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Descriptive Analysis of the Healthcare Aspects of Industrial Disasters Around the World

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Abstract

Objective: Industrial disasters can have a myriad of repercussions ranging from deaths, injuries, and long-term adverse health impacts on nearby populations, to political fallout and environmental damage. This is a descriptive epidemiological analysis of industrial disasters occurring between 1995 and 2021 which may provide useful insight for health-care systems and disaster medicine specialists to better prevent and mitigate the effects of future industrial disasters.
Methods: Data were collected using a retrospective database search of the Emergency Events Database (EM-DATS) for all industrial disasters occurring between January 1, 1995, and December 31, 2021.
Results: A total of 1054 industrial disasters were recorded from 1995 to 2021. Most of these disasters occurred in Asia (720; 68.3%), with 131 (12.4%) in Africa, 107 (10.2%) in Europe, 94 (8.9%) in the Americas, and 2 (0.2%) in Oceania. Half of these disasters were explosions (533; 50.6%), 147 (13.9%) were collapses, 143 (13.6%) were fires, 46 (4.4%) were chemical spills, 41 (3.9%) were gas leaks, and 34 (3.2%) were poisonings. There were 6 (0.6%) oil spills and 3 (0.3%) radiation events.
Conclusions: A total of 29,708 deaths and 57,605 injuries were recorded as a result of industrial disasters, and they remain a significant contributor to the health-care risks of both workers and regional communities. The need for specialized emergency response training, the potential devastation of an industrial accident, and the vulnerability of critical infrastructure as terror targets highlight the need to better understand the potential immediate and long-term consequences of such events and to improve health-care responses in the future.

Industrial disasters can have a myriad of repercussions ranging from deaths, injuries, and long-term adverse health impacts on nearby populations, to political fallout and environmental damage.

Well-publicized industrial accidents such as the 2010 Deepwater Horizon oil spill caused significant environmental and marine life damage and triggered the United States Department of Health and Human Services to set up a Gulf Long-term Follow-up Study (GuLF Study) to examine the human health consequences of the spill.[1]

The 2020 ammonium nitrate Beirut explosion killed over 200 people and injured over 7000 more with casualties from at least 22 countries, prompting the immediate mobilization of international experts across search and rescue, disaster management, and other emergency field teams (such as World Health Organisation's accredited Emergency Medical Teams) to support the humanitarian mission.[2–4]

Since the Russian invasion of Ukraine, the United Nations nuclear chief and the director general of the International Atomic Energy Agency have warned of a potential "nuclear disaster" with "catastrophic consequences" after the shelling of the Zaporizhzhya nuclear power plant in Ukraine by the Russian military.[5] This represents an escalation of risk, with Ukraine's 15 operating nuclear power stations, along with the Chernobyl site and its relatively fragile sarcophagus, being the first time such a high density of nuclear reactors exist in an active war zone. March 4, 2022, also marked the first time in history an operating nuclear power plant was struck as part of a military battle when the Zaporizhzhia station was hit with a projectile during nearby fighting.[6]

As in other disasters, process improvement opportunities are typically retrospectively identified following a major incident; however, given the widespread devastation that can result from both accidental and non-accidental (such as conflict, terrorism, or criminal related) industrial disasters, more needs to be done to mitigate the public health risks of such events.

This is a descriptive epidemiological analysis of industrial disasters occurring between 1995 and 2021 which may provide useful insight for health-care systems and disaster medicine specialists to better prevent and mitigate the effects of future industrial disasters.

Methods

Data were collected using a retrospective database search of the Emergency Events Database (EM-DATS) for all industrial disasters occurring between January 1, 1995 and December 31, 2021.

The EM-DATS provides free access for non-commercial purposes to data concerning international disasters compiled by the Centre for Research on the Epidemiology of Disasters (CRED) from sources such as United Nations (UN) agencies, nongovernmental organizations, insurance companies, research institutes, and press agencies.[7] Disasters are defined by the database as having at least 1 of the following criteria:

1. Ten or more people died.
2. One hundred or more people affected.
3. Declaration of a state of emergency.
4. Call for international assistance.

