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H_2S GAS LEAK EMERGENCY PREPAREDNESS AND COMMUNITY RESPONSE: A CRITICAL REVIEW OF BEHAVIORAL FACTORS AND GAPS

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Abstract

Hydrogen Sulfide (H2S) gas leaks are a serious threat to communities near industrial sites, endangering health and the environment. While safety technology has improved, a community's ability to respond effectively depends on how well-prepared people are. This review dives into what shapes community behavior during H2S emergencies, drawing from global research and a study in Assaluyeh and Nakhl Taghi, Iran. We found that understanding risks, trusting local authorities, and clear communication are key to safe responses. Our data shows notable differences in safety behaviors, especially tied to where people live, revealing gaps in awareness and training. We call for community-focused plans with better education, open communication, and practical training to empower people, reduce risks, and build stronger, safer communities worldwide.

***Key words**: H_2S gas leak, emergency preparedness, community safety, behavioral factors, risk communication.*

INTRODUCTION

The pervasive threat of H_2S in industrialized regions

Hydrogen sulfide (H_2S) is a colorless, toxic, and flammable gas recognized as one of the most significant industrial pollutants and environmental health hazards (Talebi, 2020). At low concentrations, it produces a distinct "rotten egg" odor that serves as a simple warning; however, at higher and more dangerous concentrations, olfactory fatigue occurs rapidly, making H_2S a true "silent killer" (Beauchamp et al., 2020; Public Services and Procurement Canada, 2023).

H_2S is primarily produced through the anaerobic decomposition of organic matter and is commonly present in industries such as crude oil and natural gas extraction and refining, wastewater treatment, and geothermal energy production (OSHA, 2015; Talebi, 2020).

Accidental or chronic releases of H_2S pose serious health risks, ranging from acute respiratory and neurological symptoms to rapid death at high concentrations (Beauchamp et al., 2020; Ng et al., 2019).

Beyond its direct health impacts, H_2S also contributes to environmental acidification and the deterioration of infrastructure and ecosystems (WHO, 2003). The global expansion of carbon-based energy industries and infrastructure, particularly in resource-rich regions, has further increased community exposure risks, underscoring the urgent need for robust emergency preparedness and effective community-based response strategies (Brahmia & Mannai, 2025).

The indispensable role of community preparedness in disaster mitigation

Although advanced engineering controls and strict industrial safety practices are the primary strategies for mitigating H_2S risks, the readiness and resilience of local communities ultimately determine the success of disaster management efforts (Batterman et al., 2023). Contemporary approaches to disaster management increasingly draw on sociotechnical systems theory, which emphasizes that human behaviors, attitudes, and interactions within a system are as critical as technological safety measures (Legator et al., 2001; Leveson, 2012). Community preparedness is a proactive, multilayered process that includes understanding risk and vulnerability factors, interpreting complex warning systems, identifying safe evacuation sites, and acquiring basic first aid and self-protection knowledge

(Lacher, 2024). Rapid and effective behavioral responses to alarms during an H_2S release are crucial and can significantly reduce exposure, injuries, and fatalities (Woodcock & Au, 2013). This paper emphasizes that community safety behaviors are not passive outcomes but active, dynamic components of industrial disaster resilience, requiring targeted interventions and continuous engagement with human factors (Siegrist, 2000; Wyche Etheridge et al., 2022).

Aim and scope of this critical review

This review aims to synthesize recent, comprehensive insights into community safety behavior in the context of H_2S gas leak emergencies. It focuses on the multifaceted determinants that shape how individuals and communities perceive, anticipate, and respond to such hazardous incidents. The review systematically integrates evidence from the broader scientific literature, including industrial safety, environmental health, behavioral psychology, human factors engineering, and disaster management. Additionally, it is enriched by empirical evidence from a study examining safety behavior in the local populations of Nakhl Taghi and Assaluyeh counties in Bushehr Province, Iran, regions characterized by extensive oil and gas industry activities and associated H_2S risks (Talebi, 2020). By identifying common challenges, evaluating effective practices, and highlighting persistent gaps in preparedness and response systems, this article seeks to provide practical recommendations to enhance public health safety and strengthen emergency response capacities in industrial environments vulnerable to H_2S hazards worldwide.

