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FIRST APPLICATION OF THE COP METHOD TO VULNERABILITY MAPPING IN THE MEFFROUCH CATCHMENT (NORTHWEST OF ALGERIA)

PREMIERE APPLICATION DE LA METHOD COP POUR LA CARTOGRAPHIE DE LA VULNERABILITE DU BASSIN VERSANT DU MEFFROUCH (NORD OUEST ALGERIEN)

BENSAOULA F.[1, 3], ADJIM N.[2], ADJIM M.[1, 3],, COLLIGNON B.[4], ZEGHID K.[5]*

[1] Hydraulic Department, Faculty of Technology, University of Tlemcen, Algeria

[2] Department of Electrical, Faculty of Electrical Engineering, Oran University of sciences and technology (USTO), Algeria

[3] University of Tlemcen research laboratory n° 60: Valorisation of Water Resources "V.R.E" BP 230, Tlemcen 13000, Algeria

[4] Hydroconseil, 198 Chemin d'Avignon, 84470 Châteauneuf-de-Gadagne, France

[5] ENSP Filiale SONATRACH, Hassi Messaoud, Algeria

fbensaoula@gmail.com

ABSTRACT

This paper presents the first application of the COP method for the vulnerability mapping in Mefrouch catchment (Tlemcen, Algeria). This method has been developed for the intrinsic vulnerability of carbonates aquifers in the frame of the European COST action 620(Zwahlen 2004). It takes into account three factors: the concentration of flow (C factor), the overlaying layers above the water table (O factor) and the precipitation (P factor). Since the method is intended for the karstic medias, it takes into account karst specific characteristics such as swallow holes and sinking streams. The vulnerability map established in this work shows that Meffrouch catchment is composed of five vulnerability classes. The method classifies 27% of the total area of the catchment as zones of high to very high vulnerability. This percentage reveals that anthropic actions can seriously affect the groundwater of the region. In order to prevent pollutants from reaching this vital resource, the established map can be used for the delineation of zones to be protected.

Keywords: Water resource; Intrinsic vulnerability; Mapping; COP method; Meffrouch catchment.

RESUME

Cet article présente l'application pour la première fois de la méthode COP pour la cartographie de la vulnérabilité à la pollution des eaux souterraines du bassin versant du Meffrouch (Tlemcen, nord-ouest algérien). Cette méthode a été développée pour la cartographie de la vulnérabilité intrinsèque des aquifères carbonatés dans le cadre de l'action européenne COST 620 (Zwahlen 2004). Elle prend en compte trois facteurs: la concentration de l'écoulement (facteur C), les couches se superposant au-dessus de l'aquifère (facteur O) et les précipitations (facteur de P). Cette méthode est destinée aux milieux karstiques et prend en compte les caractéristiques spécifiques du karst tel que les pertes ainsi que les avens, etc. La carte de vulnérabilité établie dans ce travail montre que le bassin du Meffrouch est composé de cinq degrés de vulnérabilité. La méthode classe 27% de la superficie totale du bassin versant comme une zone de forte à très forte vulnérabilité. Ce pourcentage révèle que les actions anthropiques peuvent sérieusement affecter les eaux souterraines de la région. Afin d'empêcher les polluants d'atteindre cette ressource vitale, la carte de vulnérabilité développée peut être utilisée pour la délimitation des zones à protéger.

Mots-Clés : Ressource en eau; Vulnérabilité intrinsèque; cartographie; méthode COP; Bassin du Meffrouch,

