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Potential Threat Assessment and Degree of Exposure in the event of an Explosion by Sudden Expansion of Boiling Liquid Vapor in the LPG Ground Storage Terminal in Monteverde, coastal Ecuador

Evaluación de la amenaza potencial y grado de exposición en caso de una explosión por expansión súbita del vapor de líquido hirviendo, en la terminal de almacenamiento en tierra de GLP en Monteverde, Costa del Ecuador

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Abstract

The industrial complexes that handle dangerous products with flammable characteristics have been the cause of great misfortunes when sudden explosions are generated, either due to mechanical failures or human negligence. The Monteverde Gas Complex (MGC), located in the province of Santa Elena in Ecuador, represents a potential risk by housing close to 105,000 m^3 of precursor gases such as Propane (PPN), Butane (BTN), and LPG finished product. Therefore, an analysis of the potential threat to which the population is exposed in case of the explosion of one of the tanks with the different products they contain has been carried out, considering the closest communes to the MGC, which are Monteverde and Jambelí. Tools such as the

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Probit method proposed by TNO (The Netherlands Organization for Scientific Research), and the ALOHA software of the EPA (Environmental Protection Agency, USA) were used, whose combinations allowed estimating the radius of influence, which were divided into zones according to the degree of impact on the community. The results demonstrated that the community of Monteverde, despite being more than 1 km away from the CGM, is within the red zone or high influence radius that corresponds to 2000 meters for propane and butane tanks.

Whitin this area, a person could have fatal third-degree burns. The calculations have been performed under ideal conditions, so it is recommended to review the attenuations generated by natural elevations of the terrain or the direction of the wind in further studies.

Key words: *BLEVE, Monteverde Gas Complex, Vulnerability, Santa Elena, Ecuador.*

Resumen

Los complejos industriales que manejan productos peligrosos con características inflamables, han sido causa de grandes desgracias al generar explosiones repentinas, ya sea por fallas mecánicas o por negligencia humana. El Complejo Gasífero de Monteverde (CGM), ubicado en la provincia de Santa Elena en Ecuador, representa un riesgo potencial al albergar cerca de 105.000 m^3 de gases precursores como Propano (PPN), Butano (BTN) y GLP como producto terminado.

Por este motivo, se ha realizado un análisis de la amenaza potencial a la que la población se encuentra expuesta en caso de la explosión de uno de los tanques con los diferentes productos que contienen, para esto se consideró a las comunas mas cercanas al CGM que son Monteverde y Jambelí. Se utilizaron herramientas como el método Probit propuesto por TNO (The Netherlands Organisation for Scientific Research), y el software ALOHA de la EPA (Environmental Protection Agency, USA), cuyas combinaciones permitieron estimar el radio de influencia, los cuales se dividieron en zonas según al grado de impacto en la comunidad. Los resultados demostraron que la comunidad de Monteverde, pese a encontrarse a más de 1 km del CGM, se encuentra dentro de la zona roja o de alta influencia que corresponde a 2000 metros, para los tanques de propano y butano. En ésta área, una persona podría tener quemaduras fatales de tercer grado. Los cálculos se han realizado en condiciones ideales, por lo que se recomienda revisar las atenuaciones generadas por elevaciones naturales del terreno o la dirección del viento en estudios posteriores.

Palabras clave: *BLEVE, Complejo de Gas Monteverde, Vulnerabilidad, Santa Elena, Ecuador*

1. Introduction

The global economy and industries are still predominantly dependent on energy from hydrocarbon and other fossil sources (Sarvestani *et al.*, 2021; Litvinenko, 2020; Huber, 2009). Subsequently, its exploitation, processing and storage have led to the construction of large industrial complexes that house large amounts of materials with mainly flammable characteristics (Nicoletti *et al.*, 2015; Schmidt *et al.*, 2016; Burnes & Camou, 2019; Segura-Alcívar *et al.*, 2019). These infrastructures have been on several occasions the cause of misfortunes due to improper handling or accidental release of these substances considered dangerous due to their toxicity, flammability and the pressure at which they are stored (Makhviladze *et al.*, 1998; Pietersen and Huerta, 1984; Arturson, 1987; Pietersen, 1988; de Souza, 2000; Cutter, 1991; 2012; Cutter *et al.*, 2012; Tavares, 2011; Jetel, 2017). Liquefied petroleum gas (LPG) is one of these materials that represents a potential threat since it has the ability to expand rapidly and generate an explosion (Tauseef *et al.*, 2010; Wang *et al.*, 2022; Martins *et al.*, 2016; Rasbash, 1980; Fay, 1980).

