

Mapping Environmental Risk by Application of GIS Technologies in the Southern Part of Venice Province

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1. Introduction

Inappropriate tillage practices can have serious consequences for soil fertility and structure and lead in many countries not only to loss of productivity, but also to serious environmental threats, such as soil compaction and aquifer pollution.

This study was carried out in the context of a major research effort aiming to analyze the relationships between tillage practices and soil-water environment conditions (CERA et al., 1997). The final goal of the research is to define low-impact tillage practices that are related to soil texture, structure and hydrologic properties, thus enabling farmers to choose optimal tillage practices based on farm-specific conditions. A rational soil tillage plan can lead agriculture to greater sustainability, provided good knowledge of the soil - water system is available at regional, local and farm level.

2. Objectives

Of the two elements which define the concept of environmental risk (vulnerability, which relates to intrinsic land characteristics, and hazard, depending on real land use conditions), only the first is discussed in this paper, i.e. the natural attitude of land to be affected by agriculture induced impacts.

In particular a methodology based on a hydrogeologic model and GIS technology is discussed which can be used to map areas with different rates of aquifer vulnerability over large areas. Together with similar techniques, which spatially delineate areas differently, prone to soil degradation (erosion, compaction etc.) this methodology can play a significant role in addressing sustainability in agriculture.

In order to model aquifer vulnerability we chose the SINTACS model, an adaptation for Mediterranean conditions of the well known DRASTIC model. The model takes into account several environmental factors, e.g. topography, surface water, groundwater, geolithology, hydrogeology, pedology and rainfall characteristics. Spatial knowledge of all these factors - and their mutual relationships - is needed in order to properly model aquifer vulnerability according to this model.

A GIS approach is thus required, which allows not only to efficiently store and manage large spatial databases, but also to implement the model itself by using spatial analysis capabilities.

3. Study area

The study area is located in the South-Easternmost part of Venetian plain and covers about 300 km² (fig. 1). Elevation ranges from -3 and +4 m on sea level; most of the area is located below the sea level. Original topography has been changed for several years by land reclamation practices; such activities has been applied mainly to sand dunes which consequently show reduced extensions.

Most of the descriptive data which are reported below have been derived from previous work by BASSAN et al., 1994, and GIARDINI et al., 1989.

