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Review Article

The Silent Threat Below: A Comprehensive Analysis of Manhole Gases and Health Effects

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ABSTRACT

Manhole gases, often hidden underground in cities, can be really harmful to our health. This review looks at all the important aspects of these gases. It starts by talking about the different types of manhole gases, where they come from, and how common they are in cities. Then, it explains how people can be exposed to these gases, either by breathing them in or through their skin, with real-life examples to help understand better. Next, it talks about how these gases can make people sick, both in the short term with symptoms like dizziness and in the long term, leading to problems like lung diseases or issues with the brain. It also mentions that some people, like kids and older folks, are more at risk. To protect people from these dangers, the review suggests a few important ideas. It says we need to make sure workers and anyone near manholes are safe by following strict rules and using special gear. We also need to come up with new technologies and ideas to find and stop these gases from being a problem. Everyone must know about these risks, so there should be campaigns to tell people how to stay safe. In short, this review tells us that manhole gases are a serious concern for our health in cities. But by using smart strategies and keeping an eye out for these dangers, we can make sure everyone stays safe.

Keywords: Public safety, Global threat, Manhole gases, health concern, health hazard, exposure pathways

1. Introduction

In the current global context, the escalating threat of pollution has garnered significant attention within the scientific community. This heightened concern is primarily due to its detrimental effects on water resources, leading to both water scarcity and water pollution

(Zhao et al., 2022; Yusuf 2019). Each day, a growing array of contaminants and pollutants, including inorganic heavy metal ions and organic dyes, are being introduced into our aquatic ecosystems. This influx can be attributed to the rapid pace of industrialization and urbanization, involving a multitude of industrial sectors such as textiles and clothing, battery production, distillation, mining, metallurgy, and electroplating, among others (Yusuf 2020; Yusuf 2017; Halyal et al., 2023). It is worth noting that certain metals play crucial roles in various biochemical processes that are integral to our daily lives. However, the presence of heavy metal ions and numerous organic dyes in water systems poses a severe and widespread threat. These substances are highly toxic, exhibit remarkable stability, and are non-biodegradable (Zhao et al., 2022; Yusuf 2019, Yusuf 2020, Yusuf 2017; Yusuf 2021). Consequently, they elicit numerous harmful and adverse reactions, underscoring the urgent need for effective mitigation measures (Fawad et al., 2022; Yusuf et al., 2017).

Beneath the bustling streets of our modern cities lies a network of manholes that serve as access points to critical infrastructure, including sewage systems, utility lines, and communication networks. These subterranean structures, often unnoticed by the general public, play a pivotal role in urban life (Khan et al., 2020). However, the unassuming manhole conceals a set of contemporary challenges that have increasingly come to the forefront of urban planning and public health concerns (Usher et al., 2021). As our cities continue to grow and evolve, the maintenance, safety, and health impacts associated with manholes have become pressing issues that demand comprehensive examination (Pamidimukkala et al, 2021). In the global context, the challenges posed by manholes extend beyond the boundaries of individual cities. As urbanization accelerates worldwide, particularly in densely populated regions, the demand for efficient infrastructure and utilities intensifies (Dickson et al, 2012). This global surge in urban development amplifies the significance of manholes and the associated challenges. Moreover, the variability in infrastructure standards, environmental conditions, and regulatory frameworks across different countries further complicate the manhole conundrum (Dhakal and Chevalier 2017). To address these challenges effectively, it is imperative to consider not only local issues but also the broader international landscape. Looking ahead, it is evident that the concerns surrounding manholes are only poised to grow in complexity. In light of this, this review not only aims to comprehensively analyze the current state of affairs but also explores potential remedial measures and a future outlook for manhole management. As technology continues to advance, innovative solutions for monitoring, maintenance, and safety are emerging, offering hope for improved management of manholes and reduced health risks. In this ever-evolving urban landscape, it is crucial to envision a future where manholes coexist harmoniously with the urban environment, safeguarding both infrastructure integrity and public well-being (Cothern 2016).

