Assessment of Groundwater Potential Risk by Agricultural Activities, in North Italy

Ye Zhao, Marina De Maio, and Enrico Suozzi

***Abstract*—The goal of this study was to use GIS technology to develop maps of relative groundwater risk from agriculture activity in Vercelli plain. SINTACS will be connected with a IPA Meanwhile, agricultural chemical compounds concentration, compiled from domestic wells throughout the study area will be use to calibration the index model. SINTACS model was used to determine the instinct vulnerability of the groundwater shows that most of the Vercelli plain's groundwater is at high to very high risk in terms of pollution potential. Sensitivity analysis was employed to figure out the acutely importance of the single data layer.**

***Index Terms*—Groundwater, agriculture, GIS, index model.**

I. Introduction

Italy has a very high consumption of water, about 380 liters of water per day. Meanwhile, more than 85% of the drinking water in Italy is extracted from aquifer [1]. The study area Vercelli field, which is situated on the river Sesia in the plain of the river Po, is an important centre for the cultivation of rice and maize. The use of pollutants such as inorganic fertilizers and pesticides in the farm fields has expanded enormously over the past decades. Consequently, surface waters and groundwater have become increasingly contaminated with the plant protection products [2]. In agriculture field, groundwater risk assessment should not only deal with the instinct vulnerability itself, the human and natural impacts such as the agronomic practices, irrigation and the quantity and characteristic of loading chemical compounds should also be considered. IPA a indicate method, which combine the hazard factors and control factors [3], can appropriate estimate the agriculture contaminants diffusion in groundwater. Potential hazard of nitrate contamination originating from agriculture on a regional scale can be assessed using an improved IPA method combine with SINTACS [4], [5].

II. Study Area

The selected area is located (Fig. 1) southwest of Vercelli province in North Italy. The river and fluvio-glacial deposits of Quaternary age are arranged on wide terraces in the study area with slope slightly to the east-southeast. The complex of fluvial and fluvio-glacial Quaternary takes the form of a big lens, thicker in the middle of the plain and tapered towards the edge of the plain to the north and south.

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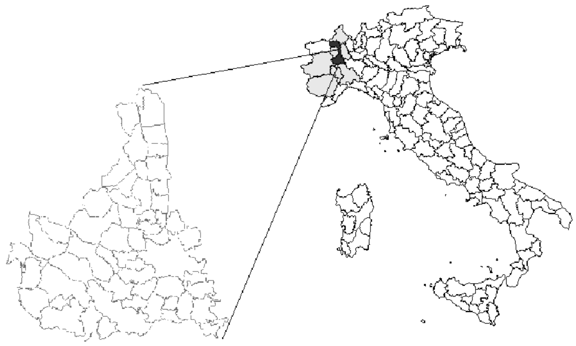

Fig. 1. Location of study area

Agricultural land covers much of the study plain. Approximately 65% of the study area is occupied by cereal land, 27% by forest, fruit crops and lawn, and 8% by other land (such as urban areas and water bodies). The major field crops are autumn-winter crops spring-summer corn, which mainly are grains. The average annual temperature in the study area is about 12.7°C and the rainfall is about 1014 mm. Standard deviation of monthly rainfall varied widely, from 48 to113 mm over the study area.

III. Material and Methodology

The data of slope, land use, infiltration soil medium, vadose zone, aquifer medium, groundwater water table depth, and conductivity (hydraulic) of the aquifer were processed in the GIS. The first six factors, they were converted to raster grids either initially in vector/polygon format or initially in vector/point format [6].

A. Vulnerability Index Model SINTACS Model [7]

SINTACS is a new method to assess groundwater vulnerability developed by Politecnico di Torino. It is a Point Count System Model based on the rating of seven factors: depth to groundwater water table (S), effective infiltration activity (I), unsaturated zone attenuation (N), soil/ overburden attenuation capacity (T), hydrogeology characteristics of the aquifer (A), hydraulic conductivity range of the aquifer (C) and topographic surface slope (S). The method was constantly tested and enhanced for ten years since 1990. The SINTACS model considers five possible scenarios used to assign the correct weights in different condition.

B. The Agriculture Hazard Index: IPA Index Model [3]

Highly productive modern agricultural practices have been wildly used in Europe and North America since the 1950s, which bring us a lot of conveniences and benefits as well as quantity of problem. As studies show that the global yield

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variability is heavily controlled by fertilizer use, irrigation and climate [8].

