GROUNDWATER POLLUTION OF SAÏS BASIN (MOROCCO), VULNERABILITY MAPPING BY DRASTIC, GOD AND PRK METHODS, INVOLVING GEOGRAPHIC INFORMATION SYSTEM (GIS)

Nezha Sadkaoui[1], Siham Boukrim [1], Abdellah Bourak[1], Ferdaous Lakhili[1] , Leila Mesrar[1], Abdel-Ali Chaouni[2], Abderrahim Lahrach [1], Raouf Jabrane[1], Brahim Akdim[3]

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Abstract. The groundwater in the plain of Fez-Meknes (Saïs, Morocco) constitutes a major natural resource in the region. The study highlights the importance of this resource. However, several inferences of pollution, either as point sources or diffuse flows, appear. It is therefore necessary to apprehend water vulnerability in terms of sensitivity to pollution in the area, in order to understand and remedy the past situations, and to prevent future problems. The present study assesses the quality of underground waters in Sais plain, based on environmental indicators (e.g. permeability, topography, lithology, depth to water etc.). Vulnerability maps were developed by the DRASTIC, GOD and PRK models to identify areas of high risk of contamination and, as a result, the study area was subdivided into several units that have different levels of vulnerability.

Introduction

Water is a key factor in economic and social development in most countries, mainly in the semi arid and arid zone. But it often faces two key challenges: depletion of water resources reservoirs, in relation to the increasing water demand, and water quality degradation, which undergoes various forms of pollution.

Underground water pollution is progressively emerging as a serious challenge in different countries in Europe, Asia and Africa for example. It gained international scientific interest during the last decades and has been studied using

[1] SMBA University, BP: 2202, Rte d'Imouzzer, Fez, Morocco – nezhasadkaoui@yahoo.fr
[2]University, BP: 1223, Taza-Gare Route d'Oujda, Taza, Morocco
[3]USMBA University, BP: 59 Route Imouzzer, CP: 30000, Fez, Morocco - akdimbrahim@yahoo.fr

several approaches and techniques. Fedrigoni *et al.* (2001) studied the origin of salinisation and hydro-geochemical behavior of a phreatic aquifer in Djebeniana (Tunisia) and found evidence of severe natural and anthropic constraints on the underground water quality. Cheng *et al.* (2003) studied the relationships between water quality and the social and economic systems to develop an improved decision making tool based on the mathematical models. They analyze the environmental impacts of economic practices in some Chinese water quality cases.

In Morocco, Leftouhi *et al.* (2003) described the extent of nitrate pollution in the wells and drill holes located in the Kourimat agriculture perimeter (Essaouira basin) and found that concentrations were over 400 mg/l. Boughriba *et al.* (2006) studied the origin and evolution of groundwater in the Moulouya Basin, combining geoelectric data with hydrochemical indicators. Bouchaou *et al.* (2009) used isotopic and geochemical data to apprehend the origin of the underground data in Tadla and noted the importance of nitrate from pollution and agriculture origin in the aquifer. Mapping the aquifers' pollution based on GIS models was developed in several academic works (e.g. Amraoui, 2005; El Aroussi, 2007). Maps of vulnerability to pollution are useful in water management and for assessing risks of groundwater pollution**.**

The vulnerability of groundwater qualitatively reflects the natural ability of the aquifer to be reached and affected by pollution from surface (landfill, cemetery, industrial wastewater discharge, chemical fertilizers, pesticides, herbicides, application of domestic wastewater, etc.). Whatever the method of disposal used, the notion of vulnerability incorporates the physical parameters determining the degree of exposure to groundwater pollution from the soil surface. The present study adopts the approach, but focuses on DRASTIC, GOD and PRK models to apprehend the spatial variability of water pollution in the Sais basin, using recent field investigation and laboratory data. Overlay analytical functions and non-coincident spatial variables were incorporated into vulnerability mapping. The application of GIS software is useful. ArcInfo and ArcView were used in this study.

The Sais basin is a major agriculture area in Morocco and contains two major cities: Meknes and Fez. These urban areas play a decisive role in the socio-economic development of the region. They are among the large and important cities in central Morocco, because of their economic activities such as industry, craft, tourism and trade. However, agriculture and urban activities in these areas influence the local environmental equilibrium and underground water quality in their context. Problems in water resources quality appear in several areas.

