The Italian Way to Prevent Groundwater Contamination Risk

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GROUNDWATER MANAGEMENT IN THE DANUBE RIVER BASIN AND OTHER LARGE RIVER BASINS

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FOREWORD

Groundwater is the most important and widespread water supply resource. Many of us associate it archetypally with the beauty and power of a mountain spring. Serbian people say that „for water to be drinkable, it needs to pass over seven stones“. European countries predominantly use groundwater, or water obtained through artificial-recharge methods, for their drinking water supply.

However, occasionally the question is raised: Why do we use groundwater so often?

The answer given to this question is sometimes quite banal: "Groundwater is used when technical and economic assessments indicate that it is more appropriate than any other competing resource". This leads to a further question: Why do we use groundwater so often, even when the source is more distant and the abstraction costlier? Part of the answer is attributed to self-purification processes in groundwater. These processes result in the stabilization, and in most cases, improvement of groundwater quality. Tradition also leads people to demand water from this resource. Professional and scientific practice indicates that an intergranular aquifer and percolation through the ground are often comparable to an extensive physical and biochemical reactor, which contributes to the safety of water supply and to a general improvement of groundwater quality. Coupled with this is the fact that the aquifer environment is very heterogeneous, and processes which take place during groundwater percolation are numerous, as are their affects.

Over time, water management has evolved into a very intricate pattern of inter-dependent activities which affect water quality, the water regime, the use of water, and protection against the adverse effects of water. It encompasses many areas of human activity and constitutes a very large system, whose proper function largely determines the state of a human community, and is even a pre-condition for its survival.

In many areas, groundwater used to be a virtually inexhaustible source of water supply, and was convenient because it was readily accessible, and because it continued to deliver a consistently good quality of water. However, increasing rates of abstraction, expansion of human settlements and industry, as well as deterioration of water quality, have all led to increasing constraints on water management, including the use of groundwater.

Water use and water management can be divided into three stages:
Stage 1: Abundance - Water use and water pollution are low relative to available resources.
Stage 2: Depletion - Water use and water pollution are considerable relative to available resources, leading to a gradual depletion of resources.
Stage 3: Sustainable development - Water management must be implemented in such a way as to conserve good water status and not deplete the resources to future detriment.

In Europe and throughout the world, major efforts are being made toward sustainable development of water systems. European water directives promote water protection and sustainable water management. Many European countries have invested heavily in water protection.

Some countries are just entering this stage. Water management within large river basins is both an important and challenging issue. Europe has made great strides in this area. A characteristic example is the Danube River Basin, where a number of countries are successfully cooperating within the scope of the International Commission for the Protection of Danube River (ICPDR). The European Water Framework Directive, the Nitrate Directive, the Groundwater Directive, and various other documents, set forth criteria for the management of groundwater resources. These criteria have to be met, and require, inter alia, adequate familiarity with natural processes.

Scientific contributions are expected in the definition of natural processes which take place in the aquifer, as well as in problem areas relating to groundwater utilization and protection of groundwater resources.

This Conference is a regional conference of the International Water Association (IWA). However, the presence of authors from countries throughout the world extends the breadth of the Conference.

The Conference is expected to lend interactive support to the achievement of the Danube River Basin Management Plan (ICPDR), the gathering and joint work of water services in the Danube River Basin (IAWD), and the interaction between the IAWD and ICPDR.

The IWA umbrella has contributed to the overall character of the Conference. UNESCO has, in addition to being a sponsor, contributed through papers of its experts.

The Conference would not have been possible without the significant support of the Serbian Government and the Serbian Academy of Sciences and Arts.

The Jaroslav Černi Institute for the Development of Water Resources and the Belgrade Water Supply and Sewerage Company played a leading role in the profiling and organization of the Conference, with organizational and material support of a large number of organizations, companies, and individuals.

The Conference objectives are:

- To provide an overview of current problems in groundwater management in the Danube River Basin and in other large rivers basins;
- To summarize available background information for the preparation of river basin management plans according to the WFD, especially in the Danube River Basin;
- To enable the exchange of knowledge relating to the transport and transformation of various substances in groundwater, and to the protection of groundwater;
- To lend room for discussion between various parties involved in groundwater issues;
- To provide a forum for the discussion of technical issues of groundwater abstraction and groundwater quality management;
- To present methodical aspects of groundwater resource status assessment; and
- To address socio-economic and legislative issues.

Conference objectives will be achieved through five discussion themes:

Theme 1: General Status of Groundwater Management in the Danube River Basin and Other River Basins
Theme 2: Problems of Groundwater Source Management and Maintenance
Theme 3: Bank Filtration and Artificial Recharge
Theme 4: Natural Attenuation and Aquifer Restoration
Theme 5: Tools for Status Assessment

More than fifty valuable papers have been submitted addressing these themes and will no doubt assure the success of the Conference.

