Groundwater Vulnerability Mapping Assessment Using Overlay and the DRASTIC Method in Catalonia

Xavier Carreras, Josep Fraile, Teresa Garrido, and Carles Cardona

Abstract There are different vulnerability methods to evaluate groundwater potential pollution. One of them is the DRASTIC model, a well-known and widely used parametric method based in the analysis of seven hydrogeological factors. The applicability of the DRASTIC method was tested in the area of Catalonia, covering all territory (more than 31,000 km^2). Available information related to groundwater characteristics was selected and taken from geological and hydrogeological cartographies, groundwater database, and bibliography. A cartography of 199 aquifers were used to group and to extrapolate the information when only spared data were available. Afterwards, data were processed in order to be adapted to the DRASTIC parameters. The outcome of the vulnerability map was a raster file with a 100 × 100 m pixel resolution. Two different coverages of vulnerability were calculated from different weightings according to the DRASTIC parameters: generic pollutants and pesticides. This analysis was made both in confined and non-confined aquifers. Resulting maps were considered very satisfactory, and they were compared with other existing vulnerability works in more local areas with high similar results. These vulnerability layers have constituted different groundwater management tools. In this project, we applied this approach in order to assess the risk of non-achievement of the Water Framework Directive's (WFD) objectives for Catalan groundwater. Pressure and subsequent risk analyses were carried out from overlaying human activity areas with groundwater chemical data. For instance, nitrogen load from agriculture sources, contaminated soil areas, or sewage sludge application was overlaid with vulnerability map in order to obtain the global pressure.

Keywords Catalonia, DRASTIC, Groundwater, Vulnerability

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Abbreviations

ACA   Catalan Water Agency
ICGC   Cartographic and Geological Institute of Catalonia
IMPRESS   Impact and human pressure analysis
WFD   Water Framework Directive (2000/60/EC)

1   Introduction

One of the earliest definitions of groundwater vulnerability came from Albinet and Margat [1, 2] as the possibility of percolation and diffusion of contaminants from the ground surface into water table reservoirs under natural conditions. Subsequent proposals defined vulnerability as an intrinsic property of a groundwater system that depends on the sensibility of that system to human and/or natural impacts [3]. Vulnerability could be considered a relative characteristic that indicates where contamination is most likely to occur, but cannot be directly measured in the field. The assessment of groundwater vulnerability is not always an easy task, and difficulties in obtaining reliable field data constitute usually an important limitation. However, it is an effective tool to delimitate areas affected by groundwater diffuse contamination, such as intensive fertilizer application, defining a control network, and also applying vulnerability maps as a management tool.

There are several methodologies for the evaluation of groundwater vulnerability. Most of them use overlays and index methods consisting in algebraic operations of hydrogeological parameters. The DRASTIC method, developed by Aller et al. (1987) [4] for the US Environmental Protection Agency (EPA), is one of the most widely and contrasted tools used in several countries for this purpose. DRASTIC and other simplified methods such as GOD [5], EPIK [6], COP [7], SINTACS [8], or CRIPTAS [9] are also used to assess groundwater vulnerability.

2 DRASTIC Methodology Applied at Groundwater of Catalonia

DRASTIC methodology was developed with the purpose of creating a systematic regional evaluation using major hydrogeological factors to infer the potential for contaminants to enter groundwater. DRASTIC was initially designed to use existing information available from a variety of sources. It was initially applied to evaluate potential groundwater pollution in different locations of the United States and requires a high degree of information, which often entails great difficulties of application. DRASTIC methodology was developed in other countries, but usually in a more reduced scale [10–13].

The DRASTIC method has four main assumptions: (1) the pollutant is introduced into the ground surface; (2) the contaminant is transported throughout the saturated zone by precipitation recharge; (3) the contaminant has the mobility of water; (4) and the minimum study area required is about 40 km^2. This system is used to estimate the intrinsic vulnerability basically in granular porosity media, although in karst and fractured environments, a modified DRASTIC has been used [7, 14, 15]. This is a parametric method, based on weighting and sorting. The DRASTIC Index considers seven hydrogeological properties (acronym of DRASTIC): D, depth to water; R, net recharge; A, aquifer media; S, soil type; T, topography of the terrain; I, impact of the vadose zone; and C, hydraulic conductivity of the aquifer. Ratings for each DRASTIC variable are assigned to a value that ranges from one to ten in an increasing order of impact to vulnerability and a weighting value from one to five (Eq. 1):

$$DRASTIC\ Index\ =\ Dr*Dw\ +\ Rr*Rw\ +\ Ar*Aw\ +\ Sr*Sw \\ +\ Tr*Tw\ +\ Ir*Iw\ +\ Cr*Cw \tag{1}$$

where r = rating and w = weight.

The applicability of DRASTIC method was tested in order to assess the groundwater vulnerability in Catalonia (Fig. 1), covering a total area over 31,000 km^2.

