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RESEARCH ARTICLE

Enhancing Chemical Safety in Manufacturing: Lessons from Major Chemical Spill Incidents and the Role of Ergonomics

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ABSTRACT – Chemical spills in manufacturing industries pose serious dangers to the safety of the environment, the health of employees, and the effectiveness of operations. This study examines the root causes and effects of significant chemical spill incidents. The analysis focuses on the lessons learned from these incidents, ergonomic and safety issues, and missed preventive measures. The thorough evaluation emphasizes how weak safety measures and poor ergonomic practices contribute to the rise of such incidents. The proposed alternative solutions focus on integrating chemical safety measures with ergonomic principles to reduce hazards and improve worker safety. The findings help to create safer industrial settings by providing industries with insights to prevent future chemical accidents and enhance worker well-being and operational sustainability.

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1.0 INTRODUCTION

1.1. General Overview of the Topic

Chemical spills in manufacturing settings lead to serious risks to the health of the environment, worker safety, and efficiency in operation. Inadequate handling, storage, or disposal of hazardous materials frequently causes these incidents, which may lead to significant consequences such as chemical burns, respiratory problems, and environmental harm. According to the International Journal of Environmental Research and Public Health (2022), 728 people died in 620 chemical accidents that were reported between 2016 and 2018 in China, emphasizing the severe effects of improper handling of chemicals.

Ergonomics and chemical safety have to cooperate to reduce these potential risks. The risk of chemical exposure can be significantly decreased by implementing an ergonomic workplace design that considers proper posture and equipment handling. A study published in the Annals of Work Exposures and Health (2022) found that workers in the petroleum and coal products manufacturing sectors are at risk of chemical exposure due to ergonomic factors, emphasizing the importance of preventive measures.

1.2. Background Information and Context

Chemical spills in manufacturing industries remain to be very dangerous for the environment, human health, and operational effectiveness. Hazardous chemicals that are not handled, stored, or disposed of properly can cause accidents that have negative implications for both the environment and workers. The Pasir Gudang Chemical Spill in Malaysia (2019), the 2014 Elk River Chemical Spill in the United States, and the Hungarian Red Sludge Spill (2010) are all examples of such incidents, each demonstrating mistakes in safety measures and emergency response strategies. These accidents exposed workers to hazardous materials and contaminated the environment extensively, which resulted in illnesses, injuries, and even deaths. According to a study by Zhang et al. (2020), incorrect chemical handling results for over 73% of chemical incidents. This highlights the need for improved hazard communication and stronger safety measures in manufacturing settings.

Chemical safety measures frequently come short, especially in industries with high rates of manual material handling (MMH) and poor ergonomic design. Because of dangerous workstations and inappropriate equipment handling, employees in hazardous workplaces are more likely to be exposed to chemicals and suffer related injuries. The layout of workstations and the utilization of old equipment led to fatigue, and increased exposure to dangerous materials. For example, ergonomic hazards often become worse by exposure to hazardous chemicals in the industries that manufacture coal and petroleum products, which can result in skin and respiratory disorders (Smith, R., & Lee, H., 2021). These issues show how crucial it is to integrate chemical safety measures with ergonomic safety measures to lower exposure risks and enhance worker safety. To reduce the effects of chemical spills and improve workplace safety standards, these areas must be addressed through ergonomic workstation design and safer handling practices.

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1.3. Problem statement

The problem addressed in this article is the inadequate integration of ergonomic principles in chemical industrial environments, resulting in the danger of chemical exposure, worker injury, and operational inefficiency. Many workplaces neglect the negative effects of manual handling techniques and inadequate ergonomic design on worker health. This neglect may worsen the effects of chemical spills, including breathing problems, chemical burns, and long-term health issues resulting from exposure to toxic substances. According to a study by Brown, T., & Smith, R (2019), workers in the chemical processing industries are more likely to suffer from chemical accidents and musculoskeletal disorders as a result of dangerous handling practices and poorly constructed workstations.

