Vulnerability of the environment in the proximity of an industrial site

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Abstract

This work is carried out in the framework of the ARAMIS project, which aims at developing a comprehensive procedure for assessing the risk level associated to an industrial site with respect to the surrounding environment. To this end, an index is defined which consists of the contribution of three terms, expressing the scenario consequence severity, the safety management efficiency and the vulnerability of the surrounding environment. The present work focuses on this last aspect by determining the vulnerability of the area in the proximity of an industrial site from the contribution of classes of elements belonging to the categories of human, environmental and material targets. The applied methodology consists in identifying and quantifying the targets by means of a geographical information system (GIS) and in assessing the contribution of each target on the basis of a multicriteria decision approach (Saaty method). The result is an operational tool allowing competent authorities, industrialists and risk experts to assess the vulnerability of the area surrounding an industrial site.
Keywords: ARAMIS, environment vulnerability assessment, geographical information system, multi criteria decision method, industrial site.

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1 Introduction

The ARAMIS project aims at developing an integrated risk index based on, among others, the vulnerability of the environment surrounding an industrial site. Indeed, environmental vulnerability is scarcely taken into account in risk assessment, and its integration in the ARAMIS project represents therefore an innovative aspect of great interest. Figure 1 better explains the problems addressed when defining the environmental vulnerability, which may be summarized as follows: is area 1, which is composed of human, environmental and material targets, more or less vulnerable than area 2 also composed of human, environmental and material targets, but in different quantity and of different nature?

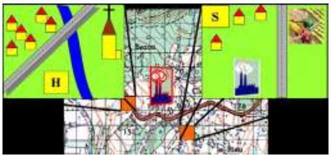

Figure 1: Problematic of environmental vulnerability definition.

The idea here developed is to define a vulnerability index to identify and characterize the vulnerability of all possible targets located in the surroundings of a Seveso industrial site (vulnerability mapping). This would require first to establish the study area and define the targets of interest, then to identify and quantify the targets in the study area and, finally, to assess their vulnerability: this last step needs a specific methodology. In this work a semi-quantitative approach to vulnerability is adopted, which is a multicriteria decision method (Saaty's method) based on expert judgements. This method allows one to take into account both the "status" of a specific target (qualitative approach) and the "census" of that target (quantitative approach).

2 Typology of vulnerabilities

The aim of this paragraph is to define the environment of an industrial site to determine the risk level of an industrial installation. It is therefore necessary to propose a set of target types to characterise with accuracy the environment, while keeping in mind the importance of the transferability of the method and its flexibility. Indeed, it is necessary to find a proper balance between the number of targets to be taken into account and the limitations due to the multicriteria decision method.

First of all, targets were divided into three categories and each of these categories is then detailed in a list of target types:

- ✓ Human (H) (Staff of the site (H_1), Local population (H_2), Population in an establishment receiving public (H_3), Users of communications ways (H_4))

- ✓ Environmental (E) (Agricultural areas (E_1), Natural areas (E_2), Specific natural area (E_3), Wetlands and water bodies (E_4))
- ✓ Material (M) (Industrial site (M_1), Public utilities and infrastructures (M_2), Private structures (M_3), Public structures (M_4))

Two databases have been retained to get most information concerning these targets.

The Corine Land Cover [1] database provides homogeneous geographical information about land use in each country of Europe. The main information included in this database corresponds to topographical map, vegetation and type of forest map and finally soil and network description.

There are five main types of territory description:

- ✓ artificial territory
- ✓ land for agricultural use
- ✓ forest and natural areas
- ✓ humid areas
- ✓ water areas

The five previous types are described by forty four classes in order to characterise the natural environment.

The TeleAtlas database is made of local data collection activities in all European countries and in the USA [2].

The included themes are road and street centre-lines, address areas, administrative areas, postal districts, land use and cover, railways, ferry connections, points of interest: built-up areas, settlement centres, water.

