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Analyzing the Hazardous Chemical Accident in Iran: A statistical Investigation

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ABSTRACT

Hazardous chemical accidents have increased in the previous decade in Iran. The analyses of these accidents helps inform accident prevention in the future. This study was aimed to characterize and analyze the chemical accidents occurring in Iran during the period of 2018-2020. This cross-sectional study was conducted in 2020. Data were obtained from the registered chemical accidents checklists in the inspection database at Ministry of Health. Descriptive analyses were applied to characterize the hazardous chemical accidents based on time, place, death, injuries, type, and cause of injury. Odds ratio and Chi de test assessed how the main variables under study were associated with the occurrence of hazardous chemical accidents. Analytical tests of Chi-square test and Chi-square test by means of Monte Carlo simulations were used to investigate the relationship between the main variables studied and the occurrence of chemical accidents. The results showed that more than half of these chemical accidents occurred in basic chemical installations and manufacturers. Among the direct causes of assessed chemical accidents, 45% of them were related to equipment/utilities failure. Providing safety data sheet for chemicals, chemical labeling, and emergency response plan as the main components of chemical safety management program were significantly related to occurrence of chemical accidents in the chemical enterprises (P-value=0.01). In spite of the implementation of chemical safety management program since 2015 in Iran and routine inspection by chemical enterprises, the trend of hazardous chemical accidents is increasing. The economically developed provinces particularly, medium and small sized chemical enterprises, need more official rules and strict supervisions in order to prevent accidents and mitigate the harmful consequences.

KEY WORD: *Hazardous Chemical Accidents, Chemical Safety Management, Supervision*

INTRODUCTION

A chemical accident is the release of uncontrolled chemicals that can harm humans, the environment, and resources [1-3]. Nowadays, over 117000 chemical installations, plants, and companies are active in three sectors including industry, services, and agriculture in Iran. Among them, 11900 chemical enterprises have hazardous chemicals and half of them are small-sized with less than 25 workers. Totally, 482496 workers are exposed to the risk of Hazardous Chemical Accidents (HCAs) occurring based on national statistics of 2019 [4]. Over the past decade, industrial chemical accidents have increased in Iran [2]. Previous studies indicated that the frequency of chemical accidents in steel, aluminum, industries as well as in refinery and petrochemical complexes is greater than compared to other industries in the country [5-6].

If an industrial chemical accident (explosion, fire, or release) occurs, not only the workers will be affected by the accident, but also more than hundreds of residents may be at risk of chemical exposure depending on the extent and severity of the chemical accident [7-10]. Whenever public safety is threatened by chemical accidents, this means that some health and safety criteria have not been considered correctly in the development of chemical industries [11]. In addition, chemical accidents are multi-factorial events [12-14].

Considering the statistics of chemical accidents and evidence, Chemical Safety Management Program (CSMP), and relevant components are necessary for Iran. Official supervisions have an effective role in strong regulatory enforcement in industries on both local and national levels [7]. Health and safety inspections by industries and enterprises have been established in the health governmental sector over the last 30 years. To improve this surveillance system, the chemical enterprise inspections were classified into three groups including fires, second and third class factories based on hazardous agents and severity of risk from 2012.

The analysis of a chemical accident is indispensable for the further development of accident prevention [15]. In the present study, we have gathered data related to the chemical accidents based on the national records of the Ministry of Health's (MOH) database. This study was aimed to characterize the chemical accidents occurring in Iran during the period of 2018-2020.

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METHODS

This cross-sectional study was conducted in 2020. The samples included all chemical accidents occurring across Iran from 23 August 2018 to 23 August 2020.

The characteristics and the number of inspections from enterprises were described as follows [16]:

Group I:

Enterprises with high chemical hazards including agents that can cause serious poisoning, cancer, reproductive or developmental disorders, strong allergic reaction, delayed immunological reaction, and death. These chemical enterprises must be inspected at least three times yearly until the hazards are controlled otherwise the surveillance should continue.

Group II:

Enterprises with moderate chemical hazards including agents that can be controlled and do not have sever effects on human health.

Group III:

Enterprises with low chemical hazards including inert agents.

Yearly or twice a year inspection should be conducted for the enterprises in groups II and III.