2. Emission of Hazardous Gases from Manhole

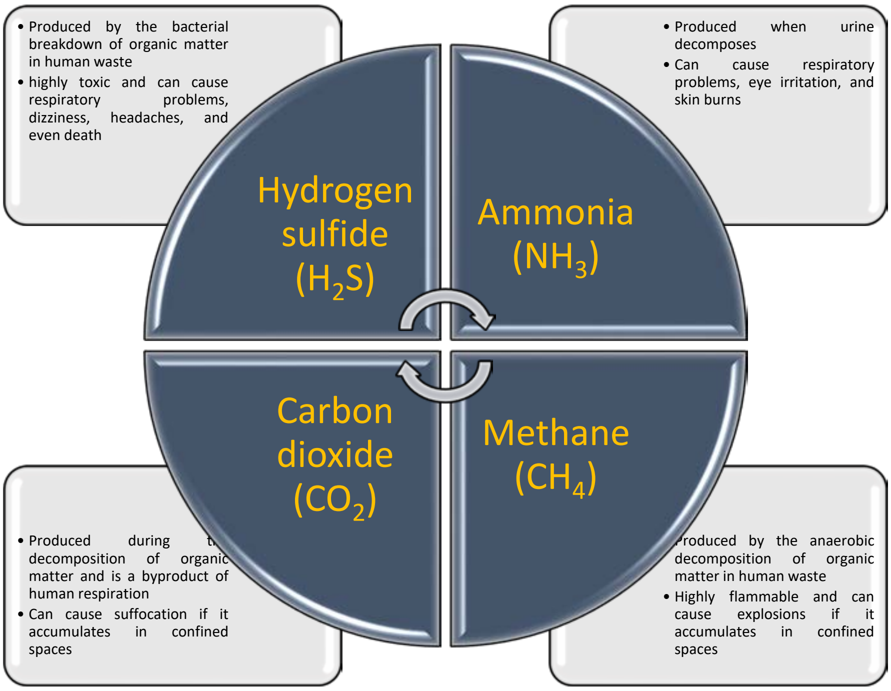
Common manhole gases are a group of potentially hazardous gases that can accumulate in underground utility tunnels, sewage systems, and confined spaces such as manholes (Smith et al, 2014; Neitzel et al., 2018). These gases pose significant risks to the health and safety of workers, first responders, and the public when they are not properly managed and controlled. While several gases can be encountered in manholes, three of the most prevalent and concerning types are methane, hydrogen sulfide, and carbon dioxide. Methane is a colorless, odorless, and highly flammable gas that is naturally produced during the decomposition of organic matter in sewage systems and underground spaces. Methane is a significant concern in manholes because it can easily ignite and create explosive atmospheres if it reaches a certain concentration. Inhalation of high concentrations of methane can also lead to asphyxiation, displacing oxygen in confined spaces (Soeder et al, 2014). Hydrogen sulfide is a colorless gas with a distinctive "rotten egg" odor. It is a byproduct of bacterial activity during the decomposition of organic matter in sewage systems and can be highly toxic even at low concentrations. Exposure to hydrogen sulfide can lead to immediate respiratory irritation, headaches, nausea, and, in high concentrations, loss of consciousness and death. It is a major concern for workers and first responders who may enter manholes without proper protection (Thomas 2007). Some of the most typical gases released during manual scavenging are presented in Fig. 1. Carbon dioxide is another common gas found in manholes, often a result of incomplete combustion processes in nearby equipment or the natural decomposition of organic material. Carbon dioxide is heavier than air and can accumulate in low-lying areas of manholes, posing a suffocation risk when it displaces oxygen. Unlike methane and hydrogen sulfide, carbon dioxide is typically odorless and colorless, making it harder to detect without specialized equipment. Many gases can be released during manual scavenging, posing a major risk to the employees' health and safety. These gases are emitted when human waste is disturbed or agitated during the cleaning process and are formed during the breakdown of human waste.

