Chemical Disasters
A Brief Periodic Insight to its Case Studies

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Abstract

Due to increase in industrial development and growth in India, chemical and allied industries have become an integral part of our society. Chemical industries, a boon to mankind has nowadays become a menace due to its improper handling causing chemical disasters. Since industrial age India has faced the most catastrophic disaster of all time - Bhopal Gas Tragedy making it of utmost importance to study, learn and reflect the aftermath mitigation measures of chemical disaster so as to make a sustainable and disaster resilient society. The current review article reflects the history and background of most tragic chemical disasters all over the world and provides an insight from the author's view in context of its mitigation and management.

Keywords: *Chemical Disasters, Industrial Disaster, Disaster Management, Sustainable Development, Case studies*

1. Introduction

Increasing population and urbanization in India has made industrial sector gear up development, continuing to become an industrialized country. The ever-increasing growth of industries in developing country like India reflects the close association and integration of economy, sustainable development, and societal welfare. Although, industrial and technology sector has gained a financial momentum in the market, it has further exposed the community to greater risk and vulnerability, inviting debacles with greater frequency, intensity and severity (Schepeers, 2015). Thus, rapid industrialization

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and population explosion within the residential areas in the close vicinity of industrial areas has exponentially raised the likelihood of occurrence of hazard or disaster and high risk of exposure to the society (Jayachandran, 2011).

Owing to geographical complexities and unique geo-climatic conditions country like India having diversified unique natural features, makes it prone for various catastrophic events (Shrivastava, 2010). According to Disaster Management Act 2005 of India, "Disasters can be defined as any catastrophe, mishap, calamity in any area, arising from natural or manmade causes, which results in substantial loss of life or human suffering, damage, destruction of, property, environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected areas". (Fig 1).

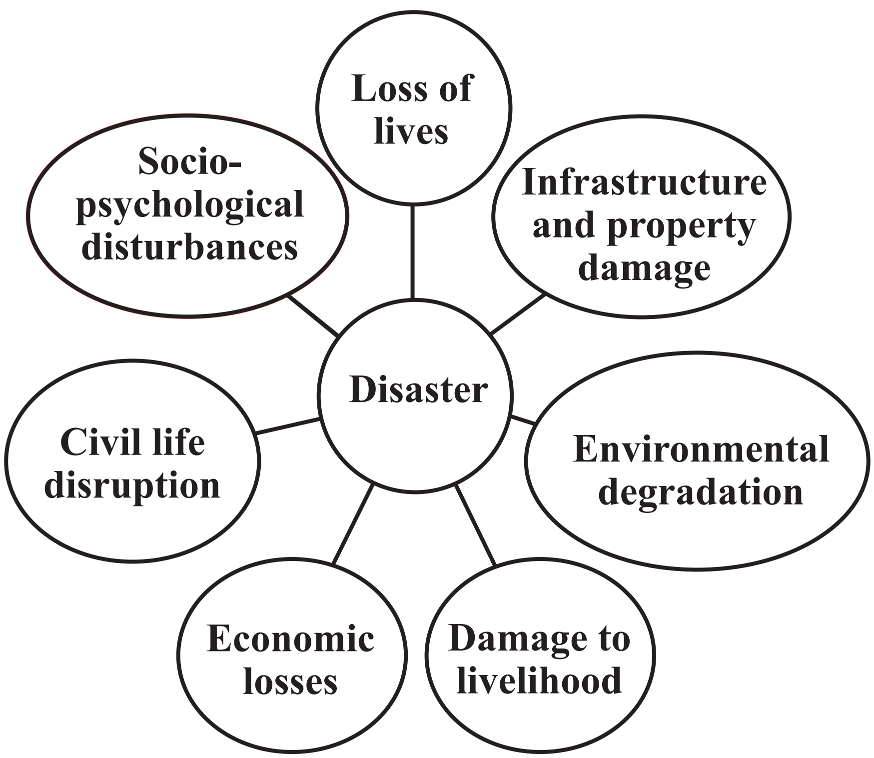
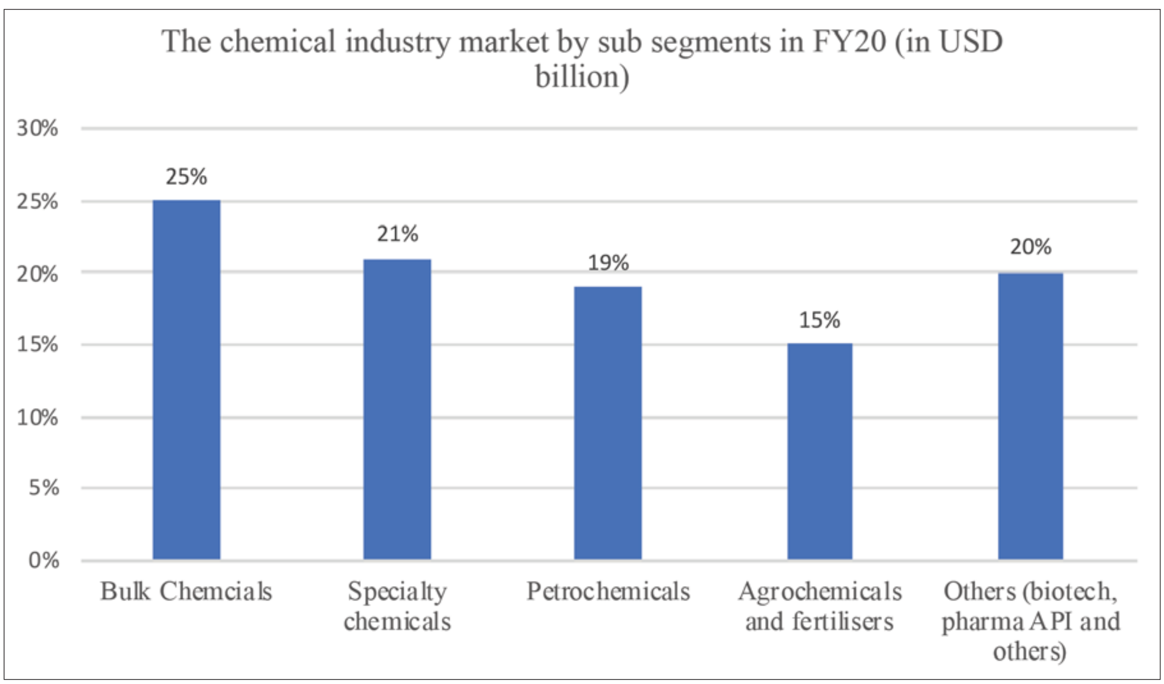


