Transactions on Ecology and the Environment vol 2, © 1993 WIT Press, www.witpress.com, ISSN 1743-3541

Methodology for a cartographic approach for the assessment of agricultural non point source pollution risk – use of remote sensing and geographical information system

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ABSTRACT

In the framework of Eureka-ISMAP program (Integrated System and services for the Management of Agricultural Pollution), an Information and Decision-Support System (ISMAP/IDSS) is developed. Among other services, methodologies for mapping agricultural non point source pollution risk are investigated under the program. A methodology applicable when runoff is predominant is presented here. Remote sensing using SPOT or LANDSAT TM (Thematic Mapper) imagery is used to locate the pollutants through the identification of the crops where they are applied. Then, a specific methodology combining surface soil texture and land surface slope through a Geographical Information System (GIS) gives the map of the pollutant's propensity to leave the place where they were applied. Such a map illustrates the surface water vulnerability to pollution due to agriculture where runoff is predominant. Combination of the location of the pollutants and the map of surface water vulnerability to pollution due to agriculture, gives the map of non point pollution risk. A spatial analysis of the influence of vegetation slowing down or stopping the transfers of pollutants in the watershed can be performed in addition. This methodology is applied to the Grand Morin watershed, in the suburbs of Paris, France. This watershed of 1200 km^2 is involved in drinkable water problems and has been studied for several years. LANDSAT TM imagery has been used to locate corn, main source of a common pesticide named Atrazine. This spatial mapping methodology for non point source pollution risk under ISMAP is designed to be reproducible in time and space in Europe.

INTRODUCTION

Water pollution from agriculture, and especially non point source one, has become a major concern for water suppliers. Among other services, methodologies for mapping agricultural non -point source pollution risk are investigated under the Eureka-ISMAP program (Integrated System and services for the Management of Agricultural Pollution), in the framework of its Information and Decision-Support System (ISMAP-IDSS) development.

Transactions on Ecology and the Environment vol 2, © 1993 WIT Press, www.witpress.com, ISSN 1743-3541

Several cartographic approaches for a cartographic assessment of non point source pollution from agriculture had been developed. At a very big scale (national) for different types of pesticides in Great Britain, Hollis [16], at a big scale for Nitrates, Phosphorus and pesticides in the French part of the Rhône watershed, Gril [15], at a medium scale (regional) in Nord-Pas de Calais, France for erosion and associated water pollution, INRA [17] and at a very little scale (Redon watershed, French Alps, 33 km^2) for Phosphorus, Bouchardy [6].

The methodology presented here is suited for scales ranging from big to medium and designed to be reproducible in time and space in France then in Europe (*i.e.* data availability problems). Moreover, its validation will be possible with the help of water quality chronicles for several sub-watersheds of the studied region are available from May 1991. Hence, this methodology has been applied to the Grand Morin watershed, in the suburbs of Paris, France (see **Figure 1**). This watershed of 1200 km^2 is involved in drinkable water problems and has been studied for several years, Mailloux *et al.* [20].

