Analysis of Chemical Incidents, under the Seveso Directive; in terms of direct fatalities and injuries

Ana María Cintora *
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†anamaria.cintora@salud.madrid.org

Eva Teresa Robledo
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†etrobledo@hotmail.com

Cristina Gómez
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†cgomezu@salud.madrid.org address

Raquel Lafuente
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†raquel.lafuente@salud.madrid.org

Ricardo García
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†rgarciamartinez2@salud.madrid.org

Cristina Horrillo
Prehospital Emergencies Medical Service
Madrid Region (SUMMA112)
Madrid, Spain
†cristina.horrillo@salud.madrid.org

ABSTRACT

This paper provides a descriptive analysis of the eMARS database, which contains compulsory information on major chemical incidents under the SEVESO Directive. This analysis serves to assess the installations with the highest number of direct fatalities and injuries. At present, the data collected to assess the status of chemical accident risk globally are rather limited. There are some sources of data on chemical accidents in government and industry that might be used to estimate the frequency and severity of some types of events, but they are far from providing a complete perspective that covers all chemical accidents, thus limiting the possibilities of obtaining a more homogeneous picture of the risk of chemical accidents worldwide.

Waste storage, treatment and disposal is one of the industrial areas with the highest number of fatalities and injuries, so we must emphasize the importance of this type of industry within the risk maps.

Keywords

Major accident hazards, Seveso, chemical accidents, loss data, emergency preparedness.

INTRODUCTION

The eMARS database[1] is a database of major chemical accidents reported under the Seveso Directive (2012/18/EU). It is an objective source of information on the actual circumstances that occurred in the most serious chemical incidents of recent years, so that lessons can be learned from them (Reche 2018). It is based on the Major Accident Reporting System first established by the EU's Seveso Directive 82/501/EEC in 1982 and has remained in place with subsequent revisions to the Seveso Directive in effect today[1].

The purpose of eMARS[1] is to facilitate the exchange of information from lessons learned from accidents and

*corresponding author
†https://comunidad.madrid/hospital/summa112 /
[1]https://emars.jrc.ec.europa.eu/en/emars/content

near misses involving hazardous substances in order to improve chemical accident prevention and the mitigation of potential consequences.

The direct impact these accidents have on society and the information they provide is very important to prevent future similar incidents. For this reason, we have analyzed the number of injuries and fatalities due to serious incidents recorded after the implementation of the SEVESO Directive. We have identified key indicators and descriptors related to the most common and hazardous substance and industry types and applied them to the development of a simulated chemical incident within the Search and Rescue Project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 882897.

AIM

To identify the industries with the highest frequency of serious chemical incidents with direct casualties (injuries or fatalities).

METHODOLOGY

A descriptive cross-sectional study using the eMARS database and covering the period from January 1980 to December 2020. The eMARS (Major Accident Reporting System) aims to facilitate the exchange of information from lessons learned from accidents and near misses involving hazardous substances in order to improve chemical accident prevention and the mitigation of potential consequences[1]. The eMARS database contains reports of chemical accidents and near misses provided to the Major Accident Hazards Bureau (MAHB) of the European Commission's Joint Research Centre (JRC) from EU, EEA, OECD and UNECE countries (under the TEIA Convention). Reporting an event into eMARS is compulsory for EU Member States when a Seveso establishment is involved, and the event meets the criteria of a "major accident" as defined by Annex VI of the Seveso III Directive (201218/EU). For non-EU OECD and UNECE countries, reporting accidents to the eMARS database is voluntary. The information of the reported event is entered into eMARS directly by the official reporting authority of the country in which the event occurred. Seven (7) variables from this database were included in the study: - date of accident, -type of industry, -accident description and classification, -substance code, -fatalities and injuries. The main outcome variables were 1) type of industry and 2) type of substance, with the number of fatalities and injuries analyzed for each of these two main variables. The total number of chemical incidents or near misses was 411. The injury and fatality rate per event caused by industry type and substance type was calculated. The statistical program used was SPSS v25.

RESULTS

From the analysis of the 411 incidents – classified as serious and very serious – covered by the SEVESO regulation, which occurred over the period 1980-2020, the following results were obtained in terms of number of fatalities and injuries (Table 2) resulting from each incident per type of industry (Table 1).

