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Groundwater nitrate risk assessment using intrinsic vulnerability methods: A comparative study of environmental impact by intensive farming in the Mediterranean region of Sicily, Italy

Antonino Pisciotta [a,*], Gioacchino Cusimano [b], Rocco Favara [a]

[a] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo, Via U. La Malfa n. 153, 90146 Palermo, Italy
[b] Dipartimento di Geologia e Geodesia dell'Università di Palermo, Via Archirafi n. 22, 90123 Palermo, Italy

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ABSTRACT

Groundwater contamination by nitrate and other nutrients is a major problem throughout the world, often occurring as the result of anthropogenic activities, lack of management, and over-exploitation of groundwater resources. In the last few decades in the majority of the Italian regions, the nitrate concentrations in groundwater have dramatically increased, mainly as a consequence of the large-scale agricultural application of manure and fertilizers. This excessive use of chemicals and fertilizers increases the risk of surface and groundwater pollution from diffuse sources, which have an important impact on human health and the environment. Sicily is located in the central Mediterranean, the total area of the island is 25,711 km^2, with more than 5 million inhabitants. The terrain of inland Sicily is mostly hilly and intensively cultivated wherever it was possible, nitrate vulnerable zone about 40% of flat areas and 5.37% of total. The test site is located in Canicattì (central Sicily); the current land use (grape, olive and almond cultivation) constitutes the main source of groundwater pollution.

In order to investigate the effect of over-farming on groundwater quality and to indentify an appropriate methodology for pollution risk management, we have carried out a comparative study on the potential risk of contamination from nitrate of agricultural origin, according to the conventional parametrical methods used in Europe; the IPNOA parametric model (agricultural nitrates hazard index) method combined with the SINTACS and DRASTIC intrinsic aquifer vulnerability methods. All parameters used in this risk assessment were prepared, classified, weighed, and integrated in a GIS environment. For calibrating the models and optimizing and/or weighing the examined factors, the modeling results were validated by comparing them with groundwater quality data, in particular nitrate content, and with census data from the potential pollution sources. The criterion for checking this method was the correlation coefficient of each model with the nitrate concentration in the groundwater. A relative coincidence of a high nitrate concentration and risk mapping was observed, but this correlation was only significant using the SINTACS method. In fact, the final risk maps show significant differences in risk quality assessment; the DRASTIC model values show an over-evaluation of the real contest. In conclusion, the SINTACS parametric method appears to be the most suitable for constructing a relevant risk map of the contamination of these aquifers, which are considered to be typical of the Mediterranean region for their hydrogeological and hydrochemical features.

1. Introduction

The contamination of groundwater from nitrate and nutrients is a major problem throughout the world. These related problems are often the result of anthropogenic activities, lack of management, and the overdevelopment of water resources. In particular, agriculture has been identified as a significant contributor to diffuse source contamination (Addiscott et al., 1991). An excessive use of chemicals and fertilizers increases the risk of groundwater contamination. Once groundwater has been contaminated, it is difficult to remediate. Thus, the prevention of contamination is the primary strategy of water quality management (Ceplecha et al., 2004). Nitrate is the primary form of inorganic nitrogen within the soil, which is essential for the growth and development of healthy crops. It has been shown in vivo that nitrite derived from nitrate can form N-nitroso compounds with amines and amides, which may have carcinogenic properties (Van Maanen et al., 1996). In Italy, high levels of nitrate in well waters are associated with an increased risk of gastric cancer (Gilli et al., 1984). Boeing (1991) also reported an association between stomach cancer and high nitrate levels.

During the last ten years, great interest has been dedicated in Sicily to the cultivation of a specific variety of table grape ("Uva Italia"). Canicattì and the surrounding area is one the most important sites of intensive table grape production. This land use has caused a progressive

* Corresponding author. Tel.: +39 091 680 9275; fax: +39 091 6809449.
E-mail address: fabio.pisciotta@ingv.it (A. Pisciotta).

