Research Paper

Assessing the Safety Situation in the Laboratories of Educational and Research Centers

Alireza Dehdashti[1,2], Farin Fatemi[1,3*], Mohammadreza Janati[3,4]

1. *Social Determinants of Health Research Center, Semnan University of Medical Sciences, Semnan, Iran.*
2. *Department of Occupational Health Engineering, Damghan School of Health, Semnan University of Medical Sciences, Damghan, Iran.*
3. *Student Research Committee, Semnan University of Medical Sciences, Semnan, Iran.*
4. *School of Graduate Studies, Memorial University of Newfoundland, Newfoundland, Canada.*

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ABSTRACT

Background: The use of chemicals in academic laboratories is a major concern for the health and safety of individuals and the environment. Academic institutions are currently developing safe work procedures to ensure compliance with standard criteria and laboratory accreditation. However, it is unclear to what extent the activities of research laboratories are safe for the personnel and environment. Therefore, this research produces a chemical hazard assessment assembling data and knowledge on the health, safety, and environmental aspects of chemical applications in laboratories.

Materials and Methods: This cross-sectional study was conducted in 2021 in five research and teaching laboratories. The collecting data tool was a checklist, developed in 7 sections with 125 items and completed in all laboratories understudy. Then, the research team conducted a risk assessment for the 10 most widely used chemicals in the laboratories. In the end, the risk categorization was conducted based on the risk matrix of ISO 31000.

Results: Determining risk levels associated with using chemicals may provide a reasonable way to assess hazards and suggest controls for working in laboratories. Most non-compliance hazards were linked to inadequate waste disposal processes, the potential for poisoning and illness effects, and emergency actions.

Conclusion: It is suggested to conduct knowledge, attitude, and practice studies of the students, staff, and faculties to provide appropriate level of training courses in the academic laboratories.

Keywords:
Risk assessment, Safety, Academic laboratory, Chemicals

*** Corresponding Author:**
Farin Fatemi, PhD.
Address: *Department of Occupational Health Engineering, Damghan School of Health, Semnan University of Medical Sciences, Damghan, Iran.*
E-mail: *f_fatemi@semums.ac.ir*

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Introduction

Laboratories play the main role in the skill development of students, particularly in health and engineering sciences [1]. Laboratories in research and teaching institutions and universities are accounted as crucial places for accidents and emergencies [2, 3]. University laboratories have been reported as even more dangerous places compared to industries [4]. There is a wide variety of potential exposures to occupational hazards in the work environments of laboratories. These exposures can be physical, chemical, biological, psychological, and social [5]. Furthermore, laboratories may be a threat to the national community by accidentally releasing hazardous chemicals into the air. In these cases, environmental pollution is the main concern in the affected communities. Furthermore, the lesson learned from some of the academic laboratory incidents indicates that such accidents could have been prevented if a more accurate method of risk assessment had been undertaken [6, 7]. Studies have shown that the most severe consequences in laboratories are related to chemicals that should be considered with high accuracy [8]. To create a safe working environment in the laboratories for faculties, students and staff are required to identify, assess, and control potential risks in health, safety, and environmental areas. Accidents in academic labs with injuries and loss of life are incidents that should be prevented and mitigated through risk management approaches [9]. Also, a literature review demonstrated that academic laboratories have parts of work-related accidents due to the wide range of diverse chemicals used [4]. The Chemical and Hazard Research Council received reports of 120 lab incidents from 2001 to 2011 in the United States [10]. Conducting a comprehensive risk assessment in academic laboratories is the first step to understanding the hazards of chemicals and prioritizing control measures based on estimated risk scores in the health, safety, and environmental domains individually [11-13]. Also, protection from accidents and emergencies in academic laboratories require a sound knowledge of the dangers and the practical measures that are to be taken. Effective training courses on chemical safety, health, and environment help to prevail the communication risk program in the universities and change the attitude of laboratory users to do safe procedures and practices that result in a positive safety culture in academic laboratories [14, 15].