MATERIALS AND METHODS

Study Design and Scope

This critical review employed a dual-method approach to synthesize evidence on community behavioral responses to H_2S gas leaks:

1. A systematic literature analysis of peer-reviewed studies (2000–2025) focusing on H_2S preparedness, risk perception, and community behavior.
2. Empirical validation using region-specific survey data from high-risk industrial zones in Assaluyeh and Nakhl Taghi counties, Iran.

Literature searches were conducted using Scopus, Web of Science, PubMed, and Google Scholar with the keywords: “H_2S leak,” “emergency preparedness,” “community behavior,” “risk perception,” and “industrial disasters” (Table 1). Inclusion criteria prioritized studies examining human behavioral factors, sociodemographic influences, and the effectiveness of communication in H_2S emergency contexts.

Table 1. Literature search keywords and strategy

Database	Keywords	Search fields	Filters applied	Results retrieved
Scopus	"H_2S leak" OR "hydrogen sulfide leak" AND "emergency preparedness"	Title, Abstract, Keywords	Peer-reviewed articles, English language, 2000-2025	142
Web of Science	("hydrogen sulfide" OR H2S) AND ("community behavior" OR "risk perception")	Topic (Title, Abstract, Keywords)	Articles, Reviews, English language, 2000-2025	98
PubMed	("H2S" OR "hydrogen sulfide") AND ("industrial disasters" OR "disaster management")	Title, Abstract	Human studies, English language, 2000-2025	76
Google Scholar	"H2S gas leak" AND ("community preparedness" OR "behavioral factors")	All fields	Exclude patents, citations; English language, 2000-2025	96

Notes:
- Search was conducted in January 2025.
- Boolean operators (AND, OR) were used to combine terms for precision and recall.
- Inclusion criteria: Studies focusing on H2S-related emergencies, community behavior, risk perception, or disaster management.
- Exclusion criteria: Non-peer-reviewed sources, studies unrelated to H2S or community response, pre-2000 publications.
- Total unique records after duplication: 412, with 127 meeting inclusion criteria after screening.

Data Collection and Sources

Literature Review

- **Screening**: a total of 412 records were identified, with 127 studies meeting the inclusion criteria after deduplication and relevance assessment (Figure 1).
- **Quality appraisal**: The included studies were evaluated for methodological rigor, risk of bias, and applicability using the Critical Appraisal Skills Programme (CASP) checklists (CASP, 2023).

Empirical Study

- **Survey instrument**: A validated questionnaire assessed safety behavior determinants, including:
  - Risk perception (5-point Likert scale; adapted from Siegrist & Zingg, 2014).
  - Trust in authorities (items derived from Siegrist, 2000).
  - Preparedness actions (e.g., evacuation plans, kit availability; Perry & Lindell, 2003).
  - Sociodemographic variables (age, education, occupation, health status).
- **Sampling**: Stratified random sampling of 680 residents in Assaluyeh (n=350) and Nakhl Taghi (n=330), ensuring proportional representation by distance from industrial sites (<5 km, 5-10 km, >10 km).
- **Ethics**: Approved by University of Tehran IRB (Ref: UT/ENV/2020-87). Written informed consent was obtained.

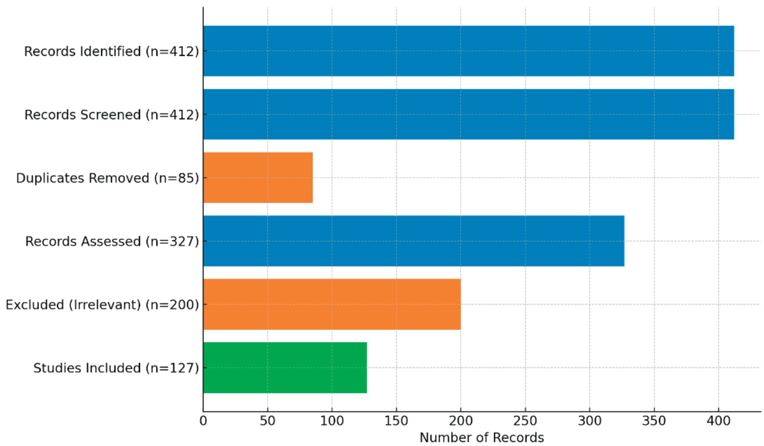

Figure 1. PRISMA flow diagram for literature screening

Data Analysis

- **Quantitative analysis**: survey data were analyzed using multiple linear regression to identify predictors of safety behavior (SPSS v28). The key model was specified as in eq. 1. Covariates included age, education, occupation, and health status. Multicollinearity was assessed using variance inflation factors (VIF), with all values below 2.5 indicating acceptable levels.