Chairman of the Programme and Scientific Committee

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The Italian Way to Prevent Groundwater Contamination Risk

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Abstract In the early 1980's the Italian scientific community, together with a number of institutional decision-makers, realized how urgent it was to protect natural and environmental resources. They agreed that an adequate level of scientifically organized knowledge allows the accurate planning and development of environmental systems through management and direction of the actual development process, without hindering it. Since the special project was first set up in 1984, as part of the gndci-cnr (National Group for the Defence against Hydrogeologic Disasters, of the Italian National Council of Research) scientific context, it has been the cardinal point of Research Line 4 "Assessment of Aquifer Vulnerability". The problem of groundwater contamination was examined in this project for the very first time in Italy in an organic and extensive manner as a key for forecasting and prevention purposes. The Italian approaches to assessing and mapping groundwater vulnerability to contamination are essentially based on two main methodologies:

- the GNDCI Basic Method a HCS (Hazard Contamination Source) type approach that can be used for any type of Italian hydrogeologic situation, even where there is a limited amount of data. A unified legend and symbols are also defined for each hydrogeologic level.
- The SINTACS [Soggiacenza (depth to groundwater); Infiltrazione (effective infiltration); Non saturo (unsaturated zone attenuation capacity); Tipologia della copertura (soil/overburden attenuation capacity); Acquifero (saturated zone characteristics); Conducibilità (hydraulic conductivity); Superficie topografica (Slope)] method, a PCSM (Point Count System Model) developed for use prevalently in areas with good data base coverage.

The methodological approaches described in this paper now make up the Italian standard which has been set in the recent very important Italian Law (152/99) and which has now been ratified in the national guidelines produced by ANPA, the Italian National Agency for Environment Protection. In this paper the structure of the Research Line, the progress obtained by the 21 Research units (over 100 researchers) in 20 years of activity, the results gained etc. are briefly highlighted.

Keywords Contamination, Groundwater resources planning, Mapping, Protection methods

INTRODUCTION

In August 2000 in Johannesburg, there were people holding placards with the slogan "Water is a human right" and, speaking on many people's behalf and in particular for the UN ambassador for water and sanitation problems, Nelson Mandela warned: "Water is a basic right of all human beings: there is no future without water, water is democracy."

It is a fact that in the world 1.2 million people suffer from thirst and that, without effective counter-measures, this number will increase to 3 million over the next 20 years. Pollution, that caused by highly dangerous agrochemicals in particular (and more specifically the highly persistent types[1]), and over-exploitation threaten water resources over practically the whole globe, and under particular threat are groundwater bodies, the most precious resource available for human consumption, that rather than increasing to face increased population needs have already begun to diminish due to climate change, because they are contaminated or because they have been plundered well beyond their sustainable limit.

Over 15 years ago the scientific community worldwide, and that in Italy in particular, had forecast the coming crisis in drinking water resources and well understood that in addition to being a question of environmental resources management and protection this was a Civil Defence problem to be tackled early and resolutely

1 *So-called POP (Persistent Organic Polluter).*

with prevention as the guiding strategy. Applied research, finally directed towards precise objectives, has been carried out by Line 4 of the GNDCI-CNR since 1985. It is worthwhile to relate the principal stages and results achieved during more than 20 years' work.
At the beginning of the '80's people were just beginning to discuss the problem of protecting groundwater bodies from pollution and to forecast demand over the next 20 years, faced with a supply that was certainly not growing. It was only then that in France, in Germany and in some East European countries studies began, in search of organic methodologies for protecting aquifers: the Italian programme was drawn up at that time and was called by the acronym VAZAR (Vulnerability of Aquifers in High Risk Zones). It set itself the goal of assessing the vulnerability[2] of groundwater bodies in a whole series of areas representing the various hydrogeological and impact settings existing in the country. A score of representative areas were chosen, scattered over the whole Italian territory, and each area was to have a research unit carrying out research in the field.
In order to operate as uniformly as possible and to produce comparable results in the field an initial methodology for intrinsic vulnerability assessment and cartography was designed (the GNDCI-CNR basic method) with a preliminary legend for the symbols to be used in the intrinsic Vulnerability Maps:

1. point sources of contamination risk (CSC Contamination Source Centre) and diffuse sources of contamination risk (DSC), that is, the real and potential originators of contamination;
2. subjects at risk, that is points at which the groundwater bodies are utilized by the community, particularly when destined to human consumption.

