Comparison of three applied methods of groundwater vulnerability mapping: A case study from the Florina basin, Northern Greece

N. Kazakis, K. Voudouris

Aristotle University of Thessaloniki, Department of Geology, Laboratory of Engineering Geology and Hydrogeology, Greece. E-mail: kvoudour@geo.auth.gr

Abstract Three different methods of intrinsic groundwater vulnerability mapping were applied in the alluvial aquifer of Florina basin (NW Greece), covering an area of 180 km^2. Vulnerability maps were produced using the parametric methods DRASTIC, GOD, AVI and the results are compared and evaluated. The three methods use different number of parameters with different weight and produce relatively different results. The comparison between these methods shows that the GOD method has the stronger correlation with the other two methods and produces vulnerability maps comparable with DRASTIC and AVI method.

1 Introduction

Groundwater is under intense anthropogenic pressure in many countries, from sources such as changes in land use, urbanisation, lack of proper sewerage, intensive agriculture and a general increase in demand (Voudouris et al. 2007). These pressures can cause severe degradation of both the quality and quantity of groundwater resources (Polemio et al. 2009). Vulnerability evaluation is fundamental in order to define policies of groundwater resources protection and safeguard, especially for aquifers characterized by a high pollution risk due to intense human activities (Voudouris 2009). Vulnerability maps are a useful tool for groundwater protection and land use planning. Their reliability is depending on data availability, density and accuracy (Vrba and Zaporozec 1994).

In order to assess the groundwater vulnerability against pollution many methods have been developed. Each method uses different number of parameters ranging between 2 (e.g. AVI method–Van Stempvoort et al. 1992) and 7 (e.g. DRASTIC-Aller et al. 1987; SINTACS-Civita 1994). On the one hand, the use of large number of parameters allows one to simulate complex hydrogeological conditions (Gogu et al. 2003). On the other hand, the large number of parameters requires many data (meteorological, hydrogeological, soil data etc), their collection of which is difficult and time-consuming. Furthermore, the required data should be independent with high level of accuracy in order to be avoided inappropriate

DOI 10.1007/978-3-642-24076-8,

protection zoning. The methods which involve fewer parameters are easily applicable, but they are generally difficult adaptable to specific geological conditions.

In this work, three different methods of intrinsic vulnerability mapping were applied in the alluvial aquifer of Florina basin, NW Greece: AVI (Van Stempvoort et al. 1992), DRASTIC (Aller et al. 1987) and GOD (Foster 1987). Vulnerability maps were illustrated from the aforementioned applied methods in GIS context (Arc/Info). The aim of this study was to compare the three methods and the producing vulnerability maps. Firstly, the hydrogeological study was carried out, in the frame of which the following data were collected: rainfall and temperature data, pumping test data, collection of 80 lithological profiles of drilled boreholes and water table measurements. Furthermore, many previous data concerning of geological conditions and soil texture data were performed. All existing geological, hydrogeological, and hydrochemical data were evaluated and reworked.

2 Description of the study area

Florina basin is located in the central part of Florina Prefecture, West Macedonia region, Greece, covering a total area about of 319 Km^2. The mean altitude of the basin is about 620 m (asl) and the mean slope 1.5%.

The land is used mainly for cultivation of cereals and cows and sheep graze the area. In a large part of the area irrigated agriculture is practiced. Lignite deposits have been occurred in the neogene sediments of the basin. The area is characterized by a semi-arid, Mediterranean climate, with an annual temperature of 12.6 °C and an annual rainfall of 472 mm. About 70-80% of annual rainfall occurs in wet period, while summers are usually dry.

3 Geological and Hydrogeological setting

From a geological point of view, the Florina basin is part of the Pelagonian geotectonic zone. The mountainous area of the basin is dominated by carbonate and crystalline rocks (Kazakis 2008). The lowlands of the study area consist of Neogene and Quaternary sediments. The Quaternary sediments are alluvial deposits and consist of alternations of sands, gravels, conglomerates and clays, while the Neogene sediments consist of marls, sandstone, sands and marly limestones.