These problems are increasing over time, following the economic activities concentration, and may constitute obstacles to sustainable development. The present study highlights action opportunities in the underground water in Saïs using spatial tools to apprehend its scarcity and pollution origins. Findings point the diffuse pollution in the aquifer and several spatial units that differ in water vulnerability.

1. General setting

The study area corresponds to the Sais basin. It is a part of the Sebou catchment. It extends over a length of 100 km and a width of 30 km between the Lambert coordinates: 465 <X <545 km and 335 <Y <385 km. It is bounded on the north by the Prerif, and in the south by the Middle Atlas mountain. The valley of Sebou is the eastern limit of Sais and the tributaries of the oued Beht form its western border. The basin includes two structural units; the Sais plain to the east and the plateau of Saïs to the west, in Meknes vicinity.

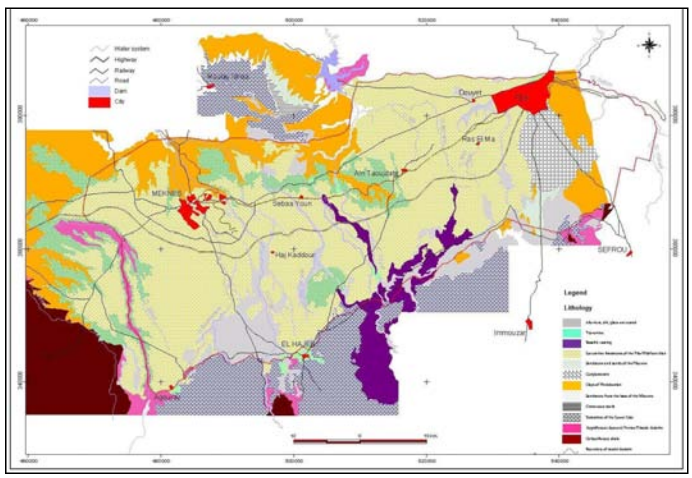

Fig.1 - Geological map of the basin of Fez-Meknes (ABHS, 2005)

The Saïs plain, also called the Fez-Meknes Basin, is a major depression, where the topographic uplift of Aïn Taoujdate separates the two parts (eastern and western) of the plain. It is due to flexure of Ain Taoujdate. Its general orientation is WNW-ESE facing NE, where the plain of Fez extends as the lower part of Sais (Fassi, 1999; Essahlaoui *et al.,* 2001; Essahlaoui, 2002; Amraoui, 2005).

The geological setting shows dominant substrates of dolomite and limestone of the Lias, and locally Triassic clays and Carboniferous shale sequence_appear, but rarely (Fig.1). The stratigraphic sequence of the basin is as follows: the Carboniferous shale, the Permo-Triassic complex deposits, the Liassic and Dogger limestone and the Miocene marl.

2. Climatologic, hydrologic and hydrogeologic settings

The climate is among essential factors that influence the hydrologic and hydrogeologic cycles in the region. Fez-Meknes basin is located in the semi-arid zone, with temperate winters. It is seasonally influenced by continental and eastern air masses. The annual variation of precipitations influences the refill of aquifers in the basin. Therefore, we used four hydrologic stations (Fez ABHS, Fez Sais, Ain Bitite and Mikkes Alhajra) to study the availability of rainfall between 1977 and 2002. We note that every year of this period is rainy and rain variation is low (Fig.2).

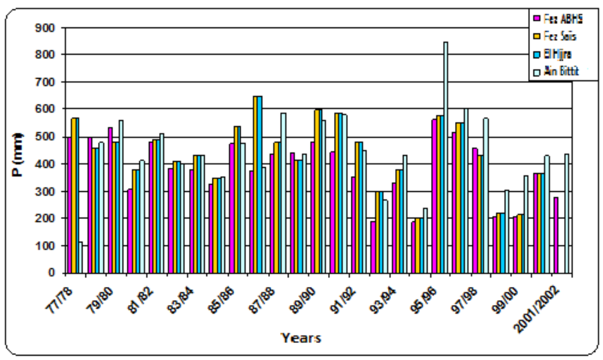

Fig.2: Spatial variation of the precipitation in four stations (1977-2002)

Temperature variation in the Sais basin has been determined from data measured in the stations of Fez-Sais (Lambert coordinates X = 536.9km, Y = 385.0km, Z = 410 m) and Meknes (X = 365km, Y = 487.5km, Z = 550 m).

