Evaluation of vulnerability to a technological hazard using the AHP method and GIS, case of fuel storage and distribution center, Hussein day Algiers, Algeria

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Abstract

In this study, we adopt a method to quantify the vulnerability to a technological hazard in case of fuel storage and distribution center Hussein day, Algiers. The applied methodology is based on multi-criteria analysis method to classify the targets in the study area and using GIS tools to the cartographic part, the results are presented in form of cartographic representation of the vulnerability of class of targets and different effects.

Keywords: Vulnerability, AHP method, GIS, maps, vulnerable targets, technological hazards, Algiers.

Introduction

A technological hazard is a hazard originating from technological or industrial conditions including accidents, dangerous procedures, infrastructure failures or specific human activities that may cause loss of life, injury, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Algeria faces the risk inherent to technological hazards, especially on the northern part of the country. The model of economic development in Algeria based on oil and industrialization has resulted in a concentration of many activities that carry risks near big cities. Currently there are more than 4000 industrial facilities in urban areas. In most situations, there is no distinction of clear limits between areas reserved for plants and complex high risk and those that remain public. Therefore, thoughtless promiscuity of industrial infrastructure with residential areas represents a potential threat to populations.

Algeria’s national disaster management and risk prevention strategy are based on law no. 04-20 of 25 December, 2004, on "the prevention of major risks and disaster management in the context of sustainable development". It aims at: improving knowledge of risks, strengthening their monitoring and forecasting; taking into account the risks in land use, in the construction and for reducing the vulnerability of people and property to hazards; and providing mechanisms to enable a coherent, integrated and adapted support to any natural or man-made disaster, about facility with high risk, the law requires the elaboration of an internal action plan (PII) ORSEC plan and a hazard study in order to identify their particular danger references. However, managing disasters in Algeria faces many problems like the differences between the discourse and the reality also, the incompatibility of the layout of industrial areas and the spatial planning schemes.

The risk is defined as the conjunction between hazard and vulnerability. For a long time, the study of hazard took precedence over vulnerability whether in researches or in risk management policies; the vulnerability component is often taken as a territorial response to hazard. But efficient risk management requires the assessment of the conjunctions of different parameters of hazard but also of territorial vulnerability, this work is part of this problem, we treat the vulnerability of an area to a technological hazard related to the fuel storage and distribution center, Hussein day Algiers, Algeria.

In this study, we used a multi-criteria method (AHP method) to classify targets present in the study area, then attribute weights to each of them (human targets, environmental targets, material targets) taking into consideration the effects generated by the hazard, then quantifying their vulnerability, final results are presented as vulnerability maps: global vulnerability map vulnerability of class of target maps, vulnerability to physical effects maps.

Study Area and data

The case of study is a fuel storage and distribution center, located in Hussein day, east of the capital Algiers (Figure1), it is the largest storage center (Naftal) in Algeria. It covers all capital needs in terms of hydrocarbons (ensures storage and distribution as its name indicates). With an area of 81357 m², its storage capacity is 86000 m³ of various petroleum products.

Given the quantity and type of products stored, it is considered as a high risk facility with three potential effects (thermal effects, toxic effects, and overpressure effects) with varying intensities, in case of an accident. The threat is materialised in PDAU (planning and urbanism plan) and EDD (hazard study) on hazard perimeter of 1.4k (figure 2) of which three thresholds are determined: Threshold of Significant Lethal Effects (SELS), Threshold for Lethal Effects (SEL) and Threshold of Irreversible Effects (SEI).

This impact area is our study area; we will identify and classify targets present in and evaluate their vulnerability.

Our study area touches 6 municipalities (Hussein day, El Magharia, Bach Djarah, Bourouba, El Harrach, El
Mohammadia); the data used are from different sources: the PDAU (Plan Directeur de l’Aménagement et de l’Urbanism), the land use plan POS N° 54 (plan d’occupation du sol) of the Hussein day municipality, updated Oued El Harrach regeneration project, census RGPH 2008 and the field work.

