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A national hazard analysis and mapping for seveso establishments

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Abstract. On 23 February 2009, the European Commission adopted a Communication on a Community approach on the prevention of natural and man-made disasters setting out an overall disaster prevention framework and proposing measures to minimize the impacts of disasters. All EU Member States were asked to develop national approaches and procedures to risk management including risk analyses, covering the potential major natural and man-made disasters, taking into account the future impact of climate change. Based on the European Commission guidelines, Romania is currently developing a national approach to risk assessment by taking into account nine major risk categories: floods, droughts, forest fires, earthquakes, mass displacement, Seveso industrial accidents, transport accidents involving hazardous materials, nuclear accidents, and epidemics/zoonoses. This paper will address the difficulties of hazard analyses and technological hazard mapping on a local, regional and national scale for all Seveso establishments. By using REHRA (Rapid Environment and Health Risk Assessment) as the basis for hazard analysis, all Seveso sites will receive a hazard index. By undergoing analysis for major physical effects, each site will go through a worst case scenario simulation of a major technological accident using modeling software. Using G.I.S. software, all spatial data collected from these establishments will be transferred to a WebGIS database. All spatial data will be expressed in a unitary standard according to the INSPIRE Directive which regulates natural risk zones. The resulting technological hazard map will be overlapped to the other hazard maps, thus creating a national hazard map and a starting point for the further national risk assessment.

Keywords: technological hazard, hazard maps, Seveso, REHRA, INSPIRE.

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1. Introduction

Following the European Commission guidelines, Romania is currently developing a national risk assessment for nine major risk categories (EC COMM, 2012). One of those categories, industrial accidents, falls under the Seveso III directive controlling major accident hazards involving hazardous substances (Directive 2012/18/EU). One of the national risk assessments main objectives consists of mapping all areas exposed to natural and man-made hazards, based on a multi-hazard approach (EC COMM, 2012). Hazard mapping will play a vital role in the further development of risk-maps.

This paper will describe a method of mapping technological hazards identified at Seveso establishment source points. Keeping the brooder objectives of the national risk assessment in mind, all hazard maps must retain a similar format so they can be properly overlapped in the process of creating an overall national hazard map. As most of the nine major risk scenarios are of natural origin, the INSPIRE directive which regulates natural risk zones, was chosen as the format source for all spatial data regarding hazard maps. The first problem arises from this unitary approach since, by definition, natural hazards and technological hazards are two different concepts. "*Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration and area of extent*" (EC COMM, 2012). More so, all natural hazards can be assessed by their probability of occurrence. As for technological hazards, the probability of occurrence indicates a risk specific variable while other characterization criteria do not apply. This problem is further highlighted in the definition of hazard maps: *"maps that portray levels of probability of a hazard occurring across a geographical area"* (EC COMM, 2012). Still, in keeping true to the INSPIRE directive guidelines, all hazards must be mapped according to their probability of occurrence and magnitude. For this purpose, a consequence based approach to technological hazard mapping was created, blending major physical effects with hazard indices.

2. Hazard mapping and hazard index methodology

2.1. Technological hazard maps

Based on the general theory of hazards (Ericcson, 2005), the resulting maps should address the following issues:

- The "threat element" or "threat source"
- The "initiating mechanism" or "main event"
- The "target" or "vulnerability"

As stated in the previous chapter, pure technological hazard maps do not serve the same purposes as their natural counterparts. Only to risk-maps can we attribute a probability of occurrence thus using a quantitative approach as suggested in the EC guidelines (EC COMM, 2012). Most risk-maps, in the Seveso context, serve a Land-use planning (LUP) purpose. Art. 13 of Seveso III requires all Member States to implement LUP criteria in their transposed legislative version. LUP criteria are used to establish appropriate separation distances, between hazardous installations and vulnerable residential areas, for mitigating the effects of industrial accidents and subsequently limiting consequences of such accidents (Christou et al., 2010). Although the European Work Group coordinated by the European Commission's Joint Research Center (JRC) has developed guidelines for a generalized approach to LUP, most Member States use different procedures in deducting safety distances. This diversity seen in LUP decision planning can be attributed to different legislative, cultural, historical and administrative backgrounds specific to each Member State (Christou et al., 2010). Nevertheless the existing methodologies can be divided into four categories:

a) Deterministic approaches with implicit judgment of risk;
b) Consequence-based approaches;
c) Risk-based (probabilistic) approaches;
d) Semi-quantitative approaches.