	Classification of Industry Type by number of recorded events and serious injuries caused
1	Waste storage, treatment and disposal
2	Chemical installations
3	LPG production, bottling and bulk distribution
4	Production, destruction and storage of explosives
5	Production and storage of fireworks
6	Production of basic organic chemicals
7	Power generation, supply and distribution
8	Handling and transportation centers (ports, airports, lorry parks, marshalling yards, etc.)
9	Mining activities (tailings & physicochemical processes)

10	Fuel storage (including heating, retail sale, etc.)
11	Processing of metals
12	Agriculture
13	Petrochemical / Oil Refineries
14	- not known / not applicable -
15	Plastic and rubber manufacture
16	Manufacture of food products and beverages
17	Wholesale and retail storage and distribution (excluding LPG)
18	Production of pharmaceuticals
19	Production and storage of fertilizers
20	Wood treatment and furniture
21	Other activity (not otherwise specified in the list)
22	General chemicals manufacture (not otherwise specified in the list)
23	Production and manufacturing of pulp and paper
24	Production and storage of pesticides, biocides, fungicides
25	Leisure and sport activities (e.g., ice rink)
26	Textiles manufacturing and treatment
27	Building & works of engineering construction
28	General engineering, manufacturing and assembly

Table 1: Classification of Industry Type

According to the type of industry, after analyzing the 28 main types of industries detected, the results obtained were classified into the industries that, by ratio (amount of deaths/number of incidents) caused fatalities in each incident according to the type of industry (Table 2).

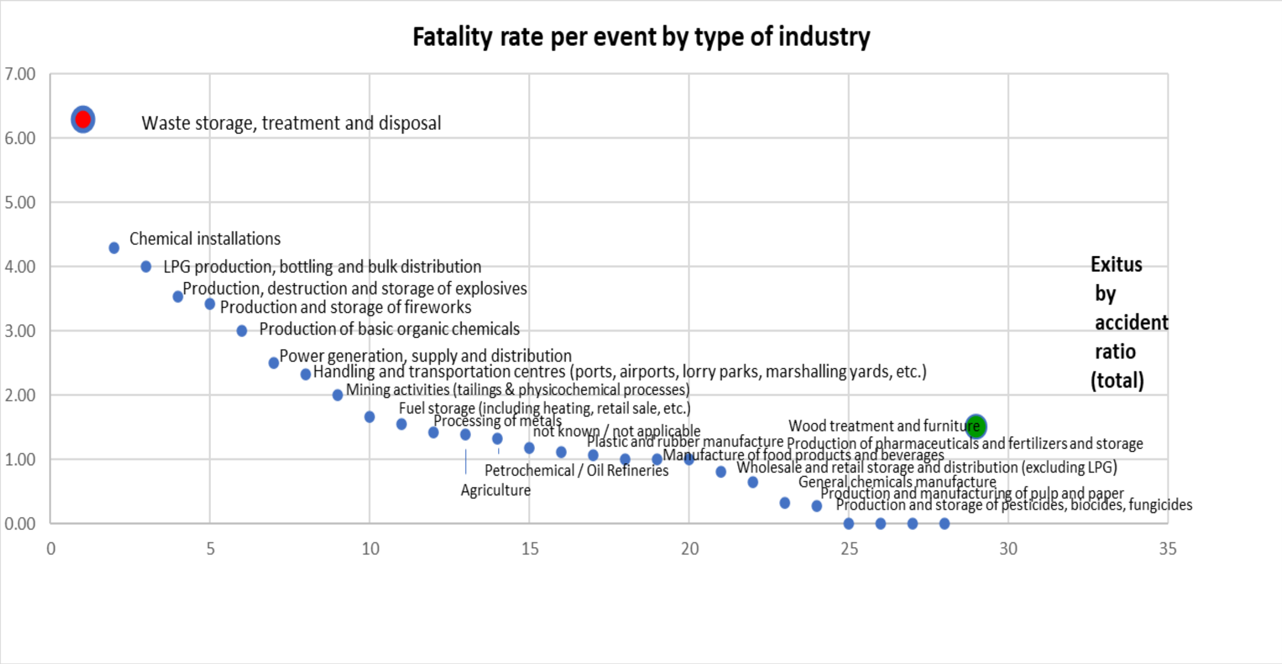
	Industry Type by number of recorded events and fatalities caused	**Events**	**Exitus caused**	**Ratio (deaths/events)**
1	Waste storage, treatment and disposal	10	63	6.30
2	Chemical installations	20	86	4.30
3	LPG production, bottling and bulk distribution	1	4	4.00
4	Production, destruction and storage of explosives	24	85	3.54
5	Production and storage of fireworks	7	24	3.43
6	Production of basic organic chemicals	5	15	3.00
7	Power generation, supply and distribution	6	15	2.50
8	Handling and transportation centers (ports, airports, lorry parks, marshalling yards, etc.)	3	7	2.33
9	Mining activities (tailings & physicochemical processes)	1	2	2.00
10	Fuel storage (including heating, retail sale, etc.)	3	5	1.67
11	Processing of metals	33	51	1.55
12	Agriculture	7	10	1.43

