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Differences in the risk profiles and risk perception of flammable liquid hazards in San Luis Potosi, Mexico

Claudia Yazmín Ortega Montoya *, Alfredo Ávila Galarza, Roberto Briones Gallardo, Israel Razo Soto, Ricardo Medina Cerda

Facultad de Ingeniería, Universidad Autónoma de San Luis Potosí, Av. Manuel Nava #8, Zona Universitaria 78290, San Luis Potosí, S.L.P., Mexico

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ABSTRACT

The pace of urbanization and industrialization in developing countries is rapidly increasing. Unfortunately, regulatory and private-sector control of hazards has not always kept pace. This work identifies the level of emergency preparedness in chemical industries and evaluates the spatial distribution of hazards using a worst-case release scenario. Consequently, we identified potentially exposed urban communities and evaluated the social perception of a hazard. This research characterizes risk scenarios in a case study of the industrial area in San Luis Potosi, Mexico. Intervention zones of major concern are recognized when deficiencies in emergency preparedness join a poor social perception of hazards in communities that are potentially exposed. The worst-case scenario radii of flammable chemicals range from 425 m to 733 m. Potentially exposed communities have a limited perception of chemical risk and no training in emergency response. Proximity to an industrial area influences communities towards a better recognition of hazards. However, communities far from the industrial area have higher exposure to low preparedness worst-case scenarios for flammable chemicals and have a larger level of vulnerability because of their lack of risk perception.

Introduction

The use and storage of hazardous materials in the industrial sector represents a threat from the occurrence of major chemical hazards, which include fire, explosions, and release of toxic substances with negative consequences to human health and the environment. A chemical hazard becomes a risk whenever a potentially exposed human system is present. In this situation, the characteristics of the hazards and the system define the degree of danger, exposure, and vulnerability.

Major accidents in developing countries that involved hazardous materials have shown that vulnerability can magnify the severity of chemical accidents, depending on the organizational level, the emergency response agencies and the level of social perception and preparedness. Vulnerability is determined by physical, social, economic, and environmental factors. Therefore, vulnerability increases the susceptibility of a community to the impact of hazards [1]. Risk perception and the willingness to adapt play an important role in adaptive risk strategy implementation [2]. The social risk level is related to community development and its capability to modify risk factors [3]. It is notable that three of the most serious major

* Corresponding author. Tel.: +52 (444) 826 23 30x3010.
E-mail addresses: yazminortegam@gmail.com (C.Y. Ortega Montoya), galarza@uaslp.mx (A. Ávila Galarza), briones@uaslp.mx (R. Briones Gallardo), israel.razo@uaslp.mx (I. Razo Soto), medinari@uaslp.mx (R. Medina Cerda).

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chemical accidents, in terms of the number of fatalities, occurred in marginalized communities of Mexico, Brazil and India, all in 1984 [4].

This paper focuses on a flammable liquids hazard assessment, taking into consideration that fire accidents are one of the most common and serious threats to public safety and have an accelerating rate in developing countries [5].

Risk assessment

Flammable liquids hazard assessment

The storage of combustible liquids in the industrial sector is potentially hazardous because they can be ignited under almost all ambient temperature conditions; these flammable liquids can also produce a hazardous atmosphere [6].

The consequence-based approach consists of evaluating accidents, calculating the distance to which the physical and/or human health impacts reach for a given exposure period, and establishing a threshold value [7]. The worst-case scenario is used as a reference in this approach; criticisms of this approach focus on the ignorance of the accident frequency [8].

This research is based on the worst-case analysis described in the US EPA's Risk Management Program Guidance for Offsite Consequence Analysis. According to this guide, the worst-case scenario for combustible liquids is a vapor cloud explosion, and the consequences are set using the TNT equivalence method [9]. It is the simplest and most widely used method for modeling vapor cloud explosions [10] and tends to be better for estimating widespread damage [11].

Land-use planning and vulnerability in risk assessment

The objective of land-use planning is the protection of the community from severe outcomes by setting minimum safety distances [12]. There are different approaches and criteria for the establishment of these safety distances, such as: generic separation and consequence-based and risk-based approaches [13–16].