Romania, and Germany amongst others, use a somewhat similar deterministic approach based on predetermined separation distances. The distances are derived from typical accident scenarios and vary in size according to the type of hazardous substances contained in the Seveso site (Christou et al., 2010). The deterministic method could not be used in the current study based on the fact that accident scenarios with a low occurrence frequency are overlooked in this approach. As for a national hazard map stand point, all scenarios must be taken into consideration with regard to their probability of occurrence. Keeping in mind the necessity to attach magnitude and probability to our technological hazard map in such a way as to distinguish it from risk-maps, a hybrid approach was chosen between a consequence-based physical effects map and a hazard index. After the 2001 Toulouse disaster, France changed their policy regarding LUP risk analysis from a manly deterministic approach to a more consequence-based one (Christou et al., 2010). After the accident, LUP in France accepts worst-case scenarios as reference scenarios, also implementing the concept of consequence-based buffer-zones. Thus, for the purpose of this paper, selecting France's LUP method would fit most of our hazard mapping criteria. A more detail description on the French LUP method can be consulted elsewhere (Conzzani et al., 2006).

By using a physical effects map we attribute a quantifiable magnitude to our scenarios. Based on a worse-case scenario approach, this method does not explicitly quantify the likelihood of the accident, only the frequency of occurrence and the related uncertainty (Pasman and Renires, 2013). For starters, all worst-case scenarios will be mapped out regardless of their frequency of occurrence. The three major accident scenarios (fire, explosion, toxic dispersion) will be taken into account at any given Seveso establishment. A color scheme will be attributed to each of the three major scenarios accordingly:

- Yellow for toxic dispersion
- Red for fire
- Blue for explosion

The resulting map will contain a maximum of three concentric areas defined by each of the three major accident scenarios. The surface areas will be defined by the extent of threshold values, described by the French LUP, specific to each physical effect accordingly (Török and Ozunu 2010):

- Concentration threshold value for toxic dispersions – IDLH (Immediately Dangerous for Life and Health), substance specific
- Fire induced effects (Török et al., 2011):

a) Effects of stationary heat radiation threshold value – 3 kW/m^{2*}

b) Effects of heat radiation threshold value, variable in time – 200 KJ/m^{2*}

- Overpressure for explosions – 70 mbar

* **-** all threshold values are chosen to represent the beginning of **irreversible effects** on humans

2.2. Hazard index methodology

As stated in the previous chapters, in order to address the problem of linking magnitude to technological hazards a different approach is needed from the one used in natural hazards. Thus, a hazard index methodology derived from the REHRA project (Environment and Health Rapid Risk Assessment in Secondary Rivers of the Mean and Lower Danube Basin) was chosen after successful implementation efforts were carried out for Seveso establishments in three countries. A more detailed description of the methodology could be studied elsewhere (Frattini and Manning, 2002). For mapping purposes, calculating the overall Installation Hazard Index (IHI) will suffice.

$$\mathrm{IHI} = \sqrt{\left[\frac{(\mathrm{IGI} + \mathrm{NHI})*10}{12}\right] * \mathrm{IDSI}} \qquad (1)$$