In the study area two aquifer systems can be distinguished, one alluvial aquifer covering an area about 180 km^2 and the second one of low hydrogeological interest in Neogene deposits. The water needs of the basin, are predominantly being covered by the exploitation of the alluvial aquifer. The hydraulic conductivity (k) values of the alluvial aquifer range between $3x10^{-3}$ m/s and $4x10^{-6}$ m/s, as deduced from pumping tests. The depth of ground water ranges from less than 1 m to more than 45 m below ground surface.

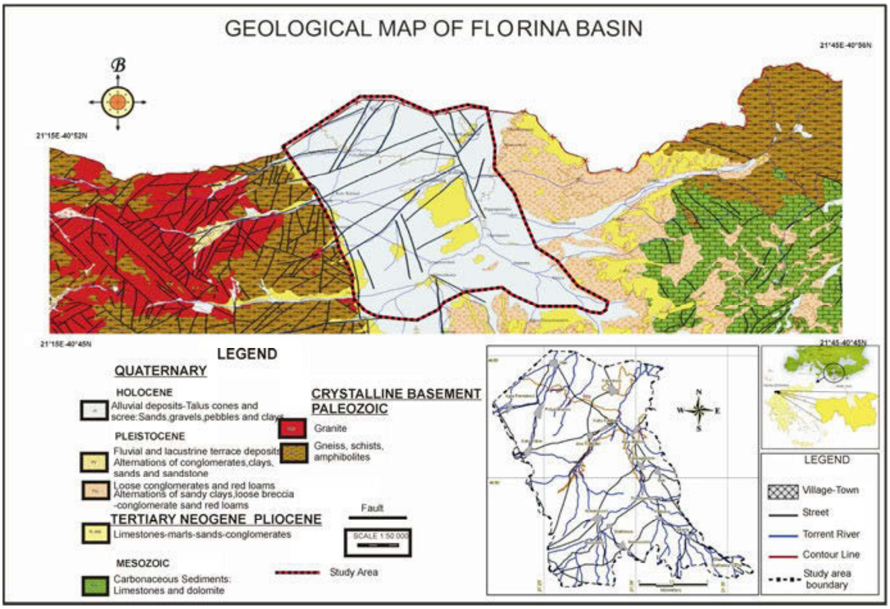

Fig. 1. Geological and topographic map of the study area (Modified from IGME Sheets Vevi and Florina, scale 1:50,000).

4 Applied methods

DRASTIC method (Aller et al. 1987) evaluates vertical vulnerability using seven parameters: Depth to groundwater, Aquifer media, net Recharge, Topography, Soil media, Impact of the vadose zone and Hydraulic Conductivity. Determination of the DRASTIC index involves multiplying each parameter weight by its site rating and summing the total. The equation for the DRASTIC Index (DI) is:

$$DI = \sum_{j=1}^{7} r_j . w_j$$

$$\text{or } DI = \mathrm{DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw}$$

where: D, R, A, S, T, I, C were defined earlier, r is the rating for the study area and w is the importance weight for the parameter. Each parameter including in the index must have a numeric value assigned between 1 and 10.

The higher the index, the greater is the groundwater pollution potential or greater aquifer vulnerability (Al-Zabet 2002). Parameters used by aforementioned method are derivable from monitoring gauges, hydrogeological field surveys including water level measurements, pumping tests and soil analyses, as well as aero-photo and remote sensing studies (Al-Adamat 2003; Panagopoulos et al. 2005). Stigter et al. (2006) and Martinez-Bastida et al. (2010) highlight that none of the parameters used in the DRASTIC method account for the influence of groundwater flow direction, a property that greatly influences whether some parts of the aquifer receive groundwater from a larger area than others.

The **GOD** method (Foster 1987) is an empirical method for the assessment of aquifer pollution vulnerability. This method uses three parameters: (1) Groundwater occurrence, (2) Overlying Lithology, (3) Depth to groundwater. The second parameter is taken into account only in unconfined aquifers. The parameters assigned a value from 0 to 1. The equation for the GOD Index (I) is:

$$I = G \cdot O \cdot D$$

The *AVI* method proposed by Van Stempoort et al. (1992), computes the Aquifer Vulnerability Index (AVI) using two parameters: the thickness of each sedimentary unit above the uppermost aquifer (d), and the estimated hydraulic conductivity of each of these layers (k). The hydraulic resistance for layers 1 to i is:

$$c = \Sigma\ d_i/K_i$$

Table 1. Values of the respective classes for each method.

