Safety Science 49 (2011) 679–685

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Designing a developed model for assessing the disaster induced vulnerability value in educational centers

J. Nouri [a], N. Mansouri [a], M. Abbaspour [b], A.R. Karbassi [c], M. Omidvari [a,*]

[a] Department of Environmental Management, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Mechanical Engineering, Sharif University of Technology and Science and Research Branch, Islamic Azad University, Tehran, Iran
[c] Department of Environmental Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 10 April 2010
Received in revised form 27 November 2010
Accepted 8 January 2011
Available online 12 February 2011

Keywords:
Academy community
Analytical hierarchy process
Disaster
Vulnerability

ABSTRACT

To date, the models developed for assessing the vulnerability of societies have only taken account of the economic problems in the societies. Offering a model based on analytical hierarchy process and failure mode and effect analysis logic, the current study aims to determine the factors influencing the vulnerability of a higher education center and finally defines a vulnerability index. This model divides the factors influencing vulnerability into three categories: (1) the structure and layout of the buildings, (2) the occupants' characteristics, (3) the controlling and warning systems. The academy community center of Science and Research Branch was assessed in terms of vulnerability. The findings indicated that the vulnerability value relating to various sections and university buildings was higher than the acceptable level which entailed the due attention of educational managers. The findings showed that if some parts of the educational and administrative buildings were used for laboratory as well as for the storage of hazardous and flammable materials, then the vulnerability value will be increased to 200. This highlights the impact that the type of buildings application has on the level of vulnerability. The study has been performed in the Science and Research Branch as an educational center in Tehran during 2009–2010.

1. Introduction

Historically, Iran has suffered from many damages emanating from natural disasters. Given the increasing pace of population expansion and the lack of facilities development, the damages due to natural disasters have intensified in consequences. On the other hand, the deterioration of damages due to natural disasters moves abreast with those resulting from economic problems in societies (Wei et al., 2004). The relationship between human activities and the effects of disaster (the socio-economical dimensions of vulnerability) was extensively discussed and studied in the 70s and the early 80s (Hewitt, 1983). In the context of disaster, the concept of vulnerability was first used by OKeefe et al. (1976). One of the widely-used definitions of vulnerability is as follows: the degree to which different classes of society are differentially at risk. As implied by the definition, there is a focus on the theories of economics. In the early 90s, two significant conceptual models of disaster management development were developed for purpose of clarifying "vulnerability": (1) capacities and vulnerabilities analysis (CVA by Anderson (1995)), (2) pressure and release. The concept of vulnerability was described as the degree to which one is resistant against disaster in various areas with different economical specifications. The analysis of the vulnerability is aimed at pinpointing the due activities which can decrease the vulnerability of a society before being inflicted by devastating events. This helps the authorities to take effective measures to improve the conditions of society when a disaster occurs. This study maintains that in order to analyze the vulnerability, the traditional models consider these indices to be based on the frequency of crises, the damages inflicted by the crises, the population in different areas and their economic problems. Augmenting these parameters, one can obtain a combined index on vulnerability in a specific area. Analytical hierarchy process (AHP) can be used in order to measure the weight of index (Wei et al., 2004; Irasema, 2002). Nouri et al. (2010) discussed the application of conceptual models and AHP for evaluating risk purpose (Nouri et al., 2010). Markin and Winder (2008) maintained that three parameters namely human, physical work environment and management influence the risk. The failure of these parameters will result in the increased level of vulnerability (Markin and Winder, 2008). Sime (1991) touched on the impact activity type, residents' characteristics and environment has on the vulnerability value (Sime, 1991). The same study concludes that the analysis of vulnerability is considered as one of the most important steps in the process of assessment and control of the impacts crises have. This was also accessible by a study conducted by (Hellstorm, 2007). The same author discussed the response time and evacuation time in 2001, proposing

* Corresponding author. Tel.: +98 21 44865666; fax: +98 21 44865666.
E-mail addresses: nourijafar@srbiau.ac.ir (J. Nouri), omidvari88@yahoo.com (M. Omidvari).