IGI – installation general index
NHI – natural hazard index
IDSI – installation dangerous substance index
12 – maximum sum value between NHI and IGI
10 – normalization value
IHI values range from 0 to 10

$$\mathrm{IGI} = \sqrt{\mathrm{ITF} * \mathrm{EOF}} \qquad (2)$$

ITF – installation technological factor
EOF – establishment organizer factor
IGI values range from 0.84 to 10

$$\mathrm{ITF} = \mathrm{ITPF}*\mathrm{ISCF} \qquad (3)$$

ITPF – installation technological process factor
ISCF – Installation safety compensatory factor
ITF values range from 1 to 10
ISCF values range from 0.7 to 1

$$ITPF = \frac{\sum Ei}{\sum \max(Ei)} \cdot 10 \quad (4)$$

Ei – numerical value attributed to each technological or process element
ITPF values range from 1 to 10

$$EOF = \frac{\sum Oi}{\sum \max(Oi)} \cdot 10 \quad (5)$$

Oi – numerical value attributed to each element
EOF values range from 1 to 10

$$NHI = \sum_{i=1}^{5} Ni \quad (6)$$

Ni – natural indices
NHI values range from 0 to 2

$$IDSF = \sum_{i=1}^{n} \frac{qi}{Qi} \quad (7)$$

qi – hazardous substance quantity present on the Seveso establishment
Qi – threshold substance quantity as described by Seveso III directive
$0 < IDSF \leq 1000$; $IDSI = (IDSF)^{1/3}$
$IDSF > 1000$; $IDSI = 10$
Equations 1 to 7 show the basic steps of reaching a numerical value for the Installation Hazard Index (IHI) necessary in quantifying a Seveso establishment's technological hazard.

Table 1. **Installation hazard magnitude according to IHI value** (Frattini and Manning, 2002)

IHI Value	Installation Hazard Magnitude
$0 \leq IHI \leq 1.6$	Low
$1.6 \leq IHI \leq 3.6$	Moderate
$3.6 \leq IHI \leq 6.4$	High
$6.4 \leq IHI \leq 10$	Very High

As seen in table 1, hazards may range between 0 and 10 based on their magnitude. Using this hazard index combined with the physical effects map we can establish a color range. Therefore, low IHI values will be plotted with a light toned color while high IHI values will be plotted with darker tones of the same color, all while utilizing the three base colors described in chapter 2.1.

3. Case study. Liquefied chlorine toxic dispersion

3.1. General description

For the case study, a chlorine bottling and storage facility was selected. The establishment is situated in the town of Turda, Romania at 330 meters above sea level. Our focal point is based on one of the two horizontal cylindrical tanks used for storing liquefied chlorine. At any given moment, only one of the two tanks can be filled, for safety reasons, at a maximum capacity of 50 tones (Török and Ozunu, 2010). Chlorine, at ambient pressure, is a dens yellow-green gas identifiable by its unpleasant suffocating odor. It is used in the chemical industry bough in organic and inorganic syntheses, valued for its high reactivity, as a strong oxidizing and chlorination agent (Török and Ozunu, 2010). According to the REACH Regulation 1272/2008/EC, chlorine toxicological hazards include:

- Fatal if inhaled
- Causes serious eye irritation
- May cause respiratory irritation
- Causes skin irritation

As discussed in chapter 2.1, IDLH is used as threshold concentration value. For chlorine IDLH is equal to 10 ppm, for 30 minute exposure (Török and Ozunu, 2010).