13	Petrochemical / Oil Refineries	56	78	1.39
14	- not known / not applicable -	3	4	1.33
15	Plastic and rubber manufacture	17	20	1.18
16	Manufacture of food products and beverages	16	18	1.13
17	Wholesale and retail storage and distribution (excluding LPG)	33	35	1.06
18	Production of pharmaceuticals	3	3	1.00
19	Production and storage of fertilizers	1	1	1.00
20	Wood treatment and furniture	1	1	1.00
21	Other activity (not otherwise specified int the list)	21	17	0.81
22	General chemicals manufacture (not otherwise specified int the list)	104	68	0.65
23	Production and manufacturing of pulp and paper	9	3	0.33
24	Production and storage of pesticides, biocides, fungicides	18	5	0.28
25	Leisure and sport activities (e.g., ice rink)	5	0	0.00
26	Textiles manufacturing and treatment	2	0	0.00
27	Building & works of engineering construction	1	0	0.00
28	General engineering, manufacturing and assembly	1	0	0.00
	Total	**411**	**620**	**1.51**

Table 2: Number of incident fatalities by type of industry

The 8 industries where the highest number of fatalities occurred in each event are shown below, being the waste storage, treatment and disposal industry the one with the highest number per ratio, with a result of 6 fatalities per event. The remaining industries with the highest number of fatalities per event, with a ratio ranging between 3 and 4 fatalities, are chemical installations and Liquefied petroleum gas (LPG) production, bottling and bulk distribution. Graphic 1 shows the number of deaths on the x-axis and the number of fatalities by industry according to the ratio on the y-axis. The Table shows that in the waste storage, treatment and disposal industry, for every 10 incidents there were 63 fatalities, giving a ratio of 6.3, and in the chemical installations industry, for every 20 incidents there were 86 fatalities, giving a ratio of 4.30.

The third industry is LPG production, bottling and distribution, which in a single event caused 4 deaths, giving a ratio of 4.00. In fourth place is the explosives industry, where 24 events resulted in 85 deaths, with a ratio of 3.54. In fifth place, the fireworks industry with 7 events that caused 24 deaths, giving a ratio of 3.43. In sixth place is the production of basic organic chemicals industry, that in 5 events caused 15 deaths, with a ratio of 3.00. In other place is the power generation, supply and distribution industry with 6 events and 15 deaths, giving a ratio of 2.50. The last industry represented in the Table (handling and transportation centers) accounted for 7 fatalities in 3 incidents, giving a ratio of 2.33.



Graphic 1: Number of deaths and industry according to ratio

On the opposite side, there are also less lethal or fatality-free industries, such as textiles manufacturing and treatment, building and works of engineering construction and general engineering, manufacturing and assembly, with an incident fatality ratio of 0. Graphic 2 represents the number of deaths on the x-axis and the number of the industry according to the ratio on the y-axis. The industries with the lowest number of fatalities are the last six.

