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AN INTELLIGENT AGENT FOR THE GROUNDWATER POLLUTION RISK EVALUATION

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ABSTRACT

The knowledge of the territory and the evaluation of the impact of local anthropic activities on it need a dynamic and relational approach to represent the qualitative variables of the environment to provide decision makers an helpful tool in planning the management of the territory.

This paper describes methodology used in order to realize an Intelligent Agent that can be considered as a useful planning tool, able to provide information on the environmental impact of anthropic activities by examining their effects on groundwater quality. Anthropic activities, in fact, through different mechanisms, can worsen groundwater quality because of chemical, physical, and biological pollution rising from civil, industrial and agricultural activities.

Very often in the planning domain there is a high degree of incompleteness of information, and so it becomes very difficult to use the complex mathematical models, which are able to simulate the phenomena in a complex system like the territorial one. In order to overcome the limits imposed by the lack of information, it becomes necessary to integrate the outcomes of the models with more qualitative representation, obtained by interaction with the experts. They, in fact, are able to resolve a complex problem using their “expertise”.

In order to evaluate the groundwater pollution risk, a methodology has been developed that allows us to combine the value of intrinsic vulnerability of a specific local aquifer, obtained by implementing the mathematical equations contained both in standard procedures (CNR - GNDCI method) and in a parametric managerial model (SINTACS), and the value of hazard, linked with human activities, obtained using the knowledge of the experts.

1. INTRODUCTION

This paper describes the methodology studied in order to define and realize an Intelligent Agent able to evaluate the environmental risk, particularly the groundwater pollution risk.

Groundwaters represent, in most of the Mediterranean countries, the primary source of fresh water for irrigation and drinking purposes. To preserve availability and the quality of this resource is then extremely important, even more so in this period, in which the water seems to become the limitative factor for sustainable growth (Busoni, Ciampalini, Venuti, 2000).

Anthropic activities can in different ways constitute a threat for the quality of groundwater because of the chemical physical biological pollution originated by the civic and industrial activities. Also excessive withdrawal can be considered a risk factor for the groundwater quality, especially near the coastal zone. In fact, in those areas excessive withdrawal produces decline in the groundwater and allows infiltration of sea water. This process is called “salinization” of groundwater and could be very dangerous also for agriculture.

The evaluation of the environmental risk linked to human activities is very important in order to mitigate or to reduce the impacts of anthropic activities on the environmental resources and, therefore, to recreate the co evolutionary process (Scandurra, 1995) between the human and natural component of the environment. We can consider the territory an outcome of a stratification process, the physical signs of which are the results of the complex interrelationship between population, activity and sites (Maciocco, 1991), that is the relationship between the population and the sites is made by the anthropic activity that the population expounds daily on their territory.

However, in spite of the fact that the anthropic component can be considered one of the most important components of the territory environment, in the last decades this co evolutionary process, this “dialog […] between two living entities, the man and the nature” (Magnaghi, 2000) seems to be almost interrupted, and we are witnesses of a monolog of the human component, while the environment plays the role of mere technical support of activities and functions. The human activities free themselves from the link that the territory imposed on them, and now they can be considered a risk for the integrity of the environmental ecosystems, whether due to the continuous and excessive use of the natural resources, that are often not renewable, or due to the emission in the environment of a quantity of pollutants that exceed the assimilative capability of the ecosystem.

This process also involves the agriculture, that considers the territory a simple support for the productive processes, which are almost fully artificial. Excessive exploitation of the territory with more and more intensive cultures, the continuous extraction of the groundwater, the use of chemical products in order to increment the productivity or in order to reduce the loss of product, are only some of the agricultural practices which have a negative impact on the environment, even if they enable getting out the maximum advantages from the agricultural land use.

In order to suggest new forms of compatibility between the anthropic development and the environmental system, it is very important to understand the interaction mechanism between the territory and the human activities carried out on it, individuating their negative impact on the natural resources.

In this sense, the environmental risk evaluation methodologies seem to be very useful for the planning domain, because they individuate the situations characterized by a high degree of environmental risk: in those areas we must exercise a major effort in order both to mitigate the impact of human activities and to avoid the realization of the structures which are very dangerous to the environment.

