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Seasonal Risk Assessment of Liquefied Petroleum Gas Leakage in Urban Area: A case Study of Meghna Filling Station, Dhaka

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Abstract

Liquefied Petroleum Gas (LPG) leakage presents a critical safety concern, especially in densely populated urban areas. This study evaluates the seasonal risk dynamics of an LPG release scenario at Meghna Filling station in Dhaka, Bangladesh, Using the ALOHA 5.4.7 air dispersion model to simulate hazard zones under differing atmospheric conditions. Simulations were conducted for both summer and winter conditions to assess toxic gas dispersion, explosion overpressure and thermal radiation hazards based on Acute Exposure Guideline Levels (AGELs) and Lower Explosive Limit (LEL) thresholds. Result show that winter conditions lead to wider dispersion zones across all risk indicators due to increased atmospheric stability and reduced vertical mixing. AGEL-3 concentrations (life- threatening exposure) extended approximately 300 meters in winter compared to approximately 240 meters in summer. Similarly, explosion over pressure zones above 3.5 psi stretched 370 meters in winter, compared to 290 meters in summer. However, in fixed locations near the source, the heat from the gas lasted longer in summer. The thermal radiation intensity that causes second-degree burns (6 kW/m²) stayed about 1 minute in summer, but only 0.4 minutes in winter. These seasonal differences significantly influenced the spatial extent and intensity of hazard zones. The findings emphasize the necessity for season-specific emergency planning and safety measures in LPG storages and distribution facilities to better protect public health and infrastructure.

Keywords: ALOHA model, Dispersion simulation, LPG leakage, Risk assessment, Seasonal atmospheric conditions, Thermal radiation, Toxic concentration zones.

I. Introduction

Fossil fuels including oil, coal and natural gas are a major source of energy in the modern world. It supports systems that help meet basic human needs such as food, shelter, jobs and transport. About 80% of the global energy supply depends on these fuels. But when fossil fuels are burned, they release harmful gases into the atmosphere, which seriously damage the environment[1].

Liquefied Petroleum Gas (LPG) is a different type of fuel than natural gas[2]. It's mostly made up of propane and butane. These gases don't have any color or smell, and they're heavier than air when kept at normal temperatures and pressures. LPG is made in two main ways either directly from oil and gas fields or as a byproduct when crude oil is refined[3]. Most of the LPG used today, around 90% to 95% goes into cooking for homes and businesses. A smaller amount is used in small workshops and to power certain vehicles[4]. These LPG powered vehicles still depend on fossil fuels. Burning LPG gives off carbon dioxide, which adds to global warming, and it also creates a bit of carbon monoxide. Compared to oil and coal, LPG release less carbon dioxide for the same amount of energy. It produces about 81% of the CO_2 that oil does, and 70% of what comes from coal. It even gives off less than half the emission compared to coal-based electricity from the grid. Since LPG is a mix of propane and butane, it gives off more carbon per unit of energy than propane but less than butane. LPG is used widely in industries and other areas because it's so useful[5], but it also comes with risks. If not handled safely, it can form dangerous vapors that are harmful to both people and the environment[6].

Bangladesh is a country rich in natural resources like coal, gas and stone. In this country, LPG is mostly used as cooking fuel and for powering certain vehicles[7]. According to industry experts, in 2015, Bangladesh consumed about 160,000 tons of LPG, of which 142,000 tons were imported and 18,000 tons were produced as a byproduct by state owned companies. By 2017, the total supply of LPG had increased to around 684,000 tons annually, averaging 57,000 tons per month[8]. As the use and demand for LPG continues to grow, it's important to pay attention to the safety risks that come with it. LPG vapor can create an explosive mix when it reaches between 2% and 10% concentration in the air. It can also cause serious skin burns because it cools the skin quickly as it evaporates, in the case of liquid propane[5]. Propane, one of the main components of LPG, can reduce oxygen levels in the air. Exposure to high concentrations such as above 10% may cause dizziness. When oxygen levels fall below 8% to 10% people may lose consciousness and even face life threatening risks[9].

Along with health risks, accidents during the transportation of LPG can be a major concern. Road tanker accidents involving LPG usually happen due to how much gas is filled

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in the tank, the level of traffic on the roads and the population density in the area. In many cases, the tank can get damaged because of mechanical issues or overfilling. This kind of damage can lead cracks in the tank or even failure in the welded joints.