INTRODUCTION

The term vulnerability was used in the sixties of the last century in France. It was introduced as a scientific term in technical literature by Albinet and Margat (Doerflinger et al. 1999). The vulnerability mapping is a concept which considers the elementary principle that some land areas are more vulnerable to groundwater contamination than others. This concept is based on the assumption that the physical environment provides some natural protection to groundwater against human impacts, especially with regard to contaminants entering the subsurface environment (Vrba and Zoporozec 1994). The intrinsic vulnerability of groundwater to contaminants takes into account the geological, hydrological and hydrogeological characteristics of an area, but is independent of the nature of the contaminants and the contamination scenario (Zwahlen 2004). The intrinsic vulnerability of groundwater to contamination is, by definition, independent of both the contaminant nature and the contamination scenario (Daly et al. 2002). The first method of vulnerability mapping taking into account the specific properties of karst was EPIK (Doerfliger and Zwahlen 1998). A new approach was proposed in the Cost action 620 (Zwahlen 2004)and finally the COP Method, a fairly complete implementation of this approach, was recommended. This method is an intrinsic resource vulnerability mapping devoted to karstic media. It was developed in 2001 and 2002 by the Hydrogeology Group of the University of Malaga (Vías et al. 2002).The COP method was validated in two carbonate aquifers in the South of Spain (Vıas et al. 2006).

In this article, the COP method is applied to Meffrouch catchment located in the wilaya (territorial division) of Tlemcen (northwest of Algeria). This method, developed for karstic regions of Europe, is applied for the first time in this karstic region of Algeria. Groundwater from karst aquifers is among the most important drinking water resource in the region of Tlemcen. The karst groundwater of this region is intensively pumped through boreholes and is an important supply of drinking water for the population (Bensaoula et al. 2007 ; Fellah et al. 2014).

Karst aquifers are, however, very vulnerable to contamination mainly due to thin soils and the existence of swallow holes and concentration of flow in the epikarst and vadose zone. These characteristics allow the contaminants to reach easily and rapidly the groundwater. The primary purpose of this work is to delineate highly vulnerable areas to pollution within Meffrouch catchment in order to provide immediate protections. Further work is necessary to provide a more efficient protection. However, this work has the merit of presenting the results of the COP method to a karst environment applied for the first time in a north-western region of Algeria.

GEOLOGICAL AND HYDRO-GEOLOGICAL SETTING

Located in the West of Algeria, Meffrouch catchment belongs to the mountains of Tlemcen and has an area of about 90 km^2. The climate that prevails is sub-humid Mediterranean with an average rainfall of 546.56 mm (1976-2010). Its main river is Oued Nchef which is an affluent of a larger catchment (Tafna catchment). The regulation of the flow of the water courses is made by Meffrouch dam (Fig.1 (a) and (b)).

