Risk of groundwater contamination by nitrate in the Po basin, Italy

Risk of groundwater contamination from nitrates in the Po basin (Italy)

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Abstract In 1991, the EU promulgated the Nitrates Directive 91/676/EEC, with which it obliged member states to set up monitoring systems, to designate areas vulnerable to nitrate pollution, especially that of agricultural origin, and to activate protection plans, setting the initial target as 1993.

After a long delay, Italy assimilated the directive in 1999 with the D.Lgs. 152/99 (legislative decree), which basically transferred responsibility for identifying vulnerable zones to the Regional Authorities.

The Po river basin was, and still is, particularly problematical, with its surface aquifers containing generally high levels of NO_3^- particularly in the lower Piedmontese plain, in the Alessandria area, in the upper Milan valley and in the Emilia-Romagna plain.

Taking these pollution levels into consideration, along with continual eutrophication of the Adriatic Sea, the EU enjoined Italy to define the entire Po valley as vulnerable, to avoid being penalised. Such a restrictive designation would, however, have had a highly negative effect on agriculture and to avoid this, the Regions of the Po basin, after long delays, set in motion a series of scientific studies in order to be able to limit the areas defined as vulnerable.

This paper, in line with Regional policies, proposes a method that can be applied on a regional scale for identifying areas vulnerable to nitrate pollution. It uses a parametric indicator of Pollution Risk, which is the product of the *SINTACS R5* and the *IPNOA* indicators: since the former indicator assesses the vulnerability of an aquifer, that is its susceptibility to absorption and spread of fluid or water-borne pollutant over time, while the latter studies the risk of pollution by nitrates of agricultural origin (that is, the amount of nitrates persisting in the territory), it is clear to us that the product of the two indicates the nitrate that may actually be present in the aquifer waters. The easy availability of input parameters for the model, the reliability of the output data, as compared with the results of monitoring various test sites in the Po valley, and the production of thematic maps, using GIS software, make the method a valid tool for the Regions when identifying zones vulnerable to nitrate pollution.

The method is presented here with application to a test site of about 250 km^2, situated in the lower Alessandria plain (Eastern Piedmont, Italy).
Keywords GIS; nitrates directive; risk of nitrate pollution

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European and Italian legislation

Groundwater bodies now represent one of the principal resources used to supply drinking water in Italy, but not only in Italy. At the same time, however, the quality of these water sources is deteriorating continuously due to various types of pollutants, one of the most widespread in surface aquifers being nitrogen, which is present in groundwater bodies principally as the NO_3^- ion.

In 1991, the EU attempted to solve the problem of poor or non-existent legislation on this matter by approving the Nitrates Directive 91/676/EEC, which aimed to reduce and prevent water pollution caused by nitrates of agricultural origin. The directive obliged member states to set up monitoring systems, to define areas vulnerable to nitrates, of agricultural origin in particular, and to draw up codes of good agricultural practice and action programmes, setting 1993 as the target date for initial results.

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Italy remained indifferent to the directive for a long period, so that on 20 May 1997 the European Commission presented a petition (C-195/97) to the European Court of Justice, given that already in 1995 the Commission had, by injunction and on reasonable grounds, drawn the attention of the Italian government to its failure to comply with the Nitrates Directive. The sentence decreed that Italy (in addition to being obliged to pay all the costs of the trial), having neither adopted nor communicated, within the set term, the provisions necessary for assimilating the Directive into its own legislation, had failed to comply with the obligations of 91/676/CEE.

The same scene was to be repeated in April 1999, when the European Commission took the Italian Government to the European Court once more (C-127/99) and this time the sentence, laid down in November 2001, forced Italy to declare itself insolvent with respect to the Nitrates Directive, in particular as regards establishment of action programmes to protect waters from nitrates of agricultural origin, setting up monitoring systems for surface and ground waters and drawing up codes of good agricultural practice, and publishing reports to summarise the situation.