Classes	INDEX		
	GOD	AVI	DRASTIC
High	0.6-1	< 0	>140
Medium	0.3-0.6	0 - 4	100-140
Low	0-0.3	>4	<100

The c or logc value is a qualitative Aquifer Vulnerability Index by a relationship table. Three vulnerability maps were produced using the classification of Table 1. The vulnerability maps are presented in Figure 2.

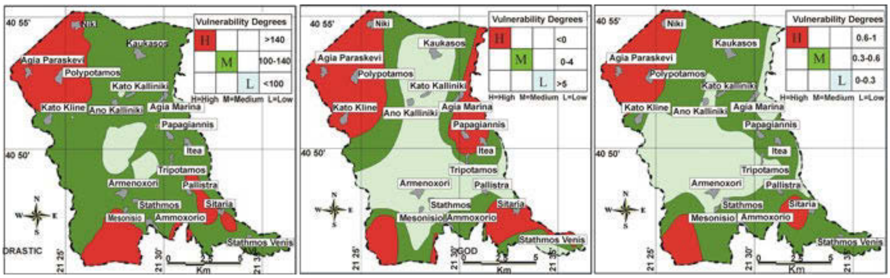

Fig. 2. Groundwater vulnerability maps with DRASTIC, AVI and GOD methods.

5 Comparison between the parametric methods

A quantitative comparison of vulnerability methods involves a normalization procedure to obtain comparable values. To make the normalization, many factors have to be considered such as the maximum and minimum values of each method and the procedure of stretching the vulnerability values between the maximum and minimum values (Corniello et al. 1997). For this reason three classes for the methods DRASTIC, AVI and GOD have been defined (Table 1). The areas representing the vulnerability classes obtained from the three methods in Km^2, as well as in percentages of the entire study area are shown in Table 2.

Table 2. Comparison between the areas representing the vulnerability classes.

Classes	DRASTIC		GOD		AVI	
	km^2	%	km^2	%	km^2	%
High	44.01	23.91	34.56	18.77	61.25	33.27
Medium	128.38	69.73	93.24	50.65	52.61	28.58
Low	11.71	6.36	56.3	30.58	70.24	38.15
total	184.1	100.0	184.1	100	184.1	100.0

According to Table 2, DRASTIC and GOD methods classify the largest area of the basin as medium vulnerability, while AVI method classifies it as high. Based on the DRASTIC method the smallest part of the area is low vulnerability.

Table 3. Correlation matrix between the maps computed using DRASTIC, AVI and GOD.

	GOD	AVI	DRASTIC
DRASTIC	0.76	0.27	1.00
AVI	0.46	1.00	
GOD	1.00		

The results of the correlation analysis between the three methods (linear regression analysis) are presented in Table 3. The highest correlation is shown between DRASTIC and GOD methods, while the lowest correlation between AVI and DRASTIC methods.

For better presentation of the differences between the three methods, the covering areas (Km^2) are presented in a histogram (Fig. 3). The graph shows that the distribution of the classes is uniform in AVI method and unimodal in medium class in DRASTIC and GOD method.

The differences between the three methods are associated with the fact that the calculation of each index takes into account different number of parameters with different weights. For the more integrated comparison, the created maps of common areas of the three methods (Fig. 4, 5) between DRASTIC-GOD, DRASTIC-AVI, GOD-AVI and DRASTIC-AVI-GOD were used.

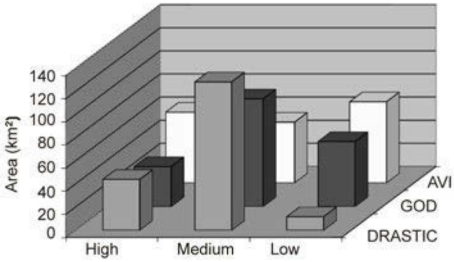

Fig. 3. Histogram showing the comparison of the areas between the vulnerability classes.