However, a Boiling Liquid Expanding Vapor Explosion (BLEVE) is considered one of the most devastating accidents that could occur in an industrial LPG plant (Keltner *et al.*, 1998; Abbasi, 2007; Eckhoff, 2014). Such catastrophic event is accompanied by a destructive wave of flames and metallic missiles from the storage tank burst (Tauseef *et al.*, 2010; Abbasi & Abbasi, 2007; Birk *et al.*, 2007). By proper definition, BLEVE is a process of sudden release of superheated combustible gas, which can occur due to mechanical defects of the container, corrosion, internal overheating, among others (Abbasi, 2007; Keltner *et al.*, 1998). The BLEVE occurs, when the temperature of the storage containers increases generating overpressure in its internal walls until, the mechanical resistance of the tank is exceeded and it explodes (Prugh, 1991).

An additional context for BLEVE´s occurrence, is loss of the mechanical integrity of the tank by external factors, creating a rupture. The sudden change in pressure and temperature caused by the rapid release of the gas causes instantaneous vaporization, which, when ignited, generates an explosion with a great expansive range (Hemmatian *et al.*, 2015; Abbasi, 2006; Chakrabarty, 2021).

Among the most unfortunate cases of accidents due to BLEVE in facilities with LPG storage occurred in San Juan de Ixhuatepec, in Mexico in 1985, killing 650 people and approximately 6,400 injuries (Mannan *et al.*, 2005; López-Molina *et al.*, 2012; Arturson, 1987). A further case occurred in Rio de Janeiro, Brazil, in 1972, where five storage spheres and cylinders exploded, causing the death of 53 people and 37 injuries (Casal *et al.*, 2001; Mannan *et al.*, 2005; Kumar, 2014). In 2007 in Texas, United States, a sphere exploded causing the death of 13 people (Sarvestani, 2021). Finally, the most recent case, occurred in the Amuay refinery, in Venezuela, where a massive leak of oleins and gas, caused an explosion that killed 47 people and injured 137 others (Schmidt *et al.*, 2016; Simanjuntak *et al.*, 2017; Klein & Vaughen, 2017).

This preamble had indicated the need to perform an analysis of the hazards and consequences of this type of facility. Clearly becomes necessary to anticipate the possible impacts on the inhabitants and assets, both public and private, to find alternatives to mitigate and reduce a potential affectation, in case of a BLEVE (Keddy, 2012; Malviya & Rushaid, 2018). These types of events are unpredictable; therefore the potential damage is underestimated by the authorities and residents who end up developing settlements closer to the facilities, without realizing the risks that entitles (Malviya & Rushaid, 2018). As part of the risk identification process, it is necessary to conduct a vulnerability analysis (Birkmann, 2007; Rausand, 2013; Cardona, 2013). This type of analysis facilitates the estimation of the possible and potential level of damage that the inhabitants could be expose to in the nearby settlements, very likely being threatened to live or work within the risk zones around these industrial complexes (Anjana *et al.*, 2016).

Therefore, the main purpose of this study is to provide a tool to assess the risk of explosion by BLEVE in the onshore Gas Storage Complex, located in Monteverde, Santa Elena province in Ecuador. Firstly, we may calculate the radius of affectation and its potential extent in all directions, in order to identify the nearby communities that could be included within the affectation radius of the event. Furthermore, we may analyze the vulnerability of the people settled in nearby localities. Consequently, this study will facilitate the implementation of safety measures and limitations to the urban expansion projects for the local authorities, and also baseline information to consider in their land use and risk population assessment plans.

1.1 Geodynamic and geological setting of Monteverde

The province of Santa Elena is located in a zone of continuous energy release, since this segment experiences subduction of the Carnegie ridge which is situated on the Nazca oceanic plate which converges ENE towards the South American and Caribbean continental plates, generating a displacement of 7 cm on average per year (Baldock 1983, Barazangi & Isacks 1976; Gutscher *et al.*, 1999, White *et al.*, 2003; Massonne & Toulkeridis, 2012; Stern, 2020; Figure 1).

