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A Comprehensive Review of the Health and Safety Risks Faced by Firefighters in Responding to Municipal Solid Waste Incidents

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ABSTRACT

This review article aims to explore the health and safety risks that firefighters may expose while responding to Municipal Solid Waste (MSW) incidents in Iran. Specifically, the article focuses on the problems faced by firefighters during rescue operations, exposure to hazardous materials, and potential injuries associated with heavy waste incidents. This research also surveys the existing practices and arrangements placed for tackling MSW-related events, to identify potential measures to mitigate these risks and ensure the safety of firefighters. The research findings provide valuable insights into the specific problems faced by firefighters in Iran and offer recommendations to enhance their safety and effectiveness in responding to MSW-related incidents. In this context, this research contributes to the development of more responsive practices in Iran by addressing the health and safety concerns of firefighters when dealing with MSW incidents.

1. Introduction

There are numerous health and safety risks for Iranian firefighters when responding to operations to incidents involving MSW. Existing literature has documented the prevalence of job stress among Iranian firefighters, showing how it significantly affects their quality of life and job satisfaction (Mousavipour et al., 2022). This issue can be further exacerbated by the dangerous conditions they may encounter when handling solid waste incidents. Firefighters are vulnerable not only to physical risks but also to environmental hazards that can pose serious threats to their health. Studies conducted in Tehran have shed light on the high-risk health, safety, and environmental hazards associated with solid waste management facilities, calling for immediate remedial actions to minimize the risks (Moloudi et al., 2021). According to the results of a study conducted by Mokuolu and Timothy (2021), the implementation and enforcement of national policies regarding solid waste management are essential through the training and retraining of staff on hazardous waste management in the studied healthcare centers. These findings highlight that prioritizing firefighters' safety by providing them with proper materials and equipment, whenever possible, can help reduce the risks when responding to incidents related to MSWs. Eliminating such hazards can prevent the exposure of firefighters to dangers, leading to a safer work environment, which may prevent work-related injuries or illnesses (Mokuolu & Timothy, 2021). Furthermore, research has correlated the Workability Index (WAI) with the mental workload and musculoskeletal disorders (MSDs) of firefighters in Tehran's firefighting processes (Rahimi et al..

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2019). This indicates a need for better working conditions and ergonomic support to enhance firefighters' occupational abilities and reduce the potential for work-related injuries. Studies on the pathogenic bacterial aerosols of MSW landfill sites have also highlighted the health risks resulting from exposure to such hazards (Samadi et al., 2021). Control measures to manage exposure to these pathogens are crucial to mitigate the probable adverse health effects that they may have on firefighters and others around solid waste management facilities. This keeps away the exposure of pathogenic bacteria to firefighters, hence infectious diseases at such places. In summary, the health and safety risks that Iranian firefighters are exposed to while conducting a rescue from an incident occurring in MSW are considerable. Proper risk assessment, hazard mitigation, and improved working conditions are essential for firefighters' safety. Prioritizing firefighters' safety and providing them with a safer working environment so that chances of getting injuries or illness from exposure to hazardous conditions must be reduced. Furthermore, measures to control exposure to pathogenic bacteria may further protect firefighters' health and minimize the risk of infectious diseases. In general, the health status and occupational ability of firefighters should be guaranteed to ensure continuous response to rescue operations of MSW. The physical hazards faced by firefighters in MSW incidents in Iran include respiratory problems, skin irritations, and exposure to contaminants like bioaerosols, volatile organic compounds, and leachate spills. These risks are further enhanced by other stressors, such as mental workload, physical strain, and emotional trauma. Addressing these risks through training, protective equipment, and access to mental health services following the incident (Ziaei et al., 2018). Additionally, firefighters in Iran face considerable mental health challenges while handling MSWs (Masalegooyan et al., 2022). Common issues with firefighters in this profession are chronic stress, sleep disorders, and strained relationships with family members. The predisposition to occupational stress, burnout, and post-traumatic stress disorder is also high for firefighters and, therefore, indicates that more emphasis needs to be given to mental health support services in firefighting. Attention should be paid to the physical and mental health risks to which firefighters expose themselves during MSW incident management for the well-being of these essential frontline workers in Iran. Investigating the health and safety risks which firefighters face while dealing with MSW incident cases in Iran is very essential due to the various challenges in this regard. The psychological effects of heavy metal contamination risks, and HSE hazards common in such situations make the situation very complicated. The findings have established that firefighters suffer from chronic stress sleep disturbances, and negative emotions while performing their duties in the line duty, which in repetition over a prolonged period substantively affects their well-being (Herfeh et al., 2021). Moreover, there are ecological risks associated with heavy metal pollution in landfill soils. pose a great danger not only to the environment but also to the form and health of those exposed to these very contaminants (Karimian et al., 2021). Hazard prioritization at various solid waste management facilities is the very pre-condition of accident avoidance and protection related to ensuring the health and safety of all personnel participating in waste management activities. It is of great significance, therefore, to know the effects of job stress on their quality of life in Iran, where firefighters bear additional burdens in extinguishing MSW incidents. Stress is identified with its relevant effects on firefighters, and intervention measures for mitigation are implemented. These effects are such that, in the event of an improvement in these areas, better well-being and safety can be achieved. The review brings forth the need to make improvements in training, risk management, and policy adjustments toward absorbing the health and safety risks of firefighters in Iran. Addressing these issues not only helps protect the safety of firefighters but can also affect the general operations of waste management for the good community as a whole. This research aims to conduct a comprehensive review of the health and safety risks faced by Iranian firefighters when responding to municipal solid waste incidents. By analyzing existing literature and identifying key risk factors, this study seeks to: a- Quantify and categorize the specific health and safety risks associated with MSW incidents. b- Evaluate the effectiveness of current safety protocols and training programs for Iranian firefighters. c- Identify gaps in knowledge and resources regarding the management of MSW incidents and their impact on firefighters' well-being. d- Develop recommendations for improved training, safety protocols, and mental health support to mitigate the risks faced by Iranian firefighters. Through this comprehensive review, this study aspires to contribute to a safer working environment for Iranian firefighters, ensuring their well-being while they perform this crucial service for the community.