0925-7535/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ssci.2011.01.002

that evacuation time can be divided into two categories of response time, evacuation time and pre-evacuation time which cannot be calculated beforehand. On the other hand, pre-evacuation time is influenced by various factors (Sime, 2004). Kobes et al. (2010) has summarized the factors contributing to the building safety and people behaviors at the time of fire break-out into three categories: 1-type of building 2-the people characteristics, 3-the type of fire. He demonstrated that the factors and conditions created these three categories influence the evacuation time, building vulnerability and finally the fire break-out risk buildings face (Kobes et al., 2010). Discussing the evacuation time in a educational center, Wong and Cheung (2006) concludes that factors such as the exit doors location, the aisles width and number of students in the center influence the evacuation time (Wong and Cheung, 2006). Martinelli et al. (2008) and Vafaeinezhad et al. (2010) defines the vulnerability value of a building against earthquake in terms of the type of land structure, building structure and the characteristics of building occupants such as age, gender and their abilities (Martinelli et al., 2008; Vafaeinezhad et al., 2010). Chu and Jinhua Sun (2008) illustrated the assessment of fire risk assessment in buildings in terms of even tree, with factors such as fire detection equipment, fire auto-extinguisher systems and manual extinguisher systems considered as important determinants (Chu and Jinhua Sun, 2008). Drawing on UN strategy of disaster amelioration, UNISDR defines vulnerability in terms of physical, social and economic factors, as well as environmental factors, which increase the extent to which a society is influenced by hazards (UN/ISDR, 2004). Wisner (2002) considers vulnerability as an intrinsic characteristic of system. However, the analysis of critical system looks at vulnerability as a risk characteristic, such as intensity and probability (Wisner, 2002). A study conducted by Colombia University in 2003 considers risk as a function of probability and intensity, defining risk in the context of disaster management as a function of vulnerability and probability. Since the risk cannot be controlled to full extent, great importance should be attached to discussions on vulnerability (Cardona, 2003). Vulnerability determines the extent to which a society is well-prepared in terms of the approach it takes to a risk (El Harbawi et al., 2008). Analyzing the vulnerability, one can determine whether the risk level is acceptable or not. On the other hand, in the context of disaster management, the extent of vulnerability should be taken into account so as to ameliorate the damages inflicted by disasters (Birkmann, 2007; Smit and Wandel, 2006). According to Tansel (1995) and Johnston (2004), vulnerability assessment can be described as a useful tool for controlling the damages as well for improving the safety level of a society (Tansel, 1995; Johnston, 2004). Educational center, where a number of people can potentially contribute in creating of disaster with their inconsiderate actions is expanding. The multiple laboratories and stock warehouses, as well as the centers where people gather in large numbers can potentially facing various crises (Nouri et al., 2010). Educational centers are of the most important society centers in crisis management. Although there is a lot of installed safety systems in the educational center units such as: laboratories, libraries and stock warehouses but still many accidents are frequently reported from those areas. They have potential to cause serious injury to personnel, major damage to equipment, structure, scientific and invaluable documents and disruption of educational operation. The past few decades have been witnessed major accidents along with a number of fatalities, economic losses and damage to the invaluable documents in educational center (Wong and Cheung, 2006). Fire in the library of Faculty of Law in University of Tehran in 1995 burned the invaluable historical documents. Explosion in biochemistry laboratory in Tarbiat Modarres University, Tehran Iran, 1996 resulted in death of a person and loss of many laboratory equipments. This study aims to offer a conceptual model and intended to determine the factors influencing the vulnerability that an educational center experiences in various crises. Eakin and Luers (2006) studied the assessment of vulnerability in socio-environmental systems, comparing and combining various approaches taken for evaluating the degree to which societies are vulnerable to climatic and environmental variations. The same study concludes that it is necessary to assess the vulnerability when crises occur so that an effective decision can be taken (Luers and Ekin, 2006).

This study has been performed in the Science and Research Branch of IA University in Tehran during 2009–2010.

2. Methodology

This study used questionnaire to collect data on the factors influencing the level of vulnerability and the degree to which educational centers are well-prepared to cope with disaster. The factors influencing vulnerability were divided into three categories: (1) factors relating to building layout and building structure, (2) the degree to which building occupants know of probable crises, as well as appropriate reactions against crises in academy community centers, (3) the availability of detection and control devices which are required to manage the disaster. The factors influencing vulnerability value described in Fig. 1.

