Arc GIS application for managing of chemical risk and transportation routes of hazardous materials
"The Case of Medellin Metropolitan Area"

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ABSTRACT

The 90% of the State of Antioquia's industry is located in the Medellín metropolitan area (Colombia, South America), and 80% of the Antioquia's GDP is produced in the same region. Furthermore, a significant number of the Colombian chemical, textile and pharmaceutical industries are located in the Medellín metropolitan area. This phenomenon increases the number of accidents caused by handling and transportation of hazardous materials. With the aid of the ArcGIS software, its programming components, and a methodology for the risk assessment, several maps of chemical risk and transportation routes of hazardous materials were built. This study, novel within the Colombian context, assessed the chemical risk, natural threat, and vulnerability triggered by handling and transportation of hazardous materials. It is expected that the results of this study will guide the development and implementation of policies to prevent and mitigate the incidence and effects of accidents caused by handling and transportation of hazardous materials within the region.

About the author

Ricardo Smith is the Director of the Medellin Metropolitan-Area and professor at the National University of Colombia. He received his Master and PhD from the Colorado State University. Gustavo Londono and Julieta Gomez are both engineers who work at the environmental department, and were in charge of the project guidelines. MSc in Geoinformatics John Ballesteros is the GIS unit coordinator at the same institution; he is in charge of the maintenance of the application.

Keywords: *GIS, Rhombus Method, Hazardous Materials, Transportation of hazard materials.*

1. INTRODUCTION

There exists a possibility of occurrence of an emergency caused by handling or transportation of hazardous materials at the Aburrá Valley. This is mainly due to the fact that it concentrates the 90.4% of the industries and the 80% of the Antioquia's region GDP. Moreover, most of the chemicals, textile, and pharmaceutics factories of the whole country are located in this region.

To face this situation, 300 factories were selected and studied out of 600 factories considered by having processes in which chemical products are used. Also, they were characterized based on the degree of danger and the volume of the product they currently use. After that, a survey at the sites was carried out to identify the worst probable chemical event. Amongst them: chemicals dam brake, fire, explosion, toxic fumes, or spills. Using a mathematical model the radius of the affectation and the consequences to people, environment and infrastructure were calculated. Additionally, making use of the Rhombus Methodology (), environmental threat, vulnerability and chemical risk were assessed for those sites.

Based on the past and historic events El AREA METROPOLITANA, as the policy maker, designed and developed an application in ArcObjects and MS .NET. This application runs over ArcGIS 9.x and allows users to display maps of chemical risk and transportation routes. Furthermore, it is a way to model the consequences of a possible worst event in an industry.

In the second part of the paper it describes the used methodology for risk assessment. After that, the steps of the methodology are described. In number 4 the ArcGIS application is studied. Finally in chapter five (5), a group of conclusions of the application are mentioned.

2. RISK ASESSMENT METHODOLOGY

The methodology used for the chemical risk assessment either for handling or transportation, is based on the Rhombus Methodology [10]. This combines four different factors located inside a bigger rhombus. It also has been used for risk assessment in the case of natural threat events. Additionally, it was modified using Dow or Mond risk indicators, which are widely cited in the raw material transformation industries. According to that, these indicators are a simple way to estimate the global risk associated to a kind of process or activity, and also allows creating a hierarchy of the factors involved in a specific industry task.

The basis of the Rhombus Methodology is to assign a score to the tour internal rhombus. They represent at the same time a natural threat, the vulnerability of people, environment, and infrastructure. The combination of the whole four rhombus colors gives the risk (figure 1).

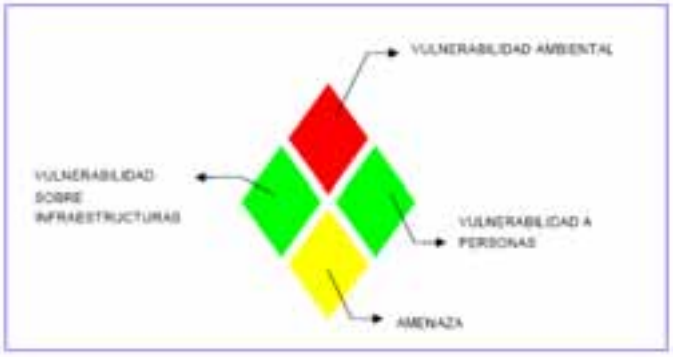

Figure 1. The four rhombuses for the risk assessment.

The calculation of the scores is as follows: low (green), medium (yellow), and high (red), figure 2 shows this convention.

Rhombus	Puntaje	Color
Threat, Vulnerability to People, Environment, and Infrastructure	< 30	
	30 – 70	
	> 70	

Figure 2. Scores for the risk assessment.

The risk is commonly obtained by the multiplication between threat and vulnerability, this equation is represented here using the bigger rhombus, and the factors are the smaller rhombus of the figure 3. The risk is calculated using the combination of the rhombus colors.

