Implementation of Chemical Health, Safety and Environmental Risk Assessment in Laboratories: A Case-Series Study

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Research Article

Keywords: Chemicals, risk assessment, Academic, Laboratories

Posted Date: March 2nd, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1396510/v1>

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Abstract

Background: Characterizing risks associated with laboratory activities in universities may improve health, safety, and environmental management and reduce work-related diseases and accidents. This study aimed to develop and implement a chemical risk assessment method to determine and prioritize more hazardous chemicals in the academic laboratories.

Methods: A case-series study was conducted at five academic laboratories and research facilities of an Iranian medical sciences university in 2021. A risk assessment was developed and implemented in three phases including identification, evaluation and classification of potential risks and hazards. The approach provided an innovative tool evaluating and prioritizing risks in chemical laboratories. Hazards were classified in a five level scale. The technique reviewed both quantitative and qualitative data and evidences using Laboratory Safety Guidance (OSHA), Occupational Hazard Datasheet (ILO) and the standards of ACGIH, IARC and NFPA codes.

Results: Overall, the frequency of risks at moderate to very high levels determined for the health hazards (9.3%), environmental hazards (35.2%), and safety hazards (20.4). Hydrochloric acid had a high consumption rate in laboratory operations and received the highest risk levels in terms of potential hazards to employees' health and environment. Nitric acid, Sulfuric acid, Formaldehyde, and Sodium hydroxide were assessed as a potential health hazards. Moreover, Ethanol and Sulfuric acid were determined to cause safety hazards. Although security provisions and procedures were considered precisely at academic laboratory activities, but lack of awareness concerning health, safety, and environmental hazards of chemical compounds and inappropriate sewage disposal system were determined as the main factors in increasing risk levels.

Conclusion: Chemicals used in laboratory activities generate workplace and environmental hazards that must be assessed and mitigated. Developing a method of rating health, safety, and environmental risks related to laboratory chemicals may assist in defining and understanding potential hazards. Our assessment suggested the need for improving risk perception of individuals involved in handling chemicals to prevent from workplace and environmental hazards.

Background

Laboratories and research facilities are considered a fundamental part of universities playing a crucial role in preparing students and researchers to obtain skills that are valuable in their future career (1). The presence of numerous chemicals in laboratories has faced safety and health managers with challenges in estimating their hazards. The chemicals and equipment that are used by laboratory personnel present a number of serious, sometimes life-threatening hazards and accidents. Laboratory managers are responsible to protect their personnel and students from exposure to chemical, biological and physical hazards (2).

A survey of Occupational Safety and Health Administration (OSHA) has reported that the potential hazards associated with conducting research at laboratories in academic institutions were eleven times more dangerous compare to laboratories in industrial sector (3). Literature review on safety and health of laboratories in higher education institutions have shown there have been a number of laboratory incidents resulting in fatalities and injuries caused by fires, explosions and equipment resulted in debilitating injuries and death (4). Previous studies on health-related hazards have reported both acute and chronic poisonings following exposure to various chemicals in laboratory environment (5). Moreover, laboratory waste water consist of hazardous chemicals have been considered a substantial environmental threat (6).

In the United States about 18% of occupational accidents in higher education institutions were related to laboratory environments and in around one-third of accidents, students were the main victims (7–9). A review of Evidences suggests that the trend of accidents was on the rise in academic laboratories over the past several years (10–11). Lack of awareness of various safety and health hazards has triggered accidents, which mainly related to the unsafe work practices of chemical and equipment in laboratories (12).