This paper deals with the definition and realization of a Intelligent Agent, which can be considered a planner tool able to support local decision makers in the sustainable management of the natural resources. In the present study the municipal area of the Bisceglie, a town in southern Italy, has been investigated. This area lies in a coastal zone and is characterized by the absence of a superficial hydrography. Therefore the defense of the groundwater quality becomes very important. Given the peculiarity of the study area, characterized by a prevailing agricultural land use, the problem found in this study has been the local groundwater pollution caused by the use of pesticides.

In order to realize a System able to evaluate the groundwater pollution risk due to the use of pesticides in the agriculture, we have elaborated a methodology that allows us to highlight the intrinsic vulnerability of the aquifer, obtained by means of the application of the deterministic management model SINTACS (Civita, 1994) in relationship with the interaction between the different chemical products and the subsoil. To overcome the limits imposed by the degree of incompleteness of the information that makes it hard to use the complex mathematical model which simulates the leach of the pesticide in the groundwater (such as GLEAMS, LEACH-P, and so on), it has become necessary to integrate algorithmic approaches, which allow us to study some characteristics of the problem, with more qualitative approach obtained from interaction with the experts.

Therefore we obtained the system combining the potentialities of a Decision Support System, based on “formal” information, with those of an Expert System, based essentially on “informal” heuristic information, personal judgment, obtaining therefore a system based on knowledge (Knowledge-based Decision Support System). The methodology used allows the system we have elaborated to deal with unstructured problems characterized by an elevated degree of uncertainty and also to simulate, in an appropriate manner, the behavior of decision making, that represents the purpose of cognitive science, the base of Artificial Intelligence.

2. THE EVALUATION OF GROUNDWATER POLLUTION RISK

In general terms, the degree of the environmental risk can be determined by means of the following expression:

Risk = Vulnerability * Hazard

In this expression, the word “vulnerability” indicates the degree of intrinsic weakness of the natural system, while the word “hazard” indicates the probability that a potentially dangerous event happens in a determined area. If we want to extend this definition to the groundwater pollution risk due to the use of pesticides in agriculture, we can say that vulnerability represents the degree of intrinsic weakness of the aquifer (Civita, 1995), which is independent of the human activities undertaken on the territory; while hazard represents the probability that a pollutant leaches along the profile of the soil, until it reaches groundwater.

In order to evaluate the groundwater pollution risk, it is necessary to combine different information concerning both the chemi physical characteristics of each pesticide, that allows evaluating its mobility in the soil, and the characteristics of the site in which the pesticide is used (Capri, Padovani, Trevisan, 1999).

The evaluation of intrinsic vulnerability can be obtained using approaches which can divide the landscape into homogenous areas (Civita, 1994). This approach starts from the study of the characteristics of the environment and enables location of areas which feature different degrees of intrinsic vulnerability. In general words, the methods for the evaluation of intrinsic vulnerability of the aquifer consider the hydrogeological and hydrodynamic characteristic of the subsoil and particularly of the aquifer (Zaghi, Lucci, 2000).

The approaches to evaluate vulnerability are essentially two, precisely the qualitative approach and the parametric approach. In this study we only use the parametric approaches. These are based on the evaluation of the most important parameters which allow us to define the soil structure and the relations between the soil and the superficial hydrological system (Capri et al., 1999). The different parametric methods are based on the same principle: that is, in this method the different parameters, which are divided in to classes of value, have a different weight according to the their importance in order to evaluate intrinsic vulnerability (Zaghi, Lucci, 2000). Among the different parametric approaches, we focalize our attention on the DRASTIC model and on the SINTACS model.

Both methodologies use a weights and scores system (PCSM). These scores and weights are calculated by a determistic approach with the aid of apposite diagrams (parameter level vs. score). Both the SINTACS and the DRASTIC models consider seven parameters which allow us to define the characteristics of the aquifer according to the groundwater pollution risk. In these methods the evaluation of vulnerability is obtained by the weighted sum of the coefficient assigned to the different parameters.

The two considered models are substantially similar: in fact, the SINTACS model derives from the DRASTIC model and they are structured in a similar way. Over time, the SINTACS becomes more and more different and, in the last versions, the two models have only details of the structure in common (Civita, De Maio, 1998). The creation of the SINTACS model derives from the necessity to adapt the DRASTIC model to the hydrogeological situations that characterize the Italian territory and a lot of countries of the Mediterranean basin (Civita, 1994).