The industries from the list, represented in the graphic according to their ratio, are the following: production and manufacturing of pulp and paper, where 9 incidents resulted in 3 fatalities, with a ratio of 0.33; production and storage of pesticides, biocides, fungicides, where 18 incidents resulted in 5 fatalities, with a ratio of 0.28, leisure and sport activities, where 5 incidents resulted in 0 fatalities, with a ratio of 0, textiles manufacturing and treatment, where 2 incidents resulted in 0 fatalities, giving a ratio of 0, construction, where 1 incident resulted in 0 fatalities, giving a ratio of 0 and general engineering, manufacturing and assembly, where 1 incident resulted in 0 fatalities, giving a ratio of 0.

Once the 28 types of industry detected have been analyzed, the results obtained are classified into industries that, by ratio (amount of deaths/number of incidents) lead to injuries in each incident according to the type of industry (Table 3).

	Industry Type	**Events**	**Injuries**	**Ratio (injuries/events)**
	Production and storage of fireworks	7	3039	434.14
	Waste storage, treatment and disposal	10	1325	132.50
	Production, destruction and storage of explosives	24	2698	112.42
	Production of pharmaceuticals	3	88	29.33
	Agriculture	7	183	26.14
	Power generation, supply and distribution	6	137	22.83
	General chemicals manufacture (not otherwise specified int the list)	104	1485	14.28
	Manufacture of food products and beverages	16	185	11.56

	Production and storage of pesticides, biocides, fungicides	18	189	10.50
	Leisure and sport activities (e.g. ice rink)	5	52	10.40
	Production and manufacturing of pulp and paper	9	90	10.00
	Processing of metals	33	275	8.33
	Petrochemical / Oil Refineries	56	451	8.05
	Textiles manufacturing and treatment	2	14	7.00
	Other activity (not otherwise specified int the list)	21	128	6.10
	Production of basic organic chemicals	5	25	5.00
	Wood treatment and furniture	1	5	5.00
	Wholesale and retail storage and distribution (excluding LPG)	33	160	4.85
	Building & works of engineering construction	1	4	4.00
	Production and storage of fertilizers	1	4	4.00
	Plastic and rubber manufacture	17	51	3.00
	Handling and transportation centers (ports, airports, lorry parks, marshalling yards, etc.)	3	9	3.00
	Chemical installations	20	56	2.80
	Fuel storage (including heating, retail sale, etc.)	3	5	1.67
	- not known / not applicable -	3	4	1.33
	LPG production, bottling and bulk distribution	1	1	1.00
	General engineering, manufacturing and assembly	1	0	0.00
	Mining activities (tailings & physicochemical processes)	1	0	0.00
	Total	**411**	**10663**	**25.94**

Table 3: Classification of industries that, by ratio, lead to injuries in each incident according to the type of industry

Analyzing the number of injuries according to the type of industry, the production and storage of fireworks, the waste storage, treatment and disposal and the production, destruction and storage of explosives industries stand out for the number of injuries caused, having a ratio of more than 100 injuries per incident.

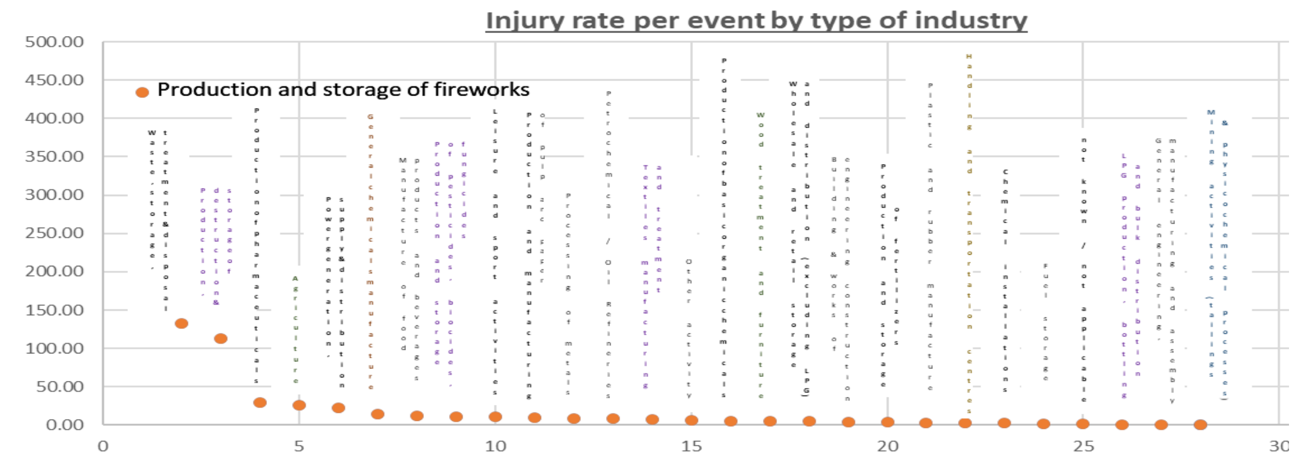
The average injury rate across all industry types is 25 injuries per incident, where the lowest rates result from the fact that there are industries that cause either very few or no injuries, being the industries that account for the least hazardous activities the general engineering, manufacturing and assembly and the LPG production, bottling and bulk distribution industries. Paradoxically, these industries account for the highest number of fatalities per incident, so it can be concluded that any incident occurring in any of these industries will lead to immediate fatalities, but due to the containment measures in place, there are very few injuries or no injuries at all. Graphic 2 represents the number of injuries on the x-axis and the number of industries by ratio on the y-axis.