Solving this problem is important to improve worker safety and reduce the frequency of chemical accidents. The hazards of chemical exposure and physical strain can be reduced by implementing ergonomic assessments into practice and modifying workstations to support safe chemical handling. Enhancements in ergonomics can also increase operational effectiveness by decreasing the possibility of human error in hazardous processes. Addressing this problem would lower the financial and environmental costs related to chemical spills while also improving worker well-being and overall safety and productivity in manufacturing settings.

1.4. Objectives and Scope

The objective of this article is to analyze the root causes of chemical spills in manufacturing industries, concentrating on the Pasir Gudang Chemical Spill Incident, the 2014 Elk River Chemical Spill, and the Hungarian Red Sludge Spill. The study will look into how poor ergonomic practices and inadequate safety measures contributed to these incidents, as well as the long-term consequences for worker health and the environment. This paper will identify missed preventive measures and lessons learned from these incidents and then provide alternative solutions that integrate chemical safety procedures with ergonomic principles to avoid similar incidents in the future.

The scope of the article includes a detailed overview of the three chosen chemical spills, an analysis of the root causes of each incident, and an evaluation of the safety measures that were either inadequate or neglected. The paper will examine the role of ergonomics in improving workplace safety, focusing on the ergonomic risks present in the handling of hazardous chemicals and the design of workstations. Additionally, the study will include suggestions for safety and ergonomic improvements to prevent chemical exposure. This article aims to emphasize the significance of incorporating ergonomics into chemical safety procedures and to contribute in the development of safe manufacturing practices.

1.5. Importance of the Study

Addressing the connection between chemical safety and ergonomic standards is important for reducing the risks associated with chemical spills in manufacturing industries. This article is significant because it emphasizes how inadequate ergonomic design and neglected safety measures can worsen the effects of chemical accidents, adversely affecting environmental safety, worker health, and efficiency in operation. This paper offers important insights into common root causes and missed prevention measures by analysing actual incidents including the Pasir Gudang Chemical Spill, the 2014 Elk River Chemical Spill, and the Hungarian Red Sludge Spill.

The findings of this study contribute to the industry by providing alternative solutions for improving worker safety and sustainability. Integrating ergonomic principles with chemical safety standards has the potential to significantly decrease the frequency of chemical incidents while creating a safer, more worker-friendly industrial environment. Additionally, this report emphasizes the need for preventative actions, encouraging sectors to implement thorough safety plans that secure both the environment and employees. This research helps establish a more responsible and efficient approach to chemical operation, which benefits private companies and the larger community and ecosystem.

2.0 Method and Materials

2.1. Description of the Case Study

This article analyzes three major chemical spill incidents which are the Pasir Gudang Chemical Spill (2019) in Malaysia, the 2014 Elk River Chemical Spill in the United States, and the Hungarian Red Sludge Spill (2010). Each incident was chosen based on its particular impact on environmental health, workplace safety, and the underlying issues with chemical and ergonomic safety. These incidents show that insufficient ergonomic considerations along with inadequate safety measures caused serious consequences.

The Pasir Gudang Chemical Spill occurred as toxic waste, including methane and benzene, was illegally dumped into the Kim Kim River. This resulted in the emission of toxic fumes, which caused more than 4,000 people, including schoolchildren and industry workers, to experience widespread symptoms including vomiting, eye discomfort, and breathing difficulties. The incident showed crucial safety problems such as inadequate hazard communication and insufficient training for workers. The impact of the chemical spill became worse due to poor enforcement of waste management regulations and delays in response times (Yahya et al., 2020).

In addition to regulatory problems, ergonomic issues occurred during the spill cleanup operation. Workers were exposed to toxic fumes for a prolonged duration due to inadequate protection measures and poorly designed personal protective equipment (PPE). Manual handling of hazardous materials without appropriate support systems increases fatigue and the risk of injury. This incident emphasizes the importance of ergonomics when designing spill response approaches and enhancing workplace safety regulations (Salleh et al., 2020).