The main effort in this regional work was the compilation and interpretation of all parameters and their extrapolation into areas with less information. A direct transposition was done when information covered all the territory, whereas if sparse information was available, it was just necessary to aggregate it. In this last case, the reference cartography was the "Aquifers map of Catalonia" [16], where a total of 199 aquifers were defined (see reference map in Fig. 2a). Among these, 13 confined aquifers are differentiated, mainly in delta areas where a silt and clay formations are clearly acting as an aquitard, differentiating two aquifers in the same vertical.

A second challenge was the transposition of selected information into DRASTIC parameters. As a general rule, classification of parameters has followed the proposal defined by Aller et al. [4]. Despite this, a specific conversion from this initial rating was applied to the vadose zone (I) and soil media (S) parameters according to
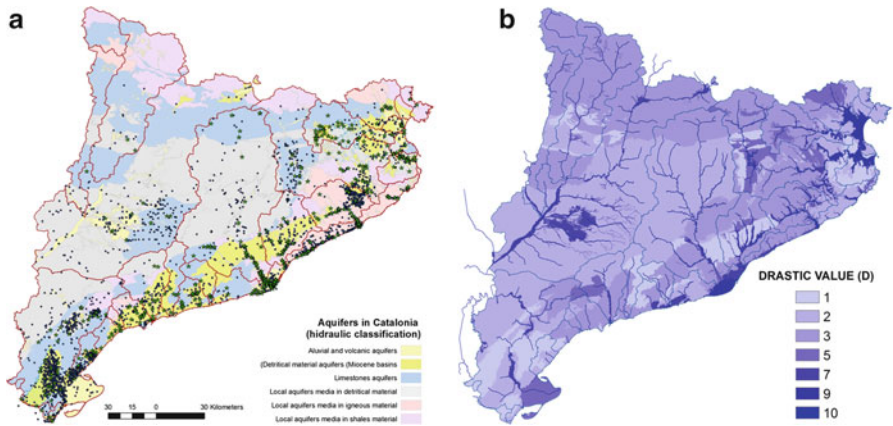
Fig. 1 Location of Catalonia

Fig. 2 Groundwater level data available (ACA); *star figures* represent points included in the monthly piezometric monitoring network. Reference map: aquifer delimitation in Catalonia (*left*). Depth to water (D) ranges according to DRASTIC method in Catalonia (*right*)

the information available in Catalonia and following the maximum accuracy possible.

Information to elaborate the seven DRASTIC hydrogeological factors came from a great variety of sources, specifically from geological and hydrogeological cartographies, from different groundwater database, and from local studies. As a result, each DRASTIC parameter was finally aggregated in layers set at different scales depending on the information source: 100×100 m cells, hydrographical basin, 199 aquifers previously defined, geological 1:50,000, and hydrogeological 1:250,000 or soil-type parcel. In order to create, treat, and overlay all these layers of information, an important development of geographic information system (GIS) tool was required. A schematic summary of the ranges and ratings finally used is showed in Table 1, while a brief description for each DRASTIC parameter is explained.

2.1   Depth of Water (D)

Depth of water (D) refers to the distance from the surface to the water table, which corresponds to the depth of material through which a contaminant must travel before reaching the aquifer. This parameter is related to the transit time of the contaminant in the unsaturated zone. It is assumed that the shallower the depth, the more vulnerable is the aquifer pollution.

Background information of water levels came mainly from the ACA hydrogeological database. It has more than 60,000 points, among which more than 3,000 have information about groundwater level. Besides, 510 points are included in the quantity monitoring network (some data from the 1970s) [17], with a monthly sampling that provides knowledge on potential variations of annual levels (Fig. 2a). Additionally, bibliographic information, mathematical models available, and other local studies (some of them inedited) [18, 19] were used in this analysis, especially in areas where groundwater level information is not so extensive. The ranges and ratings applied follow the approach defined by Aller et al. [4]. Despite that from a hydrogeological point of view it is important to know precisely the value of water level, the DRASTIC range values (Table 1) show that the influence of this parameter is relevant up to 30 m, because far from these depths the DRASTIC value was set to 1. Finally, (D) parameter was mapped, with range values grouped by each aquifer. In unconfined aquifers, this parameter corresponds to the water table, while in confined aquifers the depth to the top of the aquifer was estimated. In these cases, the knowledge of the structure and aquifer thickness was absolutely necessary. Results are showed in Fig. 2b.