2. Discussion

Investigating the health and safety risks that firefighters may encounter during incidents involving MSW is important given the potential dangers involved (Jakhar & Sachar, 2023; Juan et al., 2023; Manjunatha et al., 2023). While existing literature highlights certain occupational hazards or specific incidents of chemical spillage, there is a striking lack of comprehensive studies covering the unique challenges MS faced by firefighters in dealing with MSW incidents in Iran (Dąbrowska et al,.2023) This gap in research underlines the need to find and mitigate the specific health and safety risks that firefighters sustain in this context. Developing tailored preventive and response measures will then be crucial in reducing the risk to firefighters' well-being and improving related firefighting operations on MSW (Yamane et al., 2023). The article will also focus on possible risks and hazards that could involve the response of firefighters in MSW incidents. It is through filling this literature gap coupled with detailed research on the subject, that researchers can begin to understand the peculiar challenges of firefighters and eventually devise ways and means to mitigate such risks. Tailored prevention and response strategies under such

scenarios are therefore imperative to ensure the safety and well-being of firefighters, ultimately enhancing the effectiveness of firefighting operations involving MSW (Cimino, 1975). Further research and investigation can therefore provide insight into policy formulation and practice that could lead to the protection of firefighters and the safety of their working environments. When writing a review article focused on researching firefighter safety in MSW incidents, using a comprehensive database effectively is crucial. Below is a structured approach to how we leverage such a database for our research. We started by clarifying the aspects of firefighter safety we aimed to explore, including common hazards associated with MSW incidents, historical data on firefighter injuries or fatalities linked to waste disposal, best practices or protocols developed for enhancing safety, and analysis of emergency response case studies. The researchers used databases with relevant information on firefighting, MSW management, and occupational safety, such as the National Fire Safety Institute (NFSI) in Iran, which focuses on research, training, and improving standards in fire safety. Moreover, they accessed PubMed/ResearchGate containing research articles in excess on Firefighter Health and Safety. The researchers effectively navigated the databases, MSW using specific keywords and phrases such as "firefighter safety", "MSW incidents", "health risks in firefighting", and "waste management protocols" to narrow the search results to relevant literature. They also used the advanced search facilities of the databases to focus on recent publications, peer-reviewed journals, and influential authors or publications in this area. By carefully reviewing the abstracts and conclusions of the relevant studies, the researchers were able to recognize the information systematically, sorting the findings into categories such as incidents, safety measures, outcomes, and recommendations.