Figure 1 Impacts of Disaster

Even though society has now adapted to different catastrophes, it continues to suffer from social and economic losses mounting every year on a regular basis. Industries being actively involved in generating revenue and providing livelihood, becomes an integral part of the society. With increasing technological innovations, chemical industries have become a paramount section of the society contributing for fiscal responsibilities and welfare of the community at large. But at the same time, these chemical industries provide not only raw material or products but also have negative implications on environment and climatic transitions owing to their chemical properties causing threat to the ecosystem (Torry et al, 1979).

Although the efficacy and outreach of industries have been increased tremendously (Graph 1), improper storage and handling of the chemical substances has become a menace. As a result, India is becoming home to emerging anthropogenic disasters mainly like Chemical, Biological, Radiological and Nuclear disasters. The growth of chemical sector has increased the use of chemicals that are hazardous, or HAZCHEM (Karunakaran et al, 2013) used in manufacture, to store, to supply and to transport. The rapid growth of Major Accident Hazard (MAH) facilities has made it prone to debacles and hence increased the exposure to risk.



Graph 1 The chemical industry market by sub segments in FY20 (in USD billion)

(Source: India: A global manufacturing hub for chemicals and petrochemicals, Knowledge report on Indian chemical and petrochemical industry, 2021)

Due to increasing demand for resources and an urge to have a high standard of living, a surge in frequency and abundance of medium and small-scale industries in the last few years has been observed. Hence, increase in the numbers, size, and storage capacities of chemical and its allied industries, greater risk and vulnerability has been imposed on the nearby densely populated areas. This exponential growth of chemical industries has raised the occurrence of incidents related to hazardous chemicals. Hence, disaster occurs when hazards like this interact with vulnerabilities (Fig 2).

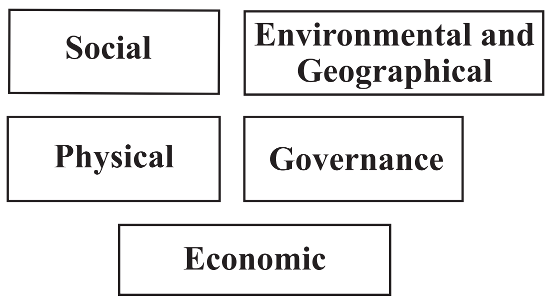


Figure 2 Types of vulnerability

Chemical Disasters and its Origin

A chemical disaster may be simply defined as a massive industrial accident caused by chemical hazards, agents, and allied substances or as occurrence of emissions, fire or explosion involving one or more hazardous chemicals in the course or premises of industrial activity like handling, manufacturing, storage, transportation or due to any other natural causes resulting into serious side effects to mankind, environment, and property. It can occur either at the production facility, storage facility, during transportation, inadequacies, improper operation and maintenance, failure in safety measures etc. either due to human, technical or management errors (Carson, 2002).

Chemical accidents may originate in manufacturing and formulation installations including during commissioning and process operations; maintenance and disposal, material handling and storage in manufacturing facilities, and isolated storages; warehouses and godowns including tank farms in ports and docks, fuel depots and transportation (road, rail, air, waterways and pipelines) (Karunakaran et al, 2013). In addition to this, due to lack of technical expertise and information, for instance defect in design system or equipment, metal corrosion, and lack of proper maintenance of the instruments. Humans error like improper handling of chemicals, lack of remedial measures, negligence of safety instructions and organizational errors such as non-updation of SOP, poor disaster management policy, lack of preventive guidelines and crisis planning, lack of coordination and non-delivery of mock drills and exercises at periodic intervals further often act as trigger mechanism for the onset of chemical disaster. Hence, it can be generally categorized that chemical hazards are mainly due to error of human, equipment, management, and the ambient environment.

Chemical industries being at the modern era of development have attained a serious and grave concern for disaster management at large. While the extent of damage and loss depends on the concentration and hazard characteristics of the chemical, quantum of chemical released and physical environment parameters, chemical disasters have proven to be traumatic in their aftermath impacts. It also causes not only damage to lives and properties, but environmental degradation has been observed at the cost of economic developments. A chemical disaster though low in frequency and small in magnitude has the potential to cause significant acute or chronic damage to the environment and incurs great loss of lives and property jeopardizing the aim of sustainable development (Mehta, 2015). Although due to improper handling and lack of awareness, India since 1980 has faced many chemical disasters mentioned below few of which are categorized under Identified Reported Chemical Disasters (IRDC) to estimate the gravity of the chemical disasters (Table 1).

Table 1 Incidents reported as chemical disaster from (1980-2020) (Karunkarann et al, 2013)

Year	Location	Chemical industry action	Description
1980	Mandir Hausad plant explosion, Chhattisgarh	Explosives	A fire explosion was reported, plant was storing explosives, around 50 people died in the Fire explosion.
1983	Dhulabar plant fire, Assam	Crude oil	In the plant fire broke out from cylinder of crude oil stored; 76 died, 60 injured.