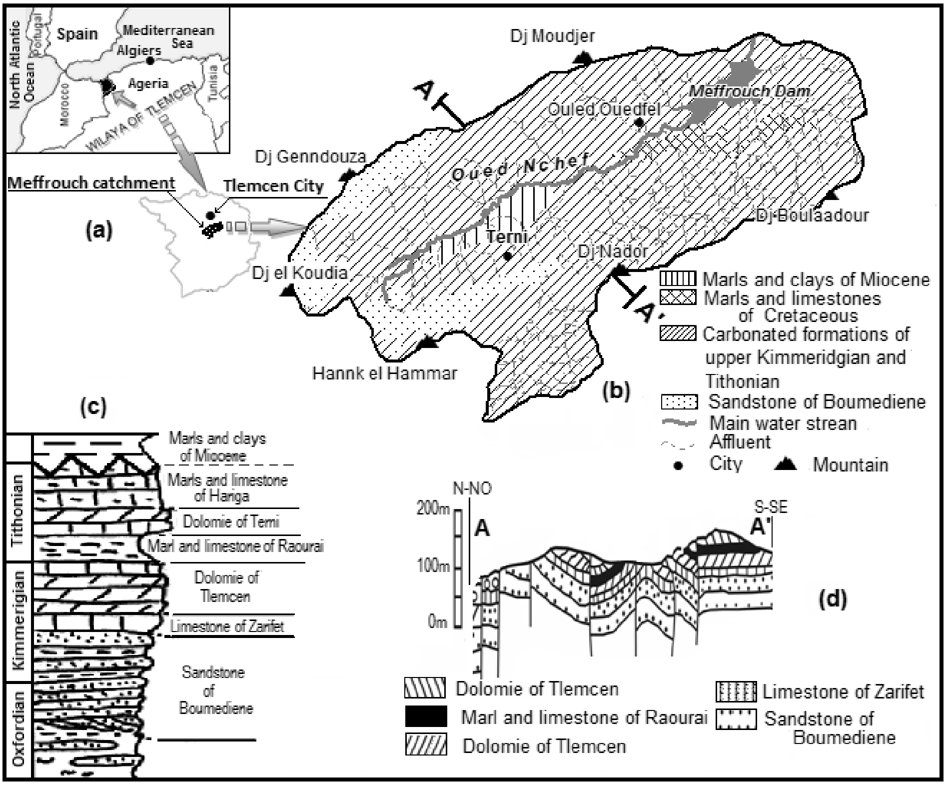

Figure 1 : Geographical and geological setting of the study area. (a) Relative location of the study area, (b) details on the study area, (c) lithostratigraphic log of the region (Bensaoula 2006) and (d) geological cross-section (Bensaoula and Bensalah 2007)

The area of the catchment is covered by Oxfordian to Cretaceous formations in a sedimentary concordance (Fig.1 (c) and (d)). However, it must be pointed out the presence of a small miocen outcrop discordant on the Jurassic formations. This testifies the lower post-Miocene age of some of the major tectonic accidents affecting the region (Gevin 1952). Outcrops of quaternary formations are very limited. This area is crossed by major faults that give a compartmentalized structure. Thus, the hydrogeology of the region is a little complicated. The cross-section along the axis AA’ shown onFig.1 (b) is given in Fig.1 (d).

The groundwater of the catchment of Meffrouch is contained in two calcareo-dolomitic formations named *“Dolomie” of Tlemcen* and *“Dolomie” of Terni*. These formations are largely karstified and are the main aquifers in the region. This water is of a good physico-chemical quality and contributes largely in supplying drinking water to the population of Tlemcen. Karstification of these two formations has been demonstrated by:

- the existence of very developed fields of lapiaz, caves and avens,
- the existence of cavities and caves detected during borehole drillings: cavities around 0.5 to 4 meters in height were crossed during drilling operations (Bensaoula 2006; Bensaoula 2007) and during the first excavation of the Meffrouch dam in 1880.

METHODOLOGY

The COP method is used in this study to establish the vulnerability map of Meffrouch catchment. This method is an intrinsic vulnerability mapping technique based on the estimation of the protection capacity of the layers overlying the aquifer represented by O factor, the surface flow recharge conditions represented by C factor and the precipitation represented by P factor. The procedure used to evaluate the vulnerability according to the COP method is shown in Fig.2 and explained in detail by (Vıas et al. 2006). A brief explanation concerning the evaluation of the C, O and P factors for the studied area and an outline of the main results are given below.