The literature review indicated that previous studies have been primarily focused on risks associated with clinical laboratory operations in Iran [16-19]; however, academic and research laboratories also have a direct impact on the safety and public health impacts of staff and students. Accordingly, they deserve serious attention. Identifying hazards and predicting risks is the primary step toward managing risks for academic laboratory staff, students, the general population, and the environment. This study explores hazard identification in the work environments of laboratories and conducts a comprehensive risk assessment of the most widely used chemicals in academic laboratories.

Materials and Methods

Study design

This study was conducted in 2021 as a survey. Five research and teaching laboratories in the School of Public Health affiliated with Semnan University of Medical Sciences were assessed. In the first stage, the collecting data tool was a checklist which was adopted from the Occupational Safety and Health Administration (OSHA), International Labor Organization (ILO), and the Princeton University laboratory safety manual and could identify hazards in the laboratories. The checklist was designed in 7 sections with 125 items and was completed in all laboratories understudy (Table 1). These instruments were applied in previous studies to determine health, security, and environmental hazards and the validity and reliability of the checklist was acceptable. The reported Cronbach α and content validity index for the checklist were 0.8 and 0.76, respectively [20, 21]. The checklist was completed in each laboratory by walk-through observations and help with working individuals in laboratories.

In the second stage, we focused on the 10 most widely used chemicals in the assessed laboratories for calculating the risk scores in the health, safety, and environment sections, individually. We recognized the chemicals with the help of the laboratory manager and staff and also documented investigations about the time intervals of providing the chemicals. For conducting the comprehensive risk assessment of considered chemicals, the literature reviewed for hazard degree of carcinogenicity, American Conference of Governmental Industrial Hygienists (ACGIH), International Agency for Research on Cancer (IARC), safety of chemicals as identified by the international organizations and standards and national fire protection agency codes [22] and the hazard rate (HR) of using chemicals was determined.

Table 1. Details of the developed checklist in this study

No.	Category	Sub-categories	Items
1	General work environment	None	12
2	Emergency planning	4 (facilities, inspections, procedures, information and postings)	24
3	Safety	6 (personal protective equipment, electrical hazards, chemical storage, flammable liquids, compressed gases, and pressure/ vacuum systems)	53
4	Health	None	11
5	Environment	None	7
6	Security	None	4
7	Laboratory knowledge	2 (training and awareness)	14
Total	7	12	125

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Further, the exposure rate (ER) for chemical risk assessment of using chemicals was quantified by calculating the Equation 1 [5]:

$$1.\ ER=\frac{F\times D\times M}{W}$$

Where F and D describe the number of exposure weekly and mean exposure time (h), respectively. The item "M" demonstrates the exposure rate (ppm or mg/m^3) and W shows the mean of work hours (40 h/week).

Classification of risk assessment

The risk scores estimated the evaluated chemicals that categorized risk into 5 varying levels from "very low" to "very high". The likelihood and severity were replaced with ER and HR, respectively. This risk categorization was conducted based on the risk matrix of ISO 31000 (Figure 1) [20].

Corrective actions and analysis

The collected information from hazard identification and risk score estimations were compared to identify the practical prevention and mitigation measures in the laboratory understudy. The collected data in each stage were entered into Excel data sheets, version 2016 and then analyzed.

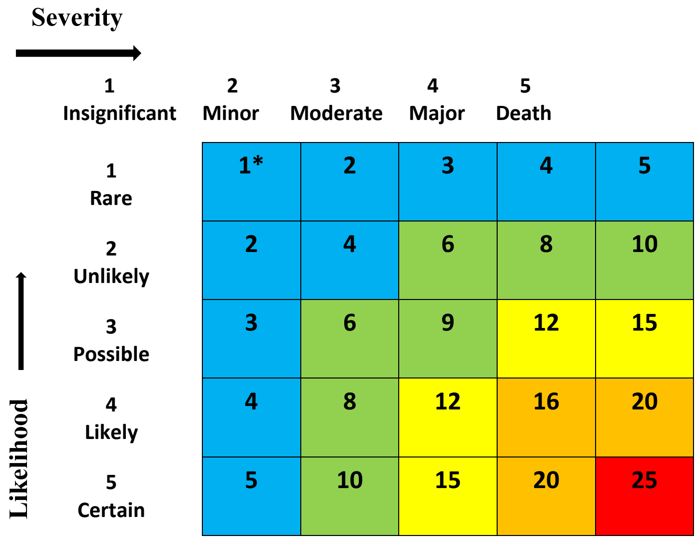

Figure 1. Risk measurement matrix (adopted of ISO31000)