These two databases fill most of our objectives to describe the natural environment and man made targets. Concerning the human targets, specific data provided by each country must be used. The information concerning the population will be obtained with the data provided by the INSEE for France which gives a status of the French population in 1999 by district [3]. In Italy, ISTAT (the National Institute for Statistics) also gives this type of information based on the 1991 [4] and, soon, on 2001 census of Italian population by district or census unit.

To use these population data, some rules must be assumed to allocate a number of people to each mesh included in a district, as discussed in the paragraph concerning the quantification of environmental targets. If more precise results are required, information at the cadastral level should be taken into account. This second approach is more time consuming than the first one.

It has to be pointed out that other more specific information concerning some important environmental features, such as parks or protected zones are available from national environmental organisations, such as APAT in Italy, or Natural zone of faunistic and floristic interest in France (ZNIEFF).

Finally, some other information, such as that concerning the industrial site, has to be provided directly from the user, since it is not available to the general public. A specific procedure is proposed to fill these data, which can be used also to add information concerning special targets, such as sites concentrating high number of people, vital infrastructures, monuments, etc.

3 Vulnerability method and prioritisation of target vulnerabilities

The objective is to quantitatively assess the environmental vulnerability. To this end the Saaty multicriteria decision method [5]) is applied, which is a ranking method using expert judgements and binary comparisons, based on four main steps:

- definition of the objective;
- description of the environment;
- organization of information in order to answer the problem;
- quantitative assessment of vulnerability factors based on the expert judgment.

To this end, the environment is described by means of three typologies:

- definition of targets categories: human, environmental and material. Each target category is subdivided in four types of targets. For human targets: staff of the site, local population, population in establishments receiving public and users of communication ways. For environmental targets: agricultural areas, natural areas, specific natural areas, wetlands and water bodies. For material targets: industrial site, public utilities and infrastructures, private structures and public structures.
- definition of physical effects: overpressure, thermal radiation, gas toxicity and liquid pollution;
- definition of the impacts: integrity, economical and psychological impacts.

The information is structured to address the objectives of the study, adopting the following definitions of the vulnerability:

- for a class of targets and a given physical effect, the vulnerability of each type of target with respect to the others is evaluated from binary comparisons, obtaining the vulnerability of each class of target to each physical effect;
- for a class of targets, the importance of each physical effect with respect to the others is evaluated from binary comparisons, obtaining the overall vulnerability of each class of targets;
- finally, the vulnerability of each class of targets is compared to the others, obtaining the global vulnerability.

From this approach, the matrixes and the functions are derived combining the quantification factors of the targets and their vulnerability factors (52 functions are defined) to give the vulnerability index. These matrixes and functions allow one to collect the expert judgement for determining the vulnerability factors of each vulnerability function. To this end, 38 experts, coming from different Countries and with different backgrounds (risk analysts, competent authorities, industrialists) were individually consulted [6] After treatment of the information collected from the expert judgement, the vulnerability factors of the 52 functions were calculated from the eigenvectors of the matrixes. For example, the global vulnerability, V_{global}, of a study area results from the following combination of human, natural environment and material vulnerabilities (V_H, V_E and V_M):

$$V_{global} = 0.752 \times V_H + 0.197 \times V_E + 0.051 \times V_M \quad (1)$$

where the vulnerability of each class of targets depend on its vulnerability to the physical effects (overpressure = op, thermal radiation = tr, toxicity = tox, pollution = poll)

$$V_H = 0.242 \times V_H^{op} + 0.225 \times V_H^{tr} + 0.466 \times V_H^{tox} + 0.067 \times V_H^{poll} \quad (2)$$

$$V_E = 0.071 \times V_E^{op} + 0.148 \times V_E^{tr}\ 0.277 \times V_E^{tox} + 0.503 \times V_E^{poll} \quad (3)$$

$$V_M = 0.446 \times V_M^{op} + 0.410 \times V_M^{tr} + 0.069 \times V_M^{tox} + 0.075 \times V_M^{poll} \quad (4)$$

