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Aquifer pollution vulnerability in the Sorrento peninsula, southern Italy, evaluated by SINTACS method

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RESUMEN

Un mapa de vulnerabilidad a la contaminación de las aguas subterráneas de los acuíferos de la península de Sorrento (Italia meridional), ha sido realizado mediante un Sistema de Información Geográfica (SIG). El método paramétrico SINTACS ha sido aplicado en esta área, esencialmente cárstica. Este método permitió una definición detallada de la vulnerabilidad, proporcionando un sistema específico de ponderación en función de los contextos hidrogeológicos (cársticos, de fisuras y de poros). El mapa resultante evidencia que las características morfológicas y litológicas condicionan la vulnerabilidad a la contaminación.

PALABRAS CLAVE: Vulnerabilidad, SINTACS, contaminación acuífera, SIG, karst, península Sorrentina, manantiales minerales.

ABSTRACT

A groundwater contamination vulnerability map of the aquifers of the Sorrentine peninsula, Italy, has been produced using a Geographical Information System (GIS). The parametric method SINTACS has been applied in this prevalently karstic area. This method allows a detailed definition of vulnerability, providing a specific set of weights for karstic, fissured and porous hydrogeological environments. The final map shows the influence of the morphological and lithological setting on the contamination vulnerability assessment.

KEY WORDS: Vulnerability assessment, SINTACS, groundwater contamination, GIS, karst, Sorrento peninsula, mineral springs.

INTRODUCTION

The hydrogeological outline of the Sorrentine peninsula is noteworthy for the following points:

- in this area important groundwater resources converge with a total discharge of about 2 m^3/s: moreover, this sector feeds the Scrajo sulphur springs and the Castellammare di Stabia spas;
- the groundwater flow is influenced by the karst network development;
- the presence of a shallow groundwater flow, testified by high productive springs.

The second point in particular shows the potential vulnerability to the contamination of this groundwater resource. However, the low population in the higher areas confers a low pollution risk. In fact, at the moment a non-point source contamination is absent, and only the groundwater of the Castellammare di Stabia area is more intensively urbanized and locally polluted.

In this hydrogeological context, the SINTACS parametric method offers a specific set of weights for karstic and fissured environments. It was selected to assess pollution vulnerability in the Sorrentine peninsula. The thematic maps and the vulnerability map are drawn up using a GIS. We describe the geographical database, supported by attribute data, specifically designed to store aquifers information and to be used by a GIS.

The aim of this paper is to assess the contamination vulnerability of this important groundwater resource and to test the SINTACS method for the definition of aquifer contamination vulnerability in karstic environment (Corniello and Ducci, 2000). This paper is a publication of the research project on aquifer vulnerability and risk assessment, supported by CNR-GNDCI, Theme 4, (Prof. M. Civita) Team 4.22: Prof. A. Corniello (Contribution n. 01.01026.42).

2. HYDROGEOLOGICAL SETTING

The sample area is approximately 200 km^2, and covers the western part of the relief of the Lattari Mountains (Southern Italy) (Figure 1). This area, with a mean elevation 660