The hazard factors include three parameters: pesticides, fertilizers and metals, each one were rating from 0 to 5(Tab. 3), where 0 mean no hazard load into the field. As for control factors, three parameters were taken account here, which are: climate, irrigation and agronomic practice.

The assessment of the potential hazard index from agricultural sources (Fig. 2) is obtained by
multiplying the different hazard score (HF) by the control classes (CF) as shown in the following equation:

$$\text{IPA Index} = \left(HF_p + HF_f + HF_m\right) \times CF_{ap} \times CF_i \times CF_c$$

The hazard factors include three parameters: pesticides, fertilizers and metals, each one were rating from 0 to 5 (Table I), where 0 mean no hazard load into the field.

As for control factors, three parameters were taken account here, which are: climate: CF_c, irrigation: CF_i and agronomic practice: CF_{ap}.

TABLE I: THE SCORE OF THE HAZARD FACTOR IN IPA METHOD

Pesticides(kg/ha)(HF_p)	fertilizer N+P2O5 (kg/ha)(HF_f)	Metal (kg/ha)(HF_m)	Score
0-0.5	0-25	0-10.4	0
0.5-1.5	25-75	10.4-51.9	1
1.5-2.5	75-125	51.9-103.9	2
2.5-4.5	125-225	103.9-207.9	3
4.5-6.5	225-324	207.9-519.7	4
>6.5	>325	>519.7	5

C. Potential Risk of Groundwater from Agricultural Practices

The potential risk of groundwater from agricultural practices was determined by combining vulnerability index model and IPA index model. It is well known that hazard (probability of the event happening), vulnerability (degree of loss of a given element) are two parameters that determine the risk of an undesirable event occurring (in this case aquifer pollution) [5].

D. Sensitivity Analysis

Sensitivity analysis are used to determine how important of every input parameter contribute to the final risk. There are two methods can perform the sensitivity test. One is the map removal sensitivity analyses which was first introduced by Lodwick et al., [9]; another is introduced by Napolitano and Fabbri [10] named single-parameter sensitivity analysis.

IV. RESULT AND DISCUSSION

A. Vulnerability Maps

The final vulnerability map was obtained by running the model in GIS environment by using the seven hydro-geological data layers. The SINTACS index value ranged from 132 to 229 in agricultural field and from 148 to 224 in urban area. In the SINTACS model, the area that class are various depend on the land use, in the agricultural field, 63.93% of the area was classed as high vulnerable zone, and 30.61% was very high vulnerable instead of 41% in the urban area (Table II and Fig. 2). This means that most of the Vercelli plain's groundwater is at high to very high risk in terms of pollution potential. These very high vulnerable areas are mainly in the east and central parts with higher groundwater water table, and the area along the Seisia River in the north part of the study area. The areas having high vulnerability are in the west and north parts, usually with a low water table or steep slop.

TABLE II: AREA UNDER VULNERABILITY TO GROUNDWATER POLLUTION IN VERCELLI PLAIN

Potential hazard class	Potential Hazard	SINTACS Index Value		area %
		total	agricultural field	urban area
1	Very low	0	0	0
2	Low	0	0	0
3	Medium	0	0	0
4	High	63.55	63.93	54.05
5	Very high	31.05	30.61	41.8
6	Extremely High	5.37	5.42	4.15

The land use here was little (SINTACS: two weight system) take account in the intrinsic vulnerability map calculation. In Vercelli plain, nitrate and pesticides contamination of groundwater was found to closely associate mainly with vegetable cultivation and to a lesser extent with urban, which will be discussed later.

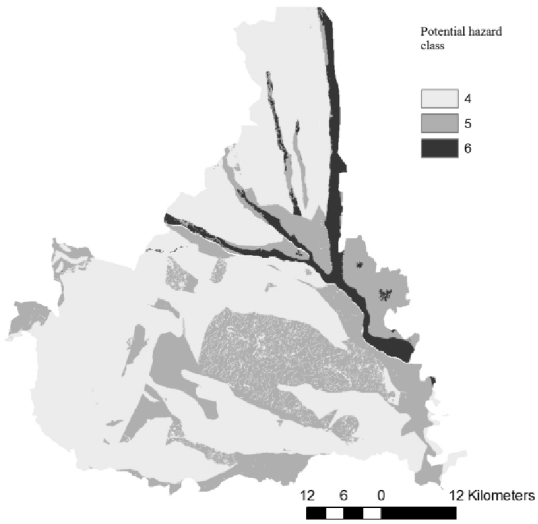

Fig. 2. Map of Vulnerability index by SINTACS model

B. Sensitivity Analysis

1) Map removal sensitivity analysis

The results of the map removal sensitivity analysis of SINTACS model is presented in Table III. The statistical analysis of the sensitivity measure was applied only to those subareas with an area more than $2500m^2$ (3636 subareas in agriculture field and 346 subareas in urban area,).