Evaluation of the hazard degree seems to be more complex than the evaluation of vulnerability. In fact, evaluation should be based on statistical analysis, which allows us to infer the probability curve regarding the likelihood of a dangerous event. The major limits of this approach regard both the difficulty to find sufficiently detailed data to reconstruct the probability of the appearance of the examined phenomenon, and the staticity of the results: in fact, this approach doesn't allow considering the changes in the structure of the territory which have happened over the years and which could influence the risk of groundwater pollution. For these reasons, it seems more appropriate to use a dynamic approach to evaluate the environmental risk: in other words, it is preferable to adopt a modellistic approach in comparison to a statistical approach.

Among the different models that allow evaluation of the groundwater pollution risk, in a more or less quantitive manner, the most important are the complex mathematical models: they are able to evaluate the quantity of pesticide that leaches along the soil profile until it reaches the groundwater level, simulating the various phenomena that influence the environmental fate of the pesticides (Capri et al., 1999). The most important limit of those models is the application scale: in fact, due to the great number of variables which are considered by the model, it is very hard to extend to outcome of the model to a large portion of the territory. Therefore, it becomes difficult to draw a risk map using the complex mathematical models, unless we use the model to study all the different soil profiles of the territory. Moreover, these models require very detailed information often very difficult to be gathered especially when we are studying a large portion of territory.

In this work, to overcome the limits imposed by the lack of information, it became necessary to integrate an algorithmic approach with a more qualitative one, obtained by interaction with the experts. In fact, when it is impossible to use the complex models, the experts seem to be able to evaluate the groundwater pollution risk resorting to approximate reasoning, to the heuristic, to the expertise, to the "artistic component of the practice" (Schon, 1993); moreover, the experience and familiarity with the cognitive domain provide additional information to calibrate individual judgment (Renn, 1998).

Embodying heuristics in the knowledge base of the System, that represents one of the most important components of an Expert System (Liebowitz, 1995), the System becomes able to evaluate the groundwater pollution risk also in situations characterized by a lack of information, simulating human experts' behavior.

Therefore, one of the most crucial phases in realizing the System is the construction of the knowledge base, which is made by an incremental process.

One preliminary operation regards individuation of the experts with whom we have to interact. This choice should be well pondered because the importance that the expert has in the construction of an Expert System. In fact, the knowledge base is based on the experts' heuristics, on their logic, on their opinion and intuition: therefore, the experts leaves a clear impression in the System (Barbanente, Borri, Maciocco, forthcoming).

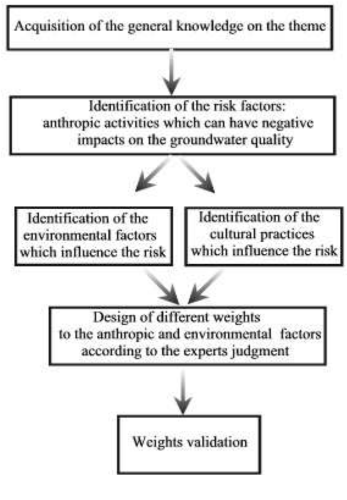
Given the complexity of the problem considered, in which the variables are manifold and they often interact with each other, we consider it important to involve experts who belong to different cognitive domains. In this way, we want to pursue the multidisciplinary aim, the conversation among knowledge, more often considered fundamental in a complex domain like the planning one, particularly when we deal with environmental problems.

The process for the acquisition of multi expert' knowledge is an incremental process. In the first interview, little structured, we tried to gather a wide and superficial knowledge which is useful to acquire familiarity with the domain under consideration, with the acquisition of information from specific literature. In this phase we individuated the fundamental features of the problem and possible aims.

In the next interviews, more structured than the first, we formulated questions in order to deepen the knowledge and to gather the fundamental heuristics to realize the System. Particularly, we tried to individuate the logical patterns that allow the experts to formulate a judgment, even if approximate, on the groundwater pollution risk.