2.1 Hydrogen Sulphide (H_2S)

It is a highly hazardous gas that can endanger the health and safety of human scavengers who come into contact with it during the cleaning process. The bacterial decomposition of organic materials in human faeces produces H_2S, which can be released when the waste is disturbed or agitated. H_2S exposure can result in a variety of health concerns, including respiratory difficulties, headaches, dizziness, nausea, and even death. At high quantities, as usually found in manholes, the gas is very poisonous and can be lethal. The intensity of the symptoms is determined by the concentration of H_2S and the length of time exposed. Human scavengers who come into contact with H_2S during the cleaning process are at a greater risk of acquiring health issues. Coughing, shortness of breath, and chest discomfort are common acute symptoms. Persistent H_2S exposure can result in chronic respiratory issues such as bronchitis and pneumonia. Apart from respiratory issues, H_2S exposure can also damage the central nervous system, resulting in symptoms such as headache, dizziness, and loss of consciousness. Long-term H_2S exposure can result in neurological issues such as memory loss, irritability, and depression. To safeguard employees from the health risks connected with H_2S and other harmful gases, it is critical to eliminate manual scavenging and offer them safer and more dignified alternatives. Table 1 lists the significant manhole gases and their association with several health impacts. Employers have a responsibility to provide their staff exposed to H_2S with appropriate personal protective equipment, which includes respirators and gas masks. They should also receive comprehensive training on how to use it effectively. In a recent study conducted by Fugazza et al. (2021), it was found that Italian immigrant workers were more likely to be exposed to physical, chemical, and psychological hazards in the workplace compared to native workers. The study also revealed that exposure to these hazards resulted in a higher incidence of health issues among both immigrant and native workers. A recent study by Khoo et al. (2021) investigated the impact of indoor air quality on occupant health. The study found that indoor air pollution can cause various health problems, including respiratory issues, allergies, and other ailments. The findings underscore the significance of improving indoor air quality in workplaces to protect employees from the harmful effects of exposure to indoor air pollution.

Table 1: Major manhole gases and their associated Health Impacts.

Major Manhole Gas	Associated Health Impacts
Methane	▪ Risk of explosions and fires when ignited ▪ Oxygen displacement leading to asphyxiation ▪ Headaches, dizziness, nausea in low exposure ▪ Loss of consciousness or death in high exposure
Hydrogen Sulfide	▪ Immediate respiratory irritation ▪ Headaches, nausea, eye and throat irritation ▪ Loss of consciousness or death in high exposure
Carbon Dioxide	▪ Oxygen displacement leading to asphyxiation ▪ Nausea, headaches, confusion in low exposure ▪ Loss of consciousness or death in high exposure



2.2 Ammonia (NH_3)

During manual scavenging, one of the gases that can be released is ammonia. This gas poses a threat to the health and safety of human scavengers who come into contact with it during the cleaning process. Ammonia is produced when urine decomposes and can be released when the waste is disturbed or agitated. Exposure to ammonia can lead to various health concerns, including respiratory issues, eye irritation, and skin burns, as noted by Guo et al. in 2021. The severity of the symptoms depends on the concentration of ammonia and the length of exposure. Those who work as human scavengers and come into contact with ammonia during the cleaning process are at a higher risk of experiencing health issues. Common acute symptoms include coughing, shortness of breath, and chest discomfort. The exposure to these gases can cause a range of health problems, such as respiratory issues, headaches, dizziness, and even death. It is crucial to put an end to manual scavenging and promote safer and more dignified alternatives for employees. Chronic exposure to ammonia can result in long-term respiratory issues, such as bronchitis and pneumonia, as reported by Ćurić et al in 2022.

It is critical to eliminate manual scavenging and offer employees safer and more dignified alternatives to safeguard them from the health risks linked with ammonia and other poisonous gases. Employers should provide suitable personal protection equipment, such as respirators and gas masks, to workers who are exposed to ammonia, as well as thorough training on how to use it. In addition to respiratory difficulties, ammonia exposure can cause eye irritation and skin burns. Employees who are exposed to ammonia may suffer redness, itching, and burning sensations in their eyes, as well as skin irritation and burns. The acute inhalation toxicity of ammonia gas in Sprague-Dawley rats was examined by (Kim et al, 2020). The rats were exposed to varying quantities of ammonia gas for 4 hours, and the scientists assessed the effects on respiratory function, histopathology, and other physiological parameters. The study discovered that high levels of ammonia gas exposure induced respiratory difficulties such as airway constriction and inflammation, and that the severity of the symptoms increased with concentration and length of exposure. The study sheds light on the health impacts of ammonia gas inhalation as well as the necessity to safeguard employees from the dangers connected with this gas exposure (Zhang et al, 2019; Xu et al, 2021).

2.3 Methane (CH_4)

It is a gas that can be created during manual scavenging and can endanger the health and safety of human scavengers exposed to it throughout the cleaning process. When organic matter decomposes, methane is created, and it can be released when the waste is disturbed or agitated. Methane exposure can result in a variety of health symptoms, including dizziness, headache, nausea, and asphyxiation. Because methane gas is colourless and odourless, it may be difficult to detect. It is also extremely combustible and will catch fire if exposed to a spark or flame (Gupta & Gupta 2019; Epstein et al, 2002).