In order to apply this methodology and assess the area vulnerability, the first step consists in the definition of the features of the study area: its size should be large enough to cover the effects of the expected accidental scenarios for the industrial site, and, for the purpose of vulnerability mapping, it should be divided into meshes. A 20 km x 20 km size for the study area, with 500 m x 500 m mesh size or less is suggested, where the mesh size may be reduced close to the industrial site, for a better visualisation of the vulnerability in that zone. Then, information about the various targets in the area has to be obtained from suitable commercial databases, and, possibly, completed with user data, to determine the quantification factors of each type of target to be inserted in the vulnerability functions. This requires one to make a census of each target category and type in each mesh of the study area. In particular, the quantification factor is a dimensionless variable assuming values in the range 0-1, where 0 indicates the absence of the target in the area under exam and 1 indicates that the quantity of that target in the area reaches its expected maximum. Details about this procedure are reported elsewhere [6].

4 Vulnerability mapping

The approach described above has been conveniently developed in the form of a GIS tool. In order to assess the vulnerability in the zone of interest, the following steps have to be performed (see Figure 2):

- select the study area and divide it into meshes;
- assess the vulnerability for each mesh, by identifying and quantifying the detailed target types of the categories human, environment and material included into the mesh;
- calculate the vulnerability indexes of the meshes;
- map the results.

These actions should be repeated for all the meshes of the studied area.

The study area will be a square centred on the industrial site. Most required information concerning location and type of the various targets are rather easily available from commercial databases (such as Corine Land Cover [1], TeleAtlas [2], etc.) including data about land use, transportation networks and points of interest, and from census data of the resident population; other useful information concerning the natural environment can be obtained from environmental organisations. Additional information, not included into commercial databases and concerning the industrial site, such as its boundaries or the exact location of special targets (for example, office buildings within the industrial site) can be easily introduced by the user.

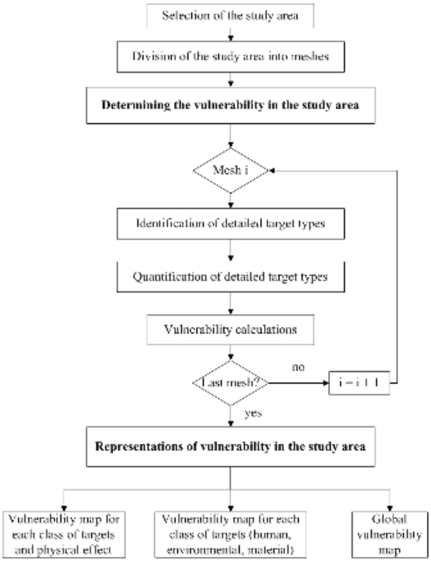

Figure 2: Structure of the GIS tool for vulnerability mapping.

The GIS tool can be developed with any commercial GIS software [7], [8]: the examples shown in the paper were obtained with MapInfo, but the ArcView tool is available as well. In any case, the tool provides the user with procedures for selecting the study area, dividing it into meshes, and identifying and quantifying the different types of targets into each mesh. The quantification step is fully automated for the targets belonging to natural and built-up environment, based on the ratio of the area covered by each target of this type to the area under exam. The same procedure cannot be adopted for human targets, where the quantification factors have to be determined based on the maximum number of persons expected in the area [6]: suitable default values are suggested to obtain the quantification factors, which, however, can be modified by the user.

5 Example

In order to validate and to underline the contribution of the vulnerability assessment, the methodology is applied on several test cases.
In the next part of this paragraph, both the environment of one test case of the ARAMIS project and the deduced maps of vulnerability are presented.

5.1 Description of the environment of the site

The study area (figure 3) is composed of two grids:

- the main grid is a square of 20 km per 20 km with meshes of 500 m per 500 m
- the inner grid is a square of 2 km per 2 km with meshes of 50 m per 50 m

The inner grid allows one to obtain a more precise representation of the vulnerability close to the industrial site.