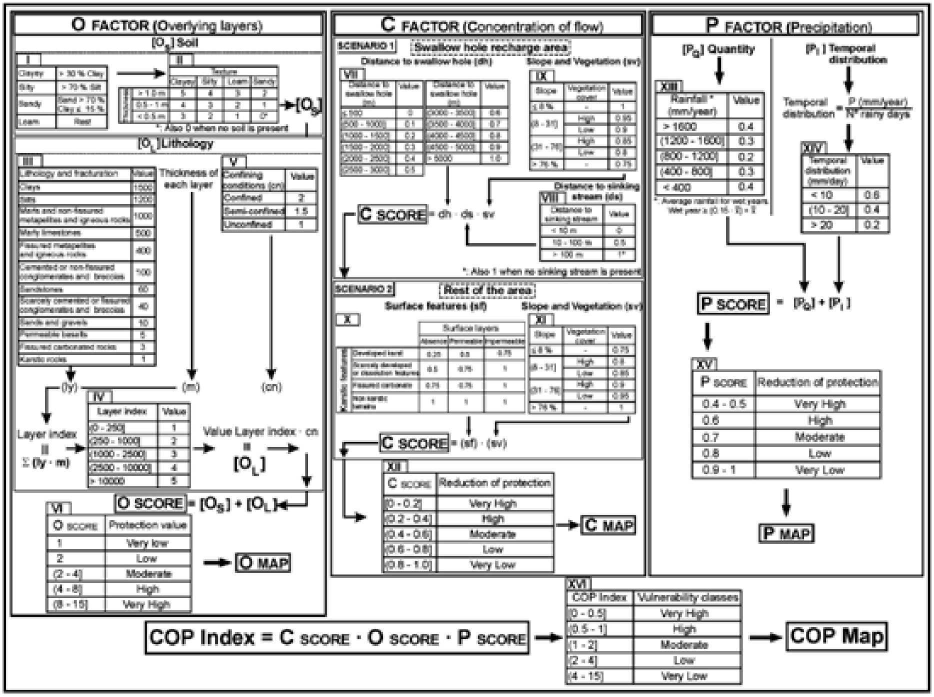

Figure 2 : Flowchart of the COP method: showing the different steps for the evaluation of the C, O, P factors and the COP index (Zwahlen 2004). Table I-VI: evaluation of the O factor, table VII-XII: evaluation of the C factor, table XII-XV: evaluation of the P factor and table XVI: evaluation of the COP index.

Estimation of the O factor

The O factor may comprise up to four layers : topsoil, subsoil, non-karst rock and unsaturated karst rock (Zwahlen 2004). This factor characterizes the natural protection provided to the groundwater by the layers above the saturated zone (Vias et al. 2010;Zwahlen 2004). This O factor is the sum of two subfactors, namely, the OS subfactor and OL subfactor. The OS subfactor takes into account the overlying layers and is evaluated according to Fig.2- (II). The results obtained in this manner for the study area are shown in the map of Fig.3. Regions with no soil represent 29.50% of the total surface area of the catchment and are affected the value 0. Soils constituted of loam with thicknesses less than 0.5m represent about 28.50% of the total surface area and are assigned the value

1. Sandy soils of thicknesses greater than 1.0 m represent 30% of the total area and are assigned the value 2. Loam soils of thicknesses varying between 0.5 m and 1.0 m represent 9% of the total area and are affected the value 2. Only 3% of the total surface area, composed by a thick layer of clay (thickness > 1m), has a maximum protection and is affected the value 5. It can be noticed, so far, that most of the soils of the studied area ensure only a small or no protection at all.

The values affected to the O_L subfactor are evaluated as specified in Fig.2-(III, IV &V) and the resulting map is shown in Fig.4. Within about 42% of the studied area, the aquifer is confined and has a high protection value (i.e. $8<O_L<10$). The rest of the aquifer within the studied region is at free surface with a very small protection ensured by the unsaturated zone corresponding to an O_L value equal to 1.