Several studies have examined the risks related to transporting LPG and another hazardous material by road [10, 11, 12]. For example, Chang et al. [13] analyzed 242 accidents involving storage tanks and found that fire and explosions are the most serious dangers linked to oil tanks. On June 5, 2017, a major leak occurred while unloading an LPG tanker at Linyi Jinyu Petrochemical Company, which lead to a big explosion and fire. For this ten people lost their lives and nine others were injured [14]. Another accident happened on august 27, 2012, at around 11:30 p.m. in Chala village, Kannur district, Kerala, India, involving an LPG bulk tanker [15]. More recently, on December 3, 2019, an LPG explosion took place in Beijing, causing four deaths and injuring ten people [16].

In recent years, Bangladesh has seen a worrying rise in accidents linked to LPG leaks, with gas cylinder blasts being especially dangerous. In one incident, a repair operation on an LPG carrying truck went horribly wrong, resulting in severe burns to three people, including a pregnant woman [17]. Another tragic event took place in Kaliakoir, Gazipur, where a cylinder fire caused serious burns to at least 36 individuals, including women and children [18].

As the capital of Bangladesh, Dhaka has become one of the largest users of LPG. The city's high population and growing energy needs both at home and in businesses are the main reasons behind this demand. But with this heavy use comes a higher risk, as Dhaka is also quite vulnerable to accidents involving LPG. The rising threat of LPG related accidents in Dhaka was once again brought in focus on May 30, 2024, when a gas cylinder exploded on the ground floor of a three-story building in Badda, claiming the life of a passerby [19]. According to the 2024 report by the Fire Service and Civil Defence[20], Dhaka witnessed 125 such explosions in 2021, followed by 94 in 2022 and 105 in 2023 reflecting a troubling and persistent safety concern for the city.

A study by Islam et al. [5] investigates how varying wind speeds influence the way LPG disperses in the environment, using the ALOHA model. The research focuses mostly on the general effects of LPG release on the environment. Still, there's a clear lack of detailed research on how seasonal variations might influence the risk of LPG leaks in specific areas across Bangladesh. In particular, no in-depth study has been done on the seasonal risks of LPG leaks at urban or city-based filling stations.

This study aims to understand the seasonal risks linked to LPG leaks at the Megna Filling Station in Dhaka, using the ALOHA (Areal Locations of Hazardous Atmospheres) software. It is focused on how changes in weather like temperature, humidity and wind affect the way LPG spreads and the size of a danger zones. By concentrating on this specific location, this research aims to enhance the comprehension of seasonal risk dynamics and support the development of safety planning and emergency response, and facilitate the adaption of effective risk reduction strategies of urban LPG stations in Bangladesh.

II. Methodology

Study Area Description

This research is conducted on the LPG tank at Meghna Filling Station, located at Newmarket thana (ward no 18), south city corporation, Dhaka, Bangladesh, with geographic coordinates of 90°23'3.97" E (latitude) and 23°44'10.63" N (longitude). The population of ward no 18 is 4,305,063. Annual population change 0.69% from 2011-2022 [21]. Newmarket is the major economic hub in south city corporation. For remarkable reason, this area is selected.