This environment contains various stakes which are detailed in figures 3 and 4.

Human stakes (figure 3, left), are mainly composed of districts with a very low and low density (ranging from 0 to 1000 people per kilometre square). Only about 20% of the study area presents districts with a medium value of density (between 1000 to 2000 people per kilometre square).

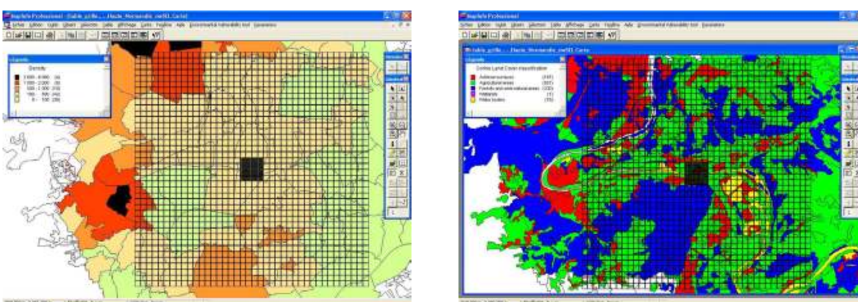

Figure 3: Human (left) and natural and material (right) stakes of the study area.

Natural and material are mainly composed of agricultural areas and of forests and semi natural areas (figure 3, right). The other part of the study area is characterised by artificial areas, wetlands and water bodies.

In a general way, from this first analysis, one can say that the vulnerability for the whole area might be low or medium.

Nevertheless, the following maps of vulnerability give an exact value of the vulnerability and also the location of sensitive spots.

5.2 Presentation and analysis of vulnerability results

In this part, two different sets of vulnerability maps are presented and commented, which are:

- a set of vulnerability maps for each type of targets (human, environmental and material) and a map of global vulnerability
- a set of vulnerability maps for each physical effect (overpressure, thermal radiation, toxicity and pollution)

The human vulnerability (figure 4, top left) is very low in great part of the study area. Indeed, the human vulnerability is strongly correlated to the population density and to urban or semi urban areas (artificial areas). So only, the artificial areas present some spots of vulnerability with a low value of vulnerability due to the low value of population density in our study area. The inner grid is characterized by a very low vulnerability for the industrial site where there are about 600 workers.

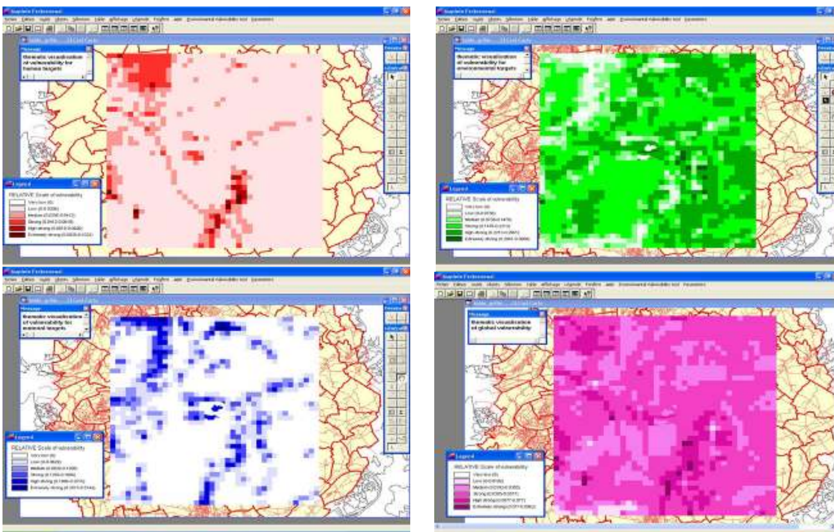

Figure 4: Maps of the human (top left), environmental (top right), material (bottom left) and global (bottom right) vulnerability.