Then, the experts were consulted to derive the factors influencing each parameter. The resulting factors were weighted against the questionnaire and the data given by the experts. Finally, the factors weight was determined and ranked, using analytical hierarchy process. The algorithm was used in this study is illustrated in eight steps. The procedure is as follows:

Step 1: Developing a questionnaire based on the factors contributing to vulnerability.
Step 2: Determining the weight of each factor by the experts. The questionnaires were mailed to three experts who were requested to assign a weight ranging from 1 to 10.
Step 3: Determining paired matrices as well as the weights of the indices based on AHP. The paired matrices for building, occupants, and controlling equipment are $6*6$, $5*5$ and $7*7$, respectively. Table 1 shows the results which are the weights of influential factors in each section (Saaty, 1980). Table 1 shows the influential factors and their estimated in the parameter. Given the weights estimated for each parameter well as the conditions of the Science and Research Complex.
Step 4: The value of IR index was calculated for each matrix which was less than 0.1. Thus, the matrices can be said to be consistent.
Step 5: The weighs of influential weights are added up in order to determine the weight of the main indices. The Eqs. (1)–(3) were used to calculate the score:

$$C = 10\sum_{i=1}^{7} W_{i(C)} \quad (1)$$

$$S = 10\sum_{i=1}^{6} W_{i(s)} \quad (2)$$

$$P = 10\sum_{i=1}^{6} W_{i(p)} \quad (3)$$

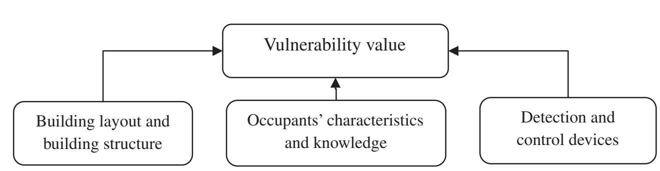

Fig. 1. The factors influencing vulnerability.

Table 1
Factors influencing the vulnerability parameters and their weight.

Parameter	Influential factors	Indices weight (w_i)
Disaster control and detection equipment (C)	Fire extinguishing equipment	0.284
	Fire detection equipment	0.171
	Chemicals leakage detection equipment	0.153
	Disaster warning equipment	0.185
	Equipment for communication with rescue and relief organizations	0.076
	Exit signs and highlighted escape paths	0.131
Total		1
Occupants' characteristics and knowledge (P)	Occupants' age and physical capability	0.151
	Training occupants on disaster and fire extinguishing	0.204
	Arranging evacuation practical exercises	0.105
	The volume of people belongings in the buildings	0.302
	Access to people specializing in fire fighting	0.238
Total		1
Building specifications and layout (S)	The situation of exit doors and evacuation line	0.061
	Building proximity to fault line and its location on the flood route	0.216
	The existence of inflammable, explosive materials in the building	0.325
	The type of raw materials and internal equipment	0.066
	The money value of equipment and the facilities in the building	0.147
	The existence of gathering venues (auditorium, praying rooms)	0.122
	The layout of building and the access to a safe place in the surrounding area	0.630
Total		1

Step 6: The procedure below was followed to combine the results derived from AHP section with FMEA logic. Here, a score ranging from 1 to 10 was assigned to the weights.

- If the sum of weights of each factor is less than or equal to 0.1, the factor will be given a score of 1.
- If the sum of weights of each factor is greater than 0.1, less than or equal to 0.2, the factor will be given a score of 2.
- If the sum of weights of each factor is greater than 0.2, less than or equal to 0.3, the factor will be given a score of 3.
- If the sum of weights of each factor is greater than 0.3, less than or equal to 0.4, the factor will be given a score of 4.
- If the sum of weights of each factor is greater than 0.4, less than or equal to 0.5, the factor will be given a score of 5.
- If the sum of weights of each factor is greater than 0.5, less than or equal to 0.6, the factor will be given a score of 6.
- If the sum of weights of each factor is greater than 0.6, less than or equal to 0.7, the factor will be given a score of 7.
- If the sum of weights of each factor is greater than 0.7, less than or equal to 0.8, the factor will be given a score of 8.
- If the sum of weights of each factor is greater than 0.8, less than or equal to 0.9, the factor will be given a score of 9.
- If the sum of weights of each factor is greater than 0.9, the factor will be given a score of 10.