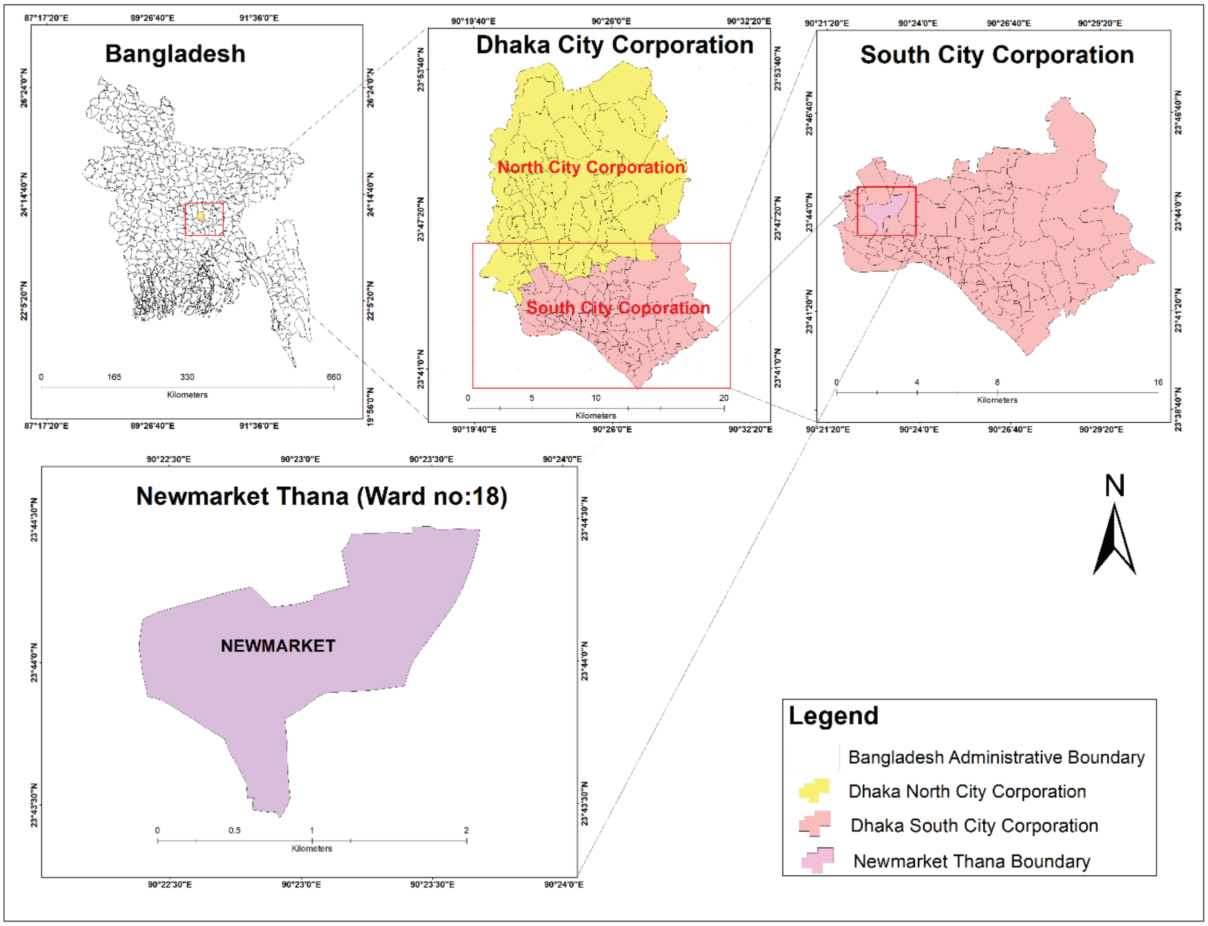


Fig.1. Geographic location of study area

Method

In this study, ALOHA 5.4.7 software is used to predict affected zones of LPG tank leaks in an LPG storage. Physical and chemical properties of tank data collect through field survey and climate data collect from Bangladesh Metrological Department.

ALOHA is a tool used to model how dangerous chemicals might spread through the air during an accidental release. It helps estimate where a leak could go and how far it might spread [22]. This model was developed by several U.S. agencies, including the Environmental Protection Agency (EPA), the Chemical Emergency Preparedness and Prevention Office (CEPPO) and the National Oceanic and Atmospheric Administration (NOAA). ALOHA uses specific danger levels, known as Levels of Concern (LOCs), to assess the risks from fire, explosions or toxic air clouds. These LOCs are different for each chemical and focus on how harmful the substance could be if inhaled. To figure this out, it pulls information from a chemical database called CAMEO, which includes thresholds for toxic exposure through breathing. One important set of safety limits used in ALOHA is called Acute Exposure Guideline Levels (AGELs). There are built into the program and act as public health guidance during chemical accidents. ALOHA shows threat zones on a map these are areas where gas levels may go above safe limits at any point during the release [23]. Several research studied have already used ALOHA to explore what might happen if LPG is accidentally released[24,25]. The model helps emergency planners test different leak scenarios, compare outcomes, and get a clearer picture of the possible risks.