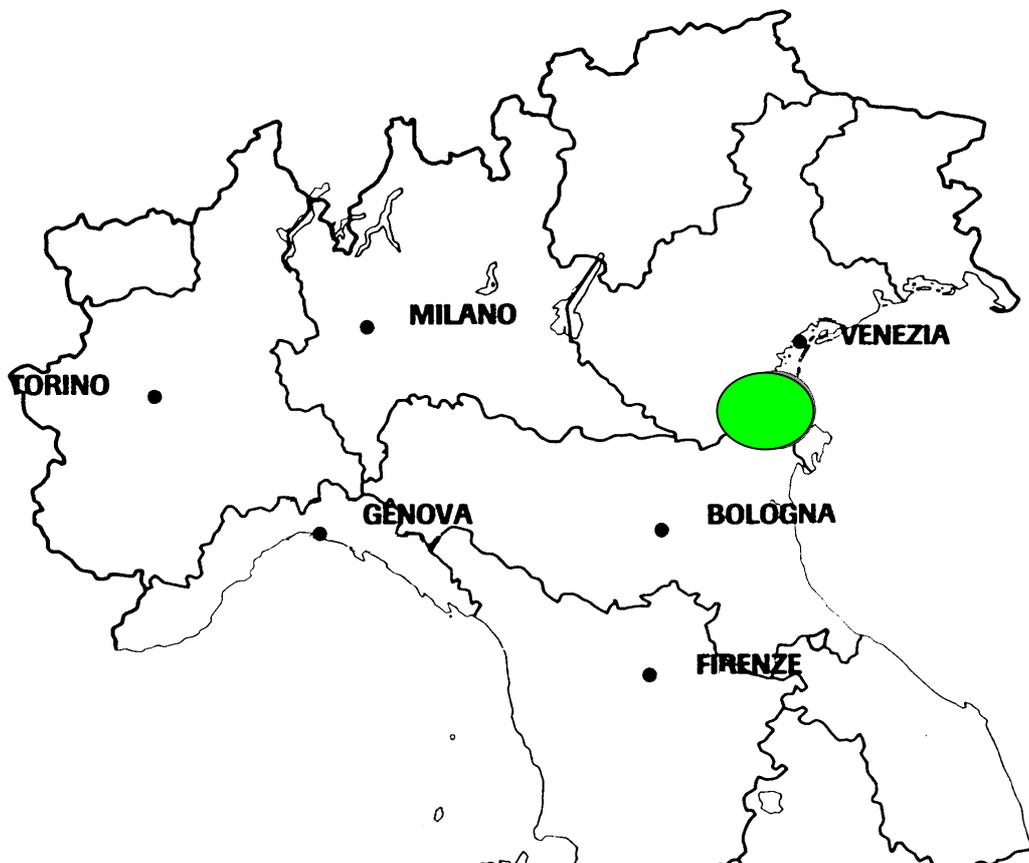


Figure 1 Chorography of the Study Area.

3.1 Geomorphology and Lithology

Coastal and plain landforms are predominant in the area, which is characterized by thick quaternary deposits (about 2000 m) sedimented in the padan basin during the Quaternary. These sedimentary bodies, as well as the present coast line, result from the interactions between solid transport by rivers (Po, Adige and Brenta) and sea level variations, that varied with the climatic changes during the Quaternary (connected to the alternation of glacial

periods). Several littoral bodies testify of coast line evolution in the holocene age as well. The landforms are characterized not only by sea and littoral deposits but also by the wide-spread ancient river bed network; within this system, recent river beds from the older ones by the different slope angles.

This complex geomorphology is conditioned by different deposition environments, notably lagoon delta and low-energy river environments. The deposit particle size ranges from sand to clay and peaty clay. Sands are present along the coastal belt, and build the internal dune system as well; such materials have a high permeability, sometimes the sands are reddish.

Sandy deposits occur in the old riverbeds as well; these ones show a higher silt content at the top. Most clayey silts, silty clays and peats originate from lagoon and marsh environment; these deposits are spread all over the study area and show an high organic matter content.

3.2 Soils

Six main landscape units can be identified, namely lagoon areas, marsh areas, coastal areas, rises, interfluvial basins, and transition areas between the latter two. Inside these units several sub-units and lower-level taxonomic categories occur.

Soils belonging to lagoon and marsh areas are generally rich in lime and salts, with hydromorphic characteristics. According to FAO-UNESCO these soils can be classified as Salic Histosols and Salic Cambiols.

In coastal areas, characterized by active sandy dunes, interdunal areas and ancient dunes, soils (Cambic Arenosols and Eutric Fluvisols) are sandy, poor in organic matter and with a shallow water table.

Rises are related with old riverbeds. Soils in these areas are generally sandy or loamy with a sub-alkaline pH, high carbonate and organic matter contents and a deep water table. These soils can be classified as Eutric Cambisols and Cambic Arenosols, Gleyic Phaeozems and Vertic Luvisols.

Interfluvial basins, corresponding to old marshes, are located below the sea level. Soil are organic to peaty e.g. Terric Histosols and Mollic Gleysols.

In transition areas the soils range from clay to loamy, with an average organic matter content, often with saturated conditions, sometimes with expandible clay. Gleyic Phaeozems, Gleyic Chernozems and Eutric Cambisols are the most common units.

3.3 Pluviometry

Analysis of rainfall collected in 16 raingauges by the Hydrografic Service from 1920 to 1980, shows that the study area is characterized by sub-lithoranean conditions, with absolute maximum and minimum in fall and winter, and relative maximum and minimum in spring and summer respectively (fig 2 and 3).

Table 1 reports rainfall data collected in or near to the study area; while fig. 4 shows annual isohyets derived from spatial interpolation of point data.

