Pyrex Journals 2035-7789

Pyrex Journal of Ecology and the Natural Environment
Vol 1 (2) pp. 007-012 July, 2015
http://www.pyrexjournals.org/pjene

Original Research Article

Using the DRASTIC method to study the vulnerability of groundwater in the aquifer of the Continental terminal of the town of Abomey-Calavi in Benin

HS Parfait* and M Daouda

Laboratoire d'Hydrologie Appliquée, Faculté des Sciences et Techniques, Université d'Abomey – Calavi, Bénin

Accepted 27th June, 2015

In recent years, the quality of groundwater has deteriorated in many parts of Benin as a result of the expansion of agriculture, the release of solid waste, industrialization and population explosion. This study reports the evaluation of the vulnerability of the aquifer of the Continental terminal of the town of Abomey-Calavi. The study of vulnerability is to evaluate the sensitivity of groundwater to any form of pollutant introduced from the ground surface based on the physical properties of the medium. The DRASTIC method was applied to assess the vulnerability of the aquifer system. The results show that the study area is not homogeneous from the point of view of the vulnerability. The highest DRASTIC index concern the area of Togbin which has an aquifer of aeolian sands and marine cord current shoreline and recent unprotected by clays. While in the rest of the town of Abomey-Calavi the aquifer is less vulnerable because it is protected by clays. In this study, a map of groundwater vulnerability was produced in the town of Abomey-Calavi. The map shows two vulnerability classes. The vulnerability of the waters of the continental terminal is average in the area of Togbin and the vulnerability of waters of the continental terminal is low throughout the rest of the town of Abomey-Calavi. This card can be used as a tool for decision support and spatial analysis for water projects in the region.

Key words: Aquifer, Groundwater vulnerability, DRASTIC method, Benin.

INTRODUCTION

The water supply is one of the main concerns of the Benin resulting from its limited water resources. The concept of groundwater vulnerability was introduced in the 1960s in France by Margat (1968). Since then, several approaches to the development of aquifer vulnerability maps were developed as DRASTIC (Aller et al, 1987), GOD (Foster, 1987), AVI (Van Stempvoort et al, 1993) and SINTACS (Cilvita, 1994). Conventional methods like DRASTIC, AVI, GOD and SINTACS could distinguish degrees of vulnerability at the regional level involving different lithologies (Vias et al, 1994). DRASTIC was a familiar method developed for the US Environmental Protection Agency (EPA) by Aller et al. (1987) (Aller et al, 1987) and was used in different regions in the world with satisfactory results (Merchant, 1994; Mohammad, 2014).

This article discusses the vulnerability of deep aquifers in the commune of Abomey-Calavi in Benin using the DRASTIC index. This index integrates the different hydrological factors such as rainfall, the depth of the water table, hydraulic conductivity, and other factors,including topography, charging capacity, aquifer environments and the unsaturated zone effects which naturally involved in the aquifer protection.

Targeted in the area, the underground waters have always a major source of drinking water in theprovision of drinking water for the local populations and, for the watering of the animals and for the irrigation. The National Society of the Waters of Benin (SONEB) to achieve in the precinct of Godomey in the township of Abomey-Calavi; the drillings which are intensively exploited to nourish in drinking water in the urban population of the township of Abomey-Calavi; the whole population of Cotonou, thebiggest city of the country and to nourish in drinking water the population of the city of Sèmè. However the quality of water represents a growing concern.

2. Materials and methods

2.1 Study area

The Republic of Benin has 12 departments (geographic regions), each department has several towns and each town has several districts or suburbs. The town of Abomey-Calavi, located in the southern part of Benin and the Department of the Atlantic is limited in the north by the municipality of Zè, south by the Atlantic Ocean, on the east by the municipalities of So-Ava and Cotonou and on the west by the municipalities of Tori-Bossito and Ouidah. It is the largest town of the department of the Atlantic which occupies more than 20% of the area. It covers an area of 536 km2 representing 0.48% of the national

Corresponding Author: doctorantparfait@yahoo.fr

area of Benin. The general census of the population in 2002 reports for Abomey-Calavi 307,745 people that is 21% of the population of the departments of Atlantique and Littoral. 74.12% of the population live in urban areas and 25.88% in rural areas. The town of Abomey-Calavi today suffers the influence of nearby Cotonou, the economic capital of the country. Indeed, the narrowness of Cotonou and its large population leads to an extension to Abomey-Calavi. In the town of Abomey-Calavi, population growth is 5.84% in urban areas and 2.89% in rural areas. Central Calavi (figure 1) is one of the districts of Abomey-Calavi. In this district the population is dense.