Overlaying information in this way made it possible to assemble an Integrated Vulnerability Map, a powerful tool for planning water supplies and the territory itself (Figure 1).
The basic method was applied experimentally in Monregalese (NW Italy), and led to publication of the first integrated Vulnerability Map for aquifers, taking a census of the CSC's and DSC's, of the subjects of risk and of the other elements included in the method. As time went on many other cartographies were drawn up using the same method, but accepting proposals at the operational level and including improvements resulting from in-depth research on the subject, as well as new data as it became available, with great variability from one area to the next. Within this context, new assessment methods and cartographic representations were tried out, leading to encouraging results for the scientific community involved in the Programme, stimulating discussion and considerably widening the field of experimentation. Comparative studies of the different methods led to validation of the results achieved.
At the same time, progress was made on other aspects of groundwater protection. VAZAR actually embraces defence of the entire territory and defence of specific points (Civita, 2005 – Figure 2), the former being based on the creation and utilisation of Vulnerability Maps; the latter on the application of protection zones for tapping works, using advanced methodologies. We then began research on the definition of base quality and target quality of water intended for human consumption, on the need for monitoring networks and for anticipating pollution, with the clear purpose of offering the nation a "basket" of integrated, synergic methods for the protection of its increasingly precious groundwater resources.
At the end of the '80's the problem of protecting aquifers from pollution and from over-exploitation became important in many countries, in the USA to begin with where the EPA published a research programme that was designed to come up with a system of assessing the pollution potential of groundwater bodies and this led to proposal of the DRASTIC (Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, hydraulic Conductivity of the aquifer) method, a working model based on points and weightings[3] based on the studies of LeGrand. Other similar initiatives were taken in the United Kingdom, the Netherlands and Germany.

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2 *The vulnerability of aquifers to contamination is defined as the specific susceptibility of aquifer systems to absorb and diffuse, also mitigating the effects, a water-borne pollutant that is such as to cause an impact on the groundwater body in space and over time (Civita, 1987).*

3 *This is a Point Count System Model (pcsm), based on a large number of parameters and factors that determine the susceptibility of groundwater systems to contamination from the surface.*

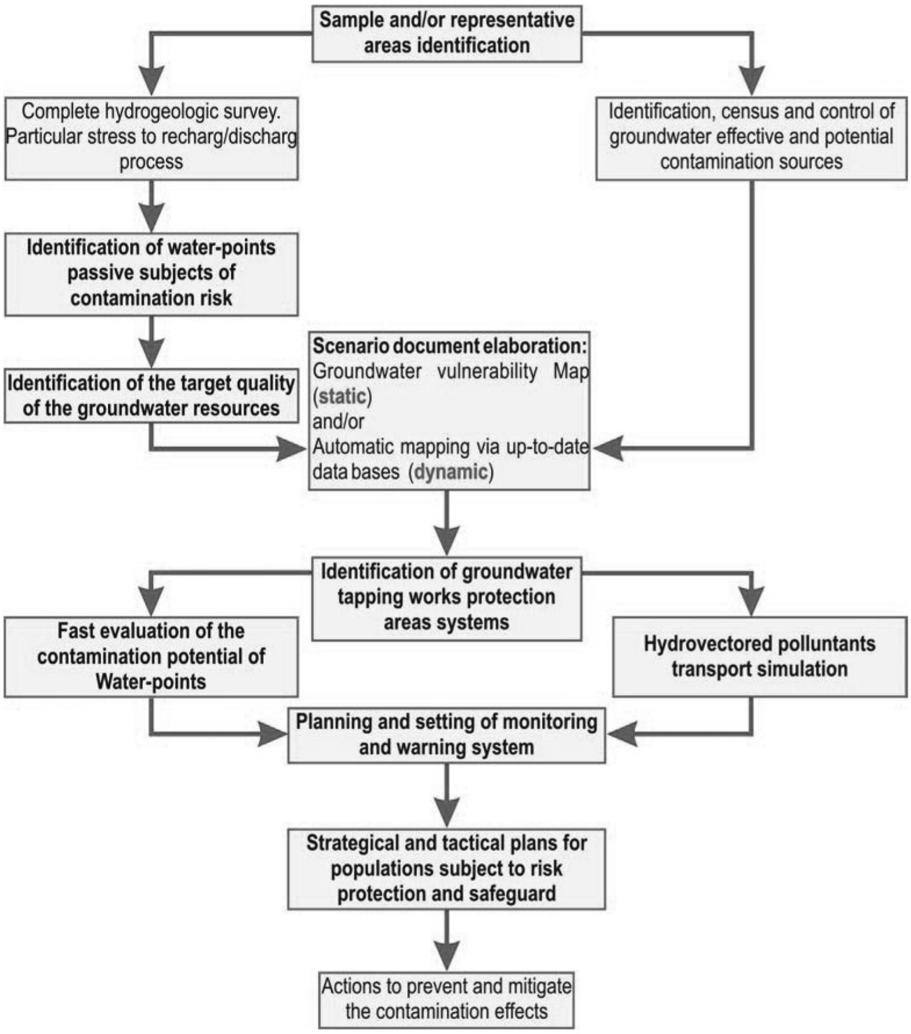


Figure 1: Flow diagram for the first stage of VAZAR (1986 – 1990) Explanation of the first stage should take place in the text