3.2. Hazard index

To determine IHI, equations (7) to (1) must be applied in this order. A detailed technical description of the chlorine storage tank, including all the necessary data required for calculating IHI, can be found elsewhere (Török, 2005). Because our study is focused on one the storage tank, IDSF will require quantities specific to chlorine, qi = 50 tones, Qi = 25 tones (Directive 2012/18/EU) for a value of IDSF = 2, which corresponds to IDSI = $(IDSF)^{1/3}$ as shown in equation 7. Based on the information collected so far we can determine IDSI = 0.67. NHI is based on five different natural hazards that can potential affect the installation. The establishment in question is not exposed to any natural hazard thus NHI = 0. EOF is based on five organizer elements: O_1 - safety training, O_2 - emergency plan, O_3 - maintenance, O_4 - inspections on critical equipment, O_5 - environment and safety system. The scores for these factors are expressed accordingly: $O_1 = 1$; $O_2 = 5$; $O_3 = 1$; $O_4 = 1$; $O_5 = 5$, for a total EOF = 2.6. ITPF is based on seven elements. E_1 – installation age, 35 years, value over 30 years for $E_1 = 10$. E_2 – last revamping, done 6 years ago, sits between 5 and 10 years for $E_2 = 5$. E_3 – process control system, the installation displays a low technological level for $E_3 = 10$. E_4 – type of operation, batch cycle, for $E_4 = 10$. E_5 – operating conditions, is based on four sub elements as following: $E_{5.1}$ – high pressure operating conditions, 16 bar, sits between 0 and 20 bar, for $E_{5.1} = 1$. $E_{5.2}$ – low pressure operating conditions, under 1 bar, for $E_{5.2} = 5$. $E_{5.3}$ - high temperature operating conditions, 20°C, sits between 0°C and 21 °C, for $E_{5.3} = 1$. $E_{5.4}$ – low temperature operating conditions, between – 29 °C and 0 °C, $E_{5.4}$ = 1. Because E_{5Base} = 8, sits between 8 and 20, E_5 = 1. E_6 – reactions, no reactions, for E_6 = 1. E_7 - loading and unloading operations, about 100, sits between 50 and 300, for E_7 = 5. Based on the calculations up to this point we can deduct ITPF = 6. ISCF is based on five elements. S_1 – vapor and gas detectors, available for critical equipment, for S_1 = 1. S_2 – liquid retention systems, collecting at least 30% of hazardous liquid, for S_2 = 5. S_3 – isolation systems, no isolation system available, for S_3 = 10. S_4 – emergency discharge systems, some emergency evacuation valves are connected to emergency receiving circuits, for S_4 = 5. S_5 – firefighting systems, hydrants, for S_5 = 5. $ISCF_{Base}$ = 26, sits between 15 and 30, for ISCF = 0.85. From ITPF and ISCF we can deduce ITF = 5.1. From ITF and EOF we can deduce IGI = 3.64. By calculating all indices so far we can determine IHI = 1.16. According to table 1, the chlorine storage tank presents a low technological hazard.

3.3. Scenario modeling and simulation

Using modeling software, Effects 10, we are able to simulate a toxic dispersion scenario. As discussed in chapter 2.1, a worse-case scenario approach is used. The logical progression of modeling is described accordingly:

- Liquefied gas instantaneous release
- Pool evaporation
- Dens gas dispersion: concentration

Taking into account the entire mass of chlorine, an instantaneous release will result in a 60 m^2 pool spread in bounds. About 43 tones of liquid chlorine is contained in the newly form pool. One hour is considered as the time interval in which evaporation takes place. For a worse-case scenario toxic dispersion to take place, an F (very stable) stability class is chosen. Meteorological data is described as follows: wind speed – 2 m/s; ambient relative humidity – 50%; solar heat flux – 0.65 kW/m^2; cloud coverage – 0%. The wind direction, although irrelevant to our hazard map, blows from WNW.

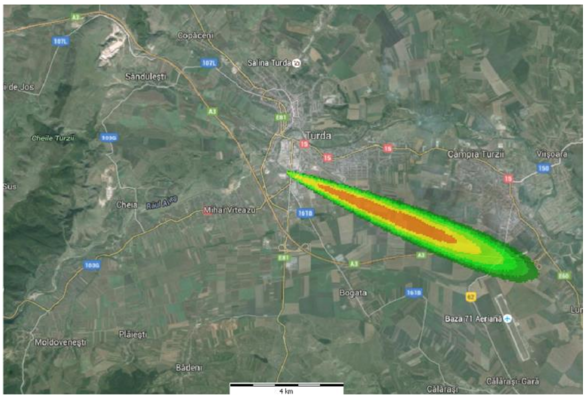

Fig. 1. Toxic chlorine cloud, IDLH (orange).