Table.1. Experimental Data

Chemical name	Propane
Tank diameter	2mete
Tank volume	20000 liters
Tank length	6.37meter
Chemical mass in tank	10.4 tons
Circular opening diameter.	11.3 centimeter
In summer	
Average wind speed	11.1 km/h or 3.08 m/s
Average temperature	35.26˚c
Wind direction	Southwest
Atmospheric stability	Unstable; B
Humidity	Medium
Cloud cove	Medium
In winter	
Average wind speed	7.75km/h or 2.15 m/s
Average temperature	26.85˚c
Wind direction	Northwest
Atmospheric stability	More stable; A
Humidity	High (Almost 80%)
Cloud cover	Medium

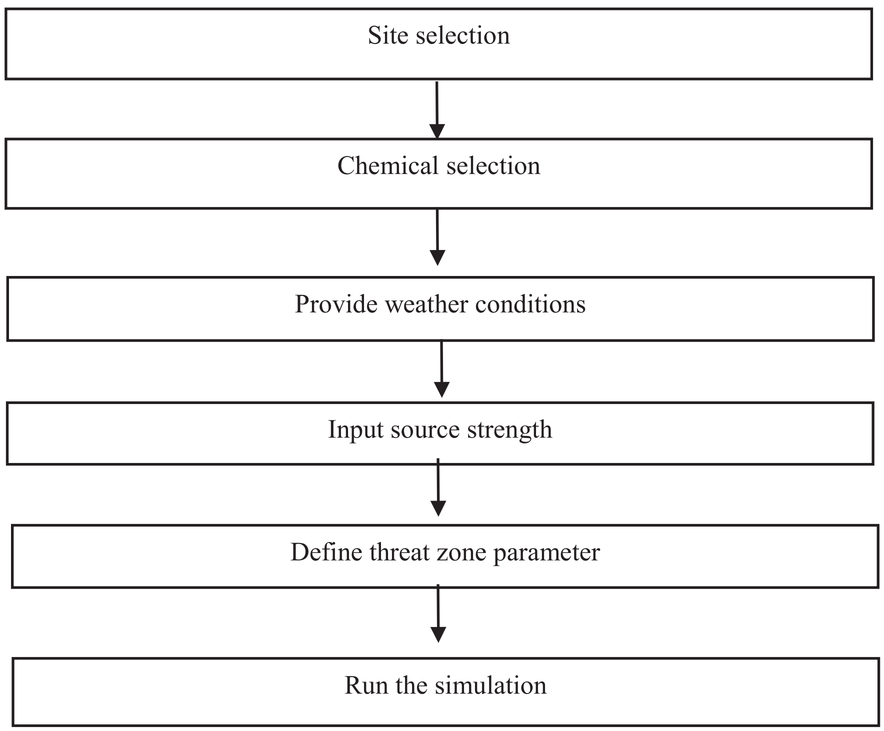


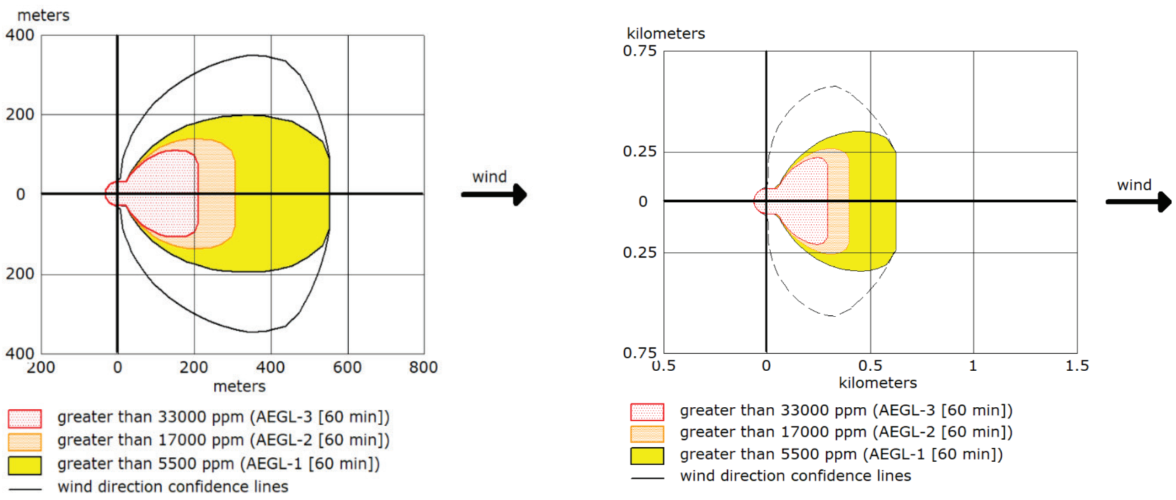
Fig.2. Steps to input data into Aloha software.