"Industrial disaster" is a pre-defined category and is further sub-classified into specific types. A disaster is defined by CRED in the glossary as "technological accidents of an industrial nature, or involving industrial buildings." All categories and definitions are predetermined by the EM-DATS as per their glossary.[8]

This classification system by the database follows the Integrated Research in Disaster Risk Peril Classification and Hazard Glossary.[9] The database was searched for all disasters occurring between 1995 and 2021 to minimize bias arising from the unavailability of records before and at the start of the database. Because industrial disasters are often sudden-onset, the date of the event could be reliably defined as the moment of occurrence. Total deaths included missing people who were presumed dead.

Results were exported into Microsoft Excel (Microsoft, Redmond, Washington) with totals tallied and percentages analyzed.

Results

A total of 1054 industrial disasters were recorded from 1995 to 2021. Most of these disasters occurred in Asia (720; 68.3%), with 131 (12.4%) in Africa, 107 (10.2%) in Europe, 94 (8.9%) in the Americas, and 2 (0.2%) in Oceania (Figure 1; Table 1).

Half of these disasters were explosions (533, 50.6%), 147 (13.9%) were collapses, 143 (13.6%) were fires, 46 (4.4%) were chemical spills, 41 (3.9%) were gas leaks, and 34 (3.2%) were poisonings. There were 6 (0.6%) oil spills and 3 (0.3%) radiation events (Figure 2).

A total of 29,708 deaths and 57,605 injuries were recorded from all industrial disasters.

Figure 3 shows deaths and injuries by year.

Explosions were the leading cause of both deaths (17,357, 58.4%) and injuries (21,736, 37.7%).

Collapses inflicted the second highest death toll (5,658, 19.0%), but had a comparatively low number of injuries (2,221, 3.9%).

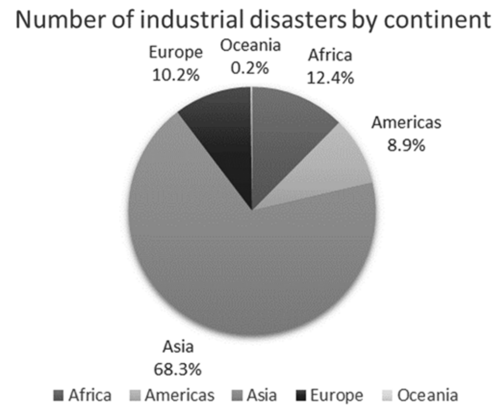

Figure 1. Number of industrial disasters from 1995 to 2021 by region.

Poisonings were the second highest contributor to injuries (16,784, 29.1%) but accounted for a proportionally small number of deaths (789, 2.7%).

Figure 4 shows deaths and injuries per event for each type of disaster.

The particularly large number of total injuries in 1996 was largely driven by a food poisoning outbreak in Sakai, Japan. 10,000 injuries and 8 deaths were reported from that episode. Similarly, the spike in total injuries in 2020 was due to 6,000 injuries from an explosion at the port of Beirut, Lebanon.

Tables 2 and 3 elaborates on the top 10 leading events by deaths and injuries, respectively. The 2013 collapse of Rana Plaza, a textile factory in Bangladesh killed 1127 and injured 1200 others. A 1998 oil pipeline explosion in Jesse Town, Nigeria, killed 1082 and injured 200. In contrast, a 1996 food poisoning outbreak in Sakai, Japan, injured 10,000 and killed a comparatively low number of 8 victims.

Discussion

The Convention on the Transboundary Effects of Industrial Accidents, signed in 1992 which went into force in April 2000, is a United Nations Economic Commission for Europe convention focusing on the protection of both people and the environment against industrial accidents.[10]

The Convention encourages international cooperation between countries in industrial disaster risk mitigation, prevention, and response by encouraging transboundary research collaborations and information sharing between states and regional organizations.

Industrial disasters with potential transboundary effects require that responsible states inform neighboring countries and regions. It is also important that before an event, regional partners ensure they have compatible emergency operations plans and a robust interoperability setup, should they need to surge and respond when local resources are overwhelmed.[11] The Industrial Accident Notification System and the Assistance and Cooperation Programme were created to facilitate these processes.[12]

The health aftermath of radiation industrial disasters such as Chernobyl and the Fukushima nuclear disaster remains controversial.[13] A 2014 report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the World Health Organization projected no increase in miscarriages, stillbirths, or physical and mental disorders in babies born after the Fukushima accident.[14,15] Although people in the

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Table 1. Number of industrial accidents of each type across continents