An integrated health, safety, and environmental risk assessment would be beneficial in understanding risks and evaluating hazards and planning a strategy to prevent accidents in laboratories (13–14). International occupational safety and health organizations have developed standards and instructions to prevent and control hazards in laboratory environments. Training of students and laboratory workers provided a culture of safety, health, and environment consciousness in dealing with laboratory risks and hazards (15). Although risk assessment has shown to be an efficient approach in identifying and introducing appropriate measures to manage risks and hazards, but workplace risk levels may differ based on tasks and personnel behavior even in the same work environment. In essence, laboratory risk assessment should be implemented for individual specific laboratory setting and each work task and role (16). Obtaining objective and comprehensive data concerning risks and hazards has presented challenges for health, safety and risk management in chemical laboratories. Planning a risk assessment requires the definition of an assessing project with an educated team. Hazard prediction and recognition are the starting step to measure the strength of the impact of a threat (2).

Many research activities are performed in chemical laboratories in universities which seldom assessed by occupational safety and health engineers (11). This study performed an integrated health, safety, and environmental risk assessment to determine the level of risks for potential workplace exposure in terms of different jobs, work duties in academic lab settings. The process includes prediction, recognition, classification, and evaluation of risks and hazards in chemical laboratories. The plan for adequate measures to prevent and mitigate risks and fitness of work to laboratory personnel and student will be discussed.

Methods

Design and setting of the study

A cross-sectional design and action research were applied to develop and conduct a comprehensive risk assessment to determine a range of health, safety, and environmental risks associated with the activities in academic laboratories. This study was implemented in 2021 at five medical and health sciences laboratories affiliated to Semnan University.

Suggested steps of risk assessment

The steps of the methodology for assessing risks in chemical laboratories in university are demonstrated in Fig. 1. These include: developing an integrated risk approach, collecting information to categorize risk factors, calculating risk levels, and Proposing health, safety and environmental measures.

Developing of an integrated risk assessment approach

Our methodology based on the structured checklist to integrate the process of predicting and recognizing hazards, evaluating the risks posed by hazards and managing the risks of hazards in the context of university laboratory. This technique reviewed both quantitative and qualitative data about the chemicals and the situations of the process and judgment to a particular laboratory process.

Recognition of potential risks and hazards in laboratory environments and activities was based on checklists, walk-through observation and interview with working individuals in laboratories. We developed a combined behavior-based and process-based checklist to conduct a broader risk assessment in identifying the risk level of work practices and in mitigating the associated risks. The study tool was adopted from Laboratory safety Guidance, Occupational Hazard Datasheet, and the Princeton University Laboratory Safety Manual. The tool consisted of 131 items which assess working areas, emergency planning, required information and documentation, personal protective equipment, electrical hazards, chemical storage and use, flammable liquids, compressed gases, disposal of chemicals used in lab, ventilation requirements, security and training.

Collecting information to categorize risk factors

We identified and grouped chemical exposure and hazards according to their properties, work procedures, and occupational exposure scenarios through the consumption rate and work behavior in studied laboratories.

Calculating risk levels

The laboratory hazard risk rating of chemical is estimated by multiplying the severity of consequence value by the likelihood of incidence value. For this stage, we assembled reliable resources to obtain a review of safety and health literature on hazard properties. Literatures were reviewed for exposure limits and carcinogenicity of chemical substances as identified by American Conference of Governmental Industrial Hygienists (ACGIH), Immediately Dangerous to Life or Health (IDLH) of toxic substances, and National Fire Protection Agency (NFPA) codes (17–18).

Then we used an assessment matrix to conduct a comparative analysis of the “severity of consequences” and “probability of incidence” to determine risk rating for individual health, safety and environmental hazards. Our estimates of hazard risk ratings used to categorize risk into varying levels of risk applying standard linear scaling. Table 1 demonstrates the matrix of risk levels and expectation of responses required to improve safety and health in laboratory (ISO 31000) (19).

Proposing health, safety and environmental measures

The prevention and mitigation of health, safety and environmental risk measures were proposed based on calculated risk scores.