III. Result and Discussion

Acute Exposure Guideline Levels (AGEL) Analysis

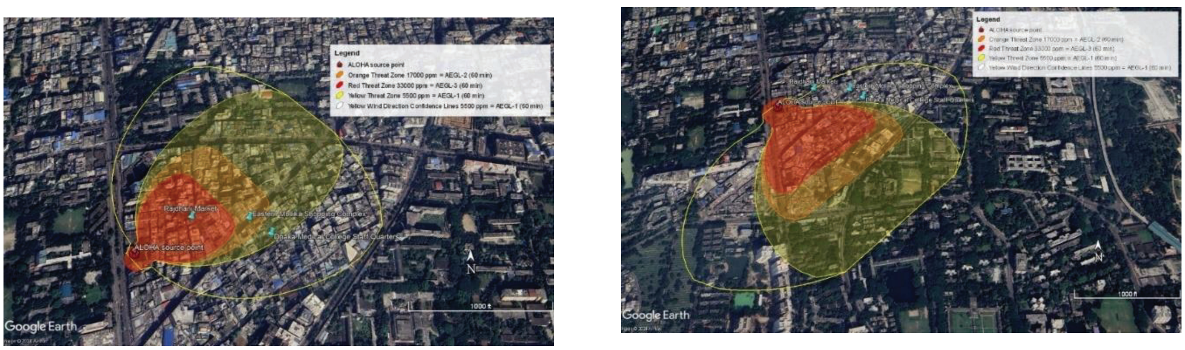
The study simulates the spread of hazardous gas concentrations under two seasonal conditions, summer and winter seasons. According to the study's findings, AGEL-3 concentrations, which represent life-threatening exposure levels at 33,000 ppm, spread up to approximately 240 meters in summer [Fig.3A] and approximately 300 meters in winter [Fig.3B]. These zones are extremely dangerous even brief exposure can result in fatal consequences. Again AGEL-2 concentrations, measured at 17,000 ppm and associated with serious or lasting health damage, extend to approximately 300 meters in summer [Fig.3A] and approximately 400 meters in winter [Fig.3B]. Areas with this range are considered unsafe without protective measures, and immediate evacuation is strongly advised. Further AGEL-1 concentrations, which indicate 5,500 ppm and may lead to mild irritation or discomfort, cover approximately 570 meters in summer [Fig.3A] and approximately 600 meters in winter [Fig.3B]. Although this is not immediately life threatening, people in these areas should evacuate promptly to avoid harm. The satellite images below [Fig.4C and 4D] depict the source points of the leak and the surrounding areas impacted by AGEL-1, AGEL-2, AGEL-3 levels as well as the scale of possible explosions. The images clearly show that the dispersion range is larger during winter, reflecting how seasonal atmospheric stability allows the gas to spread further than in summer.

To further understanding the seasonal hazard potential, the study next investigates how overpressure from possible explosions differs between summer and winter.



(A) (B)

Fig. 3. Toxic area of vapor (A) summer and (B) winter season.



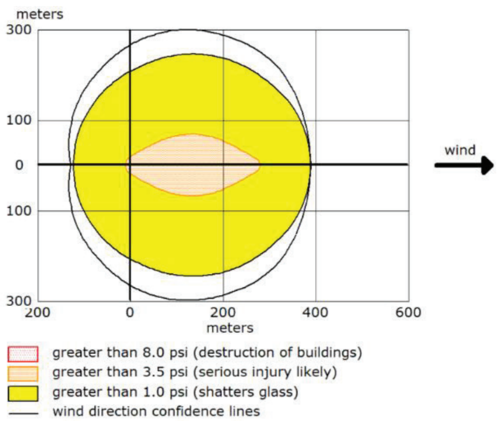
(C) (D)

Fig. 4. Graphical representation of affected area by AGEL-1,2,3 (C) summer, and (D) winter season.