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*Final risk score (1-5=very low, 6-10=low, 11-15=moderate, 16-20=high, 21-25=very high)

Results

The results for hazard identification indicated that most non-compliances with health, safety, and environmental principles were observed in the categories of environment (100%), laboratory safety and health knowledge (82%), health (59%), and emergency planning (58%). In the category of security, compliance was equal to 100%; however, the figure in the safety and general work environment categories decreased to 51% and 59%, respectively. Training and awareness as the subcategories of laboratory safety and health knowledge did not have acceptable situations with 100% and 64% non-compliance, respectively. In the sub-categories of emergency planning, major considerations should be paid for establishing emergency procedures, such as spill control plans and chemical safety programs, providing information having risk communication plans, and providing the required facilities for accidents and emergencies. In the safety category, pressure systems, personal protective equipment (PPE), electrical safety, and chemical storage were the sub-categories that needed severe supervision for implementing correction measures in the assessed laboratories. Further, the maintenance of flammable liquids and compressed gases had an acceptable compliance level with guidelines. The results of the chemical risk assessment including health, safety, and environmental risks are demonstrated in Table 2.

The results of the risk assessment showed that the highest risk score is health hazards, with 50% in the likelihood of hazards, and 50% in the severity of consequences. A total of 40% of assessed chemicals in health hazards were categorized at very high-risk levels. These chemicals included hydrochloric acid, formaldehyde, sulfuric acid, and nitric acid among the 10 most widely used chemicals in the laboratories. The other chemicals were categorized at moderate and low-risk levels with 20% and 40%, respectively.

In the case of fire, explosion, and release into the air as safety hazards, the assessed chemicals are categorized into 4 existing risk levels from 5. The highest likelihood and severity of safety hazards with 30%. Ethanol and formaldehyde were categorized at very high-risk levels and constitute 20% of assessed chemicals; however, most chemicals, including hydrochloric acid, nitric acid, toluene, benzene, and di ethyl ether ranked at high-risk levels as flammable gases and liquids with 50%. The remainder of the chemicals were classified at moderate and very low risk levels with 10% and 20%, respectively. The ferric sulfate and ammonium chloride were the safest using chemicals in the assessed categorization of safety hazards.

In the environmental hazard categorization, including water, soil, and air pollution particularly wastewater effluent disposal, the highest risk of likelihood and severity of assessed chemicals were 40% and 20%, respectively. Hydrochloric acid was assessed at a very high-risk level

Table 2. Risk score levels of using chemicals in understudy laboratories at the School of Public Health, Semnan University of Medical Sciences, 2021

Risk Assessment	Chemicals	Hydrochloric Acid	Ethanol	Ferric Sulfate	Formaldehyde	Sulfuric Acid	Toluene	Nitric Acid	Ammonium Chloride	Benzene	Di Ethyl Ether
Health	Likelihood	5	5	3	5	5	3	5	2	3	3
	Severity	5	3	3	5	5	3	5	3	5	2
	Risk score	25	15	9	25	25	9	25	6	15	6
Safety	Likelihood	5	5	1	3	5	4	4	2	4	4
	Severity	4	5	3	4	5	4	4	1	4	5
	Risk score	20	25	3	12	25	16	16	2	16	20
Environment	Likelihood	5	5	3	4	5	3	5	2	3	3
	Severity	5	3	4	5	4	3	4	2	3	3
	Risk score	25	15	12	20	20	9	20	4	9	9

Health in Emergencies and Disasters Quarterly but the most used chemicals ranked at a high-risk level with 30% in this hazard area. Further, 30%, 20%, and 10% of assessed chemicals were categorized at low, moderate, and very low-risk levels, respectively. Ammonium chloride was evaluated as the safest chemical in the environmental hazards in laboratories understudy.