Table 1
Establishing a laboratory hazard and process matrix-based risk system with standard linear scaling
(values 1-5) to determine the risk score

Likelihood	1	2	3	4	5
Severity					
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25
Interpretation					
Very Low	5– 1	Risk is acceptable and control measures is not necessary			
Low	10–5.01	.Risk is low and further studies needed in the future			
Moderate	15–10.01	Risk is intermediate and control measures have to be done in the future			
High	20–15.01	Risk is high and control measures have to be done as soon as possible			
Very High	25–20.01	Risk is very high and control measures have to be done immediately			

Results

The checklist was completed for laboratory environments in order to recognize the potential risks and hazards in this study. Health, safety, and environmental hazards associated with common chemical laboratory activities and work flow and the percentage of compliance and noncompliance with laboratory guideline are shown in Table 2.

Table 2

Results of hazard analysis checklist based on work processes and behaviors evaluated in university chemical laboratories and verified frequency of compliance and noncompliance with health, safety and environmental guidelines

Laboratory environment and facilities	Compliance (%)	Non-compliance (%)
1. General Work Environment	59	41
2. Emergency Planning	42	58
3. Required information and documentation	20	80
4. Personal protective equipment	25	75
5. Electrical hazards	56	44
6. Chemical storage	56	44
7. Flammable liquids	83	17
8. Compressed gases	87.5	12.5
9. Disposal system	NO*	100
10. Ventilation	83	17
11. Security	100	NO*
12. Training	17	83
13. Awareness	36	64
*Not Observed		

Our survey of laboratory activities showed reasonable compliances of security considerations, safe work procedures in using compressed gases and flammable liquids. However, above half of incompliances were related to the preparation in emergency situations, using personal protective equipment, poor disposal and treatment of waste products, awareness and training. The lack of written emergency action plans, chemical hygiene lab, and MSDS were identified to contribute to operational risks in chemical laboratory activities. The unsafe acts of lab staff concerning effluents and waste management mainly included risk factors of improper disposal containment and methods for experiment waste. We observed lack of compliances in emergency response plan mainly associated to inadequate knowledge of staff and students about how to identify location of fire extinguishers, how to request emergency assistance, and how to communicate potential leak, fire, and explosion scenarios. The unsafe conditions such as ageing electrical cords and plugs and contact with incorrectly grounded devices were identified to increase operational risks of instruments in laboratories. Additionally, obstructed fire alarm pull stations or not appropriate layout of fire extinguishers in the lab environments increase the reaction time in occurrence of accidents. Almost all individuals involved in handling chemical laboratories reported have not acknowledged or trained in terms of health, safety and environmental hazards. Our on-site observation showed the unsafe storage of chemicals, which may lead to leakage and increase the possibility of exposure and accidents or high potential for injuries and damages. Students and laboratory workers were more likely not to choose the safe course of action concerning the use of personal protective equipment. For example, a common unsafe act was working in university labs without wearing face and eye or respiratory protection may cause injury. Furthermore, in chemical laboratories the users frequently

violated safe work procedures during transporting or setting up the experiment or apparatus. While we identified many facilities and experiments were in compliance with environment, health, and safety codes for the use of flammable liquids and compressed gases in chemical laboratories, but the cases with inadequate compliance could result in serious consequences.

The survey evaluated a comprehensive health, safety, and environmental hazards of 54 chemicals used in chemical laboratories (Fig. 2). The proposed class-based risk assessment involves five levels of classes. The fourth and fifth-level classes characterize the main risk factors.

A total of 44 of risk factors were predicted and recognized as the “high” or “very high” level assessment classes. The number of health hazards at the risk level of “very high” was more frequent in comparison to safety and environmental hazards accounting for respectively 9.2%, 3.7%, and 1.8% of the total number of fifth-level class. Moreover, the chemicals with the level of “high” risk contributed to a greater number of environmental hazards (35.2%) followed by safety hazards (20.4%) and health hazards (11.1%). The identified health, safety and environmental hazards of chemicals at intermediate level were respectively 20.4%, 13% and 18.5% of the total number of third level category, implying preventing and control actions are required to manage the risks. Additionally, the mean value of 29.7% of assessed chemicals had very low and low health risk degrees. These mean values were about 31.5% and 22.3% at safety and environmental hazards, respectively.