A key in land-use planning is the identification of threat intensity areas for potential accidents and the level of vulnerability of nearby areas [7]. In his work, Johansson based land-use planning decisions on an assessment of benefits, costs, and consequences; these assessments were categorized in three broad areas: environment, social, and risk factors [17]. Salvi and Debray's, risk assessment was performed by considering a scenario's severity as well as the vulnerability of the surroundings [18], while Cutter et al. [19] suggested that the overlap of hazard zones and social vulnerability produces a spatial variation in overall vulnerability of the community. Social vulnerability analysis can be based on expert judgment, hierarchical structures [20], multi-criterial analysis [16] and census block statistics [19]. It is important to mention that a vulnerability assessment can be useful to prepare emergency procedures, as well as preparing risk communication materials for potential health risks [21].

An important variable in vulnerability is the social perception of risk because perceptions of risk and risk-related behaviors may amplify the social, political, and economic impacts of disasters well beyond their direct consequences [22]. Risk perception is a social construct and is culturally determined [23]; the result of the social and behavioral context in which risk is experienced and described [24].

Materials and methods

Hazard characterization

This study classifies chemical hazard internal controls by identifying the degree of fulfillment of the security aspects, followed by the international regulation of hazardous materials locations. The data used in this legislation to classify the level of risk include: accident history, potential threat to public receptors, and effectiveness of emergency response programs and risk management systems.

Deficiencies in developing countries regarding industrial regulations put every industry in a certain level of threat due to their internal hazard management. This threat can be quantified through the level of emergency preparedness, which was constructed as shown in Table 1 in this paper.

Potential exposure assessment

Potential exposure assessment is evaluated using the US EPA's Risk Management Program Guidance for Offsite Consequence Analysis following the worst-case methodology for a flammable substance [9].

The radii obtained are applied to construct circular buffers around the industrial location. Subsequently, the obtained buffer is linked to the emergency preparedness level.

Table 1
Emergency preparedness classification.

Data	Level of emergency preparedness		
	High	Medium	Low
Fire, explosions, and chemical accidents records	Absence of chemical accidents in the last 10 years	No offsite consequences accidents in the last 10 years	Presence of chemical accidents with offsite consequences in the last 10 years
Fire and hazardous material units	Fully integrated and trained brigades.	Lack of updated or training in brigade organization	No brigades
Emergency plan	Completely functional	Deficiencies in emergency plans	Non-functional emergency plans
Affiliation to a hazardous material local committee	Affiliated	Mid-term integration plans	No affiliation

Social perception analysis

Once the potential exposure assessment is made and the respective communities are identified, the third element of the study is social perception analysis. It was performed following the Mexican Agency for Disaster Prevention (CENAPRED).

For the social perception analysis, a statistically significant measure of the potentially exposed community, obtained from the worst-case scenario, is evaluated to obtain the degree of social perception. An inquiry containing the selected measurements based on 25 items is presented to a habitant that is 18 years old or older. The social perception result allows for the identification of the level of awareness of the community towards a chemical risk: the levels are very high, high, medium, low or very low. This instrument sustains that the lack of hazard perception of the population directly affects their responsiveness to a disaster [25].

Major concern classification

Areas of major concern are obtained by linking the preparedness level of potentially exposed zones, along with the social perception degree of the population, in a geographical information system (GIS). The classification of exposed areas is set by prioritizing those areas where a low industrial emergency preparedness is combined with a low community hazard perception.

The lack of hazard emergency management puts the population at a high risk of exposure. The absence of social perception of the community indicates a high level of vulnerability because a deficiency in risk awareness impedes the community from adopting protective activities or demanding governmental hazard control.

The classification of major concern areas is obtained as shown in Table 2.

Results and discussion

Case study: San Luis Potosi, Mexico

San Luis Potosi is located in central Mexico; it is a key site for communications and is connected by road or train to major cities in Mexico. San Luis Potosi's West Industrial Area consists of two public industrial parks and six private industrial parks, with a total of 288 industries.