1984	Bhopal gas tragedy, Bhopal, M. P	Methyl Iso Cynate	Toxic gas release (Methylisocynate) Bhopal 1984, on 2nd and 3rd December, Union Carbide plant in Bhopal; about 25-27 tons of the deadly methyl isocyanate gas spread. About 2500 persons died, half a million people were exposed to the gas.
1985	Shriam food and fertilizer factory, Delhi	Oleum gas	Produced products like hard technical oil & glycerin soaps. On December 4th & 6th of 1985, massive leakage of oleum gas occurred from a subsidiary of Delhi Cloth Mills at Delhi that is; one of the plants of Shriram Foods and Fertilizer Industries, leading to the death of one person and causing injuries to many others. The explosion and leakage of the gas from the tank were due to the collapse of the structure on which it was mounted.
1990	Transport accident, Patna	Gas leakage-oxyacetylene gas,	Leaking gas cylinder exploded in a moving commuter train Monday and set off a fire that left at least 80 people dead and as many as 100 others injured. The nozzle of the cylinder, apparently came off, releasing the pressurized contents in a tremendous gush.

2003	Dighboi refinery, Assam	Motor spirit liquid	Refinery had broken out with fire from a tank stored motor sprit (liquid), 11 death, 112 injured and exposed.
2010	Mumbai port trust, Mumbai, Maharashtra	Fire explosion	On the morning of 14 July 2010, nearly at 3:00 a.m., chlorine leak was reported from a gas cylinder referred as turner, weighing about 650 kg, corroding with time at the Haji Bunder hazardous cargo warehouse in Mumbai Port Trust, Sewri, affecting over 120 people. It has been observed to be a blatant case of ignorance and negligence as well as contraventions to the safety and environmental safeguard requirements under existing statues as well as non-maintenance of failsafe conditions at the site requisite for chlorine storage. The analysis revealed significant gaps in the availability of neutralization mechanism and the chlorine stored in open increased the possibility of formation of ingress mixture due to busting of chlorine filled tankers.

2014	Bhilai Steel plant, Chattisgarh	Gas leak -Methane	Almost six people were killed after a pipeline leaked methane gas in a water pump house.
2017	Uttarpradesh	Explosion	On November 1, 2017, an explosion at the 500-megwatt unit of the Feroze Gandhi Unchahar coal-fired power plant Uttar Pradesh exploded, killing over 40 people. The explosion took place in the boiler of the plant. The boiler pipe burst in the 500Mw plant and ignited a huge fire. The explosion set off a lot of dust in the air, making the rescue work very difficult. Over 100 people were injured in the incident.
2020	Vishakhapatnam	Vizag gas leak-Styrene Gas	Visakhapatnam on Thursday woke up to a gas leak at Korean company LG Polymers. Styrene gas leaked from the plant which left at least seven persons dead and 1,000 others sick. Over 3,000 people were evacuated to safety as the leak spread. The gas caused breathlessness and a burning sensation in the eyes. People started vomiting and fell unconscious.

To ensure mitigation, it is of utmost import to build resilience in the preparedness and response phase by developing a coping mechanism against the chain effect caused by chemical disasters. Disaster having a domino effect causes a series of disastrous events leading to loss of property and infrastructure (Zheng et al., 2021). It is important to understand the holistic impact of the chemical disaster on environment and human health. Hence, it becomes imperative to study the diffusion process of hazard chemical for better disaster response and recovery phase. While the whole event of chemical disaster is categorized on basis of temporal and spatial scale and in all the phases of disaster (pre, during and post phases), it is important to reflect the extent and widespread of catastrophic event (location based) and time. During the pre-disaster phase the leaked chemical substance affects the immediate surroundings reflecting the domino effect of event (Figure 4). During the disaster phase, fire, explosions or asphyxiation starts appearing caused due to explosion and blast. and the post disaster event reflects the damage and losses incurred, causalities caused, and financial setbacks occurred, along with environmental damages. When seen from disaster perspective, it is all interwoven and inter alia relationship with all the management phases having coupling effects. (Zheng et al., 2021).

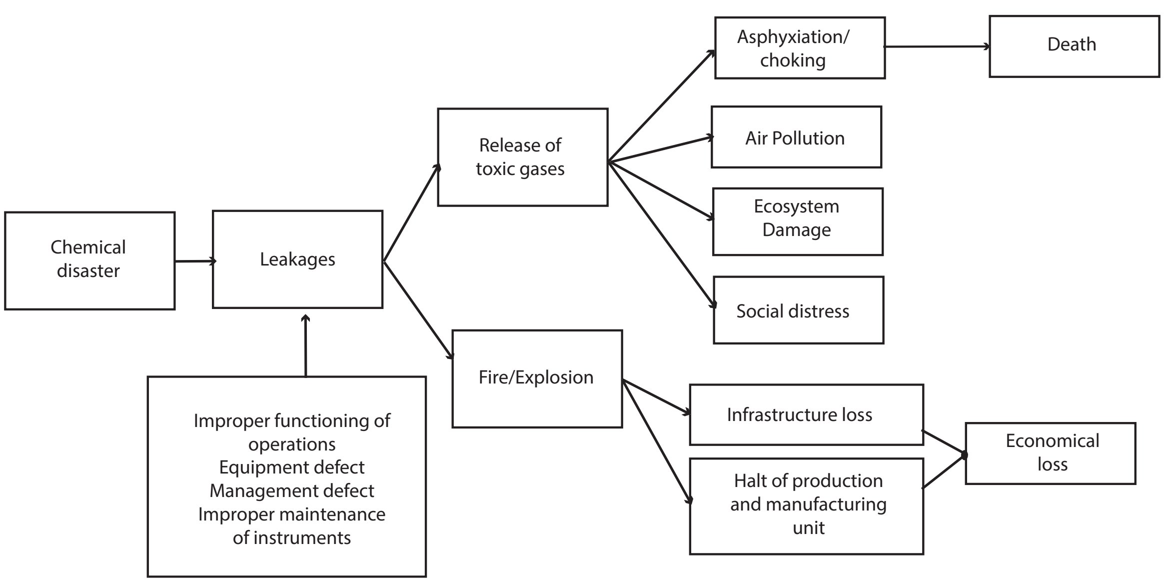


Figure 3 Chemical disaster chain of reaction and its impacts

2. Chemical Disasters - Case Studies

A. Bhopal gas tragedy -1984

History

In 1969, The Sevin Technical concentrate was imported from the United States and its formulation plant, along with its blending and grinding to be carried out in Bhopal, Madhya Pradesh. The company was constructed in Bhopal owing to its central location and easy access to transport while the city was designated for light industrial and commercial use, not for hazardous industry. In the 1980s, Union Carbide Corporation (UCC) was asked to build a plant for the manufacture of Sevin, a pesticide commonly used throughout Asia. In 1980, manufacturing of pesticide Sevin using Methyl Isocyanate (MIC) began. But due to decrease in demand for pesticides owing to crop failure and famine in 1983-84, it led to decrease in production, increase in debts and decreased capital for farmers to invest in pesticides manufacturing.