$$\text{Safety Behavior} = \beta_0+\beta_1(\text{City})+ \beta_2(\text{Distance})+ \beta_3(\text{Risk Perception})+\cdots+\epsilon \quad (1)$$

- **Qualitative synthesis**: a thematic analysis of the literature was conducted using NVivo 12 to identify recurring gaps, including training deficits and communication barriers, within the context of community preparedness and H_2S emergency response.

Integration Framework

Findings from literature and empirical data were triangulated using a **sociotechnical systems lens** (Sasou et al., 1996), evaluating interactions between:

1. *Technical factors* (warning systems, monitoring tools).

2. *Human factors* (risk perception, trust, demographics).
3. *Organizational factors* (policy, community engagement).

Limitations and Mitigation

- **Cross-sectional design** limits causal inference; future work should adopt longitudinal tracking (Barnett et al., 2023).
- **Geographical specificity**: Findings from Assaluyeh/Nakhl Taghi may not generalize globally; contextual factors were explicitly discussed (Keshmiri et al., 2018).
- **Self-reported data**: Potential recall bias was mitigated via pilot-testing instruments and anchoring responses to recent drills.

RESULTS AND DISCUSSIONS

1. Understanding H_2S Exposure and Its Multifaceted Health Impacts

1.1. Characteristics, exposure pathways, and mechanisms of toxicity on H_2S

Characteristics: hydrogen sulfide (H_2S) is a colorless, flammable, and toxic gas that emits a distinct "rotten egg" odor at low concentrations. At higher concentrations (>100 ppm), olfactory fatigue occurs rapidly, leading to an inability to detect its odor, which is why H_2S is often referred to as a "silent killer" (Beauchamp et al., 2020; Public Services and Procurement Canada, 2023).

Physical properties: H_2S is denser than air, allowing it to accumulate in low-lying areas and enclosed spaces, such as trenches and industrial environments, thereby increasing the risk of exposure (Public Services and Procurement Canada, 2023).

Exposure pathway: the primary route of exposure is inhalation, through which H_2S is rapidly absorbed across alveolar membranes into the bloodstream (Beauchamp et al., 2020).

Toxicity mechanism: once absorbed, H_2S inhibits cytochrome c oxidase (Complex IV) in the mitochondrial respiratory chain, disrupting cellular respiration and leading to cellular hypoxia. This mechanism causes rapid systemic effects, particularly in organs with high oxygen demands, such as the brain, heart, and lungs, potentially resulting in critical organ failure (Batterman et al., 2023; Ng et al., 2019; Lewis & Copley, 2015).

Long-Term effects: prolonged or sub-lethal exposure to H_2S can induce oxidative stress, inflammation, and cell death, which may contribute to long-term adverse health outcomes (Rumbeiha et al., 2016).

1.2. Health risks, dose-response relationships, and vulnerable populations

Exposure to H_2S has detrimental health effects that correlate directly with the concentration and duration of exposure (Ng et al., 2019).

- *Low-level chronic exposure* (as low as 0.3 parts per billion) has been associated with mild neurological and respiratory symptoms, including headaches, nausea, and eye and nasal irritation (Legator et al., 2001).
- *Acute moderate exposure* (50-100 ppm) can rapidly induce chest pain, coughing, shortness of breath, conjunctivitis, and keratitis (Beauchamp et al., 2020; Santana Maldonado et al., 2023).
- *High-level exposure* (>500 ppm) may cause severe central nervous system depression, convulsions, unconsciousness, and respiratory arrest, potentially resulting in death (Beauchamp et al., 2020; Lewis & Copley, 2015; Ng et al., 2019).