In this graphic they are represented by ratio, in order from highest to lowest, with the number of injuries caused in each incident. The top industries from the list are the following: production and storage of fireworks, waste storage, treatment and disposal and production, destruction and storage of explosives, with an injury rate of more than 100 per incident.

Subsequently, and in this order, are the following types of industries: production of pharmaceuticals, agriculture, power generation, supply and distribution, general chemicals manufacture, manufacture of food products and beverages, production and storage of pesticides, biocides, fungicides and leisure and sport activities, all with an injury rate higher than 10 injuries.

The following industries that, in order from highest to lowest, cause between 10 and 1 injuries per incident, are: production and manufacturing of pulp and paper, processing of metals, petrochemical/oil refineries, textiles manufacturing and treatment, other activity (not otherwise specified in the list), production of basic organic chemicals, wood treatment and furniture, wholesale and retail storage and distribution (excluding LPG), building & works of engineering construction, production and storage of fertilizers, plastic and rubber manufacture, handling and transportation centers (ports, airports, lorry parks, marshalling yards, etc.), chemical installations, fuel storage (including heating, retail sale, etc.) and LPG production, bottling and bulk distribution.

Finally, the industries that do not lead to any injuries in any incident, i.e., the industries with no injuries per event are the following: general engineering, manufacturing and assembly and mining activities (tailings & physicochemical processes).



Graphic 2: Number of injuries and industry type by ratio

Substance type

Once the substances are grouped by hazard category and according to the risks they pose, they are classified as toxic, oxidizing, explosive and flammable, besides the risks associated with each one of them (Table 4).

Hazard category (substance)	Risks
(Very) toxic	(Very) toxic when inhaled
	(Very) toxic in contact with water
Oxidizing	Can cause a fire
	Promotes the combustion of flammable materials
	Can explode when mixed with a flammable material
Explosive	(High) risk of explosion by impact, friction, fire or another ignition
(Highly/extremely) flammable	Flammable
	Highly flammable
	Extremely flammable
	Spontaneously flammable in contact with air