Human scavengers exposed to methane throughout the cleaning procedure have a significant risk of acquiring health issues. They may have acute symptoms such as dizziness, headache, and nausea, which can make it difficult for them to work safely. In severe circumstances, excessive methane concentrations can cause asphyxiation, which can result in unconsciousness, coma, and even death. Kumar and Kumar reported a study that discusses the occupational health concerns related to manual scavenging in India, especially the dangers linked with methane gas exposure (Kumar & Kumar 2020). The authors detail the symptoms of methane gas exposure and argue for increased training and protective equipment for workers exposed to this and other dangerous gases. The essay also emphasises the importance of government and business action to address the core causes of manual scavenging and to offer employees safe and dignified alternatives. In a subsequent study, Thakur et al. 2021 studied the effect of amounts of methane gas in septic tanks in Haridwar, India, recently. In this study, the authors assessed the possible dangers to personnel participating in the cleaning procedure by measuring the methane content in the tanks. The study discovered that methane gas levels in the tanks were high and that employees engaged in manual scavenging were at significant risk of exposure to this and other harmful gases. The research emphasises the importance of better waste management methods as well as the development of safer and more dignified alternatives to manual scavenging (Wankhede & Kahle 2023).

To protect employees from the health hazards associated with methane and other harmful gases, it is important to eliminate manual scavenging and offer them safer and more dignified alternatives. Companies should provide suitable personal protective equipment, such as respirators and gas masks, to personnel who are exposed to methane, and provide them with thorough training on how to use them. Additionally, enterprises should adopt improved waste management practices and alternative waste processing technologies to reduce the generation and emission of methane during trash disposal.

2.4 Carbon dioxide (CO_2)

Another gas that might be present during manual scavenging is carbon dioxide (CO_2), which can have a substantial influence on the health and safety of human scavengers. CO_2 is formed during the breakdown of organic waste and can build up in poorly ventilated locations such as septic tanks or underground drainage systems, where manual scavenging is common. High CO_2 levels can induce a variety of health symptoms, including dizziness, headache, nausea, and, in severe cases, loss of consciousness and death. Because CO_2 is odourless and colourless, it may not be immediately detectable, and employees may be unaware of its presence until they develop symptoms.

It is crucial for companies to ensure that personnel who engage in manual scavenging have the necessary personal safety equipment, such as gas masks or respirators, and are adequately trained on how to use it. Proper ventilation of the work area is also essential to prevent CO_2 build-up. To establish a safe working environment for the staff participating in the cleaning process, it is essential to have proper safety procedures and rules in place. Manual scavengers are at significant risk of health issues when exposed to high quantities of CO_2. Acute symptoms such as dizziness, headache, and nausea can make it difficult for them to work safely. In severe cases, excessive CO_2 concentrations can cause asphyxiation, which can lead to loss of consciousness and even death (Kumar & Kumar 2020). To protect employees from the dangers of CO_2 exposure during manual scavenging, it is critical to stop this dangerous activity and replace it with safer and more dignified alternatives. Singh (2021) highlighted the health risks involved with manual scavenging in India, as well as the need for improved safeguards to limit exposure to hazardous gases such as carbon dioxide. Carbon dioxide can accumulate in poorly ventilated areas such as septic tanks and underground drainage systems, where manual scavenging is common. The paper emphasises the importance of better waste management methods as well as the creation of safer and more dignified alternatives to manual scavenging. It also underscores the importance of public awareness initiatives to improve the health and safety of manual scavengers.

3. Exposure Pathways

Exposure pathways for manhole gases refer to the various routes through which individuals can come into contact with these potentially hazardous gases. Manhole gases, including methane, hydrogen sulfide, and carbon dioxide, can pose health risks when encountered, and understanding how people are exposed to these gases is crucial for implementing safety measures (Jana et al. 2022). Fig. 2 depicts the exposure pathways regarding manhole gases.