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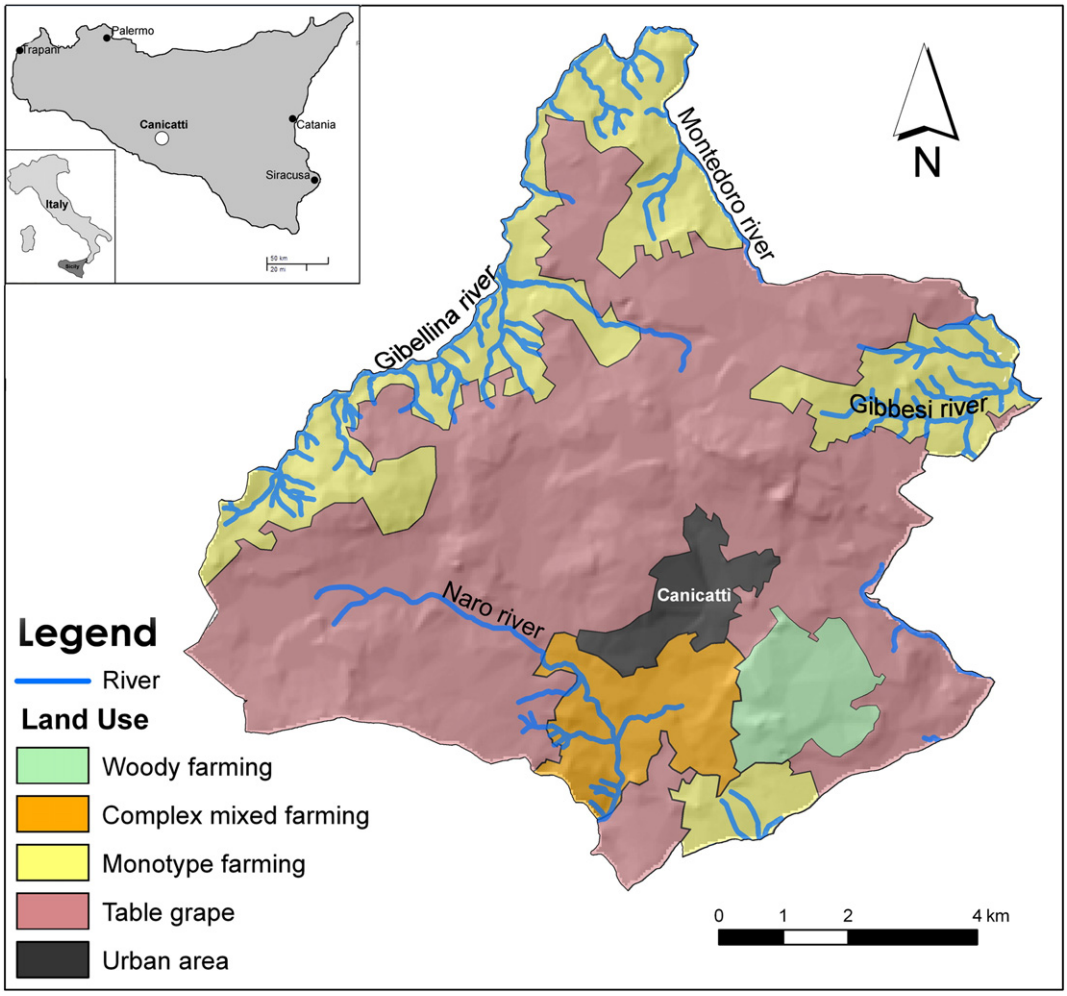

Fig. 1. Location map and land use of the study area.

qualitative and quantitative degradation of groundwater resources (Causape et al., 2006; Thirumalaivasan et al., 2003). As a consequence, the vulnerability to pollution of the unconfined aquifer system, which represents the main water resource of the area, has increased.

The term "vulnerability" refers to the specific susceptibility of an aquifer system to ingest and diffuse hydro-vectored contaminants whose impact on the groundwater quality is a function of space and time. The assessment of this intrinsic vulnerability has to be performed through a classic zoning technique via GIS, using a great deal of available parameters that are processed using a count-point-system model (Civita, 1994; Vrba and Zaporozec, 1994). The pollution risk depends not only on vulnerability, but also on the existence of significant pollutant loading. The scope of the impact on water-use depends on the magnitude of the pollution event and the amount of the groundwater resource.

In many countries, the governments have been forced to introduce several specific regulations to control nitrate pollution, because it potentially poses as a serious health hazard to all human inhabitants on a global scale. Agricultural activities are well-known causes of nonpoint source pollution of groundwater through nitrate. An excessive use of chemicals and fertilizers increases the risk of groundwater contamination. However the difference between rural and urban nitrate concentrations is often small, due to the non-agricultural sources of nitrogen that are concentrated in cities (Wakida and Lerner, 2005).

The prevention, control and combat of groundwater pollution are addressed in various European Union (EU) and national legislative acts, since groundwater is considered a valuable natural source. The EU Water Framework Directive (2000/60/EC, 2000), WFD, and its daughter Directive on the Protection of groundwater against Pollution (2006/118/EC, 2006), GWD, establish criteria for the definition of groundwater status (quality and quantity). Regarding nitrates, the GWD establishes the quality standard for assessing groundwater chemical status of 50 mg/l. Moreover, the Nitrates Directive (91/676/EEC, 1991) is an integral part of the WFD and it was drawn up with the specific purpose to reduce water pollution caused by nitrates from agricultural sources and prevent further such pollution. EU members are required to identify waters affected by nitrate pollution, designate nitrate vulnerable zones (NVZs) and several spatial analysis techniques were adopted to identify them. Italy formally acknowledged this directive in 1999 and in 2006 with the Italian Legislative Decree 152/99 and 152/06. This national regulation suggests a parametric system based on empirical relationships between the soil or sub-soil characteristics and N leaching risk.

Numerous studies have been performed to develop and to check of hybrid methods for specific aquifer vulnerability assessment based upon the parameters, using statistical criteria and weights based on the vulnerability models (Antonakos and Lambrakis, 2007; Baalousha, 2010; Bukowski et al., 2006; Capri et al., 2009; Draoui et al., 2008; Ghiglieri et al., 2009; Pacheco and Sanches Fernandes, 2013; Roelsma and Hendriks, 2014; Saidi et al., 2011; Sener and Davraz, 2013).

In this study, the potential risk of nitrate pollution in aquifers from agricultural practices was assessed by combining the SINTACS R5 (Civita and De Maio, 1997, 2000) and DRASTIC (Aller et al., 1987) parametric methods in order to calculate an aquifer's intrinsic