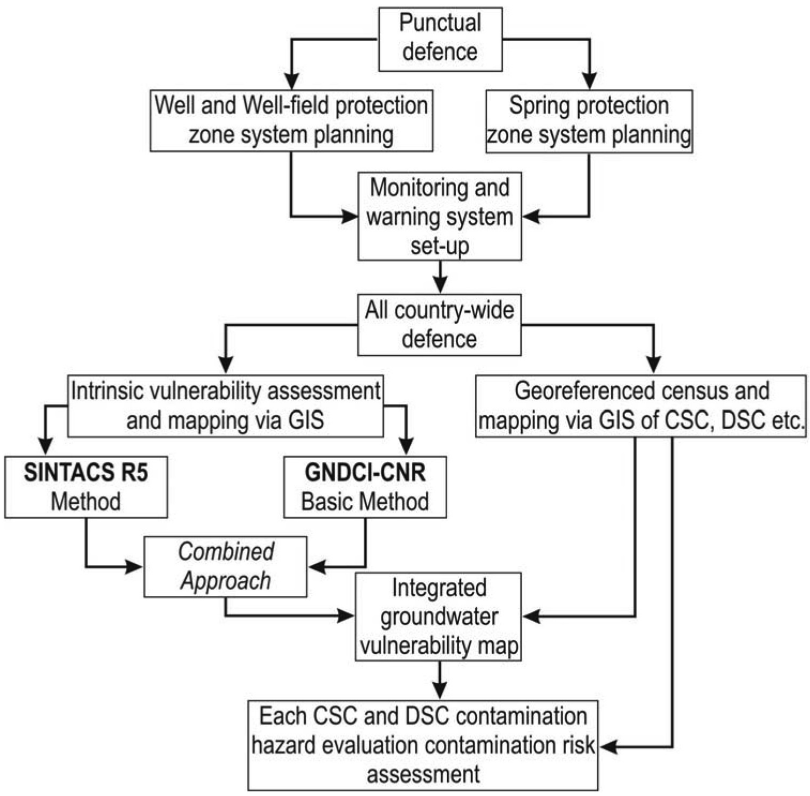


Figure 2: Flow chart of the Italian approach to defending groundwater bodies and tapping works against contamination

UNESCO, in agreement with the IAH, set up an International Working Group in 1990 to produce a kind of handbook for vulnerability assessment and for creating the corresponding maps. This handbook was intended for use by all the nations affiliated to UNESCO as a contribution to their development and to prevent, as far as possible, damage to water resources like that already experienced in developed countries, learning by their mistakes and applying technological measures and methods to avert the resurgence of water crises. The Working Group drew abundantly from the Italian experience, completing its work only in 1995 (Vrba & Zaporozec edit., 1995).

In 1990 Italy had, however, already examined the possibility of using the drastic model extensively, as it seemed a powerful innovation in the assessment of the intrinsic vulnerability of aquifers. It soon became apparent, however, that the method could not be used as such due to the vast diversity and heterogeneity of Italian territory, because of the lack of certain specific data required by the model, and because of the at times exaggerated results it gave when it was applied. Some research units attempted to build and apply similar models, in some carbonate zones in Campania and Molise for example. But researchers soon concluded that it would be necessary to prepare a new PCSM suited to the hydrogeological and impact settings in Italy itself and, first and foremost, one that could be implemented using a GIS (Geographical Information System) to obtain dynamic assessments and maps, with connection to databases that users and managers of the resources needing protection would be able to update continuously.

The new PCSM SINTACS was presented in 1990 in its preliminary version (Release 1), it was subsequently improved (Release2) and then applied to a vast zone south of Turin (1990) and in the large massif of the Apuanian Alps (Central Italy - 1991).

Research continued, building on the results taken from the model's application on the part of almost all the GNDCI Research units taking part in VAZAR. SINTACS (Release 3) cartographies were prepared in Campania, Lazio, Tuscany, Piedmont and Basilicata.

Release 4 followed, to be published in 1997 and accompanied by numerous examples of applications while SINTACS took on its pre-definitive form from the methodological point of view. Three further years of experimentation were needed before the publication of Release 5, completely computerised with GIS: this is a really new chapter in operational thematic cartography giving institutional and non-institutional users a powerful, updatable information medium that provides complete scenarios in real time for land use planners and Civil Defence managers.

In 2000 an important application of the methodologies described above was brought to fruition, for the Tanaro river basin, which had been struck by devastating floods in 1994. The area under study had highly mixed morphology and hydrogeology (hill and plain), making it possible to carry out extensive tests on the SINTACS model. It was noted that in the hilly zones the data needed in order to apply the parametric model were no longer available, but that the basic method could be profitably applied. We therefore posed the problem of validating the borderline representing the passage from one methodology to another, without invalidating the complete scenario. After a whole series of tests, we reached the conclusion that the interface between the two methods could be used to crosscheck each one's validity: from this came the so-called combined approach which solves the longstanding problem of assessing intrinsic vulnerability in regions with variable morphology.

In 1999 a key law, D.Lgs 152/99 (Protecting water from pollution), was passed, in which much importance was attached to the vulnerability of aquifers to pollution, that of agricultural origin in particular. It was established that the Regional Authorities were to be responsible for drawing up Vulnerability Maps on various scales for their own territory and they were advised to use the methods produced by Line 4 of the GNDCI-CNR. The ANPA (National Environmental Protection Agency) decided to adopt operational guidelines for drawing up and using Vulnerability Maps and asked Line 4 to compile them. The guidelines were published at the end of 2001 and are the volume of reference for institutional users at all levels: the publication is accompanied by a database containing all the cartographies that had been prepared for Italy as of 2000.