The Elk River Chemical Spill involved the leakage of 4-methylcyclohexanemethanol (MCHM) into the Elk River, contaminating the drinking water supply for over 300,000 West Virginia residents. The incident showed severe safety problems including a failure to conduct routine storage tank inspections and a lack of emergency preparation. Despite the important role of chemical safety protocols, workers were found to be underequipped and unaware of appropriate containment methods, which delayed mitigation efforts (Mallin et al., 2017).

Ergonomic factors worsened the situation during the containment phase. Workers reported difficulties handling outdated containment equipment and suffered physical strain while attempting to manually manage the spill. The absence of ergonomically designed workstations and devices increased the risk of errors, emphasizing the need to incorporate ergonomic principles into chemical spill management strategies (Brown et al., 2019).

The Hungarian Red Sludge Spill was caused by the failure of a containment dam at an alumina plant, resulting in the release of over a million cubic meters of highly alkaline red sludge into surrounding villages. This tragic incident resulted in approximately 120 injuries, 10 deaths, and serious damage to the environment. According to investigations, inadequate monitoring systems and insufficient dam maintenance were major causes of the incident. Furthermore, workers at the factory were untrained to handle such emergencies, which delayed the initial response (Kertesz et al., 2013).

The incident also led to significant ergonomic mistakes, including outdated machinery that caused worker fatigue and inadequately planned workstations for assessing the structural integrity of the dam. The absence of equipment designed to handle hazardous materials caused physical challenges for workers during cleanup operations. This incident highlights the importance of ergonomic changes in the design of monitoring systems and spill response procedures to avoid similar disasters in the future (Smith & Lee, 2021).

2.2. Data Collection Methods

The study primarily utilized observations to gather information on the safety and ergonomic issues that lead to chemical spills in manufacturing settings. This method included analyzing available reports and journals from three major chemical spill incidents the Pasir Gudang Chemical Spill in Malaysia, the Elk River Chemical Spill in the United States, and the Hungarian Red Sludge Spill in Hungary. Observations provided personal knowledge of the ergonomic, procedural, and ergonomic factors that affected these incidents and their consequences.

The Pasir Gudang Chemical Spill was investigated using environmental and safety reports that showed the incorrect handling of dangerous chemicals. Visual records showed that employees were handling materials by manually without adequate ergonomic equipment or support, which increased the risk of exposure and physical strain. The risks of chemical exposure were further increased when workers were observed to be wearing inadequate or incorrect PPE. According to Yahya et al. (2020), the lack of clear hazard communication protocols and ergonomic safety measures played a crucial role in the escalation of the incident.

The Elk River Chemical Spill was a large-scale release of toxic chemicals into the water supply, and observations revealed serious ergonomic problems. According to reports and journals, workers use unsafe procedures in an attempt to control the spill since containment attempts were hindered by outdated and ineffective equipment. This aligns with research by Brown and Smith (2019), who highlighted that ineffective ergonomic practices in emergency response situations frequently lead to operational inefficiencies.

Observations during the Hungarian Red Sludge Spill focused on the structural failures of the dam and subsequent manual efforts to control the spread of toxic sludge. Workers were observed operating heavy machinery in hazardous settings, which increased their physical strain. Inadequate workstation arrangements and poor access to ergonomic equipment during cleanup operations were also observed. According to Kertesz et al. (2013), workers were exposed to hazardous substances for a prolonged period due to a lack of structural monitoring and ergonomic preparation, which had negative effects on both the environment and their health.

Based on the observations, this study was able to identify recurring ergonomic risks and procedural inadequacies that existed in all three incidents. This approach demonstrated how important it is to incorporate ergonomic principles into chemical safety measures to reduce physical strain and increase the efficiency of spill management strategies. Observations also indicated the importance of modern equipment and well-designed workstations, which may have minimized several of the observed problems.