The industrial zone was established in 1963 by government decree [26]. This establishment led to altered growth, giving a new shape to the urban area of the municipality of San Luis Potosi. Despite the restrictions on land-use in the area, this sector had the biggest population growth in the city during 1990–2000 [27]. The industrial zone grew from north to south in the original area.

The 57 federal route borders the northeast zone of the industrial area and is the major communicating road linking San Luis Potosi with Mexico City (Fig. 1).

Hazard characterization

The hazard characterization of the West Industrial Area in San Luis Potosi was supported by the office of civil defense. A selection of facilities was made by prioritizing high volume chemical storage, according to the Office of Civil Defense and the State Agency of Ecology and Environmental Management. The industrial sectors surveyed were: chemical (19), food (7), metalworking (6), automotive (4) casting (4), agrochemicals (3), hazardous waste management (2), industrial gases (2) and textiles (1). However, to have updated information for the flammable material storage capacity, field research was performed on 48 facilities of the studied area.

Flammable substances from selected facilities were subject to an exposure assessment analysis (Table 3). Considering all of the different flammable substances, a database of storage capacities was developed. This database shows that flammable materials such as ethyl alcohol, heptane, and ethyl acetate are stored in larger volumes for production processes. Also, fuel oil and diesel are flammable materials that are widely used in support activities by the companies.

The level of emergency preparedness of the industries showed that only 62.5% of the 48 companies had brigades and emergency plans. Therefore, 37.5% of these industries lack trained and organized personnel and do not have the material resources to address a chemical emergency.

Potential exposure assessment

A total of 24 facilities that use flammable chemicals with storage volumes from 500 L to 400,000 L were evaluated using the worst-case scenario of flammable chemicals (Table 3); as a result, the consequence radii range from 425 m to 733 m.

Subsequently, the prioritization of hazards was identified (Fig. 2). The results show that facilities rated to be ''medium'' and ''high'', in terms of emergency preparedness, are located in the south of the industrial area, while the north contains industries rated to have ''high'' and ''low'' degrees of emergency preparedness.

From the 24 facilities studied; 58.4% had a high, 20.8% had a medium level, and 20.8% had a low level of emergency preparedness. The low emergency preparedness areas are located mainly at the north, northeast and northwest of the industrial area. Urban areas located at the east of route 57 and those bordering the north industrial area of San Luis Potosi are located within these areas of exposure.

It can be concluded that low levels of emergency preparedness are concentrated in the northern industrial areas, which were the first areas in the city to be industrialized. Hence, these facilities are older than those located at the southern industrial area, where emergency preparedness levels range from medium to high. This may be the result of hazard control deficiencies, which are effective only in the installation of new facilities, when risk assessment and prevention of accidents programs are required by law. Although old facilities should update these studies, it is done only when production or internal capacities are modified. Nonetheless, these changes are not brought to the attention of governmental agencies, and hazard assessment and emergency plans are never updated.

Social perception analysis

To evaluate social perception, worst-case areas with a low emergency preparedness classification for the northern facilities were assessed to determine the population's awareness of risk. To analyze social perception, two communities of interest were determined. Community 1 was located northwest of the industrial area. Community 2 was located northeast and closest to the route 57 (Fig. 3).

A census performed in both communities showed that 3166 and 7869 homes were located in communities 1 and 2, respectively. A pilot study was conducted to determine the sample size, using the estimated variance of the social perception of the vulnerability. The sample included 61 homes from community 1 and 65 from community 2, with a standard error of 0.05.

The local perception evaluated in community 1 and community 2 showed the following: 68% of the respondents were women, and the most frequent level of education was middle-school. The most frequent level of income was from 2 to 3 times the minimum wage (9.5–14 dollars per day). With respect to social perception, 51% of the respondents did not recognize a source of threat in their home, 80% had never participated in an emergency drill exercise, 65% did not know what to do in case of emergency, and 86% did not know any institution that works in emergency care.