Table 1 Range and rating of the DRASTIC parameters

D (m)		R (mm)		A	
0–1.5	10	0–51	1	Gravels, sands (alluvial and deltaic fm.)	6–8
1.5–5	9	51–102	3	Massive conglomerates and sands	6–8
5–10	7	102–178	6	Massive limestone and dolomite	6–9
10–15	5	178–254	8	Marl and detrital limestone	4–7
15–20	3	>254	9	Conglomerates, sands, and marl	3–5
20–30	2			Marl and evaporate formations	3–5
> 30	1			Metamorphic formation	4
				Granite formation	5–7
				Mixed formation and Neocene basins	4–8
S				T (%)	
Urban and industrial zones		1		0–2	10
Forest land, meadows, bushes		4		2–6	9
Urban soils		6		6–12	5
Riparian forests		5		12–18	3
Non-riparian forests		7		> 18	1
Beach		9			
Rocks, round dish		10			
Agricultural land (depending slope value)		2–8			
I				C (m/day)	
Silt, clay, gypsum, and sales		1		0.04–4	1
Shale		3		4–12	2
Igneous rocks and local shale		4		12–28	4
Marl/silty limestone		4		28–40	6
Dolomite		5		40–80	8
Limestone, sand, and conglomerate		6		> 80	10
Travertine and reef limestone		7			
Sand, gravel, travertine, and carbonated roof		8			
Basalts		9			

D depth to water, *R* net recharge, *A* aquifer media, *S* soil type, *T* topography of the terrain, *I* impact of the vadose zone, *C* hydraulic conductivity of the aquifer

2.2 Net Recharge (R)

Considering the precipitation as the most important source of recharge in groundwater, this parameter refers to the total quantity of precipitation (per unit area), which infiltrates and percolates to the water table. This recharge of water is the main vehicle to leach and transport a contaminant vertically to the water table and horizontally within the aquifer. Therefore, the vulnerability to pollution is enhanced by high recharge rates. Practices like irrigation or artificial recharges could be other sources that may enhance net recharge and could be taken into account, but they haven't been considered in this project.
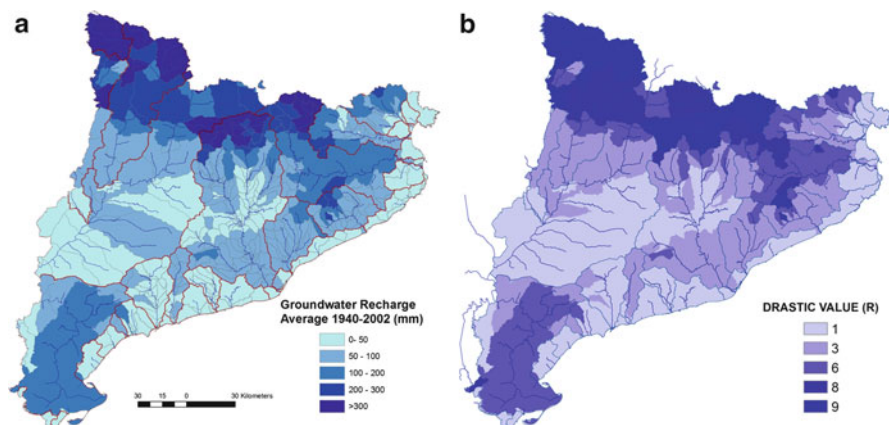
Fig. 3 Average groundwater recharge (mm) for hydrographical subbasin defined in Catalonia (506) with the hydrometeorological Sacramento model (*left*). Net recharge (R) ranges according to DRASTIC method in Catalonia (*right*)

Information used for this parameter came from an estimation of groundwater recharge in Catalonia [20]. This subterranean recharge was calculated from a hydro-meteorological model named "Sacramento Soil Moisture Accounting (SAC-SMA)," from the US National Weather Service and California Department of Water Resources [21, 22]. It's a contrasted model applied in several countries and used also in ACA to assess the total water resources and as a water management tool. The work scale in this project was 506 hydrographical basins defined, with an average area of 91 km^2 (minimum 1.3 km^2, maximum 1,650 km^2). With a monthly discretization, the model was finished and calibrated with flow data from gauging stations (more than 70). The analyzed period ranges from 1940 to 2002, with an average ground-water recharge calculated near 130 mm, which represents 16% of the rain (between 10 and 20%) and around 60% of total water contribution. This average value calculated in all 506 basins was the value adopted for the calculation of this DRAS-TIC parameter (Table 1 and Fig. 3a). In unconfined aquifers, the ranges and ratings applied follow the proposal defined by Aller et al. [4]. In confined aquifers, a value between 0 to 3 points was subtracted to the parameter value from the upper aquifer, based on expert criteria and knowledge of the depth to the top of the aquifer and the aquitard developed. The resulting map is showed in Fig.3b, where a clear relation between the upper basin areas and the groundwater recharge is observed. Also the areas of limestone and karstification formations have a high groundwater recharge.