Table 4: Hazard category and risk

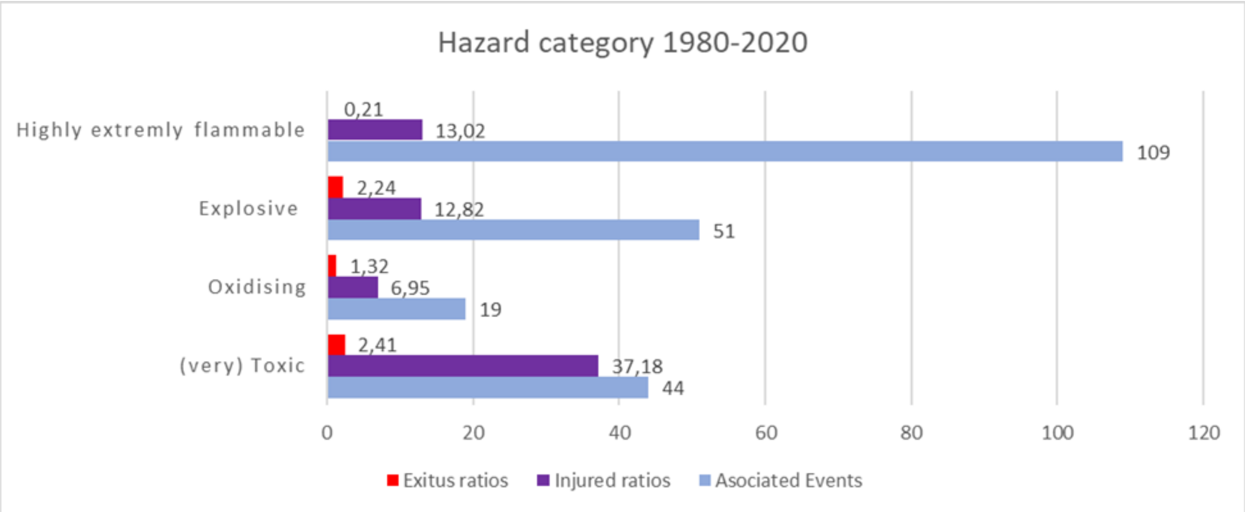
With all the events produced according to the group of substances described in the previous Table, applying all the categories involved to each substance, we obtain the total number of fatalities and injuries for each substance, as shown in Table 5.

Hazard substances	Injuries	Exitus	Associated Events	Injured ratios	Exitus ratios
(very) Toxic	1636	106	44	37.18	2.41
Oxidizing	132	25	19	6.95	1.32
Explosive	654	114	51	12.82	2.24
Highly extremely flammable	1419	23	109	13.02	0.21
Others	6822	352	188	36.29	1.87

Table 5: Total number of fatalities and injuries for each substance

An analysis of the above (Graphic 3) shows that each incident involving toxic substances results in 37 injuries and between 2 and 3 fatalities; each incident involving oxidizing substances results in 7 injuries and between 1 and 2 fatalities; each incident involving explosive substances results in 12 injuries and 2 fatalities and each incident involving flammable substances results in 13 injuries and between 0 and 1 fatalities.

It should be noted that there are significantly more incidents involving flammable substances where the risk to people in absolute numbers is lower, whereas the injuries caused by incidents involving toxic substances, although these are significantly fewer in number, increases considerably. Thus, we can assume that an incident involving toxic substances will result in a higher number of injuries and fatalities than an incident involving other types of substances.



Graphic 3: Total number of fatalities and injuries for each substance

Discussion

Databases are a source of information of national and international interest that serve as a tool to reduce the impact of critical events on society ((Reche 2018)). Rigor in the collection of data makes it possible to accurately describe the reality of these scenarios and to draw conclusions with adequate levels of evidence for an analysis based on lessons learned. The development of risk maps based on the analyses performed and a better understanding of the weaknesses and strengths of our critical event response services will enable us to improve our response to critical events. The purpose of our study by analyzing eMARS data[1] is to identify the types of industries and substances that cause the most injuries and fatalities.

The industry that accounted for the highest number of fatalities per incident was waste storage, treatment and disposal. This is usually not the industry that is most studied, nor is it the one on which research is proactively focused on. Therefore, based on the results of this analysis, it is worth assessing its importance, as it does not tend to occupy the highest priority points on the risk maps of health emergencies (5). On the opposite side, there are industries producing no fatalities, such as textiles manufacturing and treatment, building and works of engineering construction and general engineering, manufacturing and assembly, with a fatality-to-incident ratio of zero, which would allow us to adapt risk prevention maps to this casuistry (reflect on the cause). In order to draw up a risk map for planning the intervention and rehabilitation phase leading to a return to normality, it would be useful to take into account incidents that do not result in casualties but lead to a high percentage of the population being exposed to the toxic cloud generated and the adverse weather conditions. In cases such as these, the threat mitigation and evacuation secondary and tertiary prevention measures would be more important than those of the emergency services as such. We have found that if we take an incident where we put all hazardous substances together in groups of toxics, oxidants, explosives and flammables, there will always be between 5 and 40 injuries and 1 to 3 fatalities. This is important for emergency call centers and emergency health responders since we can use predictable data in crisis management.