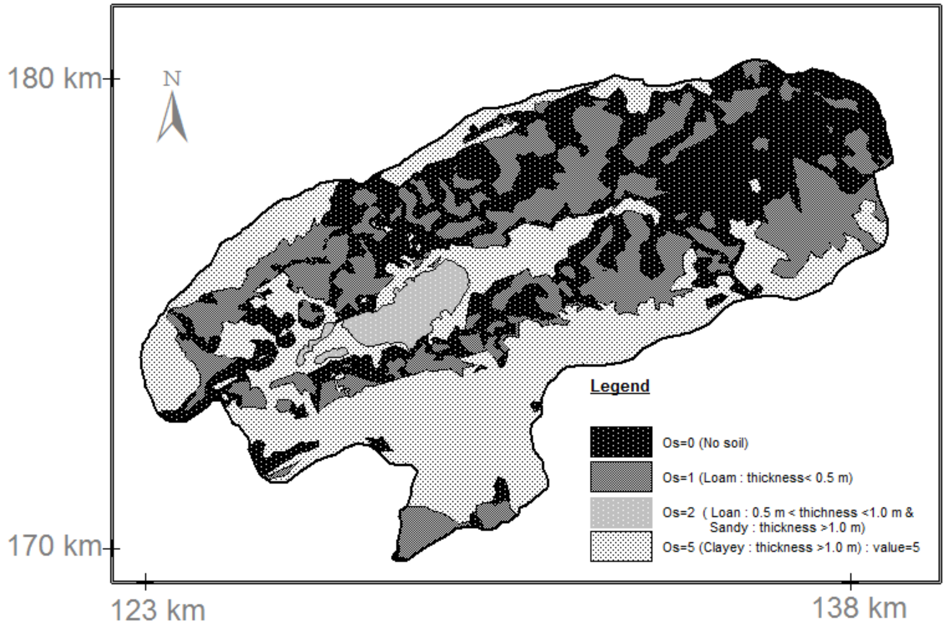

Figure 3 : The Os map: protection provided by the overlying soils,

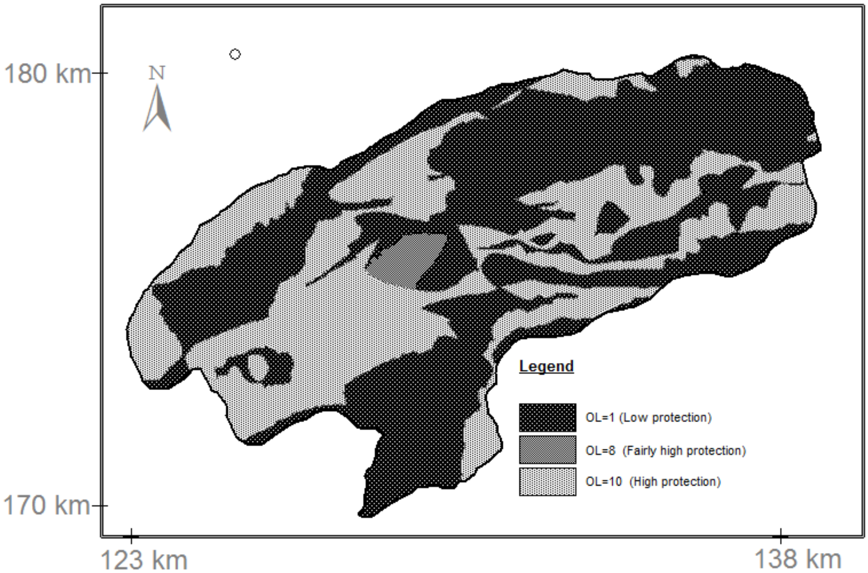

Figure 4 : The O_L map: protection provided by the unsaturated zones

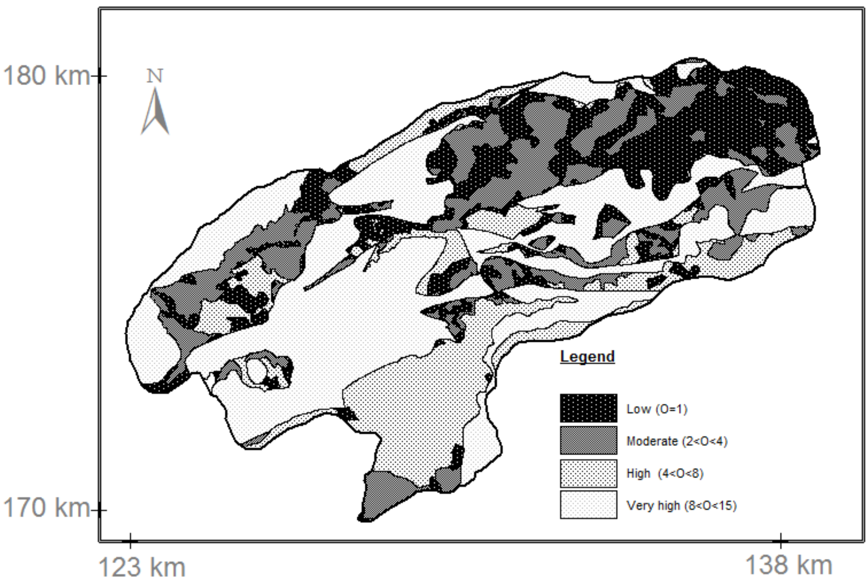

Figure 5 : The O map: total natural protection provided both by soils and saturated zones

The total natural protection provided to the groundwater of the region is depicted by Fig. 5. This O map is obtained by superposing the O_S and O_L maps and adding their scores (cf. Fig.2–(VI)). This map represents the natural protection ensured both by the overlying soils and the unsaturated zones. The lowest values of the O factor (higher vulnerability) correspond to regions constituted of karstic rocks outcrop and where the soil is poorly developed or absent. Regions having high protection correspond to areas covered with soils or areas having low permeability lithologies.