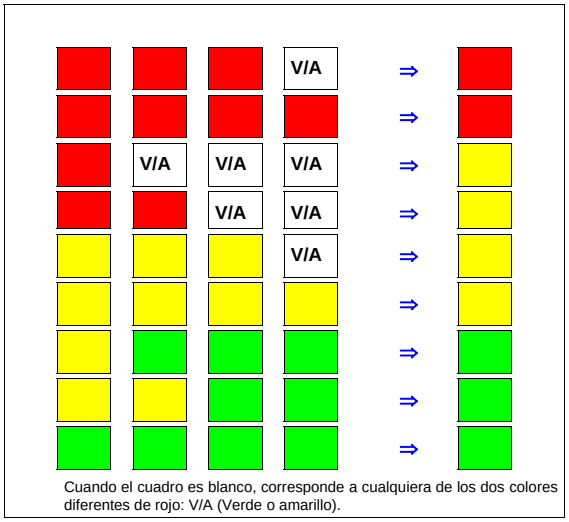

Figure 3. Combination of colors in the rhombus for the risk assessment.

The chemical risk assessment is performed for the 300 different industries and their routes. The industries and routes taken into account are based on the use of chemical materials that comply with any of the following characteristics: corrosive, reactive, explosive, toxic, infectious, volatile, or flammable (CRETIVF) [3]. The Rhombus Methodology performs and evaluation of the risk associated to the worst case event. The internal rhombus corresponds to a natural threat, and the vulnerability to people, environment, and infrastructure.

3. CARRYING OUT THE METHODOLOGY STEPS

This methodology has nine steps, these are:

Step 1: Selection of the industries. A search of industries in which chemical products are used was performed mainly in governmental trade databases, and offices for industry and commerce of the city. The selected industries were visited and collection of information on the site was performed. The worst possible event was described based on variables like pressure, temperature, chemicals, and amount or volume of chemicals. Information about routes for hazardous materials was also gathered.

Step 2: Industry Identification. A classification of the 300 industries was performed as follows: chemical producers, distributors, pharmaceuticals, cleaning, dying and paint, textile, food, cosmetics, transportation, plastics, gas e petroleum).

Step 3. Inventory of chemical products. An inventory of the type of products and their quantities was carried out.

Step 4. Industry characteristics. An evaluation of the operational characteristics and risk-free methods to handle and transport chemical products was performed.

Step 5. Identification of the possible events. Based on the information gathered on the visit, a scenario of the worst chemical risk case was described. The selection of this scenario depends upon the conditions of operation, such as: temperature and pressure, chemical product volume, and storage. There are different kina of scenarios for the worst case event, the most common are:

- Spills, chemical dam breaks, leaks.
- Fire of flammable materials, toxic fumes.
- Exploitation of pressurized containers.

Step 6. Modeling of consequences. This allows find corridors of affectation given by the "worst case", this is the maximum distance in which people, environment, or infrastructure can suffer any severe damage (figure 4). These corridors may be affected by a thermal radiation of a fire, concentration of a toxic fume and the influence of a biological infectious, corrosive, volatile or radioactive product.

Step 7. Risk assessment. It is carried out based on the use of the rhombus. This also has into account the frequency of the similar events and the risk free procedures to avoid the occurrence of accidents.

Step 8. Threat assessment. It corresponds to the calculation of the probability of occurrence of the worst event associated to a technological phenomenon. This phenomenon may happen in a specific place and time with the possibility to cause damage to people, environment, or infrastructure. Technically speaking, it is the probability that an undesired event, capable of causing damage, takes place.
The methodology to calculate the threat considers the following factors: type of products, type of operation and external natural threats (floods, landslides, earthquakes, and aerial accidents).

Step 9. Analysis of vulnerability. This is related to the quantification of exposed people within an area which probability is 50% of fatality (for thermal radiation, and toxic fumes). The rest of the events (explosion, and fire) were considered under the parameters of "Las Guías para el análisis cuantitativo de riesgos para procesos químicos" [2]. The environmental vulnerability analysis was based on the affectation to the found ecosystems in the local region, the current land use of the affected soil, or the damaged water bodies. In case of spills an intersection of a linear corridor with the water bodies is performed. The vulnerability analysis of the infrastructure was calculated based on the type of infrastructure in the area and its cost. The order of importance of the infrastructure is considered to be: security and first aids, health, transportation, education, cultural, religion and recreational.