The town of Abomey-Calavi is a uneven relief. The main features are: a band with sandy spits of land and barprettylowporosityanddepression. The coastal plain of low altitude (0-5m) is separated by the Djonou lagoon. It is entirely sandy or swampy places. The town of Abomey-Calavi is located in an intertropical area inthetropics. In this area, the climate is sub-equatorial and characterized by two rainy seasons (September to November and March to July) and two dry seasons (November to March and July to September). The study covers two main types of geological formations (Degbey, 2004):

- The Quaternary formations that are sandy deposits of the barrierbeach, lagoon deposits of clay and sand and alluvial deposits consist of sand and clay. Coarse sand on the coastfaçade have a thickness of about 6m with a porosity exceeding 40%. Up the coast, the fine, grayish marine silty sands, have a thickness of 15m and a porosity of around 35%. Finally, follow the clay gravelly sand from alluvionswhose characteristics are fairly similar to ordinary sands of the coastal façade.
- The tertiary formations consist mainly of clay and sand of terminal continental.

Two large units can be distinguished in this group:

- The first consists of sandy clay deposit changed to bar sand dating from the Upper Miocene. In this unit and a little deeper, we note the presence of an alternation of clay and quartz sand and lower gravel with a particle size that is increasing or decreasing upwards.
- The second is made of rounded and angular gravel deposit bathed in sandy-clayey matrix generally brick red and altered facies barsand (figure 2).

There are three aquifers on the plateau: the terminal continental aquifer is shallow (120m), the Paleocene aquifer at a depth of 320m, the Maastrichtian aquifer at 1500m depth (Degbey, 2004).

3. Methodology

We used the DRASTIC method to assess the vulnerability of water drilling of the town of Abomey-Calavi:
More than 24 methods for assessing the vulnerability of groundwater pollution are identified in the international literature (Civita, 1993). The most current method in the world is that defined by Aller et al in 1987, known as the DRASTIC method name. It is a method which belongs to the group of the assessment methods (the vulnerability of aquifers) Weighted based on assigning a rating to the various parameters used (usually between 1 and 10) and their grouping into classes different. A ponderation is allocated according to the relative importance of each of the parameters used.

The DRASTIC method is based on the estimate of 7 parameters for charging, soil, vadose zone and the saturated zone of the aquifer (Smida et al, 2009).
[D]: Depth of water;
[R]: Net Recharge;
[A]: Nature of the lithological Aquifer;
[S]: Sol (particle size and facies);
[T]: Topography of the land;
[I]: Impact of the vadose zone (lithology and thickness);
[C]: hydraulic conductivity (permeability) of the saturated zone.

Ponderations of DRASTIC parameters

The scores or coefficients are assigned to parameters according to their importance to the vulnerability of the aquifer. The coefficient corresponds to a punctuation attributed to a physical unit of land or a hydrogeological characteristics of the aquifer. These coefficients have values within a range of given numerical classes. The classes defined taking into account the transfer time of the pollutant to the aquifer and starting from the most favorable condition or low vulnerability (the value of the score is 1) to the most critical condition (the value of the score is 10). Each critical factor was analyzed and evaluated in comparison with other parameters to define its relative importance in the estimation of vulnerability. This ponderation is defined as weight factor. Weights are between 1 and 5 according to their importance in increasing the vulnerability assessment (Table 1). The high weight assigned to the factors facilitating the infiltration of pollutants from the soil surface to the watertable (SMIDA et al, 2009).

Drinking water is primarily drawn from the aquifer of the Continental Terminal (Poulichet et al, 2002).