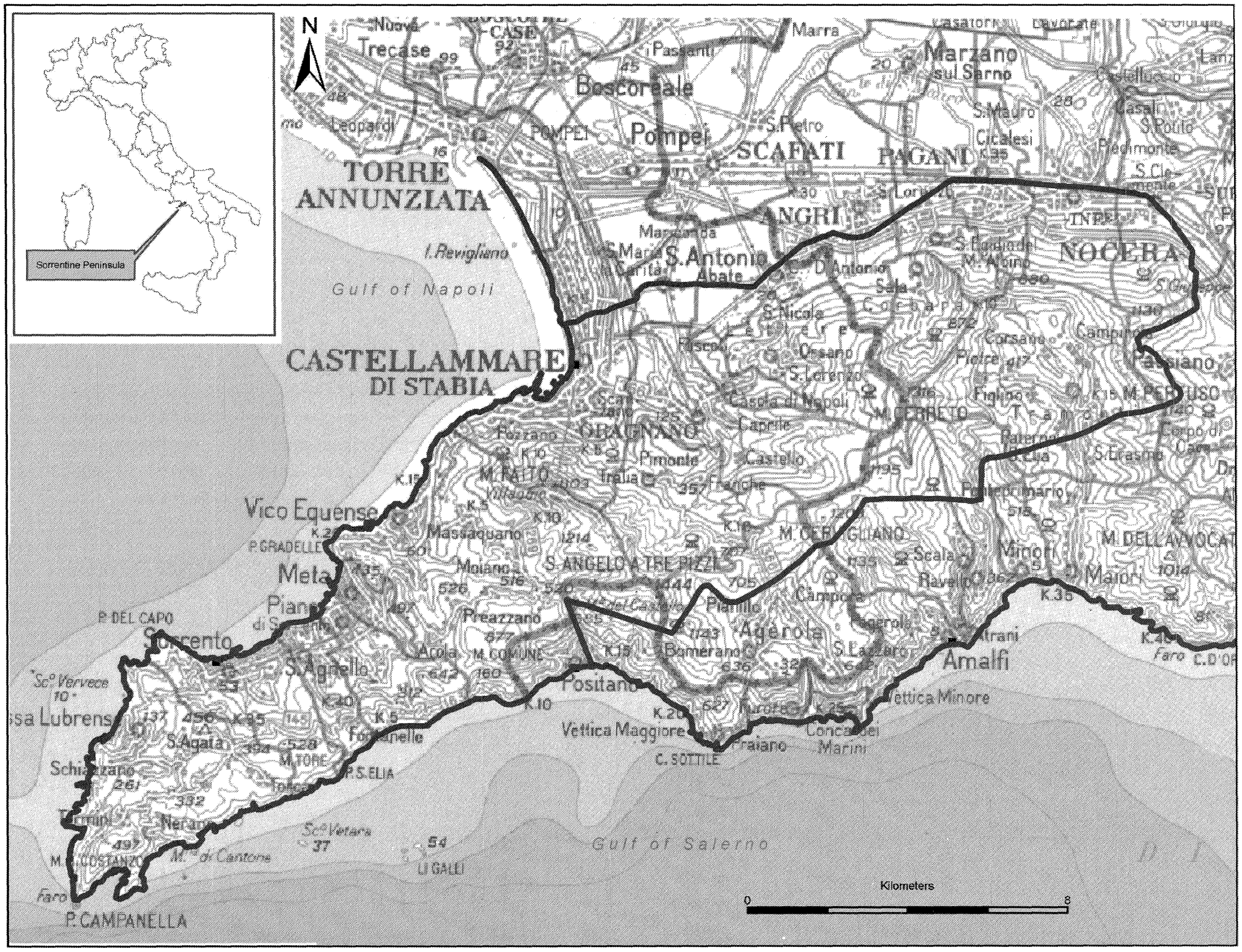


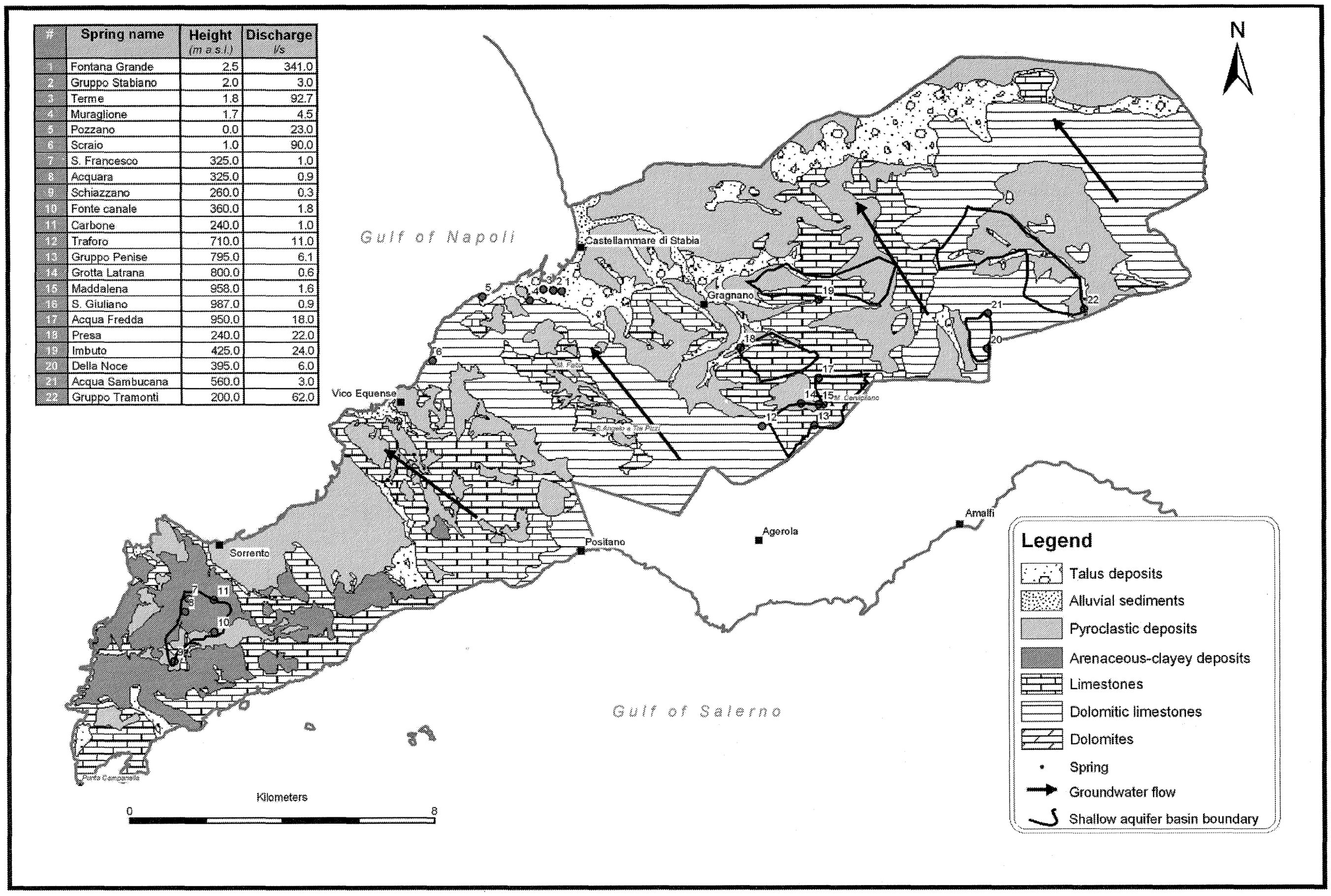
Fig. 1. Location and boundary of the study area.

m.a.s.l., and a maximum of 1400 m a.s.l. is a horst transversally oriented towards the Apennine chain, separating two tectonic depressions, the Campanian Plain to the north and the Gulf of Salerno to the south. The structure is a monoclinal inclined towards the NW which on the southern side is faulted by major NE-SW-oriented faults and is affected by numerous transverse faults NW-SE-oriented, many of which are strike-slip faults (Capotorti and Tozzi, 1991).

The Lattari Mountains are constituted by thick Mesozoic dolomitic limestone sequences on which Miocene flysch has been conserved in small structural depressions; lesser quantities of Quaternary clastic deposits together with pyroclastics have also been conserved. The present-day orographic setting of the peninsula is the result of the Mio-Pliocene compressive phases and of Plio-Quaternary phases of tectonic uplift and erosion. The combined action of linear erosion and karst erosion, especially active during some periods (in the last Glacial Wurm the sea level was approximately 130 m lower than at present), shaped definitively the relief, determining the actual morpho-structural features of the Lattari Mts.

In the study area (Figure 2) outcrops calcareous-dolomitic rocks (Triassic-Jurassic), Cretaceous limestones, sometimes covered by Miocene flysch. Recent pyroclastic deposits cover the flat areas (Sorrento, Vico and Agerola Plains) and diffusely, but with thin thickness, the calcareous relieves.