Discussion

Hazards identification and conducting a comprehensive risk assessment in the academic laboratories were the main parts of this study. Strict monitoring for considering prevention and mitigation measures must be focused on using chemicals with high-risk scores in health, safety, and environmental assessment [23, 24]. The findings revealed that the most remarkable non-compliance is waste disposal system as an important environmental risk factor. The findings of one study in Thailand were in line with our results and indicated that building a safety system for laboratory liquid waste disposal has become an important issue in the environmental protection of universities during their quick development [25]. Not sealing all waste containers, not establishing a procedure for disposing of empty glass chemical containers, or not applying chemical containers of materials that will not be affected by the substances that are stored in them were the important points in the environmental hazard categorization.

The other outstanding non-compliances are related to health hazards and emergency planning. The lack of appropriate ventilation systems in all assessed laboratories, including not strong and active hoods or not installing the local exhaust ventilation for controlling airborne, gases or vapor contaminants were the threatening risk factors for health users in the laboratories understudy. These findings are similar to a study that was conducted in 2016 [26]. Imperfective or non-availability of required procedures and equipment for emergency planning is another important risk factor in the laboratories. The lack of self-contained breathing apparatus damaged eyewash, and safety showers or having a written spill control plan for each laboratory were the instances of faults in emergency planning. Unless the safety non-compliances were more limited in comparison to health and environment hazards, some defects in electrical hazards, chemical storage, flammable liquids, or lack of appropriate PPE in relevance to identified hazards may result in catastrophic incidents, severe injuries, and even death in the academic laboratories. All the mentioned cases of safety hazards in this study were confirmed in a risk assessment study that has been done in establishing a chemical safety program at the University of Kufa, Iraq [27].

Providing a safety data sheet is sufficient as a part of chemical safety programs in the work environments of laboratories. The lab employees and managers should optimize the use of the information available in these documents, and most critically validate this information with other authoritative chemical safety information sources [28].

A general lack of safety culture among the faculties, staff, and students could be a main barrier to providing safe work environments in the laboratories to protect the users. One approach for promoting the safety culture is implementing compulsory training courses and increasing the awareness of target groups [29]. This point has been ignored in the laboratory understudy. Although, just this training might not result in providing a safety culture in laboratory environments; however, if it is associated with monitoring and inspecting, we could observe a positive modification in the behavior safety of laboratory users. All laboratory workers should receive an orientation to the laboratory which includes where the chemical safety plan is kept, how to use laboratory equipment, how and when to use PPE, where emergency equipment is, who to contact in accidents and emergencies, where SDS is kept, spill control procedures, emergency procedures, and incident reporting. Furthermore, all training should be repeated at specific intervals and documented [30, 31]. One study in 2019 in Mexico indicated that students reported a sense of safety in the workplace at laboratories because the laboratory employees who were around them had received adequate safety training and the students should take adequate safety training and act responsibly to be able to face unexpected situations in laboratories [32]. Also, the results of a study about electrical safety in academic laboratories highlighted that qualified personnel who work on energized equipment including direct contact or contact using tools must be trained on how to work safely on energized circuits [33].

Conclusion

An increasing number of health, safety, and environmental hazards in academic laboratories warrant the need for a comprehensive risk assessment alongside a compilation of the safest laboratory practices.

The tools in this study identified the potential hazards and also helped to determine mitigative actions. Further, the results enable the lab managers to make informed decisions on the corrective measures required for using chemicals and work environments according to their estimated risk scores in health, safety, and environmental categories individually. Seriously, it is required to install disposal equipment at the source of pollutants, PPE used during activities in the laboratories, and labeling on the chemical containers or bottles such as images, symbols, letters, risk statements, or a combination of them. Furthermore, the training programs should be provided according to the knowledge level of staff and faculties and safety culture situation to improve health, safety, and environment in the laboratory environment. Therefore, it is recommended to conduct knowledge, attitudes, and practice studies of the users' laboratories concerning being able to identify hazards.

Ethical Considerations

Compliance with ethical guidelines

This study was performed in line with the principles of the Declaration of Helsinki. The research protocol was approved by the Research Ethics Committee of Semnan University of Medical Sciences (Code: IR.SEMUMS.REC.1398.131).

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Authors' contributions

Study design and writing: Alireza Dehdashti and Farin Fatemi; Data collection and entering data into the dataset: Mohammadreza Janati; Final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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