The names isocyanates, cyanides, and cyanates appear to be linked on the surface. The structure and toxicity of these three categories of compounds, however, varied significantly. In Bhopal, the unfamiliarity with this terminology, as well as the widespread notion that cyanide is the most dangerous of all compounds known, caused a lot of uncertainty. Cyanates have the overall structure of –CNO. As a result, sodium cyanate is abbreviated as NaCNO and methyl cyanate is abbreviated as CH_3CNO. The least dangerous of the three categories of compounds, cyanates cannot be transformed to cyanides in the body. Cyanide (–CN) has a strong affinity for cellular cytochrome oxidase, and inactivation of this enzyme prevents cells from using oxygen, resulting in death due to extreme throttling. Isocyanates are found to be toxic, and their toxicity is higher when inhaled rather than consumed orally.

Hence, when MIC reacts with water, it produces heat that is well over the boiling point of the water. During the cleaning procedure on December 2, 1984, a tiny amount of water entered the MIC Tank 610 through the pipe. The heat created (exothermic) by the water-MIC interaction turned liquid MIC into gas. When the pressure was high enough, the disc ruptured, and MIC blasted into the atmosphere through the vent.

It was the midnight of December 2, 1984, when the city of Bhopal faced the disastrous incident of MIC leak. Nearly 30 of the 42 metric tons of the chemical stored in tank 610 of the UCIL pesticide plant escaped with substantial velocity within almost 1 hour. The dense cloud of the air heavier than gas soon emerged and settled on the nearby towns causing the loss of lives and property. Attributes like prolonged storage of nearly 42 tons of MIC, inappropriate operation and maintenance of safety measures, malfunctioning of equipment, overloading, non-functioning of machinery and lack of information about the identity and toxicity of the gas worsened the effects of the accident lead to occurrence of such chemical debacle.

Analysis:

Three tanks, each with a capacity of 15,000 gallons were used to store MIC. One tank was intended to be kept free in case of an emergency. MIC was either used up as it was manufactured or kept for short periods of time in the United States, Japan, and Germany, but never in such large quantities as in Bhopal. Prior to October 7, Tank 610 held 6.4 tons of MIC, to which was added MIC produced from October 7 to October 22. Not only was MIC maintained for 55 days, but there were two different pools of MIC in Tank 610. Tanks should be no more than half full; yet, prior to the tragic night in Bhopal, the tank 610 was 87% full, well above the recommended capacity of the West Virginia plant at 50% and the specifications of the Bhopal plant at 60%. Hence, at midnight of December 3, MIC escaped through the nozzle of the 33-meter-high vent and the rest is history. (Broughton, E, 2005)

B. Seveso Disaster -1976

This case study is about an explosion that occurred following the contact between sodium hypochlorite and an oxidizer. The plant was manufacturing 2,4,5-trichlorophenol, an intermediary for cosmetics and pharmaceuticals. The Seveso accident was an industrial chemical accident that occurred at a small chemical factory in Italy when a chemical reactor exploded at ICMESA plant around July 10, 1976. The ICMESA trichlorophenol reactor released dioxin cloud and other pollutants due to sudden exothermic reaction which further caused failure of safety valve. A runaway chemical reaction resulted in the release of an aerosol cloud that included sodium hydroxide, ethylene glycol, sodium trichlorophenate, and an estimated 15 to 30 kg of TCDD over an 18-km2 area. Since it was a combustion by-product, it was a common environmental pollutant in industrial areas and although background levels were reduced, it was widespread. Hence, it was found that the town was contaminated by an explosive discharge of a chemical reactor manufacturing trichlorophenol and further contaminated the air with the dioxins. Due to wind dispersion the pollutant settled on buildings and backyards of Seveso and nearby cities. While there were no immediate effects, and the effect went unnoticed except from the nasty smell in the vicinity. It was taken under observation that leaves started falling with sudden death of birds and occurrence of chlorance disease in children. After research it was open found that not much of information was available on dioxin in terms of its chemical characteristics, severity and its impact on environment and mankind. This opened a window of opportunity for government officials to take mitigatory steps against for community and environmental damages (Centemeri, 2010).

Analysis:

At a factory which produces 2,4,5-trichlorophenol in batches, the batch operation was completed using a process different from the process described in the instruction manual. As a result, the temperature rose, uncontrollable reactions generated large amounts of dioxins, the rupture discs were activated and components such as dioxins diffused into the atmosphere.

Furthermore, it was carried by the wind and the reaction products containing dioxins were spread widely degrading the environment and harming mankind.

Approximately 1800 hectares of land was polluted, injuring 220,000 people which resulted in great damage. There was no correct knowledge among researchers and managers about the runaway reaction of the reactor and the generation of dioxins. The result was fatal accidents, property and environmental damage (Eskenazi et al., 2018). It resulted in the highest known exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in the resident population, leading to much needed scientific research and standardized health and safety regulations.

In order to avoid and eliminate the same event from occurring, the European Union (EU) came up with Seveso directives providing narrative to take measure to enhance preparedness and further strengthen their safety measures with collaboration of all the actors involved.