The presence of several karst forms influence the groundwater flow, which is very complex (Celico and Corniello, 1979; Celico *et al.*, 1986; Piscopo *et al.*, 1995, 2000): the main groundwater flow direction is towards north (towards the Sarno River plain, the sea and the Castellammare di Stabia and Scrajo springs). The secondary groundwater

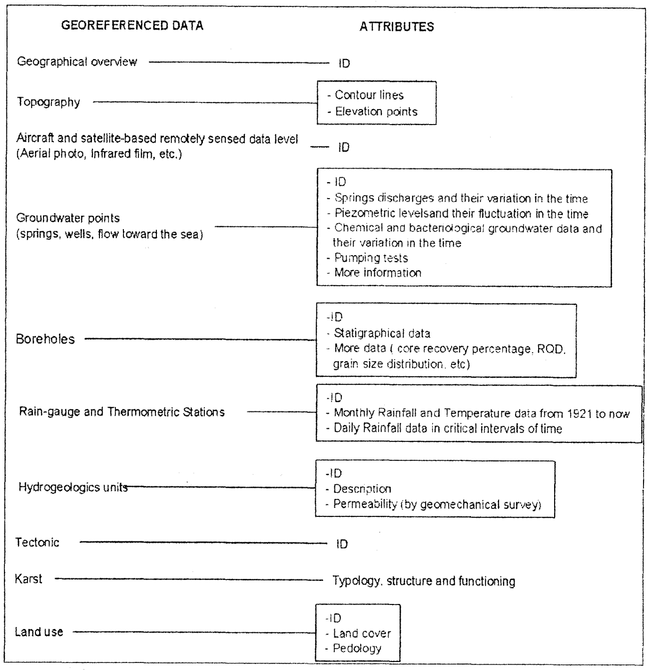


#	Spring name	Height (m a.s.l.)	Discharge l/s
1	Fontana Grande	2.5	341.0
2	Gruppo Stabiano	2.0	3.0
3	Terme	1.8	92.7
4	Muraglione	1.7	4.5
5	Pozzano	0.0	23.0
6	Scraio	1.0	90.0
7	S. Francesco	325.0	1.0
8	Acquara	325.0	0.9
9	Schiazzano	260.0	0.3
10	Fonte canale	360.0	1.8
11	Carbone	240.0	1.0
12	Traforo	710.0	11.0
13	Gruppo Penise	795.0	6.1
14	Grotta Latrana	800.0	0.6
15	Maddalena	958.0	1.6
16	S. Giuliano	987.0	0.9
17	Acqua Fredda	950.0	18.0
18	Presa	240.0	22.0
19	Imbuto	425.0	24.0
20	Della Noce	395.0	6.0
21	Acqua Sambucana	560.0	3.0
22	Gruppo Tramonti	200.0	62.0

Fig. 2. Hydrogeological map of the study area.

flow is SW, where there are also submarine springs in the Positano-Vietri area. The groundwater divide between this sector and the first one is the boundary of the study area, which therefore not includes these aquifers. The spring front of Castellammare di Stabia Spas (n.3 in Figure 2) is placed, near the sea, at the northern foot of the calcareous relief of Faito Mt. This zone is characterized by the presence, in a small area, of numerous springs (nn.1÷5 in Figure 3) differently mineralized (sulphur, iron, magnesium) even if the basic mark is chlorinated-alkaline-earthy; the Fontana Grande spring (n.1 in Figure 2), located few meters at the N, is very less mineralized and it presents a remarkable discharge (about 340 l/s).

Some authors (Celico *et al.*, 1986; Corniello, 1994; Piscopo *et al.*, 2000) indicate that the springs are supplied from the basal flow of Faito Mt. that is sustained by marine water that intrudes into the relieves for the absence of impermeable materials between it and the sea. Deep gaseous supplies (fundamentally CO_2 and H_2S), actives along local and important tectonics lineaments, cause the mixing between the marine water and the overlying bicarbonate-calcic groundwater. The hydrochemical differentiation of the spring front



GEOREFERENCED DATA	ATTRIBUTES
Geographical overview	ID
Topography	- Contour lines - Elevation points
Aircraft and satellite-based remotely sensed data level (Aerial photo, Infrared film, etc.)	ID
Groundwater points (springs, wells, flow toward the sea)	- ID - Springs discharges and their variation in the time - Piezometric levelsand their fluctuation in the time - Chemical and bacteriological groundwater data and their variation in the time - Pumping tests - More information
Boreholes	-ID - Statigraphical data - More data (core recovery percentage, RQD, grain size distribution, etc)
Rain-gauge and Thermometric Stations	-ID - Monthly Rainfall and Temperature data from 1921 to now - Daily Rainfall data in critical intervals of time
Hydrogeologics units	-ID - Description - Permeability (by geomechanical survey)
Tectonic	ID
Karst	Typology, structure and functioning
Land use	-ID - Land cover - Pedology

Fig. 3. Hydrogeologic Database Structure of the Sorrento peninsula.

is due to the groundwater pathways, to the mixing percentage and to the entity of gaseous supplies. The hydrogeological data show the same origin also for the Scrajo mineral waters (n.6 in Figure 2).