From 1986 until now, the work of Line 4 has been able to cover as many as 141,000 km^2 of the 190,000 considered at risk of pollution, which is almost two thirds of all Italian territory, covering 301,000 km^2. To these gratifying results we should also add the Vulnerability Maps that have been drawn up, always with the participation and/or scientific and technical advice of the Line 4 Research units, by some of the Regions, Provinces, Municipalities, Regional Environmental Agencies (ARPA), Water Supply Providers and other local bodies. 2001 saw the publication of an Atlas containing all the cartographies published in Italy, with the corresponding methodological characteristics (Figure 3).

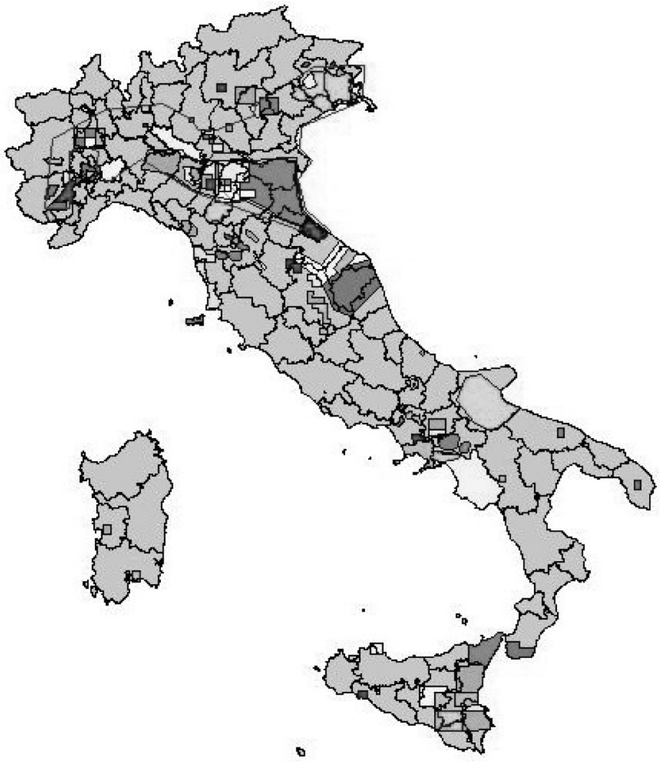


Figure 3: Coverage of Italian territory by Pollution Vulnerability Maps. What do the colours mean?
The colours don't have a specific meaning.

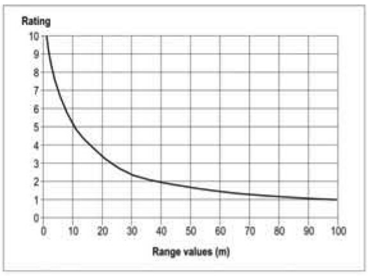
The methods prepared by Line 4 of the GNDCI-CNR are also applied intensively abroad, from North Africa to Brazil, from Turkey to Slovenia, Russia and Mexico. UNESCO has recently set up a Project[1] to apply Italian methodologies in various countries around the Mediterranean Basin (Croatia, Montenegro, Tunisia, Morocco), the aim being to train technical staff in these countries in the protection and management of groundwater bodies.
It is hoped that this joint work, in which over 100 Italian research workers have taken part, will make a contribution to solving the serious problems related to the protection and management of drinking water resources that were so strongly expressed at the Summit on Sustainable Development in Johannesburg.

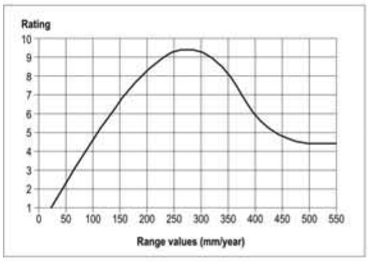
A SHORT DESCRIPTION OF THE METHODS

PCSM SINTACS R5. The vulnerability of a groundwater body is a function of several factors, the most important of which are lithology, structure, geometry of the hydrogeologic system, the type of overburden, the recharge-discharge process, the interaction between the physical and hydrochemical processes that regulate the quality of the groundwater, and the fate of the contaminants that impact on the system.
The acronym sintacs comes from the Italian names of the factors that are used, i.e. Soggiacenza (depth to groundwater); Infiltrazione (effective infiltration); Non saturo (unsaturated zone attenuation capacity); Tipologia della copertura (soil/overburden attenuation capacity); Acquifero (saturated zone characteristics); Conducibilità (hydraulic conductivity); Superficie topografica (Slope).
Where the data base is complete and the frequency of the available information is adequate, the factors that are used to assess aquifer vulnerability to contamination are selected; a subdivision into value intervals and/or declared types is applied to each selected factor; a progressive rating (P, ranging 1 – 10) is given to each interval as a function of its importance in the final assessment (Fig. 4); the selected ratings of each factor must be multiplied by a choice of weight (W) strings, which are used in parallel and not in series (Table 1), each one describing a hydrogeologic and impact setting that highlights the action of each parameter.