Data source:

The chemical accident data were obtained from the chemical accident registration system's database in Iran. It is categorized by the inspectors of the Ministry of Health in four levels: Deputy Minister of Health, city health center, comprehensive health service center, and health house. The total inspection data from all enterprises and industries are registered in the database by occupational health inspectors

throughout Iran. Furthermore, the occupational health inspectors record the locations of previous chemical accidents history and register the detailed accident report in the inspection database. This data consisted of variables such as time of chemical events, occurrence of chemical accident, identification of chemicals, labeling, employee access to safety data sheet (SDS), building and storage method, isolation of hazardous chemicals, safe transport of chemicals, unloading/loading and disposal of chemical waste, observation of order and cleanliness, number of employees, type of chemicals, amount of chemical, factory establishment time, and education.

Data selection

This study was conducted in the chemical enterprises and industries with more than 25 employees. They had potential to cause chemical accidents and requiring development of a chemical accident plan in an emergency. These industries are located throughout the country, and mainly include fuel stations, petrochemicals, refineries, and chemical industries which maintain the chemicals listed in the threshold planning quantity (TPQ) list or other chemicals that have the potential to cause accidents.

In the current study, industries were classified according to the main chemicals responsible for causing the accident, including chlorine and ammonia, liquid fuels such as gasoline, naphtha, oil and diesel, sulfuric acid, H_2S and other chemicals used in industries.

The limits announced by the US Environmental Protection Agency (EPA) are available as TPQ tables.

In the MOH inspection database, data were registered in two ways: a detailed report before the chemical accident provided during routine inspections. This detailed report provides key information data about the type and quantity of chemicals, place and method of storing, prevention or mitigation strategies from chemical accidents, and totally presents the situation of chemical enterprises in chemical risk management. Another data consists of a detailed accident report after the chemical accidents occurred in the included enterprises.

The report presents chemical events in terms of feedback on the causes of events, consequences, follow-up measures taken in the short or medium-term after chemical accidents occurred.

The research team screened the registered data for total chemical enterprises including the ones with chemical incidents occurring as well as those were without chemical accidents in the study from August 2018 to August 2020. Additionally, there were some missing data in registered data, but they had been completed using contact to local officials. In this study, deactivation, closure or change of use of the selected workshop were the exclusion criteria.

Data analysis

Descriptive statistics were applied to measure the chemical accidents' frequency and percentage based on time, location, deaths, injuries, type, and causes of injury. Thereafter, the classified enterprises (Group I, II and III) were compared in terms of occurrence and non-occurrence of chemical events. Also, a comparison was done between these enterprises regarding 19 effective factors in chemical risk management.

Analytical tests were used to examine associations between the main variables of the study. The Chi-square test was applied to the qualitative categorical variables including risk degree of enterprises and chemical accident occurrence to determine the relationship and the significant difference between the variables. The Chi-square test by means of Monte Carlo simulations was used to understand the relationship between the occupational health expert in a chemical plant and occurrence or non-occurrence of a chemical accident. Additionally, Odds Ratio (OR) was calculated to determine the relationship between increase in the risk degree of the enterprise and chemical incidents occurrence. Data were analyzed using SPSS version 21, and 0.05 was considered as a cutoff for the significant level.

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RESULTS

Descriptive analysis

Totally, 40 HCA have been reported in Iran during 2018-2020. Based on the analysis of the chemical incidents, it was found that the most involved chemical sectors were refineries, petrochemical companies, oil industries, mines, producing basic chemicals, filling gas cylinders, and other industries where chemicals were used as a raw material or during the production process.

In the terms of chemicals type, the reviewed accidents caused by corrosive and flammable liquids were the largest, followed by explosives/toxic gases. Chemicals of Chlorine, ammonium and hydrogen sulfide were the hazardous chemicals among Iranian workplaces. 65% of chemical incidents (26 events out of 40) caused injuries where 121 injured person and 35% of chemical events were associated with 20 deaths in the years under study (Table 1). Further, 88% of these events had occurred in the indoor areas while12 % were in the outdoor areas.