When the experts deal with a complex problem, they effect a qualitative pre selection (Maciocco, 1997) of the context, and they consider only the factor that, according to their judgment, can influence the risk. In other words, the experts select the "object of the situation" (Schon, 1993). Therefore, in order to evaluate the hazard degree the system considers the factors which can influence the risk, simulating human expert behavior. In the next phases of the knowledge acquisition process we try to individuate these factors and we try to gather useful information about the importance of the different factor, according to expert judgment.

The knowledge acquisition process can be drawn in the following way:



During the knowledge acquisition process, the experts indicate a lot of factors that influence the groundwater pollution risk, some of which influence intrinsic vulnerability while the others influence the hazard degree. These factors belong to two different classes: those bound to the characteristics of the site (which influence vulnerability) and those bound to the cultural practice (which influence hazard).

The factors, indicated by the experts, are shown in the following table:

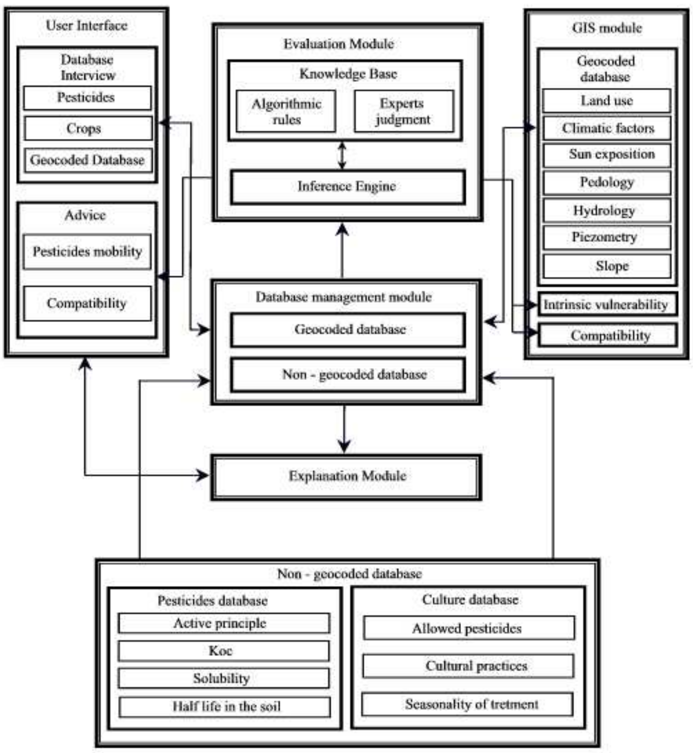
Factors linked to the site characteristics	Factors linked to cultural practices
Exposition to the sun	Kinds of pesticides
Presence of the organic matter in the soil	Quantity of pesticides used
Soils structure	Seasonality of treatment
Slope of the soil surface	Kind of tillage
Pedology	Kind of pruning
Temperature and raininess	Irrigation technique
	Presence of draining systems

Many factors bound to the characteristics of the site are already considered in the intrinsic vulnerability evaluation and so we do not consider them in the hazard evaluation, in this way we do not overestimate the importance of these factors.

3. THE SYSTEM ARCHITECTURE

As we can see in the table, some factors, that influence the groundwater pollution risk, are bound to the characteristics of the site, while the others depend on cultural practice. Therefore, in order to obtain the value of the risk it becomes necessary to combine different information, some of which are contained in a geocoded database and the other is contained in a non-geocoded database concerning the characteristic of the pesticides and the different cultural practice.

We can schematize the system architecture in this way:



The database management module allows us to manage and to combine this different kind of information. This module directly interacts with the evaluation module in which the information are elaborated. The evaluation module contains the knowledge base and the inference engine.

The first operation of the process regards evaluation of intrinsic vulnerability using the SINTACS method. In order to perform this operation it is necessary to insert in the geocoded database, which is contained in the GIS module, the information regarding the pedological, and hydrogeological characteristics of the aquifer. The system assigns the value of the intrinsic vulnerability to any element of the grid in which the territory has been divided. This value is stored in the geocoded database.

In order to evaluate the hazard, the System considers the different factors highlighted during the knowledge acquisition phase. Among these factors there is also the type of pesticide, with particular reference to the chemi - physical characteristics. Therefore, the System allows the user to introduce the trade name of the pesticides which are used in the study area. This information let the database management module retrieve from the pesticide database the information regarding the chemi-physical characteristics and send this information to the evaluation module. The System, using the rules contained in this module, is able to evaluate the mobility degree of the pesticides in the soil. The System provides, through the user interface, advice to the user containing the value of the mobility.