Depth to water table has the highest sensitive measure index both in agricultural field and urban area in STINTACS model. This could mainly be attributed to the relatively high theoretical weight assigned to these parameters (with a weight of 5 both two parameters in two models respectively). In the agricultural field, the SINTACS index seems also relative high upon the parameters of hydraulic conductive and topography (mean sensitive measure are 0.87 and 0.65, respectively). However, in urban area, the least sensitive parameter is hydraulic conductive, the mean variation index being 0.27%, although it has a weight of 3 rather than a weight of 2 in agricultural field. We can infer that the variation index of single parameter not only depend on the weight and rate itself, also the other parameter in the index system.

Furthermore, we also study the variation of the vulnerability index due to the removal of more than one layer at a time from the model computation. The removal of the maps was based on the single map removal sensitivity measure. The layers, which compel less variation of the final vulnerability index, were preferentially removed and then next lesser one and so on the parameter that least impact the various index is depend on the weight system: aquifer media in agricultural field and hydraulic conductivity in urban area. The average variation index increases, as more parameters are removed from the computation of the vulnerability index. Although the internal variation of the individual parameter cannot been indicated here, mean variation index is lower. This result is different from the previous study [11].

TABLE III: SENSITIVE MEASURE OF MAP REMOVAL SENSITIVITY ANALYSIS IN SINTACS

		Variation index (%)		
		Agriculture		
Map removed	Min	Max	Mean	SD
S	0	2.83	1.2	0.56
I	0	2.64	0.46	0.34
N	0	1.54	0.42	0.28
T	0	2.22	0.45	0.28
A	0	0.78	0.3	0.18
C	0.18	1.31	0.87	0.21
S	0.05	2.22	0.65	0.24
I,N,T,A,C,S	0	16.96	7.21	3.33
N,T,A,C,S	0	8.56	3.65	1.56
T,A,C,S	0.03	6.68	3.24	0.8
A,C,S	0.65	5.37	2.69	0.77
A,C	0	3.19	1.11	0.42
		Urban		
	Min	Max	Mean	SD
S	0.01	2.44	1.14	0.52
I	0	1.36	0.55	0.32
N	0.34	1.98	1.04	0.28
T	0	1.35	0.38	0.26
A	0	0.75	0.34	0.16
C	0	0.75	0.27	0.18
S	0.32	2.19	0.7	0.22
I,N,T,A,C,S	0.07	14.62	6.81	3.14
N,T,A,C,S	0	8.19	1.9	1.56
T,A,C,S	0.03	5.98	3.06	0.87
A,C,S	0.02	3.96	1.81	0.7
C,S	0.05	2.8	1.05	0.4

2) Single parameter sensitivity analysis

The single parameter sensitivity analysis is to compare their 'theoretical' weights with that of 'effective' weights. The 'effective' weight is a function of value of the single parameter with regard to the other six parameters as well as the weight assigned to it by the model.

Table IV presents that in SINTACS index model, in agricultural field, the depth to water table tends to be the most effective parameter in the vulnerability assessment (mean effective wt.% is 20.58%) having an agreement result with the result of map removal sensitivity analysis. Although impact of vadose zone and soil media layers display lower effective weights (mean effective wt. % are 15.17% and 15.34%, respectively) when compared with their theoretical weights (mean theoretical wt. % are both 19.2%), they also have significant impact on SINTACS index computation. As for the urban area, the most effective parameter in the vulnerability assessment is also depth to water table, while different from the result of map remove analysis (mean variation index being 0.27%), the hydraulic conductive show a significant impact on vulnerability index, with a higher effective weight (mean effective wt. % is 13.25%) than theoretical weight (mean theoretical wt. % is 11.5%).