In the meantime the Italian Government had passed the D.Lgs 152/99 (since modified by law 152/2006), which finally assimilated the Nitrates Directive; the law transferred responsibility to the Regions for monitoring systems, for definition of zones vulnerable to nitrates and for the establishment of action programmes, but it did set out the guidelines.

The Po river basin

Art. 3 of the Nitrates Directive requires all known zones in the territory that discharge into polluted water to be classed as vulnerable. The situation of the Po basin was particularly alarming, as the EC itself had already noted in 2000: given that the whole of the northern Adriatic Sea was eutrophic, the entire Po basin was to be declared vulnerable, with the exception of the hilly and mountainous zones.

Indeed, as some studies on the area have also shown (Giuliano *et al.*, 1997), the situation as regards groundwater resources (RIS) in the Po valley is anything but rosy. The potability limit for NO_3^- concentration has been set at 50 mg/l and this limit has been exceeded in at least four zones of the Po valley: lower Piedmont, Alessandria area, upper Milan and the Emilia-Romagna plain.

Applying the classification as requested by the EC would, however, have been an unsustainable burden for the entire agricultural-animal breeding sector and the Po valley regions (Piedmont, Lombardy, Emilia Romagna and Veneto) therefore decided to set up a series of studies aimed at demonstrating that the areas vulnerable to nitrate pollution were actually more restricted than those indicated by the Commission.

These studies led to the promulgation of regional laws in which portions of the Po valley were designated as vulnerable. These definitions did not satisfy the EC, however, and last year (2006), almost 15 years after notification of the Nitrates Directive, the commission opened a formal process against Italy (procedure 2006/2163) for infringement, not only singling out for criticism the Po Basin and designation of vulnerable areas, but also criticising the action programmes that have been set in motion.

In order to avoid penalties, the Regions had to take remedial action, with more detailed studies and new monitoring programmes but as of now, of the Po valley regions only Lombardy (law D.G.R. 8/3297 of October 2006) and Veneto (law DGR 62, of May 2006) have proceeded to increase the percentage of their territory designated as vulnerable to nitrates, while Piedmont and Emilia Romagna are still stuck with, respectively, law DPGR n. 9/R of 18/10/2002 and subsequent amendment DPGR n. 2/R of 15/03/2004, and law DGR 9162 of 18 July 2003.

A parametric method for evaluating risk: application at a test site

The following paper follows the line of scientific research concerned with pollution by nitrates of agricultural origin, and, as we have shown, is currently of great interest to the public administration in Italy (and not only Italy).

We propose a parametric method for evaluating the risk of pollution (Civita, 1999; Civita *et al.*, 2003; Civita and Fiorucci, 2003), meaning the product of the intrinsic vulnerability of an aquifer (Civita, 1987) and the pollution hazard presented by nitrates of agricultural origin. Vulnerability has been evaluated adopting the parametric model using points and weightings, *SINTACS R5* (Civita and De Maio, 2000), while for the pollution hazard the *IPNOA* parametric model has been used (Padovani *et al.*, 2000; Padovani and Trevisan, 2002).

To be precise, we are considering a potential risk, as this study has not evaluated the value of the subject at risk.

The area covered by the study

We chose a portion of the plain around Alessandria, covering about 250 km^2; it is situated S. of the R. Tanaro and E. of the R. Bormida. In the southern part of the area the Orba Torrent, a tributary flowing into the right of the Bormida, runs from SSE to NNW, and in Basaluzzo municipality the Bormida receives the waters of the Lemme Torrent, its most important tributary. The whole area is crossed by numerous canals and channels.

Industrial activity, strongly present, is mainly concentrated S. of the city of Alessandria and in the environs of the centres of population comprising Spinetta Marengo and Bosco Marengo. Agricultural activities are also carried out in the area, characterised mainly by cultivation of maize, wheat, sugar-beet and sunflowers, while as regards animal breeding there are modestly sized pig farms and cattle farms, for both meat and milk production, mainly in the central and southern part of the area, and also poultry and ostrich farms.