Since the same pesticide has different degrees of hazard in the different cultures in which it is used, the System makes a query to the user regarding the different type of crop. Before the System performs this operation, in order to facilitate the work, the database management module retrieves the information regarding the culture in which regulations allow the use of this pesticide; it compares this information with land use information, and it considers only the cultures that are present on the territory under consideration. Finally, the System allows the user to select the crops

After this operation, the database management module associates the mobility in the soil of the pesticides (non-geocoded data) with the different cultures (geocoded data). Now it becomes fundamental to consider also the other factors that influence the risk of groundwater pollution (irrigation methods, kind of tillage, seasonality of treatment, and so on) which are linked to the different kind of culture. First we insert in the knowledge base some rules that allow the System to assign different weights to different cultures. In fact, the experts rank the different agricultural land use depending more or less on thequantity of pesticides needed. Of course, the system doesn't implement this rule when the user is able to insert in the system the information regarding the real quantity of pesticide employed.

In this module the information regarding the different kinds of cultural practices and the relative weights (based on the probable quantity of pesticides used), assigned them by the experts are also inserted. The user interface, which represents one of the most important modules of the system, allows the user to follow the evaluation process, and he can specify the adopted cultural practice, depending on his own knowledge of the study area.

After this operation, the system can evaluate the hazard degree, which is linked with the land use.

Finally, in order to evaluate the groundwater pollution risk, it is necessary to combine the value of vulnerability with the value of hazard. In most of the application, the final value is simply obtained by multiplying the two values. Given the complexity of the problem considered, this kind of approach seems to be excessively deterministic: for this reason, in this work we evaluate the risk using some fuzzy logic operators, and in particularly operators proposed by Zimmermann and Zysno (Zimmermann, 1987):

$$\mu_{A \cap B} = \gamma \min(\mu_A, \mu_B) + (1 - \gamma)(½)(\mu_A + \mu_B)$$

in which, represents the degree of membership of an element to a certain set of elements.

These operators allow us to well formalize the approximate reasoning used by the experts to formulate a judgment about the risk of pollution: “The truer the statement A is (in this case the high degree of vulnerability) and more true is the statement B (in this case the high degree of hazard), then the truer the conclusion is (in this case the high degree of the pollution risk). Moreover, this operator allows us to consider the different weight that the experts assign to vulnerability and hazard in different situations.

The value of risk is provided as a compatibility degree of the use of these particular pesticides in this territory. The system's output is advice to the user and, mainly, a map of the risk, contained in the GIS module. In this map, the areas with a high degree of groundwater pollution risk, due to the actual cultural practice, are evidenced.

The explanation module completes the system's architecture. This module is very important in the Experts' Systems because it facilitates interaction between the user and the system. In fact, the E.S., like other kinds of support systems, must aid the decision maker rather to automatize the decision process. Therefore, the user must be able to interact with the system, and not insert only the data in the system when it needs this information. To reach this aim the system must be “transparent”: that is, the system must be clear and easy to understand. The explanation mechanism must be able to provide information to make clear all the aspect of the system, and it also must provide the causes and the reasons which lead to particular outcomes during the evaluation process.

4. METHODOLOGICAL EXAMPLE

We used the methodology that we have proposed above to evaluate the groundwater pollution risk in a real case study, regarding the municipality of Bisceglie, in the south of Italy. For this territory a large quantity of information is already available regarding the hydrological characteristics and the quality of the groundwater. These data will be useful in the validation phase of the system.

In order to evaluate the groundwater pollution risk, first we have to individuate the risk center, that is, the human activity which may represent a risk for the quality of groundwater. For this purpose, we used the ortophotos made in the 1997. These photos allowed us to obtain a land use map (fig.1) in order to locate the potential risk center.

The land use map has been realized using the ESRI's ArcView software. Given the aim of the our system, that is the individuation of the areas in which the pollution risk due to the use of pesticides is high, we focalized our attention only on the agricultural land use.

