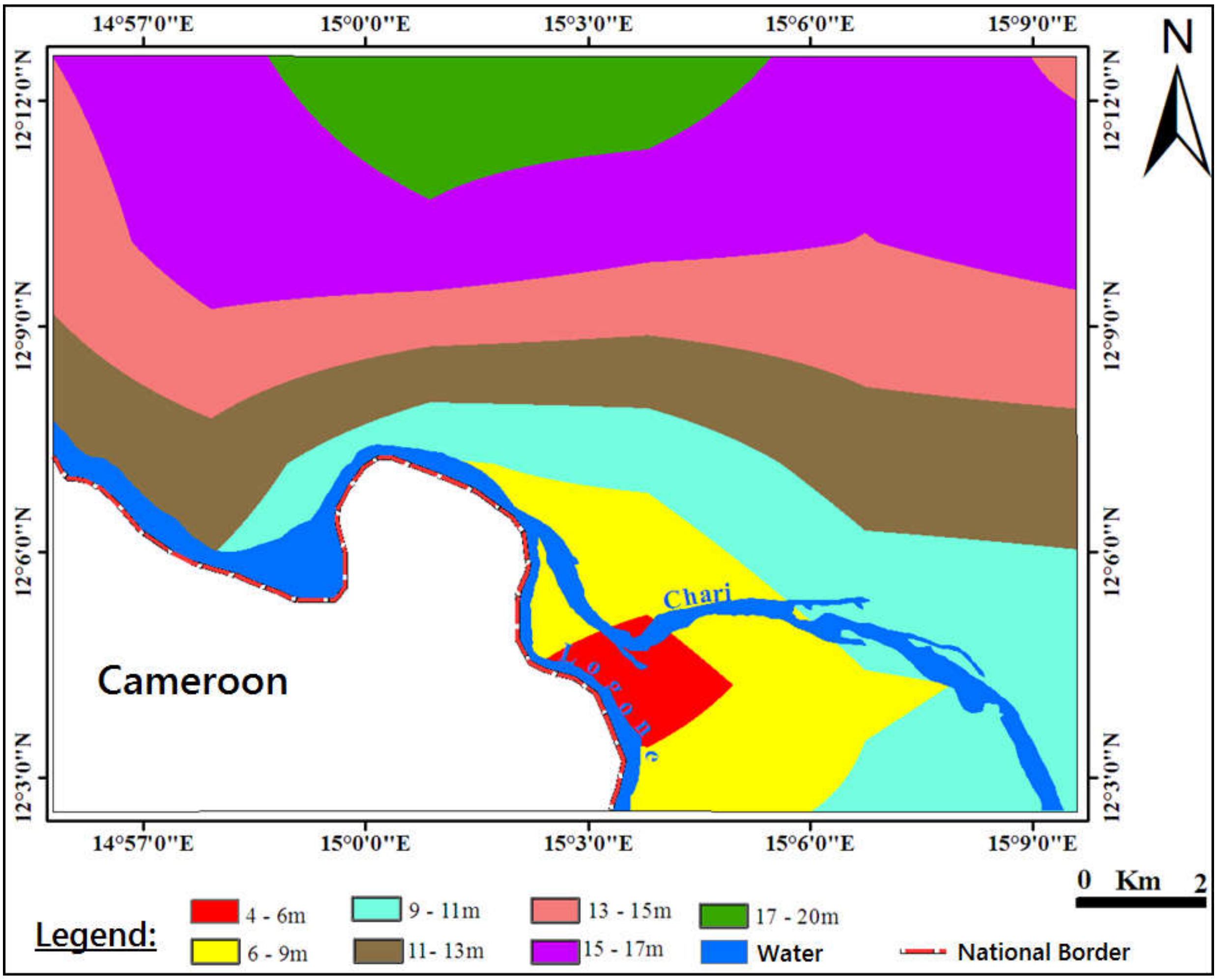

Figure 5. Water depth map of N'Djamena

The value of the standard permeability of mean sands which is 6 10^{-4} m/s (Castany, 1982; Hamit, 2012) was selected for the distribution of this parameter. The thematic maps were obtained by kriging under ArcGis for the spatial distribution of the various parameters.