Overall, using chemicals in laboratory operations produced wide range of risk levels. Cyclohexane, Nitric acid, Sulfuric acid, Formaldehyde and Sodium Hydroxide were classified as “very high” level risks (9.3%) contributed to potential hazards to health (score estimated at 25). Many chemicals (35.2%) classified as “high” risk level involved in environmental hazards. In contrast, very limited number of chemicals (1.8%) presented “very high” level of risk to environmental hazards.

Table 3 demonstrates the potential health, safety and environmental hazards of under study chemicals and the relevant calculated risk scores in this study.

Table 3

Health, safety and environmental risk assessment matrix of common chemicals used in university laboratories

Chemicals Name	Environmental Risk			Safety Risk			Health Risk		
	Probability	Severity	R.S*	Probability	Severity	R.S	Probability	Severity	R.S
Acetone	4	1	4	4	5	20	4	3	12
Acetic acid	4	4	16	3	4	12	4	3	12
Ethanol	5	3	15	5	5	25	5	3	15
Ammoniac	4	5	20	3	5	15	4	4	16
Benzene	3	3	9	4	4	16	3	5	15
Butanol	4	4	8	4	5	20	2	2	4
Chloroform	4	5	20	4	5	20	2	3	6
Cyclo Hexanol	3	2	6	3	5	15	3	2	6
Hydrochloric Acid	5	5	25	5	4	20	5	5	25
Hydrogen Peroxide	4	4	16	4	3	12	4	4	16
Methanol	3	5	15	5	4	20	3	2	6
Nitric Acid	5	4	20	4	4	16	5	5	25
Sulfuric Acid	5	4	20	5	5	25	5	5	25
Di Chloromethane	4	1	4	4	2	8	3	3	9
Di Ethyl Ether	3	3	9	4	5	20	3	2	6
Ethylene Glycol	2	2	4	2	2	4	2	3	6
Formaldehyde	4	5	20	3	4	12	5	5	25
Isopropanol	3	3	9	4	4	16	3	2	6
Orto Toluidine	1	5	5	2	4	8	1	4	4
Toluene	3	3	9	4	4	20	3	3	9
Carbon disulfide	4	3	12	4	5	20	3	4	12
Paraffin	4	1	4	1	2	2	2	2	4
Aluminum Sulfate	4	4	16	1	3	3	3	3	9
Arsenic Oxide	2	5	10	3	3	9	2	5	10
Barium Chloride	2	5	10	1	2	2	2	3	6

Chemicals Name	Environmental Risk			Safety Risk			Health Risk		
	Probability	Severity	R.S*	Probability	Severity	R.S	Probability	Severity	R.S
Cadmium Chloride	3	5	15	1	2	2	3	5	15
Iodine	4	5	20	2	2	4	5	4	20
Ferric Sulfate	3	4	12	1	3	3	3	3	9
Ferric Chloride	3	3	9	2	1	2	3	4	12
Ammonium Carbonate	2	5	10	2	4	8	2	3	6
Ammonium Chloride	2	2	4	2	1	2	2	3	6
Asbestos	4	4	8	2	4	8	1	5	5
Brome	2	5	10	3	3	9	2	4	8
Calcium Carbonate	3	1	3	1	1	1	3	3	9
Calcium Hydroxide	3	4	12	1	3	3	3	4	12
Magnesium Oxide	2	5	10	1	2	2	2	3	6
Phenol	4	5	20	2	3	6	2	5	10
Manganese Sulfate	4	5	20	1	2	2	2	4	8
Potassium Hydroxide	5	4	20	3	3	9	5	4	20
Silver Nitrate	3	5	15	2	3	6	3	4	12
Sodium Azide	1	5	5	3	2	6	1	4	4
Sodium Fluoride	3	5	15	2	2	4	3	4	12
Sodium Hydroxide	5	4	20	3	3	9	5	5	25
Mercury	4	5	20	2	3	6	2	4	8
Potassium Cyanide	4	5	20	3	4	12	2	4	8
Sodium Cyanide	1	5	5	2	3	6	1	4	4
Potassium Chromate	4	5	20	2	3	6	5	4	20
Tin Chloride	4	5	20	2	3	6	4	4	16
Citric Acid	2	2	4	1	2	2	2	2	4