Table 2: Seveso directives by European Union

Directive	Directive narrative
Seveso I Directive	In 1982, EU authorized the Seveso directive to control chemical accident hazards that pose great threat to the wellbeing of the society. The directive emphasized on the coherent participatory measures of community members along with the other stakeholders to effectively communicate the risk associated.
Seveso II Directive	The second directive issued in the year 1996 highlighted the importance of disseminating information regarding the HAZMAT (Hazardous material) for instance, storage specifications, emergency plans, crisis scenarios and potential impacts in the nearby vicinity in order to bear the chemical event consequences.
Seveso III Directive	The III directive came into force in 2012 taking into consideration the evolution of legislation with HAZMAT classification. the main focus was to reduce the impacts on mankind and environment. The aim of directive was to lay out clear and correct disclosures to public and increase community participation in decision making.

Source: Centemeri, L. 2010.

C. Love Canal - 1942

In 19th century the canal was excavated to provide high low hydroelectric power for the upcoming plant industrial facility, but it was never built. While the population started migrating towards the city as the expansion of industry it kicked off and provided better job opportunities on the other hand agricultural activities also took a good expansion.

Over a period, it was observed by the residents in the vicinity that there was an increase in seepage of chemical waste product and alleged collection was observed along with noxious order was reported occurring due to chemical breakthrough of topsoil (Fowlkes and Miller, 1983).

In the year 1942, the company "Hooker chemical and plastic company" purchased the abandoned and barred excavation site for dumping industrial waste that included pesticides residues, slurries, and waste solvents. In the span of 11 years, approximately 22,000 tons of waste contained in metal drums was placed in the excavation which earlier contained impounded water which resulted in leaching. The dumped waste contained chlorinated hydrocarbon residues, processed sludge, fly ash, and other materials, including municipal garbage including the carcinogens benzene, dioxin, and PCBs in large metal barrels and covered them with more clay.

It was in 1953, when the land was sold to Niagara Falls school board and construction started, the residents came to know that the canal's clay cap and walls were breached, damaging some of the metal barrels resulting in leakage of chemical waste to the surrounding area. Apart from the common consequences of disaster, Love Canal reflects the diminished individual functioning, community disorganization and financial costs (Fowlkes and Miller, 1983). After carrying out various research by the method of data collection and sampling it was suspected that chemical waste constituted more than a narrowly confined public nuisance and had a great potential to public health open. The love canal become such a disastrous event when speculation regarding the source of contamination centered near school premises. Some toxic chemicals were further identified on the playground of the school which further confirmed the presence of chemicals. On examination dioxin was found in the black creek which borders the school ground, and the teachers were further instructed to carry out blood and liver function test and school was subsequently closed for some time. While the New York Division of Safety and Health confirmed the presence of chemical leachate below the wider love canal area in November,1978 which resulted not only into the misfunctioning of liver but also ailments like pregnancy issue chromosome damage and genetic mutation (Fowlkes and Miller, 1983).

The local geology further provided some degree of natural containment due to presence of soft clay deposits underneath the canal. This provided low permeability and hence limiting the potential for groundwater contamination whereby water percolated through the clay cap, mixed with the chemicals and seeped laterally through sand and silt as the trench overflowed.

Analysis

Although deposition occurred in the 1940s it was not till late 1960s when the contamination became evident when the native complained of fumes and explosions. These compounds include chloroform, trichloroethene, tetrachloroethene, chlorobenzene, and chlorotoluene. Dioxin (2,3,7,8) tetrachlorodibenzo-p-dioxin (TCDD)], considered one of the most toxic man-made compounds based on animal experimental studies, is one of the chemicals found in the landfill. Since dioxin (TCDD) is a contaminant by-product formed during the manufacture of tri- chlorophenols (TCPs), its presence in the Love Canal was suspected when 200 tons of TCPs appeared on the list of chemicals buried at the site. (Phllips et al, 2007)

3. Aftermath and Mitigation Measures

It was inferred from all the three chemical industrial disasters that chemical disaster have grave impacts on environment, ecosystem and mankind. It was observed that storing of the hazardous chemical caused leachate generation leading to land pollution and contamination of the landfill. Therefore, it was recommended to carry out excavation and interim storage of the sewer and creek sediments so as to avoid leachate collection (Fowlkes and Miller, 1983).

It also reflected that community when came in contact with such kind of chemicals suffered from ailments like SARS, severe pulmonary edema, cardio-respiratory diseases, acute bronchitis, and drowsiness, cough and throat irritation followed by mutation till generations. (Broughton, 2005) The acute toxicity of the chemical leak often caused vomiting, unconsciousness, tiredness and fatality. The growing evidence reflected a higher risk of sub-acute and chronic health hazards, as well as spontaneous abortions and congenital malformations (Fig 5) (Mehta et al, 2015).

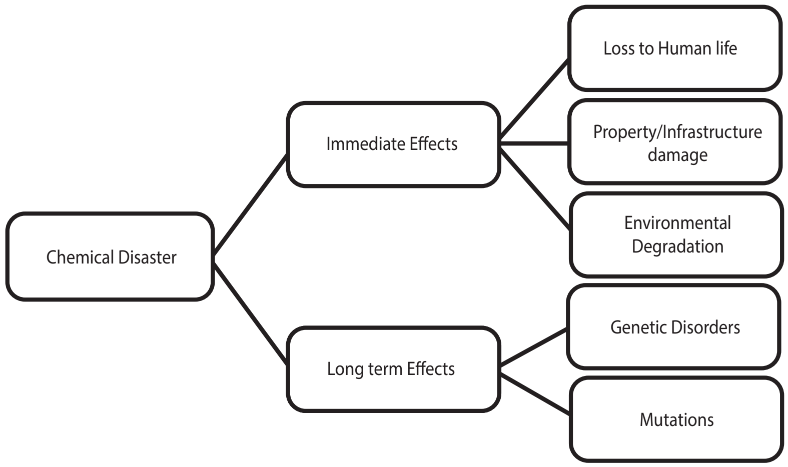


Figure 4 Impacts of Chemical Disaster

Lessons learnt from this case studies are to keep an updated hazard map. The firm should also ensure periodic maintenance of safety measures available and evaluate the probable sources of accidents before the construction of the same. (Park and Cruz,2022). The study revealed a neglected overview on the fiscal aspect of the disastrous event, there occurred direct and indirect losses which further deteriorated the condition of environment and society (Figure 6).