2.1 MSW incidents in Iran

While there has been some development in the management of MSW in Iran, significant issues still exist and remain unresolved. The per capita MSW generation in the country ranges from 630 to 839 g per day, with organic waste comprising the major portion of the waste stream, ranging from 65.85% to 70% (Golhosseini & Ghazizade, 2021; Bakhshipour et al., 2021; Esmaeilizadeh et al., 2020). This is a highly alarming fact as over 90% of the MSW in Iran is openly dumped, posing potential health and environmental threats (Kamarehie et al., 2020). In specific regions, like Rasht City, waste-to-energy conversion may also offer some help in reducing the overall quantum of waste. Similarly, in areas like the Shadegan wetland, the potential for recycling and composting is appreciable, with estimates of 0.55 to 0.8 kg of waste per capita per day, but structured waste management programs are lacking. With respect to this, MSW management deficiencies in Iran must consider essential requirements like comprehensive waste monitoring, source separation (Fekri et al., 2023), policies, and integrated waste management plans. All these strategies can contribute to the effective management of the increasing amount of generated waste produced and reduce the environmental and health risks arising from the open dumping of MSW in Iran (Jomehpour & Behzad, 2020). If Iran is to take preemptive measures regarding the situation and implement sustainable waste management practices, it stands a good chance of significantly improving its MSW management system and ensuring a cleaner, healthier environment for its citizens.

2.2 Health and safety risks faced by firefighters

The health and safety risks that firefighters are exposed to are not only physical perils but also involve the long-term effects of exposure to hazardous chemicals and emotional strain. There is evidence that firefighters have had to bear an increased risk of many non-cancer end-makers. Diseases like lumbar disc herniation, lower back pain, angina pectoris, and acute myocardial infarction. Infarction post-traumatic stress disorder, and other occupational groups (Wolffe et al., 2023). Exposure to contaminants during firefighting activities can have both acute and long-term health effects, underscoring the critical need for proper Personal Protective Equipment (PPE). This further illustrates the importance of preventative measures being realized through the supply of appropriate PPE, adequate training, and well-worked safety management systems that limit these risks and support firefighters' overall well-being. Acute exposure to contaminants as involved in firefighting activities, together with the fact that their health effects are long-term, makes the use of appropriate PPE very critical (Everaert et al., 2023; Cuenca & Ramírez, 2023). If properly equipped and trained, a firefighter would be exposed to more smoke from fires with contaminants and its possible health complications. There is, therefore, a need for refresher courses on education and awareness among firefighters to ensure that they are empowered in such cases through learning and having the means of protection against the various perils of the occupation. Only this way can prevention and investment in health and safety measures for firefighters help us avoid these negative health outcomes and also create a more secure and supportive work environment for people who have given their lives towards protecting others.

2.3 Current practices and protocols for waste incident response

Current practices and protocols taken for responding to a waste incident are very manifold and important for ensuring the safety of workers and the environment. Employee training plays a key role in worker training in hazardous waste management, as mandated by law (Khanna et al., 2022). International protocols further underline the importance of incident command systems, decontamination processes, and PPE in responding to waste incidents (Grano, 2022). Proper site characterization is necessary for understanding the type of waste. Involve and determine proper control measures to contain the spill and prevent environmental contamination. Moreover, it is very important

to develop effective disposal strategies so that ensure no secondary pollution events take place, and limit the impact of solid waste incidents on the surrounding areas (Anbari et al., 2015). Environmental Protection Agency (EPA) has recognized gaps in waste disposal preparedness and is currently engaged in closing these gaps through workshops and exercises. This may also be effective for any organization desirous of improving waste disposal preparedness and response capabilities so that it is in a better position to decisively respond to a waste incident by the adoption of some effective measures for ensuring human health and the safe environment (Vimercati et al., 2016). Proper planning, training, and coordination are essential for reducing the impact of a waste incident and taking timely and appropriate actions to protect human health and the environment.

2.4 Existing research on health impacts of waste exposure

In particular, exposure to electronic waste, MSWs, and associated hazardous wastes might pose some serious threats to human health. Emissions from the combustion of MSWs and hazardous waste are major concerns to public health (Desye et al., 2023; Cole et al., 2020; Fazzo et al., 2020). Exposure to lead from e-waste has been shown to impact the health of children in terms of neurobehavioral and physical development. Other health implications caused by e-waste include symptoms such as headaches, memory problems, and tremors, which have been documented among people living near landfills where MSW is burned (Chen et al., 2010). Proper waste management is necessary to minimize health risks due to waste exposure. Well-run Waste-to-Energy (WTE) facilities have long been considered promising for reducing hazardous emissions and improving overall environmental quality and public health in an ambient environment. WTE is a process of generating energy, either in the form of electricity or heat, through the treatment of wastes. It involves the burning of organic material and, can reduce the volume of waste sent to landfills while providing a source of energy. The adoption of Geographic Information System (GIS) technology has been instrumental in measuring waste risk exposure, indicating illegal sites of waste dumping and burning, and facilitating the mapping of disposal sites specifically and helps in ascertaining more effective strategies for waste management (Fazzo et al., 2020). This information is valuable to policymakers and public health officials in designing interventions to reduce exposure and improve community health. The health risks associated with diverse forms of waste demand a holistic approach, including proper waste management, GIS technology utilization, and engaging communities in promoting sustainable waste disposal solutions (Mouganie et al., 2020).