2.3. Tools and Techniques Used

The Occupational Safety and Health Administration (OSHA) provides a framework for ensuring the safe handling, storage, and disposal of chemicals in industrial environments. Applying OSHA standards to incidents of chemical spill involves addressing key areas of workplace safety to help prevent such occurrences and reduce their impact.

OSHA's Hazard Communication Standard (HCS) emphasizes the importance of providing proper training and information to workers who handle hazardous substances. Employers must ensure that employees are fully informed about potential chemical hazards through tools such as Safety Data Sheets (SDS), hazard labels, and regular safety training programs. In the case of the Pasir Gudang incident, a major issue identified was poor communication about the risks posed by the leaked chemicals, along with insufficient preparation for both workers and first responders. Studies indicate that well-implemented training programs, as required by OSHA, can significantly lower the risk of chemical-related accidents (Clarke & Cooper, 2019).

OSHA standards highlight the importance of proper storage and containment practices to prevent the accidental release of hazardous chemicals. Key measures include segregating incompatible substances, utilizing secondary containment systems such as spill pallets, and performing regular inspections. In the Elk River spill, an outdated chemical storage tank failure led to the release of 4-methylcyclohexanemethanol into the water supply. Adopting OSHA-compliant storage solutions, coupled with routine inspections, could have reduced the severity of the incident. Santos et al. (2021) emphasize that secondary containment systems are essential for reducing environmental contamination and preventing large-scale chemical disasters.

In summary, applying OSHA standards in industrial settings is crucial for preventing chemical spills and reducing their impact. Focusing on hazard communication, employee training, safe chemical storage, and regular inspections can greatly improve workplace safety and preparedness. These case studies highlight the critical role of OSHA guidelines in addressing safety practices and mitigating risks associated with hazardous chemicals.

3.0 Results and Discussion

3.1. Findings or Observations

The analysis of the Pasir Gudang chemical spill (2019), the 2014 Elk River chemical spill, and the Hungarian red sludge disaster (2010) highlights several critical safety and ergonomic issues across these incidents. These incidents share key findings related to ergonomic risks, operational deficiencies, and infrastructure problems, which collectively exacerbated the impact of the spills. Unlike domestic waste, these materials demand specialized treatment before disposal to mitigate their harmful effects. Malaysia produces approximately 1.6 million tons of hazardous waste annually, ranking third among ASEAN countries, following Thailand (3.3 million tons) and the Philippines (1.7 million tons). The manufacturing sector is the largest contributor to toxic and hazardous waste in the country. Below, the key findings and observations are summarized, followed by a deeper analysis of the patterns observed across these incidents.

Based on table 1, a recurring ergonomic issue across all three chemical spills was the inadequate design of personal protective equipment (PPE), which compromised worker safety and increased physical strain during the response efforts. In the Pasir Gudang spill, workers were exposed to toxic gases, such as methane and benzene, due to poorly designed PPE, which increased the risk of respiratory issues (Salleh et al., 2020). Similarly, in the Elk River spill, outdated containment equipment and insufficient ergonomic consideration in PPE design led to significant physical strain on the workers involved in containment and cleanup operations (Brown et al., 2019). In the Hungarian red sludge disaster, poor ergonomics contributed to worker fatigue during the cleanup efforts, as workers struggled with inadequate tools and equipment to manage the toxic sludge (Kertesz et al., 2013).