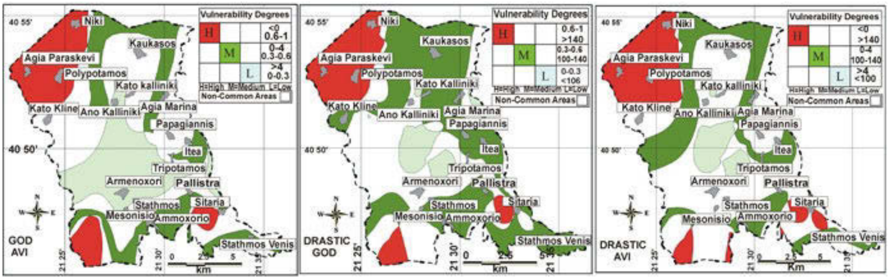

Fig. 4. Maps with common areas between the three methods.

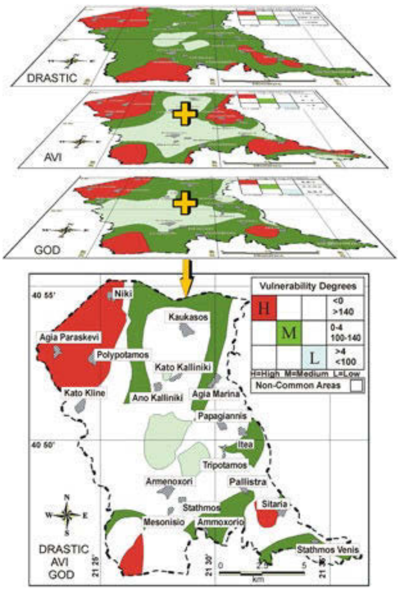

Fig. 5. Map of common areas between the three methods.

The results are shown in Table 4. Based on this Table it is concluded that, the classes of DRASTIC and GOD methods have the greater coincidence in percent 63.3%, while DRASTIC and AVI have the lower (48.4%). The three methods identify in 37.8%, while the area with high vulnerability covers 38.2%.

Table 4. Comparison of common areas between the three methods.

Classes	Drastic-GOD		Drastic-AVI		GOD-AVI		Drastic-AVI-GOD	
	km^2	%	km^2	%	km^2	%	km^2	%
High	28.42	24.37	32.30	36.26	31.8	30.23	26.64	38.23
Medium	77.26	66.27	45.94	51.56	37.76	35.89	32.82	47.10
Low	10.92	9.36	10.86	12.18	35.64	33.88	10.22	14.67
Total	116.6	63.33	89.1	48.39	105.2	57.14	69.68	37.85

According to the three applied methods, areas with high vulnerability are located in the northwestern and southwestern parts and in a small part between Sitaria and Pallistra village of the Florina basin. Low vulnerability values are recorded in the central part of the basin. The rest of the basin is characterized by medium vulnerability values with significant differences among the three methods.

Furthermore, it is concluded that the depth of groundwater table is very important parameter for the three methods, because the great depth is associated with low vulnerability values (Voudouris et al. 2010). Based on the results of chemical analyses (Gianneli et al. 2007) it is concluded that area of high vulnerability is related to high nitrate concentrations in groundwater.

6 Conclusions

Based on the comparison of the three applied methods DRASTIC, AVI and GOD the following considerations can be revealed:

1. According to DRASTIC and GOD methods, medium vulnerability zones cover the largest area in Florina basin, while using AVI method the largest part of the basin was estimated to be of low vulnerability.
2. The higher correlation and coincidence has been observed between the methods DRASTIC and GOD and the lower correlation between the methods DRASTIC and AVI.
3. The differences between the three methods are associated with the fact that the calculation of the indices of each method take into account different number of parameters with different weights.
4. The three methods identify in percent 38%, indicating that the methods produce different results.

The application of GOD method is more simple than the DRASTIC method. The GOD method should be applied before DRASTIC method in a region in order to make a rapid assessment of groundwater vulnerability of the region and guide the field research focusing on specific areas.