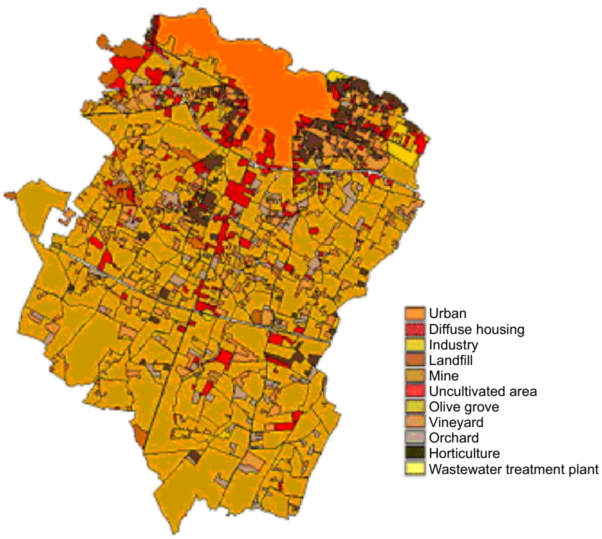


Figure 1. Land Use Map

The territory under consideration is characterized by a prevalent agricultural land use, while the industries are few and localized near the city. The olive groves are the most popular culture in the area . Also present are vineyards, while orchards and horticulture are rare .

Applying the SINTACS model we were able to individuate wide zones with a high degree of vulnerability due to the high concentration of fractures in the subsoil. The fractures facilitate the percolation of the water in the soil and the leach of the pesticides and increment the groundwater risk pollution degree. We can individuate on the vulnerability map (fig.2) the creeks present in the territory of Bisceglie. Those areas are characterized by a low degree of vulnerability since they are ancient rivers that favor the runoff rather than the percolation of the water.

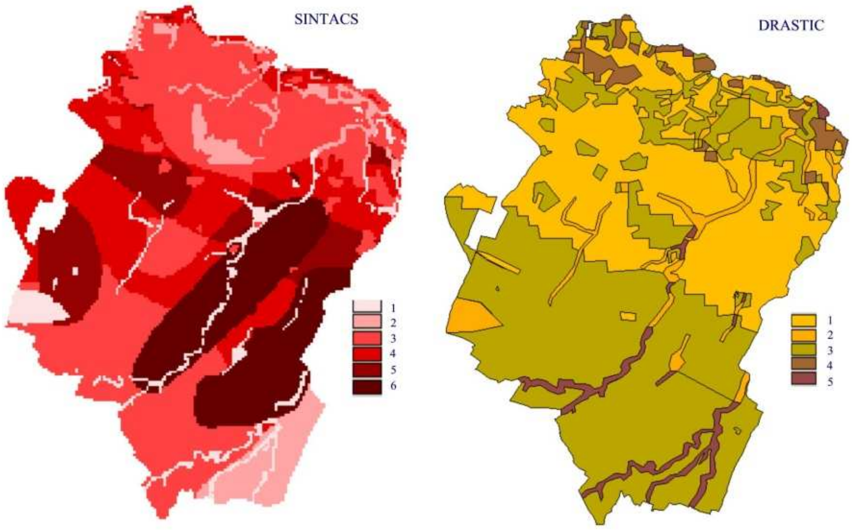


Figure 2. Vulnerability Map

The comparison of the two maps of vulnerability, obtained by using the two models, allows us to point out the different degree of the intrinsic vulnerability of the areas characterized by the presence of the geological fractures: in fact the SINTACS model assigns a high degree of vulnerability tothe same areas to which the DRASTIC model assigns a medium degree of vulnerability.

As we can see in the map (fig.3) the areas with a medium high degree of risk are concentrated near the areas with a high degree of vulnerability, in this way the system follows the reasoning of the experts, who give more importance to vulnerability.

