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Seasonal Assessment of Aquifer Vulnerability to Pollution in Garoua Using G.O.D Method

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ABSTRACT

The increase in population, urbanization and agricultural activities in Garoua, can lead to deterioration of water resources in Garoua. This study aimed to determine the vulnerability of the Garoua aquiferous formations to pollution. The acronym of G.O.D is; groundwater confinement (G), overlying strata (O) and depth to groundwater (D). The results of GOD vulnerability indices for various seasons are: 0.34 - 0.72 Wet, 0.32 - 0.68 Wet-Dry, 0.28 - 0.64 Dry and 0.32 - 0.7 Dry-Wet. The study area is classified G.O.D indices into four vulnerability classes with seasons: Low (0.6%), moderate (16.5%) and high (82.9%) in Wet season; Low (23.2 %) and high (76.8%) Wet-Dry season; Low (1.7%), moderate (30.5%) and high (67.8%) in the Dry season; Moderate (15.2%), high (79.9%) and extreme (4.9%), Dry-Wet season; High vulnerability to pollution occurs in all seasons with the extreme class in the dry season. High to extreme vulnerabilities occur due to low depth to water table and the high permeability that allow easy infiltration of dissolved pollutants. During the Wet season water is available, thereby increasing the pollution opportunity to carry pollutants into the aquifers while in the Dry season there is water scarcity that increases demand and the stress on the aquiferous formations. This study serves as a blueprint to enable stakeholders exploit, monitor and manage groundwater resources in the aquiferous formations in Garoua.

Keywords: *Aquifer-vulnerability; pollution potentials; G.O.D method; GIS; Garoua*

1. Introduction

The increasing population, urbanization, industrial activities and creation of large scale agro industrial farms in this part of the North region creates point and non-point source of pollution in the Aquiferous formation in the Garoua basin.

Aquifer vulnerability is defined as the tendency of contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer (Worrall and Besien, 2005; Rahman, 2008; *Bai et al.,* 2011). It is a function of the geologic setting of an area, as this largely controls the amount of time, i.e. the residence time of the groundwater that has passed since the water fell as rain, infiltrated through the soil, reached the water table, and began flowing to its present location (Prior *et al.,* 2003). Groundwater is a valuable resource in Garoua and is also the main source of drinking water hence its vulnerability assessment in delineate areas that are more susceptible to contamination is very important (Ighbal *et al.,* 2014). However groundwater dynamics reflects the response of the groundwater system to external factors such as climate condition, water storage, groundwater consumption, and other human activities (Minville *et al.,* 2010). Infiltration of industrial and urban wastewater can recharge groundwater, but can also pollute aquifers used for potable supply (Oiste *et al.,* 2014).

Groundwater is considered as an important source of water supply due to its relatively low susceptibility to pollution compare to surface water. Groundwater quality is usually subject to contamination especially in agriculture-dominated areas having intensive activity involving the use of fertilizers and pesticides.

Vulnerability assessment has been recognized for its ability to delineate areas which are more easily contaminated than others as a result of anthropogenic activity on/or near the earth's surface (Mendoza and Barmen, 2006).

In any given area, the groundwater within an aquifer, or the groundwater produced by a well, has some vulnerability to contamination from human activities (Rahman, 2008). Vulnerability studies can thus provide valuable information for stakeholders working on preventing further deterioration of the environment (Mendoza and Barmen 2006). The process of water degradation, although very slow, can have serious effects (Baghvand *et al.,* 2010), especially on human health.

There are two classes of vulnerability, intrinsic vulnerability, which depends exclusively on the properties of the groundwater system, and specific vulnerability, where these intrinsic properties are referenced to a particular contaminant or human activity. Vulnerability assessment is based on the expected travel time for water to move from the ground surface to the water table. The greater the travel time, the greater are the opportunity for contaminant concentration and further subdivided into broad classes like very high, high, low and very low, depending upon the governing criteria.

Aquifer vulnerability assessment can be done using different tools and techniques, such as DRASTIC (Aller *et al.*, 1987), SINTACS (Van Stempvoort *et al.*, 1993) and GALDIT (Chachadi and Lobo-Ferreira, 2001) methods. This study used the G.O.D method for the assessment of the aquiferous formation to pollution. This approach was made by taking advantage of GIS software which permitted the compilation of geospatial data, to compute G.O.D index, and to generate the final vulnerability map.

Few works have been done on groundwater quality in Garoua (Njitchoua, 1997), but all of these works concentrated on the groundwater chemistry. No work has been done on pollution potentials of the aquifer, thereby making this study of great value. This paper aims to assess aquifer vulnerability to pollution of Garoua using GOD method.

1.2 Description of study area

Garoua covers a total surface area of about 4,700 km^2 (Fig. 1). Groundwater is the major source of water. It is characterized by a tropical climate having a dry season from October to April and a rainy season from May to September. The mean monthly temperatures vary from 26.1 °C in December-January to 32.7°C in April, with a mean annual value of 29°C. This area is characterized by mean annual precipitations of 1018mm and the mean annual potential evapotranspiration is 1855mm.