2.3 Aquifer Media (A)

This parameter refers to the properties of the rock which serves as an aquifer. That includes basically the degree of consolidation of the subsurface environment and also the lithology and the structure of the aquifer, the nature of porosity, and the
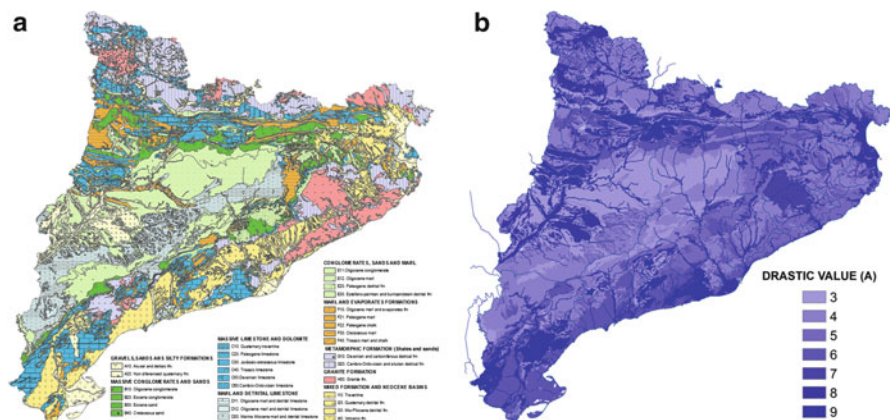
Fig. 4 Map of hydro-areas of Catalonia 1:250.000 (*left*). Aquifer media (A) ranges according to DRASTIC method in Catalonia (*right*)

potential karstification (porosity secondary). These properties control the transport of pollutants within the aquifer. In general, the larger the grain size and the more fractures or openings within the aquifer, the higher the permeability and the lower the attenuation capacity and, consequently, the greater is the potential pollution. The two hydrogeological parameters that are related to this property are the permeability (property of a rock to be pervaded by a fluid) and the porosity (fraction of void space in the material). Therefore, some authors [11] decide to join together this DRASTIC parameter with the "C" DRASTIC parameter (conductivity) and treat them as a single parameter.

In this project, it was opted to use the available cartography of the "Map of hydro-areas of Catalonia 1:250,000" [23] (Fig. 4a). DRASTIC ranges of Aller et al. [4] were adapted from the hydrogeological classification of defined geological formations in this cartography (lithology type and geological ages) (Table 1). Also, an expert criteria allowed to differentiate in each hydrogeological class some aquifers with different behaviors (knowledge of the dominant lithologies, karstification, etc.), being able to associate different DRASTIC values. The resulting map is showed in Fig. 4b. The same methodology was applied in unconfined and confined aquifers.

2.4 Soil Type (S)

Soil type (S) refers to the uppermost portion of the vadose zone, commonly considered the first 1.5 m, which has a significant biological activity. Soil has a significant importance because it is related with the amount of recharge that can infiltrate. Also, where soil zones are well developed, the first attenuation processes of filtration, sorption, volatilization, or biodegradation can be done before the

contaminant penetrates into the vadose zone. The amount of clay, granulometry, and organic matter are the relevant parameters associated to the soil zone that control the pollutant infiltration. In general, the presence of clay and small grain size, along with the potential presence of organic matter, reduces the vulnerability of the groundwater to pollution.

Information about soil characteristics is in general difficult to obtain; hence, this is the most difficult DRASTIC parameter to assess. Due to the lack of a soil map at regional scale, this DRASTIC setting was assessed with the "Land cover map of Catalonia 1:250,000, v. 4" [24] (Fig. 5a). The land cover classification (level 2) (further information can be found in [25]) was used for the assessment of the potential development of soil. Then, the DRASTIC ranges were defined taking into account the lithological soil classification of the land cover map and adopting the proposal of Aller et al. [4] (Table 1). For example, rock areas have a value of 10, while urban and industrial zones, which have lost most of their natural soil and have been replaced by all sorts of artificial covers, have a value of 1. On agricultural land zones, a specific analysis was undertaken. The slope, as well as the lower proportion of fine material in deltaic areas, was taken into account (see more information in [26]). Then, depending on the slope percentage, the range of the adopted values was 2 if the slope was less than 2%, 3 if the slope ranged between 2 and 5%, 5 if the slope ranged between 5 and 10%, 7 if the slope ranged between 10 and 20%, and 8 if the slope was higher than 20%. Additionally, in deltaic areas, S DRASTIC value had an increase of 2 points. The same methodology was applied in unconfined and confined aquifers. The resulting map is showed in Fig. 5b, where urban areas (metropolitan area of Barcelona) and agricultural zones with a low slope (in general with a soil zone well developed) can be differentiated from forest areas with higher rating values. An exhaustive analysis of the proposed values in these forests areas and in agricultural areas is clearly one of the main improvements to develop.

2.5 Topography (T)

Topography (T) refers to the slope of the land surface. This parameter has an influence on the runoff capacity of the media; so, typically, vulnerability to contamination is reduced as the slope increases.

