

Vulnerability Mapping of Carbonate Aquifer using Geographic Information Systems

E. Ricchetti
Dept. Geology & Geophysics
University of Bari
Via Orabona 4
70125, Bari, Italy
evaristo@geo.uniba.it

M. Polemio
CNR - CERIST
Politecnico di Bari
Via Orabona 4
70125, Bari, Italy
polemio@area.area.ba.cnr.it

Abstract - Computer techniques such as Geographic Information Systems are applied to the evaluation of the vulnerability of a deep carbonate aquifer.

The study area is located in the low Murgia Plateau (Apulia) and characterized by Mesozoic limestone and dolomite rocks of several thousand meters thickness. A wide and thick aquifer resides in these carbonate rocks. Its groundwater flows toward the sea mainly under pressure. Due to their high quality, the water resources of this aquifer are particularly valuable for the local communities and therefore must be protected from pollution and inappropriate use.

The vulnerability map of the aquifer is an indispensable tool for the effective management of water resources and to support environmental planning. Geographic Information Systems can be effectively applied to the implementation of vulnerability models. In this study the SINTACS evaluation method was implemented in a GIS and a digital vulnerability map produced.

The computerized multilayer analysis performed by the GIS is time effective and leads to more comprehensive and accurate results with better spatial resolution.

INTRODUCTION

Due to their geologic and hydrogeologic characteristics Apulian groundwater are very susceptible to pollution. Human activities that were developed in the last decade without comprehensive planning support may severely increase this risk locally. The intrinsic vulnerability map of aquifers is an effective information tool for these planning activities. This kind of maps quantitatively represents the sensitivity of any aquifer to receiving and transporting pollutants that may worsen groundwater quality.

In this paper we describe the use of Geographic Information Systems (GIS) to produce an intrinsic vulnerability map of a sample area in Murgia, applying the SINTACS method [1] [2]. This research takes place following the production of the vulnerability map for the same area using a traditional approach with a 500 m regular spaced grid [4].

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The study area is located in the wide hydrogeological unit of Murgia, made of Cretaceous carbonate rocks of platform environment with a total thickness of more than 3000 m.

The outcropping rocks in the study area can be distinguished in the following three main geological units: Calcare di Bari; calcarenite deposits and alluvial deposits.

The Calcare di Bari formation is represented by a succession of Cretaceous limestone in beddings of variable thickness with some irregular sequences of dolomite limestone.

The calcarenite deposits of Pleistocene age locally overlay the Mesozoic carbonate rocks in transgressive contact over abrasion flights. These calcarenites belong to the Calcare di Gravina formation, representing the opening of the Fossa Bradanica sedimentary cycle, and to marine terrace deposits transgressive over all the other formations.

Alluvial deposits of variable texture from coarse to fine, with a high content of residual deposit of red color (terra rossa), are present along the main drainage valleys (*lame*) and in the endoreic depression.

In the Mesozoic carbonate rocks of Murgia lies a thick and large coastal aquifer, characterized by karstic phenomena and a highly variable fracture grade. The hydraulic conductivity is anisotropy and uneven, with local high values due to karst and fractures. The sea level is the base level of groundwater flow. As a consequence the intruded seawater underlies fresh groundwater below sea level, owing to a difference in density. Over wide areas of Murgia the groundwater flows under pressure along several levels, at large depths of up to about 200-400 m below sea level in southeast Murgia.

The surface drainage is typical of karstic environments in temperate climates, with very low density and few gorges (*lame*) that flood during extremely exceptional intense rain.

In the study area, the aquifer is characterized by several high hydraulic conductivity levels at different depths; due to intense fracturing and karst solution, these levels intersect each other and make the groundwater extremely vulnerable to pollutants coming from the terrain surface.

The groundwater flow velocity, determined by tracer tests, is generally high, between 0.5 and 4 m/day, and increasing toward low terrain areas. A remarkable vertical component of groundwater flow from up to down has been frequently detected in tested wells.

VULNERABILITY ASSESSMENT OF THE EXPERIMENTAL AREA

The intrinsic vulnerability of the aquifer was evaluated using the SINTACS method [2]. This approach divides the landscape into a grid with regularly spaced cells and assigns scores to selected variables for each cell. The variables used in this method are as follows:

- S = depth to water;
- I = actual infiltration or net recharge;
- N = unsaturated zone;
- T = soil media;
- A = aquifer media;
- C = hydraulic conductivity;
- S = terrain slope;

A weight factor is associated to each variable according to its contribution to vulnerability. These weights are defined as functions of the local hydrogeological setting on the basis of many experimental evaluations in Italian test sites.