Information campaigns are a major area of opportunity; this is because 98% of the respondents have never participated in one. The results indicate that the local perception of risk is low in residents located northeast of the West Industrial area (community 1), while it is of medium level in areas of the northeast (community 2), see Fig. 3. It appears that proximity to an industrial area influences community 1 to have a better recognition of hazards. In contrast, with community 2 being farther from the industrial area, there is a lower perception of risk. However, as we can observe in the exposure assessment and emergency preparedness (Fig. 2), community 2 has a higher exposure to worst-case scenarios for flammable chemicals and a higher exposure to low preparedness for potential accidents than community 1. The lack of perception and greater degree of exposure indicate that community 2 has a larger level of vulnerability because their lack of knowledge and perception prevent them from demanding control measures for hazards and community emergency preparedness plans.

In urban settlements with low risk perception (community 2), 95% are uninformed about emergency programs and 60% do not know the function and location of the Civil Defense Units. In the area with medium risk perception (community 1),

Table 2
Major concern classification.

Social perception index	Level of emergency preparedness		
	Low	Medium	High
Very low/low	Low	Low	Medium
Medium	Low	Medium	High
Very high/high	Medium	High	High

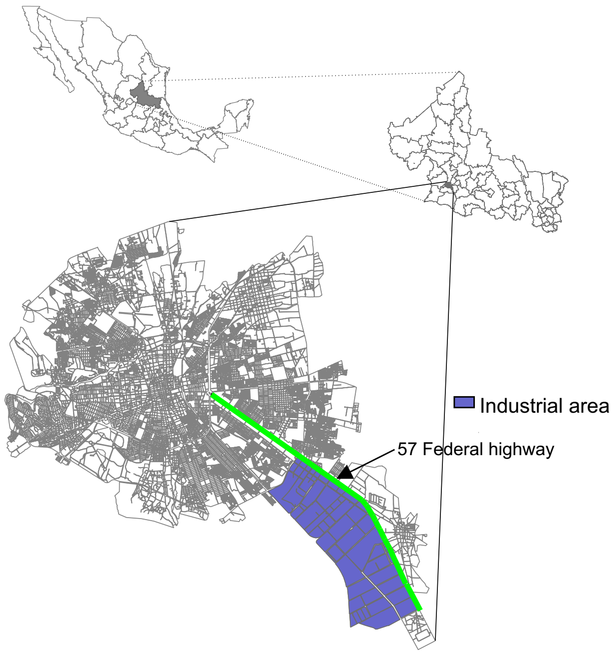

Fig. 1. Location of San Luis Potosi and the industrial area study object.

Table 3
Flammable substances in the case study.

Chemical name	Total quantity (kg)	Number of facilities	Offsite consequence radii (m)
Diesel	339064	15	202–591
Ethanol	613435	4	425–727
Heptane	366959	4	453–649
Ethyl acetate	355977	4	557–661
Methylbenzene	317552	4	666–733
n-Hexane	179798	2	464–467
Methanol	177981	2	556–612
Acetone	113924	2	491–617
1-Propanol	158041	2	596–673
Propyl acetate	67416	1	549
Ethoxyethane	63380	1	616
Fuel oil	15232	4	150–337

41% reported knowing that their homes are located in an area susceptible to threats, 74% were uninformed about emergency institutions, and only 50% had any knowledge about Civil Defense Units. In both cases, the knowledge of emergency programs and institutions was limited as well as the identification of hazards to the community, especially coming from a chemical threat.

The risk identified in the study did not correspond with the perception level within the community. Kasperson [28] reported that the experience of risk is the result of processes by which groups and individuals learn to acquire or create an interpretation of risk interaction with a wide range of psychological, social, institutional or cultural processes in ways that intensify or attenuate perceptions of risk and its manageability.

The levels of perception identified in the study may be influenced by the benefit that the population received from the industrial area. Alhakami and Slovic [29] recognized that lower perceived risks are associated with higher perceived benefits from various activities and technologies. Feelings are another component that shapes perceived risks. If people's feelings toward an activity are favorable, they tend to judge the risks as low and the benefits as high [30,31]

The lack of perception may be influenced by the history of the settlements because they grew after the industrialization of the area, and they have been present throughout history. In this case, threats become a part of everyday life, and the risk component is integrated into daily life with a belief that the danger is not real or that it is a distant threat [32]. The lack of outrage factors towards a chemical hazard can be considered to be another explanation about the lack of an identified perception. Outrage has a significant effect on risk perception [33] Regulatory agencies may be in the same lack of perception state, which makes it impossible for them to modify the situation.