The rocks fracturing and the presence of impervious layers generate a shallow groundwater flow, testified by some "high" springs, some of them with a discharge of more than 20 l/s. Six groundwater basins with a shallow flow, feeding these springs have been recognised in the present study (Figure 2).

3 THE VULNERABILITY MAP

3.1 The hydrogeological database

A hydrogeological database was purposely designed to satisfy the analytical needs of the vulnerability assessment studies.

The geographic database (ILWIS 3.1, ARCVIEW 8.2) has been drawn up supported by an alphanumeric database (ACCESS, EXCEL). In fact, the database combines significant hydrogeologic data for the study and is composed by two parts: the first is a spatial database containing various thematic maps (geological, hydrogeological, soil, etc. data). The second is a descriptive database including attribute data related to the carbonatic reliefs (borehole stratigraphies), to the hydrogeologic units (permeability, transmissivity, etc), to the groundwater points (continuous measurements), etc. (Barone *et al.*, 1999).

In order to make its management easier, a simple tabular structure was adopted for the descriptive database. Attribute data were organized, so that the information necessary for vulnerability assessment could be easily extracted and exported to a Geographic Information System. For the construction of the seven SINTACS maps, different data inputs must be available about topography, lithology, hydrologic, climate, etc. (Figure 3). The data were collected during the last few years by the authors.

The parametric method SINTACS has been used in this prevalently karstic area, because this method, giving comparable results to other methods specially designed, allows a more detailed and objective definition of the vulnerability (Corniello and Ducci, 2000).

The SINTACS method (Civita and De Maio, 2000), originally derived from DRASTIC, in the latest release 5, retains only the structure of DRASTIC. It evaluates the vertical vulnerability using the same seven parameters: depth to groundwater (S), recharge action (I), attenuation potential of the vadose zone (N), attenuation potential of the soil (T), hydrogeologic characteristics of the aquifer (A), hydraulic conductivity (C) and topographic slope (S). Each mapped factor is classified into ratings (from 1 to 10) which have an impact on potential pollution. Weight multipliers are then used for each factor to balance and enhance their importance. The final vulnerability index (I_v) is a weighted sum of the seven factors.

The weight classes used by SINTACS depend on the hydrogeological features of each area. It is possible to use, in the same map, different weight classes in different sectors. In the study area the classes adopted are the followings:

a. relatively uncontaminated scenario (absence of non-point sources of contamination): in the areas where the aquifer is constituted by pyroclastic or sandy sediments;

b. karstic areas with fast connection between the aquifer and the recharge water (the vadose zone plays a negligible role and the net recharge is often equal to the precipitation rate): in the areas where the aquifer is constituted by limestones and the epikarst features are evident;

c. sectors dominated by an elevated fracture index and limited or absent karst features: where carbonatic rocks are less pervious fissured rocks (dolomitic limestone or dolomite).

The range variation of each parameter and the rating assigned are shown in Table 1.

The final Vulnerability Index (Figures 4, 5) ranges between 64 and 240 for the main aquifers and between 70 and 180 in the basins with shallow flow. In sub-basins where the groundwater flow is shallow, the superficial vulnerability has been evaluated using different class of weight as above specified. The parameters S, I, N, A and C are different from the main aquifer. In this zone the recharge of the main underlying aquifer has been reduced by the discharge rate of the springs fed by the basins with shallow flow. The vulnerability of these basins is prevalently moderate and high, with a small sector (basin located in the western part with a sand aquifer) with low and very low vulnerability (Figure 5).

4. CONCLUSIONS

The vulnerability maps show the markedly influence in the study area of the lithological and morphological karst setting on the contamination vulnerability assessment. The SINTACS methods showed its versatility even in this complex hydrogeological environment, karst.