TABLE IV: STATISTICS OF SINGLE PARAMETER SENSITIVITY ANALYSIS OF SINTACS

Para-meters	Theoretical weight	Theoretical weight (%)	Effective weight (%)			
			Min	Max	Mean	SD
	Agriculture					
S	5	19.2	7.35	31.25	20.58	4.84
I	5	19.2	7.61	30.12	15.17	3.31
N	4	15.4	12.84	23.53	16.82	1.7
T	5	19.2	7.73	27.6	15.34	3.03
A	3	11.5	9.63	17.65	12.62	1.28
C	2	7.7	6.42	13.24	9.08	1.28
S	2	7.7	0.97	13.99	10.38	1.48
	Urban					
S	5	19.2	7.43	28.9	19.71	5.18
I	4	15.4	6.32	22.47	11.84	2.92
N	5	19.2	13.08	20.92	16.4	1.36
T	4	15.4	6.18	20.45	12.32	1.93
A	3	11.5	9.81	15.69	12.3	1.02
C	3	11.5	9.81	17.65	13.25	1.67
S	2	7.7	1.16	12.35	10.08	1.35

C. IPA Index

The hazard factor maps were assigned ratings ranging from 0 to 5, depend on the land use and land cover. Most represented classes, in the study area, are very low (15.49%), mainly occupied by urban and natural areas, high (16.58%), very high (0.66%) extremely High (67.27%), occupied by rice paddy field, shown in Fig 3.

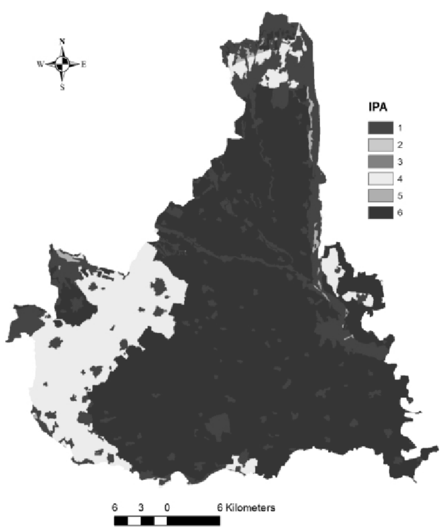

Fig. 3. Agricultural hazard in Aquifer map.

D. Potential Risks Pollution in Aquifers from Agricultural Practices

Four potential risk levels have been identified within the study area both in IPA combined with SINTACS (IPASIN), the areal distribution is presented in Fig. 4.

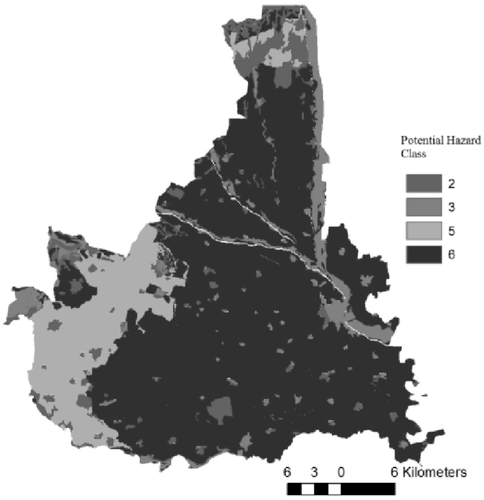

Fig. 4. Potential risks of pollution in aquifers from agricultural practices

In SINTACS model, the agriculture field and urban area was considered separated, as a result, we can see clearly the difference between these two kinds of land use. More than 99% of the total urban area was in a low and medium IPASIN class, instead of very low class, as here most of the urban areas are discontinue, which means a easily influenced from the around agricultural field. While in the agricultural field, about 85% of the total area was assigned from very high to extremely high potential risk. The rest part in agricultural field was contributed by uncultivated area and some nature area, as in this study, only urban area was considered separated from the other area.

E. Model Validation

Index model cannot and was not aimed at providing an accurate quantitative estimate of the contaminants content in groundwater, but rather at ranking potential risk pollution in the different parts of the study areas. Groundwater pollution is a complex process ad result of different environment and manual factors have to be examined on a large time and spatial scale [12], [13]

The aim of this part is try to assess the relationship between groundwater potential risk map and trace elements (pesticides, fertilizer, and metals) concentration in groundwater. As calibration against real groundwater observations is required for a more effective index model [14].