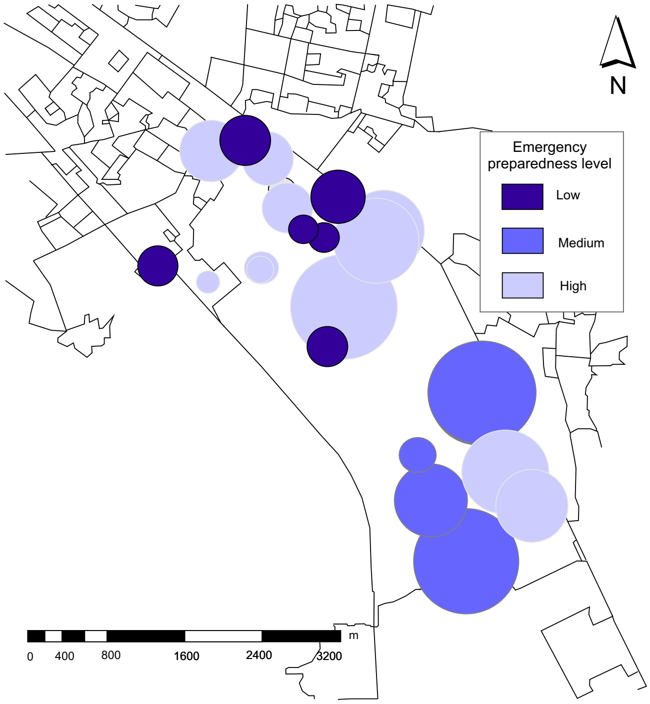

Fig. 2. Worst case scenario radii in the San Luis Potosi west industrial area.

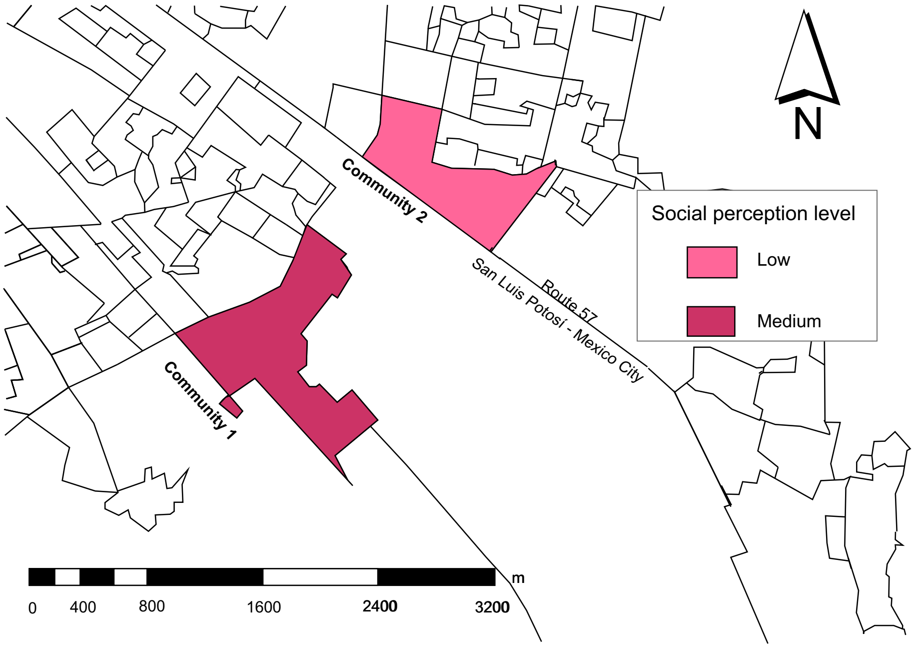

Fig. 3. Social perception levels in communities 1 and 2.

Areas of major concern

The methodology already described for areas of major concern suggests that local perception of risk along with emergency prevention and preparedness of industries, play a leading role in determining the priority areas for intervention.