Estimation of the C factor

The O factor map may be sufficient to describe natural protection of groundwater to contamination if all rainfalls infiltrate diffusely into the soil and percolate through the unsaturated zone towards the groundwater. However, this is not the case in the Meffrouch catchment where many swallow holes were identified. The C factor is specific to karst aquifers and is taken as a corrector coefficient of the O factor. It characterizes the nature of the infiltration process (diffuse or concentrated) (Zwahlen 2004). Hence, the C factor represents the potential for contaminated water to bypass the protection provided by the overlying layers (Daly et al. 2002). This factor was adapted from the I factor of the EPIK (Doerfliger and Zwahlen 1998) and PI methods (Goldscheider et al. 2000).The various steps to evaluate this factor are given in Fig 2- (VII-XII). The estimation of the C factor in the studied area was carried out according to scenario 1 as described in Fig 2-(VII, IIX, IX and XII) in regions with low permeability where the flow is concentrated towards swallow holes. For this purpose, the swallow holes existing in the study area were identified both by in situ visits and by using a topographic map of the region. In the rest of the study area where the flow is diffuse, the C factor was evaluated by scenario 2 as described in Fig.2-(X, XI and XII).

The resulting C map is given in Fig.6where it is noticed that the higher reduction of protection (low values of the C factor) is found in karstic formation regions with low slops and no surface layers as well as in regions with concentrated infiltration via swallow holes.

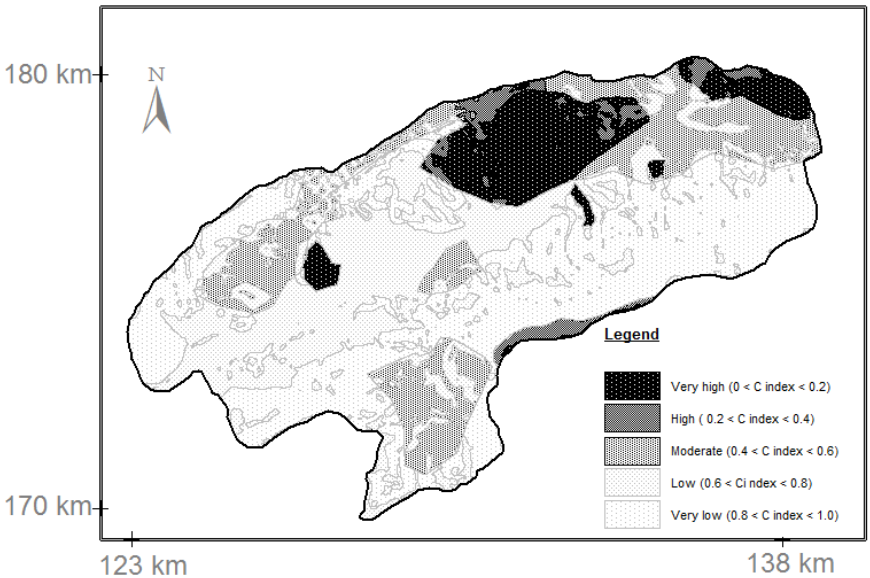

Figure 6 : The C map: reduction of protection due to the specific karts characteristics

Estimation of the P factor

The P factor characterizes the climatic conditions. This latter differentiates zones with widely varying rates of rainfall. It considers the spatial and temporal variability of precipitation which is the transport agent of contamination from the surface of soil to the groundwater resource. The P factor is the sum of two subfactors, namely, the P_Q subfactor, which characterizes the quantity of precipitation, and the P_I subfactor, which characterizes the intensity of precipitation. This factor was evaluated for the studied area according to figure 2-(XIII-XV). The precipitation data used for the estimation of the P factor was provided by the Algerian National Agency of Hydrologic Resources (ANRH) for the period lying between 1976 and 2011. The average value of rainfall of the wettest years for this period and the average number of rainy days per year were found respectively equal to 783.27 mm and 113 days. These values led to a P factor equal to 0.9. This P factor value reflects that the reduction in the level of protection due to the precipitation is very low.