The intrinsic vulnerability for each cell is computed using the sum of the product of the scores and the weight of each variable.

A. Data set

The underground data used in this study were from the stratigraphy data of wells drilled in this area in the last decades. Besides cyclic surveys of the piezometric level, multiparametric logs (of temperature, electrical conductivity, pH, dissolved oxygen, oxidation-reduction potential) and measurements of groundwater flow and vertical flow velocity have been carried out in about 200 drillholes [3].

Topographic data were acquired from contour maps at 1:25,000 scale. These maps were digitized and linearly interpolated to produce a Digital Terrain Model. These data in digital format allow an easy quantitative analysis of terrain characteristics such as slope gradient and surface drainage pattern.

Monthly rainfall and temperature were acquired from the monitoring network of the *Servizio Idrografico* and *Servizio Mareografico*.

B. Data Analysis

All the data collected for this study were converted into digital format to implement in a Geographic Information System (GIS) for the vulnerability analysis. The analysis was accomplished on the basis of a raster grid with spatial resolution of 10 m.

The data and the analysis processes developed in this study to produce the intrinsic vulnerability map are schematically described in the flow chart shown in Fig. 1.

All well data were input in a Data Base Management System (DBMS) linked to a point file reporting well locations in UTM coordinates. In order to produce maps of all the different variables measured in the drillholes and needed for computing the intrinsic vulnerability, well data were interpolated using a geostatistical approach. A semi-variogram for each variable was made from point data to define the interpolation function. Then several raster maps

with 10 m resolution were computed for the different variables using kriging.

A geological map produced by aerial photointerpretation was digitized on-screen using the digital aerial photos as background. This vector map was input in the GIS using the same coordinate system as the other data

Since the groundwater flows under pressure, the depth of the aquifer top measured in the drillholes was used to produce the depth to water map. The depth to water is generally between 100 and 200 m over the study area, with large values of up to over 500 m in the southern zone. The depth to water increases toward the coastline in the NE.

The actual infiltration map was computed on the basis of climatic and hydrologic data. The precipitation and temperature data were acquired in three gauges located within or in the neighborhood of the study area. The net precipitation Q was computed by applying the Thornthwaite-Mather method [5]. The hydraulic characteristics of the terrain were analyzed using the DTM. The drainage pattern was computed automatically using simple neighborhood functions. The digital map of the drainage pattern was combined with the interpolated map of net precipitation to produce an actual infiltration map. The resulting mean value of actual infiltration over the whole area is 112 mm/year, with minimum and maximum values of 86 mm/year and 176 mm/year respectively.

To evaluate the contribution of the unsaturated zone, firstly its thickness was calculated by overlaying the interpolated maps of soil thickness and depth to water. The unsaturated zone thickness was normalized to 1 and combined with a weighted geological map in order to consider the variations in permeability and porosity of the different geological units.

In the study area there is a high correlation between geology and soil characteristics. Over the Mesozoic limestone a discontinuous thin layer of clay soil is present. A loam to clay soil of thickness between 50 and 150 cm covers the calcarenite deposits. Thick layers of clay soil are present

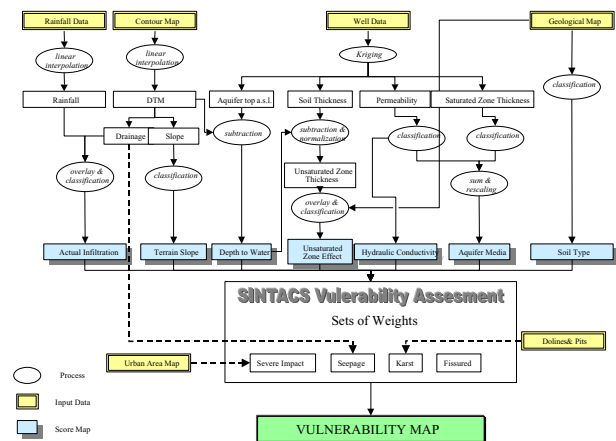


Fig. 1. Vulnerability analysis process

along the valleys and in the dolines. The geological map was used to assign the scores for the soil variable.

The maps of hydraulic conductivity and unsaturated zone thickness were reclassified and combined together to produce a map of aquifer media characteristics.

The hydraulic conductivity map was derived from the map computed by interpolation of values measured in piezometers and wells. Due to the karst nature of the aquifer, the hydraulic conductivity values are medium-low in average with high variability in space.