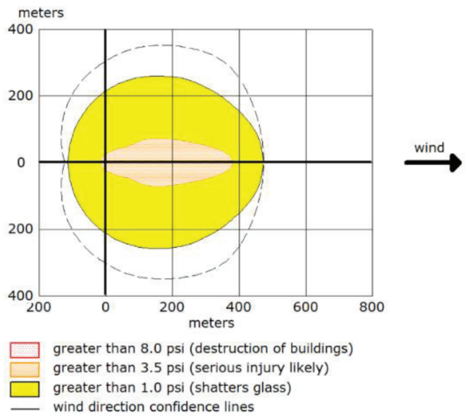
Lower Explosive Limit (LEL) Analysis

The Lower Explosive Limit (LEL) analysis in this study assessed the pressure from potential explosions during both summer and winter seasons in the study area.Although the legend shows >8.0 psi, the over pressure zone doesn't appear in the figure because the explosion likely wasn't strong enough to create such high pressure. It's also possible that any zone above 8.0 psi was too small to be visible. This is common in smaller or less intense blast scenarios. Moderate overpressure areas, where the overpressure is more than 3.5 psi, reach approximately 290 meters in summer [Fig.5E] and approximately 370 meters in winter [Fig.5F], extending 80 meters farther during the colder months. These zones are especially dangerous in closed or poorly ventilated spaces, such as small rooms, narrow alleys, or enclosed structures, because gas can build up more easily raising the risk of sudden ignition and serious harm. The low overpressure zone (over 1.0 psi) spreads up to approximately 380 meters in summer [Fig.5E] and approximately 440 meters in winter [Fig.5F], marking an increase of 60 meters in the winter season. Although the chance of serious structural damage is low here, people may still be injured by broken glass or flying debris. Fire risk in this zone is generally low but can increase if flammable gas builds up. The satellite images in [Fig.6G and H] show the areas affected by potential vapor cloud explosions for both summer and winter conditions.

After understanding the pressure related risks, the study also explores the threat posed by thermal radiation and how far it can reach under seasonal differences.

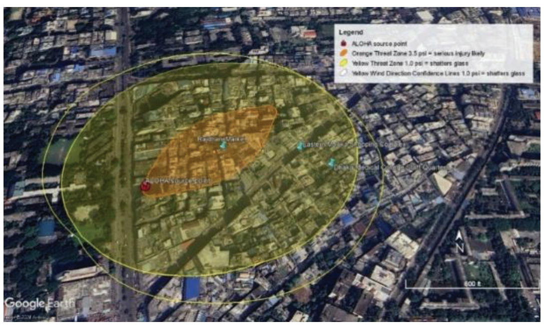


(E)

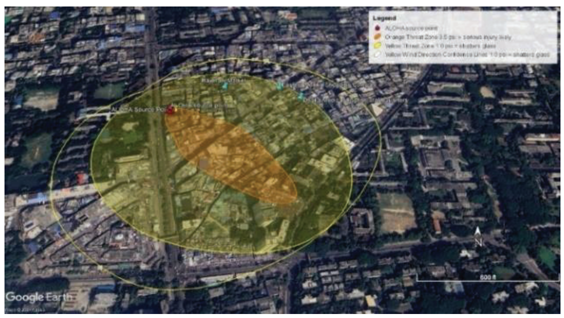


(F)

Fig. 5. Blast area of vapor cloud explosion (E) summer and (F) winter season.



(G)

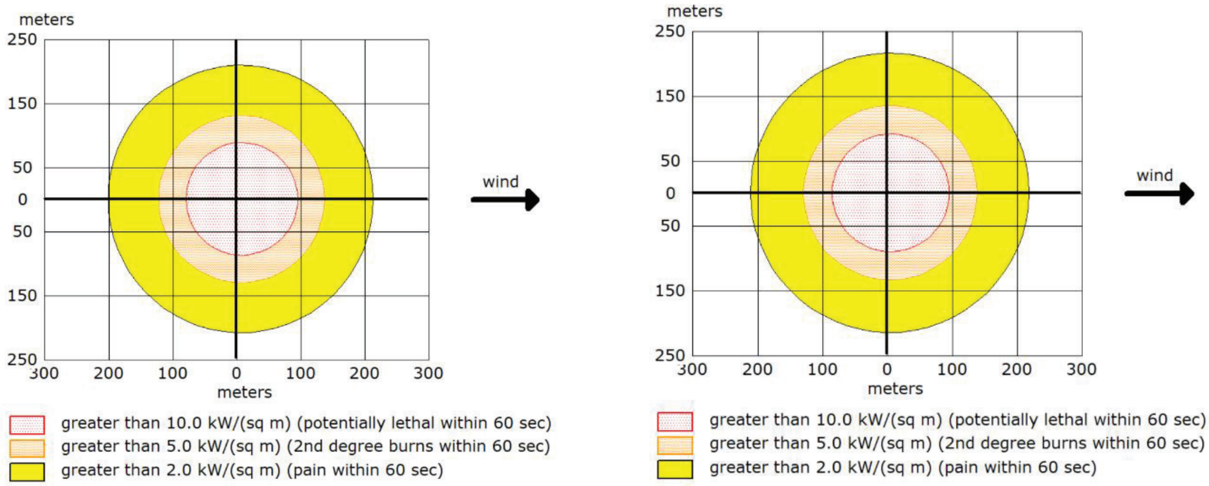


(H)

Fig. 6. Graphical representation of affected Area by potential vapor cloud explosions (G) summer and (H) winter season.