Step 7: Given the results derived from step 6 and drawing on Eq. (4), the weights of building, occupants' characteristics, and controlling equipment are multiplied. This yields the *V.V.* index.

$$V.V = S \times P \times C \tag{4}$$

where *V.V.* is the Vulnerability value, *S* the building layout and structure score, *P*building occupants score, and *C* disaster detection and controlling equipment score.

Step 8: The *V.V.* index less than or equal to 100 counts as an acceptable score. The *V.V.* scores greater than 100 counts as unacceptable score, entailing the corrective and control measures.

In the next step (in case study), the conceptual model of vulnerability value assessment was administered in one of the largest educational center affiliated to the Islamic Azad University of Science and Research Branch in Tehran. The checklist was used as the main data collection instrument. Each parameter weight was estimated using the assessment method, as well as the relevant filled-out checklist. Then a questionnaire was administered to tap the knowledge, belief and performance of the university occupants who were divided and assessed into three categories of professors, students and employees (staff). 1234 subjects were randomly selected. Given the obtained results and drawing on the method offered in this study, the weight of each index was estimated. Finally the vulnerability value was calculated followed by decision-making regarding whether these scores are acceptable or not. The subjectivity which influences the quality of evaluation is considered as one of the main bottlenecks in the process of vulnerability evaluation. This method can make up for this shortcoming, limiting the subjective contributions to evaluation. Consequently, it offers an accurate evaluation in educational contexts. A great concern in vulnerability assessment is the potential impact of the personal judgment and attitudes of the assessor which results in various assessments of a single vulnerability value. In this article, attempts are made to determine the potential degree of influence of each parameter underlying the vulnerability utilizing the AHP method as an original and pioneering application at this stage of the study of vulnerability assessment. Also, the proposed model may pave the way for reducing the contaminating effect of assessor's personal judgments and enhance consistency of assessment of the factors influencing vulnerability in educational centers by various individuals.

3. Results

Having a student population of 20,000, the Science and Research Complex located in northern part of Tehran was studied. Sitting on the Moradabad and Farahzad flood basin, this Center is situated along a fault in north eastern part of Tehran. Fig. 2 shows the Science and Research Branch location.

The complex is comprised of seven buildings, three of which are used for educational purposes, covering classrooms, libraries and administrative sections. The remaining four buildings are allocated to academic affairs and laboratories. The heating system is comprised of a central heating system and the cooling system is comprised of absorbing chillers. The buildings in which administrative and educational affairs are run are comprised of the classrooms in various dimensions and capacities. These buildings are different in terms of floor number and the area. Basic Science building in which most science majors and some technical and environmental majors