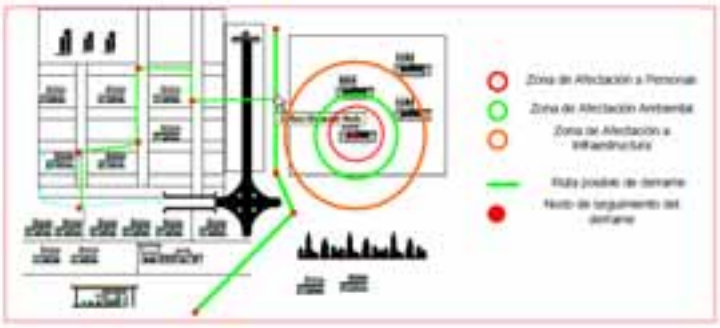

Figure 5. Determination of affected corridors.

4. THE ESRI BASED APPLICATION

A GIS application based on the Rhombus Methodology for risk assessment was designed and programmed. This application runs over the ESRI's ArcGIS 9.1 platform. Due to that, it can benefit from editing and spatial analysis tools. The required functionalities for the application were developed in Microsoft .NET. The database manager system is Oracle 9i.

Figure 5. Interface for the GIS application.

The scale used for the Project was 1:2000 and the geographical extent was the whole jurisdiction of the Medellin Metropolitan Area (10 municipalities).

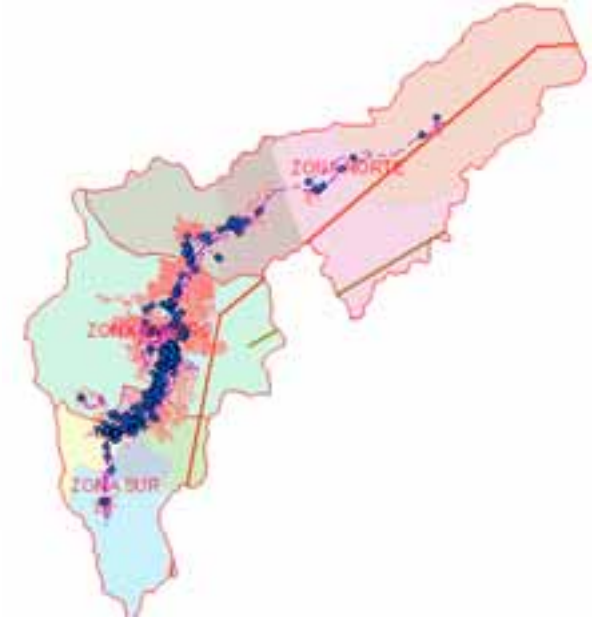

Figure 6. Geographical extent for the application.

The GIS application allows the user to execute the following tasks, not only for the industries, but for the hazardous transportation routes.

- Creation, updating and edition of information: It is the calculation of the Rhombus through the chemical risk for each individual industry.
- Storage of information: A Personal Geodatabase was integrated to the Multiuser Corporate Geodatabase of the Area Metropolitana del Valle de Aburrá. This application interfaces with ARECNAVA as a main environmental information system of the institution.
- Management of risks and presentation of reports: The application allows identifying the main transportation routes. Furthermore, it is useful for the risk assessment in any part of those routes. The major environmental, infrastructure and population potential consequences are measured respect to the occurrence of an emergency.

The available queries are:

- Type of event: the user may choose an specific chemical event, and see in which industries they may happen, what chemical products are involved and their characteristics. Moreover, circular buffers for the affectation to infrastructure, people and environment are showed. Figure 7 shows a map and the query interface for a specific event.

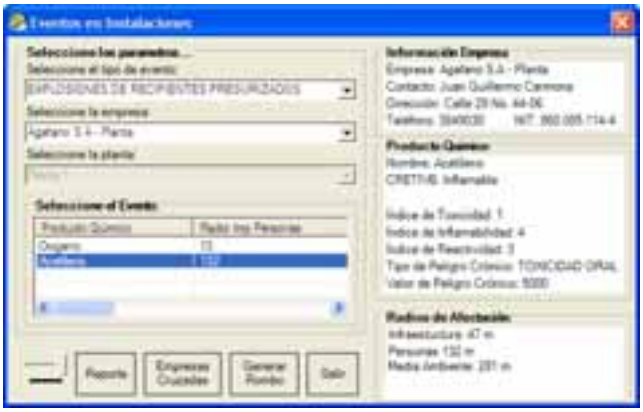

Figure 7. Query by type of event.

- Query by industry: this is the inverse of the previous Query. The user can search an industry of his/her interest; find the worst events and its hazardous chemical materials. Figure 8 shows an example of this query.

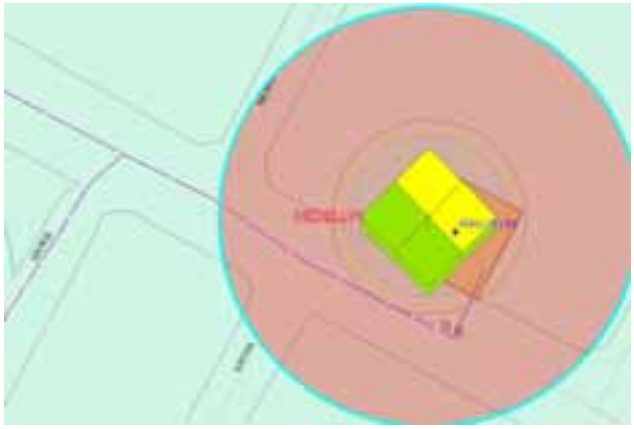

Figure 8. Query by industry.