The slope gradient was calculated by the DTM. The steepest gradient in the area is 37% on the gouge slopes.

A set of scores was assigned to all the variables used for the SINTACS method. In order to do so the interpolated maps were reclassified using classification tables.

The local hydrogeological setting and impact of human activities can be classified into four of the different categories defined in the SINTACS method: severe impact, seepage, karst and fissured [2]. For each of these categories a different set of weights were used. The urban and industrial areas were classified as “severe impact”, the drainage network as “seepage”, the dolines and quarries and their surroundings as “karst”, and all the other areas as “fissured”. A digital map representing the spatial distribution of these categories was produced in the GIS.

The computing of the final intrinsic vulnerability map was carried out by a digital overlay process of the different variable maps and the SINTACS categories map. The vulnerability values, in percentage, were then classified in qualitative vulnerability categories as defined in the SINTACS method. The output digital vulnerability map is shown in Fig. 2.

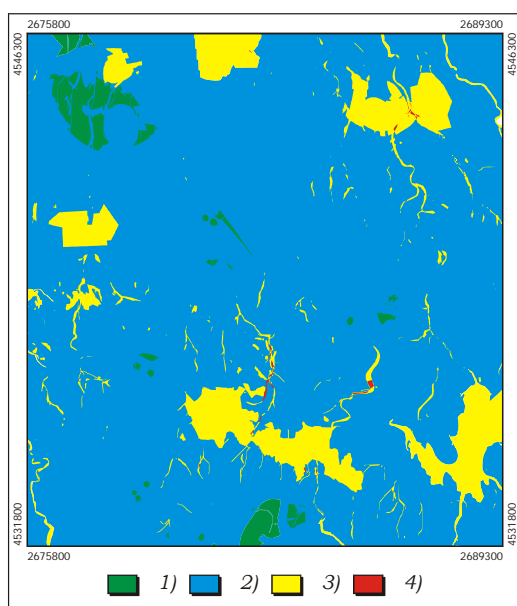


Fig. 2. Vulnerability map. 1) low; 2) medium; 3) high; 4) very high.

CONCLUSION

The intrinsic vulnerability map produced using the GIS approach reports the presence of four vulnerability classes in the study area: low, medium, high and very high. Most of the area is classified as highly vulnerable. Very high risk is reported where karst features are present on the terrain (dolines) or the hydrodynamic characteristics of the aquifer make it particularly vulnerable. The urban areas are generally classified as medium vulnerable.

In general, this map reports a moderately lower grade of vulnerability than in the study accomplished by Cotecchia et al. [4]. Comparing the vulnerability at each point, it can be observed that these small differences are mainly due to the different spatial resolutions used in the two studies (10 m and 500 m). Furthermore the methods used to assign the scores to each variable in this study generally appear to guarantee a more prudent vulnerability evaluation. The two vulnerability maps are substantially similar despite the slightly lower vulnerability values in this study.

In general, the results of this study confirm the high vulnerability of the groundwater in the Murgia aquifer. The intrinsic vulnerability map produced can provide useful information with sufficient spatial resolution and precision for the planning of local human activities..

REFERENCES

- [1] M. Civita, *Le carte della vulnerabilità degli acquiferi all'inquinamento*. Pitagora Ed., Bologna, 1994.
- [2] M. Civita and M. De Maio, *S.I.N.T.A.C.S. un sistema parametrico per la valutazione e la cartografia della vulnerabilità degli acquiferi all'inquinamento*. Pitagora Ed., Bologna, 1997.
- [3] V.Cotecchia, M. Daurù, P.P. Limoni, D. Mitolo and M. Polemio, “La vulnerabilità intrinseca di un'area campione dell'acquifero della Murgia (Puglia),” *Pubbl. GNDCI n. 2007, III Conv. Naz. Sulla Protezione e Gestione delle Acque Sotterranee per il III Millennio*, 1.11-1.20, Parma, 1999.
- [4] V.Cotecchia, M. Daurù, P.P. Limoni, D. Mitolo and M. Polemio, “Carta della Vulnerabilità dell'acquifero murgiano; Area campione a Sud-Est di Bari,” *Pubbl. GNDCI n.1964, Atti del 3° Conv. Naz. sulla Protez. e Gest. delle Acque Sotterranee per il III Millennio*, Parma, 1999.
- [5] C.W. Thornthwaite and J.R. Mather, *Instructions and tables for computing potential evapotranspiration and the water balance*. *Pubbl. Clim. Drexel Ins. Technol.*, 10, 1957.