Certain demographic groups and individuals with pre-existing conditions are particularly vulnerable to H_2S exposure and require targeted protective measures (Talebi, 2020):

- *Children* are more susceptible due to smaller lung capacities, higher metabolic rates, and proportionally larger alveolar surface areas (Talebi, 2020).
- *Elderly people* often have neurological, cardiovascular, or respiratory comorbidities that can be exacerbated by H_2S exposure (ATSDR, 2016; Legator et al., 2001).
- *Individuals with pre-existing conditions*, such as cardiovascular disease, asthma, or chronic obstructive pulmonary disease (COPD), may experience more severe symptoms even at lower exposure levels, as highlighted in studies from Assaluyeh and Nakhl Taghi (Talebi, 2020).
- *Occupational groups* working in high-risk industries with potential H_2S exposure are particularly vulnerable, and their workplace experiences can influence overall community safety practices and perceptions (OSHA, 2005).

Developing accurate emergency alerts and preventative measures that are inclusive and successful across various community segments requires an understanding of these particular vulnerabilities (Ogie et al., 2018).

2. Factors Influencing Community Safety Behavior in Emergencies

Effective community safety behavior in response to H_2S leaks results from a complex interplay of individual cognitive processes, social dynamics, and environmental factors. The empirical study conducted in Assaluyeh and Nakhl Taghi offered valuable real-world insights by systematically examining various demographic and situational factors that influence safety behavior in high-risk industrial contexts (Talebi, 2020).

2.1. Risk perceptions and knowledge

Accurate knowledge of hazards and the subjective estimation of associated risks are central drivers of safety behavior (Siegrist & Zingg, 2014). In the context of H_2S, this includes understanding its odorless nature at hazardous concentrations, its specific health effects, the limitations of odor detection due to olfactory fatigue, and awareness of appropriate first-line protective actions (e.g., moving upwind or uphill, seeking shelter indoors and sealing openings, and activating personal warning systems) (Morgan et al., 2001).

Empirical findings from Nakhl Taghi and Assaluyeh indicate varying levels of knowledge among residents regarding H_2S properties and emergency response strategies (Talebi, 2020). Notably, the significant correlation between “city of residence” and safety behavior suggests variability in risk perception and knowledge distribution, potentially influenced by proximity to industrial areas, prior exposure to industrial incidents, and differing historical exposure levels between the two districts (Talebi, 2020). Groups with a clearer and more precise understanding of specific hazards are more likely to exhibit appropriate and anticipatory safety behaviors during emergencies (Santoro et al., 2023; Siegrist & Zingg, 2014). However, over-reliance on the “rotten egg” odor as an indicator of danger can lead to fatal complacency, highlighting a critical knowledge gap regarding the limitations of sensory detection of H_2S at dangerous concentrations (Public Services and Procurement Canada, 2023).

2.2. Emergency communication and warning systems

Clear, prompt, consistent, and credible communication is the key to effective emergency response (Ogie et al., 2022). Warning systems must be robust, stable, and accessible to all population groups, including vulnerable populations (Karimiziarani & Moradkhani, 2023). Effective strategies necessitate multi-channel communication techniques (e.g., sirens, SMS, local radio/TV, social media, door-to-door warning, community alarm systems) to ensure message penetration and redundancy (Ogie et al., 2022; Tzioutzios et al., 2024). The coherence, specificity, and concision of messages, conveying clear-cut instructions on "what to do", "where to go", and "who to contact", are crucial for triggering appropriate action (Hinsberg & Lamanna, 2024; Woodcock & Au, 2013). Risk communication must also be recognized as an iterative, integrative process throughout the entire risk management stages - preparedness, response, and recovery - calling for openness, participation, and two-way communication to enable informed decision-making and adaptive capacity building (Hinsberg & Lamanna, 2024; Pidgeon & O'Leary, 2000). The variable safety behavior present in the thesis between the two cities could have implicitly shown differences in communication effectiveness or public acceptance of warnings in the two cities (Talebi, 2020).