Table 1. distribution of chemicals accidents and consequences in Iran, 2018-2020

Characteristics	Causative chemical agent						Total
	Chlorine/ Ammonium	*Sulfuric acid*	*Naphtha/ Petrol*	*Gas cylinders*	*Hydrogen sulfide*	*Others*	
Number of accidents	8	8	7	5	4	8	40
Death	2	1	4	4	6	3	20
Injuries	53	9	3	37	18	1	121

Although, chemical accidents were distributed across the country some major cities had a share in these accident reports. The accident distribution considering different provinces has been presented in Figure 1.

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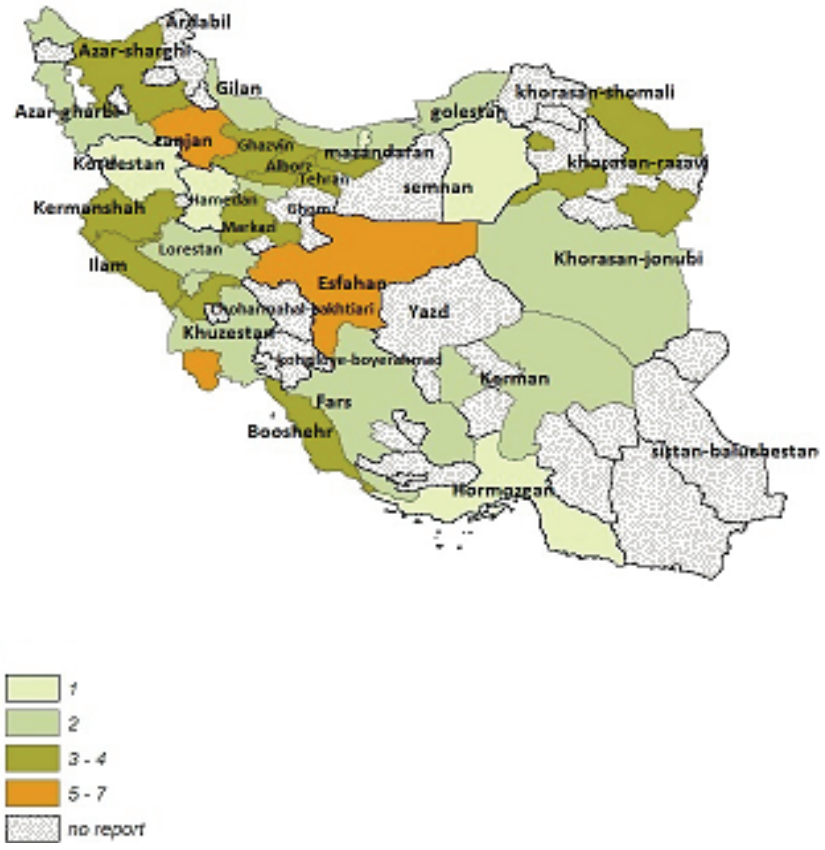

Fig1. Provincial distribution of HCAs during 2018-2020 in Iran

According to the results of Figure 1, it can be concluded that the north-west, south, and central provinces (e.g., Zanjan, Khuzestan, Boushehr and Esfahan) have more HCA and, the north, northeast, and western provinces (e.g., Mazandaran, Khorasan-Razavi, Kermanshah, and Ilam). In terms of the death toll of every accident, Khuzestan and Boushehr provinces had the largest number, followed by Isfahan and Kermanshah. Time statistical analysis was conducted at two levels including season and month, shift work, and hour. Time statistical characteristics have been shown in Figure 2 based on each defined level.

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Fig 2. Time statistical characteristics of chemical accidents

The seasonally and monthly occurrence of chemical accidents indicated a decreasing trend from spring to winter as well as from March to February in the subsequent years. Meanwhile, the study of chemical accidents occurrence according to shift work and hour showed a similar decreasing trend from morning to night.

Several causes can result in chemical accidents. Thus, in the analysis of chemical accidents, two or three parameters might interact to each chemical event occurring in the present study. According to the data analysis of the direct cause of chemical incidents, 45% were related to equipment/utilities failure. Defective chemical process and lack of familiarity with situation and process (illegal or improper operations) were the other main causes of chemical events with 32.5% and 27.5%. The contribution of various causal factors to HCAs has been shown in Table 2.