Table 1. List of raingauges located in or near the study area

N.	Place	Elevation [m.s.m.]	Observation period	Annual average rainfall [mm]
1	Botti Barbarighe	7	1929-1980	665.2
2	Cavanella Motte	1	1940-1980	699.2
3	Chioggia	2	1922-1980	702.1
4	Conetta	4	1920-1980	767.4
5	S.Margherita di Codevigo	4	1920-1980	752.6

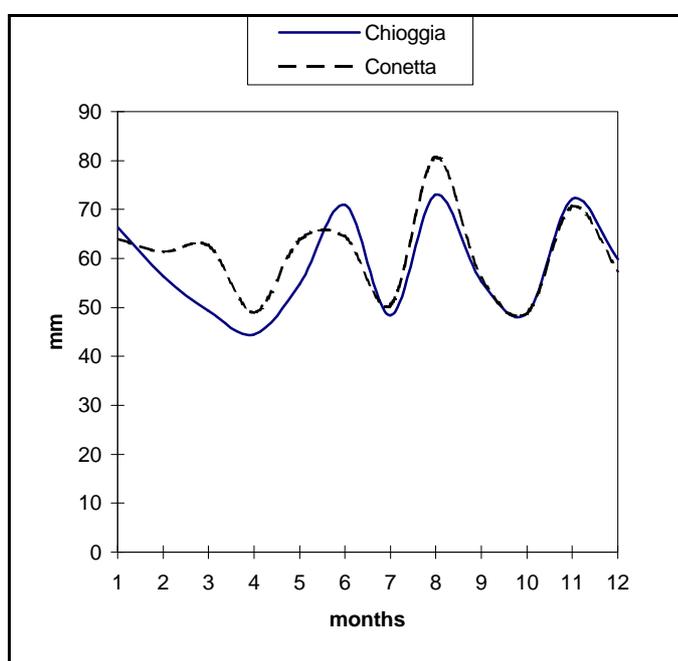


Figure 2. Rainfall annual distribution at Chioggia and Conetta.

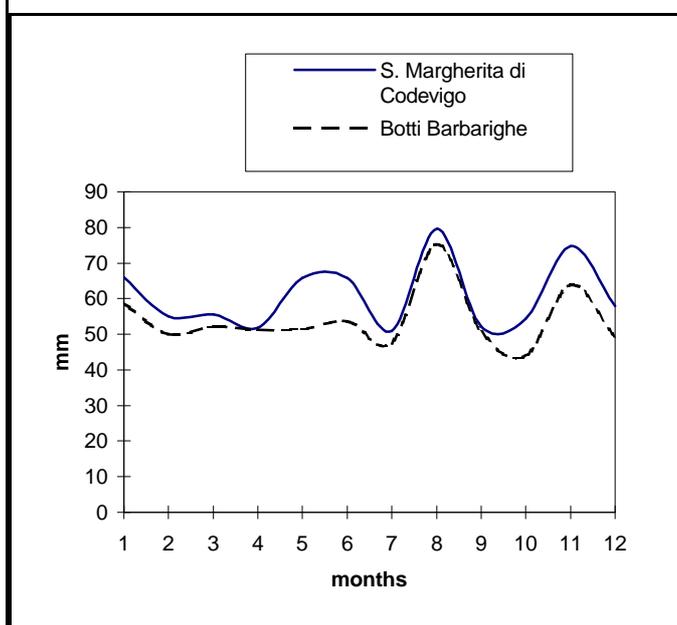


Figure 3. Rainfall annual distribution at S. Margherita di Codevigo and Botti Barbarighe.

3.4 Hydrology and hydrogeology

Hydrography is conditioned by downstream tracts of the Adige, Brenta and Bacchiglione rivers. Besides the natural hydrography, a wide hydraulic network exists which has been created by reclamation activities since the late 1800's. Embankment works have modified relationships between aquifers and natural hydrography. The surface water table is located between 0.7 and 2.5 m below the topographic surface (fig. 5), and its level is strongly influenced by both natural and artificial hydrography; water losses from surface bodies towards aquifers, together with precipitation recharge phreatic aquifers.

Previous studies suggest that as the water table oscillations are influenced by pumping rates from the hydraulic hydrography to the rivers and by irrigation practices.