2.5 International comparisons and best practices

International comparisons of MSW management emphasize the disparities between developed and developing countries. Rapid urbanization has led to a common problem faced by many cities in developing countries: a lack of resources and infrastructure to handle waste, resulting in open dumping and environmental degradation (Sharma & Jain, 2020). In contrast, developed countries have focused on reducing, reusing, and recycling waste to mitigate, the potential effect of these increasing MSW generation on the environment and public health (Sohkhlet & Nagargoje, 2020). There is a need for effective waste management MS strategies that address challenges specific to the different regions. Sustainable waste management technologies, like waste-to-energy projects, have gained prominence as a solution to mitigate the environmental impact of MSW disposal (Karim & Wetterhan, 2020). By understanding the differences in waste generation, composition, and management practices across the world policymakers can adopt effective MSW policies that promote sustainable environments and public health (Ram & Kumar, 2021). Through collaboration, countries can strive towards the improvement of MSW management through cooperation and knowledge-sharing for a cleaner and healthier future.

2.6 Policy recommendations for improved firefighter safety in waste incidents

There is an immediate requirement for policy recommendations to enhance the safety of firefighters during waste incidents. Numerous technologies can be employed in saving the lives of first responders and incident management. Proper equipping of firefighters with mandatory monitoring of PPE based on intoxication markers and deploying foreground incident safety officers are the steps to ensure a safe working environment for firefighters (Juan et al., 2023; Paplicki et al., 2018). Indeed, paying attention to these recommendations could make a very big difference in risk reduction for firefighters responding to waste fires (Nigl et al., 2019). Finally, understanding the specific origins associated with fires in waste treatment facilities, such as lithium-ion battery self-heating and runaway, and human activities, becomes critical to the prevention of another such incident in the future. Such risks may be mitigated by improving regulatory frameworks and their corresponding oversight so that they offer protection against environmental and economic impacts arising from waste fires. This means that the prevention of fires, risk assessment, and sustainability in the industry of waste management should be based on policy decisions to ensure better safety and minimize the occurrence of waste fires (Stenis & Hogland, 2011). Computer modeling could also be used regularly to evaluate measures of safety so that firefighting strategies are effective for incidents involving wastes, equipping firefighters better and preparing them for the incident.

2.7 Firefighters' challenges with MSW

2.7.1 Hazardous materials

One of the risks that firefighters face within MSW is hazardous materials. MSW can contain a variety of

hazardous materials, such as toxic chemicals, flammable materials, batteries, and electronic waste. When these materials catch fire or are disturbed, they can MSW produce toxic fumes, gases, or dust, which firefighters may inhale, leading to respiratory issues, skin problems, and other health-related concerns. In addition, some hazardous materials in MSW are highly flammable or reactive, posing threats of explosions and fires, as well as chemical reactions, to response personnel and citizens alike (Mazzucco et al., 2020). To mitigate these risks, firefighters undergo specialized hazardous materials response training and utilize appropriate PPE during handling or extinguishing of fires involving hazardous materials in MSW. They also equip themselves with specialized equipment, such as gas detectors and chemical neutralizers, to help them safely manage the dangers presented by hazardous waste. It therefore follows that the hazardous materials found in MSW pose another challenge to firefighters to be vigilant, knowledgeable, and well-prepared for the safe handling and extinguishing of hazardous-material fires.

2.7.2 Fire risks

Due to the considerably large quantities that form piles, MSW is a major fire risk challenge to firefighters. Landfills, representing areas where most municipal solid wastages are disposed of, can easily catch fire from many flammable materials, such as paper, plastic, and organic wastes. Additionally, organic waste decomposes, generating heat that will further increase the aspect of risk factors of spontaneous combustion. Landfill fires can be hard to stamp out by firefighters once they break out because the continuous fuel sources feed the fire (El-Fadel et al., 1997). This can also be due to the large size of the landfills and the compact nature of the waste piles, because of which it is hard to access the core of the problem and hence completely extinguish the fire. In addition, the materials in the pile of waste can give off a lot of hazardous fumes when burning and hence become a health hazard to both the firefighters and the people living near these landfills. Specialized equipment and training may be necessary for firefighters to successfully put out a landfill fire, such as heavy machinery to move and spread out burning refuse, as well as firefighting foam or other agents designed to starve the flames (Kumar et al., 2016). Coordination with waste facility workers may also be required to control the movement and extinguish the fire while minimizing environmental impacts. Managing fires in MSW is a complex and dangerous challenge that demands a comprehensive approach from well-equipped and trained firefighters.