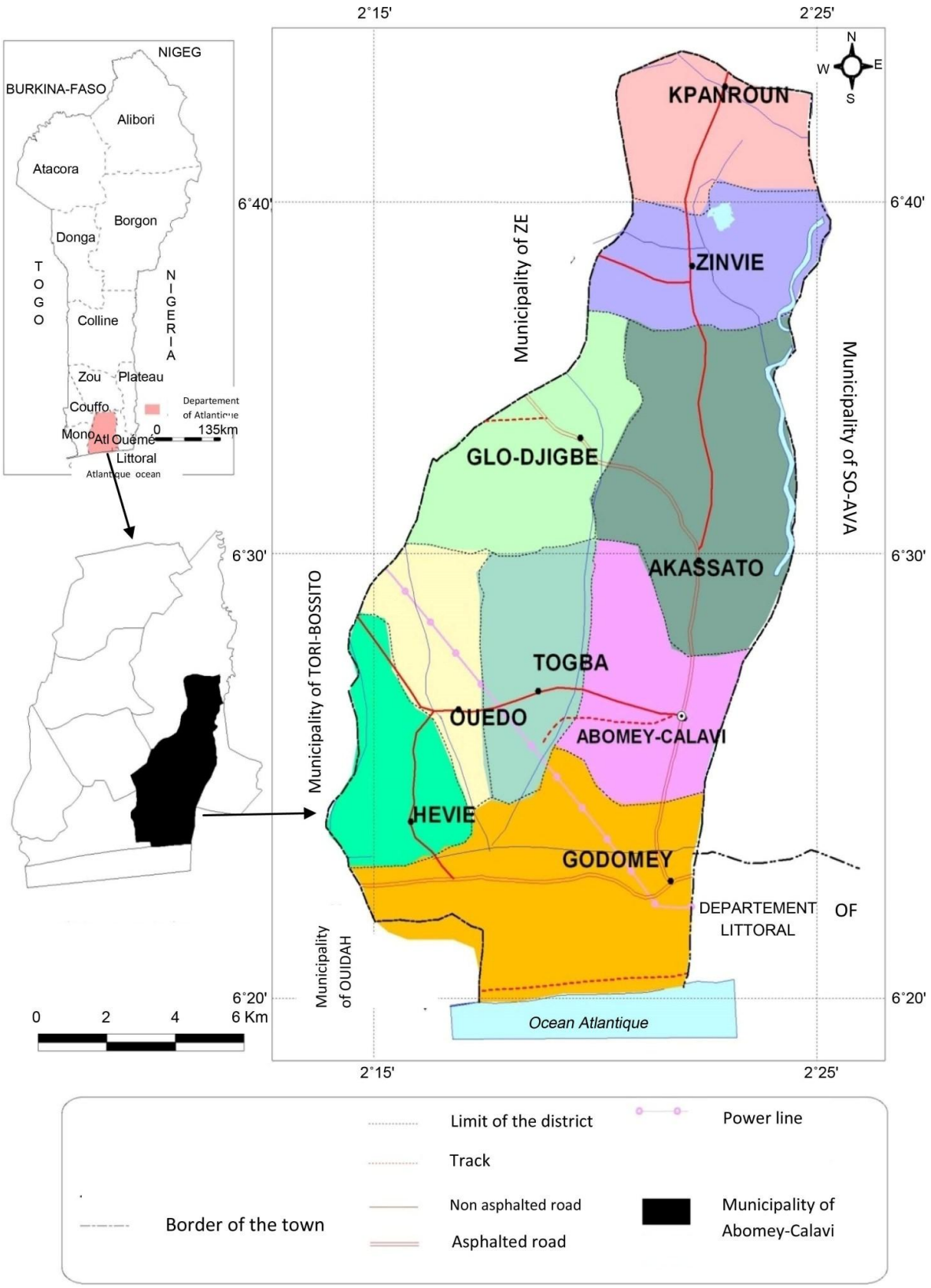

Figure1: Location of the municipality of Abomey-Calavi

Table 1: Parameter's classification for the use of DRASTIC index. (Aller et al, 1987; Hentati, 2004)

Parameter	Range	Ratin	Relative weighting
Depth to water (D)	0-2m	7	5
	2-5m	6	
	5-9m	5	
	9-15m	4	
	15-23m	3	
	23-30m	2	
	>30m	1	
Recharge from rainfall(cm/an)(R)	2-5m	1	4
	5-10m	3	
	10-15m	6	
Aquifer media (A)	SoilSebkha	1	3
	Sandy clay	2	
	Clayey sand	4	
	Sand	6	
	Sandstone	7	
	Gravel	9	
Sol media (S)	Soil thin or absent	10	2
	Gravel	9	
	Sand	8	
	Peat	7	
	Shrinking and/or aggregated clay Sandy	4	
	Loam	5	
	Loam silty loam	4	
	Clay loam	3	
	Muck	2	
	Non-shrinking and non-aggregated clay	1	
Topography (T)	0% - 2%	7	1
	2%-6 %	6	
	6% - 10%	5	
	10% - 16%	3	
	16% - 25%	2	
	>25%	1	
Impact of vadose zone (I)	Sebkha saline soils (clay and gypsum silt).	1	5
	Gypsum.	2	
	Limon.	3	
	Mamo limestone	4	
	Alluvium (mixture of clay, sand and silt).	5	
	Limestone, dolomiteand sandyloam.	6	
	Sand.	7	
	Sandstones, conglomerates.	8	
	Deposit,gravel	9	
Hydraulic conductivity	≤ 0.000000001	1	3
	0.000000001- 0.0000001	2	
	0.0000001- 0.00001	4	
	0.00001- 0.001	6	
	0.001- 0.1	7	
	0.1- 10	9	