The P factor was taken as homogeneous all over the study area because of the lack of other meteorological stations in the region. A unique value attributed to this parameter, all over the studied region, does not influence the distribution of the vulnerability classes but it affects the indexes given by the C and O factors. This factor reduces the protection provided by the O factor by 10% all over the region.

Finally, the COP map was obtained by superposing the O, C and P maps and multiplying their scores (cf. Fig.2- (XVI)). This map, shown in Fig.7, reveals the existence of five vulnerability classes within the area of study. Details in percentages of area for each vulnerability class are given in Table 1. The COP map of Meffrouch catchment shows a very high vulnerability throughout 12.15% of the total surface area: this is due to the existence of many swallow holes and to the high degree of karstification of the outcrop of the dolomite of Tlemcen and Terni (O_L=1). In addition, these areas have no soils (Os=0) or have only loam soils with thicknesses less than 0.1m (O_S=1). Areas of high and moderate vulnerabilities cover more than 29.80% of the total surface area of the catchment. These areas are coinciding with outcrops where the protection assigned by the O factor is low or moderate. Areas of very low and low vulnerabilities represent 58.05% of the total surface area. These areas correspond to regions where the protection provided by the unsaturated zone is very high (cf. Fig. 4).The aquifer under these areas is confined, and protected by thick layers of clays and marlylimestones.

Table 1 : Area percentages of the various vulnerability classes within the Meffrouch catchment

Vulnerability class	COP index	Area (km^2)	Area percentage (%)
Very high	0- 0.5	10.74	12.15
High	0.5-1.0	13.12	14.85
Moderate	1.0-2.0	13.18	14.95
Low	2.0-4.0	16.05	18.15
Very low	4-15	35.27	39.90