2.7.3 Limited access

Access to landfills and waste disposal facilities is very limited during incident response. Construction areas are sited in remote or industrial areas; access roads are narrow and badly maintained. This directly affects the response of fire trucks, especially large apparatus, and other emergency vehicles to the actual site, increasing response times and allowing fires to build in intensity. Together with this in landfills and waste disposal facilities, a complex layout can be found, besides multiple storage areas, equipment, and structures that may hinder access for firefighters. This would also lead to situations wherein access is very difficult for a firefighter to gain an overview of the situation, locate a fire origin, and make effective resource deployment (Nanda & Berruti, 2020). This limited access to waste disposal facilities is also a safety concern for firefighters. Dangerous materials, explosions, collapses, and problems of visibility are just some of the complications that might threaten or hinder firefighters from moving around and working inside these facilities. Specialized training for municipal solid-waste-related incident response would imbue firefighting personnel with such knowledge as layout configurations, hazard identification, and access and extinguishing strategies for fires occurring in these settings. Ultimately, however, very instrumental to availing the information and materials needed for effective taming of the break-out incidents within any waste disposal facility are collaborations between waste management companies, municipal authorities, and other stakeholders. Indeed, investment in resources and equipment specifically tailored for combating such fires including specialized vehicles for operating in these conditions and firefighting foams may help increase firefighters' potential to minimize threats to public safety.

2.7.4 Heavy machinery

During fire response at a facility for waste disposal, firefighters have to move through and around heavy machinery used for compacting, sorting, and processing wastes. Such machinery makes its way from very large trucks and forklifts to conveyor belts and shredders; it will impede access points into the buildings, create barriers, and limit visibility for firefighters to try and extinguish flames and rescue individuals inside facilities. Besides firefighting, heavy machinery also entails numerous significant safety risks to firefighters. Firefighters who work close to such machinery are constantly exposed to the risk of being hit, crushed, or caught between moving parts (McCann, 2006). Additional noise, vibrations, and heat emission from the apparatus further exacerbate the exposure to risk and safety conditions for those attending the scene. Moreover, the presence of heavy machinery introduces other hazards regarding the behavior and spread of fire (Tomašková et al, 2019). combustible materials such as flammable liquids or flammable gases may exist within very short distances from operating machinery, thereby raising the possibility of 388 extremely rapid growth in fire, hence escalation. Structural collapse or equipment failure is also more likely when firefighting operations are conducted around heavy machinery. Firefighters will be required to undergo specific training on how to safely move around heavy equipment and work with staff at a waste disposal facility to identify potential hazards and formulate effective response plans (Kontogianni & Moussiopoulos, 2017). Fire departments may

want to equip themselves with specialized equipment, such as heavy-duty protective gear and tools, to enhance the safety and efficiency of firefighting operations within a waste disposal facility. The application of heavy machinery within waste management facilities should be done in coordination with the regulatory agencies and industry players to ensure observance of set safety standards and regulations.

2.7.5 Toxic fumes

During MSW fires, firefighters are exposed to a myriad of fumes and other gases that pose serious health risks. Among the exposure routes are inhalation and skin contact, while, on the other hand, exposures might result in various health problems, such as respiratory effects, skin irritation, and long-lasting impacts on health. The biggest problem posed to firefighters is that they do not have the right protective gear to defend themselves from such fumes (Fent et al., 2014). Indeed, in most cases, a firefighter may not be equipped with equipment like respirators or full-body suits to help them withstand such dangerous chemicals resulting from the burning of waste, which exposes them to the inhalation of dangerous fumes in their line of duty. Moreover, MSW is so composite that firefighters cannot be sure what kind of toxins they are exposed to. All the materials, plastics, chemicals, electronic wastes, and so on, emit during burning and create a whole bunch of different kinds of toxic fumes, further putting firefighters into trouble. This is why it becomes paramount that any fire department taking action toward a waste fire ensures that all firefighters respond with proper protective equipment and training. Firefighters have to be equipped with respirators, protective clothing, and other apparatuses that will reduce the level of toxic fumes inhaled (Park et al., 2014). Further, fire departments must also institute monitoring procedures for air quality at waste fire scenes so that firefighters are informed of the toxicity level and can initiate safety precautions accordingly.