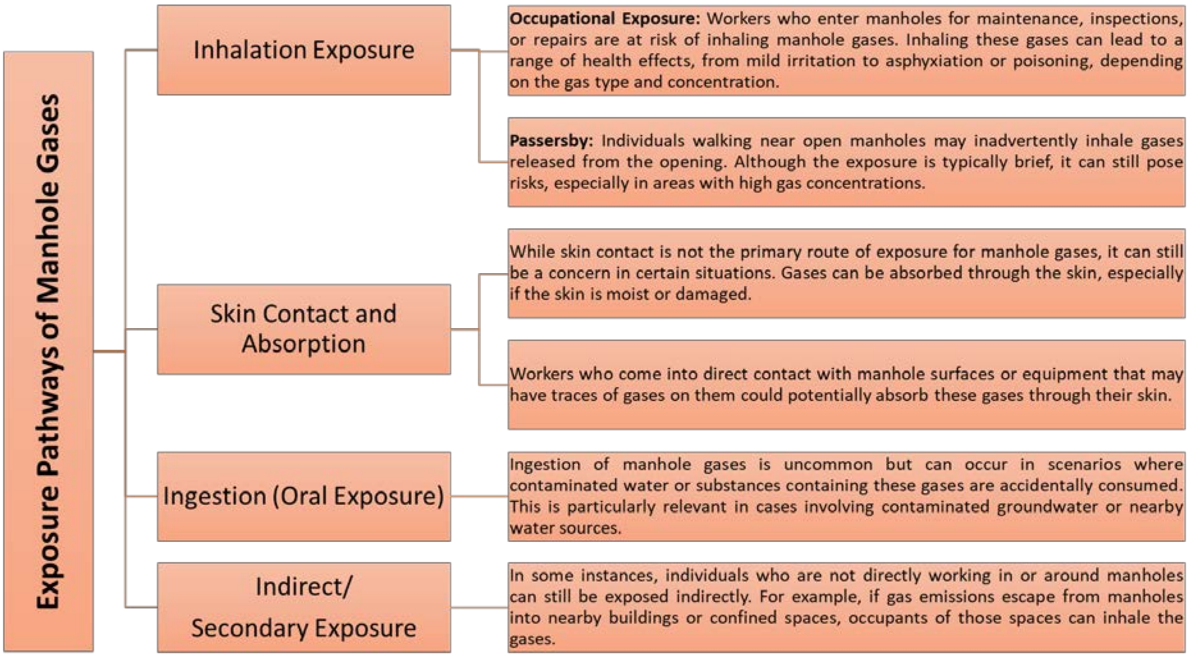


Figure 2: Illustration of the pathways of exposure in relation to manhole gases.

It is important to emphasize that the extent of health consequences hinges on variables including the gas's type and concentration, the duration of exposure, and an individual's susceptibility (Golden 2011). Given the inherent hazards linked to manhole gases, the implementation of stringent safety protocols, the use of personal protective equipment (PPE), and the deployment of monitoring systems are imperative for the well-being of workers and all individuals engaged in activities associated with manholes. Furthermore, ensuring adequate ventilation and providing comprehensive training are effective measures to reduce the potential risks stemming from manhole gas exposure.

Human skin contact and absorption of manhole gases typically occur under specific conditions, although it is not the primary route of exposure. The extent of skin absorption also depends on the characteristics of the specific gas. Some gases have a higher potential for skin absorption than others. For instance, hydrogen sulfide (H_2S) is known to be absorbed through the skin more readily than gases like methane or carbon dioxide. The skin is a protective barrier against external substances, but some gases can be absorbed through the skin, particularly if it is moist, damaged, or in prolonged contact with the gases, given herein:

- *Moist Skin:* When the skin is moist or wet, it becomes more permeable to certain gases. For example, if a worker has sweaty skin or is exposed to water or damp conditions inside a manhole, the skin's barrier properties may be compromised. This increased permeability can allow some gases to enter the body through the skin.
- *Prolonged Contact:* Extended contact with manhole surfaces or equipment that may have traces of gases on them can increase the likelihood of skin absorption. Workers who handle contaminated tools or surfaces for an extended period may be at risk of absorbing gases through their skin.
- *Skin Damage:* Skin that is damaged or compromised due to cuts, abrasions, or skin conditions may be more susceptible to gas absorption. In such cases, the barrier

function of the skin is weakened, making it easier for gases to penetrate and enter the bloodstream.

In most cases, the primary concern is inhaling these gases, which can lead to more immediate and severe health effects. Nevertheless, to minimize the risk of skin contact and absorption, workers are typically advised to wear appropriate personal protective equipment (PPE), including gloves and clothing that can provide a barrier against gases, and to avoid prolonged exposure in damp or contaminated environments. Proper hygiene practices, such as washing the skin after exposure, can also help reduce the potential for skin absorption (Khan 2020).