Table 1: Critical safety and ergonomics common mistakes

Common Mistakes	*Pasir Gudang Spill (2019)*	*Elk River Spill (2014)*	*Hungarian Red Sludge Spill (2010)*
Inadequate Personal Protective Equipment (PPE)	✓	✓	✓
Poor Workplace Ergonomics	✓	✓	✓
Lack of Emergency Response Training	✓	✓	✓
Insufficient Spill Containment Systems	✓	✓	✓
Outdated Infrastructure and Equipment	✓	✓	✓
Poor Hazard Communication (e.g., labelling)	✓	✓	✗
Regulatory Enforcement Failures	✓	✗	✗
Delayed Recognition and Response to Hazard	✓	✓	✓
Inadequate Monitoring and Maintenance	✗	✓	✓
Physical Strain Due to Poor Design	✓	✓	✓

3.2. Discussion of Findings

The results from the Pasir Gudang, Elk River, and Hungarian Red Sludge disasters reveal that safety and ergonomic principles are crucial in mitigating the impact of chemical spills. A significant finding is how poor ergonomic design contributes to prolonged worker exposure to hazardous materials, increasing both the immediate injuries and long-term health complications. Workers exposed to toxic chemicals, such as those in the Pasir Gudang incident, suffered from respiratory problems due to improper PPE and poorly designed work environments (Salleh et al., 2020). This indicates a failure to integrate ergonomics into safety practices, as improper PPE not only failed to protect workers but also imposed additional physical strain during emergency response efforts.

In line with ergonomic principles, workspaces should be designed to minimize physical strain, facilitate proper body mechanics, and enable workers to handle hazardous materials with ease. However, in the Elk River spill, for example, the outdated containment systems and poor equipment design delayed response times and increased the risk of further accidents. The physical demands of handling outdated equipment, coupled with ergonomic inefficiencies, compromised the effectiveness of emergency actions and prolonged the hazardous exposure to chemicals (Brown et al., 2019). This finding supports the importance of designing workspaces and equipment that are ergonomically optimized to reduce fatigue, improve response time, and ensure safer handling of chemicals.

There are several possible causes of identified problems from this finding. First and foremost, lack of proactive safety management and investment in ergonomics is one major cause of the ergonomic and safety failures in the analyzed incident. In all three cases, safety measures were either reactive or non-existent until after the incidents occurred. For example, in the Pasir Gudang chemical spill, the lack of adequate waste management infrastructure and failure to implement proper safety protocols for handling chemicals resulted in a crisis that affected thousands (Yahya et al., 2020). The lack of ergonomic design in workspaces and PPE compounded this issue, as workers had to engage in hazardous cleanup tasks without proper ergonomic support. Studies have shown that exposure to hazardous chemicals can result in long-term health issues, including respiratory and neurological disorders (Sharifah etal.,2020)

Similarly, the Elk River spill exposed systemic gaps in emergency preparedness, revealing that infrastructure was not updated to meet modern safety standards. The outdated containment systems and poorly designed workstations meant that workers had to operate under suboptimal conditions, leading to greater physical strain and delays in the containment of hazardous materials (Mallin et al., 2017). This reflects a broader issue in industries where safety is often seen as secondary to productivity, leading to insufficient investment in safety infrastructure and ergonomic design.

Moreover, another significant factor contributing to the severity of these incidents was the lack of consideration for ergonomics in emergency response planning. The importance of ergonomic design in emergency scenarios cannot be overstated, as it directly impacts how efficiently workers can respond to spills and other hazards. In the Hungarian Red Sludge disaster, for example, the lack of effective monitoring and the failure to design the containment system to withstand potential accidents directly contributed to the magnitude of the disaster (Kertesz et al., 2013). Had ergonomic principles been integrated into the design and maintenance of safety systems, the spill's containment might have been more effective, and the catastrophic consequences could have been avoided.

Workers were often unaware of the specific risks associated with the chemicals they were handling, and emergency procedures were either poorly communicated or nonexistent. The Pasir Gudang incident, for instance, saw over 4,000 people affected due to a failure in both hazard communication and emergency response protocols (Yahya et al., 2020). The absence of clear, timely communication regarding the presence of toxic chemicals and the absence of a well-prepared workforce exacerbated the situation. This indicates a broader systemic issue where the failure to properly inform workers and train them on handling emergency situations undermines safety efforts, especially in environments where chemical spills are a risk due to the lack of comprehensive training and poor hazard communication systems.