The distribution of the average temperatures in the area is indicated in figure 3.

A decrease of temperature is observed from September to January and February, where the lowest values are registered. During the rest of the year, temperatures increase reaching a peak in July, August and September.

The Fez-Meknes basin has a hydrological network underdeveloped, due to the karstic nature of the Middle Atlas mountain. The study area is drained by many rivers (El Kell, R'Dom, Mikkas and Fez). They flow from NNW to SSE, except for Fez river, which flows from west to east (Fig. 2). Several springs appear, especially in the plateau borders and the valleys' flanks (Fig. 3). These sources are characterized by variability of their flows (a few l/s to more than $1m^3/s$); variability of the origins of groundwater and the degree of water mixture and the difference of water temperatures and depending on the origin depth (eg. Hot Springs of Sidi Harazem, 30 to 33°C; Moulay Yacoub, 54°C and Skhounat, 38°C). The difference in chemical composition depends on the natural and anthropogenic parameters' influence.

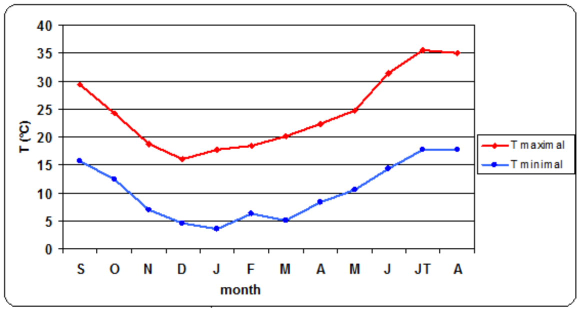

Fig.3: Variation of the monthly averages of the minimal and maximal temperatures of the stations (2007-2008)

The endoreism in the study area is characterized by the presence of two natural lakes: the lake of El Douyet (X = 523250 ; Y = 382500) and Dayet Kochtam (X 33.85 et Y -5.16).

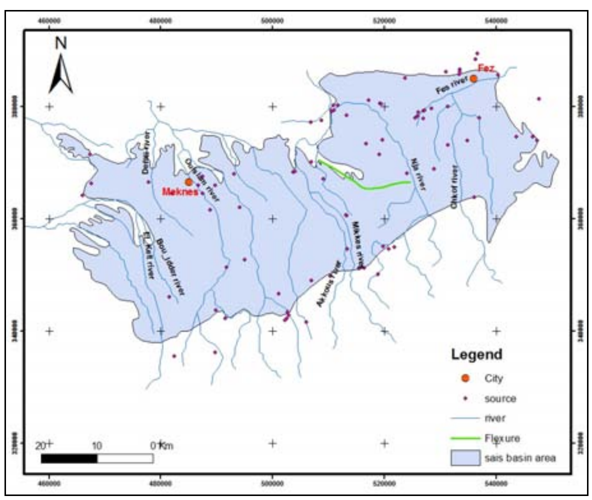

Fig. 4: The main rivers and springs in the Fez – Meknes (Saïs) basin

From the hydrogeological point of view, the watershed has been studied in terms of water potential and socioeconomic activities. Its geologic structure favors the genesis of aquifers (ABHS, 2005; Essahlaoui, 2002). The main layers are:

The lacustrine Plio-Villafranchian sands, conglomerates and limestone, on the subsurface, where the groundwater flows depend on the rainwater infiltration and the drainage of the deep aquifer. Water percolation from irrigated farms is also important.

The deep aquifer, circulating in the Lias dolomitic limestone. It starts to charge water under the thick series of the Miocene marl raincoats. This aquifer has an artesian importance but it is in decline due to the overuse of the underground water in Saïs.

These two aquifers are separated by thick series of the Miocene marl.

