The SINTACS method for evaluating aquifer vulnerability to pollution and saltwater intrusion

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ABSTRACT

Point Count Model Systems (PCMS) (Aller *et alii,* 1987) and particularly DRASTIC (**D**epth, **R**echarge, **A**quifer, **S**oil, **T**opography, vadose zone **I**mpact, aquifer hydraulic **C**onductivity) are the most commonly used methods for evaluating intrinsic aquifer vulnerability to pollution.

In early 1980's, the Italian scientific community, together with a number of institutional decision-makers, realized it was urgent to adopt actions to protect natural and environmental resources. Thereafter, the problem of groundwater contamination was examined and tackled for the first time in Italy in an organic and extensive manner with the special VAZAR project ("Aquifer Vulnerability Assessment in High Risk Zones") set up in 1984 as a tool for forecasting and preventing groundwater pollution in the frame of the GNDCI-CNR, for National Group of the Italian National Council of Research for the Defence against Hydrogeologic Disasters.

Since then, the SINTACS method (Civita and De Maio, 1997), directly derived from DRASTIC, has been extensively adopted in all the Italian regions and is presently prescribed by the Italian environmental regulations for assessing intrinsic vulnerability, considered as "the specific susceptibility of aquifer systems, in their various parts and in the various geometric and hydrodynamic settings, to ingest and diffuse fluid and/or hydro-vectored contaminants, the impact of which, on the groundwater quality, is a function of space and time" (Civita, 1987). The following seven parameters are considered by SINTACS, each with a score ranging from 1-10: groundwater table depth from surface (**S**oggiacenza), actual infiltration (**I**nfiltrazione), self-depuration effect unsaturated zone (effetto autodepurativo del **N**on-saturo), overburden type (**T**ipologia della copertura), hydrogeological characteristics of the aquifer (caratteristiche idrogeologiche dell'**A**cquifero), hydraulic conductivity (**C**onducibilità idraulica), and topographical surface slope (acclività della **S**uperficie topografica). Furthermore, the method uses different weight coefficient multipliers for every impact situation examined, so as to increase the score proportionately to the importance of the parameter in determining the degree of vulnerability (Civita, 1994).

The attenuation potential depends on source characteristics, pollutant quality and quantity, release mechanism, and inflow velocity (Civita, 1994). In theory, a specific vulnerability should be assessed case by case, taking into account the chemical and physical features of every single contaminant (or group of similar contaminants), the type of source (punctual or diffused), quantity, means and rates of contaminant applications. This approach, although scientifically valuable and adequate to assess a potential contamination of a CSC (Contamination Spreading Centre) in small areas, is

quite impracticable where the goal is to assess large area aquifer vulnerability or when it is carried out to prevent contamination in aquifer protection planning (Civita, 2010).

In this work we wish to draw the attention on the complex specific aspects to be taken into consideration when assessing intrinsic and integrated vulnerability of coastal aquifer, jeopardized on the one hand by saltwater intrusion, on the other hand by human impacts becoming stronger and stronger. According to our opinion, any-type aquifer (Polemio *et alii*, 2009) and any-type pollutant are inadequate to define intrinsic vulnerability in coastal aquifers.

In our experience, some parameters so far regarded as invariable, such as actual porosity and hydraulic conductivity, may change with increasing salinity, resulting in pH variations, element desorption from clay and recontamination due to their mobilization. In coastal aquifers, the chemical status of groundwaters is strongly influenced by seawater intrusion. Mixing processes cause not only the increase of salinity, but the variation of other chemical-physical parameters as well: such variations affect the solubility of heavy metals, by altering the ion-exchange equilibrium, increasing soluble complexation and decreasing chemical thermodynamic activities in solution. As a consequence, in coastal aquifers heavy metal mobility may be subject to cyclic changes according to the dynamics of seawater intrusion.

Heavy metals accumulated in soil and sediments represent a potential risk of groundwater contamination when they are subject to changing environmental conditions that can affect their chemical speciation. Heavy metal mobility in groundwaters is strictly dependent on the variations of a number of factors controlling soil-water equilibrium. Thus, the assessment of potential retoxification processes due to heavy metals and the identification of their control parameters, require an accurate analysis of the hydrogeochemical framework of the system.

In a coastal aquifer in south-eastern Sardinia, affected by heavy metal contamination due to the past mining activity, the spatial and time variability of a few hydrogeochemical parameters and heavy metals was analyzed by geostatistical methods in order to assess system potential for retoxification processes (Sodde *et alii*, 2007).

The results of the study suggest that, when salinity increases, ion exchange processes, triggered by seawater intrusion, are the most important mechanisms of heavy metals release from the contaminated coastal aquifer. However, also salinisation due to evaporite solution, which occurs under reducing conditions, and salinisation due to sea spray or mixing with brines can contribute to produce heavy metal release. Se and Sb are the heavy metals most sensitive to salinity changes. Comparison of heavy metals and pH, Eh and salinity distributions suggests salinization dynamics affects mobilization of most heavy metals. Some heavy metal concentrations and distributions in groundwater proved to be affected by variations in chemical characteristics rather than by distribution and concentration in contaminated sediments. Relationships between heavy metals and retoxification factors obtained by comparing spatial distributions of different parameters was confirmed by Factor Analysis.

Remediation strategies and actions for restoring heavy metals contaminated sites located on the coasts should consider the effects of possible retoxification processes of heavy metals accumulated in soils and sediments on groundwater contamination.

Coastal aquifer vulnerability zoning should be periodically validated by accurate monitoring before using it for assessing integrated vulnerability scenarios for planning coastal area management.

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