	Type of industrial disaster									
Continent	Chemical spill	Collapse	Explosion	Fire	Gas leak	Oil spill	Other	Poisoning	Radiation	Grand Total
Africa	3	62	42	10	0	0	11	3	0	131 (12.4%)
Americas	16	10	43	6	6	3	6	4	0	94 (8.9%)
Asia	13	71	393	106	29	2	80	23	3	720 (68.3%)
Europe	14	4	54	21	6	1	3	4	0	107 (10.2%)
Oceania	0	0	1	0	0	0	1	0	0	2 (0.2%)
Total	46 (4.4%)	147 (13.9%)	533 (50.6%)	143 (13.5%)	41 (3.9%)	6 (0.6%)	101 (9.6%)	34 (3.2%)	3 (0.3%)	1054 (100%)

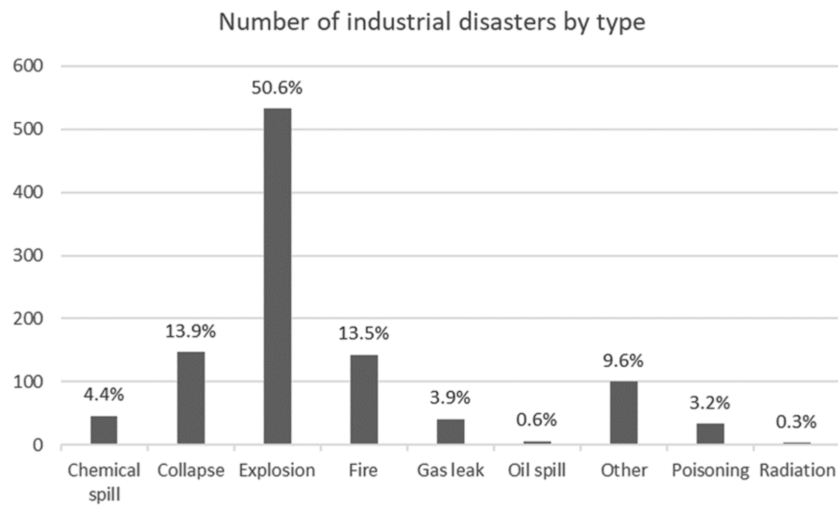

Figure 2. Number of industrial disasters from 1995 to 2021 by type.

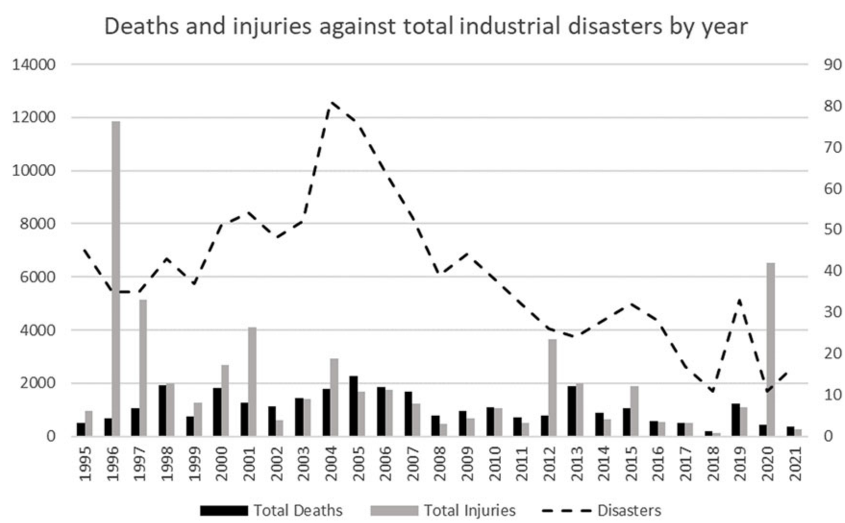

Figure 3. Total deaths and injuries caused by industrial disasters 1995 - 2021. The broken line represents the number of industrial disaster events.

incident's worst affected areas have a slightly higher risk of developing certain cancers such as leukemia, solid cancers, thyroid cancer, and breast cancer, the predicted risks for those in surrounding areas remain low, and no observable increases in cancer above natural variation in baseline rates are anticipated.[16] However, data from atomic bomb survivors and Chernobyl demonstrated a peak incidence of thyroid cancer at 25 y, with significant increase above baseline up to 60 y out.[17] As the Fukushima accident occurred in 2011, we cannot rely on data from it as being conclusive of the totality of effect.