2.7.6 Structural instability

Firefighters are frequently expected to traverse unstable stacks of MSW that are configured in a variety of ways during operations related to their management. It is not uncommon for such stacks to suddenly collapse or slide, resulting in substantial risk to firefighters working nearby. Some factors cause structural instability in the waste piles which may be attributed to the weight and composition of the waste or extrinsic circumstances that include weather conditions and hazardous content materials. As firefighters potentially work inside these piles, searching for victims or fighting smoldering fires, they must constantly guard against collapse and take precautions to minimize the risk (Shimizu et al., 2009). Moreover, structure instability may hinder firefighting processes through easy denial of access to parts of a building or barring firefighters from effectively controlling the spread of a fire to reduce further threats to firefighters while making extinguishing processes more difficult. In essence, the challenge that structural instability of waste piles adds to firefighting operations is a step into an element of danger. Vigilance and strategy are two core firewalling dispositive needed to manage such situations effectively and safely.

2.7.7 Lack of resources

Firefighters are not implicitly trained for MSW incidents due to limited resources. The risks associated with MSW incidents, including fires, fumes, and structural collapses, require a specific set of knowledge and skills that many fire departments may not possess MSW. The lack of adequate training for fire departments is a primary concern when dealing with MSW incidents. These fires are typically complex, requiring specialized strategies for effective containment and extinguishment MSW fires are usually very complex and require special kinds of knowledge and skills to be effectively tackled. The situation assessment, hazard determination, and strategy formulation for confining and extinguishing the fires may prove very tough for fire officers without adequate training (Ibrahim et al., 2013). Moreover, if the firefighters are not properly trained in hazardous materials handling, they may be exposed to dangerous materials constituting the waste. Another problem is the lack of proper equipment and resources. The unique characteristics of MSW fires often require specialized firefighting equipment and techniques, such as foam suppressants or thermal imaging cameras, which may not be readily available to many fire departments. The use of conventional firefighting equipment may prove ineffective, leaving firefighters and the surrounding community at risk (Taha & Marhoon, 2018). Altogether, the shortage of resources and specialized training poses a big obstacle for firefighters dealing with incidents involving MSW. To address this challenge, fire departments must prioritize the provision of specialized training and equipment to their personnel, enabling them to respond effectively in incidents such as these. In addition, the involvement of other agencies or organizations, such as hazardous materials teams and waste management facilities, can extend the capability of fire departments to mitigate MSW-related incidents.

2.7.8 Environmental concerns

One of the challenges firefighters face in dealing with MSW is the environmental concerns associated with fires at waste disposal facilities. Landfill fires or those at the waste transfer station can release hazardous chemicals that become dangerous toxins and pollutants in local air, soil, and water. This can be major in influencing several health effects on firefighters on the scene and those living nearby. Moreover, hazardous chemicals and materials from waste can contaminate the water used in extinguishing the fire, thereby polluting the water. This contaminated water can get into sources of groundwater, rivers, streams, and hence spread further than the environmental effect of the fire (Hasan et al., 2021). Furthermore, it can also release smoke and fumes from the burning hazardous wastes that emit toxic gases and particulate matter from combustion into the atmosphere,

thus causing air pollution, which will have dire implications on the respiratory health of firefighters and communities in adjoining localities. Essentially, fires in such facilities pose a different challenge to any firefighter because of possible environmental contamination and pollution that may result from such incidents (Stracher & Taylor, 2004). More care should be taken to prevent these environmental dangers from happening, and protection for both public health and the environment should be ensured when taming these fires.

2.8 Strategies to deal with MSW

2.8.1 Hazardous Materials

1- Organize mass training for the fire service on the identification and handling of hazardous materials that come into contact with MSW. 2- Use appropriate PPE for firefighters including respirators, gloves, and suits, that protect one from hazardous materials. 3- Enter a contract with hazardous waste disposal companies, which shall remove hazardous materials from such facilities safely for disposal (Pántya & Horváth, 2023).

2.8.2 Fire Risks

1- Fire risks at waste disposal facilities are to be assessed regularly for identification of possible fire hazards and realization of preventive measures. 2- Train firefighters in specialized techniques for extinguishing the fires in the waste piles by initial attacks with foam or water curtains to limit flame spread. 3- Thermal Imaging Camera shall be used for hot-spot detection and temperature monitoring of a waste pile during firefighting operations (Nazari et al., 2020).