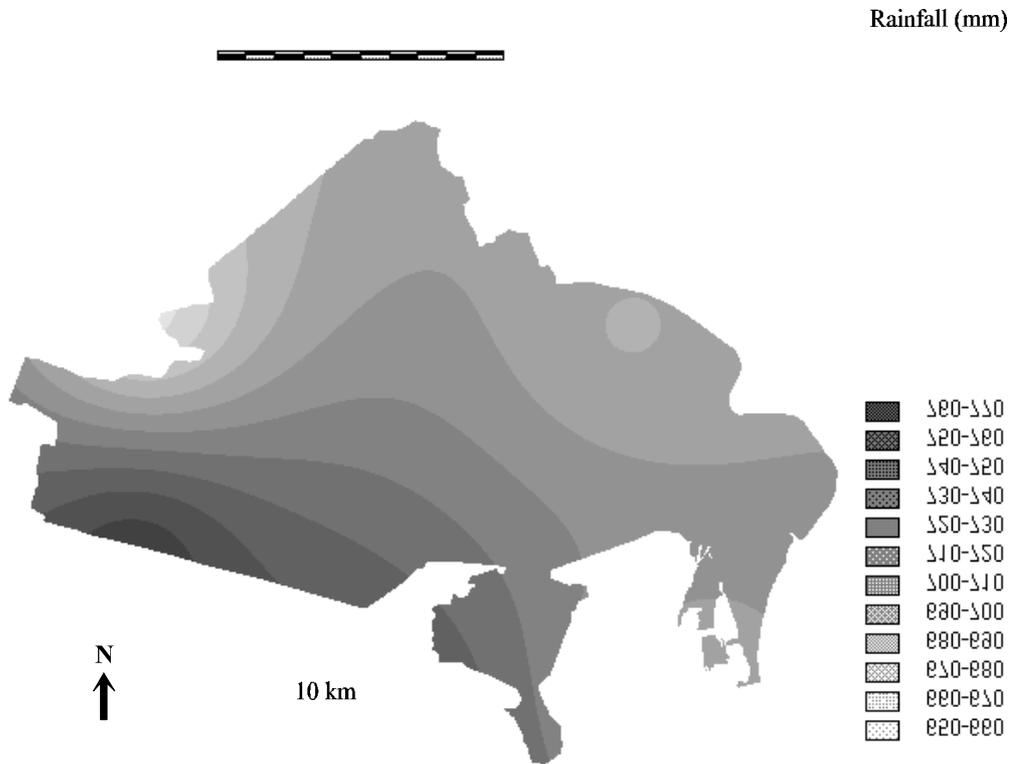


Figure 4. Spatial distribution of annual rainfall.

3.5 Land use

Land use is dominated by intensive agriculture, with differences at least partly due to variable agronomic and pedologic conditions. In the westernmost part summer crops like maize and soybean are grown in association with winter cereals (wheat and barley), beets and forage crops. In the eastern part horticulture is widespread, especially on sandy soils closer to the coast. Tree plantations, and pasture areas, are poorly represented in the area. Some uncultivated areas still remain, alongside remnants of ancient plain forest or aquatic systems, with great naturalistic value (e.g. “Bosco Nordio”).

4. Materials and Methods

4.1 GIS software

For spatial database management and model implementation we used GRASS (Geographic Resources Analysis Support System), a powerful set of GIS and Image Processing modules developed by U.S. Army CERL (USACERL, 1992). The system supports all main steps of a GIS implementation: data input, database management, data analysis and output presentation.

The system analysis capabilities are strongly based on a spatial modeling language which allows users to implement mathematical, logical and conditional operations on data in raster format (SHAPIRO, WESTERWELT, 1992). The system has been installed on a PC running under the Linux operating system.