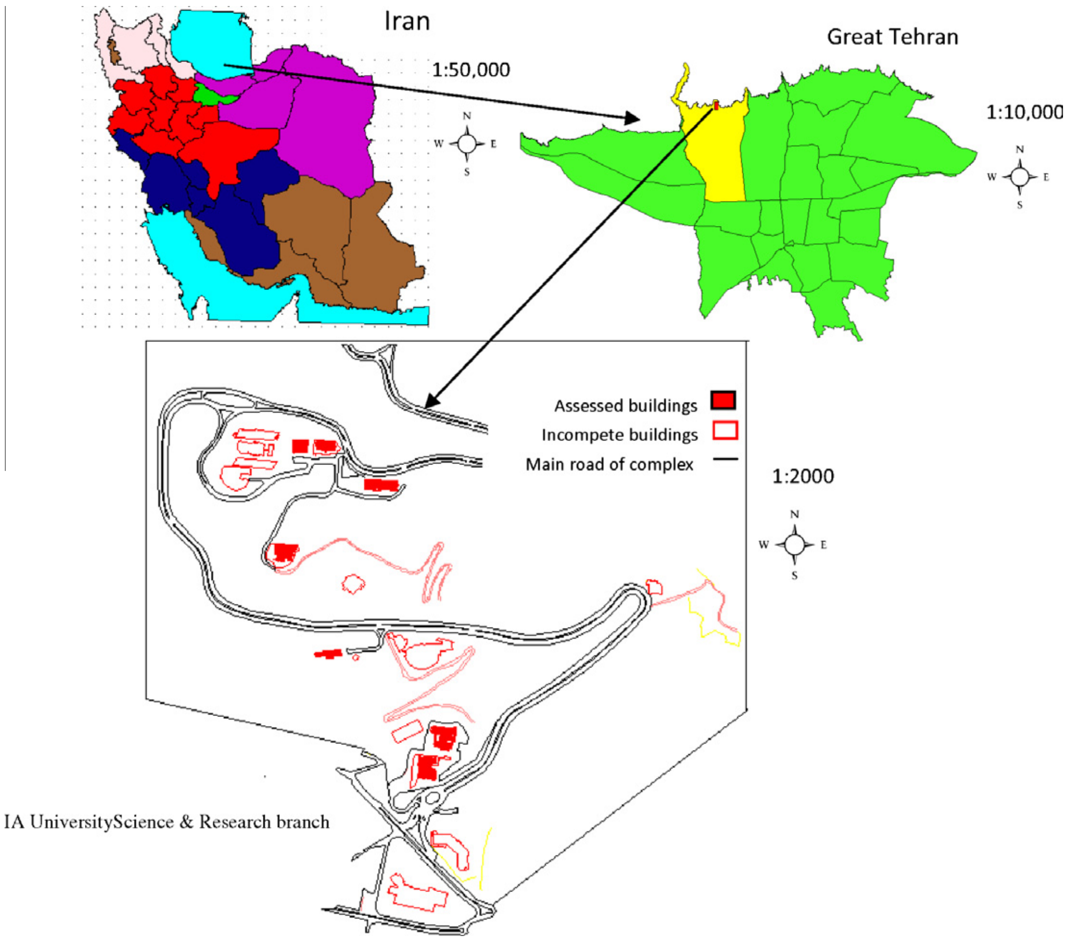

Fig. 2. Science and Research Branch location.

Table 2
Occupants' characteristics and knowledge regarding the disaster.

Occupants' criteria	Buildings													
	School of Humanities		School of Basic Science		School of Management		Laboratory #1 Building		Complex Building Laboratory		Plasma and Physics Laboratory Building		Metallurgy Laboratory Building	
	S[*]	US[**]	S	US	S	US	S	US	S	US	S	US	S	US
Age/physical suitable	*		*		*		*		*		*		*	
Fire fighting training		*	*			*	*		*			*		*
Practical training for evacuation and disaster (maneuver)		*		*		*		*		*		*		*
Personal belongings in building		*		*		*		*		*		*		*
People trained in fire fighting		*	*			*	*		*			*		*

[*] S: Suitable: young/occupants' fire fighting training program/practical training exercises/lack of personal belongings in building (major document/lab-tap/child room)/ access to people trained in fire fighting.
[**] US: Unsuitable: elder/lack of occupants' fire fighting training program/lack of practical training exercises/personal belongings in building (major document/lab-tap/child room)/no access to people trained in fire fighting.

are taught has been built in six floors and humanities building in which most humanities majors are taught has been built in seven floors. Management building in which management and economics majors are taught has been built in two floors. All the buildings are equipped with an auditorium the biggest of which is located on the 6th floor of Basic Science School. The laboratory and workshop complex is comprised of four buildings one of which houses the chemistry, agricultural, biochemistry and physics laboratories in two floors. The Plasma Physics Laboratory building with four floors is also used for educational and administrative affairs, though most sections are used for plasma physics and nuclear experiments. Metallurgy workshop is mainly used for hydraulic, welding, foundry and machinery work. There is a 4-floor building in laboratory complex. The floors 2, 3, 4 are applied for administrative and educational affairs purposes covering technical vocational fields. The first floor houses the electronics and electricity laboratories, as well as computer site. The checklist was used to investigate the level of vulnerability. Table 2 shows the occupant checklist and the

Table 3
Building specifications and the layout of the Science and Research Complex.