Due to this geodynamic constellation, the entire province is situated along an active continental margin where a constant seismic hazard is present and being documented by historic earthquakes and tsunamis (Chunga and Toulkeridis, 2014; Rodriguez et al., 2016; Toulkeridis, 2016; Toulkeridis et al., 2017; Chunga *et al.*, 2017; Mato and Toulkeridis, 2018; Chunga *et al.*, 2019).

One of the most remarkable earthquakes within the study area of Monteverde occurred in October 1933 with a 6.9 Mw, situated 66 km away from the coast, with tsunamigenic potential and with wave height not greater than 2.5 m. The most recent earthquake occurred in 2016 with 7.8 Mw, at 248° north of the study site (CERESIS, 2022; Dumont *et al.*, 2005; Toulkeridis *et al.*, 2019). Based on the aforementioned, the Monteverde area was classified as very high seismicity, based on the Ecuadorian Construction Standard (NEC), where the Peak Ground Acceleration (PGA) can vary in a range of 0.45 g to 0.68 g, representing the potential to have earthquakes stronger than Mw 7.7 (Chunga *et al.*, 2019; Aviles-Campoverde *et al.*, 2020; Ortiz-Hernández *et al.*, 2022a; Ortiz-Hernández *et al.*, 2022b).

The geological unit evidenced in the study area corresponds to an Eocene sequence that encompasses conglomerates of high-density underwater currents (bed of pebbles and clay), shales and sandstones corresponding to the submarine fan of the Socorro Formation, and finally sediments deposited from the continental platform and alluvial fans from the Seca Formation (Dumont *et al.*, 2005; Malone *et al.*, 1999). This sequence is known as the Ancón group, which begins around 56 Ma and lasts up to 39 Ma (Dumont *et al.*, 2005; Malone *et al.*, 1999).

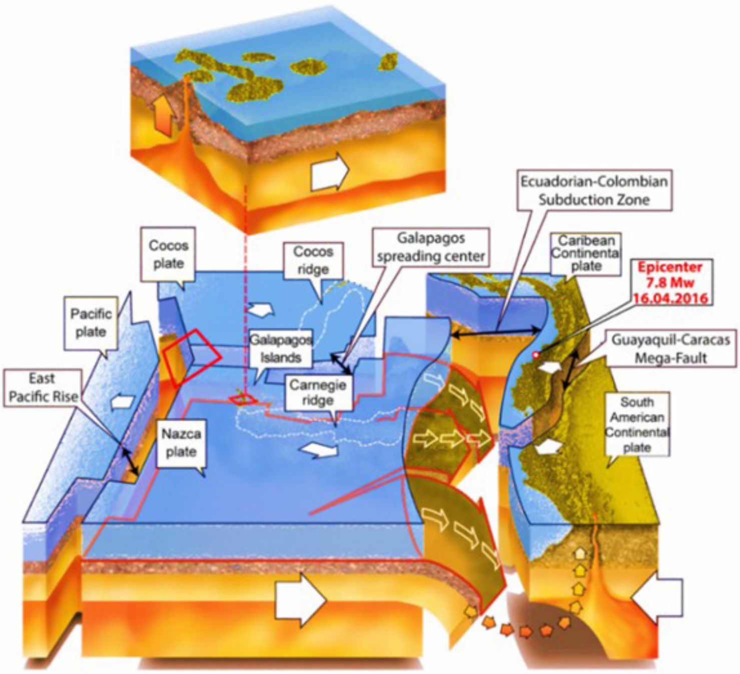

Figure 1. Geodynamic setting of Ecuador and its surrounding. The Galapagos Islands and the Carnegie Ridge form part of the oceanic Nazca plate, which subducts below the South American continent. This map shows also the location of the most recent earthquake in 2016 in coastal Ecuador. Adapted from Toulkeridis *et. al.*, 2017.