3. Methodology

Mapping the intrinsic vulnerability to pollution of groundwater is considered an effective technique with a lower cost. It was applied in several studies all over the world (e.g. Hamzaa *et al.,* 2007; Leone *et al.,* 2009; Huan *et al.,* 2012). It allows:

- the identification of areas at high risk of contamination;
- the subdivision of the study area into several units that have different levels of vulnerability;
- better management of the aquifer and;
- prompt and appropriate interventions in cases of pollution to ensure good water quality.

This type of work is based on processing a large amount of data in connection with geological substrates located between the aquifer and the soil surface. The steps followed during the investigation are:

- the collection and acquisition of data;
- data processing and mapping;
- analysis focusing on the results applied to vulnerable areas.

The literature shows the diversity of approaches and criteria that can be taken into account when estimating and mapping groundwater vulnerability to pollution from surface. However, two factors were often considered:

- the vector of pollution or the transit of pollutants from the soil surface to the underground water;
- the extension of the pollutants in the area.

Gogu and Dassargues (2000) have done a complete overview of existing methods adopted in the groundwater vulnerability assessment, and discuss their future challenges on vulnerability mapping. The DRASTIC, GOD and PRK approaches are the three most recognized and used today.

3.1. DRASTIC method. It was developed in the eighties of last century (Aller *et al.* 1987) and is a weighting and rating method that assesses vulnerability by means of the seven following parameters: D is the depth to groundwater; R is the recharge of the aquifer; A is the aquifer media, S, the soil media; T, the topography in %; I, the impact of the vadose zone and C, the conductivity.

Table 1 - The general coding of the seven parameters of the DRASTIC method (Aller *et al.* 1987)

Parameter	**Range**	**Rating**
Depth to groundwater (D) (m)	up to 30 and [22.5 – 30] to[0 – 1.5]	1 to 10
Recharge (R) (mm)	[0 – 50] to [175 – 255] and up to 255	1 to 9
Aquifer media (A)	Massive Shale to Limestone karst	2 to 10
Soil media (S)	Unaggregated clay to Thin or absent	1 to 10
Topography (T) (%)	Up to 18 and [12 – 18] to [0 – 2]	1 to 10
Impact to vadose zone (I)	Silt and clay to limestone karst	3 to 10
Hydraulic conductivity (C) (m/s)	[1.5 e^{-7} – 5 e^{-5}] to [5 e^{-4} – 9.5 e^{-4}] and up to 6.5 e^{-4}	1 to 10

The purpose of DRASTIC is to provide a standard classification of the vulnerability index which gives reliable results for efforts to protect groundwater. This caused the ratings awarded to the seven parameters cited as DRASTIC method and are presented in the table below:

The final vulnerability index (Di) is the sum of the seven parameters using the following formula:

$$Di = DnDp + RnRp + AnAp + SnSp + TnTp + InIp + CnCp$$

Where:

D, R, A, S, T, I, C are the parameters already mentioned;

n: rating given to each parameter and p: weight given to each parameter.

Thus, the resulting maps to visualize the relative degree of vulnerability of a sector of the study area and the potential pollution increases in the same direction as the index. Higher the results, higher the vulnerability of water.

3.2. PRK method. In this second conceptual model, only the approaches or physiographic and hydrogeological parameters are considered. Aquifer vulnerability index (AVI) is an analogical relation or numerical method that uses two parameters: the thickness of each sedimentary layer above the uppermost saturated aquifer (d) and the estimated hydraulic conductivity (k) of each of these sedimentary layers (Van Stempoort *et al.,* 1993).

This method does not consider ratings and/or weights. The index is determined from the relation between the two parameters, taking into account variations of an order of magnitude.

We consider another parameter which is the slope and add it to AVI and make combinations between the various sub-indices according to the grouping operations below:

IP × IR = C1 (1) IK × C1 = C2 (2)

The overall index (Iv) will be the product of all partial indices (Ii) calculated. IP: partial index on the topographic slope; IR: partial index on the ratio R, IK: partial index on the permeability of the aquifer; C1: first combination, C2: second combination.

Thus, the lithologic section is considered compartmentalized into three areas only: the surface soil (SS), the unsaturated zone (UZ) in its broadest sense and the saturated zone (SZ).