From a hydrogeologic point of view (Civita *et al.*, 2000), the main complex present in this area is the Alluvial Complex, of Quaternary origin, (this in turn is divided into three sub-complexes) comprising mainly gravel alternating with sand and argillaceous horizons. The value of relative permeability varies from medium to high depending on the presence of fine particles in the gravel. The depth of this complex is significantly reduced in the San Giuliano area (E. of Alessandria), where, due to ancient tectonic movements, there is a structural elevation with older deposits rising to the surface.

Another Quaternary type complex is the Current Alluvial Complex, which can be identified along the axes of the principal water courses.

Below the alluvial complexes there is a complex resembling V*illafranchiano*-type deposits, the Argillaceous-Gravel Complex. This complex, reaching even hundreds of metres in depth, disappears in the San Giuliano area, where the Limestone-Sandstone-Argillaceous Complex rises to 15 below the surface (and in direct contact with the Alluvial Complex), grouping together the formations belonging to the *Appenine Units*. These formations consist of marl, sandstone and limestone, characterised by low relative permeability. To the S. of the structural elevation, in the space of a few kilometres, the complex sinks below the alluvial and Villafranchiano complexes.

The confining bed of the Quaternary complexes comprises the Argillaceous-Gravel and the Limestone-Sandstone-Argillaceous Complexes below them; they hold a single unconfined aquifer with a flow field (see Figure 1) in the N-S direction, indicating that the River Tanaro is the main destination of the water from the aquifer. The main water courses act as drainage axes upstream, while they tend to recharge the aquifer as they