In addition, the Chernobyl data demonstrated similar elevations of thyroid cancer, as well as other cancers; however, due to the loss of follow-up on upward of 800,000 liquidators (those brought in from around the Soviet Union tasked with the clean-up of the site over 3 y), definitive analysis of the stochastic effects of the Chernobyl disaster is impossible.[17] Review of historic

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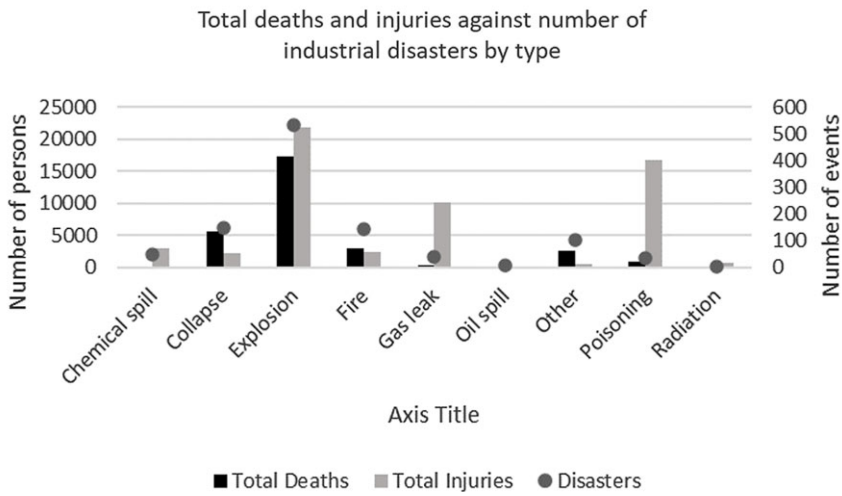

Figure 4. Total deaths and injuries according to types of industrial disasters. The round points represent the number of events within each type of industrial disaster.

radiation disasters have also shown a large socio-economic and psychosocial impact of the fear of radiation.

From a chemical exposure perspective, the acute toxicity of direct chemical exposure such as the Bhopal gas tragedy in 1984 can be devastating, but the longer-term burden of disease to certain toxic industrial chemicals remains uncertain (but likely under-estimated) as they may not have been measured or measurement may be difficult due to episodic exposure, unique chemistry, or low concentrations. There may also be absent or incomplete chemical monitoring data or other confounding factors might be present.[18,19]

The psychological impact of industrial and technological disasters, such as post-traumatic stress disorder (PTSD), guilt by association, and anger toward individuals held accountable can be profound and longstanding.[20] Peri-traumatic dissociation and distress, acute stress, and depression are all related to the development of PTSD after an industrial disaster.[21] In addition to PTSD, survivors of an industrial or technological disaster may also experience the compounded trauma of job loss, social stigmatization, as well as anxiety associated with the prolonged physical health effects from chemical or toxic exposures such as cancer, fertility issues, and heritability effects.[22]

Densely populated communities are frequently affected by industrial and technological disasters, often causing significant downstream effects on the local economy, ecology, and property, all of which may contribute to a public health crisis. While industrial disasters can be catastrophic, even the threat of such a disaster, such as the Three Mile Island nuclear reactor accident, can be enormously impactful on a community.[23] Due to the complex nature of industrial and technical disasters, the synergy between public health preparedness and emergency management is vital to community resilience within the all-hazards approach to disaster preparedness.[24,25] Preventative measures, early recognition, and adequate response are keys to mitigation and preparedness. As well, access to care, on-site specialized medical care, transportation of affected individuals to appropriate treatment facilities, and early rehabilitation are essential to optimize public health outcomes in the response and recovery phases of the disaster cycle.[26]

Though the data offer little insight regarding mortality/morbidity and other risk reduction measures in industrial disasters, many pre-hospital systems around the world have taken the incentive to better prepare their first responders. In Australia, for example, where a large mining, oil, and gas industry exists, "industrial paramedics" often have additional qualifications such as Major Incident Medical Management and Support Course and Basic Offshore Safety Induction and Emergency Training, as well as site and industry-specific training such as confined space rescue, self-contained breathing apparatus training in chemical exposures as well as vertical rescue qualifications.[27] Other short courses include safe access and egress training and scene management training of a major incident.[28] Other more extensive industrial disaster-specific medical courses also do exist but remain a relatively niche branch of disaster medicine.[29] Furthermore, injury-specific resources such as the Advanced Burns Life Support course, the American Burn Association's Disaster Response guidelines, and the World Health Organisation's Emergency Medical Teams Technical Working Group on Burns have widespread global support and expert consensus of their utility in improving mortality and morbidity outcomes in mass casualty burns disasters.[30–33]