- Events simulation: The GIS application allows users to simulate an event; this can have the characteristics of the user defined event in the user defined location. Figure 9 illustrates this.

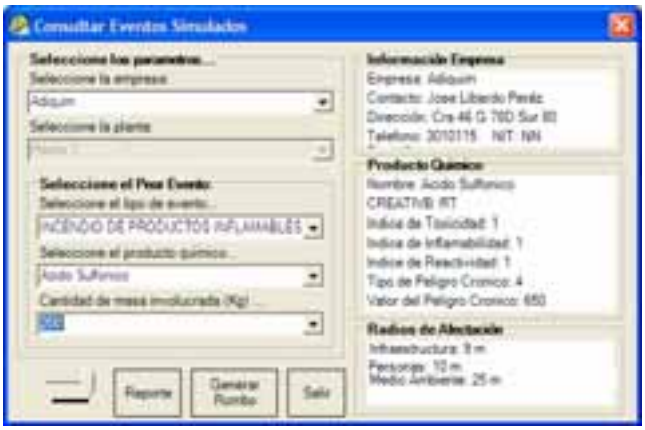

Figure 9. Events simulation.

- Query of chemical products: if an user does not know the characteristics of an specific product, he/she may open the Orange Book and find the product of interest. See figure 10.

Figure 10. Query by chemical product.

- Rhombus and radius calculation, edition and new industry entry: The application counts on the use of several tools for calculation of rhombus and radius, data storing and entrance, and edition. Figure 11 shows an example of those tools.

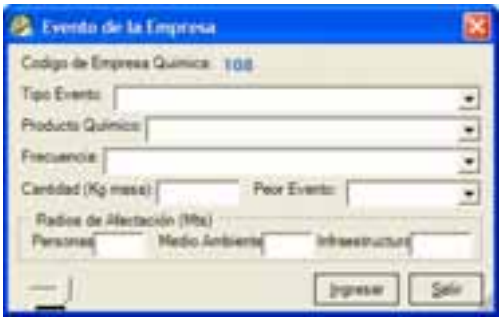

Figure 11. Some edition, calculation, and new information entry tools.

- Creation and visualization transportation routes information: The application allows users to create, assign and visualize hazardous materials transportation routes. Figure 12 shows a menu to do that.

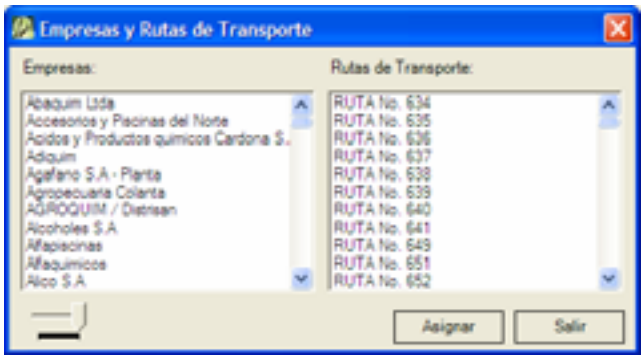

Figure 12. Some creation and visualization of hazardous material transportation routes.

5 CONCLUSIONS

- A GIS application for chemical risk assessment was designed and built based on the Rhombus Method. The use of this application allows Area Metropolitana del Valle de Aburrá to quantify the different factors involved in the determination of the chemical risk. Furthermore, this is a key factor for the institution to observe policy fulfillment and environmental management systems by industries in the region.

- With the use of this application an assessment of some geographical factors like natural threats can be performed in an automatically way. This also serves as a geographical interface for other information systems at the Area Metropolitana.

- The application of the Rhombus methodology within a GIS is composed of several successive steps. These are summarized in site information collection, data entry, design and development f the geodatabase, GIS programming using mathematical and logical procedures, and risk calculation using rhombus.

- A distribution and classification of industries was performed using the application and in agreement with the level of risk: high (0%), medium (11%), and low (89%). The level of threat is low (79%), only the 21 % is medium. There is no any industry located in a level of high natural threat. 57% of industries are located in a medium level of threat.

- 1.4% of industries show a high environmental vulnerability. The rest of them are in a low level vulnerability. Industries located in high populated zones such as Caldas, Sabaneta y La Estrella, are classified as high vulnerability to people. There are a 17% of the industries with a high level of vulnerability to people.

- Chlorine and hydrosulfide are products that exhibit the highest level of danger.

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