1.2 General characteristics of the Monteverde Gas Complex (CGM)

The CGM is in the province of Santa Elena, within the Colonche parish, in the commune of Monteverde, from where it takes its name (Figure 2). The complex has two cryogenic propane tanks with a capacity of 32,700 m³ each, two cryogenic butane tanks with 14,900 m³ of individual storage and three spheres for LPG with 3,180 m³ of storage each. This volume of gas storage provides the country with a 30-day supply of LPG (Mindiola Robayo & Recalde Mosquera, 2009). The CGM, house storage tanks than contains compressed gas with flammable characteristics that are at low temperature and high pressure. This particularity makes the complex a potential hazard, which needs to be analyzed to establish a safe area for human settlements, to prevent disasters such as those mentioned previously (Mindiola Robayo & Recalde Mosquera, 2009; Markley *et al.*, 2022; Makhviladze *et al.*, 1998; Fay, 1980). The norm NFPA 30, for Flammable and combustible liquids, includes LP-gases under the definition of flammable liquids, mentioning, “include those having a flash point below 100 °F (37.8 °C) and a pressure not to exceed 40 psia (276 kPa)” (NFPA 30, 2003) (Table 1).

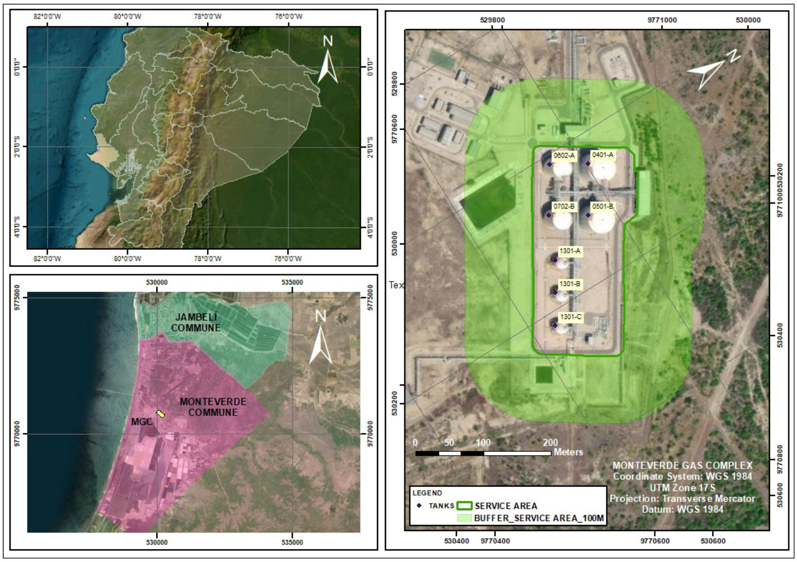

Figure 2. Upper left: Location of the province of Santa Elena on the map of Ecuador. Lower left: Monteverde and Jambelí communes within the Santa Elena canton and location of the CGM, marked in yellow. Right: Facilities of the Monteverde Gas Complex.

Table 1. Physical characteristics of the product in storage tanks and spheres

Technical characteristics	*Propane Tanks*	*Butane tanks*	*LPG spheres*
Volumetric capacity (m³)	32,700	14,900	3,180
Flash point (˚C)	-156	-60	-98
Internal pressure (bar)	0.118	0.118	2.7 – 14.7
Internal temperature (˚C)	-42	-3	21
Height (m)	34	26	-
Internal diameter (m)	35	27	18.25
State of the stored product		Liquid state	

The commune of Monteverde has around 3,200 inhabitants and is located 4 meters above sea level. This area handles a range of ambient temperatures from 19.5 °C to 28.5 °C, a relative humidity of 80% on average and speeds of 8 knots also annual average with direction SE.

2. Methodology

The main aim has been to perform the calculation of the overpressure wave based on the NTP 293 Standard, which allows quantitatively the estimation of the value of thermal radiation associated with the explosion by BLEVE in liquefied gas storage containers (Belloví & Sierra, 2023). One of the most popular methods for the risk explosion analysis of tanks containing flammable liquids is the TNT equivalent method, however, it is necessary to mention that this method was not applied, since it constitutes the analysis of a flammable liquid substance with an oxygen content and caloric power different from the gases stored in the CGM, so it becomes inconclusive to use it. In general, the analysis applied is quantitative, which means that proven empirical methods have been used to obtain maximum and minimum values to model the behavior of the explosion, mainly of the thermal radiation received by a spectator at different distances.