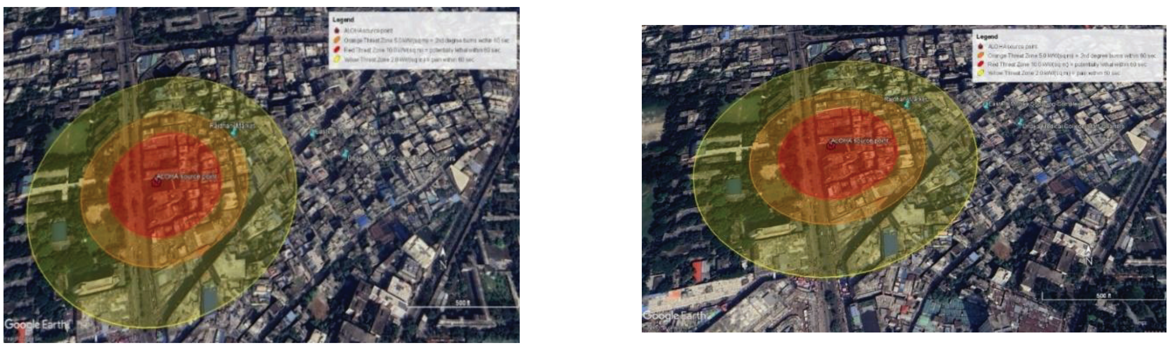
Thermal Radiation Analysis

The thermal radiation exposure under both summer and winter seasons. In the Red Zone (Potential Lethal), lethal radiation levels above 10.0 kW/m² are recorded within distances of approximately 95 meters in summer [Fig.7I] and approximately 97 meters in winter [Fig.7J], making the winter zone 2 meters larger, necessitating immediate evacuation due to the high risk of fatality within 60 seconds. The Orange Zone demonstrates radiation intensities above 5.0 kW/m² at distances of approximately 137 meters in summer [Fig.7I] and approximately 140 meters in winter [Fig.7J], which is 3 meters farther in winter, sufficient to cause second-degree burns within 60 seconds. This level of exposure requires urgent medical intervention to mitigate severe burn injuries. The Yellow Zone reaches radiation levels over 2.0 kW/m², recoded at distances up to approximately 220 meters in summer [Fig.7I] and approximately 240 meters in winter [Fig.7J], increasing 20 meters longer during winter season. This level surpasses the pain threshold, signaling discomfort and making the boundary for implementing safety measures. The satellite images in (Fig.8 K and L) show the chemical burning zones as jet fire in summer and winter seasons.



(I) (J)

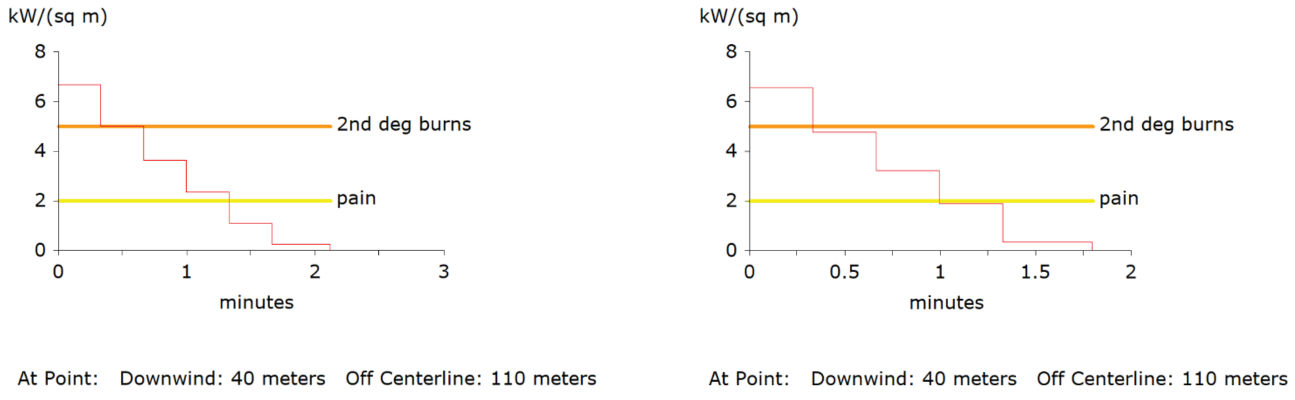
Fig. 7. Chemical is burning as jet fire (I) summer and (J) winter season.