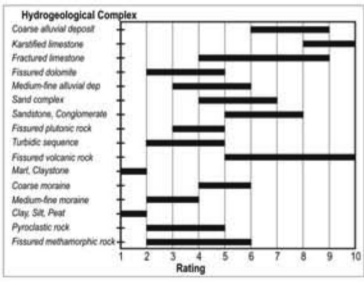
1 *MED-VUCAM Project (Vulnerability of Coastal Aquifers - Maps in the Mediterranean Basin)*

S: DEPTH TO GROUNDWATER: is defined as the depth of the piezometric level (both for confined or unconfined aquifers) with reference to the ground surface and it was a great impact on the vulnerability because its absolute value, together with the unsaturated zone characteristics, determine the time of travel (TOT) of a hydro-vectored or fluid contaminant and the duration of the attenuation process of the unsaturated thickness, in particular the oxidation process due to atmospheric O_2. The SINTACS rating of depth-to-groundwater therefore decreases with an increase of the depth, i.e. with an increase of

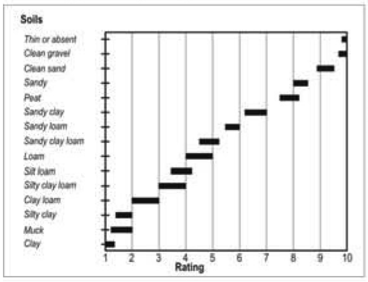




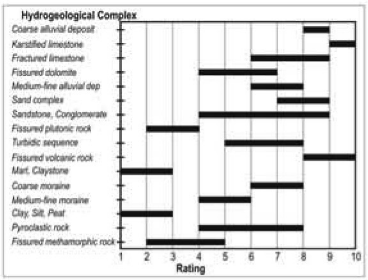
I: EFFECTIVE INFILTRATION ACTION: The role that the effective infiltration plays in aquifer vulnerability assessment is very significant because of the dragging down surface of the pollutant but also their dilution, first during the travel through the unsaturated zone and then within the saturated zone. Direct infiltration is the only or widely prevalent component of the net recharge in all the areas where there are no interflow linking aquifers or surficial water bodies or no irrigation practices using large water volumes.



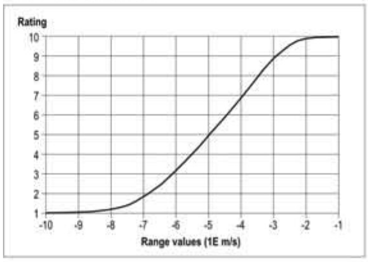
N: UNSATURATED ZONE ATTENUATION CAPACITY: The unsaturated zone is the "second defense line" of the hydrogeologic system against fluids or hydro-vectored contaminants. A four dimension process takes place inside the unsaturated thickness in which physical and chemical factors synergically work to promote the contaminant attenuation. The unsaturated zone attenuation capacity is assessed starting from the hydro-lithologic features (texture, mineral composition, grain size, fracturing, karst development, etc.).



T: SOIL/OVERBURDEN ATTENUATION CAPACITY This is the "first defense line" of the hydrogeologic system: several important processes take place inside the soil that built up the attenuation capacity of a contaminant traveling inside a hydrogeologic system and therefore in aquifer vulnerability assessment and mapping. Soil is identified as an open, three-phase, accumulator and transformer of matter and an energy sub-system which develops through the physical, chemical and biological alterations of the bottom lithotypes and of the organic matter that it is made up of.



A: HYDROGEOLOGIC CHARACTERISTICS OF THE AQUIFER: In vulnerability assessment models, the aquifer characteristics describe the process that takes place below the piezometric level when a contaminant is mixed with groundwater with a loss of a small or more relevant part of its original concentration during the traveling through the soil and the unsaturated thickness. Naturally these processes are: molecular and cinematic dispersion, dilution, sorption and chemical reactions between the rock and the contaminants.



C: HYDRAULIC CONDUCTIVITY RANGE OF THE AQUIFER: Hydraulic conductivity represents the capacity of the groundwater to move inside the saturated media, thus the mobility potential of a hydro-vectored contaminant which as a density and viscosity almost the same as the groundwater. In the SINTACS assessment context, the hydraulic gradient and the flux cross section being equal, this parameter determines, the aquifer unit yield and flow velocity that go toward the effluences or the tapping work that indicates the of risk targets.

S: HYDROLOGIC ROLE OF THE TOPOGRAPHIC SLOPE: The topographic slope is an important factor in vulnerability assessment because it determines the amount of surface runoff that is produced, the precipitation rate and displacement velocity of the water (or a fluid and/or hydro-vectorable contaminant) over the surface being equal. A high rating is assigned to slight slopes i.e. to surface zones where a pollutant may be less displaced under gravity action or even stop in the outlet place favoring percolation. The slope may be a genetic factor due to the type of soil and its thickness, and can indirectly determine the attenuation potential of the hydrogeologic system.