Information of slope values was determined directly from the Topographic map of Catalonia 1:50,000, v. 1 [27] generating a slope map raster 100×100 m (Fig. 6a). Then, the ranges and ratings applied are exactly to those proposed for Aller et al. [4] (Table 1). The same methodology was applied in unconfined and confined aquifers. The resulting map is showed in Fig. 6b where clearly defined mountainous areas with a general range of 1 are differentiated from plain areas with DRASTIC ranges around 9 and 10.
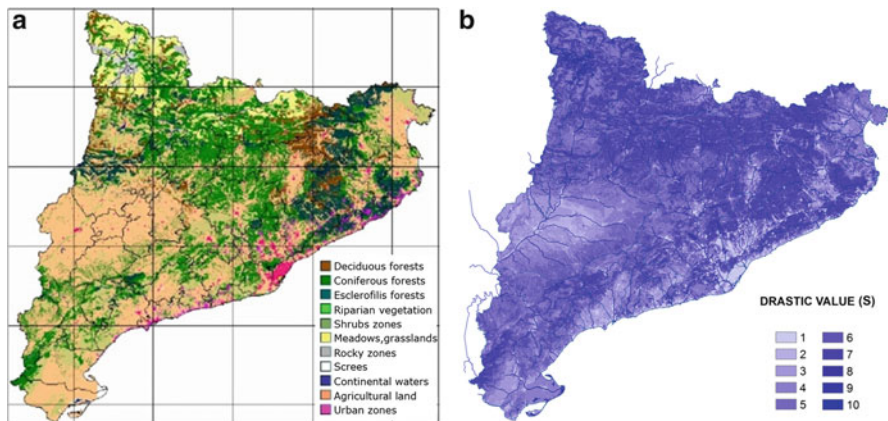
Fig. 5 Land cover map of Catalonia 1:250.000, v. 4 (CREAF, 2009) (*left*). Soil type (S) ranges according to DRASTIC method in Catalonia (*right*)
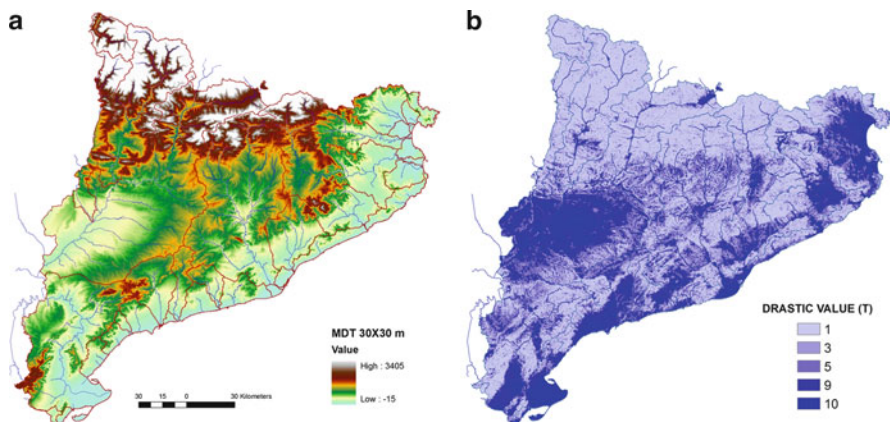

Fig. 6 Digital model topography (raster 30×30 m) (ICGC) (*left*). Topography of the terrain (T) ranges according to DRASTIC method in Catalonia (*right*)

2.6 Impact of the Vadose Zone (I)

Impact of the vadose zone (I) refers to the unsaturated zone above the water table. Although usually it could be considered the upper layer from which the soil is derived, it also must take into account other formations that can interfere when the upper layers are thin and the groundwater levels are deep. The characteristic of the vadose zone determines the attenuation processes that could occur, such as biodegradation, chemical reactions, and volatilization. Like soil type, the analysis of this parameter depends on granulometry, organic matter, and primary or secondary porosity.
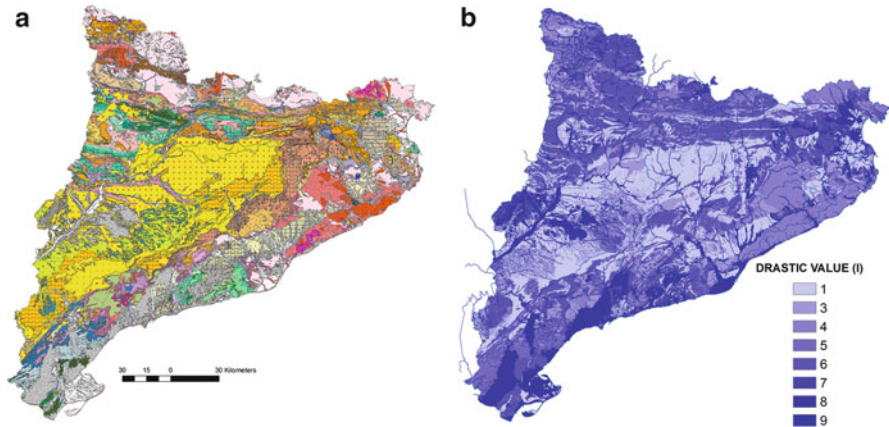
Fig. 7 Geologic map of Catalonia 1:250.000 (ICGC, 2010; legend consultable at www.icgc.cat) (*left*). Impact of the vadose zone (I) ranges according to DRASTIC method in Catalonia (*right*)

The information used to evaluate this parameter came from the "Geologic map of Catalonia 1:50,000" [28]. Figure 7a shows the geological map at a scale of 1:250,000 [29]. DRASTIC ranges provided by Aller et al. [4] were adapted from the lithological classification of this cartography (Table 1). In confined aquifers, the assessment of this parameter was extended to include the vadose zone and any saturated zone which overlie the aquifer. In this case, it was adopted that up to 3 points have been subtracted to the parameter value from the non-confined aquifer, depending if a clay/silt aquitard formation was developed (mainly deltaic aquifers). The resulting map is showed in Fig. 7b. Limestone and granular-sized lithologic units, with ratings of 7–9, are well defined and highly differentiated from zones associated to clay, silt, and shale formations, with range values of 1–2 (Oligocene central area and some Miocene formations).