2.8.3 Limited Access

1- Make pre-arranged paired response procedures with landfills, and MSW facilities so that emergency vehicles would quickly gain access. 2- Engage the authorities at government levels in liaison towards upgrading the road infrastructure and access routes to facilities for wastes. 3- The ability to use smaller, agile firefighting vehicles that may move on narrow pathways and tight spaces in this facility (Nanda & Berruti, 2020).

2.8.4 Heavy Machinery

1- Conduct joint training exercises with facility operators for refuse and other waste handling and make firefighters familiar with at least the layout and, in particular, the operation of heavy on-site machinery. 2- Define clearly lines of communication between the team of firefighters and the operators of any machinery to allow for coordination in the conduct of firefighting operations. 3- Apply safe working procedures, avoiding any exclusion areas around a running plant/machinery to eliminate accidents and injuries (Pawlak et al., 2015).

2.8.5 Toxic Fumes

1- Proper training in respiratory protection and hazardous materials should be given to all firefighters to reduce exposure to toxic fumes. 2- Landfill air monitoring systems- an ongoing air quality response from all Waste Management air monitoring systems at landfills notify firefighters of potential hazards. 3- Design decontamination procedures for the removal of hazardous materials and fumes from firefighting gear and equipment at incident scenes in a safe manner (Gainey et al., 2018).

2.8.6 Structural Instability

1- Structural assessments of the waste piles on sites should be made before any firefighting operations for the identification of unstable areas that could, at a later moment, collapse. 2- Using engineering support with heavy equipment, such as cranes and bulldozers, during fire-fighting operations to provide stability to unstable sections of a waste pile. 3- Define procedures for withdrawal and safe areas of refuge for firefighters should structural collapse or instability occur (Mingmin et al., 2015).

2.8.7 Lack of Resources

1- Sufficient Advocacy: Fund and resource increase advocacy within the fire department to acquire special equipment and training programs for MSW incident responses. 2- Be prepared to coordinate response efforts with nearby fire departments or regional teams as incidents at solid-waste facilities require that resources and expertise be pooled together. 3- Mutual aid agreements with operators of solid waste disposal facilities stipulate a supply of additional equipment and efforts in the event of an emergency (Al-Khatib et al., 2015).

2.8.8 Environmental Concerns

1- Containment barriers and water curtains shall be installed to contain runoff from firefighting operations and to prevent environmental contamination. The water curtains are normally used to prevent the diffusion of some pollutants in enclosed spaces, but their use in open areas can still have grounds, especially when managing runoff from firefighting activities. During firefighter intervention in open environments, runoff can occur that may contain hazardous materials, chemicals, or any other kind of pollutant. Water curtains can be used to establish containment barriers to restrict the movement of the contaminants and make them flow toward predestined areas for collection and further treatment. Further, the use of water curtains in open spaces could minimize the direct effect of runoff water on the soil, vegetation, and nearby water bodies, hence reducing the possibility of large-scale environmental contamination. In this way, a water curtain can be used for catching potential pollutants, but it will have further cooling effects that would be advantageously applied to gain control over fires. 2- Develop procedures to manage hazardous materials and hazardous waste disposal under environment-related laws and regulations. 3- Liaise with environmental agencies and waste management experts on implementing the best practices in environment-friendly measures to minimize the

ecological impact of fire-fighting operations within the facilities of waste disposal organizations (Bara & Dusserre, 1997). Figure 1 below shows a mind map of the Firefighters' limitations, risks, and solutions in waste incidents. It graphically summarizes the problems and solutions in dealing with the present risks of solid waste.

3. Conclusion

Firefighters form an integral part of any emergency response system, and this may include incidents related to MSW in Iran. The purpose of the study was to identify the health and safety risks faced by firefighters when responding to these incidents and to propose strategies, based on the literature and findings, to mitigate such risks. Several strategies were identified to make firefighters safer while dealing with MSW incidents. These include ensuring firefighters have proper PPE, providing education about the hazards from incidents involving solid waste, and implementing proper management practices to avoid the occurrence of such incidents. These findings align with and support earlier studies concerning health and safety risks that firefighters are exposed to in a variety of emergency response situations. In essence, this research has brought into challenges firefighters face in tackling MSW incidents in Iran and has suggested useful strategies that could be implemented to safeguard their health and safety. These strategies can serve as a guide for policymakers and emergency management agencies, contributing to the creation of a safer environment for firefighters and reducing the risks associated with incidents involving solid waste. This review highlighted the health and safety risks that firefighters are exposed to during an MSW incident response in Iran. Through an in-depth review of the available relevant literature and case studies, the study has identified key challenges facing these first responders in their line of duty. The review also listed effective strategies and made practical recommendations to enhance the protection of firefighting personnel in such situations. Firefighters must be provided with appropriate PPE, comprehensive training programs on handling hazardous materials are instituted, and effective communication and coordination among all stakeholders are fostered. The findings are in line with previous studies carried out in different regions regarding the challenges faced by firefighters at MSW emergencies. Collectively, these studies underscore the urgent need to take decisive action to ensure firefighters' health and safety and to argue for improved equipment and resources to support their operational effectiveness. In conclusion, the health and safety risks arising during MSW incidents for firefighters pose a huge problem, not only in Iran but globally. In this context, the proactive strategies identified in the existing literature can be transposed to further protect our first responders and provide a much safer work environment for those who put themselves in harmful ways for the greater good.