2.3. Trust in authorities and industry

The baseline level of the community's trust in the government agencies and the nearby industrial sector is an understated but profound determinant of safety behaviour (Siegrist, 2000). High levels of such trust in the community make them much more likely to respond to official warnings, quickly obey evacuation orders, and take voluntary courses in preparedness (Frewer et al., 1996; Siegrist, 2000). Contributing to the development and sustenance of trust are open communication of information, perceived expertise and responsiveness of emergency departments, sustained interaction with the population, and established accountability for past errors or incidents (Health and Safety Executive (HSE), 2013; Siegrist, 2000). Conversely, prior experience with unresolved problems, expectation of privacy, lack of transparency, or inadequate response to prior incidents can destroy trust, leading to cynicism, delayed responses, or self-imposed non-compliance in a real emergency (Renn & Levine, 1991; Siegrist, 2000). The diversified safety behavior in Assaluyeh and Nakhl Taghi indirectly represents the differences in community-industry/government relations and trust levels in those regions, which reinforce the important role of social capital in crisis management (Behera, 2023; Talebi, 2020).

2.4. Preparedness actions and evacuation behavior

Personal and family preparedness actions are at the heart of community resilience (Lacher, 2024). This includes emergency kit preparations, having family communication plans, establishing safe meeting points, and being familiar with prearranged evacuation routes (Perry & Lindell, 2003). Evacuation decisions are decided by a multidimensional array of factors, including perceived threat severity and proximity, clarity and credibility of directions to evacuate, presence and influence of social networks, and personal resources (Lewis & and Copley, 2015; Shrivastava, 2005). These are barriers to evacuation success and include the absence of transport, caregiving responsibilities (e.g., children or elderly), physical disability, socioeconomic constraints, as well as psychological aspects such as "normalcy bias," where the affected person underestimates the threat and is certain that all would go back to normal (Lewis & and Copley, 2015; Rumbeiha et al., 2016). The thesis, in its general "safety behavior" indicator, indirectly encompasses the dimensions of preparedness behaviors and mentions the role of demographic variables like "number of dependents" and "age" in one's ability or willingness to prepare and evacuate. For instance, individuals with a greater number of dependents will find it more challenging to quickly evacuate, and elderly people will have different mobility problems, which indicates the necessity of inclusive disaster planning (Akama et al., 2014; Talebi, 2020).

2.5. Socioeconomic and demographic factors

Socioeconomic and demographic factors significantly influence individual and collective safety behavior by conditioning access to information, resources, and social networks (Cutter et al., 2003; Legator et al., 2001). Your thesis particularly tested the influence of several such factors, adding empirical validation from the regional context (Talebi, 2020):

- *Gender and age:* both emerged as variables influencing safety behavior, with implications for age- and gender-sensitive communication and training programs (Talebi, 2020).
- *Education level:* a significant influence, with higher levels of education generally linked to better risk understanding, heightened critical thinking, and adherence to safety protocols and emergency instructions (Becker, 2009; Legator et al., 2001).
- *Health status (smoking, chronic illness, medication use):* such health conditions can have direct impacts on one's physical capacity and psychological ability to act effectively in an emergency and demand special planning measures (Ogie et al., 2018; Talebi, 2020).
- *Occupation type, work experience, shift work, second job:* these work-related variables suggest an exploration of whether occupational exposure or experience would translate into general safety awareness and behavior in the broader community. Individuals who work in hazardous industries might have a higher perception of risk or suitable safety awareness that would influence their household's preparedness (Occupational Safety and Health Administration (OSHA), 2005; Talebi, 2020).
- *City of residence (Nakhl Taghi vs. Assaluyeh):* this was the variable most strongly associated with safety behavior (Talebi, 2020). This robust finding highlights that immediate geographical proximity to the industrial complex, coupled with special local policies, community outreach activities, historical exposure to incidents, and socio-economic status within each city, has a dominant and highly localized impact on safety behavior. This highlights the context-dependent nature of preparedness.

3. H_2S Emergency Preparedness and Response Gaps and Challenges

Despite ongoing advancements in industrial safety and emergency management, there are still ongoing and pertinent gaps in fully preparing and enabling communities to respond most effectively to H2S gas releases and other chemical threats.

3.1. Absence of standardized training and drills

The majority of communities residing near chemical hazard sites are seriously short of exposure to routine, standardized, and realistic emergency training exercises specifically targeting chemical releases like H_2S (Santana Maldonado et al., 2023; United Nations Office for Disaster Risk Reduction (UNDRR), 2015). Bystander disaster preparedness training is typically not satisfactory in meeting the unique features of H_2S (e.g., odorlessness in high concentrations, quick onset of bad symptoms, specific ventilation requirements) (Santana Maldonado et al., 2023). Further, the absence of proper public training on H_2S hazards and related protective precautions also increases extensive knowledge gaps, directly hurting proper safety performance (Mileti, 1999). Drills should include escape procedures, shelter-in-place drills, and realistic scenarios in order to create muscle memory and self-assurance (Centers for Disease Control and Prevention (U.S). Center for Preparedness and Response, 2018).