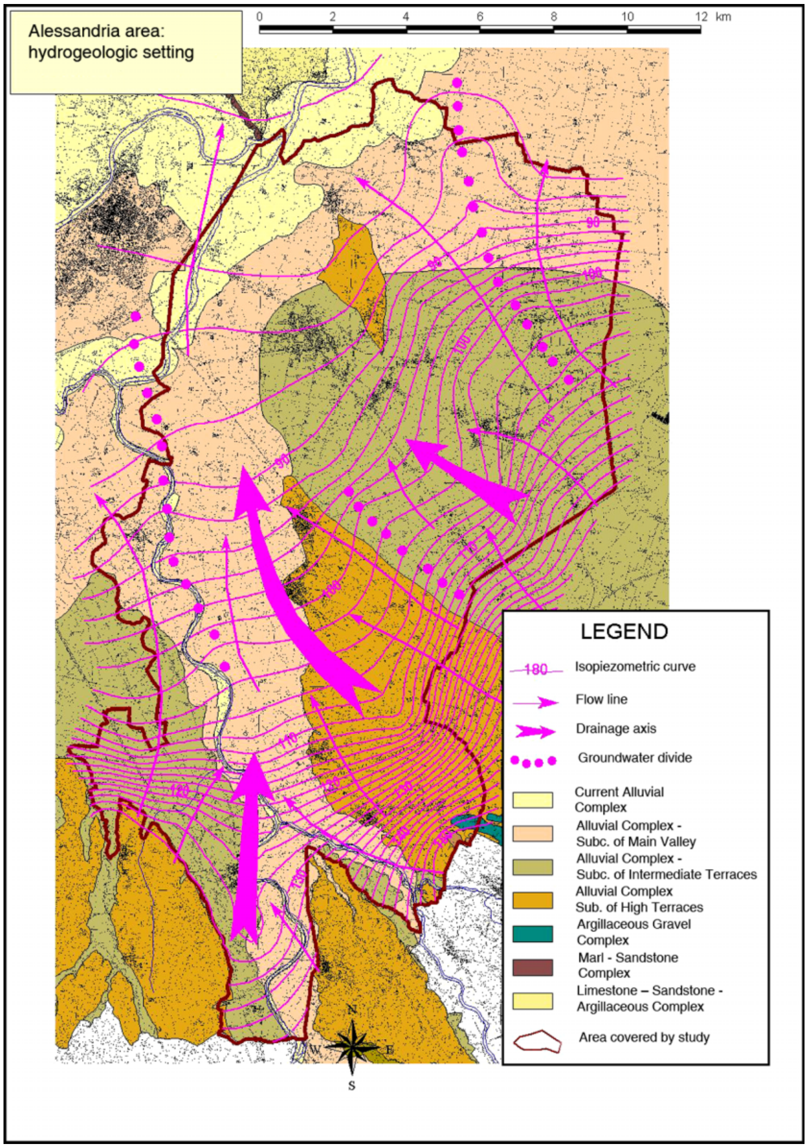

Figure 1 Alessandria area: flow pattern of the unconfined aquifer and hydrogeologic setting

flow downstream. The hydraulic gradient passes, from upstream to downstream, from 1.2% to 0.057%.

The SINTACS R5 model

In order to apply this parametric model we created a discretization grid over the area being studied, with a mesh of 50 m square cells, so that at the end of the study each square would have a vulnerability rating obtained from the SINTACS indicator.

The model assigns each cell of the discretization grid with a point value for each of the 7 parameters: depth to water table (S), effective infiltration (I), unsaturated zone attenuation capacity (N), soil/overburden attenuation capacity (T), saturated zone characteristics (A), hydraulic conductivity (C), topographic surface slope (S). For each cell, we multiplied the point vector by a string of weights, chosen according to the hydrogeologic and impact setting of the particular cell (normal impact, severe impact, seepage, karst, fissured). The sum of the products gives the SINTACS indicator, which is then normalized and divided into 6 classes to obtain six ratings of vulnerability to pollution, from 1 (very low) to 6 (extremely high).

Practically speaking, the data for the aquifer, for the unsaturated zone attenuation capacity and the hydraulic conductivity, were obtained from analysis of stratigraphic descriptions of wells and piezometers that had been excavated in the area under study and also from hydrogeologic work for the area; data from the analysis of about fifty soil samples were used to define the point ratings for soil/overburden attenuation capacity and effective infiltration, performing cross-checks for the latter with data from precipitation stations in the area; depth to water table was obtained by piezometric measurements taken in the field in April 2006 for 70 water points; topographic surface slope was taken from the DEM for Piedmont region.

The IPNOA model

For the pollution hazard due to nitrates of agricultural origin we used the IPNOA point and weight method, which considers 7 parameters divided into two groups, as contemplated by Italian legislation:

- hazard factors (chemical fertilisers -FP_{fc}-, organic fertilisers -FP_{fo}-, spread of purification plant effluent -FP_{fd}-), which represent the effective sources of nitrate pollution;
- control factors (climate -FC_c-, natural nitrogen content of the ground -FC_a-, agricultural practice -FC_{pa}-, type of irrigation -FC_i-), which are parameters that either negatively or positively control the percolation of nitrate into the (saturated or unsaturated) aquifer.

For each parameter we began by working on the basis of land registry sheets (except for organic fertilisers where we worked at the municipality level) assigning a point value to each sheet (or municipality) for each factor, as required by the method; we then discretized the area using the same grid as the one used for the SINTACS method; for each cell we calculated the total hazard factor and control factor using the following equations:

$$FP_{\mathrm{tot}} = FP_{\mathrm{fm}} + FP_{\mathrm{fo}} + FP_{\mathrm{fd}}$$

$$FC_{\mathrm{tot}} = FC_{\mathrm{a}} \times FC_{\mathrm{c}} \times FC_{\mathrm{pa}} \times FC_{\mathrm{i}}$$

The product of the two totals gives the IPNOA hazard factor. Also in this case the hazard factor is divided into 6 classes, obtaining six levels of nitrate pollution hazard from 1 (Improbable) to 6 (High).