Figure 1: Localization of the case of study

Figure 2: Hazard perimeter map
Methodology

Concept vulnerability: Vulnerability is defined as the exposed elements susceptible to be affected. It is also defined as characteristic of spaces potentially exposed to a hazard; vulnerable territory is composed of targets with varying sensitivity and less or more exposed, and the place of potentially malfunction caused by the effects of a technological accident.

Exposure as a dimension of vulnerability largely depends on the land uses and the density of people, activities or buildings. Density is usually considered as one of the main gradients, especially when taking the spatial dimension into account and when looking for management resources: the more territories are densely occupied, the greater is the vulnerability. These definitions represent the conceptual framework of this study.

AHP method: The aim of this study is to manage into hierarchy different targets (with different nature) according to their degree of vulnerability, for that we needed to require to a multi-criteria method which is AHP method.

The Analytic Hierarchy Process (AHP) is a multi-criteria decision method that uses hierarchical structures through pairwise comparisons to present a problem and then develop priority scales based on judgments of experts, the decision maker is asked to which degree a criterion is more important than the other. By means of these comparisons, the method defines the relative position of one criterion in relation to all other criteria. By using an Eigen value matrix technique, this method was chosen according to parameters such as simplicity of use, the finesse of the assessment and flexibility.

To apply this method and generate priorities, we need to follow these steps:

1) Definition and decomposition of the problem.

2) Creation of the hierarchical structure, it gives us a structured view of the problem in terms of goals, criteria and sub-criteria.

3) Construction of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it, and a group of experts is asked to fill them.

Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below to add its weighed values and obtain its overall or global priority.

Application to the determination of the vulnerability index: The objective of this part is to identify targets of interest and classify them and attributes weights all taking in consideration the three potential effects (toxicity, thermal, overpressure), and finally evaluate their vulnerability, the hazard is taken with qualitative approach.

Ones all targets are identified, we first drew up a hierarchical structure (Figure 3) composed of goal which is global vulnerability and two ranks: one is the type of target (human, natural and material), and the lowest level of the hierarchy is composed of targets.

Then pairwise comparison matrices were established for each level of hierarchical structure, and for each potential effect (table 1), then submitted to a group of experts (7 experts in risk and the industrial risk: academics and researchers, civil security and prevention officers) to give their judgment using a scale based on classic numerical variables or more qualitative variables contributing to take into account qualitative aspects (table 2).

| Table 1 |
| Comparison matrix of vulnerability of human targets |
| Residential population | transit population |
| Residential population | 1 |
| Transit population | 1 |

A specific treatment was required to aggregate the appreciation of the above mentioned experts. Each appreciation was aggregated with the use of geometrical mean. Finally, Eigen vectors of the matrixes were calculated using PriEst software, solution corresponding to the priorities that determines the targets weighting; results are presented as vulnerability functions. To validate the coherence of expert judgments appreciation, a ratio of coherence (RC) was calculated. It must be lower than 10% to consider the results as coherent.

GIS for vulnerability mapping: After priorities assessment, it is necessary to materialize our work on maps and giving the vulnerability a spatial dimension, which is a very important component of vulnerability study, for that we need GIS. The GIS by these cartographic tools allows transforming a database into spatial information or map (Figure 4) (map processing and presentation).

First, we represented our area data in the form of the raw map for all targets. Each target, according to its nature, example of residential population data, was presented as density map (Figure 5).

Then the following steps have to be performed in order to do the map data processing:

1) Creation of the grid: makes grids allows us to divide the territory into standard spatial units which allows a better comparison and analysis of the phenomenon. In our study
area of 7 km$^2$ the most suitable layout is a grid of 517 meshes, with meshes of 270m.

2) Identifying and quantifying the detailed target types of the categories (human, environment and material) included in the mesh (presence of the target in the mesh).