2.7   Hydraulic Conductivity of the Aquifer (C)

Hydraulic conductivity of the aquifer (C) refers to the ability of aquifer materials to transmit water. The rate at which the groundwater flows is directly related with the rate that a contaminant moves into saturated zones. Hydraulic conductivity is an intrinsic aquifer characteristic that depends on intergranular porosity, fracturing, and bedding planes. As mentioned, this DRASTIC setting is treated sometimes together with the aquifer media (A) because these data are normally scarce and have a large spatial variability (especially in limestone aquifers). Thus, the analysis of this parameter is supported with bibliographic information, such those provided by Davis [30] and Freeze and Cherry [31], that relates conductivity values to aquifer lithology.
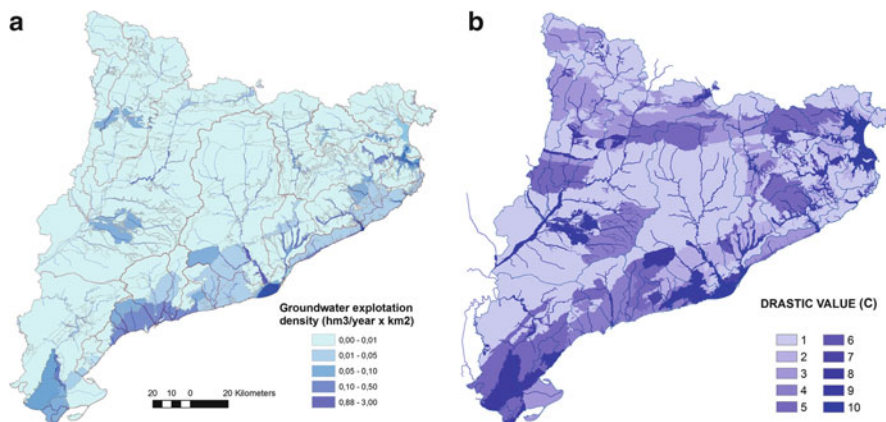
Fig. 8 Groundwater exploitation density map of Catalonia (ACA) (*left*). Hydraulic conductivity of the aquifer (C) ranges according to DRASTIC method in Catalonia (*right*)

A range of hydraulic conductivity was estimated for each of the 199 confined and unconfined aquifers defined in Catalonia, taking into account information about aquifer lithology and bibliographic information from local studies [18, 32] that include sometimes some data pumping tests and expert criteria. Additionally, information of groundwater exploitation in some cases was contrasted to decide some range values. As a general view, Fig. 8a shows the density of exploitation of groundwater (hm^3/year $\times$ km^2) and how the almost 570 hm^3/year total of groundwater extraction estimated in Catalonia is distributed. Although the effect of demographic distribution and water uses is evident, this information reveals the importance of an aquifer and consequently their hydraulic conductivity. The ranges and ratings applied were defined by Aller et al. [4] (Table 1). In Fig. 8b, the resulting map shows that the most relevant aquifers are in deltaic and limestone formations, where the density of groundwater exploitation is also significant.

3 Results of DRASTIC Methodology in Catalonia

Vulnerability maps were obtained, transposing on a fine mesh with a grid spacing of 100 m, by overlaying each individual maps under a GIS environment. Two different coverages of vulnerability were calculated according to different weightings exposed by Aller et al. [4]: for generic pollutants and for aquifer exposed to pesticide pollution. DRASTIC weights finally adopted are shown in Table 2.

For each grid cell, the two indices (generic and pesticide pollution) were calculated. With the ranges defined in Table 2, pesticide values are higher than generic, with maximum values that reach 234, while the maximum value of generic vulnerability is 204. Statistics analysis for generic and pesticide DRASTIC results is shown in Table 3.

Table 2 DRASTIC weights by Aller et al. [4]

Feature	Generic	Pesticide
Depth to water	5	5
Net recharge	4	4
Aquifer media	3	3
Soil media	2	5
Topography	1	3
Impact of the vadose zone	5	4
Hydraulic conductivity	3	2

Table 3 Statistics parameter values for generic and pesticide DRASTIC analysis

Statistics	Generic	Pesticides
Numbers of cells	3,181,185	3,181,185
Minimum value	32	35
Maximum value	204	234
Mean value	93	109
Standard deviation	28	26
Q_{25}	71	90
Q_{75}	111	127

After an analysis of the statistical parameters and taking into account different bibliography and some local works [4, 10, 33], values were finally distributed among five classes, which are attributed to a qualitative degree of vulnerability, ranging from "very low" to "very high." These range values were defined in order to evaluate several pressures that could affect groundwater quality. For this reason, one should consider that range values of the indices could not be compared directly with other groundwater vulnerability analyses. Resulting maps with range values are shown in Figs. 9 and 10 for generic and pesticide analysis, respectively.