In each of these compartments, the parameters chosen were:

The topographic slope (P);

The ratio (R), representing the variation of the amplitude fluctuations of groundwater level relative to the thickness of the vadose zone and

Permeability of the aquifer (K).

Hence, the generic term P.R.K. presented in Table 2, shows the intervals and notes corresponding to the study area:

Table 2 - Notes corresponding to the parameters of PRK in the Fez-Meknes basin

Parameter	**Range**	**Rating**	**Degree**
Topographic slope P (%)	≥ 74,71 and [10,5 – 17,47[to [0 – 1,8[	1 to 10	Very low vulnerability to Extremely vulnerable
Fluctuations amplitude / Thickness of U.Z. R (mm)	[0,00012 – 0,022[to [0,27 – 0,40 [	1 to 10	Very low vulnerability to Extremely vulnerable
Permeability K (m/s)	[4,93. 10^{-7} – 4,1.10^{-5}] to [3,4.10^{-4} – 6,6.10^{-4}[	1 to 9	Very low vulnerability to Extremely vulnerable

3.3. GOD Method. Its fundamentals were presented by Foster (1987). This model requires fewer parameters and aims to achieve a quick estimation of the vulnerability of an aquifer. Assessing vulnerability by means of three variables:

- Groundwater occurrence (G).
- Overall class of aquifer (O), aquifer type in terms of lithologic factors;
- Depth to groundwater table (D).

The vulnerability index (I_{GOD}) is obtained by multiplying indices of each of these three parameters:

$$I_{GOD} = CA * CL * CD$$

With:

• CA: type of aquifer;

• CL: clearance lithology;
• CD: Rating the depth to water table.

The final result is a map of vulnerability, which supports all the three criteria. The value of the index may vary from 0 (minimum vulnerability) to 1 (maximum vulnerability). Five vulnerability classes are differentiated by the method.

Table 3 - The general coding of the three parameters of the method of GOD (Foster, 1987).

Parameter	**Range**	**Rating**	**Note**
G	No aquifer to unconfined aquifer	0 to 1	Allows identification of the aquifer type, depending on its degree of confinement
O	Clay to fractured limestone or karst	0,3 to 1	The characteristics of the layers overlying the saturated zone of the aquifer with respect to their relative degree of porosity, permeability and to their water content.
D	> 100 m and 50 to 2 and < 2 m	0,4 to 1	Depth of unsaturated zone

Foster (1987) suggested ratings specified for each parameter as summarized in Table 3.

3. Results and discussion

The map obtained by the models' application shows that the mean susceptibility occupies a large area and scattered throughout the Saïs basin. The vulnerability is identified in the high plain of Fez with extreme vulnerability in the South, in contact with the Middle Atlas plateau. Low and very low vulnerability is localized, mainly in the plateau of Meknes and usually concentrated in the northwest part of the aquifer (Fig. 5).

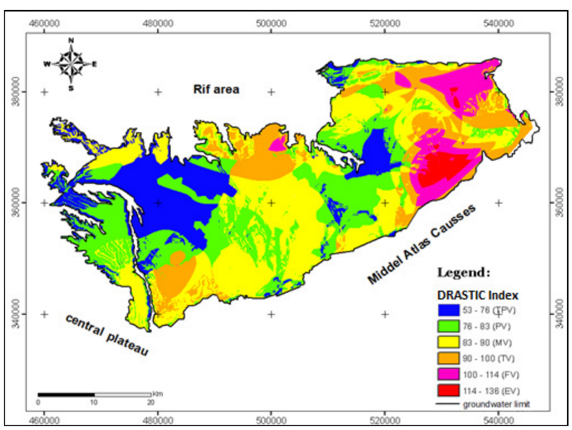

Fig.5. Map of intrinsic vulnerability of groundwater basin of Fez-Meknes by DRASTIC method.

The marks defined to each criterion for this method were used to assess the spatial distribution of the intrinsic vulnerability of groundwater to pollution. The zones in high risks of vulnerability are mainly located in the South of the plateau of Meknes. Moderate vulnerability areas occupy the central parts of the plain of Sais and the Northwest Shelf of Meknes, while low levels are in the rest of the basin (Fig. 5).