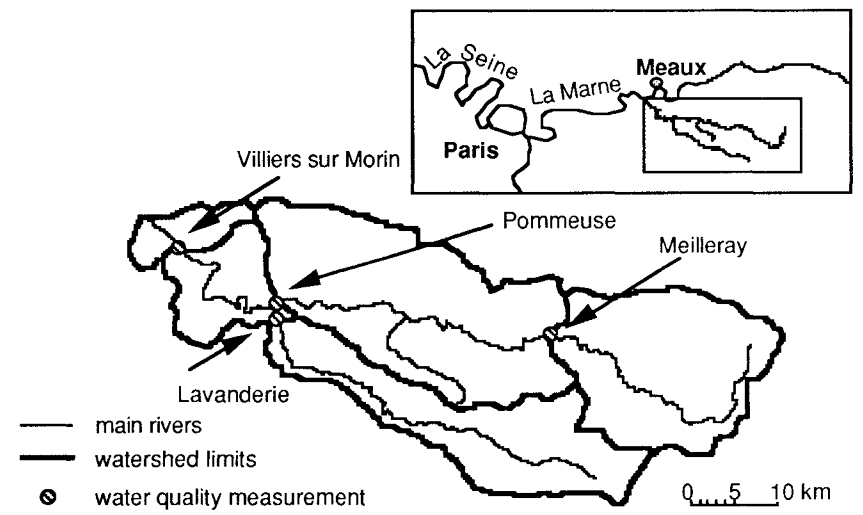

Figure 1 - Location of the Grand Morin watershed

1. PESTICIDE ENTRAINMENT AND TRANSPORT IN RUNOFF

1.1. Presentation

According to Bailey *et al.* [5] cited by Leonard [19], pesticide entrainment and transport in runoff can be described as mechanisms of (i) diffusion and turbulent transport of dissolved pesticide from soil pores to the runoff stream; (ii) desorption from soil particles into the moving liquid boundary; (iii) dissolution of stationary pesticide particulate; (iv) scouring of pesticide particulate and their subsequent dissolution in the moving water (v) entrainment attached to suspended soil particles. Such mechanisms take place in rills, which are limited to depths that can be crossed by farm machinery and filled in by tillage, Auzey [3-4] but also in interrill. Hence, runoff ,which is the vector of pollutant transfer, should be both considered at the rill scale and at the interrill scale, Monnier *et al.*. [23], Eimberck [12] and INRA [17].

The following classification of factors governing pesticide entrainment and transport in runoff is proposed completed and adapted from Leonard [19] to the Grand-Morin:

- *Climatic* (rainfall and runoff timing with respect to pesticide application, rainfall intensity, rainfall duration and amount, time to runoff after interception of rainfall, water temperature);
- *Soil* (soil texture and organic matter contents, surface crusting and compaction, water content, slope, degree of aggregation and stability);
- *Pesticide* (solubility, sorption properties, polarity/ionic nature, persistence, formulation, application rate, placement);
- *Management* (residue management, vegetative buffer area, irrigation, cropping systems, agricultural drainage network).

1.2. Selection of pertinent and available factors

As the aim was to design a qualitative and cartographic approach, reproducible in time and space, the selection of fewest factors were the best. Moreover, cartographic data available in France were taken into account, especially concerning soils and factors compatible with a yearly assessment of pollution risks. Thus a conciliation between the relevance of factors and their availability had been performed.
In a qualitative approach, the rill and interrill scale were not actually distinguished.

Climatic related factors : None of them had been taken in account, in spite of their relevance for three reasons (i) lack of information on rainfall intensity, duration, amount and temperature on most of the stations of the National Climatic Measurement Network handled by Météo France; (ii) difficulty to define a spatial unit concerning rainfall; (iii) necessity of too many inquiries to assess rainfall/ runoff timing with respect to pesticide application and time to runoff after interception of rainfall. Additional tools will be presented in perspective to take them into account.

Soil related factors : Thanks to the IGCS program (Inventaire Gestion et Conservation des Sols), handled by the French Ministry of Agriculture and the National Institute for Agronomic Research (INRA), a Geographical Information System for soils is setting up. Within seven years, geo-referenced databases will be available for the whole France. Yet, data are available for a part of the Grand Morin watershed. Factors unstable in time like the organic matter and water contents were not taken into account. Moreover, land surface slope classes were determined and the others factors regrouped under the soil surface crusting sensibility, assessed with the soil surface texture and the triangle of texture where this sensibility is shown (see **Figure 2**).

Pesticide related factors : As a single pesticide was considered (Atrazine) there is no variability of such factors except application rate. Nevertheless, on such a large area, application rate could be assessed only by either a gallop or considering an average quantity.

Management related factors : Irrigation practices, cropping systems, residue management, drainage networks influences, specific to each farmer and then implying enquiries, were not taken into account. The target is to see how additional spatial analysis could assess the influence of vegetative buffer area as forest cover on pesticide entrainment in runoff.

Additional factor: immediate proximity of the river : Bouchardy [6] proposed this factor and distinguished several classes of proximity. Nevertheless, a correct representation of the vulnerability by the other selected factors outside a single buffer around the hydrologic network was assessed. Thus a single buffer, 500 meters wide, was taken in account and associated to the highest vulnerability for the river. As the altitude of the watershed is relatively homogeneous, it represents the immediate proximity to the river.