Fig. 1 shows the formation of the toxic cloud, while the color scheme indicates the extent of the threshold concentration. The software calculates the maximum reach for the threshold concentration IDLH = 10 ppm, depicted by an orange color, at 6970 m from the release point.

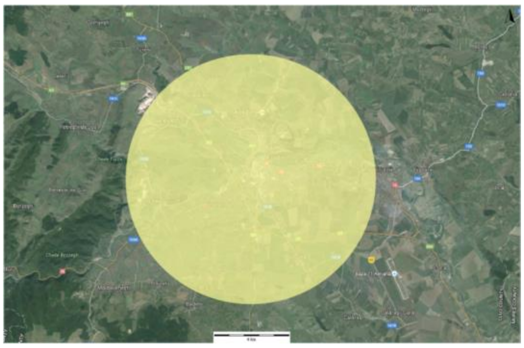

Fig. 2. Technological hazard map.

Fig. 2 shows the resulting technological hazard map generated. A circular area 6970 m in radius over the release point is depicted while the light yellow color tone indicates a toxic dispersion originating from a low hazard Seveso establishment.

4. Results and discussions

For the chlorine tank presented in the case study, the low value of IHI reflects the simplicity of the installation. A low IDSI value is due to the presence of only one hazardous substance, chlorine, while other more complex installation may contain several such substances. NHI also plays a vital part in this case lowering the overall IHI value due to the lack of natural hazards that may affect the establishment. EOF is also somewhat low as chlorine related activities demand a highly organized approach regarding health and safety regulations. Although the ITPF value is just above average, more complex processes operating on a wider range of condition may also elevate this index. Overall the chlorine storage tank represents a low technological hazard. The IHI index from REHRA was successfully implemented in 3 countries across the Danube basin. It was designed to be easy to use based on the fact that some establishments may contain more then 50 hazardous substances in several different installations requiring a large volume of time spent on gathering data and calculating indices.

The resulting hazard map depicts a 38.46 km^2 area potentially exposed to 10 ppm (IDLH) of toxic chlorine. Humans exposed to such concentrations over an hour may exhibit the following symptoms: apnea, eye tearing, eye irritation, respiratory track irritation, coughing (Török, 2005). It is essential to understand that a worse-case scenario, like the one presented in this paper, although highly unlikely is still possible. Identifying worse-case scenarios can prove to be difficult especially when choosing a stability class. Fast evaporation rates depend on higher heat flux values from solar radiation. Wind also plays an important role. On one hand, higher wind speeds help disperse toxic clouds more efficiently over greater distances, and they can also help with faster evaporation rates. On the other hand, higher wind speeds can dilute cloud concentrations lowering the risk of exposure to threshold concentrations. Using such hazard maps may prove to be an effective tool in identifying different types of technological hazards based on their color scheme. As for helping authorities in the process of decision making, an easy to understand map such as this one ca be an important tool. By observing this map, three aspects can be identified. Yellow indicates a toxic dispersion. A light transparent coloring theme indicates a low hazard index. The size of the circle suggests the possibility of a large exposed area. Thus, only the size of the area may need addressing. If in such cases a further risk assessment is conducted resulting in the need to reduce the effects generated by the toxic dispersion, one simple solution could arise by changing the way chlorine is stored from one big tank, to several smaller ones. In this case, hazard areas would be drastically reduced.

5. Conclusions

Hazardous substances utilized in the process industry pose a vast array of threats to human health. For the purpose of nation wide unified hazard maps, using a hybrid between a consequence-based effects map and a technological hazard index may be the way to go. The hazard installation index is based on an easy to utilize methodology that has been proven to be effective in past situations. LUP methods may help in future developments of technological hazard maps as long as specific threshold values are implemented. It is important to correctly assess all necessary data in the hopes of identifying the worse-case scenario. Maps, such as the one presented in this paper, may represent important tools for identifying Seveso establishments in need of a more detailed risk assessment. Based on the framework implemented in this paper, an effective starting point may be drawn for future national risk-maps.

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