A great part of the study area is characterized by a medium vulnerability value (figure 4, top right). Only the part which corresponds to the artificial areas has a low value of vulnerability. In the inner grid, the presence of water bodies increases the value of environmental vulnerability.

The material vulnerability map (figure 4, bottom left) underlines some specific spots of medium vulnerability mostly due to the location of artificial areas in the study area. In the inner grid, close to the industrial site two spots of high vulnerability are present.

From the comparison of the three maps (human, environmental and material) we can deduce that the spatial location of the most vulnerable zones is really similar for the human and the material targets. We can also point out that the spatial location of most vulnerable areas on the map of environmental vulnerability are opposite from those for human or material vulnerability maps.

From the three previous maps of vulnerability (human, environmental and material), the map of global vulnerability (figure 4, bottom right) can be deduced.

The global vulnerability is low for this study area. This map is clearly linked, even for the spots of higher vulnerability, to the map of human vulnerability which represents 75% of global vulnerability.

The values of vulnerability to physical effects (figure 5) are low for overpressure and thermal radiation, and medium for toxicity and pollution effects. Concerning the maps of vulnerability for overpressure, thermal radiation and toxicity, the location of the most vulnerable areas are linked to the human vulnerability. For pollution effect, the spots of vulnerability are linked to natural environment.

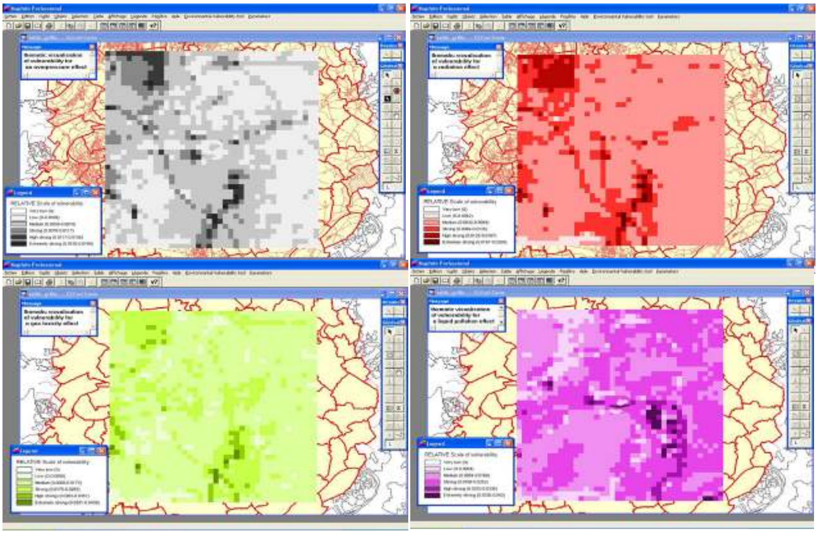

Figure 5: Maps of vulnerability for each physical effect (overpressure: top left; thermal radiation: top right; toxicity: bottom left; pollution: bottom right).

6 Conclusion

The vulnerability values obtained in the previous phases can be mapped, for each mesh, by associating to the calculated values of vulnerability a class of vulnerability represented with a characteristic color.

Three cartographic representations of vulnerability can be obtained:

- a global vulnerability in the study area;
- a vulnerability of a class of target (human, environmental or material);
- a vulnerability of a physical effect (overpressure, thermal radiation, toxicity and pollution).

The maps of the vulnerability layers relevant to each physical effect (Vop, Vtr, Vtox and Vpoll) should be then compared with the corresponding severity maps. These two representations (severity and vulnerability) provide the end users, (industrialists, risk analysts and/or the competent authorities), with a complete picture of the situation in the area surrounding the industrial site.

This information not only allows one to draw considerations on the risk of a specific industrial site in order to validate the level of safety, but also highlights dangerous situations, from a vulnerability or a severity point of view. Therefore, specific efforts can be made, in order to improve the level of safety of the industrial site

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