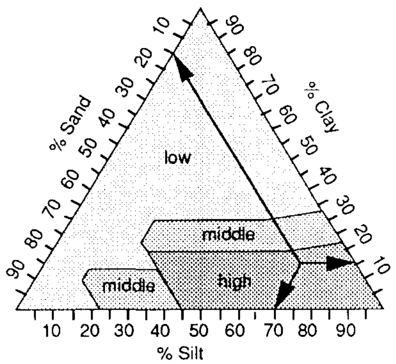

Figure 2 - Soil surface crusting sensibility and soil surface variation, after INRA [17]

2. METHOD

The factors selected to assess the surface water vulnerability to pesticide pollution when runoff is predominant are the soil surface crusting sensibility; and the land surface slope.

2.1. Data necessary to obtain the vulnerability map

First, a digital soil surface texture map was required. Such map contains the following elements:
- boundaries of soil spatial unit (a soil spatial unit is a polygon which is supposed to be homogeneous at a given organisation level, as far as the soil is concerned);
- relations between soil spatial units and soil topologic units which represent the type of soils encountered on the map area. As a soil topologic unit contains information on modal soil texture for the unit considered on each horizon, it was possible to relate the soil spatial unit to soil surface texture. Then polygons were selected on their soil surface crusting sensibility appreciated through the texture triangle, as shown on **figure 2**.

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Second, a digital elevation model, giving the altitude for each node of a lattice, was required to calculate surface terrain slope in percent. The method proposed and developed by Depraetere [9] was used. Finally, a surface terrain slope map was deduced with four slope classes, 4% wide, ranging from 0% to 16%, due to the relatively low variations of the slope.

2.2. Data necessary to obtain a map of Atrazine input areas

Considering the different crops where Atrazine is usually applied (almost corn in continental areas) and the National Agricultural Statistics of 1988 for the studied area, we can assess that, in 1991, Atrazine input areas square with corn fields. Thus, a land use map was required. A couple of Landsat TM images, first on April 4th 1991, second on September 9th 1991 were used. They permitted to take benefit of the phenological states differences between crops to discriminate them from each other, Girard and Girard [14]. But, " ground truth " for image classification is necessary, *i.e.* 5% of the remote sensory fields classified must be known, Girard and Girard [14]. Thus, a hundred fields were mapped within the studied watershed, in 1991. Finally, thanks to those fields and 1/50,000 maps provided by the National Geographic Institute (IGN), we distinguished the following land use themes: (i) corn; (ii) forest; (iii) active vegetation in September (other than corn); (iv) active vegetation in April (v) others.

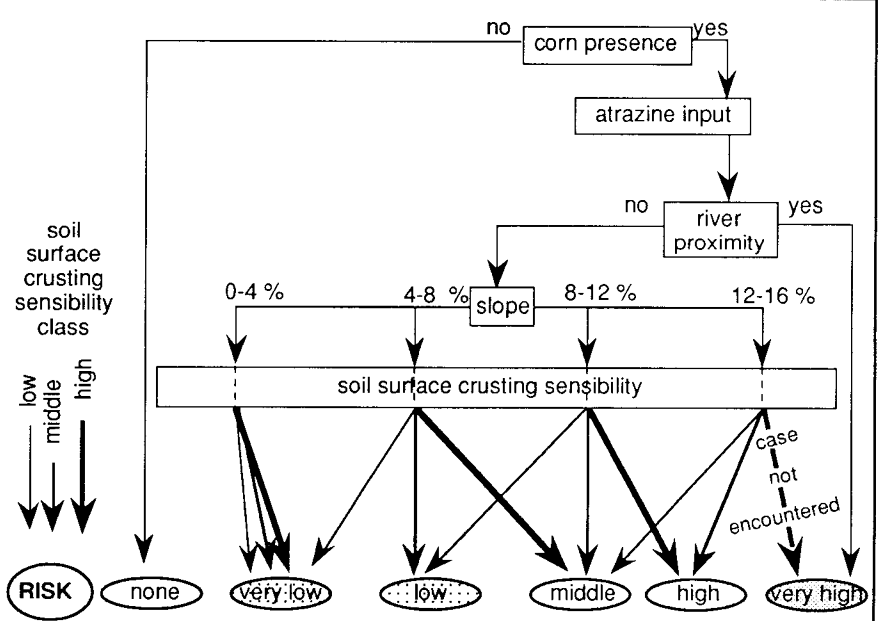

Figure 3 - Decision tree do assess surface water risk of pollution by pesticide through runoff. River proximity, slope and soil surface crusting sensibility represent the river vulnerability to Atrazine transfer.