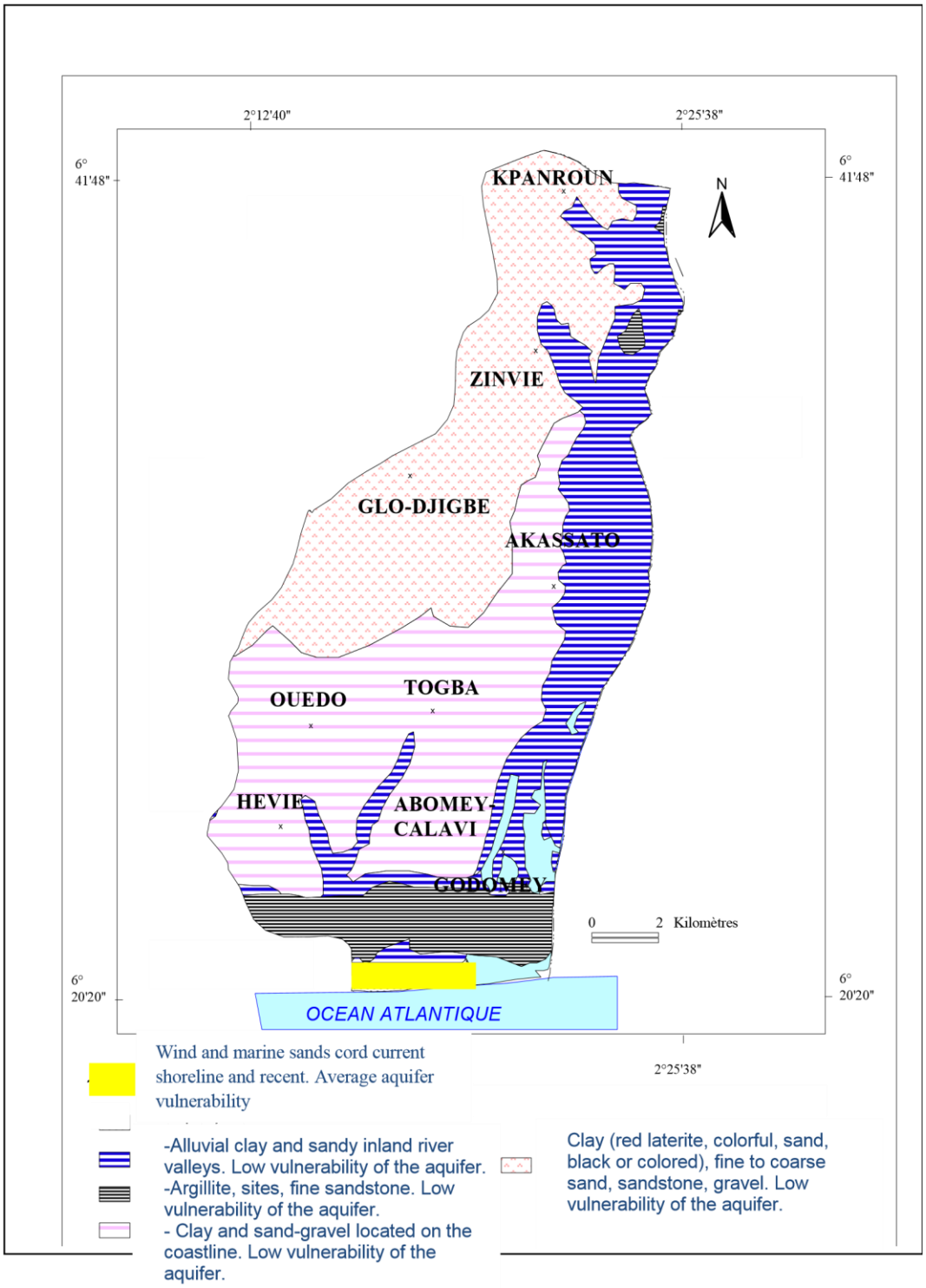

Figure 2: Geological and vulnerability map of the aquifer waters of the continental terminal of the town of Abomey-Calavi.