There are other databases containing information on chemical accidents, such as ARIA, ZEMA, the U.S. Chemical Safety Board, the Japanese Failure Knowledge Database, the Tukes VARO registry of chemical accidents in Finland[1], which have not been analyzed but have been used as supporting literature. The interoperability of these databases in the future could reduce variability in data collection and consequently improve the results obtained.

The confidentiality of the company names and their location in the eMARS data recording is intended to prevent said industries from being sanctioned or penalized and to encourage the reporting of accidents[1]. This data, which is positive in terms of encouraging occurrence reporting, has the negative effect that additional data describing the environment and demographics where chemical events occurred are not available to include variables for drawing conclusions from the number of casualties. Thus, we might think that chemical accidents occurring in geographically dispersed areas may result in fewer casualties for being more isolated. Alternatively, we could try to explain whether the highest number of injuries or immediate deaths occurred in unpopulated areas or locations outside cities with difficult access to emergency services. Further studies that include the definition of these concepts are needed to better understand the mechanism of injury in these critical chemical accidents.

Although not addressed in this descriptive study as the Seveso Directive aims at increasing the prevention and protection against major accidents in installations where dangerous products are used, it would be interesting to analyze and determine whether the number of accidents in the industries involved in major accidents has decreased over the years or whether in the same industry the accidents sustained over the years have had fewer consequences in terms of number of injuries/fatalities. This would provide data on lessons learned, prevention strategies and corrective measures adopted, and would also show whether these have had a positive impact on the accidents. The eMARS database offers an aggregate count of injuries and fatalities for each event, and in some cases – although this is not a regulatory requirement – the victim profile (operator, worker, rescue service staff) is also recorded. To be consistent with one of the objectives of eMARS, it would be of great interest for emergency services and first responders to specifically and individually identify whether the injured/fatalities belong to any of these groups, as this can contribute to research on improving safety in the response to CBRN (Chemical, Biological, Radiological and Nuclear) incidents in critical events and disasters.

On the other hand, the results obtained in this study and the elaboration of a regional risk map could be useful for predicting consequences (as is currently done with the data classifications in the COVID-19 effect forecast) by developing a prediction model based on certain items such as: - type of industry, - type of substance, - population proximity to each industrial area... (Gothai 2021).

One of the limitations of data collection in compliance with the Seveso Directive is that installations which have registered quantities of dangerous products below their respective lower thresholds are not affected by the Seveso regulations and, therefore, the Competent Authorities in this area would not be informed about the potential hazards of such facilities, which could seriously affect the effectiveness of protective actions (Reche 2018).

Another shortcoming found when analyzing eMARS is the number of incidents in which there are no data on the substances involved[1]. This may have an impact on the safety of first responders and emergency services. Future studies to assess the incorporation of chemical substance sensors in first response equipment would be advisable to improve and be more efficient in the response provided. European research projects, such as the H2020 Search and Rescue project[2], are currently underway to improve the safety of first responders in such incidents[2] involving collapsed structures and CBRN (Chemical, Biological, Radiological and Nuclear

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[2]https://search-and-rescue.eu/overview/

Threats) environments by developing technologies that include, among others, hazardous gas detection sensors. To facilitate this, more specific and concise databases are needed (Heraty 2019).

CONCLUSIONS

- Substances classified as "highly toxic" cause the highest percentage of injuries and fatalities. "Oxidizing" and "highly flammable" substances cause the least injuries and fatalities, respectively.

-The "general chemicals manufacture" industry produces the highest number of adverse events. The "waste storage, treatment and disposal" industry has the highest ratio of fatalities and injuries.

-The "general engineering, manufacturing and assembly" and the "mining activities tailings & physicochemical processes" industries are the safest, with the lowest number of adverse events and no fatalities or injuries.

-The rapid and effective response of the emergency services to incidents caused by these types of substances and industries is essential. For this reason, the data obtained will allow us to draw up a regional risk map of chemical incidents in the most relevant cities, located within our scope of action, in Spain.

- The statistical results of the study could be used to predict the consequences first responders' actions in the hot zone. These results are also important as lessons learned for professionals and decision-makers.

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