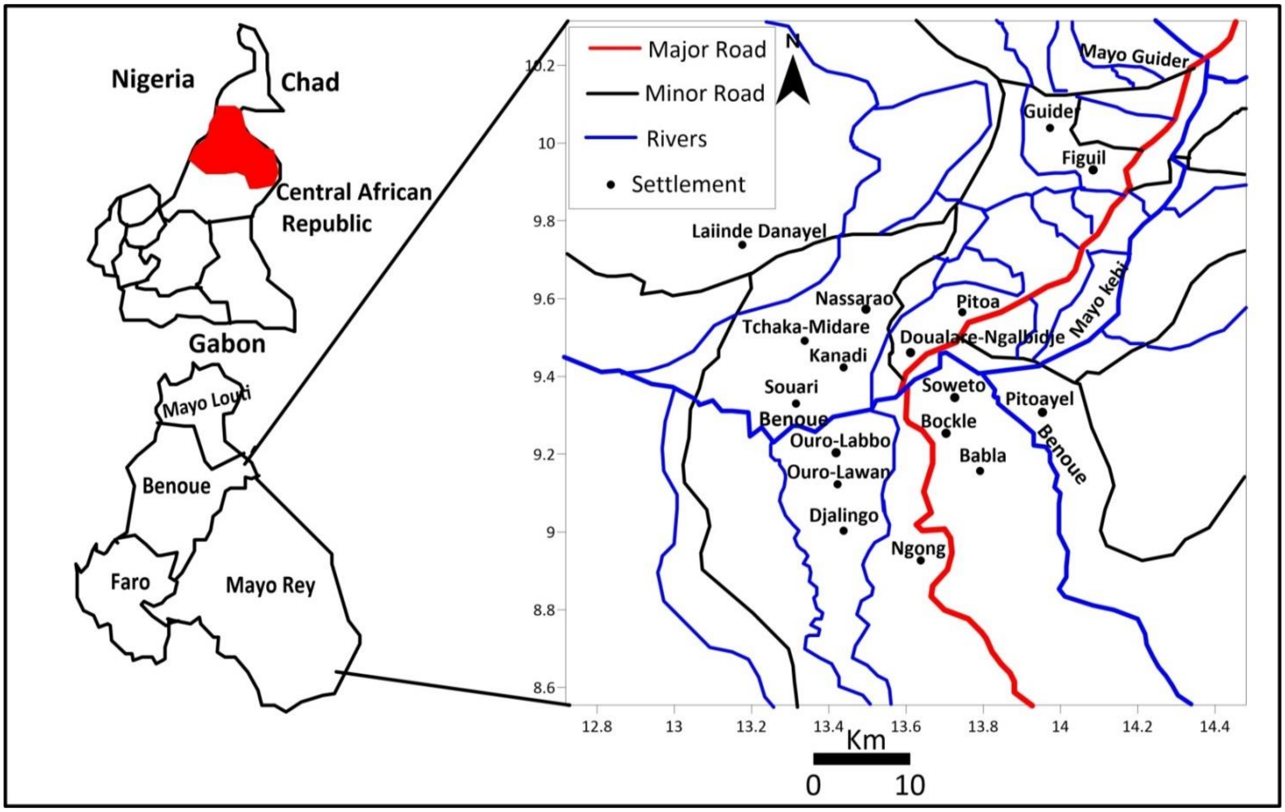

Fig. 1 Garoua and environs (insert Cameroon and Northern Region with four Divisions)

1.3 Geological settings of the Garoua Basin

The Northern region of Cameroon belongs to the mobile zone of Central Africa. This mobile zone is situated between the Western African craton and the Congo craton. The Benue trough is one of the most interesting sedimentary basins of West Africa because of the tectonic movements that account for the marine and continental sediments found there, and also because of the presence of volcanism and the intrusion of plutonic rocks. This trough is directed NE-SW and extends a distance of about 1000 km, with a width of 50–150 km (Moïse et al. 2018). It consist a great part of the sedimentary basin of North Cameroon, including the Garoua basin. Its origin is related to the opening of the South Atlantic during the Cretaceous, which led to the separation of the African and South American continents (Guiraud and Maurin, 1992). It is made of the sedimentary marine, continental series and is divided into three parts: the low, middle and high Benue. The high Benue includes the Gongola rift and the Yola-Garoua rift. The Yola-Garoua rift extends into Cameroonian territory and is directed E-W while the Gongola rift goes to Niger and is directed N-S. The area of this study (Figure 1) is situated in the Cameroonian territory of the Benue rift (Yola Garoua branch) and especially in the formation known as Garoua sandstone. Its base is made up of two great lithological sets which underwent a metamorphic and tectonic evolution. The Garoua basin is an intracratonic basin and part of the Benue Sedimentary Basin that was formed during the opening of the Gulf of Guinea. It is the eastward continuation of the Yola arm of the northern Benue Trough of Nigeria into the north Cameroon.

The Benue trough is a NE-SW trending basin that spans from the Niger delta basin to Lake Chad. The trough strikes approximately NE–SW and is about 1000 km long and 100 km wide. This basin was formed over the Berremian-Aptian age and it is the biggest of a series of basins formed in northern Cameroon and south-western Chad at this time bounded to the north by the Mokolo Plateau and the south by the Adamawa Plateau. The structures are asymmetrical syn-sedimentary synclines superimposed on half-graben structures (Eyike *et al.,* 2010). This basin-like many other sedimentary basins that belonged to the West and Central African Rift System is believed to have potential for hydrocarbons generation and accumulation. The Garoua basin is an E-W to N120 trending trough that is filled by Middle to Upper Cretaceous marine sandstones (Serge *et al.,* 2019). The Basin is filled by continental sediments of Middle to Upper Cretaceous age. The bedrock is made up of igneous and metamorphic rocks of the basement complex, and volcanic rocks of the Tertiary age. This formation is characterized by sandstone sequences which are intercalated by clayey layers. X-Ray diffraction analyses carried out by Njitchoua and Ngounou-Ngatcha, 1997 indicated that the sandstones are dominated mainly by quartz, feldspars, and kaolinite, but also include minor amounts of illite and calcite. The Garoua Sandstone formation is overlain by quaternary alluvial deposits of the Benue River and its tributaries, which are made up mainly of gravel, sand, silt and clay (Njitchoua *et al.,* 1997).