RESULTS AND DISCUSSION

Table 3 summarizes the properties and values of each parameter as well as the typical weight and scores allocated to it, highlighting its influence on the DRASTIC vulnerability index. The water level is generally low in the boreholes. It varies from 4. 4m to 20.1m, and increases as one moves away from the banks of Logone and Chari rivers. South to North (Figure 5), it corresponds to seven subclasses for the study area, which is summarized in three classes of the method (table 1). This low depth near the two water courses causes the interaction with the ground waters (during the floods) and facilitates their contamination. The study area is mostly covered with recent Quaternary deposits (Figure 6). They are mainly composed of the loamy clay soils (45. 59%) and the clay soils (37. 85%). In parallel, there are sandy-clay soils (9. 1%) and sandy soils (9. 33%) along the banks of the Chari river. Thus, the study area consists of semi-impermeable formations except the former major river beds of Chari which are made up of sandy formations. The study area is characterized by light slopes due to its location in an alluvial plain (Figure 7). The slopes lower than 5% occupy 98% of the surface paving the way for a greater infiltration potential of contaminants/a huge vulnerability to contamination.

The light slopes (0-2%) constitute the dominant entity, occupying approximately 75% of the study area. The steep slopes (higher than 12%) account for only 2% of the study area. This class is generally located on the banks of river courses and results from the erosion attributed to floods. Those which are observed beyond/inside would be small quarries used to manufacture bricks.

Table 1. Assessment criteria of the vulnerability using the DRASTIC index (ALLER *et al.*, 1987)

Vulnerability DRASTIC index	Vulnerability level
< 80	Very low
80 – 120	Low
121 – 160	Medium
161 – 200	High
> 200	Very high

Table 2. Assessment criteria of the vulnerability using the DRASTIC index

Vulnerability DRASTIC index	Vulnerability level
< 101	Low
101 – 140	Medium
141 – 200	High
> 200	Very high

The unsaturated area consists of two types of materials: sandy clays and compact clays (Figure 8). The sandy clay material (48. 75%) is available along the Chari river from the SE to NW parts while the compact clay material (51. 25%) extends on both sides of this river from Center-south to the North-Eastern part of the study area.