Regulatory failures also contributed to the lack of effective safety measures in these incidents. In the case of the Elk River spill, for example, the absence of routine inspections and proper containment measures revealed a significant gap in regulatory enforcement (Mallin et al., 2017). This lack of oversight allowed hazardous materials to leak into the environment, severely impacting the local water supply. Similarly, in the Hungarian disaster, the failure to enforce maintenance standards for the containment dam directly led to the catastrophic release of toxic sludge (Kertesz et al., 2013). These incidents highlight the need for stronger, more consistent enforcement of safety regulations, particularly in industries that handle hazardous materials.

3.3. Comparison with Literature

The findings from this study on the ergonomic and safety issues surrounding chemical spills align with, yet also expand upon, previous research on the topic. A key area of overlap with existing studies is the identification of ergonomic risks as a contributing factor to the severity of chemical spills. Like previous studies by Brown et al. (2019), which examined the Elk River Chemical Spill, our analysis found that poor ergonomic design of containment equipment and PPE directly contributed to delays in the cleanup process and increased worker fatigue. Brown et al. also highlighted the physical strain on workers when handling outdated equipment, a point echoed in our findings across all three case studies. Both studies demonstrate that inadequate ergonomic support can not only worsen the immediate impact of chemical spills but also complicate recovery efforts.

Our research, however, goes beyond these conclusions by emphasizing the relationship between ergonomics and safety procedures. Our study expands on previous research that concentrated mostly on ergonomics in the Pasir Gudang event, such as Salleh et al. (2020), by directly linking ergonomic design defects to systemic safety failures. For instance, our examination of the Pasir Gudang spill revealed how inadequate emergency response training and badly constructed personal protective equipment (PPE) worsened the incident's impact. This information is sometimes overlooked in earlier studies that concentrate more narrowly on ergonomic or safety considerations alone. This research provides a more comprehensive understanding of the intricate connection between safety and ergonomics in situations involving chemical spills.

On the other hand, earlier research on the Hungarian Red Sludge Disaster, such as that conducted by Kertesz et al. (2013), focused mostly on the breakdown of the infrastructure and the absence of maintenance in the years preceding the disaster. These studies touched on ergonomics in passing, but they didn't go as far as ours in examining the function of ergonomic design in emergency response systems. Inadequate structural integrity and maintenance caused the dam to collapse, according to the analysis of the Hungarian Red Sludge Disaster. However, our study goes one step further and contends that the physical strain on employees, which is made worse by shoddy workstation design and a lack of ergonomic accommodations, can cause response times to be delayed and safety measures to be less effective in an emergency.

This study also provides unique insights by emphasizing the importance of proactive safety measures**.** While earlier research, such as Yahya et al. (2020)**,** showed that inadequate waste management and regulatory oversight were key causes of the Pasir Gudang incident, our findings stress the need to incorporate ergonomics into preventative planning**.** The proactive design of both PPE and workstations, as well as comprehensive ergonomic training for emergency responses, could significantly reduce the risk of such disasters occurring in the first place.

In summary, our study adds to and validates previous research by illuminating the complex interrelationship between safety procedures and ergonomics. We provide practical insights to enhance operational effectiveness, environmental sustainability, and worker safety in industrial settings by detecting integration gaps. Our comprehensive approach highlights the vital requirement for integrated ergonomic design and strong safety measures to successfully limit chemical spill risks, even when earlier research provided insightful individual factor evaluations.

4.0 Conclusions

4.1. Summary of Key Points

The terrible consequences of industrial chemical accidents are best expressed by the Pasir Gudang Chemical Spill in Malaysia (2019), the Elk River Chemical Spill in the United States (2014), and the Hungarian Red Sludge Spill (2010). Such incidents show that poor chemical handling is an important contributing factor, showing the urgent need for better hazard communication and strengthened safety protocols in industrial settings. These enhancements need to cover things like facility layout, equipment management, workstation design, and updating antiquated machines.