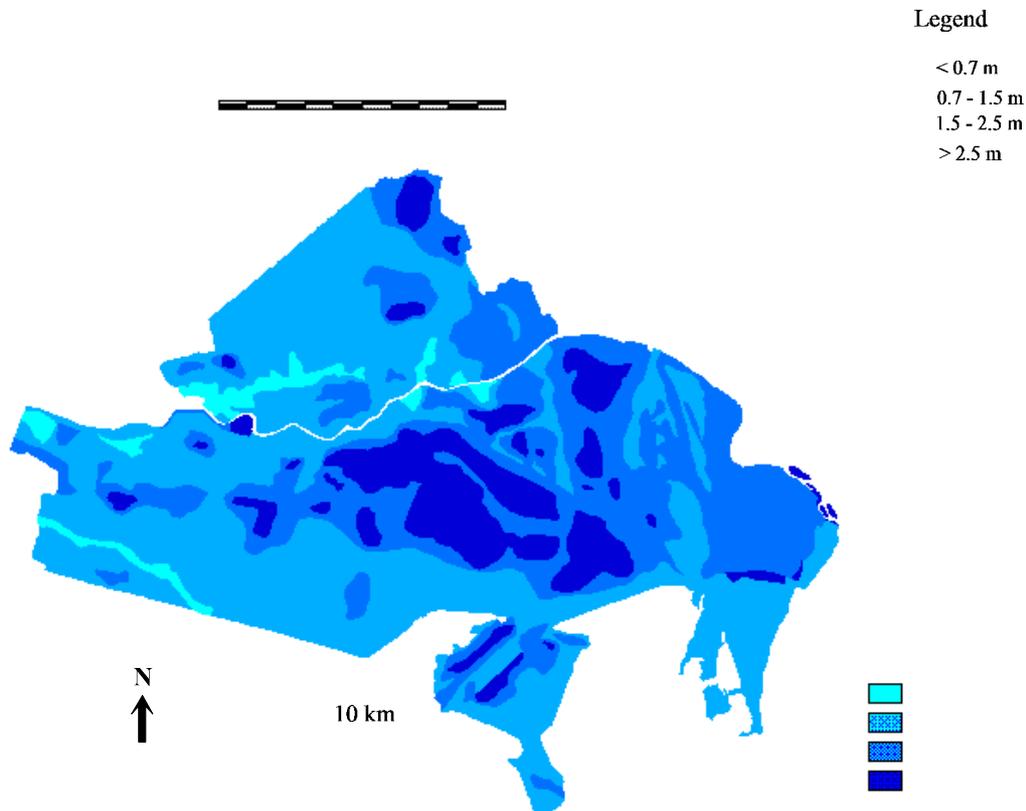


Figure 5 Surface Aquifer Water Table Depth.

4.2 Base Data

The data used in this study can be divided in two main groups, viz. maps and tabular (rainfall) data.

Map data have been derived from previous researches conducted in the recent past. Among the others we used the following maps at a 1:50,000 scale:

- base maps (Italian Military Geographic Institute sheets),
- thematic maps (lithologic systems, groundwater depth, soil hydrologic properties),

First of all, map data in analogue format have been converted to digital format using a digitizing tablet. A sampling density of 1 point each 50 m was used. At the end of this step, the result was a vector database with each layer corresponding to a source map.

The next step is vector-to-raster conversion, for which a grid cell resolution of 30 x 30 m, corresponding to 0.6 mm on the map, has been chosen. The resulting grid is 768 rows by 988

columns. As a result, each source map is now stored as an independent grid accessible to the GRASS' system. All data are georeferenced according to the UTM system.

A rainfall distribution map has been produced from point data by using a local interpolator based on the weighted moving average. This approach has been preferred to others (like Thiessen polygons or Isohyetal methods) since it results in fully distributed values incorporating the concept of gradual variation.

4.3 Model description

The parametric models utilized belongs to the PCSM group (Point Count System Model) in which every factor has not only its own score but also an additional weight in order to reduce or amplify its importance during the analysis. The additional weight is set in relation to environmental characteristics, such as high dispersion phenomena from surface water bodies to groundwater or spread pollution sources.

The model used to predict aquifer vulnerability is SINTACS, developed by the National Research Council (CIVITA, 1994). It is an evolution of the U.S. DRASTIC model adapted to Mediterranean conditions.

The model takes into account the following seven factors:

- water table depth;
- infiltration;
- unsaturated conditions;
- soil texture;
- aquifer hydrogeologic characteristics;
- aquifer permeability;
- topographic slope.

Each factor is assigned a score in the 0-10 range, according to its importance in defining vulnerability. Scores are then modified by weights which are related to the specific environmental and/or antropic conditions of the area. The particular SINTACS model considers four possible conditions:

- normal areas
- areas with spread pollution sources
- areas with intense water losses from hydraulic networks towards aquifers
- areas with karstic phenomena

Finally, an intrinsic vulnerability index I is calculated by summing the product of scores by weights, according to the following expression:

$$I_{sintacs} = \sum (p_j \cdot w_i)$$

where p_j represents the j score and w_i the i weight.

The I index ranges between 23 and 260. However, in order to facilitate interpretation of the results, this range has been normalized to 0-100. This normalization allows a 6 level classification of vulnerability, from very low to very high (see further).

The authors carried out a sampling process of input parameters in a 50 meters grid. Informative layers relevant to the analysis were processed in advance and adapted with the aim to compare these data with the tables of SINTACS model.

