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Evaluation of intrinsic groundwater vulnerability to pollution: COP method for pilot area of Carrara hydrogeological system (Northern Tuscany, Italy)

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During the characterization of the Apuan Alps groundwater body ("*Corpo Idrico Sotterraneo Significativo*", briefly CISS) (Regione Toscana, 2007) the intrinsic vulnerability has been evaluated for Carrara hydrogeological system (Northern Tuscany, Italy) by means of COP method, developed within COST 620 European Action (Zwalhlen, 2003). This system is both characterized by large data availability and it is considered an highly risky zone since groundwater protection problems (turbidity of the tapped spring waters and hydrocarbons contamination) and anthropic activity (marble quarries).

The study area, 20 Km^2large, has high relief energy, with elevations ranging from 5 to 1700 m amsl in almost 5 km. Runoff is scarce except during heavy rainfall; due to the presence of carbonate rocks infiltration is high: groundwater discharge at 155-255 m amsl.

The area is located in the north-western part of Apuan Alps Metamorphic Complex, characterized by carbonate and non-carbonate rocks belonging to the non-metamorphic Tuscan Units (Carnic-Oligocene), Mesozoic Succession, Middle-Triassic Succession, and metamorphic Paleozoic rocks. The main geological structure of the area is the Carrara Syncline, constituted prevalently by dolostones, marbles and cherty limestones. These carbonate formations define several moderately to highly productive hydrogeological units, characterized by fissured and karst flow. Hydrogeological system may be subdivided in two different subsets, because of both geo-structural set up and area conformation. However, these are hydrogeologically connected since anisotropy and fractures of karst groundwater. The southern boundary of Carrara hydrogeological system shows important dammed springs, defined by low productive units of Massa Unit (Cambriano?-Carnic).

COP methodology for evaluating intrinsic vulnerability of karst groundwater is based on three main factors for the definition of vulnerability itself: COP_{Index} = C (flow Concentration) *O (Overlying layers) *P (Precipitation). In this way it is possible to estimate the natural grade of groundwater protection (O factor), determined by both soils properties and vadose zone lithology, and then evaluate how this protection could be modified by infiltration processes (diffused or concentrated, C factor) and climatic conditions (P factor).

Factor elaborations have been calculated by study area discretization by means of raster grid with square cells, 100 m large, yielding the values distribution of sub-factor for each factor, and then the spatial distribution of intrinsic vulnerability, as result of geoprocessing and map analysis raster techniques in software ESRI ArcInfo® 9.1.

Results shows in the study area:

1) Medium and high values of vulnerability classes;

2) Areas with high vulnerability located in zones with low O protection index and moderate protection reduction;

3) C factor contributes to the high vulnerability where superficial cover supports more the infiltration than the run-off (slope between 8 and 31%);

4) Low vulnerability grade areas are either inside unproductive hydrogeological units, or with thick superficial covers.

Comparing these results with previous study, the distribution obtained by COP methodology shows larger variations between very high and high vulnerability area distribution. Most of the first areas are located in the central part of hydrogeological system, near to the main spring, and also in northern areas, where there is a swallow hole. This result yields a more precautionary scenario for particularly sensitive are characterized by high anthropogenic activity (marble quarry). Moreover, the vulnerability of such area is confirmed by both natural tracers (*Lycopodium clavatum*; Baldi, 2004) and environmental isotopes (^{2}H, ^{3}H, ^{18}O; Doveri, 2005).

This methodology allowed adding further information about intrinsic vulnerability of a hydrological contest very sensitive to anthropogenic pressures, and it is important for water resource as well. Such vulnerability map highlights higher vulnerability areas than those showed in previous studies, demonstrating that relying on just one methodology may lead to underestimation of groundwater protection level, especially in karst systems where anthropogenic contexts are developed.

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