To be able to assign point values to each parameter we used mainly CAP data from which we obtained soil use, and by matching this information with that for chemical fertiliser application for each type of cultivation (this data was available in the Piedmont Region database) we were able to obtain the point value for FP_{fc}; CAP data was then also used for irrigation and agricultural practice; climate was calculated using the rainfall and temperature data already taken from the precipitation stations for SINTACS; and finally, the data used to calculate the FP_{fo} point values were obtained from the General Agricultural Census taken in 2001. There were no areas where spreading of purification plant effluent was practised.

The risk

At this point, to obtain the potential risk of pollution by nitrates of agricultural origin, for each cell we just multiplied the vulnerability rating by the hazard factor. The values obtained were then assigned to 6 classes defining the relative risk from 1 (very low) to 6 (extremely high).

Results and discussion

Application of the latest GIS software to the working method used above allowed us, among other things, to create thematic maps, as illustrated in Figures 2–4, which show, respectively, the map of aquifer vulnerability to pollution, the map of nitrate pollution risk and the map of potential nitrate pollution risk.

As we can see from Figure 2, over 80% of the area included in the study falls into the high vulnerability class and this corresponds to areas with lower depths to water table and coarser saturated zones (and hence correspondingly higher point values) or to zones where the aquifer is drained by surface water courses. In the most northerly part, near the R. Tanaro, increasingly small depths to water table result in High and Extremely High vulnerability classes. The medium vulnerability class is present in the SE of the zone under study.