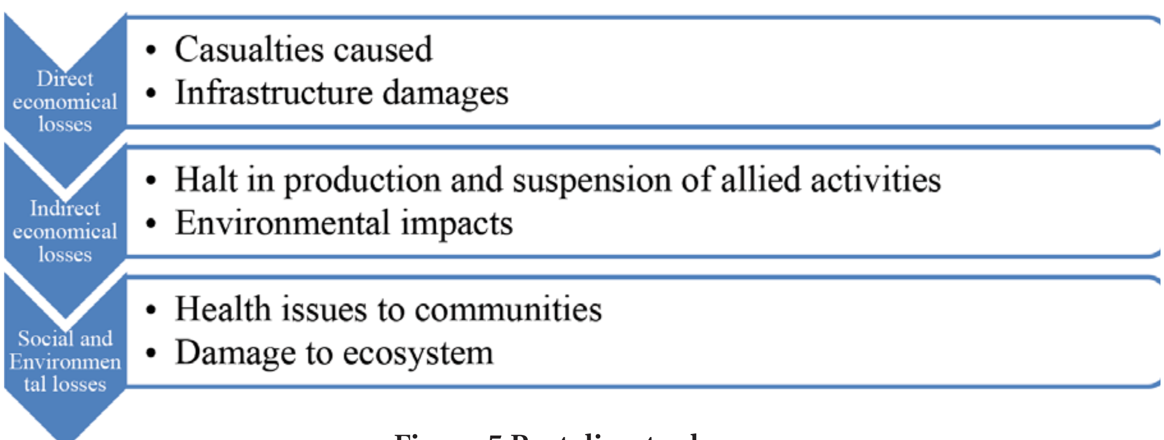


Figure 5 Post disaster losses

The case studies also reflect the importance of various environmental parameters. For instance, Wind direction and temperature play a decisive role here. Dispersing the effects of chemicals is the only way to protect the public from the aftereffects of chemical disasters. A list of protective equipment such as respirators, rubber gloves, cotton gloves, over boots, haversacks, etc. should be kept prepared. Unscientific construction and development and lack of awareness and preparedness further makes the community prone and vulnerable to disasters. Hence, the long term and immediate effect poses grave consequences emphasizing the need for proper safety measures (Figure 7). The scarcity of safety knowledge and safety consciousness is a root cause of so many chemical accidents caused by human errors.

It can be highlighted from the series of events that the increase in industrialization have led to more disastrous results in the Bhopal Gas Tragedy as the safety law and regulation were not stringent in a developing country like India. The authors observed that the violation and non-compliance of environmental and safety measures was the main cause for the damage. Poor public health infrastructure, no functioning sewage system, shortage of hospital beds and medical facilities can be listed as the major shortcoming. In addition to this, lack of information about chemical antidote, emergency response and negligence of factory and audit inspection, deficiency of the training of the workers and proper expertise, location of the site and scarcity of resources lead to multiple casualty and severe losses. Analysis of major chemical accidents has exhibited deficiencies like laxity towards safety measures, non-conformance to techno-legal systems and lesser public consultation. A paradigm shift has occurred in government's focus from rescue, relief, restoration-centric approach to planning, prevention/mitigation and preparedness approach. The designing of safer engineering practices, standard operating procedures, well-rehearsed on/off-site emergency plans, community awareness, resource and risk inventory built up, training, education, capacity built up, are important practices that may eventually help in development of community mindset to bravely face disasters so as to reduce their impact.

Management of Chemical Disasters

As the global chemical industry has increased in size in recent years, chemical accidents, such as fires, leaks and explosions, have occurred repeatedly, and concerns regarding the lack of chemical safety management at the global level have emerged (Lee et al., 2016). It becomes difficult to deal with chemical accidents appropriately, even after the cause of the accident is clearly understood because of their complexity and diverse characteristics (Mannan et al., 2005). To understand the mechanisms, causes, damage potential and likelihood of accidents and to develop accident prevention and mitigation strategies, it is essential to learn from past accidents and safety legislation. Learning from accidents helps integrate knowledge and experience and also identify the need of future research (Lindberg et al., 2010).

Chemical disaster management is defined as an activity to integrate several interrelated components to work in an effectively coordinated manner to ensure efficient management of available resources to safeguard the life of people and their rehabilitation with the integrated and multi-stakeholder approach to risk management. The guidelines have been prepared for chemical disaster management by the international agencies, such as that by the Organisation for Economic Co-operation and Development (OECD, 2003) and the United Nations Environment Programme (UNEP, 2010).

Chemical disaster management as an activity involves reducing the risk associated with such incidents through timely measures, long-term and short-term policies, providing the required assistance to the victims, and ensuring sustained recovery (Carter, 1991). At present, the focus is on hazard vulnerability, risk assessment, disaster prevention, and towards sustainable development. Further, chemical accidents can be prevented by regular checking of safety devices in industries, use of safer engineering practices, and minimization of human error. Risk minimization can be done by designing a safer process and developing a safer alternative for the generation of required products. Continuous training and skills development are important elements of disaster management support system (Figure 6).