Table 1

Simplified layout of the SINTACS method for contamination vulnerability assessment. Vulnerability classes established in CIVITA and DE MAIO, 2000

SINTACS Parameter	**Range of the values Comments**	**Predominant Value**	**Predominant Rating (P)**
S Depth to water	The values range between few meters close to the sea and more than 1000 m in the central sector (≈100 m in the sub-basins).	600 100	1
I Recharge action	The values, drawn from the hydrogeologic budget expressly evaluated, range between 40 and 700 mm/year.	350	4
N Effect of the vadose zone	From the graphs in CIVITA and DE MAIO, 2000.	-	8-9
T Effect of the soil media	From DI GENNARO and TERRIBILE (1999) and, in a small eastern sector, from photointerpretation.	silty loam texture	4-6
A Characteristic of the aquifer	From the graphs in CIVITA and DE MAIO, 2000.	-	7-9
C Hydraulic conductivity	Partially from the pumping tests data in PISCOPO *et al.* (1995) The values range between $1*10^{-6}$ and $1*10^{-2}$ m/s	1*10-6 and 1*10-2 m/s	7 and 9
S Topographic slope	From the digital elevation model using the GIS ILWIS. The values are generally >50%. Less than 10% in the Sorrento Plain and in the northern sector.	100%	1

Iv (vulnerability index)= $\Sigma\ [P_{(1,7)} * W_{(1,n)}]$
where $W_{(1,n)}$ is the weight in each class

VULNERABILITY DEGREE: Extremely high (Iv $\geq$211); Very high (210$\geq$Iv $\geq$187); High (186$\geq$Iv $\geq$141);
Moderate (140$\geq$Iv $\geq$106); Low (105$\geq$Iv $\geq$81); Very low(Iv $\leq$80)

The most prevalent vulnerability degree is moderate; the high vulnerability class is diffuse, especially where the aquifer is represented by karstified limestones. In the western sector, with sandy aquifer, the vulnerability is low or very low. The vulnerability of the shallow aquifer reproduces the vulnerability of the main aquifer, even if it was obtained using different parameters.