In this study area, two high priority scenarios for intervention were identified. The first one, northwest of the industrial area, had a 275 m damage radius by using the TNT-equivalent worst-case scenario, which also shows low industrial

Fig. 4. Areas of major concern.

emergency preparedness along with a medium social perception of risk. Meanwhile, a second high priority scenario was identified north of the area and had a 367 m damage radius of low industrial preparedness combined with a low social risk perception (Fig. 4). In these areas, an intervention program is urgent to improve the industrial accident measures and the public perception of risks.

The high priority scenarios for intervention in the studied area are examples of industrial areas in developing countries where heavy industrialization proceeds more rapidly than appropriate regulatory activities [34] and off-site emergency preparedness plans are often not enforced by law [4]. The risk-management deficiencies in developing countries can be explained considering that the economic, political and cultural mechanisms of societal control over technological risks are inexistent or ineffective [35].

A risk inventory is needed to evaluate all of the potential sources of chemical hazards and alternative release scenarios in the industrial area. The results of this inventory could be a basis for the improvement of the stakeholders' risk perception in the area. Governmental agencies could support regulatory programs to improve industrial prevention and response to chemical accidents. Corporate entities could recognize the characteristics and vulnerability of the population exposed to their activities and develop a closer relationship with communities as a result of their social responsibility. The Office of Civil Defense could develop emergency community plans focused on improving social risk perception through participatory methodologies. Finally, better risk recognition should avoid problems arising from aggravating the risk and implementing effective land use controls that prohibit new human settlements in the area.

Conclusion

In this study, the main elemental standards of risk management were evaluated to discover basic deficiencies in hazard control and risk communication. A consequence-based approach was used for classifying the level of protection posed by every facility, considering the degree of internal risk management. The population potentially exposed to chemical risks was evaluated using a social vulnerability methodology to identify chemical hazard awareness in the community. As a result, areas of prior concern were identified using a GIS. This methodology could provide a baseline for government intervention in hazard management, risk communication, and emergency community planning.

Worst-case scenarios that result from flammable substances in San Luis Potosi's west industrial area show that overpressured radii have the possibility to damage industrial property and tangible goods in the surrounding communities. The lack of emergency preparedness in the industries was categorized into low and medium levels, which confirms the need for greater supervision and regulation by governmental agencies.

The medium and low levels of chemical hazard perception evaluated in the case study may be influenced by economic benefits and the favorable feelings of communities towards the industrial area, as well as the history of the settlements and the absence of outrage signals