Figure 6 Strategies to manage chemical disaster

Communication plays an effective role in the mitigation and management of chemical disaster. During emergencies, transportation agents need to assess the emergency and provide immediate response such as public broadcasting messages, road closures, alternative detours, debris removal, etc. Yoon et al. (2008) mentioned communication as one of the important aspects that can help in running the support system for disaster management smoothly. In communication, hardware and software systems such as GSM network, satellite mobile phones or information exchange system dedicated within the industrial areas should be taken into consideration. Chemical disaster management includes hazard mapping, hazardous material identification, inspection of chemical plants and storage facilities, monitoring toxic waste disposal, monitoring pollution levels, creating awareness among workers in hazardous industries, establishing the procedure for warning, immediate action plan, fixing responsibilities of officials, providing effective training, plan for casualty evacuation and medical aid, constructing firefighting arrangements and creating command, control, and communication system (Balachandar, 2021)

A good communication system, training and understanding of emergency procedures, regular interaction between government agencies and industries and a high level of availability of emergency equipment are the key areas for effective disaster management taken in consideration all the active stakeholders.

Early Warning Dissemination System for Chemical Industries

To ensure the proper management and mitigation of a chemical event, safety remains the number one priority in most of the refinery's factories and generally in the whole chemical sector. Although the safety parameters and the initiatives have been drastically changed after the Bhopal Gas Tragedy 1984, there still remain the presence of dangerous and hazardous substance which must be continuously monitored, and necessary actions have to be taken against the harmful substances. It becomes of utmost important to disseminate the information regarding any disastrous event in the chemical industry when the level of hazardous substance exceed above the two levels which is increase level and emergency level. Although the increased levels are not that much harmful to human lives when in exceeding concentration, the emergency level indicates that the concentration has been increased above the critical threshold and has jeopardized the live of mankind.

Hence, to monitor the same up early warning dissemination system is required which monitors, warns and simultaneously communicates the message of disaster to the last mile it should be adaptable to the environment requirement and be automated and should be able to identify the problem on the employees working and the nearby communities and facilitate a response in direction of recovery and relief.

Emergency Preparedness, Capacity Building and Safety Measures

The disaster paved a way for the need to enforce international standards for environmental safety, preventative strategies to avoid similar accidents and industrial disaster preparedness. Proposed safety measures can be categorized as follows:

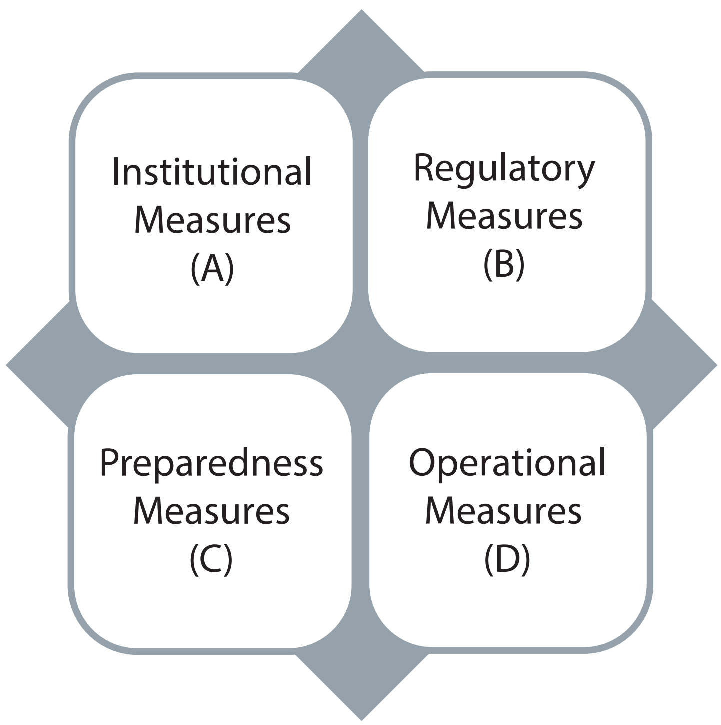


Figure 7 Management of Chemical Disaster

For institutional measures, a roadmap can be developed with an action plan. The roadmap should be implemented and reviewed on a regular basis, considering all the guidelines. The localized risks and behavioral based safety should be included along with analytical research surveys Institutes which impart training and are involved in capacity building with ample number of resources and upgraded infrastructure should be supported at national and state levels. Furthermore, onsite and offsite emergency plans should be devised and the list of toxicants, their hazardous effects, information on antidotes, medical equipment and patient evacuation plan should be made easily available and accessible.

Regulatory measures imply strict adherence to regulatory frameworks and emergency plans formulated for chemical units so as to ensure proper and safe disposal of hazardous chemical waste. Different departments can be allotted with the work of setting and monitoring standards.

Formation of unit wise Major Accidents Hazards Database, comprehensive Risk Mapping, Hazard Mapping, development of Disaster Management Resource Network - along with the status of available resources and manpower, well-equipped Emergency Operation Centers should be included under the category of preparedness measures. Sensitization of workers can be done by organizing mockdrills, co-ordinated activities and periodic training modules imparting awareness and education for the use of early warning tools.

Industrial (chemical) installations and storages of hazardous materials, regular testing of the equipment's, Hazard Operability (HAZOP), Hazardous Chem (HAZCHEM) Hazard Analysis (HAZAN), safe transport of chemicals (via rail, road, marine, pipeline or air, etc.) and considerations of land use planning should be taken into account when focusing on the operational measures. The tracking and locations of vehicles transporting hazardous chemicals can be done by using Global Positioning System coupled with space technology. Also, class labels can be placed on the vehicle transporting hazardous chemicals.

Development of industries has gained rapid momentum due to easy availability of raw material, cheap labor and economic feasibility. Simultaneously, due to lack of geographical space and unplanned development, traditional industrial units are becoming more and more crowded with the emergence of new ones hence making the community prone to debacle. Inappropriate and disorganized construction, lack of awareness and preparedness on the part of the community further enhance their vulnerability towards the disaster. The potential of heavy losses and adverse consequences on the environment due to a chemical accident has inclined the policy makers to frame the management and policies aiming for disaster resilience and risk reduction to achieve sustainability in all the sectors of the community.