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Table 2. main causes of HCAs in Iran, 2018-2020

No.	Main cause of chemical accidents	Frequency	Percent (%)
1	Not considering 5S in workplace	4	10
2	Equipment/utilities failure	18	45
3	Defective process	13	32.5
4	External/environmental factors	6	15
5	Not familiar with situation and process	11	27.5
6	Fatigue/distraction	4	10
7	Anger/precipitancy	3	7.5
8	Non or insufficient training of employees	2	5
9	Others	9	22.5

The CSMP in chemical industries of Iran has been started since 2015. During this program, the employers are enforced to take some effective measures in workplaces to prevent chemical incidents. The occupational health inspectors supervise and register data about the implementation of chemical safety management measures during the inspection of chemical workplaces. According to the legal requirements of the CSMP implementation, the employer of a hazardous chemical installation must also prepare and submit the CSMP report to the regional office health. The outcomes of Figure 4 indicates that the conducted measures of CSMP in the chemical enterprises were compared to accident-free cases.

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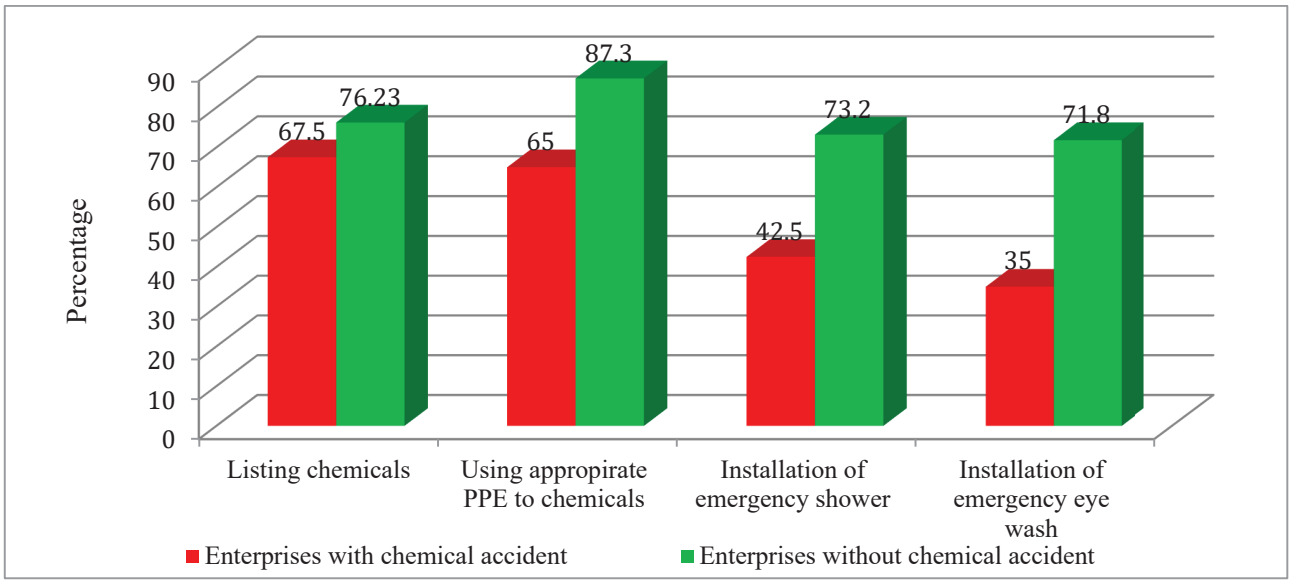

Fig4. Conducted measures of CSMP in the surveyed workplaces

Analytical analysis:

The odds ratio was calculated to show the probability of the chemical accident occurs in relation to the probability where the chemical event does not occur due on the chemical accidents statistics and risk degree of chemical enterprises (Group I in comparison to Group II and Group III)(Table 3).

Table 3. frequency distribution of chemical enterprises according to degree of risk and the number of chemical accidents.

No.	Risk degree of chemical enterprises	With chemical event		Without chemical event	
		Frequency	*Percent (%)*	*Frequency*	***Percent (%)***
1	Group I	31	78	289	**53**
2	Group II	8	20	251	**46**
3	Group III	1	2	6	**1**

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The odds ratio calculation indicated that the probability of occurrence of a chemical event in Group I enterprises was 3.4 times higher than that of event in Group II and Group III enterprises. On the other hand, the estimate of the odds ratio that a chemical event would not occur was 1.12. The estimate of the odds ratio was therefore 3.03.