Training and education aside, the Occupational Safety and Health Administration (OSHA) under the jurisdiction of the United States Department of Labor, sets robust emergency preparedness and response guidelines for the industrial sector which are considered gold standard around the world.[34]

While research around occupational morbidity and mortality in the industrial sector does exist around the world and continuously informs changes in safety policies and protocols, they are predominantly focused on causal factors of single accident events, rather than mass casualty events.[35,36] As expected, data collection in all disasters (whether it be natural or man-made) remains a difficult proposition but proposals and suggestions for interdisciplinary collaboration on critical data collection do exist, although adoption remains uncertain.[37,38] The international, Inter-Agency Coordination Group for industrial and chemical accidents have also published recommendations and framework for industrial and chemical accidents prevention, preparedness, and response, recognizing the need for a global strategy against such events.[39]

Most recently, a "Chain of Survival in Industrial Emergencies and Disasters" (early prevention, early recognition, early response system, early advanced care, and early rehabilitation) was proposed as a concept to reduce and mitigate risks of disasters but research specifically on industrial disasters related mortality and morbidity remains an area which needs further exploration.[40]

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Table 2. Ten leading industrial disaster events by total deaths

No.	Year	Location	Description	Deaths	Injuries
1	2013	Savar, Bangladesh	Collapse of Rana Plaza textile factory building	1127	1200
2	1998	Jesse Town, Nigeria	Explosion of oil pipeline	1082	200
3	2019	Minas Gerais, Brazil	Collapse of Brumadinho dam	334	0
4	2014	Manisa, Turkey	Explosion at Eynez coal mine	301	80
5	2006	Lagos, Nigeria	Explosion of Abule Egba pipeline	269	65
6	2000	Oviri Court and Aeje, Nigeria	Explosion of Warri pipeline	260	19
7	2012	Karachi, Pakistan	Fire at Baldia Town textile factory	240	0
8	2003	Kaixian, China	Explosion at Gao Qiao town gas well	234	700
9	2005	Fuxin, China	Explosion at Sunjiawan mine	214	29
10	2020	Beirut, Lebanon	Explosion at port of Beirut	206	6000

Table 3. Ten leading industrial disaster events by total injuries

No.	Year	Location	Description	Injuries	Deaths
1	1996	Sakai, Japan	Food poisoning outbreak in Sakai	10000	8
2	2020	Beirut, Lebanon	Explosion at port of Beirut	6000	206
3	2012	Gyeongsang, South Korea	Gas leak at Gumi National Industrial Complex	3178	5
4	2001	Toulouse, France	Explosion at AZF chemical factory	2442	31
5	1997	Cairo, Egypt	Unspecified poisoning at "Sel de tannerie"	2000	0
6	2013	Savar, Bangladesh	Collapse of Rana Plaza textile factory building	1200	1127
7	2000	Kaohsiung, Taiwan	Gas leak at Lee Chang Yung Chemical Company	1050	0
8	1997	Lahore, Pakistan	Gas leak from truck	900	32
9	2006	Leon, Nicaragua	Poisoning in city	800	44
10	2015	Tianjin, China	Explosion at Port of Tianjin	798	173

Prompt response to industrial disasters is crucial in reducing human health and environmental fallout, but can pose significant challenges when first responder safety is at risk. Chemical spills, infrastructure collapse, and explosions all pose unique dangers necessitating specialized skills, knowledge, and equipment to operate within those warm zones. Effective training of local first responders, emergency medical services (EMS), hospital personnel, and community volunteers is key to mitigating the adverse impacts of an industrial disaster. In addition, the lingering effects of industrial disasters, such as the health impacts of contamination and exposures, require a multidisciplinary approach of academic institutions, government officials, and community partners to better prevent future disasters and address their long-term ramifications.[41]

The frequency of industrial disasters has been down-trending since 2004, and pre-20th century, compensation for workers injured or killed while at work was comparatively cheap. Today, however, the financial cost of an injured worker includes medical bills, compensation, and productivity losses, and are much more significant, with the National Safety Council (NSC) estimating an average cost of $44,000.00 USD per injury requiring medical care and $1,300,000.00 USD per death.[42] While these figures may not be directly applicable to disasters outside of the United States, it does provide some context for the economic impact of industrial accidents and the importance of preventing them. The Convention on the Transboundary Effects of Industrial Accidents, as mentioned earlier, is 1 example of an international agreement aimed at preventing industrial accidents and mitigating their impact.