Chemicals Name	Environmental Risk			Safety Risk			Health Risk		
	Probability	Severity	R.S*	Probability	Severity	R.S	Probability	Severity	R.S
Cobalt Chloride	4	5	20	2	3	6	2	4	8
Lead Acetate	1	5	5	2	2	4	1	3	3
Lead Nitrate	1	5	5	2	4	8	1	4	4
Mercury Chloride	4	5	20	3	5	15	1	5	5
Nitrate Nickle	1	5	5	2	4	8	1	3	3
* R.S: Risk Score; 1-5: Very low 5.01-10: Low 10.01-15: Moderate 1.01-20: High 20.01-25: Very high									

Totally, 25.9% of chemicals were involved in the highest degree of exposure (scored at 5 or 4) and the severity of outcome was classified at the highest degree for 57.4% of chemicals. The results demonstrated that Ethanol and Sulfuric acid presented “very high” risk level (scored at 25) in safety risk assessment. Further, 27.8% and 44.4% of chemicals rated high scores in probability and severity at in the safety risk assessment, respectively. Hydrochloric Acid was the only chemical that rated the highest risk level (very high) in the environmental risk assessment with a score estimated at 25. While probability of hazardous exposure, for almost half of the evaluated chemicals determined at “very high” risk level, 72.2% of chemical exposures could result in the highest level of consequences.

Discussion

This study assessed health, safety and environmental risks in academic laboratories that use from chemicals for educational and research activities. The diversity of using chemicals and work procedures in laboratories of academic institution might lead to various health, safety and environmental risk factors. This is in line with prior study suggested that educational and research laboratories of academic institutions need to assess their vulnerabilities and plan their own risk mitigation accordingly (20).

Our risk assessment indicated that the percentage of health hazards in very high-risk level was higher in comparison to safety and environmental hazards. Overall, the mean values of 13.6%, 12.4% and 18.5% of assessed chemicals were classified in moderate to very high categories of health, safety, and environmental hazards, respectively. Therefore, health and safety rules must be considered strictly by the people who working with chemicals in laboratories for reducing the risk of chemical related diseases and accidents (21). After completing the laboratory health and safety checklist in this study, the most non-compliance were observed in chemical storage and training/awareness sections. The most faults about chemical storage were related to labeling of cabinets by chemical class and labeling of chemical containers particularly, when chemicals are transferred from the original containers. Additionally, quantities of chemicals in storage don't be consistent with short term needs of the assessed laboratories. All of these non-compliances in chemical storage may result in extensive fire or explosion in laboratories of academic settings. Omidvari et al. found similar results in their study at Azad University in Iran, which reported fire risk and accidents in educational buildings, particularly in laboratories (22).

Due to importance of training and awareness in reducing exposures, accidents and injuries, all laboratory workers including faculty, staff and students should receive laboratory standard training. These training programs involve

chemical safety program, chemical emergency action plan and laboratory security plan. After holding these training courses, it should be ensured that the laboratory workers know who and when to use personal protective equipment, how to use emergency equipment such as eye washes and safety showers, where Safety Data Sheets (SDSs) are kept, spill control procedures, emergency procedures and chemical waste procedures. The previous studies recommended the periodic training courses for laboratory staff and approving the laboratory safety and security curriculum in most faculties in order to increase awareness, safety and security culture among laboratory workers and allow them to distinguish what to do to before, during and after emergencies (23–26).