The case studies reflect the inter relationship of disaster with the immediate surrounding, hazard affected bodies and the post disaster losses incurred by industry and the community. They further reflect the mechanism of a static situation when provided a stimulus, gets triggered into catastrophic event. (Figure 3) When any chemical leaks from storage tanks or pipelines due to any manufacturing defect or external forces results into serious of chain event for instance

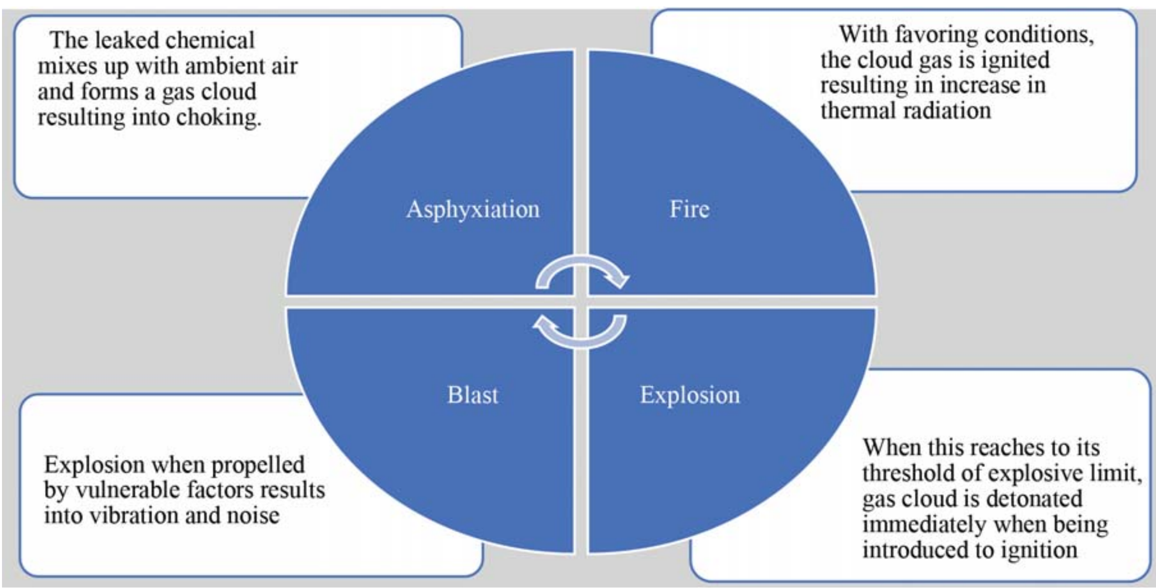


Figure 8 Disaster causing chain of effects

Conclusion:

"This may be how the world will end not with a bang but with an ecological whimper," wrote Abu Abraham in Bombay's Sunday Observer of December 23, 1984.

Chemical disasters are highly challenging as they are multifaceted. Chemical disasters create mass destruction and hampers the progress of the people. Proper action plan with an integrated-holistic approach is needed to improve the areas of weakness so as to achieve the necessary capacities for chemical safety, preparedness and response to chemical disasters in line with the existing Rules & Regulations. Chemical companies should continuously invest more in safety culture rather than just safety technologies. Safety investments in a chemical company not only are part of risk management but also have a great impact on the effectiveness of a company's prevention policy as well as the company's profitability in the long run which facilitates the sustainable development of chemical companies.

In the era of constant development, chemicals have become an indispensable part of industrial production, but at the same time creates a crisis-like scenario due to improper storage and handling of chemical pose a great threat to mankind and its environment. Factors like proper land use planning and zonation must be taken into consideration before the setting of chemical industries. Hence, an action-oriented approach must be opted for. (James N).

Regulatory frameworks like Sendai Framework for Disaster Risk Reduction (SFDRR) reflects the practical approach of multi stakeholders to manage risk including technological hazards and further helps to foster the technological growth with compliance to society and mankind (Park and Miller, 2022). The policy frameworks such as National Disasters Management Guidelines-Chemical disasters and manufacture, storage, and import of hazardous chemicals, 1989, describes protocols for responding to emergencies, safe storage, and periodic risk assessment. (Jain Piyush). An integrated approach is required to address the issue of chemical disaster by enforcing proper policy implementation and law adherence to enhance the response measures and further strengthen the mitigation phase. Hence, a multidisciplinary method has to be unified, to successfully cascade the effects of increasing chemical disaster by dealing responsibly with them (Park and Miller, 2022).

Chemical disaster demands to have a strategic response mechanism based on the vulnerabilities identified and further design local emergency plan to ensure the timely and safe evacuation of the communities at time of disaster along with involvement of all the stakeholders i.e. government and municipal officials, community representer, industrialists, operators, safety managers. The author emphasizes the need to have stringent adherence to DM Act, 2005, Environment Protection Act, 1986 and The Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 1998, amended in 2008 and other regulations like Factories Act, 1948, Public Liability Insurance Act,1991, National Green tribunal, 2010, Chemical accidents rules, 1996 and Manufacture, Storage, And Import of Hazardous Chemical Rules, 1989.

Author further recommends concretization of emergency response mechanism for chemical emergencies along with proper communication to all the active actors involved. (Park and Miller, 2022)

Although the effects of chemical disasters cannot be eliminated but can be mitigated through proper policy and management carried out in coordination by different stakeholders. The above-mentioned case studies provide us with the way forward in how to get prepared for any chemical industrial disaster keeping in mind the benefit of mankind and to aim for a sustainable and disaster resilient society. The need for developing high standards in industries is required for not only operation and maintenance but also to ensure safety in industrial units. It reflected the need of public education and awareness towards hazards of toxic and chemical materials which are hazardous to human life and to the environment.

Also, the chemical disasters depict the importance of periodic safety audits to ensure safety in any industrial unit, also to carry out regular Environmental Impact Assessment of hazardous units becomes an inescapable necessity for the welfare of human life. Developing country like India, although lacks a proper contingency plan to meet possible emergency situations, it is important to work on and be prepared for the worst-case scenario. The author suggests that developmental activities should be carried in such a way that the damage to the environment is bearable and does not lead to catastrophic events.

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