Building criteria	Buildings													
	School of Humanities		School of Basic Science		School of Management		Laboratory 1 Building		Complex Building Laboratory		Plasma and Physics Laboratory Building		Metallurgy Laboratory Building	
	S*	US**	S	US	S	US	S	US	S	US	S	US	S	US
The situation of exit doors and evacuation line		*		*		*		*		*		*		*
Building proximity to fault line and its location on the flood route		*		*		*		*		*		*		*
The existence of inflammable, explosive materials in the building	*			*	*			*		*		*		*
The type of raw materials and internal equipment	*		*		*			*		*		*		*
The money value of equipment and the facilities in the building	*		*		*		*			*		*	*	
The existence of gathering venues (auditorium, Mosque)		*		*		*	*		*			*	*	
The layout of building and the access to a safe place in the surrounding area	*		*		*		*		*			*		*

[*] S: suitable/suitable width of stairs/the suitable arrangement of equipment/the low value price of equipment/the lack of gathering venues/access to a safe place.
[**] US: unsuitable/narrow staircase/door facing inward/the unsuitable arrangement of equipment/the high money value of equipment/the existence of gatherings venues/no safe place.

Table 4
Disaster detection and control equipment in buildings.

Control criteria	Buildings													
	School of Humanities		School of Basic Science		School of Management		Laboratory 1 Building		Complex Building Laboratory		Physics Laboratory Building		Metallurgy Laboratory Building	
	S*	US**	S	US	S	US	S	US	S	US	S	US	S	US
Fire fighting devices	*		*		*		*		*		*		*	
Fire detector devices	*		*		*		*		*		*		*	
Chemical leakage detector devices	*			*	*			*		*		*		*
Alarm devices		*		*		*		*		*		*		*
Communication with rescue organization		*		*		*		*		*		*		*
Warning signs	*		*		*		*		*		*		*	

[*] S: availability of fire extinguisher/availability of automatic fire extinguisher/the availability of chemicals leakage detector devices/availability of alarm/access to intranet system and communication with rescue organization/availability of warning signs.
[**] Us: the lack of fire extinguisher/lack of fire detectors/lack of chemicals detectors/lack of alarm/lack of intranet system for communication with rescue organization/lack of warning signs.

resulting data. Table 3 shows the resulting data on building layout and Table 4 shows the resulting data on disaster detection and control equipment.

Fig. 3 shows the resulting data on people's knowledge level, belief and performance, making it clear that most occupant of the university lack unacceptable level of score with most people having little knowledge in this regard. The occupants of buildings, in which environmental science, civil engineering, mechanical engineering and architectural major are taught, enjoy a higher level of knowledge and confidence than those of other occupants of buildings. Fig. 3 shows the average score obtained by occupants of the university. As the table shows, the employees gaining a score less than 10 outnumber other people in the university, implying the insufficient knowledge the university employees have of disaster. In sum, the results show that most occupants of the university lack the sufficient knowledge regarding disaster.

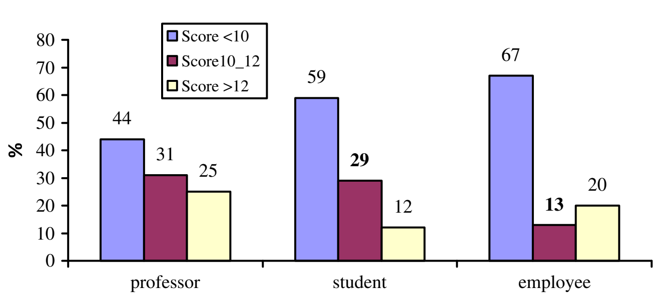

Fig. 3. The average score of occupants' knowledge, attitude and practice in disaster situation.

Table 5 shows the results of study on the different parameter of vulnerability value based on the model offered in the IA University Science and Research Branch. As the table shows, Plasma Physics Laboratory has the highest indicator of vulnerability due to the storage of explosives and hazardous materials as well as the unsuitable layout of Plasma and Physics Laboratory building followed by Complex Laboratory, Metallurgy Laboratory and Basic Science buildings respectively, due to the existing inflammable and explosive materials, as well as the gathering venues in the buildings.

Fig. 4 shows the results of vulnerability level based on the model offered. As the figure shows, Plasma Physics laboratory building has the highest level of index followed by Metallurgy Laboratory building and Laboratories Complex building.

4. Discussion

Evaluating the vulnerability in security sector, Johnston (2004) maintains that characteristics of people and residents exposed to risk account for the main factor influencing the vulnerability. This study uses checklist to estimate the level of vulnerability by examining the areas. This is similar to the method used in current study

Table 5
Measurement of different parameter of vulnerability based on the model offered in the proposed Campus.