3.2. Inadequate use of local knowledge and participatory approaches

Traditional top-down emergency planning tends to overlook or insufficiently incorporate valuable local knowledge, accessible community social networks, and unique vulnerabilities and assets of affected groups (Atlanta (GA): Agency for Toxic Substances and Disease Registry (US), 2016). This can lead to technically competent but operationally worthless, culturally insensitive, and even unimplementable state plans on the ground (Perry et al., 2001). Effective preparedness demands genuinely participatory approaches where active involvement of community members is made in the risk identification, collaborative plan development, dissemination of information, and feedback so that strategies are feasible to implement, culturally appropriate, and sensitive (Atlanta (GA): Agency for Toxic Substances and Disease Registry (US), 2016; Paton & Johnston, 2006). Disregard of local knowledge can also enhance psychosocial risks among communities who reside in toxic pollution (Couch & Coles, 2011).

3.3. Technological limitations in detection and distribution systems

Although sophisticated H_2S detection systems exist, challenges persist in creating real-time, widespread, and detailed localized monitoring, especially across vast industrial and adjacent residential areas (Morgan et al., 2001; WHO, 2003). Also, providing real-time and focused warning to all at risk, taking into account multiple communication barriers (e.g., language, illiteracy, digital divide, disability), is a significant challenge (Comfort & Haase, 2006; Karimiziarani & Moradkhani, 2023). Obscure warning systems, overreliance on a single mode of communication, or lack of harmonization with smart city systems may lead to vulnerable groups being uninformed or misinformed at moments of high demand (Comfort & Haase, 2006; Elvas et al., 2021).

3.4. Persevering psychological and behavioral barriers

Even with proper knowledge and timely notification, basic human psychological responses can interfere with best safety practice (Rumbeiha et al., 2016). "Normalcy bias" (denial or minimizing of threat), "optimism bias" (sensing personal probability of being harmed as low), "bystander effect," or "panic" (while actual panic is rare, improper conduct can occur) can lead to response delay, maladaptive conduct, or non-compliance (Rumbeiha et al., 2016; Shrivastava, 2005). Neutralizing such widespread behavioral barriers involves not just provision of information but also realistic practice under stress, psychological preparation techniques, and training that aims at the likely exposure to emotional and mental responses to an unexpected, unseen, and lethal threat (Perry & Quarantelli, 2005).

3.5. Policy and regulatory framework gaps

Although industrial emissions, workplace safety, and general disaster management are regulated by law in most nations, policy frameworks specifically addressing general community emergency preparedness for H_2S and other chemical hazards can have significant gaps (Santana Maldonado et al., 2023; UNEP, 2025). These include the absence of clear mandates for industries to get actively engaged and make financial contributions towards community preparedness activities, defined roles and responsibilities for inter-agency coordination (e.g., between industrial operators, local government, emergency services, and public health agencies), and enforceable standards for risk communication and public education (Santana Maldonado et al., 2023; Tierney, 2025). Moreover, there is sparse scientific monitoring and assessment of environmental and health impacts in communities around long-established industrial facilities, reflecting significant knowledge and policy gaps at national and regional levels (Willis et al., 2018). Inadequate land-use planning around dangerous industrial factories can also exacerbate community vulnerability (Walker, 1991).

4. Future Perspectives and Conclusion

4.1. Towards integrated, community-centric preparedness paradigms

Future effective emergency preparedness for H2S will demand a paradigm shift to synergistic, genuinely community-oriented solutions. This demands integrated synergism of robust technical solutions (e.g., advanced, comprehensive H_2S monitoring networks, hybrid early warning systems), sophisticated human factors analysis (e.g., cognitive ergonomics of signals, behavior-based training on psychological principles), and sophisticated socio-ecological knowledge (e.g., linking to community networks, interpreting cultural matters, reducing social vulnerability) (Legator et al., 2001; Leveson, 2012; Siegrist & Zingg, 2014). Multi-stakeholder collaboration, comprising industry, government departments, emergency services, academia, and not least of all the local communities themselves, is required in a bid to establish common responsibility for resilience and safety (Paton & Johnston, 2006; Siegrist, 2000). Pre-emergent activities like joint drills, scenario planning in unison, and unfettered information sharing can build needed trust and significantly enhance collective response capacities, thus overall preparedness and adaptive capacity of a community (Pidgeon & O'Leary, 2000).