Results from the generic vulnerability map are very satisfactory. The highest values were calculated in alluvial aquifers, with high permeability, and where the groundwater level is near the surface. Also, high values were shown in main header basin aquifers associated with aquifer media made up of calcareous and karstified limestone, while the lower values were associated to tertiary (Oligocene) silt and clay units, with a flat topography and a soil generally well developed. In other cases like sedimentary Miocene basins and shale or igneous areas, a moderate or low vulnerability was assessed.

Comparing generic versus pesticide indices (Table 2), in the pesticide case, the specific hydrogeological settings (hydraulic conductivity and aquifer media) do not have a significant importance, whereas soil media parameter has the most influence. Also the topography parameter has a different weight between the two indices. The results shown in Figs. 9 and 10, considering the range scale difference, are considered quite similar, and only with a detailed analysis some differences could be assessed. Then, in areas with a well-developed soil, DRASTIC values from pesticide analysis are lower than the generic values: central-west area (Lleida Plain) and south area (Plana de la Galera) of Catalonia. On the contrary, only in local areas in
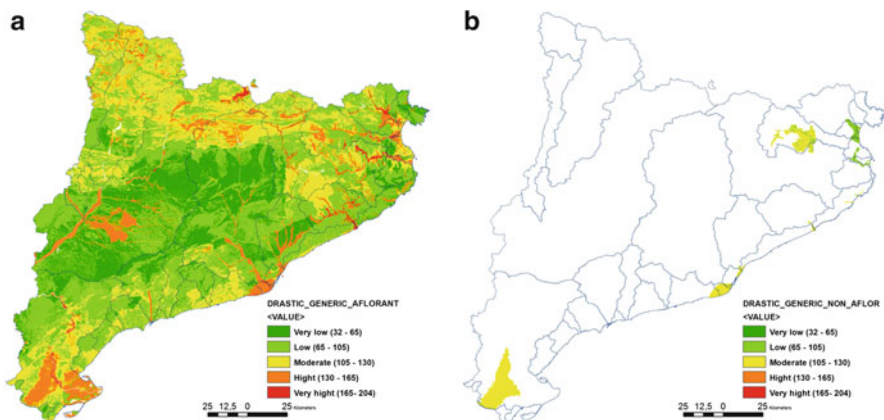
Fig. 9 Generic groundwater vulnerability result of Catalonia: non-confined aquifers (*left*) and confined aquifers (*right*)
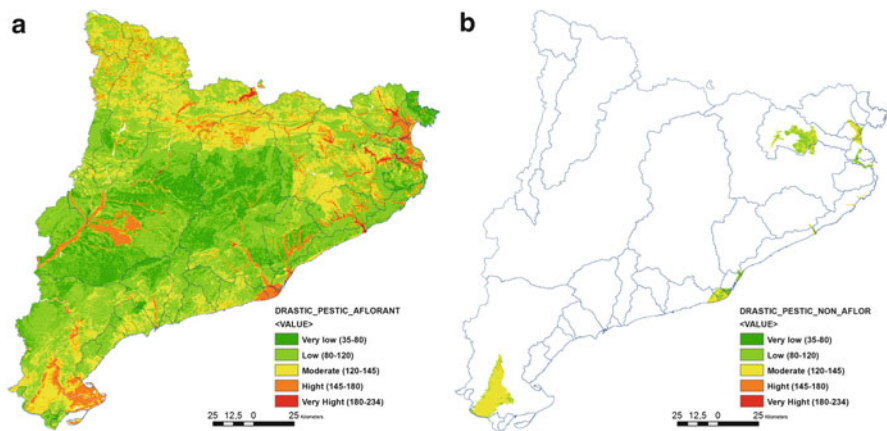

Fig. 10 Pesticide groundwater vulnerability result of Catalonia: non-confined aquifers (*left*) and confined aquifers (*right*)

alluvial aquifers, with a very flat topography and soil development assessed as very low, values from pesticides are higher (local alluvial in north and northeast of Catalonia).