The dominant sedimentary facies in Garoua are indurated conglomeratic to coarse-grained alluvial sandstones with siliceous cement often rich in iron oxides and in some localities numerous intercalations of reddish ferruginous sandstones are seen. The depth of the basement is 4.4 km to 8.9 km. This represents the thickness of the sedimentary formation overlying the basement complex. Western parts of the basin exhibits numerous volcanic necks of the Cenozoic age while veins of basic rocks are outcrop to the east. The Garoua basin has outcrops of sandstone and intrusive granites, which form the basement complex below the sediments, and intrusive diorites along the Poli-Lere axis. Some hypo volcanic dykes are found within the Garoua sandstones (Fig. 2). The basaltic lavas of this area are similar to those of the Cameroon volcanic line

The Precambrian gneisses, migmatite, and schist outcrop in the southern part of Garoua Basin with an extension of the gneisses to the northeast. The intrusive granites outcrop extensively in the Garoua Basin in the northeast and southwest. These rock units from the basement complex below the sediments are referred to as the gneissic-granitic basement. Intrusive diorites also occur along the Poli-Lere axis (Poudjom *et al.,* 1992).

The regional structural setting of the Garoua Basin is characterized by three major normal faults striking mainly in the NW-SE to NNE-SSW direction (Mouzong *et al.,* 2014). The continental crust underneath the basin (about 24 km) is thinner than the normal crust, but may be a little thicker to the east (Serge *et al.,* 2019). This thinning of the crust is due to extensional regional stress and the uplift of the Asthenosphere is as a consequence and this result to isostatic compensation, this lead to an average sedimentary pile thickness of about 6km from results obtained by Kamguia *et al.*, (2005) and Mouzong *et al.*, (2014).

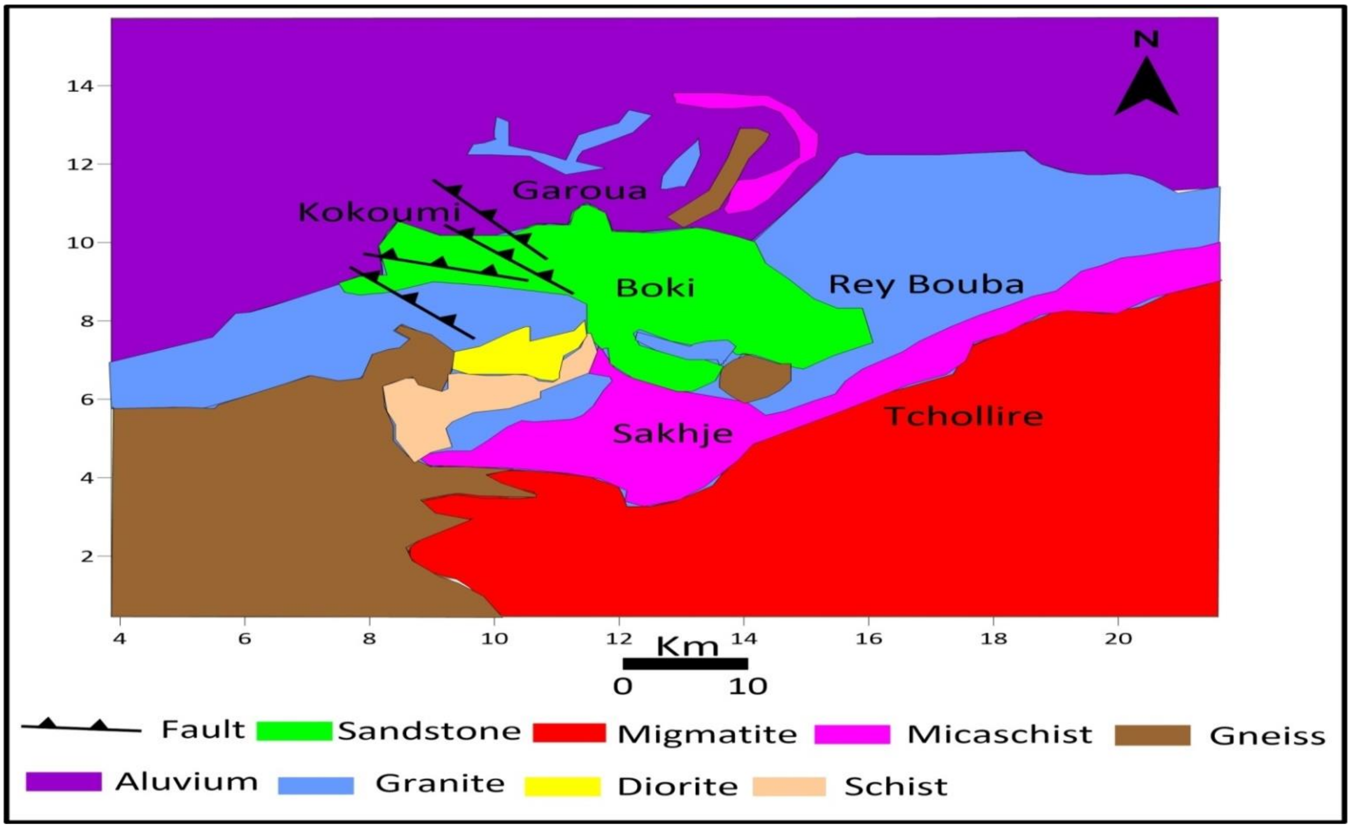

Fig. 2 Geology of Garoua basin (modified after Poudjom *et al.,* 1992)

1.4 Hydrogeology

The Garoua basin has two aquifers; (1) The Garoua alluvial aquifer which is extensively utilized for water supply through hand-dug wells; it is of limited lateral extent. Aquifer tests results indicate that transmissivity in the upper part of the aquifer varies between 10^{-1} and 10^{-5} $m^2 s^{-1}$ and the hydraulic conductivity ranges from 10^{-4} to $10^{-5} ms^{-1}$ (Njitchoua and Ngounou-Ngatcha, 1997). Groundwater mainly occurs under water-table conditions. (2) The Garoua Sandstone aquifer with a permeability of around 8 to 80 m/day; transmissivity of 300 to1700 m²/day; and a storage coefficient of 0.025. Typically boreholes are between 40 and 200 m deep. According to (Njitchoua *et al.*, 1997), the Garoua Sandstone aquifer constitutes the most extensive aquifer in the Garoua basin. The thickness of Garoua Sandstone aquifer increases towards the central part of the basin. The crystalline bedrock acts as boundaries of the groundwater reservoir. The presence of many lenses of clay within the sandstone sequences imposes local confinement. The natural hydraulic gradients are low, owing to the low topography of the basin. The groundwater flow is generally towards the Benue River. Recharge is through precipitation. The discharge of groundwater takes place by evapotranspiration wherever the water table is closer to the land surface, by the Benue River and its tributaries, and by several boreholes tapping the water reservoir.