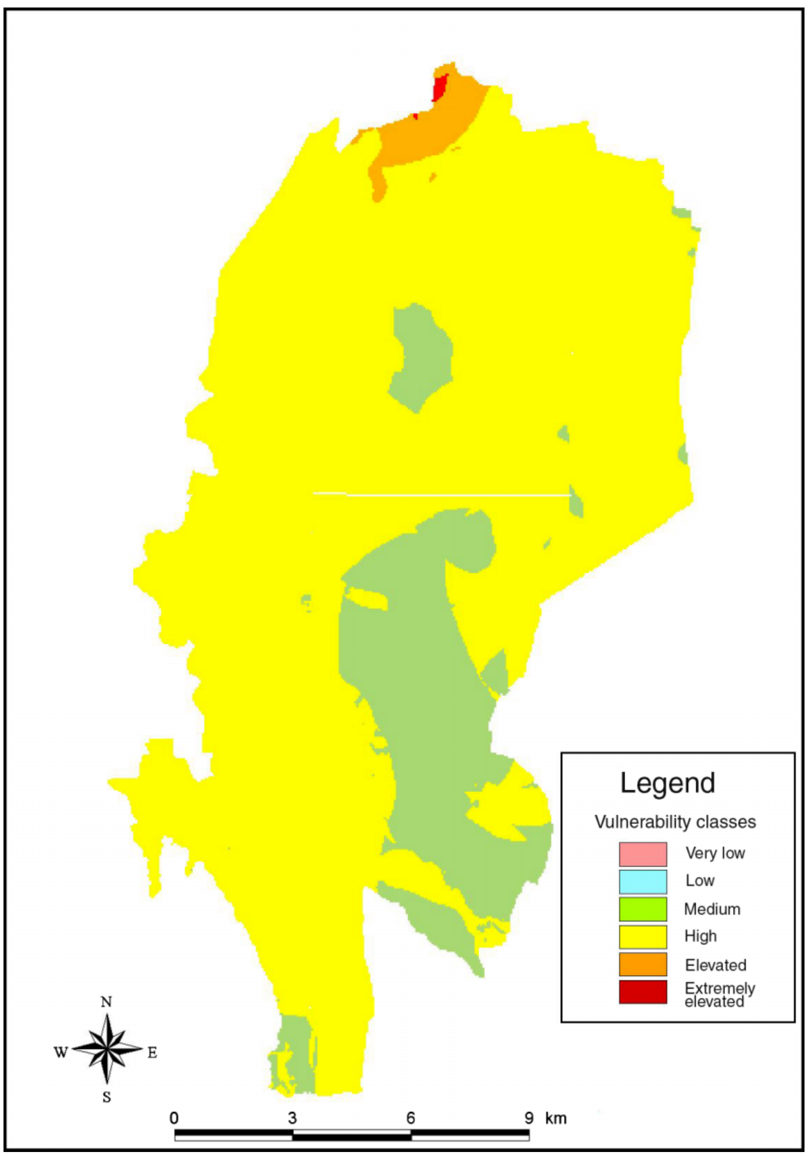

Figure 2 Map of aquifer vulnerability in the Alessandria area

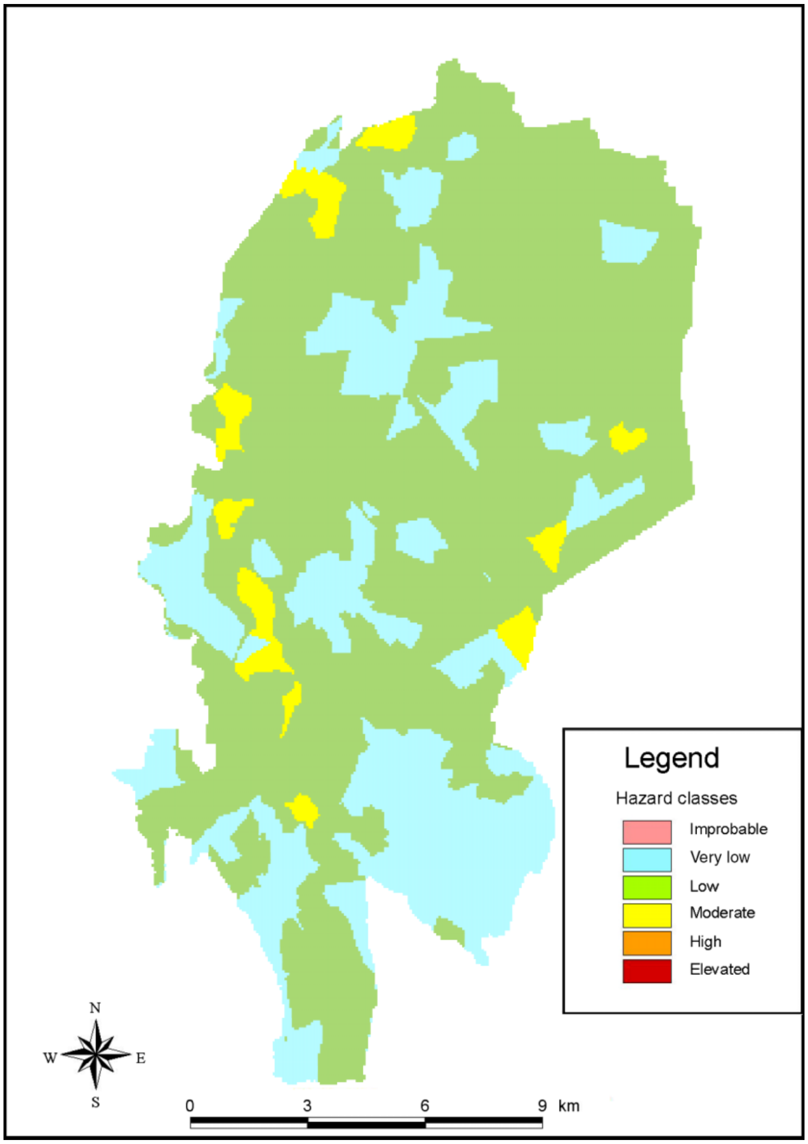

Figure 3 Map of IPNOA index of nitrate hazard in the Alessandria area

As for the hazard (Figure 3), the situation is quite good, as in most of the area the hazard is very low or low; there are very few cells showing moderate hazard.

Lastly, Figure 4 shows the risk map as a product of the previous two. Most of the area is high risk, which, as for the vulnerability map, becomes extremely high to the north. There are high and medium risk areas in the central and southern zones.