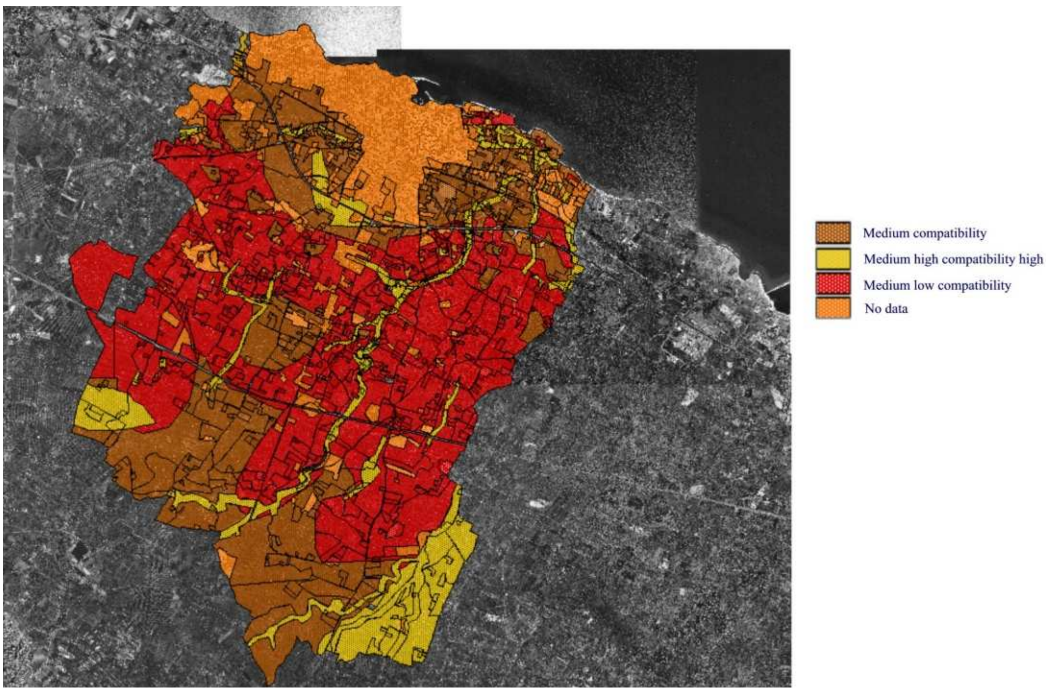


Figure 3. Groundwater Pollution Risk Map

5. CONCLUSION

The system obtained with the methodology descripted above is able, using the experts' heuristics, to evaluate the groundwater pollution risk due to the use of pesticides in agriculture. This system can be a useful decision support system which aids the decision makers in the difficult task of the management of environmental resources.

This system, in fact, allows us to relate different human activities carried out in a territory with their impacts on the groundwater quality. In this way, it becomes possible to locate different activities, ranked by their hazard, in areas with intrinsic vulnerability, so as to reduce the possibility that a pollutant leaches along the soil profile and reaches the groundwater. As regards the activities already present in the territory, which have a high degree of hazard, it is necessary to individuate action to mitigate the impact of the activities. This action would be more and more restrictive according to the hazard of the activity.

As regards the case study, that is the risk of pollution due to the use of pesticides, it is, for us, wrong to think that it is enough to introduce a lot of severe bonds. In this way, we don't resolve the problem, "The laws, the politics and the works, which come into operation in the final phase of the environmental and territorial degradation process, are not able to contrast the exponential growth of the degradation factors" (Magnaghi, 2000), and we shall probably transform the territory into a museum, removing the anthropic component. Therefore, if it is true that there is a strict "correspondence between the environmental crisis and the loss of territoriality […] which appears as a loss of the site […]indifference towards to the physical context of our lives" (Maciocco, 2000), it becomes necessary to facilitate , with the aid of planning tools, the dialog between manand nature, which at the same time accommodates himand is created by him. Actions of "territorializzazione" (Magnaghi, 2000) are needed in order to recreate the "virtuous relationships between the constitutive components of the territory: the natural environment, the built environment, the anthropic environment" (Magnaghi, 2000). In this way, we can reach the aim of the sustainable development (Magnaghi, 2000).

We can't reach this aim by the application of severe bonds (qui stai dicendo bonds, legami, o bounds, confini?), which could not be followed and then become inefficient; "planning through consensus building" (Innes, 1996) seems to be more profitable. This kind of planning allows us both to mediate the conflicts (which emerge always when we deal with environmental problems) and give information to the people on the outcome of the actual development model., In this way we can build the basis of a shrewd use of the territory.

Thus, the system could provide useful indications about the areas in which we should concentrate efforts to direct the farmer towards more eco - compatible agricultural practice, using in particular the incentive mechanism.

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