The groundwater monitoring data used by this study was collected by the Piemonte Region of Italy. The parameters calculation was results from 92 domestic wells of shallow aquifer (the depth of water table less than 45m) sampled from 2000 to 2011. All wells were sampled over two periods (March-April, and July-August) the mean annual value was calculated to analysis the relationship between groundwater potential risk map and monitoring data. However, the classification is not certain, as until now the hazard to human health still little was known. The maximum allowable contaminant level for atrazine in drinking water is 2 μg L^{-1} [15] or 3 μg L^{-1} (United States Environmental Protection Agency -USEPA). In European Union 0.1 μg L^{-1} was set as a precautionary value without toxicological effects for humans [16], [17] Table V displays the classification of herbicide and nitrate [15], [16], [18]-[20]. The classification envisages three groundwater quality classes: low, medium, high (combine with very high and extremely high in integrated map) which are then put into three groups with respect to the guideline value and the maximum permissible concentration in accordance with Italian legislation (D.L. 258/2000) and international laws. Fig. 5 and Fig. 6 present the distribution of herbicides, and nitrate concentration on groundwater potential risk map (IPASIN). It should be pointed out that is not easy to determine a general trend for agricultural contamination in groundwater, due to the lack of long-term analytic data and enough density monitor point.

TABLE V: CLASSIFICATION BY QUALITY OF HERBICIDES AND NITRATE CONCENTRATIONS

quality class	pesticide(μg L^{-1})	nitrate(mg L^{-1})
1	<0.1	<5
2	0.1-1	5-50
3	>1	>50

In the soil and unsaturated area there was quantity of biological and physical and chemical proceeds happened to pesticides such as adsorption and degradation, as there are abundant of microbes, and enough oxygen. While in the aquifer the pesticides usually has a longer half life than in surface soil, as there were less microbes and lack the appropriate condition for chemical process, while on the other hand, the pollutants can easily trans with the flow of groundwater. Intensive pesticide use may result in frequent surface and ground water detections adjacent to rice cultivated region [21]. In the non- pounded rice paddy field, with a flood irrigation way, the herbicide extremely easy to leaching into the shallow aquifer with the large quantity of deep percolation water. So from the Fig. 5, we can seen that the high quality class of herbicides are concentration in the extremely high potential risk class (IPASIN), mainly occupied by rice paddy.

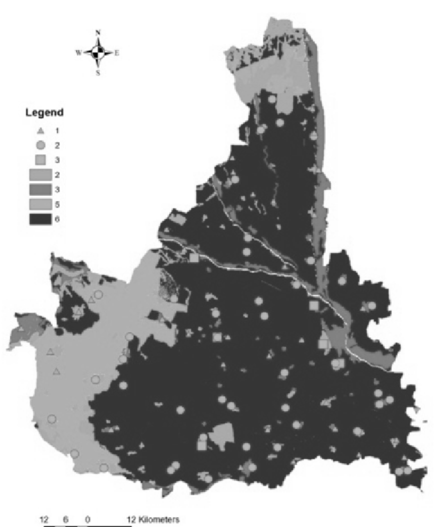

Fig. 5. distribution of herbicides concentration on groundwater potential risk map

The distribution of nitrate is not accordance with the potential risk map, as shown in Fig. 6. As the presence of nitrate in groundwater depends on: crop type; the amount, type and timing of surface fertilizer loadings; soil nitrate levels [22] and climate, such as rainfall. However, we still can gain some relationship between nitrate concentration in groundwater and the index risk map, especially in the urban area, where most samples have a quality class of 1. In the north part of the study area without intensive crop farm are carry out, but with a high concentration of nitrate in groundwater, which we reckon is coincide with semi-extensive cattle and sheep raising is practiced here, farm manures were identified as a major source of nitrate pollution[23]. Meanwhile, Babiker et al [24] indicated that vegetable fields had a higher NO_3-N concentration in surface aquifer than in the aquifer under rice paddy field. In the rice paddy the nitrate concentration is not obvious as the high level of risk potential of groundwater, as a result of the rice paddy field is efficient in nitrogen removal [25].

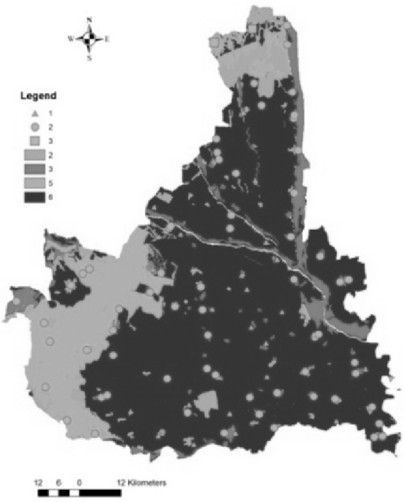

Fig. 6. distribution of nitrate concentration on groundwater potential risk map

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