**Table 2**

<table>
<thead>
<tr>
<th>Degree of importance</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal vulnerability of two element</td>
</tr>
<tr>
<td>3</td>
<td>Weak vulnerability of an element in comparison to the other one</td>
</tr>
<tr>
<td>5</td>
<td>Strong vulnerability of an element in comparison to the other one</td>
</tr>
<tr>
<td>7</td>
<td>Certified vulnerability of an element in comparison to the other one</td>
</tr>
<tr>
<td>9</td>
<td>Absolute vulnerability of an element in comparison to the other one</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values between two appreciation</td>
</tr>
<tr>
<td>$1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9$</td>
<td>Reciprocal values of the previous appreciation</td>
</tr>
</tbody>
</table>

**Figure 3**: Hierarchical structure for the global vulnerability
A quantification factor is defined as a dimensionless variable, assuming values in the range 0–1, where 0 indicates the absence of the target in the area and 1 indicates that the quantity of that target in the area reaches its expected maximum.

Therefore, the quantification factors aim at obtaining a normalized counting of each detailed type of targets whose Ni=Ai /Am ax.

where Ni is the quantification factor relevant to each of the-i-types of targets, Ai is the quantity of target in the mesh and Am ax is maximum quantity of the target- i- in a mesh.

Calculation of the vulnerability of each mesh is the application of vulnerability functions, weight assignment, for factors calculated using the tools in the GIS software.

Results and Discussion

Vulnerability functions: Functions of vulnerability are obtained for each level of the hierarchical structure for a representative example of the global vulnerability function shows a great importance to human vulnerability with a percentage of 65% followed by material vulnerability with a percentage of 25% of global vulnerability, last environmental vulnerability with a percentage of 9%.

V Global = 0.655 × V Human+ 0.095 × V Environmental + 0.250 × V Material

The rest of the functions are as follows:

V Global = V (toxicity) + V (thermal) + V (overpressure)
V (toxicity) = 0.661 × V Human (toxicity) + 0.235 × V Environmental (toxicity) + 0.104 × V Material (toxicity)
V (thermal) = 0.637 × V_iumo(overpressure) + 0.113 × V_Enni(overpressure) + 0.250 × V_Maer(overpressure) + 0.677 × V_Hum (thermal) + 0.171 × V_Enni(thermal) + 0.152 × M_3(thermal)

**Human vulnerability functions:**

\[ V_{\text{Hum}} = 0.352 \times V_H (\text{toxicity}) + 0.282 \times V_H (\text{overpressure}) + 0.365 \times V_H (\text{thermal}) \]

**Toxicity effect**

\[ V_H (\text{toxicity}) = 0.836 \times V_{\text{Resid-p0p}} + 0.164 \times V_{\text{Transit-p0p}} \]

**Overpressure effect**

\[ V_H (\text{overpressure}) = 0.831 \times V_{\text{Resid-p0p}} + 0.169 \times V_{\text{Transit-p0p}} \]

**Thermal effect**

\[ V_H (\text{thermal}) = 0.824 \times V_{\text{Resid-p0p}} + 0.176 \times V_{\text{Transit-p0p}} \]

**Environmental vulnerability functions:**

\[ V_{\text{Envi}} = 0.408 \times V_E (\text{toxicity}) + 0.127 \times V_E (\text{overpressure}) + 0.466 \times V_E (\text{thermal}) \]

**Toxicity effect**

\[ V_E (\text{toxicity}) = 0.206 \times V_{\text{park}} + 0.548 \times V_{\text{watercourse-sea}} + 0.103 \times V_{\text{urb-tree}} + 0.143 \times V_{\text{natural area}} \]

**Overpressure effect**

\[ V_E (\text{overpressure}) = 0.294 \times V_{\text{park}} + 0.162 \times V_{\text{watercourse-sea}} + 0.240 \times V_{\text{urb-tree}} + 0.304 \times V_{\text{natural area}} \]