The delimitation of the immediate intervention zones and the alert zone will also be managed, based on the Basic Civil Protection Guideline for the control and planning in the event of serious risks involving dangerous substances (Grossel, 1996; Freeman, 1990). For the estimation of thermal radiation, the procedure proposed in method 3 of the manual on the dynamics of industrial explosions by Botta was considered (Botta, 2015; Chen *et al.*, 2020; Mejia *et al.*, 2022). The procedure encompasses the systematic calculation of mass dependent variables and the properties of the substance ensuing attainment of the amount of thermal radiation generated, and as a direct consequence the vulnerability estimation of people in major events (Turmo, 2016). To calculate the diameter of the fireball, the following equation (1) was used:

$$D=6{,}48*W^{0{,}325} \tag{1}$$

Where, D (m) is the maximum diameter and W (Kg) corresponds to the total mass of the fuel. To calculate the height of the fireball H (m), we have:

$$H=0{,}75D \tag{2}$$

The duration of the fireball t (s), corresponds to the time it takes to consume the mass of gas:

$$t=0{,}852\ W^{0{,}26} \tag{3}$$

The thermal radiation received, I (kW/m²), as:

$$I=d*F*E \tag{4}$$

The atmospheric transmission coefficient (d), is a function of:

$$d=2{,}02(P'_v*X')^{-0{,}09} \tag{5}$$

being P'_v (Pa) the absolute partial pressure of ambient air vapor is 1008 hPa on average considering an average relative humidity of 50%, these data has been consulted from the meteorological stations of the National Institute of Meteorology and Hydrology in Ecuador (INAMHI, 2022). The storage temperature of the gases is 20 ˚C. The parameter X (m) is the distance between the fireball and the location point of an observer.

The vision geometric factor (F), depends on the shape of the emitting focus and the location of the receiver, where D (m), corresponds to the maximum diameter of the fireball and X (m), the distance between the center of the sphere and the irradiated body has been taken from 250, 500, 1000, 2000, 3000, 4000 and 5000 meters.

$$F = \frac{D^2}{4X^2} \tag{6}$$

Finally, the average intensity of radiation E (KJ/m² s), is the radiant flux per unit area and time:

$$E = \frac{f_r * W * H_c}{\pi * D^2 * t} \tag{7}$$

Where,

f_r = is the radiation coefficient, with values between 0,25 – 0,40

W= total mass of fuel in kg

H_c = heat of combustion (kJ/kg)

D = maximum fireball diameter (m)

t = duration time of the bleve (sec).

The radiation coefficient f_r, indicates the fraction of total energy developed in combustion, this energy is dissipated by the convective effect generated by the smoke. In Santa Elena, the radiation coefficient is estimated at 0.25, due to Monteverde's climatic conditions, relative humidity, temperature, and wind speed and direction.

The Thermal Radiation Dose is calculated using the Eisenberg equation (Eisenberg *et al.*, 1975):

$$Dosis = t * I^{4/3} \tag{8}$$

Where;

t = exposure time (s)

I = received irradiation (W/m²)

Applying the NTP 291 standard, the estimation of the vulnerability of people due to an accident of these magnitudes was realized. The procedure consists of calculating the impact on a person due to the amount of thermal radiation received, depending on the intensity and time of exposure. The equations used have been proposed by the Dutch organization for scientific research (Turmo, 2016). First-degree burn involvement was determined using the equation:

$$Pr = -39,83 + 3,0186 \ln(t * I^{4/3}) \tag{9}$$

Second-degree burns were determined using equation (10):

$$Pr= -43,14 + 3,0188 \ ln \ (t * I4/3) \qquad (10)$$

And, to estimate full thickness burns, considering unclothed body area of exposed population to be lower than 30%:

$$Pr = -14,9 + 2,56 \ ln \left(\frac{t * I^{4/3}}{10^4}\right) \qquad (11)$$

Thermal irradiation mortality is calculated using the method suggested by Eisenberg (Eisenberg *et al.*, 1975):

$$Pr = -14,9 + 2,56 \ ln \left(\frac{t * I^{4/3}}{10^4}\right) \qquad (12)$$

3. Results and discussion

The probit method is mass dependent; therefore, it is expected for the radius of influence to vary linearly with the mass of the inflammable fluid stored. The main concern around the MGC is its large storage capacity. Initially, the radio of influence was identified considering each stored flammable product at the MGC using the fireball diameter and its duration. These variables have been plotted as a function of the mass for each product available, supporting the linear behavior statement.