2.0 Materials and Methods

2.1 Materials

The field materials and equipment used in the study are listed in Table 1.

Table1. Field Equipment, Specifications and Functions

Equipment/Softwares	Specifications	Functions
Bike	Commercial bikes (Bensikin)	To transport fieldworkers to wells
GPS	GARMIN GPSMAP 60CSx	To measure longitude, latitude and elevation of wells
Triameter		To measure pH, EC, TDS, Temp of water.
Water level indicator	Solinst Model 102M	To indicate static water levels of water in wells
Measuring Tape	Weighted measuring tape	Measurement of well diameter and depth.
ArcGIS	Version 10.1	GIS Drawing sampling/Tests location maps
Global Mapper	Version 15	GIS Geolocation of wells
Surfer Golden Software	Version 12	GIS plotting contours for spatial distribution

2.3 Methods

GOD model was chosen to assess aquifer vulnerability in Garoua due to: The availability of data on the aquifer characteristics as well as the characteristics of the wider geological and hydrological environment and equipment. Each parameter has been assigned a rating that ranges from 0 to 1 (Table 2), depending upon the contribution of the parameter in defining the degree of vulnerability. The final index is obtained from the formula:

G.O.D= GR× OR× DR (Foster, 1987)

G=groundwater confinement, O=Overlying strata, D=depth to groundwater, R=rating of parameters

The acronym GOD is:

Groundwater confinement (G): The type of aquifer was determined based on subsurface conditions obtained from the results of the drill log and seasonal temperature variation. The temperatures are similar with seasons which are indicative of unconfined aquifers (Akoachere et al., 2019). Determining the values for unconfined aquifers is based on the characteristics of unconfined aquifers which have a tendency to be closer to the surface.

Overlying strata (O): The overlying strata were determined based on subsurface conditions which are obtained from the results of the drilled logs. The research area has aquifer lithology types consisting of sands, gravel and Clays.

Depth to groundwater (D): The Depth to groundwater (D) represents the depth of material from the ground surface to the water table through which a contaminant travels before reaching the aquifer (Aller *et al.,* 1987; Babiker *et al.,* 2005). Depth of groundwater was calculated by the difference between surface elevation and water table elevation. The surface elevation data was taken from digital elevation model (DEM) and the water level map was obtained by field measurements of water levels using the Solinst meter.

G.O.D index vulnerability map was created via overlapping of groundwater confinement, overlying strata and depth to groundwater using Surfer V 12 software.

3.0 Results

3.1 GOD Method: Parameters and Ratings

The level of vulnerability of groundwater in Garoua was determined by analysis using the GOD method. The parameters used include the type of aquifer, type of lithology, and depth of groundwater. Parameters of aquifer type and aquifer lithology type were obtained from the results of the drill logs and the depth parameters of groundwater obtained from the results of hydrogeological mapping.

Table 2: Rating values of the vulnerability parameters for G.O.D method for the study area

Parameter	Range	Rating
G (groundwater confinement)	Unconfined Aquifer	1
O (overlying strata)	Sands	0.7
	Gravel	0.5
	Clays	0.4

D (depth to groundwater)	<5 m	0.9
	5-20 m	0.8

3.1.1 Groundwater confinement

The type of aquifer is one of the parameters used in the analysis of the level of vulnerability of groundwater. The groundwater was determined based on subsurface conditions obtained from the results of the drill log and seasonal temperature variation. The temperatures are similar with seasons which are indicative of unconfined aquifers (Akoachere *et al.*, 2019) as in figure 3, thus the type of aquifer in Garoua consists of unconfined aquifers. This aquifer was given a rating value of 1 in the G.O.D classification as in Table 2.