Massive environmental damage, worker exposure to hazardous chemicals, and a high human cost in terms of illnesses, injuries, and fatalities were all consequences of these chemical accidents. Inadequate security measures, poor emergency response plans, and unethical corporate behavior were mainly blamed for the underlying causes. But in order to reduce hazards and protect worker health, these tragedies highlight how crucial it is to combine chemical safety with ergonomic principles.

This study highlights the importance of using several strategies to improve worker safety and industrial sustainability. Chemical incidents can be significantly decreased by creating a safer and more ergonomic industrial environment. Creating a safe and healthy environment that benefits private businesses, and the larger society is a shared duty among all parties involved. Besides the prevention of the chemical accident, we can also learn the emergency response of each case to reduce the damage to the victim. After the emergency response, the recovery phase and reconstruction phase also important to take note that how can we rebuild all the damage efficiently. All in all, an accident is an incident we all don’t want to happen, but if it happens, we might need to do our best to handle it, clear the damage and rebuild the society.

4.2. Lessons Learned

The incident of toxic chemical pollution in Pasir Gudang industrial area Johor Malaysia in 2019 has affected more than 5000 people, mainly children with respiratory symptoms such as breathing difficulties, nausea, and vomiting after breath in the poisonous gases. It was reported that these children were having a manifestation of psychology due to anxiety about chemical exposure. However, there is no clear evidence to prove this argument. Besides, the chemical exposure was unable to be detected in the children's urine and blood biomarkers.

Table 2: The route of chemical exposure and effects (Adapted from Syed Ismail, S. N., et al., 2020)

Routes of entry	Description	Chemical processes in the body
Inhalation	• Most chemicals in the form of vapors, gases, mists, or particulates • Inhalation is the major route of entry. Chemicals are either exhaled or deposited in the respiratory tract. • Through direct contact with tissue or the chemical may diffuse into the blood through the lung-blood interface. Upon contact with tissue in the upper respiratory tract or lungs, chemicals may cause. • Health effects ranging from simple irritation to severe tissue destruction	• Metabolism Many chemicals are metabolized or transformed via chemical reactions in the body. • Storage In some cases, chemicals are distributed and stored in specific organs. Storage may reduce metabolism and therefore, increase the persistence of the chemicals in the body. • Excretion The various excretory mechanisms (exhaled breath, perspiration, urine, feces, or detoxification) rid the body, over a period of time, of the chemical. For some chemicals elimination may be a matter of days or months; for others, the elimination rate is so low that they may persist in the body for a lifetime and cause deleterious effects.
Skin (dermal)	• Contact can cause effects such as redness or mild dermatitis or severe effects such as destruction of skin tissue or other debilitating conditions. • Many chemicals can also cross the skin barrier and absorbed into the blood system. Once absorbed, they may produce systemic damage to internal organs.	
Eyes	• Short exposure can cause severe effects to the eyes or the substance can be absorbed through the eyes and be transported to other parts of the body causing harmful effects.	
Ingestion	• Chemicals that inadvertently get into the mouth and are swallowed do not generally harm the gastrointestinal tract itself unless they are irritating or corrosive. • Chemicals that are insoluble in the fluids of the gastrointestinal tract (stomach, small, and large intestines) are generally excreted. Others that are soluble are absorbed through the lining of the gastrointestinal tract. • They are then transported by the blood to internal organs where they can cause damage.	
Injection	• Substances may enter the body if the skin is penetrated or punctured by contaminated objects • Effects can then occur as the substance is circulated in the blood and deposited in the target organs.	

It was also reported that the children in this incident were probably having a manifestation of psychology due to anxiety about chemical exposure. People spreading issues associated with toxic pollution, prolonged with uncertain anxiety. The most reported post-disaster psychological problem was post-traumatic stress disorders (PTSD) which was estimated to be within the range of 30–40% among direct victims which later resolved over time. Similar results were also found locally in Malaysia showing that the majority of the flood victims experienced mild to moderate depression (29%) and PTSD (28%). According to the Malaysian Journal of Medicine and Health Sciences (2020), only 2% of them had severe depression and 9.3% had severe anxiety disorders.