2.3. Decision tree

The following was assessed: (i) a corn field represents an Atrazine input; (ii) an Atrazine input located nearer than 250m represents the highest risk for the surface waters; (iii) a high surface slope permits the surface transfer downstream and may emphasise this interrill runoff into a rill runoff and consequently the transfer itself ; (iv) a soil surface crusting sensibility induce, when it rains, an interrill runoff which carry Atrazine.

According to those hypothesis, the following decision tree was used to assess the surface water risk of contamination by Atrazine through runoff (see **Figure 3**). The highest risk is represented by the immediate proximity to the river of an Atrazine input; the lowest by lack of Atrazine input. Thus, an Atrazine input alone is assessed to be risk itself.

2.4. Data processing

It consisted in an overlay of the following informations cover through an arc/node Geographical Information System, Burrough [7] (see **Figure 4**)

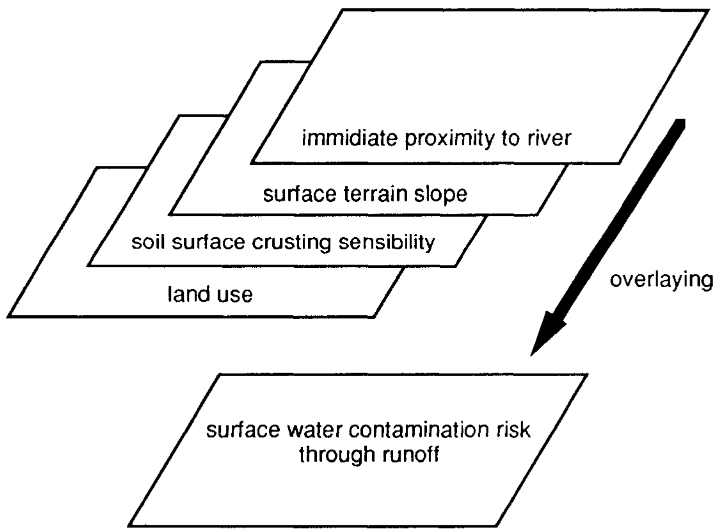

Figure 4 - Overlay of four maps containing the selected factors to obtain a resultant map of surface water contamination risk

2.5. Additional data processing to assess the vegetative buffer area influence on pesticide transport in runoff

The decision tree used leads to consider runoff at the field scale. In fact, there is no reason that all the runoff reach the hydrologic network. Desbordes and Valadas [1979], CEMAGREF [1986], Duvoux [1990], Kauark-Leite [1990], Bouchardy [1992] underlined that the vegetative buffer areas slow down or even stop runoff. Nevertheless, assessing their influence lead to a watershed-scale analysis.

To perform such analysis, the following steps should be followed, Soyeux [23]: (i) identification of vegetative buffer area and especially the largest (*i.e.* forest); (ii) delimitation of the watershed associated to each vegetative buffer area.

Then, taking into account that inside such watersheds, pesticide transfers through runoff are lowered, would be possible.

3. RESULTS AND DISCUSSION

We obtained five maps as indicated **Figure 4**. They display the spatial distribution of the variables studied. Moreover, sub-watersheds statistics, concerning the sub-watershed associated to the water quality measurement stations, were performed. Unfortunately, data collection was not yet completed thus those statistics are partial (see **Table I**).

The main results of those maps are the following:
- the risk majority are linked to the corn presence near the hydrologic network and mainly in the Lavanderie sub-watershed (see **Figure 1**);
- the other risks are less frequent as the spatial unit where slope is high and soil surface crusting sensibility is high.

The surface known is the surface which has been identified by remote sensing.

WATERSHED	Grand Morin	Villiers sur Morin	Pommeuse	Lavanderie	Meilleray
surface (km^2)	1187	1140	757	274	319
LAND USE					
surface known (km^2)	831	784	461	214	23
% known	70%	69%	61%	78%	7%
VULNERABILITY					
surface known (km^2)	482	436	236	91	0
% known	41%	38%	31%	33%	0%
RISK					
surface known (km^2)	482	436	236	91	0
% known	41%	38%	31%	33%	0%