(K) (L)

Fig. 8. Graphical representation of chemical burning zones as jet fire (K) summer and (L) winter season

To extend the seasonal hazard analysis, the study examines thermal radiation impact near an adjacent educational institution (Dhaka College), which is located 40 meters downwind and 110 meters off centerline from Meghna Filling Station, the LPG source. The simulation results show that in the summer, exposure above the second-degree burn threshold (6 kW/m²) persists for approximately 1 minute, and the pain threshold (2 kW/m²) lasts around 2.2 minutes [Fig.9 M]. Conversely, in the winter, the durations are shorter 0.4 minutes for second-degree burn and 1.7 minutes for pain [Fig.9 N]. This seasonal contrast aligns with the broader thermal radiation patterns observed earlier and also supported by prior research, which suggests that in stable atmospheric conditions, heavier gases tend to spread more widely along the ground due to limited vertical air movement, promoting horizontal dispersion [27] because in winter, colder and denser air allows LPG to disperse farther and remain close to the ground. Yet, due to faster vapor dilution and lower ambient temperatures, the thermal energy at a fixed point dissipates more quickly, resulting in shorter but wider reaching exposure. And in summer, the atmosphere is less stable, slowing down horizontal dispersion. This leads to more concentrated gas clouds near the source, resulting in longer-lasting and more intense thermal radiation at nearby fixed locations.



(M) (N)

Fig. 9. Chemical dispersion in educational institution (M) summer and (N) winter season.

Table. 2. Summary of Major Findings

Scenarios	Dispersion Distance in Summer (meter)	Dispersion Distance in Winter (meter)	Distance from Tank Source	Chemical Release Duration in Summer (min)	Chemical Release Duration in Winter (min)
Toxic Area of Vapor					
AGEL-1	570	600			
AGEL-2	300	400			
AGEL-3	240	300			
Blast Area of Vapor Cloud Explosion					
Moderate overpressure	290	370			
High overpressure	380	440			
Chemical is Burning as Jet Fire					
Red Zone	95	97			
Orange Zone	137	140			
Yellow Zone	220	240			
Thermal Radiation Intensity			X; axis-110 meter and Y; axis-40 meter.		
2^{nd} Degree Burns				1	0.4
Pain				2.2	1.7

IV. Conclusion

This study examined the effects seasonal variation of liquefied petroleum gas (LPG) in both summer and winter, alongside the associated risks. The results show that in winter, cold and heavy air helps the gas spread farther along the ground, but the heat goes away faster, so the danger doesn't last long. While, in summer, the gas doesn't spread as far, but it stays more concentrated near the source, causing stronger and longer heat at nearby areas. These seasonal differences result in significant variations in gas dispersion and concentration duration. Specifically, AEGL-3 (33,000 ppm) concentrations disperse over approximately 300 meters in winter versus approximately 240 meters in summer, while AEGL-2 (17,000 ppm) concentrations extend to approximately 400 meters in winter, compared to approximately 300 meters in summer. Additionally, overpressure levels exceeding 3.0 psi reach 370 meters in winter, compared to 290 meters in summer, suggesting a higher explosion risk in winter. Although thermal radiation exposure distances remain almost similar across seasons (97 meters in winter and 95 meters in summer). Atmospheric stability plays a crucial role in the dispersion of LPG and the associated risks. The AEGL levels highlight the varying severity of health risks, with AEGL-3 zones indicating immediate life-threatening exposure, AEGL-2 areas signifying severe health consequences, and AEGL-1 zones causing mild discomfort. Future energy policies should prioritize the development of sustainable alternatives, such as solar and wind power, to ensure a safer and more environmentally responsible energy future.

Glossary

ALOHA: Areal Locations of Hazardous Atmospheres
AEGL: Acute Exposure Guideline Levels
CAMEO: The ComputerAided Management of Emergency Operations.
LEL: Lower Explosive Limit
LPG: Liquefied Petroleum Gas

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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