Next, the incident of the 2014 Elk River near Charleston spilled approximately 37,800 Liter of crude 4-methylcyclohexanemethanol, at the 1.6 km upstream from the intake of a municipal water treatment facility operated by West Virginia American Water. This incident affected likely 300,000, across nine counties in West Virginia. However, the good new is the chemical substances has a strong smell and noticed immediately by the civilians and quickly spreading "Do Not Use" the polluted water. Over the two weeks, only 584 cases reported which 369 were directly attributed to exposure to water contaminated with the chemical, causing worry about the long-term exposure of the chemical to the water and people. (Case study on managing environmental risks, April 2005)

On the other hand, on 4th October 2010, The Ajka Alumina plant collapsed and caused the incident, Red Sludge take place, releasing approximately 2,000,000 cubic meters of toxic alumina residue into surrounding area. Luckily, the incident took place in the daytime, when most people were away from their homes. Even so, some of them are not that lucky, 10 were killed and almost 300 injured, 120 of them requiring hospitalization due to chemical burns. Over 4,000 hectares (40 km^2) of land were contaminated, with 1,036 hectares of arable land. The environmental impact was substantial, as the sludge also found its wat into local rivers, killing fish and livestock. The Hungarian Red Cross come in quick to take care the accident, rebuild and recovering the area, putting a full stop to the incident. (IFRC Technological and Biological (CBRN) Hazard Preparedness Programme)

4.3. Future Work and Limitations

Environmental monitoring system

Developing a regular environmental monitoring program is necessary for large-scale chemical exposure incidents as part of the chemical system for managing incidents. It should be pointed out that if chemical exposure takes place in an area with people living in it. Regular monitoring of chemical levels at certain times in multiple types of exposure media, including air, water, soil or food produced or sampled in the locations at risk for potential chemical release.

Continuous and thorough data collection, analysis, and interpretation form environmental sample collection have to be part of the monitoring program. The goal of the monitoring program is to gather data on the background concentration of chemicals in the environment, detect concentration deviations, act as warning when chemical level spike, compare levels in the event of different incidents, and determine whether background levels have decreased to their previous levels. (Malaysian Journal of Medicine and Health Science, 2020)

The application of biomarkers in chemical detection

Chemical concentration or metabolites excreted from body fluids or obtained from tissues in samples of the exposed population are called biomarkers. Examples of a biomarker that is widely used in testing include urine, blood, hair, fingernails, etc. Analysis of urine and blood from human samples can provide both qualitative and quantitative evidence of recent chemical exposures. Some assays are sensitive enough and are replicable to identify the human body burden. WHO has also reported that it is a possibility to use physiological measurements such as enzyme inhibition to measure the health effects from chemical exposure. These types of measurements are called biomarkers of effects. The changes that are measured are rarely linked with environmental contaminants. However, it is suggested that reference groups or comparison groups are included in the measurement to help researchers assess whether abnormalities detected are linked with the exposure being studied. WHO also emphasizes the tests to assess immune function, neuro behavioral and respiratory factors which are all commonly applied in environmental investigation.

Limitation

According to Technological and Biological (CBRN) Hazards about Hungary, 2010, the big and most challenging part of the accident was communications. Due to a lack of prior awareness-raising, the communities surrounding the Ajka reservoirs were unaware of the potential risks involved. Most of them are not understanding the toxicity of the “red mud” (Alumina residue), causing them injured by not avoiding it. After that, the rescue phase is becoming difficult as communication is not reliable, slowing down the process and causing conflict between HRC and the locals. Such behaviors are not optimal as the accident does not easily recover, causing more people to be injured and more cost and human resources are required to rebuild the area. Accidents are unavoidable, but injury is avoidable, with suitable knowledge and skills.

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