The vulnerability index is calculated as a sum of products (score * weight) of the seven DRASTIC parameters as follows:
V = sum of all Wi*Si; with
V: potential pollution index (index DRASTIC) or vulnerability;
Wi: weight factor;
Si: score factor.

The calculated DRASTIC index is a measure of the vulnerability of the aquifer. Larger values indicate a very high vulnerability of aquifers. The degree of vulnerability is defined in the following way (Hentati, 2004):

- Very low vulnerability, if V <80;
- Low Vulnerability, if 80 ≤ V <100;
- Average vulnerability if 100 ≤ V <140;
- High vulnerability if 140 ≤ V <160;
- Very high vulnerability if V ≥ 160.

4. Results

Note that the reservoir has a homogeneous index of the depth. The depth of drillings for taking water into the aquifer is higher than 30 m. The weight of the depth is 5, we get a depth index equal to 5 for thefull extent of the study area.

The estimated recharge in our study area was conducted from theclimatic data Cotonou station according to the thornthwaite water balance method defined by the following equation (Maliki, 1993):

P =ETR+ R + I, therefore I = P-ETR-R

ETR = real evapotranspiration;

R = Runoff; $R = P^3/(3ETP^2)$ (Maliki, 1993).

I = Infiltration

RTP: Average annual of the potential evapotranspiration calculated by the method of Thornthwaite in mm.

P (mm) = 1309

EPT (mm) = 1730

R (mm) = 249.84

ETR (mm) = 945.6

So I (mm)= 113.63

According the DRASTIC intervals for charging, the efficient charging obtained at the station of Cotonou has the score 6 because the infiltration is 11.3 cm. The weight of the refill being 4, one obtains a charging index equal to 24 for the full extent of the study area.

Note that the index is not homogeneous for the type of aquifer. Except Togbin a coastal area of the town, all of the aquifer of the town of Abomey-Calavi consists of sand, gravel and clay, and therefore the index is 12. In the district of Togbin, the aquifer consists of aeolian sands and marine cord current and recent coastline and therefore the index is 18.

We note as to the type of aquifer, the index is not homogeneous for the soil type. The index for soil type is 16 in the area of Togbin and equal to 8 in the rest of the town of Abomey-Calavi. Note also that the index is not homogeneous for the unsaturated zone. The index of the unsaturated zone is 35 in the area of Togbin and equal to 25 in the rest of the town of Abomey-Calavi.

The slopes are relatively important in 6 to 10%. The average index for the slope is 5. The higher slopes are the banks of rivers (10-16%). The index for the slope to the banks of water courses is 3.

The "aquifer permeability factor" has the same importance as the "media aquifer" in the DRASTIC method that assigns equal weight to 6 in Togbin district and 4 in the rest of the town. The two parameters are associated because more a reservoir consists of coarse detrital its permeability is highand therefore the pollution can spread more easily in the aquifer. The index of the permeability of the aquifer is 18 in the area of Togbin and equal to 12 in the rest of the town of Abomey-Calavi.

The DRASTIC index has an average of 121 in the area of Togbin and equal on average to 91 in the rest of the town of Abomey-Calavi. This corresponds to an average of the vulnerability of waters of the continental terminal in the district of Togbin and a low vulnerability of the waters of the continental terminal in the rest of the town of Abomey-Calavi (Figure 2).

Conclusion

The index of the DRASTIC model was used to determine the vulnerability of the aquifer of the Continental terminal of the town of Abomey-Calavi. The index ranges between 36 and 176. This variation margin is used to classify the vulnerability into five classes; very low, low, medium, high and very high. These degrees of vulnerability are superimposed with the various sources of pollution in the region to identify risk areas in the town of Abomey-Calavi. The DRASTIC indices calculated shows that the vulnerability of the waters of the continental terminal in the area of Togbin is average and the vulnerability of waters of the continental terminal is low throughout the rest of the town of Abomey. We conducted a vulnerability map of the study area. The card can be used as a tool to aid decisions and spatial analysis for projects in the region.