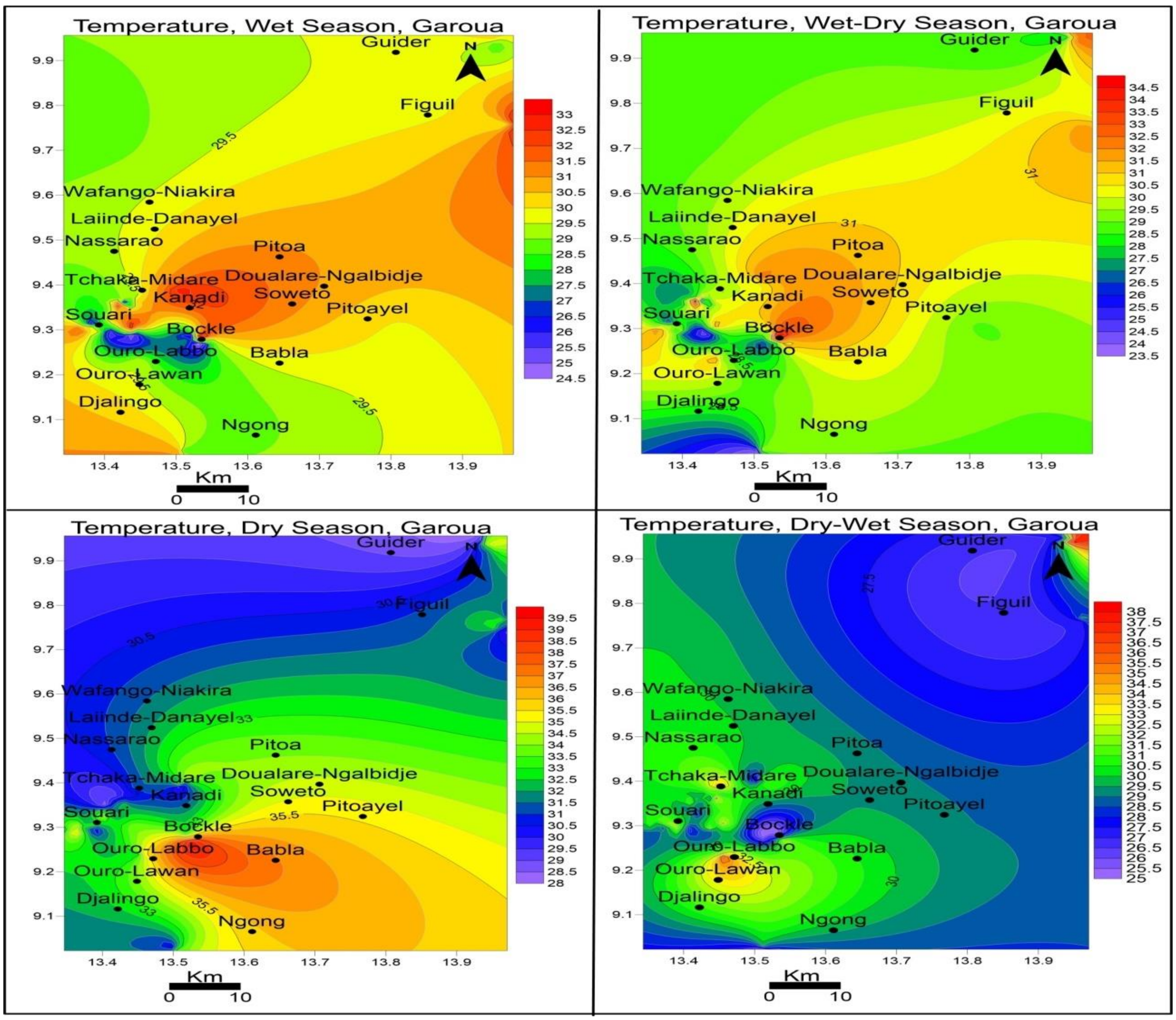

Fig. 3 Garoua groundwater temperature for four seasons; groundwater temperatures are similar which is indicative of unconfined aquifers.

3.1.2 Overlying strata

Overlying strata describes the type of materials present in the unsaturated zone above the aquifer, in keeping with their ability to neutralize contaminants. The research area has aquifer lithology types consisting of sands, gravel and Clays. Determining the rating of aquifer lithology type is adjusted by referring to the G.O.D classification which can be seen in table 2. Based on the classification value of G.O.D Overlying strata have values of 0.4-0.7.

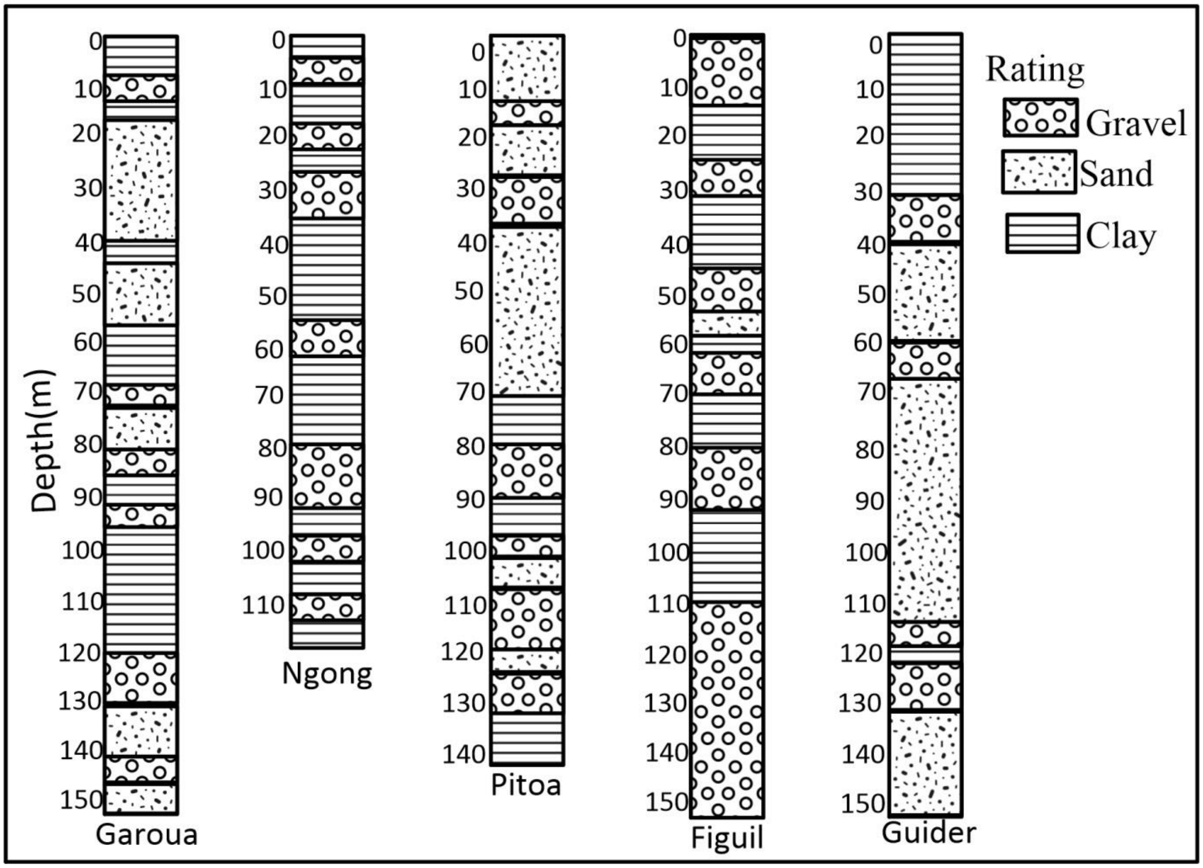

Fig. 4 Borehole lithologic logs from Garoua showing the major lithological distribution

3.1.3 Depth to groundwater

The depth of groundwater is one of the parameters used to analyze the level of vulnerability of groundwater. The data of groundwater depth is obtained from the measurement of the dug wells in Garoua. The more shallow groundwater level, the greater the value of vulnerability to pollution. Determining the groundwater depth value is adjusted by referring to the GOD classification. Table 2 indicates GOD rating values for the various hydrogeological settings in the study area.