Table I - Completion of data collection for each kind of data by watershed

WATERSHED	Grand Morin	Villiers sur Morin	Pommeuse	Lavanderie	Meilleray
Total known (km^2)	831	784	461	214	23
	surface (% Total)	surface (% Total)	surface (% Total)	surface (% Total)	surface (% Total)
active vegetation in September	58 (7,0%)	54 (6,9%)	33 (7,2%)	14 (6,6%)	1 (6,4%)
forest	50 (6,0%)	49 (6,2%)	23 (5,0%)	9 (4,1%)	0 (0,4%)
corn	112 **(13,5%)**	106 **(13,5%)**	62 **(13,4%)**	32 **(14,8%)**	3 **(13,1%)**
active vegetation in April	305 (36,7%)	293 (37,3%)	176 (38,2%)	89 (41,6%)	10 (43,8%)
others	305 (36,8%)	283 (36,1%)	167 (36,2%)	70 (32,9%)	8 (36,2%)
total	831 (100,0%)	784 (100,0%)	461 (100,0%)	214 (100,0%)	23 (100,0%)

Table IIa - Land use by watershed

WATERSHED	Grand Morin	Villiers sur Morin	Pommeuse	Lavanderie
Total known (km^2)	482	436	236	91
	surface (% Total)	surface (% Total)	surface (% Total)	surface (% Total)
very low	319 (66,2%)	290 (66,7%)	163 (69,2%)	61 (67,1%)
low	25 (5,2%)	19 (4,3%)	7 (2,8%)	3 (2,8%)
middle	30 (6,3%)	28 (6,4%)	13 (5,7%)	5 (5,4%)
high	4 (0,7%)	3 (0,8%)	2 (0,8%)	0 (0,2%)
very high	104 (21,6%)	95 (21,8%)	51 (21,5%)	22 (24,5%)
total	482 (100,0%)	436 (100,0%)	236 (100,0%)	91 (100,0%)

Table IIb - Vulnerability by watershed

WATERSHED	Grand Morin	Villiers sur Morin	Pommeuse	Lavanderie
Total known (km^2)	482	436	236	91
	surface (% Total)	surface (% Total)	surface (% Total)	surface (% Total)
none	418 (86,6%)	377 (86,6%)	206 (87,3%)	75 (82,9%)
very low	44 (9,2%)	40 (9,2%)	22 (9,5%)	10 (10,5%)
low	3 (0,6%)	2 (0,5%)	1 (0,3%)	1 (0,6%)
middle	3 (0,6%)	3 (0,7%)	1 (0,4%)	1 (1,0%)
high	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)
very high	14 **(3,0%)**	13 **(3,0%)**	6 **(2,5%)**	5 **(5,0%)**
total	482 (100,0%)	436 (100,0%)	236 (100,0%)	91 (100,0%)

Table IIc- Risk by watershed

Moreover, with the help of the statistics and field studies, we can consider that the surface known for each sub-watershed are representative of the whole considered sub-watershed, corn surfaces are quite homogeneous on the whole Grand Morin watershed (see **Table IIa**).

As Atrazine concentration chronics are available from the surface water quality measurement performed from 1991 on, they could be compared to the results obtained here in order to validate the methodology. Nevertheless, in order to perform this validation, the following is necessary: (i) runoff occurrence for the considered year; (ii) assessment of surface water pollution risk through ground water links with surface water.

CONCLUSION - PERSPECTIVE

This methodology could be used to map surface water contamination risk combining the pollutant input with the surface water vulnerability to contamination through runoff assessed with the terrain slope and the soil surface crusting sensibility.

The availability in the near future of digital elevation models and digital soil maps will permit its reproducibility elsewhere, for instance in the others ISMAP test sites in France and in Italy. On the other hand, the reliability of satellite programs like SPOT or LANDSAT will permit its reproducibility in time as only land use changes.

Moreover, under the condition that Corn is identify as the own Atrazine source, the few factors used allows an intuitive understanding for the map user which allows such maps to be used for decision support.

The validation of this methodology needs further investigations on surface water contamination through ground water and runoff occurrence (which we didn't perform in 1991).

Finally, we underlined the difficulty to define spatial units concerning climatic factors. Hence, Geographical Information System linkage with hydrologic modelling would be a solution, Petach *et al.* [22]. Such models -spatially distributed like the European Hydrologic System (SHE), Abbot et al. [1] and [2] or SOURCE, Girard and Dufaure [13]- will be coupled with Geographical Information System in the framework of ISMAP Information Decision Support System.

ACKNOWLEDGEMENTS

This program was supported by the Syndicat des Eaux d'Ile de France, Paris.

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