References

[1] ALASSANE A (2004). Etude hydrogéologique du continental terminal et des formations de la plaine littorale dans la région de Porto Novo (sud du Bénin) : Identification des aquifères et vulnérabilité de la nappe superficielle. Thèse de doctorat de troisième cycle. Université cheikh Anta Diop de Dakar. Faculté des sciences et techniques département de geologie.

[2] Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hachet, G. (1987) DRASTIC: A Standardised System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings (EPA 600/2-87). Environmental Research Laboratory, Office of Research and Development, US Environmental Protection Agency Report, Tucson, 622.

[3] Civita, M. (1994) Le carte della vulnerabilit`a degli acquiferi all'inquinamiento: Teoria e pratica [Contamination Vulnerability Mapping of the Aquifer: Theory and Practice]. Quaderni di Tecniche di Protezione Ambientale, Pitagora.

[4] Dégbey C; (2004). La qualité de l'eau de puits dans la commune d'Abomey-Calavi et les facteurs exogènes de sa pollution. Mémoire de fin de formation de DEA, Environnement et Santé Publique FLASH, UAC, Bénin

[5] Foster, S.S.D. (1987) Fundamental Concepts in Aquifer Vulnerability, Pollution Risk and Protection Strategy. In: van Duijvanbooden, W. and van Waegeningh, H.G., Eds., Vulnerability of Soil and Groundwater to Pollution, Proceedings and Information No. 38 of the International Conference Held in the Netherlands, in 1987, TNO Committee on Hydrological Research.

[6] Hentati I. (2004) : Etude et cartographie de la vulnérabilité environnementale de la nappe phréatique de Sfax-Agareb. Mémoire de MASTERE. Fac. Sc. Sfax. 102p.

[7] Margat, J. (1960) Carte Hydrogéologique du Basin de Fès-Meknès au 1/100,000. Agence du Bassin Hydrauliques de Sebou, Fès.

[8] Maliki R, (1993) - Etude hydrogéologique du littoral béninois d3ns la région de Cotonou. Thèse de doctorat de. 3èllle cycle. Version provisoire. Ucad ; Dakar, Sénégal. 162p + annexes..

[9] Merchant, J.M. (1994) GIS-Based Groundwater Pollution Hazard Assessment: A Critical Review of the DRASTIC Model. Photograommetric Engineering & Remote Sensing, 60, 1117-1127.

[10] Mohammad, A.H. (2014) New Groundwater Vulnerability Index for the Main Aquifers in Central Catchment Area in Jordan and Validation of the Results Using NO3 Concentrations Maps. World Environment, 4, 22-32.

[11] Mohammad, A.H., Almomani, T. and Alhejoj, I. (2015) Groundwater Vulnerability for the Surface Outcropping Aquifers in Jordan. Journal of Environmental Protection, 6, 250-258.

[12] Poulichet F. E., Favreau G., Leduc C., Seidel J. L; (2002). Major in chemitry of ground water in the continental terminal water table of South Western Niger (Africa). Applied Geochemistry, 17 (10) 1343-1349

[13] Smida H, Maiza N, Zairi M, Dhia H B. (2009) Gestion quantitative et qualitative des ressources en eaux dans la région de Sidi Bouzid (Tunisie centrale) à l'aide d'un SIG : Etude de la recharge induite des nappes et leur vulnérabilité à la pollution. Conférence ESRI, 30 septembre et 1er octobre à Versailles.

[14] Van Stempvoort, D., Ewert, L. and Wassenaar, L. (1993) Aquifer Vulnerability Index (AVI): A GIS Compatible Method for Groundwater Vulnerability Mapping. Canadian Water Resources Journal, 18, 25-37. Giambastiani, B.M.S. (2007) Evoluzione Idrologica ed Idrogeologica Della Pineta di san Vitale (Ravenna). Ph.D. Thesis, Bologna University, Bologna.

[15] Vias, J.M., Andreo, B., Perles, M.J. and Carrasco, F. (2005) A Comparative Study of Four Schemes for Groundwater Vulnerability Mapping in a Diffuse Flow Carbonate Aquifer under Mediterranean Climatic Conditions. EnvironmentalGeology, 47, 586-595. http://dx.doi.org/10.1007/s00254-004-1185-y.