The results indicated several relationships between the studied factors of CSMP and enterprises with/without chemical accidents as shown in Table 4. The Chi-Square test was applied for all factors under study and Chi-square test by means of Monte Carlo simulations was used for cases with more than 20% of expected counts are less than 5 or any individual expected was less than 1.

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Table 4. Significant results of analytical tests between the variables of the study and enterprises with /without chemical accidents

Interfering factors of CSMP	Chemical enterprises								Statistical test	P-value
	With accidents				Without accidents					
	Yes	*(%)*	*No*	*(%)*	*Yes*	*(%)*	*No*	*(%)*		
Providing SDS for all chemicals	23	57.5	11	27.5	396	74.72	47	8.87	Chi-Square	**0.001**
Chemical labeling	23	57.5	13	32.5	408	76.98	44	8.3	Chi-Square	**0.014**
Safe storage of Hazardous chemical	18	45	13	32.5	407	76.79	57	10.75	Chi-Square	**0.001**
Isolating the hazardous chemicals	19	47.5	11	27.5	456	86.04	41	7.74	Chi-Square	**0.001**
Appropriate warehouse for storage of chemicals	15	37.5	14	35	482	85.47	43	8.11	Chi-Square	**0.001**
Chemical safe loading and discharge	28	70	9	22.5	410	77.36	74	13.96	Monte Carlo	**0.028**
Chemical safe transportation	26	65	9	22.5	433	81.7	45	8.49	Monte Carlo	**0.013**
Healthy and safe elimination of chemicals	15	37.5	15	37.5	444	83.77	52	9.81	Chi-Square	**0.001**
Installation of fire distinguish system in workplace	26	65	8	20	456	86.04	58	10.94	Monte Carlo	**0.004**
Workers chemical training	26	65	9	22.5	409	77.17	82	15.47	Monte Carlo	**0.028**
Employers chemical training	28	70	9	22.5	291	54.91	169	31.89	Monte Carlo	**0.646**
Occupational health experts chemical training	20	50	16	40	500	94	30	6	Chi-Square	**0.001**
Filling out the checklist of chemical accidents prevention regularly by employers	16	40	17	42.5	324	61.13	182	34.34	Chi-Square	**0.228**
Providing emergency response plan	15	37.5	18	45	381	71.89	149	28.11	Chi-Square	**0.001**

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The CSMP main elements including providing Safety Data Sheet (SDS), chemical labeling and emergency response plan, safe storage, transportation, and elimination of chemicals, isolating the hazardous chemicals in the workplace, and training of occupational health experts were significantly related to accident occurrence in the chemical industries (P-value<0.01). These significant results were also observed in other similar relationships between the safe loading and discharge of chemicals and training of workers and chemical accident occurrence (P-value<0.05). Thus, the alternate hypothesis which stated that; "there are positive and significant relations between the mentioned parameters and occurrence of chemical accidents" was accepted. In addition, the installation of a fire distinguishing system had a significant relationship with chemical accidents in the surveyed workplaces (P-value<0.001).

DISCUSSION

He results of this study indicated that the risk of HCAs occurrence in group I workplaces was higher than in chemical enterprises of group II and group III. The chemical plants that considered the elements of CSMP in their work environments had fewer HCAs. The related evidence also showed that the chemical enterprises which neglected the regulations and principles of CSMP had more chemical accidents in their background. Esfahan as one of the industrial provinces in the center of Iran has the largest steel industries across the country. In this study, Esfahan province had the most chemical accidents. It was followed by Khuzestan and Bushehr provinces in the south of Iran due to the existence of refinery and petrochemical complexes in these provinces [17]. Almost every province is investing in establishing chemical plants and industries. The HCAs exhibited regional differences, but the data analysis showed that the more accident-prone provinces have been located in the north-west, center, and south of Iran. A necessity for stricter rules and regulations for chemical safety management in the high density industrial provinces should be implemented to control the occurrence of chemical accidents.. This finding is confirmed by different studies that the economically developed provinces need more official rules and supervisions in order to prevent accidents and mitigate the harmful consequences [7-18]. In this regard, Heo et al. identified the potential chemical accident occurrence in South Korea by analyzing the spatial distribution of chemical factories and accidents [19].