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References

[1] UN/ISDR. Living with risk. A global review of disaster reduction initiatives. Geneva: United Nations/International Strategy for Disaster Reduction; 2004.
[2] Hufschmidt G. A comparative analysis of several vulnerability concepts. Nat Hazards 2011;58:621–43.
[3] Cardona OD. The notions of disaster risk: conceptual framework for integrated management. Information and indicators program for disaster risk management. Manizales: Inter-American Development Bank; 2003.
[4] De Souza MF, De Freitas CM. Vulnerability and industrial hazards in industrializing countries: an integrative approach. Futures 2003;35:717–36.
[5] Yang P, Tan X, Sun H, Chen D, Li C. Fire accident reconstruction based on LES field model by using orthogonal experimental design method. Adv Eng Softw 2011;42:954–62.
[6] NFPA. National fire protection association 704, standard system for the identification of the hazards of materials for emergency response. National Fire Protection Association; 2011.
[7] Sebos I, Progioub A, Symeonidisc P, Ziomasa I. Land-use planning in the vicinity of major accident hazard installations in Greece. J Hazard Mater 2010;179:901–10.
[8] Török Z, Ajtai N, Turcu AT, Ozunua A. Comparative consequence analysis of the BLEVE phenomena in the context on land use planning; case study: the Feyzin accident. Process Saf Environ Prot 2011;89:1–7.
[9] USEPA. Risk management program guidance for offsite consequence analysis. Washington: Environmental Protection Agency; 1999.
[10] Yang S, Fang Q, Zhang Y, Wu H, Ma L. An integrated quantitative hazard analysis method for natural gas jet release from underground gas storage caverns in salt rock. I: Models and validation. J Loss Prev Proc Ind 2013;26:74–81.
[11] Committee for the prevention of disasters. Methods for the calculation of physical effects "The Yellow Book". The Hague SDU; 2005.
[12] Tugnoli A, Gyenes Z, Van Wijk L, Christou M, Spadoni G, Cozzani V. Reference criteria for the identification of accident scenarios in the framework of land use planning. J Loss Prev Process Industries 2013;26(4):1–14.
[13] Papazoglou IA, Nivolianitou ZS, Bonanos GS. Land use planning policies stemming from the implementation of the SEVESO-II Directive in the EU. J Hazard Mater 1998;61:345–53.
[14] Christou MD, Amendola A, Smeder M. The control of major accident hazards: the land-use planning issue. J Hazard Mater 1999;65:151–78.
[15] Cozzani V, Bandini R, Basta C, Christou MD. Application of land-use planning criteria for the control of major accident hazards: a case-study. J Hazard Mater 2006;136:170–80.
[16] Kontić D, Kontić B. Introduction of threat analysis into the land-use planning process. J Hazard Mater 2009;163:683–700.
[17] Johansson I. Simulation as a tool for consideration of safety aspects in the land-use planning process. Pract Plann Res 2003;18:327–35.
[18] Salvi O, Debray B. A global view on ARAMIS, a risk assessment methodology for industries in the framework of the SEVESO II directive. J Hazard Mater 2006;130:187–99.
[19] Cutter SL, Mitchell JT, Scott MS. Revealing the vulnerability of people and places: a case study of Georgetown Country, South Carolina. Ann Assoc Am Geogr 2000;90:713–37.
[20] Tixier J, Dandrieux A, Dusserre G. Environmental vulnerability assessment in the vicinity of an industrial site in the frame of ARAMIS European project. J Hazard Mater 2006;130(2006):251–64.
[21] Margai FL. Health risks and environmental inequity – a geographical analysis of accidental releases of hazardous materials. Prof Geogr 2001;53(2001):422–34.
[22] Burns WJ, Slovic P. Risk perception and behaviors: anticipating and responding to crises. Risk Anal 2012;32:579–82.
[23] García V. El riesgo como construcción social y la construcción social de riesgos. Desacatos 2005, Septiembre–Diciembre;19:11–24.
[24] Barnes P. Approaches to community safety: risk perception and social meaning. Aust J Emerg Manage 2002:15–23.
[25] García N, Marín R, Méndez K. Vulnerabilidad social, in Guía Básica para la Elaboración de Atlas Estatales y Municipales de Peligros y Riesgos: Evaluación de la vulnerabilidad física y social, México; 2006 p. 75–154.
[26] INEGI. Instituto Nacional de Estadística y Geografía, Ciudades capitales: una visión histórica urbana. Volumen 3, México, DF; 2000.
[27] INEGI. Censos Generales de Población y Vivienda, México, DF; 2010.
[28] Kasperson RE. Bulletin of the Atomic Scientists 2012;68:59–66.
[29] Alhakami AS, Slovic P. A psychological study of the inverse relationship between perceived risk and perceived benefit. Risk Anal 1994;14:1085–96.
[30] Finucane MI, Alhakami A, Slovic P, Johnson SM. The affect heuristic in judgments of risks and benefits. J Behav Decis Making 2000;13:1–17.
[31] Slovic P, Peters E. Risk perceptions and affect. Curr Dir Psychol Sci 2006;15:322–52.
[32] Chardon AC. La percepción del riesgo y los factores socioculturales de vulnerabilidad. Caso de la ciudad de Manizales, Colombia. Desastres y Sociedad. Especial: Psicología social y desastres 1997;8:4–34.
[33] Sandman PM, Miller PM, Johnson BB, Weinstein ND. Risk Anal 1993;13:585–98.
[34] Rusell D, John S. Emergency planning and preparedness for the deliberate release of toxic industrial chemicals. Clin Toxicol 2010;48:171–6.
[35] Shrivastava P. Democratic control of technological risks in developing countries. Ecol Econ 1995;14:195–208.