References

Al-Adamat RAN, Foster IDL, Baban SMJ (2003) Groundwater vulnerability and risk mapping for the basaltic aquifer of the Azraq basin of Jordan using GIS, Remote sensing and DRASTIC. Applied Geography 23, 303-324

Aller L, Bennett T, Lehr JH, Petty, RJ, Hackett G (1987) DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings. US Environmental Protection Agency, Report 600/2-85/018, Washington

Al-Zabet T (2002) Evaluation of aquifer vulnerability to contamination potential using the DRASTIC method. Environmental Geology 43, 203-208

Civita M (1994) Le carte della vulnerabilità degli acquiferi all' inquinamento. Teoria and practica. (Aquifer pollution vulnerability maps). Pitarora Ed., Bologna (in Italian)

Corniello A, Ducci D, Napolitano P (1997) Comparison between parametric methods to evaluate aquifer pollution vulnerability using a GIS: An example in the 'Piana Campana', southern Italy. In: Marinos P, Koukis G., Tsiambaos G., Stournaras G. (Eds) Engineering Geology and the Environment, Balkema, Rotterdam, 1721-1726

Foster SSD (1987) Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In Van Duijvenbooden W, Waegeningh HG (eds) TNO Committee on Hydrological research, the Hague. Vulnerability of soil and groundwater to pollutants, Proc. Inf. 38, 69-86

Gianneli Ch, Stamos Al, Stamos Ap, Voudouris K (2007) Surface and groundwater quality in Florina prefecture. Proc. 1st Conf. on Environmental Management, Engineering, Planning and Economics (CEMEPE). Skiathos, June 24-28, 765-770

Gogu RC, Hallet V, Dassargues A (2003) Comparison of aquifer vulnerability assessment techniques. Application to the Néblon river basin (Belgium). Env. Geology 44, 881-892

Kazakis N (2008) Groundwater vulnerability assessment in Florina basin. MSc thesis, Dept. of Geology, Aristotle University of Thessaloniki, Greece (in Greek)

Martinez-Bastida JJ, Arauzp M, Valladolid M (2010) Intrinsic and specific vulnerability of groundwater in central Spain: the risk of nitrate pollution. Hydrogeology J. 18, 681-698

Panagopoulos G, Antonakos A, Lambrakis N (2005) Optimization of the DRASTIC method for groundwater vulnerability assessment via the use of simple statistical methods and GIS. Hydrogeology Journal 14, 894-911

Polemio M, Casarano D, Limoni PP (2009) Karstic aquifer vulnerability assessment methods and results at a test site (Apulia, southern Italy). Natural Hazards and Earth System Sciences 9(4), 1461-1470.

Stigter TY, Riberio L, Carvalho Dill, AMM (2006) Evaluation of an intrinsic and specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the S. Portugal. Hydrogeology J. 14, 79-99

Van Stempoort D, Ewert L, Wassenaar L (1993) Aquifer vulnerability index (AVI): a GIS compatible method for groundwater vulnerability mapping. Can. Water Res. J. 18, 25-37

Voudouris K, Manos B et al. (2007) Development and utilization of vulnerability maps for the monitoring and management of groundwater resources in the ARCHIMED areas: Presentation of an INTERREG III B Project. Proc. of International Scientific Conference

"Modern Management of Mine Producing, Geology and Environmental Protection (SGEM 2007)". 11-15 June, Varna, Bulgaria

Voudouris K (2009) Assessing groundwater pollution risk in Sarigkiol basin, NW Greece. In: M. Gallo and M. Herrari (Eds) River Pollution Research Progress, Chapter 7, 265-281. Nova Science Publishers Inc

Voudouris K, Kazakis N, Polemio M, Kareklas K (2010) Assessment of intrinsic vulnerability using DRASTIC model and GIS in the Kiti aquifer, Cyprus. European Water 30, 13-24

Vrba J, Zaporozec A (1994) Guidebook on mapping groundwater vulnerability. Int. Association of Hydrogeologists. Int. Contributions to Hydrogeology; 16. Verlag Heinz Heise, Hannover