Proper awareness, monitoring, and safety precautions are essential when dealing with these common manhole gases to prevent accidents, injuries, and fatalities. Understanding their characteristics and potential risks is crucial for maintaining the health and safety of those working in and around manholes.

4. Future perspectives

Looking ahead, the field of manhole gas management will be greatly influenced by emerging technologies for gas detection. Recent developments in sensor technology, data analysis, and real-time monitoring systems offer promising possibilities for enhanced safety. Miniaturized, cost-effective sensors can be strategically placed in manholes, providing continuous monitoring and transmitting data in real time to central control centres. These sensors can detect gas concentrations, temperature fluctuations, and unusual vibrations, enabling swift identification of potential hazards. Moreover, the integration of artificial intelligence (AI) and machine learning algorithms can enable predictive modelling, allowing authorities to anticipate and prevent gas-related incidents proactively. The development and implementation of such technologies will revolutionize manhole gas management, making urban environments safer and more resilient.

Day-by-day, while our understanding of the acute health effects of manhole gases has advanced significantly, future research will focus on comprehending the long-term health consequences of chronic exposure. Robust epidemiological studies will be crucial for monitoring and evaluating the health outcomes of individuals exposed to manhole gases over extended periods. These studies should encompass diverse populations, including workers, residents living near manholes, and individuals in high-risk urban areas. Establishing evidence-based guidelines and regulations by examining the correlation between prolonged exposure and the development of chronic respiratory diseases, neurological disorders, and other health conditions can help safeguard the long-term health of those at risk of manhole gas exposure. This research will provide valuable information to policymakers, occupational health professionals, and urban planners, allowing them to take proactive measures to protect the public's health.

Innovative approaches to manhole maintenance will also play a crucial role in minimizing the risks associated with manhole gases. Future maintenance strategies will prioritize preventative measures that leverage technology and sustainability. Robotics and remotely operated vehicles (ROVs) equipped with gas sensors and cameras can access and inspect manholes, reducing the need for human entry and minimizing exposure risks (Chen, 2022). In addition, using sustainable materials for manhole covers and infrastructure can mitigate corrosion, which often leads to gas leaks. Innovative designs that incorporate improved ventilation and gas capture systems within manholes can aid in controlling emissions at the source (Khan 2019). Collaborative efforts among municipalities, engineering firms, and environmental organizations will drive these innovative solutions, making manhole maintenance safer and more environmentally friendly.

5. Conclusion

Manhole gases pose a significant danger to human health and safety, lurking silently in our urban infrastructure. A comprehensive study of manhole gases has revealed that it is a multifaceted challenge that requires a holistic approach. It covers the inherent risks of exposure and the potential for long-term health effects. To establish evidence-based policies and regulations, epidemiological research needs to be conducted, focusing on the long-term health effects of manhole gas exposure. By exploring the correlation between chronic exposure and health conditions, we can proactively protect the health of vulnerable populations and those at risk. Moreover, innovative maintenance practices such as robotics, sustainable materials, and improved ventilation systems offer environmentally friendly and effective solutions to mitigate gas emissions and minimize exposure risks. As we continue to navigate the evolving landscape of manhole gas safety, it is essential to recognize that ongoing research, collaboration among stakeholders, and the implementation of these progressive measures will be the cornerstone of our success. Our focus should be on addressing this silent threat, ensuring not only the safety of urban environments but also the health and prosperity of the communities that thrive above. The future of manhole gas management holds great promise, thanks to emerging technologies such as advanced sensors, real-time monitoring systems, and predictive analytics. These innovations will not only enhance safety for those working within manholes but also protect the well-being of communities living in proximity to these concealed dangers.

Author’s Contribution

Each author has made significant contributions to the development and completion of this paper on manhole gases and their health impacts. Their individual roles are:

Dr. Waseem Ahmed: Conducted extensive literature review on manhole gases, and exposure pathways& analysed and drafted the paper's content.

Dr. Mohd Yusuf: Concept, designed graphics, analysed global perspectives on manhole gases related to health and environment, drafted the paper's content and corresponded the paper.

Dr. Mohd Wazid Khan: Assisted in making the final shape and contributed to the paper's discussion and conclusion section.

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