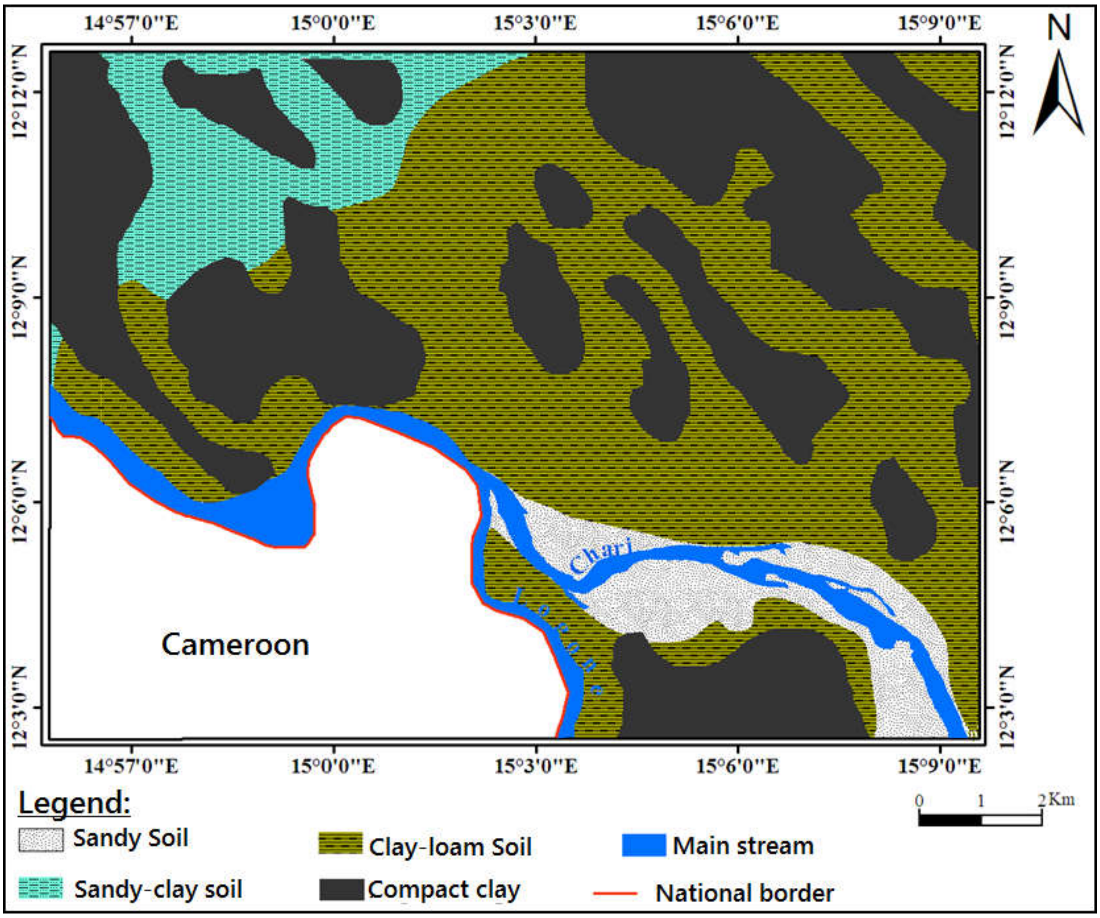

Figure 6. Soil map of N'Djamena

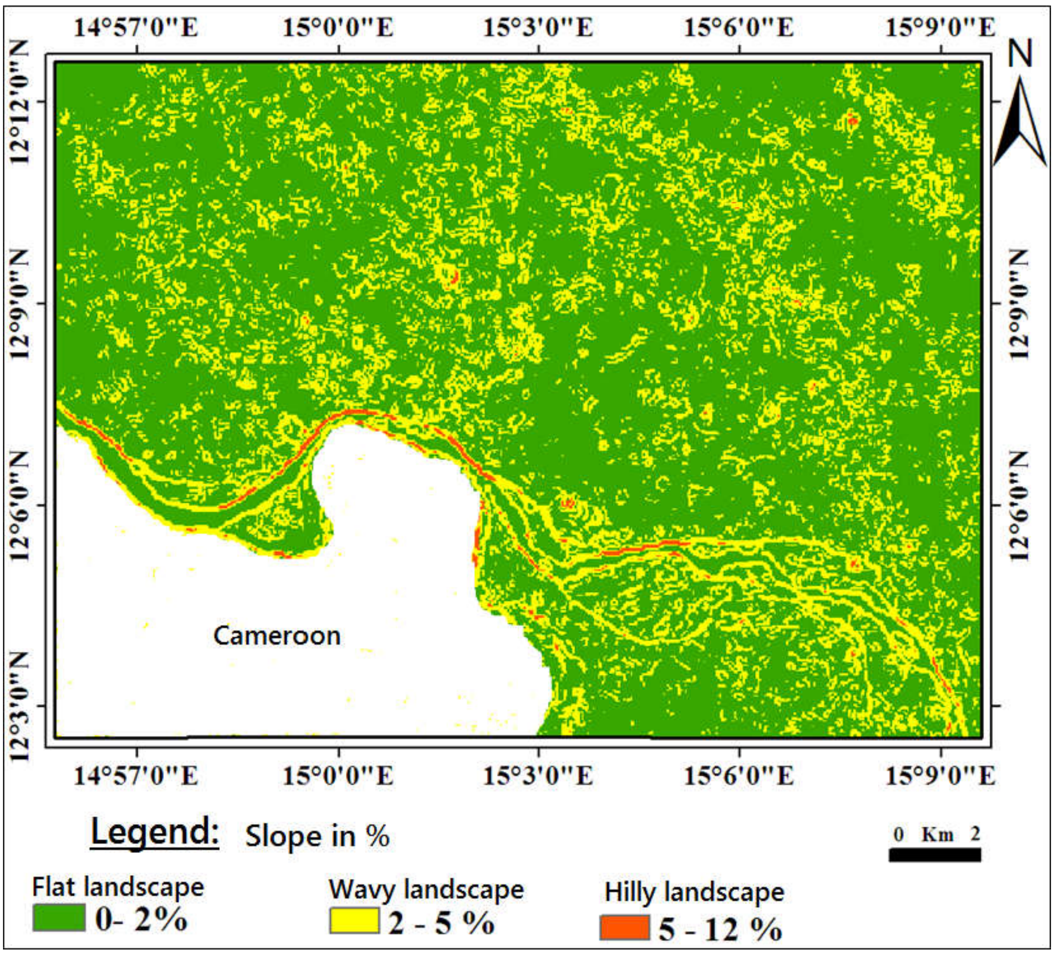

Figure 7. Slope map of N'Djamena

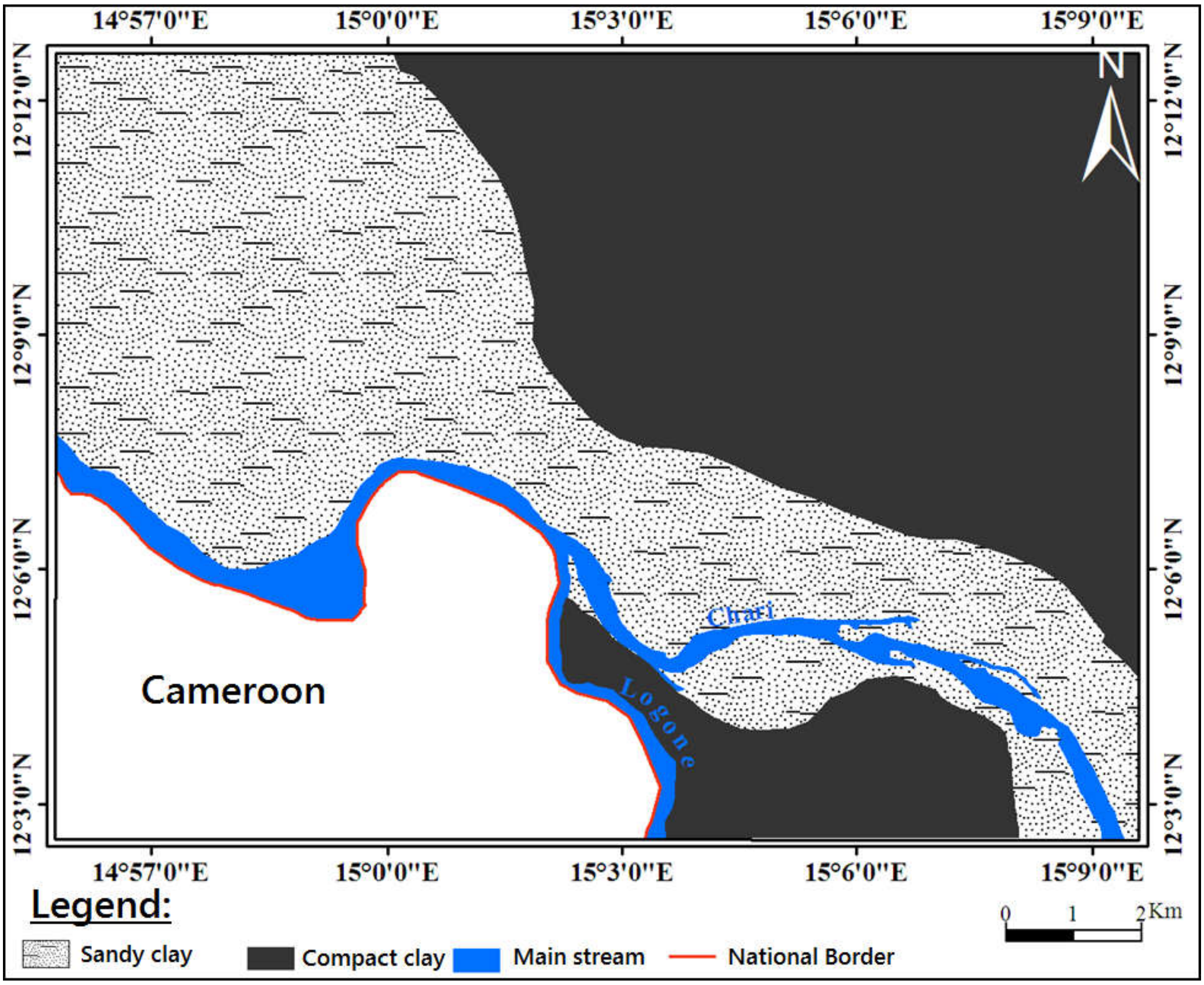

Figure 8. Map of the unsaturated area

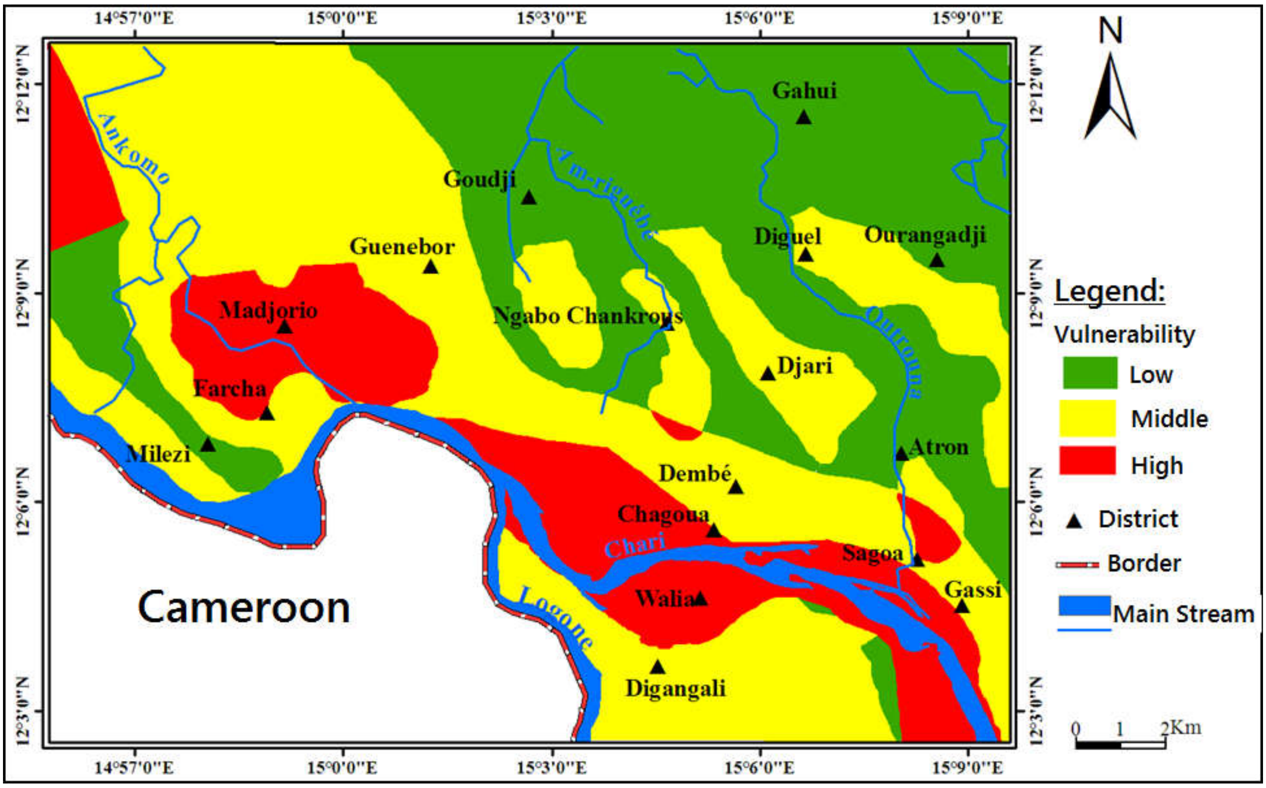

Figure 9. Specific vulnerability map

Table 3. Parameters and their input to the DRASTIC index in the study area

Parameters	Values	Scores (n)	Weight (p)	Id
Depth (m)	4.4-6.7	7	5	35
	6.7-8.9	7	5	35
	8.9-11.1	5	5	25
	11.1-13.4	5	5	25
	13.4-15.6	5	5	25
	15.6-17.9	3	5	15
	17.9-20.1	3	5	15
Recharge (mm)	4-17	1	4	4
Nature of the aquifer	Medium sand	8	3	24
Type of soils	Loamy clay	3	2	6
	Sandy clay	5	2	10
	Compact clay	7	2	14
	Sand	9	2	18
Slope	0-2%	10	1	10
	2-5%	9	1	9
	5-12%	6	1	6
Nature of the	Sandy clay	6	4	24
material	Compact clay	1	4	4
Conductivity (m/s)	6.10^{-4}	8	4	32

Id : Partial index

These impermeable surface formations could explain the stagnation of water for several days following rainfall. The aquifer environment is only constituted of mean dimension sand. Depending on the nature of various superposed materials and their respective scores, the values of