In April 2006 samples were taken in the field for 35 water points, which were uniformly distributed over the area under study. The results of chemical analysis were used to create the map showing distribution of nitrate concentration (Figure 5). Most of all we note the positive effect of the surface water courses on the aquifer: indeed, the waters of the Lemme, the Orba and the Bormida, which have low nitrate levels and are drained by the aquifer, have a dilution effect on the aquifer, so that the points straddling the water courses show lower concentrations of nitrate. In any case the most striking result is that almost 50% of the area has nitrate concentrations of over 50 mg/l, with some points

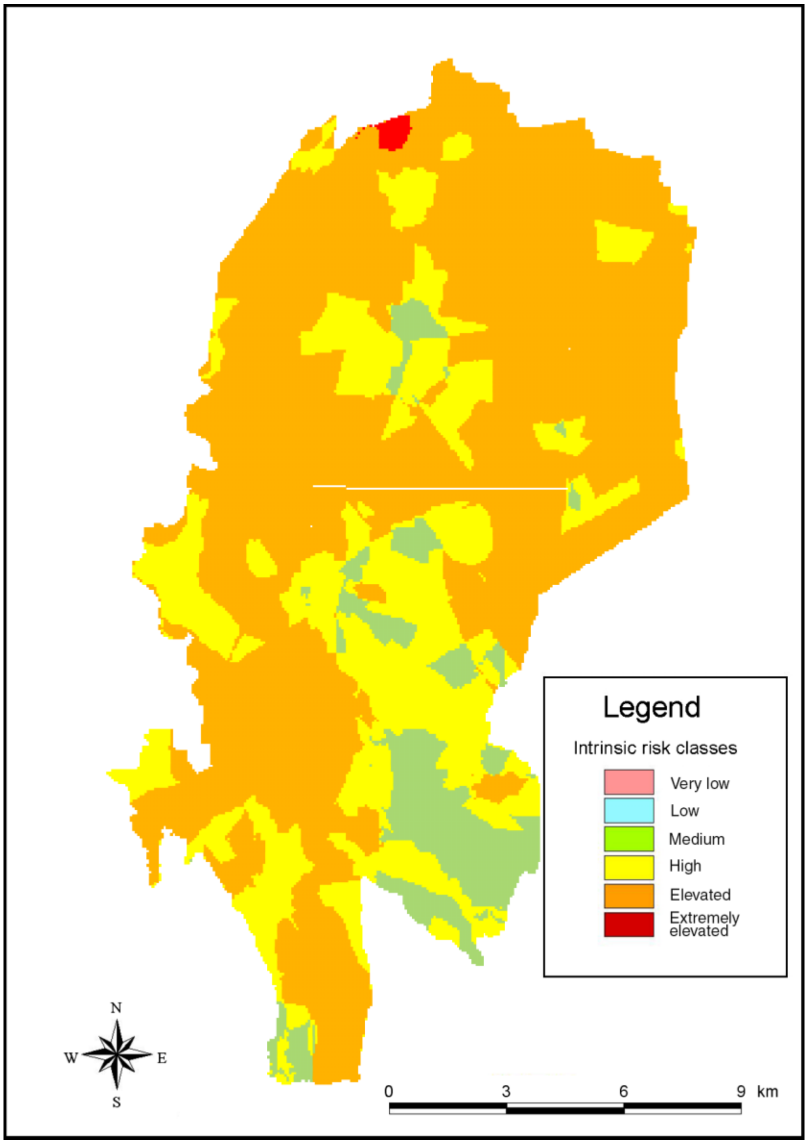

Figure 4 Map of intrinsic nitrate pollution risk from agricultural sources in the Fossano area

exceeding 100 mg/l. And while on the one hand it is reassuring to compare this map with the risk map, because the areas with concentrations above the limit correspond quite well with those identified as high risk, on the other hand it is difficult to justify such high levels of NO_3^- in the groundwater resource, when there is no zone classified as at extremely high risk.