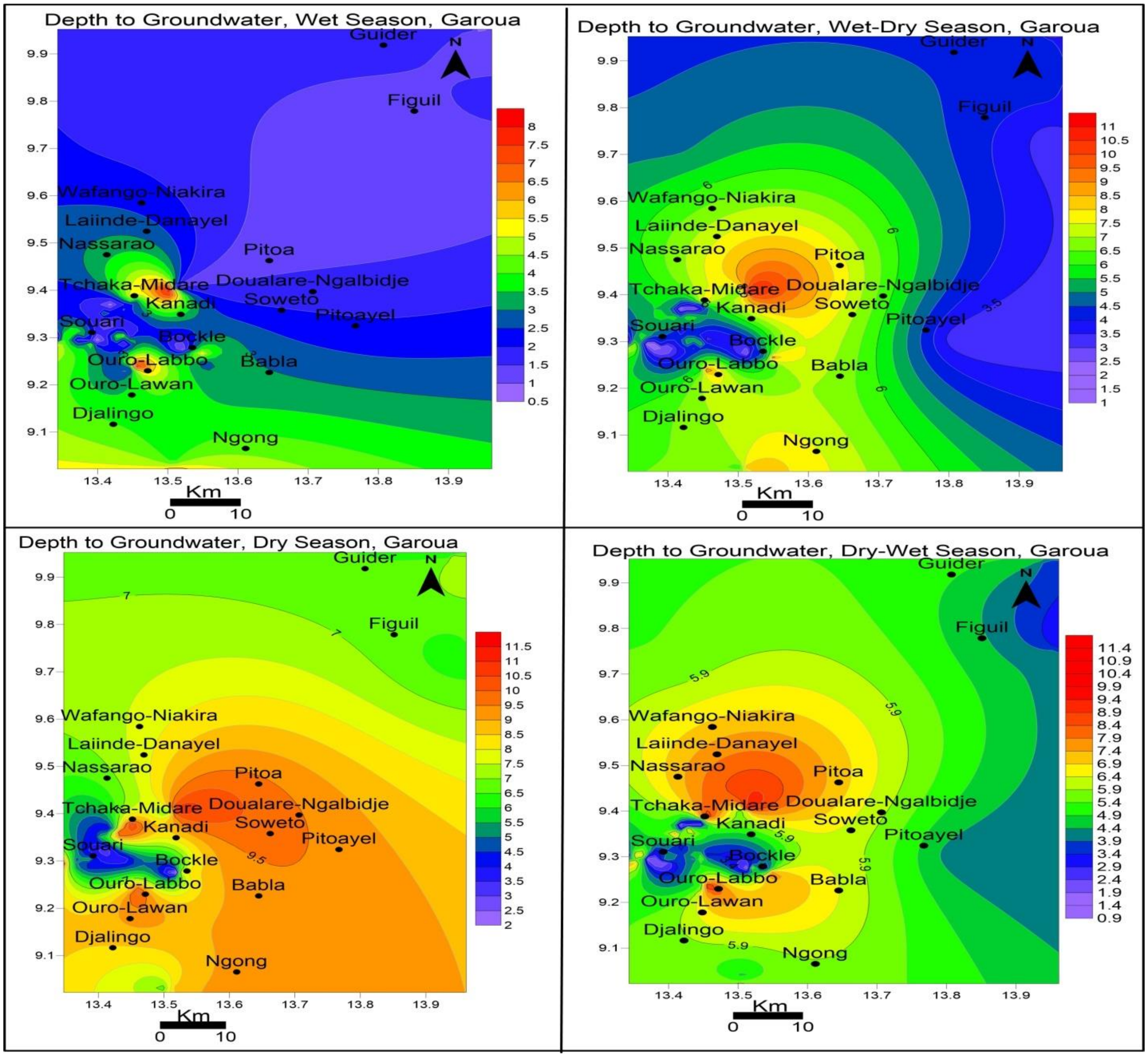

Fig. 5 Spatial variation of depth to groundwater in Garoua for four hydrogeological seasons

3.2 Classes of aquifer Vulnerability to pollution in Garoua

G.O.D index vulnerability map was created via overlapping of groundwater confinement, overlying strata and depth to groundwater. In general all aquifers are vulnerable to persistent, mobile contaminants; however natural aquifer conditions such as high permeability and shallow water table increase the risk of contamination (Khodapanah *et al.*, 2011).

The study area was classified into four classes of vulnerability to pollution as in Figure 3: low, moderate, high and very high vulnerable zones as. The decline in the quality and quantity of groundwater is a problem in the research area. Results of the assessment of aquifer vulnerability to contaminants using the G.O.D method were: 0.34 - 0.72 wet, 0.32 - 0.68wet-dry, 0.28-0.64 dry and 0.32 - 0.7 in the dry-wet season (Table 3).

Table 3: Interval values of G.O.D index and corresponding classes

Vulnerability Class	Index	Wet Season		Wet-Dry Season		Dry Season		Dry Wet Season	
		No	%	No	%	No	%	No	%
Low	0.1-0.3	-	-	1	0.6	1	1.7	-	
Moderate	0.3-0.5	27	16.5	37	22.6	18	30.5	25	15.2
High	0.5-0.7	137	83.5	126	76.8	40	67.8	131	79.9
Extreme	0.7-1	-	-	-	-	-		8	4.9

The class of low vulnerability is located in the southwestern part of the study area where it represents 0.6% in the wet-dry season and 1.7% in the dry season of the study area as in figure 4 and table 2. This less severe vulnerability class could be due to the nature of the unsaturated zone made up of clay, which is not very permeable and which could probably act as a purifier for pollutants.