the DRASTIC Index (DI) vary from 75 to 145, corresponding to low and high vulnerabilities. They enable to define three classes corresponding to three of the four different areas of specific vulnerability as gathered in table 2. The low vulnerability class consists of DRASTIC indexes between 75-100. This class accounts for 37. 85% of the area (Figure 9). It is located in the North-Eastern part of the area. This could be due not only to the values of average depth of this sector, but also to the fact that in this part, the unsaturated area comprises the compact clay materials which could slow down the migration of pollutants towards the aquifer. These areas contain some corners where the vulnerability rises to the average degree. The mean vulnerability class includes the portions of maps of which DI ranges from 100 to 140. It accounts for 45. 59% of the area. This class covers most of the North-western and South-eastern part of the area. In these areas, apart from the values of low depths of water, the sandy clay nature of the unsaturated area more permeable than the preceding one, would be the cause of the increase of DI. These areas have huge vulnerability corners. They are defined by layers of which DI is higher than 140. This class which is slightly represented (16. 80% of the area) covers the shoreline of the Chari River. It probably results from the low depth of water along this river and the sandy clay nature of the unsaturated area, especially the connection between the surface and groundwaters. The classes of specific high vulnerability can be favorable to the infiltration of any contaminant found on the surface to the aquifer because of the human activities. These two classes cover 61. 39% of the study area and require a special attention in terms of making decisions on the use of land.

Conclusion

As we are discovering the environmental benefits, the protection of water resources, especially the groundwater resources should be part of the activities of land managers. The DRASTIC method enabled to characterize the vulnerability of the water table in N'Djamena. The key factors of this vulnerability include the depth of water and the nature of the unsaturated area. The DI enabled to distinguish three vulnerability levels. The vulnerability level of groundwater to pollution ranges from medium to low. The map drawn afterwards is instrumental in the control of sanitation systems. Although the high vulnerability class accounts for only 16.80% of the study area, the risk is significant considering the presence of several pollution sources in the city. The vulnerability of the medium and low classes which account respectively for 45.59% and 37.85% of the mapped surface can evolve as a result of human activities. However, in spite of the slightly vulnerable nature of the study area, the measurement campaign of pollutants would be necessary in a bid to check the accuracy of the related map. Although it is hard to thoroughly protect the groundwater resources from potential contamination sources, the contaminations can be minimized by prioritizing preventive actions through harmonized actions such as the regular monitoring of the water table, the systematic control of surface activities, the protection of identified vulnerability areas, the sensitization of managers of industries and other productive sectors on the prevention of contamination.

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