In reality, it can be noted that the zones with the highest concentrations of nitrates are situated downstream of industrial sites or of the largest centres of population, and this would lead us to hypothesise human activity as the origin of these nitrates, or at least a dual origin: agriculture and human activity. One way of finding an answer would be to use isotope chemistry to determine the origin of the nitrogen present in the waters. And this will be one of the fields developed by the project presented here.

In conclusion, when we consider the results obtained here and those for other work mentioned in the literature (Civita *et al.*, 2003, 2007) synergistic application of the

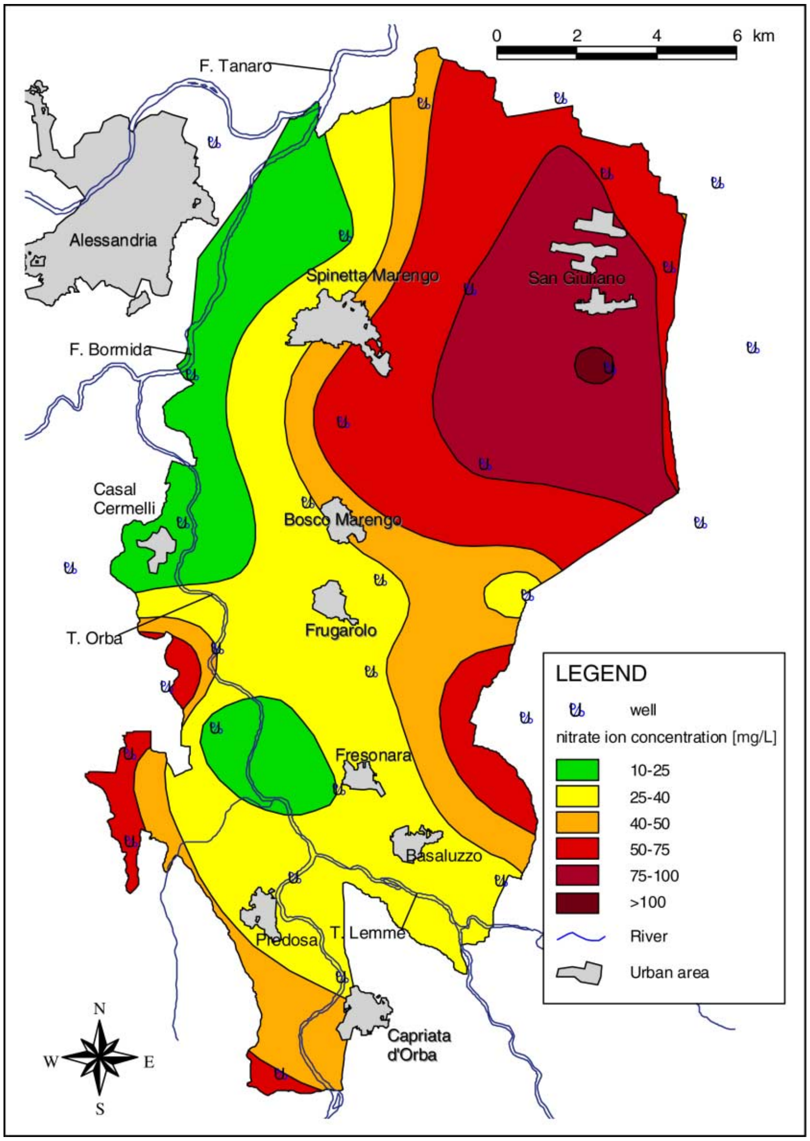

Figure 5 Isoconcentration map for NO_3^- in the unconfined aquifer in the Fossano area

SINTACS R5 and IPNOA parametric models for evaluating potential risk of pollution by nitrates of agricultural origin, developed using GIS, represents a valid tool for the public administration in managing and protecting water resources when defining, for example, what the legislation calls "areas vulnerable to nitrates". Moreover, when we compare the results with the monitoring data, it is possible to hypothesise the actual origin of the nitrates present in the groundwater resources and, when necessary, to carry out more specific research, using isotope chemistry for example.

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