As a result of this upward shift in cost, along with other factors such as company reputation, and more robust industrial safety regulatory requirements, it became an industrial priority to invest in safety programs and equipment, with many industries pivoting from a previously reactive to a much more proactive approach today.[43]

While accidental events are largely preventable, intentional attacks on critical infrastructures such as the 2019 drone attacks on oil facilities in Saudi Arabia, the 2021 cyberattack on the Colonial pipelines in Texas, and the ongoing wartime shelling around the Zaporizhzhia nuclear plant in Ukraine are all cause for concern.[44]

Counter-Terrorism Medicine studies and analyzes the health-care impacts of intentional attacks and is an emerging subspecialty field of Disaster Medicine gaining traction as conflicts and threats escalate around the globe.[45,46] The compounding complexities of intentional attacks on critical infrastructure necessitates early multi-agency conversations around health system risk vulnerability analysis and mitigation and preparedness strategies in case of catastrophic events.[41,47]

Recommendations

Planning

Health systems should develop comprehensive local and regional preparedness plans, including strategies against Chemical, Biological, Radiation, Nuclear, and Explosives (CBRNe) exposure and injuries and other unique regional or local hazards, as well as protocols for escalating medical support, and evacuating and treating affected populations.

Education

Health systems should educate and train health-care workers, emergency responders, and the public on the potential health risks associated with industrial disasters. This includes specific training on CBRNe-related conditions as well as emergency management and mass casualty/counter-terrorism medicine/disaster education. This can also include participating in tabletop exercises, mass casualty simulation drills and being involved in creating after-action reports of such events.

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Collaborations

Health systems should work closely with other non-health agencies and organizations, such as environmental protection agencies and local governments, to better understand potential conflicts and hurdles in achieving a more streamlined industrial disaster response strategy.

Risk Assessment and Regulation

Health systems should participate in risk assessments and regulatory processes to identify and mitigate potential unique and general risks and better understand the industry standards required of industrial sites.

Surveillance Systems

Health systems should participate in the monitoring of the health effects of industrial disasters and engage in research to better understand the health impacts of such events on both the affected on-site workers, as well as the broader community.

Limitations

While EM-DATS is one of the most widely used databases on worldwide disasters from multiple credible sources, the lack of a universally agreed-upon definition of terms such as "industrial disaster" can create inconsistencies between databases in the labeling of such events.[48,49]

Although the definition used by EM-DAT agrees with other representative organizations like the Centers for Disease Control and Prevention, generalizability is limited and potentially excludes events that share the same hazard and risk, but take place in residential areas without registering as an industry. Another example is categorizing different hazards bearing different risks and implications as poisons on a database.

Reliance wholly on the EM-DATS is partially mitigated by confirmation with other lay sources and online searches, but if there are incidents not reported in the EM-DATS, this could limit the accuracy of the findings.

Using pre-existing databases such as the EM-DATS as a data source also inherently introduces potential challenges such as miscoding errors or data entry errors.

Clear and detailed documentation of events is further hindered by potential limitations and restrictions on reporting, the lack of independent corroboration, and the lack of transparency within certain government sources. The infrastructure needed to report and investigate such events may also be lacking in many parts of the world leading to potential under-reporting.

Conclusions

A total of 1054 industrial disasters were recorded from 1995 to 2021; 68.3% of these occurred in Asia, 12.4% in Africa, 10.2% in Europe, 8.9% in the Americas, and 0.2% in Oceania. A total of 50.6% of these were explosions, 13.9% were collapses, 13.6% were fires, 4.4% were chemical spills, 3.9% were gas leaks, 3.2% resulted in poisonings, 0.6% were oil spills, and 0.3% were radiation events. A total of 29,708 deaths and 57,605 injuries were recorded as a result of these events.

Industrial disasters remain a significant contributor to the health-care risks of both workers and regional communities. The need for specialized emergency response training, the potential devastation of an industrial accident, and the vulnerability of critical infrastructure as terror targets highlight the need to better understand the potential immediate and long-term consequences of such events and to improve health-care responses in the future.

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