Moreover, general work environment, emergency planning and required information for chemical laboratories were the other parts of checklist involved the highest numbers of non-compliance in this study. Not only, allocating one room of chemistry laboratory to chemical warehouse has been increased the safety risk, but also the layout of chemicals was not in accordance to safety principles. For instance, the chemical storage was not at least 18 inches below sprinkler head or at least 24 inches below ceiling. Not considering the 5S principles in work environment of at least 2 laboratories and storage of materials such as paper goods, plastic containers, boxes and empty containers that would fuel to burning fire was the other fault. Additionally, the alternative exits, chemicals SDS, safety instructions, SCBA and required special security system or controls to limit access, were not available in the assessed laboratories. Lack of an emergency action plan was the other major fault in this study. The findings of this study and similar researches provide useful information to plan and develop an emergency action plan for prevention and mitigation the emergencies and their harmful consequences in the laboratories of academic institutions (27–29). Prevention and mitigation measures should be prioritized for implementation accordance to available fund and resources. Prior studies reported low-cost interventions that might involve reducing major risks and their consequences. Planning a safe layout for gas cylinders or fire extinguishers, providing the SDSs for using chemicals in the laboratories, chemicals labeling of cabinets and containers and non-structural mitigation measures are some of these instances (28, 30–31).

In the domain of environmental risk assessment, 44.5% of chemicals were classified in very low and low categories but 55.5% of them indicated intermediate to very high-risk degrees. The most important of chemical environment-related hazard was waste disposal. Lack of an individual sewage system for laboratories and releasing chemicals into the urban sewage system can contaminate the underground water with hazardous chemicals. Previous studies assessed a high level of environmental risk on underground water reservoirs related to hazardous chemical effluents from academic laboratories (32–33).

Conclusions

This chemical health, safety and environmental risk assessment was developed and conducted according to the standards and guidelines set by the international occupational health and safety organizations. The applied approach determined the significant risks of using chemicals at the laboratories. The instrument developed in this study will be put into use in helping health and safety engineers define and classify potential risks of laboratory operations to health, safety and environment. Prevention and mitigation measures should be based on a detailed risk assessment method to minimize identified risks and provide a safe and free of diseases and incidents in the laboratory and research environments.

The provision of training courses in curriculum on health and safety in laboratories particularly for new students at the first of each semester, and periodic similar training courses for faculty and staff plays a key role in increasing awareness and risk perception for considering significant risks at the laboratories. Furthermore, inspecting and

assessing the laboratories and research facilities accordance to standard laboratory checklists routinely and removing the non-compliances at the earliest time are essential in such working environments.

Abbreviations

OSHA: Occupational Safety and Health Administration

ACGIH: American Conference of Governmental Industrial Hygienists

IDLH: Immediately Dangerous to Life or Health

NFPA: National Fire Protection Agency

SDSs: Safety Data Sheets

SCBA: Self-Contained Breathing Apparatus

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee Review Board at Semnan university of Medical Sciences (IR.SEMUMS.REC.1398.131). All the participants signed a consent form and were informed on the purpose of the study prior to interview as per local protocol on research ethics.

Consent for publication

Not applicable

Availability of data and materials

The data supporting the conclusions in this article are available in the additional files. Data supporting study findings are available upon request.

Competing interests

The authors declare that they have no competing interests.

Funding

There is no funding source for this research.

Authors' contributions

FF and AD designed study, analyzed data, and prepared the manuscript. MJ collected data and contributed to entering data into dataset. All authors read and approved the final manuscript.

Acknowledgments

We thank all colleagues and staff of the School of Public Health who supported and assisted for conducting this research.

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Figures

Figure 1

Flowchart of the suggested methodology for risk assessment

Figure 2

Frequency of chemicals at estimated risk level classes in university laboratory activities