5. Results

As discussed previously resulting values have been then normalized in a 0-100 scale, which in turn can be classified in six levels of vulnerability, from very low to very high. The spatial distribution of I index in the study area is shown on fig 6; on Table 2, we can read the relation between the vulnerability levels, from low to high, and the SINTACS index percentage for each class, together with their respective areal extensions.

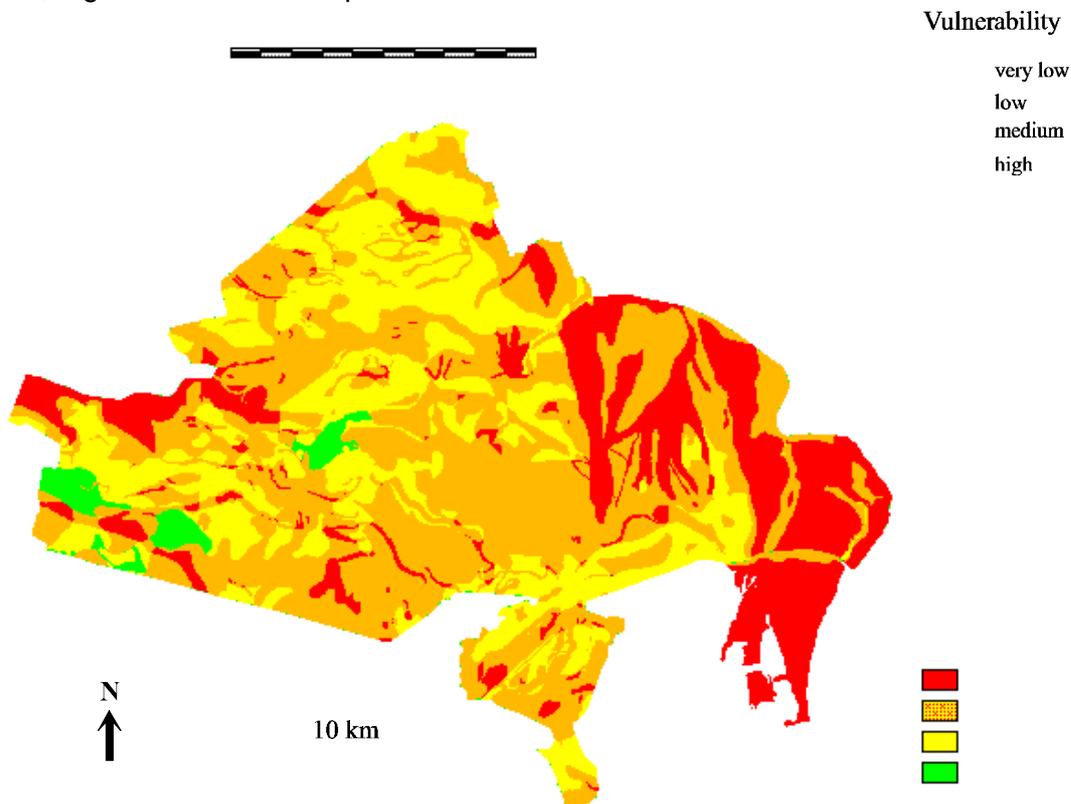


Figure 6. Map of Aquifer Vulnerability.

The map shows high vulnerability level areas on the sandy eastern portion and on limited sectors of the western part. The medium level, the most important class, spreads out over the central and northern area. The southern belt stands out a low or medium-low level of vulnerability. Only in small sectors can we find a high level.

Table 2. Relationships between Vulnerability Levels and SINTACS Index Values

vulnerability level	Sintacs Index value [%]	Area [ha]
very low	0-24	647.5
low	25-35	8309.84
medium	36-49	14294.47
high	50-69	6553.44

6. Discussion and Future Work

The vulnerability map produced can be considered a rather satisfactory result. Given the accuracies of the source maps (scale 1:50,000 to 1:100,000) and the dimensions of the study area (about 300 km²), the map can give useful information for planning activities at Province and County levels. However, using this information at the farm level could be hazardous.

The next step of the research should be to find a closer relationship with farm-level experiments in order to delineate mechanization possibilities in relation with the soil-water system. It should also involve integration of Remote Sensing techniques in order to detect agricultural land uses and their dynamics all over the area. This would allow taking into account the anthropic factor into account, thus passing from *vulnerability* to *risk* mapping.

7. Acknowledgments

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