The moderate vulnerability class occurs in the center and west along a strip and in the southern part of the study area. It represents 27% of the total area as in figure 4 and table 2.

The moderate vulnerability class occurs in the southern and northeastern part of the study area. It represents 16.5%, wet season, 22.6% wet-dry season, 30.5% dry season and 15.2% in the dry wet season of the study area. This moderate degree of vulnerability can be explained by the nature of the unsaturated zone made up of silty sand that is not very permeable to infiltration, to which is added the occupation of the land by housing. These conditions favor the infiltration of contaminants and make these sectors sensitive to pollution. The moderate degree of vulnerability of these areas can also be explained by the fact that these areas are possibly marked by the use pollutants (fertilizer, herbicide), and they are constituted of sands and silts which are very permeable because of their porosity. In these areas of moderate vulnerability, there are also areas where the sewage system is defective, areas previously filled with garbage before the construction of houses and this is common in Garoua.

The high to extreme vulnerability class occurs in a band along the southern part of the study area. The high vulnerability class represents 83.5% in the wet season, 76.8% wet-dry season, 67.8% dry season and 79.9% in the dry-wet season while 4.9% constitute the very high vulnerability of the area of the study area as in figure 4, 7 and table 2. These classes occupy relatively all of the areas along the central, northern, western and eastern parts of the study area. The high degree of vulnerability can be explaining by the litho-stratigraphic context of the unsaturated zone dominated by sands.

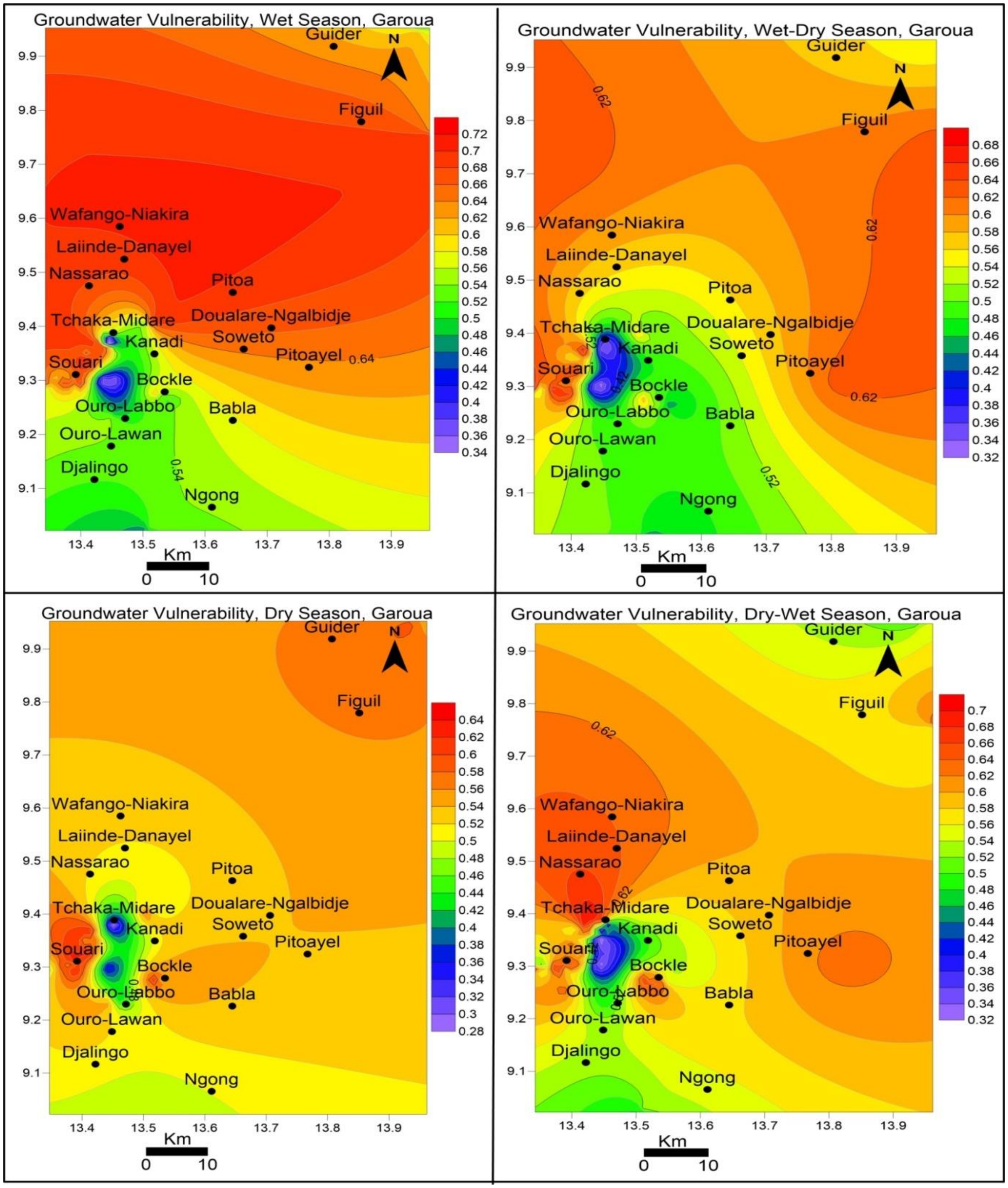

Fig. 6 Aquifer vulnerability map using G.O.D method

4.0 Discussion

Comparing the percentages of surfaces occupied by the different classes of vulnerability according to G.O.D as in table 2, the high vulnerability class occupies the highest surface followed by the moderate, low and very high vulnerability classes.

This observed difference in the number of classes may be relating to the fact that the class boundaries and dimensions that are assigned to different parameters are not absolute. This implies that the standard class boundaries may not reflect the reality on the ground where one class may surround different hydrogeological units (Ewodo *et al.,* 2015). This finding is in agreement with work done in some sub-Saharan regions such as Cameroon (Ewodo *et al.*, 2016).