**Thermal effect**

\[ V_E (\text{thermal}) = 0.354 \times V_{\text{park}} - 0.099 \times V_{\text{watercourse-sea}} + 0.182 \times V_{\text{urb-tree}} + 0.364 \times V_{\text{natural area}} \]

**Material vulnerability functions:**

\[ V_M = 0.118 \times V_M (\text{toxicity}) + 0.561 \times V_M (\text{overpressure}) + 0.321 \times V_M (\text{thermal}) \]

**Toxicity effect**

\[ V_M (\text{toxicity}) = 0.256 \times V_{\text{residential-ful}} + 0.256 \times V_{\text{economic-ful}} + 0.256 \times V_{\text{otheract-ful}} + 0.233 \times V_{\text{transport-infra}} \]

**Overpressure effect**

\[ V_M (\text{overpressure}) = 0.484 \times V_{\text{residential-ful}} + 0.094 \times V_{\text{otheract-ful}} + 0.686 \times V_{\text{transport-infra}} \]

**Thermal effect**

\[ V_M (\text{thermal}) = 0.547 \times V_{\text{residential-ful}} + 0.198 \times V_{\text{economic-ful}} + 0.164 \times V_{\text{otheract-ful}} + 0.092 \times V_{\text{transport-infra}} \]

**Presentation of vulnerability maps:** The vulnerability maps can be presented according to the class of targets on: human vulnerability map (Figure 6), environmental vulnerability map (Figure 7) and material vulnerability (Figure 8) it also can be presented according to physical effects on: toxicity map, thermal map, overpressure map (Figure 9).

\[ V\text{ global} = V (\text{toxicity}) + V (\text{thermal}) + V (\text{overpressure}) \]

**V**

Human vulnerability covers almost the entire study area, the map shows high human vulnerability values between 0.5 and 0.8 in the southern part of the area.

Regarding the environmental vulnerability, these values are average because of the urban character of land use. 0.1 to 0.3 as maximal values represent the grouping of some natural elements (oued, natural areas and sea) in the area.

The material vulnerability map is inverse to the environmental vulnerability map, with values varying between 0.1-0.3; the material vulnerability is concentrated in the central and southern part of the zone.

In the absolute, the results of this method represented as a global vulnerability map (Figure 10) indicate that the study area or territory is vulnerable in its entirety and in its majority of high vulnerability reaches high values (0.3 to 0.5), this can be explained by the urban characteristics of the area, it represents the eastern part of the metropolitan Algiers whose flagrant characteristics are: the high density of population, a high density of the built environment, grouping of equipment, consolidation of major infrastructure.

This work exposes the great risk present in this area not only because of the danger generated by the storage and distribution unit, but also because of the characteristics of the environment from which there are no consideration of the regulation or urban planning instrument instructions.

The results constitute a contribution to guide prevention and disasters, protection actions and to improve risk management and allow local actors to see this risk and the spaces that are most sensitive and that require intervention actions. It can be a reference if, in the future, the vulnerability component will be taken into account in development plans and management plans in general.
Figure 6: Map of human vulnerability

Figure 7: Map of environmental vulnerability
Figure 8: Map of material vulnerability

Figure 9: Map of the vulnerability to physical effects
Conclusion

The methodology proposed for vulnerability evaluation is based on a multi-criteria analysis method to classify and quantify the targets in the study area and completed with mapping work for spatialisation of vulnerability using mapping GIS tools by exploiting a database for all targets. The results show that the study area is strongly vulnerable; the spaces most vulnerable are those with the highest population density as human life is the most important target. These results offer also a simple and didactic representation, giving an overview for decision-makers to guide their strategic choices of action, especially in the case of an accident. Maps are then used to track the effectiveness of strategies implemented and finally form a very effective tool of communication on the inventory of fixtures.

This work is based only on a single vulnerability indicator which is the spatial density and targets distributions in the territory with a qualitative consideration of hazard; however, our study is still ongoing with the exploitation of other qualitative and quantitative indicators to enrich the work to have a more relevant analysis and a more accurate model of risk assessment.

References


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