Index	Buildings						
	School of Humanities	School of Basic Science	School of Management	Laboratory 1 Building	Complex Building Laboratory	Plasma and Physics Laboratory Building	Metallurgy Laboratory Building
Building layout/equipment	4	8	4	7	9	10	8
Resident (knowledge, individual characteristics)	9	5	9	5	5	9	9
Control and detection equipment	3	5	3	5	5	5	5

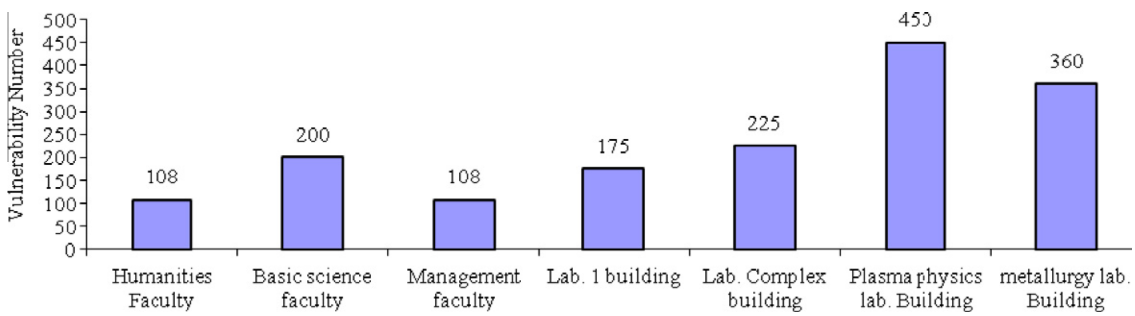

Fig. 4. Results of vulnerability number based on the model offered.

in that the characteristics of people in society are taken as an important parameter influencing the level of vulnerability. People mobility in time of disaster and evacuation time following a fire break-out count as another parameter influence the level of vulnerability. This parameter, in turn, is influenced by different factors, the most important of which is the volume of properties and assets in the affected building (Kobes et al., 2010). Present study has also taken account of the same parameter namely volume of properties and assets as an important factor influencing vulnerability of educational centers. Offering a model on the basis of a set of factors influencing the layout and structure of buildings which have been included in the present study, Martinelli et al. (2008) as well as Schonwiese et al. (2003) and Emanuel (2005) estimated vulnerability on the basis of economic problems in a society whereas the present study maintains that vulnerability is influenced by factors beyond the economic domain, dealing with other factors as well (Schonwiese et al., 2003; Emanuel, 2005; Martinelli et al., 2008). Chow (2003) proposed that the new buildings layout needs to be designed in such a way that the time needed for evacuation buildings is reduced. This, in turn, reduces the vulnerability (Chow, 2003). However, if the vulnerability were assessed based only on economy parameters according to Martinelli et al. (2008), in the case of School of Management and Basic Science the vulnerability value of these two Schools would have been higher than the acceptable value. While, in reality the vulnerability value in both Schools were less than acceptable value. Thus, the obtained results by the model offered in this study were found more accurate than those obtained by the model offered by Martinelli et al. (2008).

5. Conclusion

The assessment model offered in this study proved to satisfactorily assess the vulnerability of an educational center. Given highly motivated employees in academy community centers, the society can encourage them to participate in training course on disaster management, hence promoting the society preparation when a disaster occurs. The findings indicate that many parameters, including building structure, people and detection and control devices influence the vulnerability of buildings. The building where expensive hazardous materials and equipment are kept can have a higher vulnerability value. Building used for educational purposes, where there is no hazardous material, is subject to less vulnerability. If the same buildings are equipped with laboratory and warehouse, the vulnerability will increase. The laboratories in which the employees are trained in the fields of disaster management and fire extinguishing, will experience a reduced probability of vulnerability.