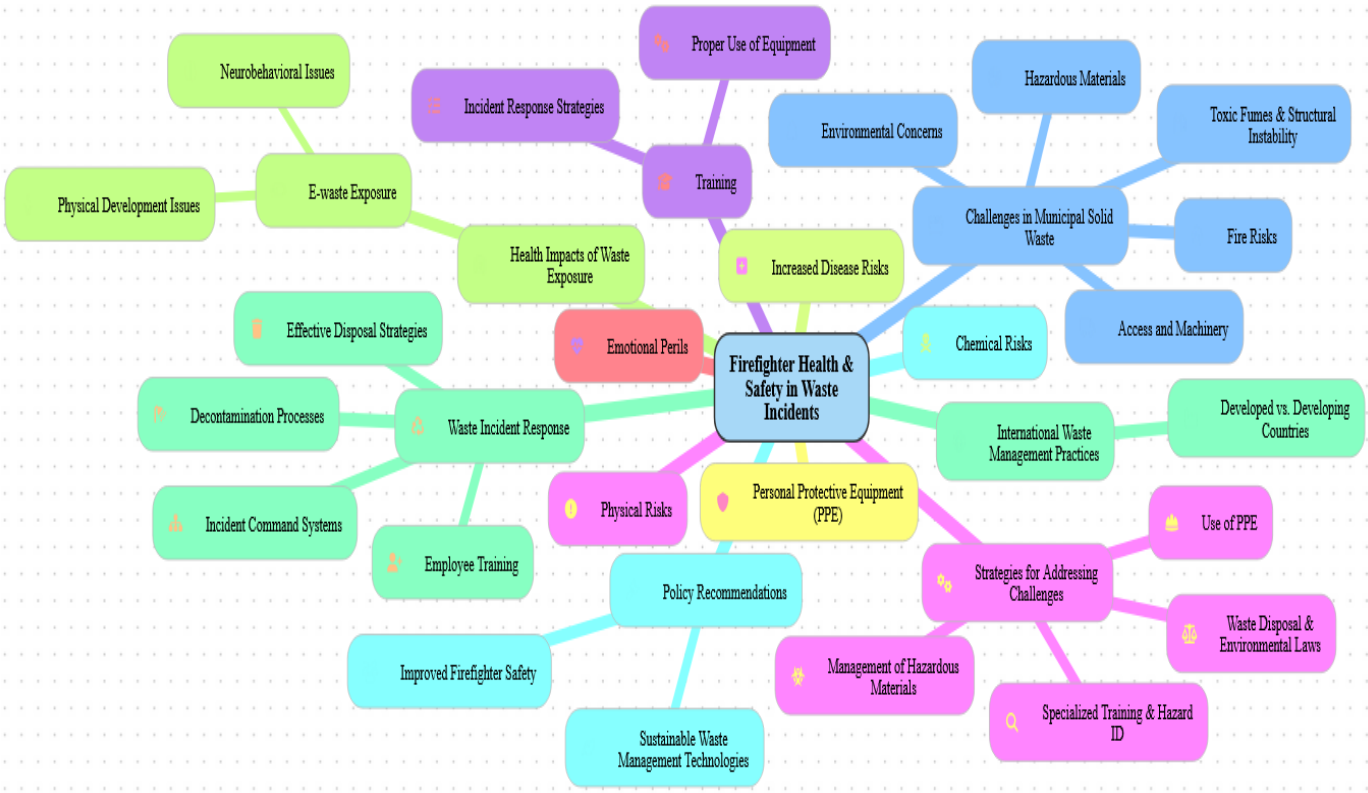

Figure 1. Firefighters' limitations risks and solutions in waste incidents

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Conflicts of Interest

We have no conflicts of interest to disclose.

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Ethical considerations

There were no ethical considerations to be considered in this research.

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