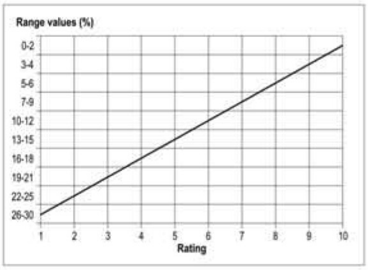


Figure 4: Description of the parameters and related rating graphs for PCSM SINTACS

Table 1 Strings of multiplier weights given for sintacs

Parameter	Normal I	Severe I.	Seepage	Karst	Fissured	Nitrates*
S	5	5	4	2	3	5
I	4	5	4	5	3	5
N	5	4	4	1	3	4
T	3	5	2	3	4	5
A	3	3	5	5	4	2
C	3	2	5	5	5	2
S	3	2	2	5	4	3

* *Subject to evaluation*

A vulnerability index is calculated for each cell of a discretization grid that is overlaid on the Natural map of the zone under consideration:

$$I_{SINTACS} = \sum_{j=1}^{7} p_j \, w_j \qquad (1)$$

The types of Natural information, the processing needed to transform them into SINTACS factors and the definition of the hydrogeologic and impact settings used to select the weight strings can be found in Civita (1994) and in Civita & De Maio (2000), together with a number of application tests.

GNDCI-CNR Basic (Natural) method. This method [Civita M., in: AA. VV. (1988); Civita M. (1990.b)] is based on a standard in which data for a number (about 20 – see Table 2) of hydrogeologic settings that can be found in the Italian territory are collected and the intrinsic vulnerability characteristics of the aquifer are identified. This method is highly flexible and can be adapted, if necessary, to other situations that are not dealt with in the standard. The lithologic, structural, piezometric and hydrodynamic indexes are not rigorously quantified. Starting from a complete examination of the main Italian hydrogeologic settings, the representative sites were extracted from those that best define the settings, e.g. the Po river Plain, the carbonate massifs of the Apennine ridge, the karst settings of Apulia and Trieste, the volcanic terrain of central Italy, the ancient basement of the Alps, and so on. The main factors contributing to aquifer vulnerability (e.g. depth to groundwater, porosity, fracturing index, karst index, linkage between stream and aquifer, and so on) were identified for each representative site.
Bearing in mind the dynamics and frequency of the cases of contamination that were collected and previous similar experience at an international level, the settings were distributed over the 6 intrinsic vulnerability ratings (i.e. contamination potential) that form the synoptic legend of the maps.

The combined approach. From what has been seen, in many areas where it is necessary to cover vast areas defined by administrative (i.e. Municipalities, Provinces, Regions) or physical boundaries (interregional watershed) with a Vulnerability Map, the parametric models that have been set up cannot be applied due a lack of data at those points where the terrain changes from a plain morphology to a hilly or mountainous area. In these situations, in the past, a simple method was chosen that was able to perform a less refined and detailed assessment, but which however was applied to many land and environmental problems connected to the contamination of aquifers, giving good results.

Table 2 Standards for Italian hydrogeologic settings (GNDCI-CNR Basic [Natural] Method)

Vulnerability rating	Features of hydrogeologic complexes and settings
Extremely high	Unconfined (water table) aquifer in alluvial deposits: streams that freely recharge the groundwater body; well or multiple well systems that drawdown the water table to under the stream level (forced recharge). Aquifer in carbonate (and sulphate) rocks affected by completely developed karst phenomena (holokarst with high karst index [ki]).
Very high	Unconfined (water-table) aquifer in coarse to medium-grained alluvial deposits, without any surficial protecting layer. Aquifer in highly fractured (high fracturing index [fi]) limestone with low or null ki and depth to water <50m.
High	Confined, semiconfined (leaky) and unconfined aquifer with impervious (aquaculture) or semi-pervious (aquitard) superficial protecting layer. Aquifer in highly fractured (high fracturing index) limestone with low or null ki and depth to water >50m. Aquifer in highly fractured (but not cataclastic) dolomite with low or null ki and depth to water <50m. Aquifer in highly clivated volcanic rocks and non-weathered plutonic igneous rocks with high fi.
Medium	Aquifer in highly fractured (but not cataclastic) dolomite with low or null ki and depth to water >50m. Aquifer in medium to fine-grained sand. Aquifer in glacial till and prevalently coarse-grained moraines.
Medium - Low	Strip aquifers imbedded sedimentary sequences (shale-limestone-sandstone flysch) with highly variable diffusion rates layer by layer. Multi-layered aquifer in pyroclastic non indurated rocks (tuff, ash, etc.): different diffusion rates layer by layer close to the change in grain size.
Low	Aquifer in fissured sandstone and/or non-carbonate cemented conglomerate. Aquifer in fissured plutonic igneous rocks. Aquifer in glacial till and prevalently fine-grained moraines. Fracture network aquifer in medium to high metamorphism rock complexes.
Very low or null	Practically impermeable (aquifuge) marl and clay sedimentary complexes (also marly flysch): contamination directly reaches the surface waters. Practically impermeable (aquifuge) Fine-grained sedimentary complexes (clay, silt, peat, etc.) contamination directly reaches the surface waters. Meta-sediment complexes or poorly fissured highly tectonized clayey complexes low metamorphism complexes, almost aquifuge: contamination directly reaches the surface waters.