4.2. Leveraging emerging digital technologies for enhanced response

Emerging digital technologies offer game-changing possibilities for transforming H_2S emergency preparedness and response:

- *Predictive analytics & real-time monitoring:* IoT sensors deployed for widespread H_2S sensing, combined with advanced atmospheric dispersion modeling and AI for predictive analytics, have the potential to provide real-time, highly localized risk assessment and hazard mapping (Morgan et al., 2001; Prasad et al., 2024).
- *Customized alerts & communication:* Mobile applications and geo-fencing technologies enable rapid, hyper-targeted alerts to individuals in affected areas, with customized directions based on their precise real-time location and known vulnerabilities (Morgan et al., 2001; Mota et al., 2023).
- *Immersive training & simulation:* Virtual Reality (VR) and Augmented Reality (AR) technologies can offer realistic, safe, and repeatable environments for community members to practice complex emergency response behaviors, e.g., evacuation and shelter-in-place. This addresses the limitations of traditional drills via immersive experiential learning (Perry & Quarantelli, 2005; Srinivasan et al., 2022).
- *Social media & crowdsourcing for situational awareness*: While unofficial, social media can also offer valuable sources of real-time information, citizen reporting, and community sentiment during an emergency. Advanced data analytics can allow emergency managers to rapidly identify emerging needs, identify gaps in resource deployment, and refute misinformation (Elvas et al., 2021; Ogie et al., 2022).

4.3. Imperative research priorities for future advancement

Future research efforts in this critical field should be directed towards:

- *Longitudinal studies:* Investigating the long-term psychosocial and physical health consequences of H2S exposure on residents and the sustainability of safety behavior changes following various interventions (Couch & Coles, 2011; Legator et al., 2001).

- *Culturally sensitive communication:* Developing and rigorously testing communication strategies and warning systems that are not only technologically advanced but also culturally sensitive, linguistically appropriate, and actually resonate with multicultural community segments in H2S-risk zones (Ogie et al., 2018; Tzioutzios et al., 2024).
- *Behavioral economics in safety:* Applying findings from behavioral economics and nudge theory to better comprehend and actively influence pro-safety behaviors and compliance with emergency procedures in high-risk environments (Perry & Quarantelli, 2005).
- *In-depth resilience measurement:* Exhaustively measuring the performance of comprehensive community resilience-building initiatives that are specific to industrial chemical threats, extending beyond preparedness actions (Brahmia & Mannai, 2025; Gisela van et al., 2025).
- *Chronic threat psychological effect:* In-depth exploration of the psychosocial stress and mental health consequences for communities under constant threat of H2S exposure, and the development of community-level coping mechanisms and support systems (Couch & Coles, 2011; Galea et al., 2002).
- *Cost-Benefit analysis of preparedness:* Quantifying the economic and social benefits of robust community preparedness programs versus the cost of inaction in industrial disaster scenarios (Botzen et al., 2019).

CONCLUSIONS

Empirical evidence, supported by findings from Assaluyeh and Nakhl Taghi, demonstrates that adaptive and conscious community safety behavior is a critical pillar for effective emergency response to H_2S gas leaks. The observed variations in safety behavior, particularly influenced by the city of residence, underscore the highly localized, context-dependent, and complex nature of preparedness challenges.

Addressing existing gaps in knowledge, trust, communication, and training requires coordinated, multidisciplinary, and multi-stakeholder efforts. By embracing integrated planning, leveraging advanced digital technologies, and fostering genuine community participation and empowerment, it is possible to create environments where communities near H_2S sources are not only safeguarded by industrial systems but are also equipped to respond promptly and effectively during emergencies.

The overarching goal is to build resilient communities capable of mitigating the human, environmental, and economic impacts of H_2S incidents, thereby ensuring public health safety and promoting sustainable industrial development in high-risk regions globally.

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