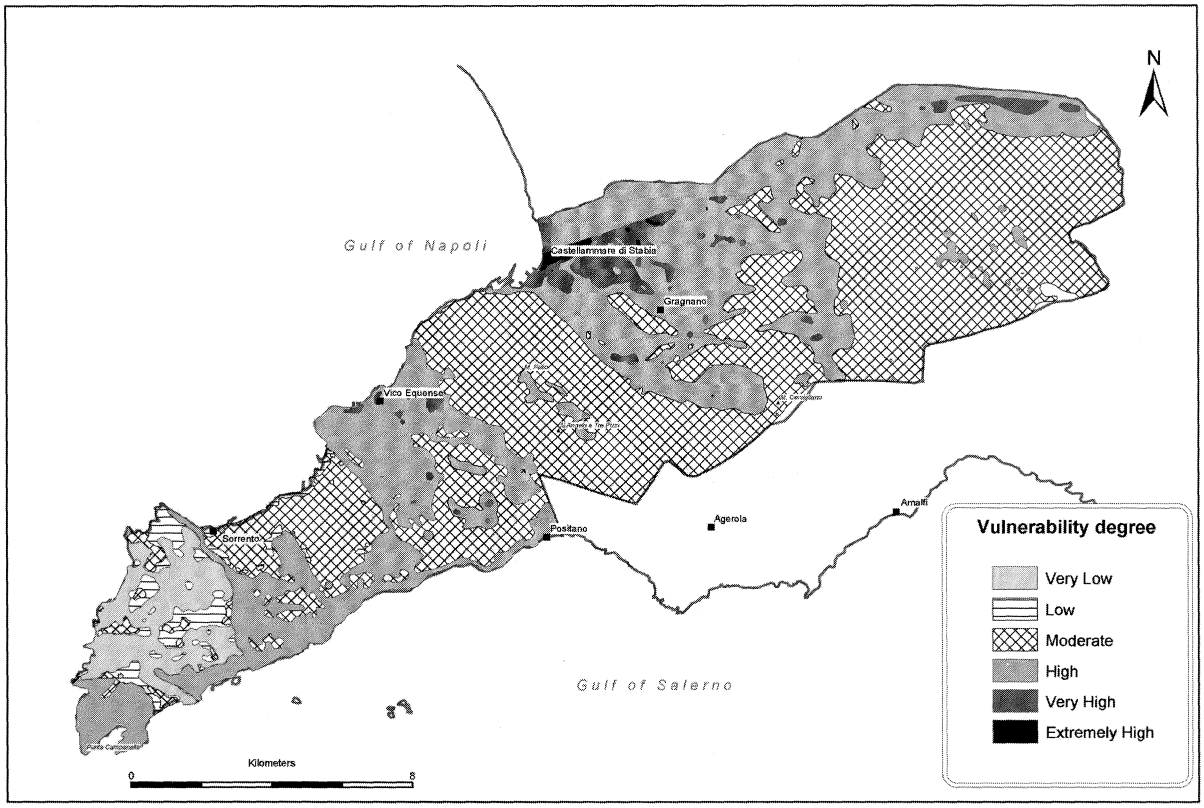


Fig. 4. Vulnerability map, computed by SINTACS method, of the main aquifers.

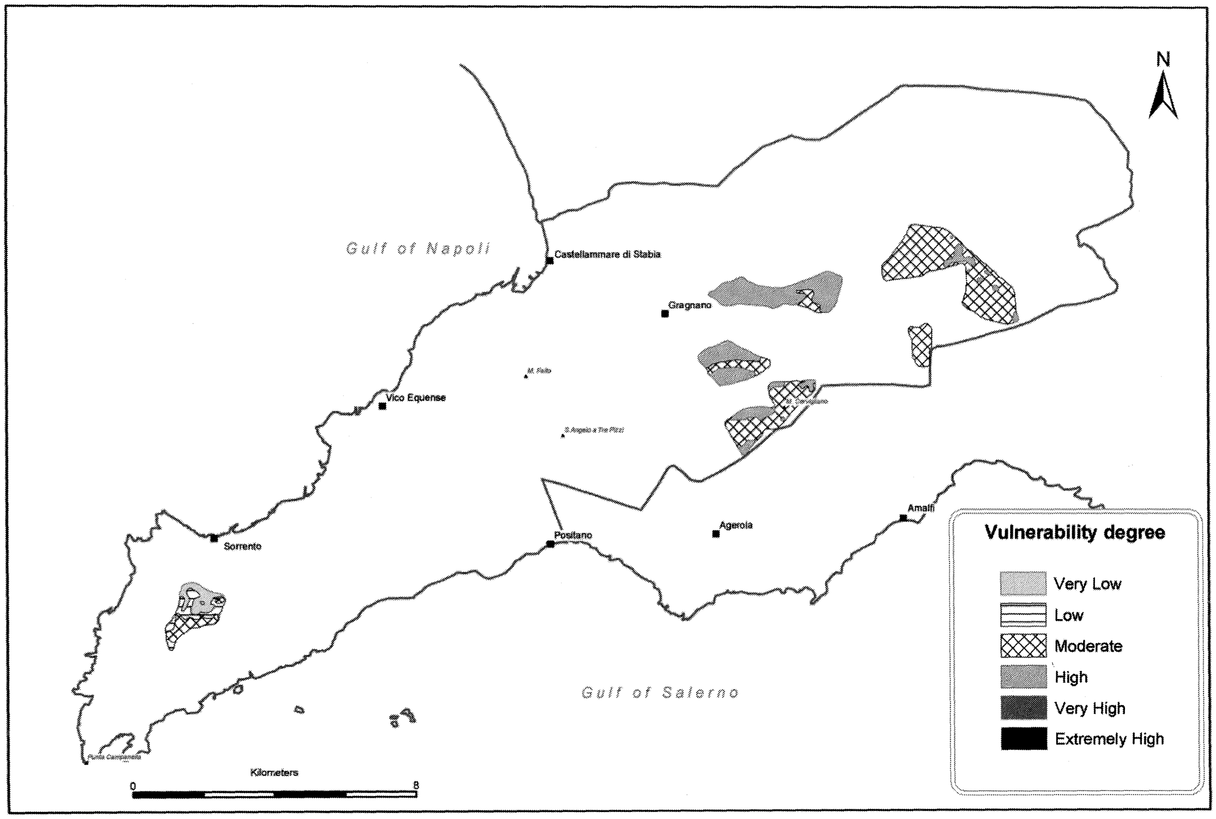


Fig. 5. Vulnerability map, computed by SINTACS method, of the shallow aquifers.

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