Comparing these results with other local works in Catalonia such as the vulnerability map included in the published "Hydrogeological Maps 1:25,000 of Catalonia" [33], they have a significant similarity. Figure 11 shows an example of this comparison, although with a different map scale, the results are clearly concordant always taking into account the differences in range values (note the difference range adopted especially in moderate, high, and very high values). Currently, in order to improve this 1:25,000 groundwater vulnerability map, a review of the
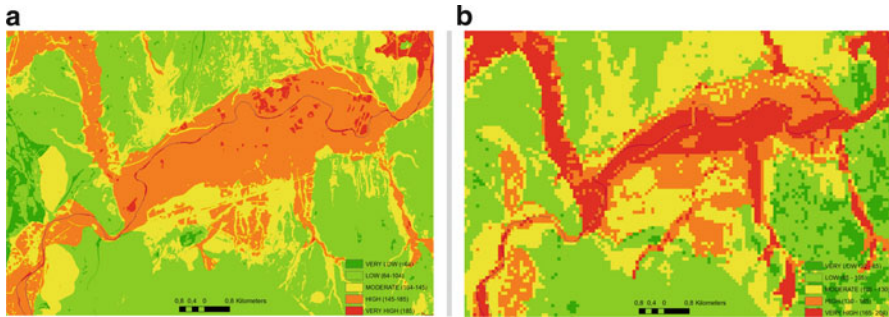
Fig. 11 Comparison between groundwater vulnerability results in local area of "Sarrià de Ter." Hydrogeological map Sarrià de Ter (ICGC, 1:25.000) (*left*). Groundwater generic vulnerability results in same area (*right*)

source of the information and methodological aspect of the DRASTIC parameter assessment has been done by ICGC.

4 Applications and Discussion

These groundwater vulnerability maps constitute a helpful groundwater management tool in a regional scale. As an example, they were applied in order to assess the risk of non-achievement of the WFD's [34] objectives for Catalan groundwater. In detail, groundwater vulnerability maps were applied to groundwater bodies pressures analysis, included in the IMPRESS document [35]. It has to be pointed that although the vulnerability map covers all the Catalan territory, the Catalan River Basin Management Plan is restricted in a half part of Catalonia (where the Catalan Government has full competence on water planning). One of the main objectives of the IMPRESS work was to evaluate the principal human activities that affect the chemical status in groundwater bodies, according to the European methodological guide [36]. In particular, with the aim to assess a pollution pressure, vulnerability maps were overlaid with several groundwater driving forces: contaminated soils, agricultural livestock, urban discharges, sewage sludge application, linear infrastructure (pipelines), gas station locations, etc. Figure 12 shows the example of nitrogen load from agriculture sources that have been overlaid with vulnerability map in order to obtain the pressure to agricultural activities. A subsequent risk analysis was carried out from overlaying each pressure with the results of chemical data. In addition, another direct application of these maps is the impact assessment where potential contaminant activities are being developed (agricultural activity areas, potentially dangerous industrial sites, sewage, water recharge, etc.).

Groundwater vulnerability maps are the result of treating and aggregating information related to hydrogeological properties. Finally, this information is
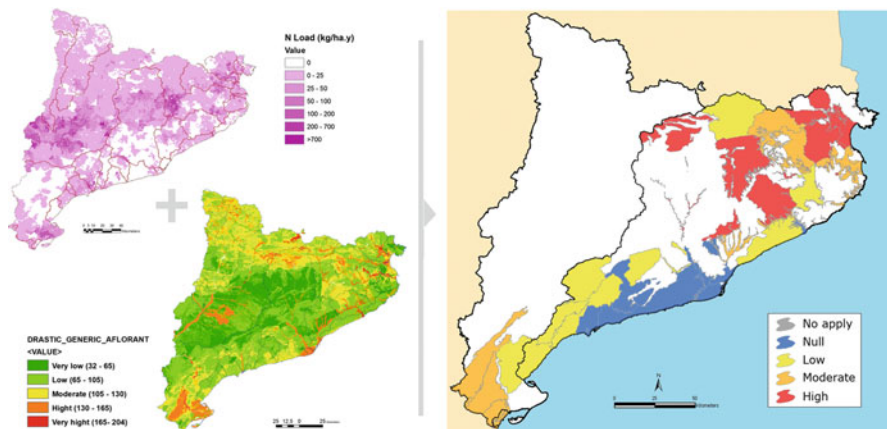
Fig. 12 Example of overlaying maps: nitrogen load in groundwater in Catalonia (*left*); generic groundwater vulnerability result of Catalonia (*central*); potential pressure for N application in groundwater bodies in Catalan Fluvial District

summarized in seven DRASTIC parameters. Some of these layers of information could be applied easily to other sectorial projects. In this sense, it could be considered that the final result is as important as the partial results of each parameter.

The results displayed represent an initial assessment of vulnerability. The analysis carried out could have some limitations that might influence the results obtained. A major restriction could be the absence of information of some DRAS-TIC parameters in cases where a local-scale analysis of the groundwater vulnerability is needed. Especially important is obtaining detailed groundwater levels that could corroborate vulnerability "D" parameter value, which has a very high influence in the DRASTIC method (Table 2). Similarly, a comprehensive analysis of the development and type of soil could be a very useful task to calibrate and improve the vulnerability results. In this sense, from the ICGC is planned to develop a cover of soil map at a scale of 1:250,000 that could be published by the year 2016. Finally, a more exhaustive validation of the vulnerability map with some impacts measured can be done (e.g., nitrates and pesticides).

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