References

Anderson, M.B., 1995. Vulnerability to disaster and sustainable development: a general framework for assessing vulnerability. In: Munasinghe, C., (Ed.). Disaster Prevention for Sustainable Development. World Bank, Washington, DC, pp. 17–27.
Birkmann, J., 2007. Risk and vulnerability indicators at different scales: applicability, usefulness and policy implications. Environ. Hazards 7, 20–31.
Cardona, O.D. 2003. Information and Indicator Program for Disaster Risk Management, University of Colombia, pp. 7–11.
Chow, W.K., 2003. Preliminary views on implementing engineering performance-based fire codes in Hong Kong: what should be done? Int. J. Eng. Performance, Based Fire Codes 4 (1), 1–9.
Chu, G., Jinhua Sun, J., 2008. Decision analysis on fire safety design based on evaluating building fire risk to life. Safety Sci. 46, 1125–1136.
Eakin, H., Luers, A.L., 2006. Assessing the vulnerability of social–environmental system. Annu. Rev. Environ. Resour. 31, 365–394.
El Harbawi, M., Mustapha, S., Choong, T.S.Y., Abdul Rashid, S., Kadir, S.A.S., Abdul Rashid, A.Z., 2008. Rapid analysis of risk assessment using developed simulation of chemical industrial accidents software package. Int. J. Environ. Sci. Technol. 5 (1), 65–74.
Emanuel, K., 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686–688.
Hellstorm, T., 2007. Critical infrastructure and systemic vulnerability: towards a planning framework. Safety Sci. 45, 415–430.
Hewitt, K., 1983. Interpretations of Calamity: From the Viewpoint of Human Ecology. Allen & Unwin, Boston, MA.
Irasema, A.A., 2002. Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47, 107–124.
Johnston, R.G., 2004. Adversarial safety analysis: borrowing the methods of security vulnerability assessments. J. Safety Res. 35, 245–248.
Kobes, M., Helsloot, I., Vries de, B., Post, J.G., 2010. Building safety and human behavior in fire: a literature review. Fire Safety J. 45 (1), 1–11.
Markin, A.M., Winder, C., 2008. A new conceptual framework to improve the application of occupational health and safety management systems. Safety Sci. 46, 935–948.

Martinelli, A., Cifani, G., Cialone, G., Corazza, L., Petracca, L., Petrucci, G., 2008. Building vulnerability assessment and damage scenarios in Celano (Italy) using a quick survey data-based methodology. Soil Dyn. Earthquake Eng. 28, 875–889.

Nouri, J., Omidvari, M., Tehrani, M.S., 2010. Risk assessment and crisis management in gas filling stations. Int. J. Environ. Res. 4 (1), 143–152.

OKeefe, P., Westgate, K., Wisner, B., 1976. Taking the naturalness out of natural disasters. Nature 260, 566–567.

Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Schonwiese, C.D., Grieser, J., Tromel, S., 2003. Secular change of extreme monthly precipitation in Europe. Theor. Appl. Climatol. 4, 132–139.

Sime, J.D., 1991. Accidents and disasters: vulnerability in the built environment. Safety Sci. 14 (2), 109–124.

Sime, J.D., 2004. An occupant response shelter escape time (ORSET) model. Safety Sci. 38, 109–125.

Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environ. Change 16, 282–292.

Tansel, B., 1995. Natural and manmade disasters: accepting and managing risks. Safety Sci. 20 (1), 91–99.

United Nations International Strategy for Disaster Reduction (UN/ISDR), 2004. Living with Risk. A Global Review of Disaster Reduction Initiatives, 2004 Version, UN Publications, Geneva.

Vafaeinezhad, A.R., Alesheikh, A.A., Nouri, J., 2010. Developing a spatio-temporal model of risk management for earthquake life detection rescue team. Int. J. Environ. Sci. Technol. 7 (2), 243–250.

Wei, M.Y., Fan, Y., Lu, C., Tsai, H.T., 2004. The assessment of vulnerability to natural disasters in China by using the DEA method. Environ. Impact Assess. Rev. 24, 427–439.

Wisner, B., 2002. Who? What? Where? When? In an emergency: notes on possible indicators of vulnerability and resilience: by phase of the disaster management cycle and social actor. In: Plate, E., (Ed.), Environment and Human Security: Contributions to a Workshop in Bonn, Germany, 23–25 October 2002, pp. 12/7–12/14.

Wong, L.T., Cheung, T.F., 2006. Evaluating probable risk of evacuees in institutional buildings. Safety Sci. 44, 169–181.