Although many laws, regulations, and instructions are constantly updated and compulsory for implementation in chemical industries, HCAs still occur in Iran [5]. The occurrence of chemical accident is often the result of multiple factors and interaction of different parameters [20]. The equipment and utilities failure, and lack of familiarity with the situation and process were the most common factor related to the causes of accidents.

The equipment and utilities failure would happen due to human factors as direct cause while managerial and organizational factors occur as the root cause of chemical accidents [21-22]. This finding was similar to the results of a study performed by Wang et al, on HCAs during hot season in china, 2020 [23]. Thus, strict safety inspections and auditing programs, providing and promoting safety culture are indispensable components of chemical safety that should be associated with implementation of chemical rules and regulations in workplaces [24-25].

Furthermore, increased awareness and measures to prevent and control the chemical accident occurrence is necessary through gaining access to updated information on chemical accidents, adequate training for employers, and personnel of chemical plants or enterprises [26]. these training courses should be continued for local communities in order to prepare the residents against chemical accidents [27-28]. In Iranian small-sized chemical enterprises there are more problems as they more suffer from lack of expertise, economic resources and awareness of chemical health and safety legislation in comparison to medium- and large-sized chemical enterprises.

Previous studies results also showed that the promoting awareness of employers and workers may plays an important role in the prevention of chemical accidents in small and medium-sized enterprises [29-30]. Additionally, providing emergency response plan and conducting exercises regularly in chemical workplaces assist people to make a correct decision during emergency [31-32].

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Limitations:

Due to the scope of this research, we encountered limitations during the study. The most important limitations of this research are as follows:

• Refusal of employers to inform and report chemical accidents

• Incomplete registration of information such as date, time of the accident, number of casualties, deaths and damages caused by the accident, the chemicals responsible for causing the accident and the like.

• Lack of strict actions of occupational health inspectors against employers who refuse to provide information.

• Carelessness of experts in recording chemical accident information and incorrect information.

CONCLUSION

Based on the findings of this study, chlorine, ammonia, naphtha, gasoline and heavy fuels, hydrogen sulfide, pressurized cylinders such as oxygen capsules, and sulfuric acid were the main chemicals agents for occurrence of chemical accidents in Iranian industries and result the biggest share of casualties.

The main factors for occurrence of chemical accidents in Iran were defective equipment and tools, defective processes, lack of familiarity of employees with the conditions and processes, lack of staff training, inappropriate environmental conditions, lack of order and cleanliness, fatigue and distraction, anger, and haste.

Having a written emergency response plan, separation of hazardous chemicals, suitability of the chemical storage facility, safe and hygienic storage of hazardous chemicals, labeling containers and goods containing hazardous chemicals, preparation of SDS and making it available to the staff, safe loading, unloading and transportation of chemicals, hygienic disposal and safe hazardous chemicals were important considerations in preventing accidents.

Training the target groups, including employees working with chemicals, employers and industry owners, health experts responsible for the prevention of chemical accidents in industry had a significant impact on the prevention of chemical accidents.

Providing the necessary facilities and equipment by the employer, such as personal protective equipment for hazardous chemicals, providing emergency showers as well as eyewash plays an important role in preventing or reducing injuries caused by chemical accidents.

Continuous monitoring by the employer or his representative (industry occupational health expert) for compliance with GHS regulations also plays an important role in preventing the occurrence of chemical accidents.

Continuous and active supervision of health and labor inspectors and timely warning of defects to the employer and introducing them to the competent authorities in case of not paying attention to these health and safety warnings are significant in preventing the occurrence of chemical accidents.

The analysis of past events is an effective method to detect weaknesses in the chemical industries. The lesson learned from chemical accidents would develop prevention plans, in order to reduce the number of incidents in chemical industry. Further, because of probable underestimation of registered records on the national database, particularly in the small-sized chemical enterprises, there is a need for surveillance system to data collection at the local level. As a final recommendation, the strict supervision on rules and regulation of CSMP, as a tool forth assurance of inherently safer chemical enterprises and the prevention of major accidents should be intensified.

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CONFLICT OF INTEREST:

The authors declare that there is no conflict of interest.

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