Knowing that the study area is an urban area, in this context it can consider that the classes of high and extreme vulnerability represent areas threatened by pollution. They cover about 83.5% and 30.5% respectively.

The moderate and high vulnerability zones in the central and northeastern part of the study area correspond to areas where the influence of human activities responsible for increasing anthropogenic pollution this is similar to studies of (Djoret, 2000) in France and (Kadjangaba *et al.*, 2006) in N'Djamena.

The high to extreme class of vulnerability could be as result of the type of soil made up of very permeable alluvial deposits present the study area, moreover the water table is not very deep (Kadjangaba *et al.,* 2017).

The low vulnerability class of the study area and are probably relating to the low permeability of the clay-rich unsaturated zone formations.

G.O.D outcome maps show a more heterogeneous distribution of vulnerability classes compared to similar remarks were made by Agüero and Pujol, (2002) while discussing their experience in applying the same models in the Central Valley of Costa Rica.

The application of G.O.D model is in accordance to remarks by Gogu and Dassargues, (2000) considering the concept of aquifer vulnerability as a useful tool for environmental planning and decision-making and this applies to the aquiferous formations of Garoua.

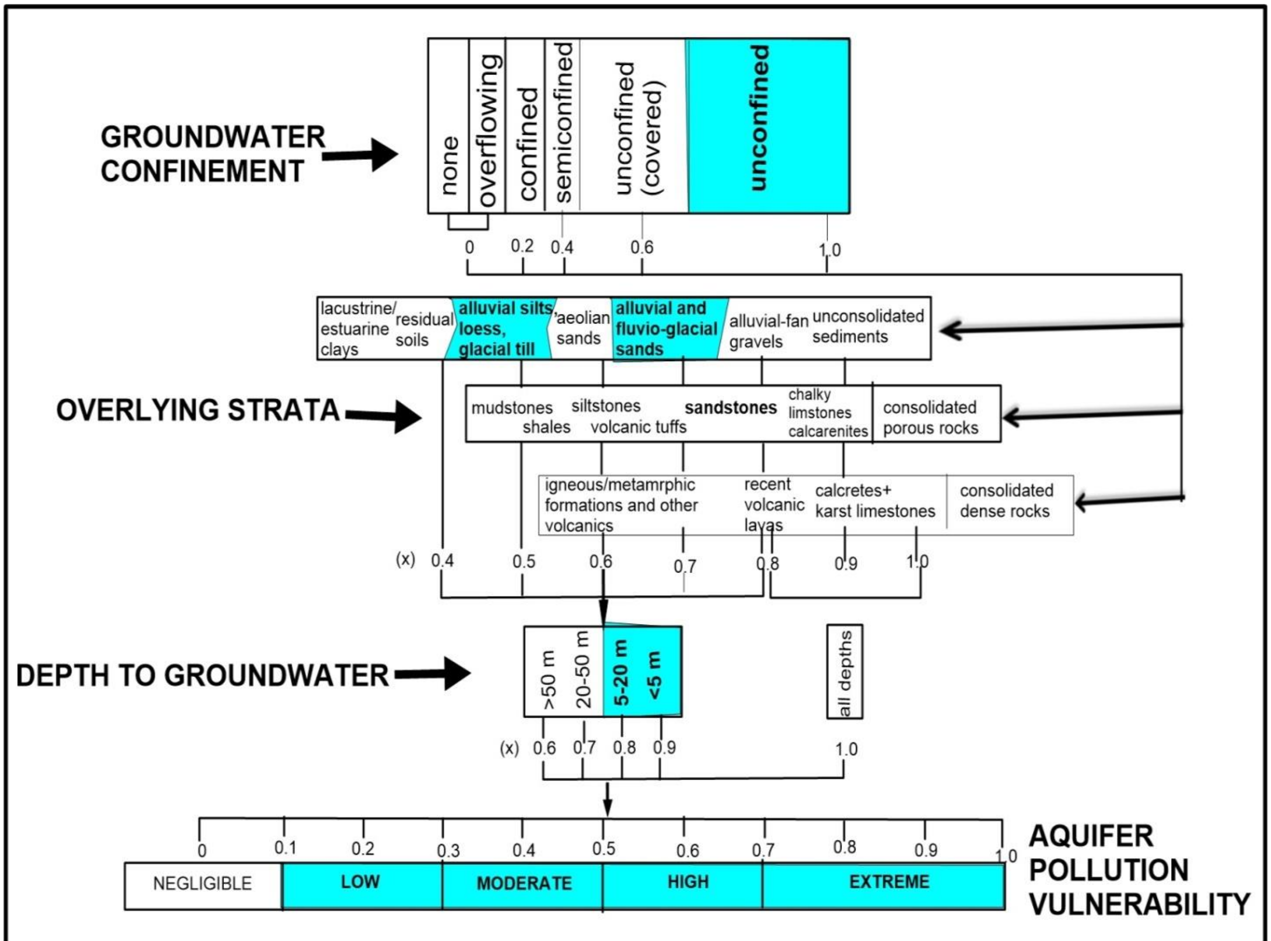

Fig. 7 Flowchart of the GIS applied to the G.O.D method in Garoua

5.0 Conclusion

The Garoua aquifer has been assessed using the G.O.D method for its vulnerability to pollution and found to be of low to extreme vulnerability.

High to extreme vulnerability to pollution is indicative of shallow wells in porous formations, probably due to porous sandstone formations and the presence of fractured gneisses and granites.

High vulnerabilities to pollution occur in all the four seasons.

The highest vulnerabilities to pollution occur during the wet and dry-wet seasons; this is of particular importance since during these periods water is available thereby, increasing the pollution opportunity as there is increased stress on the aquiferous formations.

There is seasonal variability in the aquifer vulnerability to pollution in Garoua as such stakeholders must take measures to protect the phreatic aquiferous formations in all the seasons.

G.O.D is thus an effective tool to assist authorities who manage and monitor the aquiferous formations in Garoua.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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