The figure 6 shows that the highest degrees of vulnerability are essentially localized in the South of the plateau of Meknes; the zones with average vulnerability occupy large parts in the upper plain of Saïs and in its Northwest of the plateau of Meknes, while the low degrees are represented in the rest of the basin.

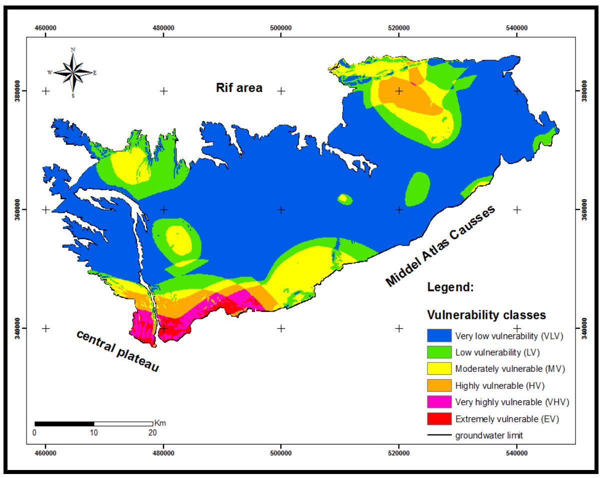

Fig.6. Map of intrinsic vulnerability of groundwater basin Fez-Meknes by PRK method.

The development of vulnerability maps in the Fez-Meknes basin aquifer shows that its distribution is different regarding the area and site location. This distribution is shown by carefully chosen colors attributed to each vulnerability index. The maps of groundwater vulnerability listed with each method are significant in terms of spatial analysis of water pollution. The resulting vulnerability classes (Fig.7) emphasize only three classes of vulnerability: a high vulnerability to the center and edges of the plateau of Meknes, a medium vulnerability which occupies a large part of the basin and a low vulnerability negligible.

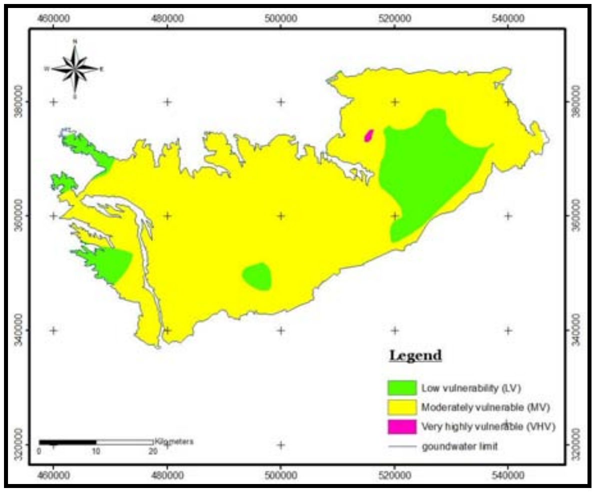

Fig.7. The map of intrinsic groundwater vulnerability of the Fez-Meknes basin by GOD method

Conclusion

The study assesses the vulnerability of the groundwater aquifer in the Fez Meknes basin. It apprehends the sensitivity of water resources due to the pollution coming from the soil surface. Three methods (DRASTIC, GOD and PRK) were applied. The obtained results show a finer evaluation with the DRASTIC method. The GOD method shows that the most vulnerable zones appear where the permeability of layers of the saturated zone is raised, and appear more exactly in the South of the plain of Sais in the contact with the Lias limestone and dolomites of the Atlas mountain. Zones with average vulnerability scatter on the whole basin.

The gathering of the indications by class, in PRK method, translates the intrinsic vulnerability of the aquifers' system in the region. It allows the distinction of different levels of vulnerability. The most dominant class is "less vulnerable", including a very large surface of the basin.

With the GOD method, only three classes may be recognized with strong, average and low vulnerability. But globally, the basin appears altogether in average vulnerability.

In conclusion, the obtained maps allow having a general idea on the parameters which condition the vulnerability of water and estimate the sensitive zones, which can be affected seriously by pollution effects. They may be considered as tools of planning and action guiding to fight pollution and engage water protection processes.

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