Experience gained over recent years has led to a reconsideration of the methodological problem: why relinquish the detail that can be offered by point count system models (Civita, 1990, 1994) in areas with moderate relief, in which the majority of the csc's and the dcs's and many of the supply springs are actually concentrated (that is, the subjects at risk - SAR)? On the other hand, how can we carry out the assessment of vulnerability and of the risk of contamination for areas with great depth to water, areas that can be described in less detail on the basis of hydrogeologic complexes and settings?

The solution that has been found for this problem and which has been tested, is the combined approach. This approach allows the GNDCI-CNR Natural method to be combined with the PCSM SINTACS method without continuity solutions: the latter in areas where the data that are necessary and sufficient to apply a parametric model exist; the former in areas where the great depth to water, the hydrolithologic and hydrostructural complexity and the lack of certain data on the terrain, the hydraulic conductivity and active recharge make it impossible to obtain details that are comparable with those that can be obtained using SINTACS.

The necessary connection, whether conceptual or cartographic, between adjacent areas where different methodologies are to be applied, is supplied by the parametric assessments. In practice, for the complex areas where a parametric evaluation already exists, the same degrees of vulnerability are applied but the changed slope and water table conditions are also taken into account. All this is possible thanks to the fact that calibration with SINTACS was carried out by comparing and crosschecking, as already mentioned, the SINTACS evaluation with that obtained with the GNDCI-CNR Natural method, on over 600 test sites distributed throughout the different Italian areas and territories. Division of the numerical index into 6 degrees of vulnerability, the same as those used for the Natural Method, makes the two methods comparable and the results optimally combinable. Application of the combined approach has given excellent results in the Tanaro Project area (Regione Piemonte, 2000) and led to complete coverage being obtained without any loss of Natural information or precision of synthesis. The same numbers of cartographic examples of vulnerability have been formulated using the Combined Approach with the two methods are shown in Fig. 5. The thick black line in the figure represents the dividing line between the areas treated with the two methods. The homogenization that the approach brings is clearly visible.

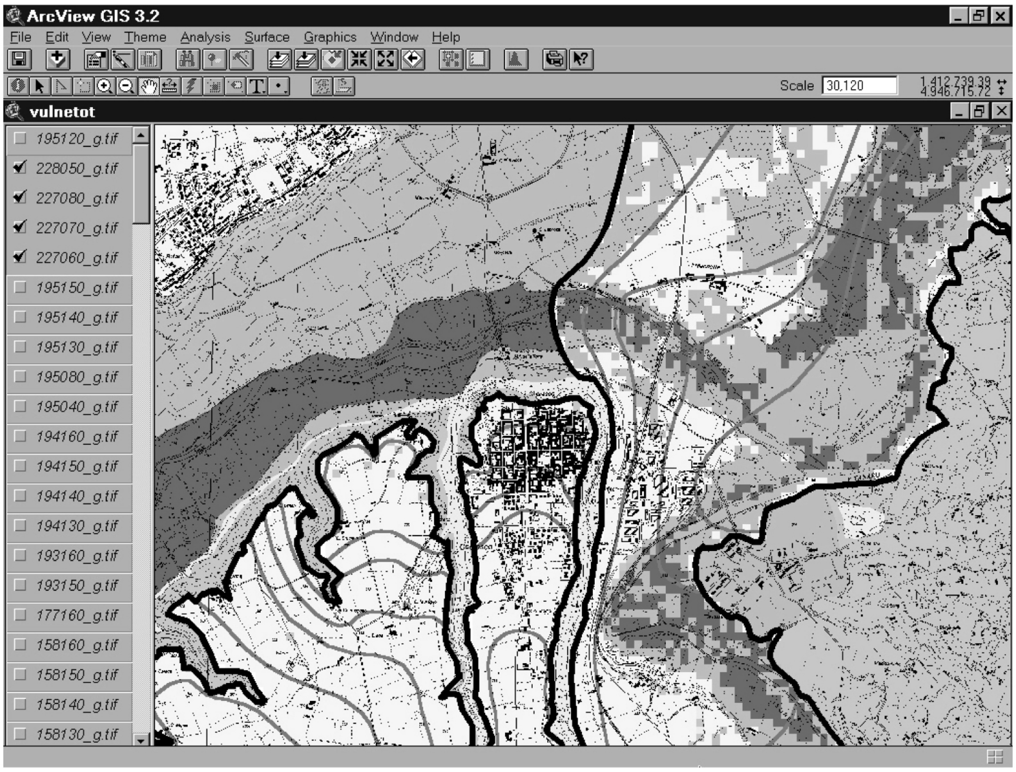


Figure 5: Vulnerability Map: (Red) Extremely High Degree; (Orange) Very High Degree; (Yellow) High Degree; (Green) Medium Degree and (Cyan) Extremely Low Degree of vulnerability.

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