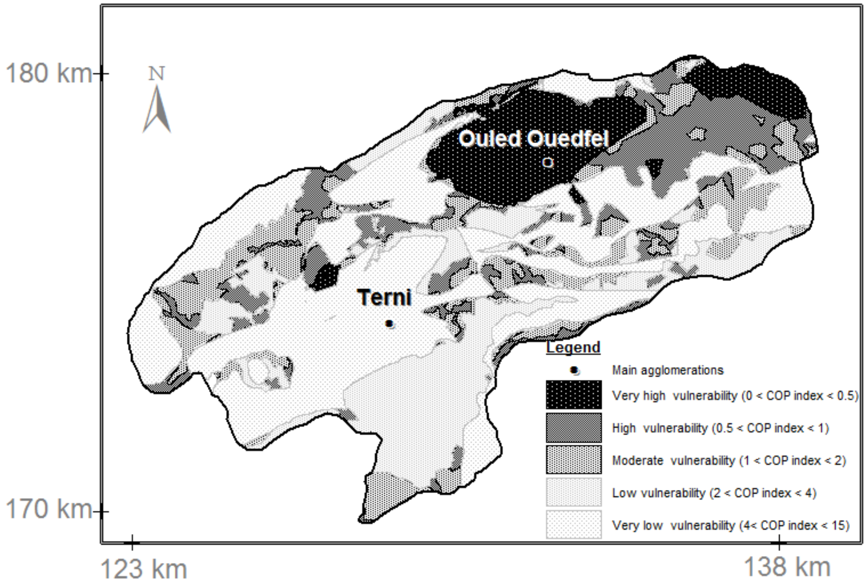

Figure 7 : Intrinsic vulnerability map of Meffrouch catchment based on COP model

The COP map, shown in Fig 7, can be used to delineate highly vulnerable areas to pollution within Meffrouch catchment in order to provide immediate protection perimeters. To simplify this map, a more practical map is proposed in this work. This map, depicted in Fig.8, is simple to use in order to regulate polluting activities on the studied area. It was elaborated from Fig.7 by dividing the studied area into only three classes of vulnerability, namely, zones of high vulnerability, zones of moderate vulnerability and zones of low vulnerability. Zones of high vulnerability comprise areas of very high vulnerability and immediate surrounding areas of high and moderate vulnerabilities as classified by Fig. 7. Zones of moderate vulnerability include areas of high vulnerability and areas of moderate vulnerability of the map in Fig.7. These zones may include some small areas of low and very low vulnerability, which are located within areas of high and moderate vulnerability shown by the COP map model. Zones of low vulnerability include areas of low and very low vulnerability given by the COP model.

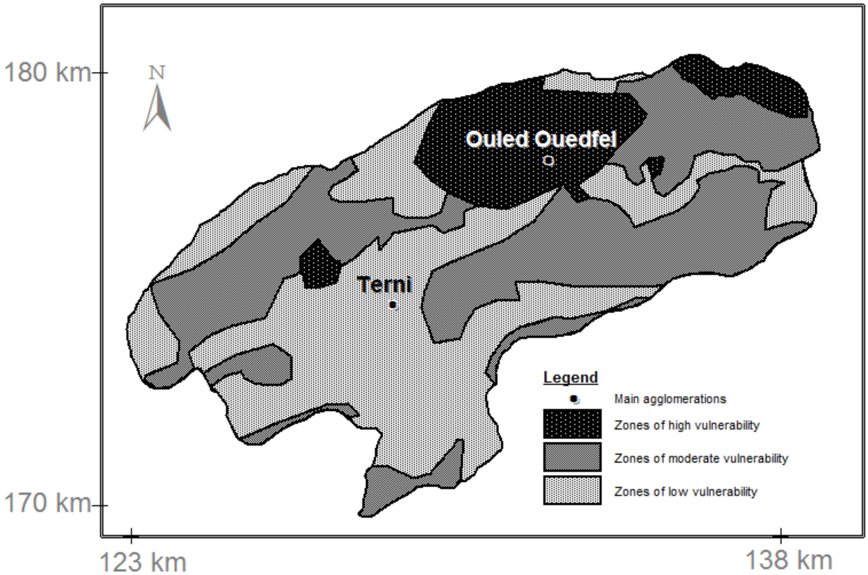

Figure 8 : Simplified vulnerability map of Meffrouch catchment based on COP model

The local authorities can easily use the simple zoning map proposed in this work in order to prohibit potentially polluting activities on zones of high vulnerability. They may allow certain polluting activities on moderate vulnerability areas while imposing strict technical inspections. Particular attention is drawn to Ouled Ouedfel agglomeration (Fig.7 & Fig. 8).This town is located on a high vulnerability zone and ejects its wastewater without any treatment to its environment. This wastewater flows directly towards swallow holes located just downstream. The impact of this wastewater on the quality of the groundwater of the region cannot be officially confirmed because of lack of regular water quality control points but, so far, this may be affirmed by the existence of some polluted springs in the region.

CONCLUSION

It is for the first time that the "COP" model of intrinsic vulnerability mapping is applied, outside Europe, to a northern region of Algeria. The COP map elaborated in this work seems to match correctly to the nature of the studied region in terms of vulnerability to pollution. The existence of some polluted springs in the region may affirm the direct relation between anthropic activities on the Mefrouch catchment and the deterioration of the groundwater quality. The COP model elaborated in this work can be validated by installing quality control points in the region and regulating polluting activities on the catchment.

Special and urgent actions should be undertaken in order to strictly control wastewater and solid wastes produced by the town of Ouled Ouedfel located on a high vulnerability zone. In addition to the two main towns of the region, many spread hamlets eject their wastewaters directly to the environment without any treatments. The simplified vulnerability map elaborated in this work can help the local authorities of the wilaya of Tlemcen to regulate adequately anthropic actions on the Meffrouch catchment and to establish a rational land-use planning of the region.

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