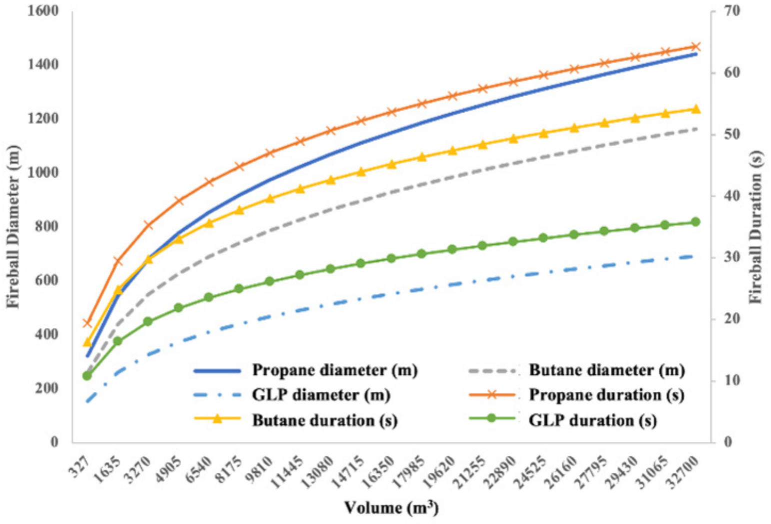

Figure 3. Mass-dependent variables behavior for each substance analyzed in the MGC.

We observed that the greater the mass of propane, the diameter of the fireball, as well as its duration, increases (Figure 3). With the minimum nominal capacity considered for this exercise, equal to 10%, a propane tank can generate a fireball of 323 m, with a duration of 19 seconds. In the opposite scenario, considering its maximum volume of 100%, the radius of the fireball reaches 1441 m, with a duration time of 64 seconds. The same variables are presented for a Butane tank and an LPG sphere. It was obtained for Butane, radius in the range of 261 m to 1164 m with times from 16 to 54 seconds, and for LPG radios from 155 to 693 meters with duration times of 11 to 36 seconds respectively.

Table 1 summarizes the mass-dependent variables in case of a BLEVE explosion event at the MGC, using equations (1), (2), and (3). For calculation and analysis purposes, the worst scenario will be considered, this means, that each container is at 100% of its nominal capacity.

Table 1. Estimation of the effects in case of an explosion by BLEVE in the CGM by product

Container	*Net capacity (m^3)*	*Density Condition Liquid (Kg/m^3)*	*W Value (kg)*	*Diameter of fireball (m)*	*Height of fireball (m)*	*Duration of fireball (s)*
Propane tank	32.700	510	16.677.000	1.441	1.080	64
Butane tank	14.900	580	8.642.000	1.164	873	54
LPG sphere	3.180	550	1.749.000	693	519	36

The following figures illustrate the relationship between the radiation intensity received by an object that is vertical at a certain distance from the center of explosion. Figure 4, shows that the amount of energy generated and therefore radiated increases with the mass available within the container, as mentioned previously.

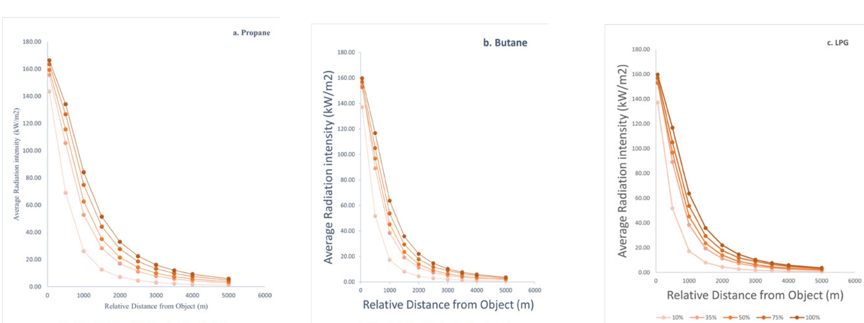

Figure 4. Relationship between the amount of radiation received by a vertical object with the horizontal distance by product of the CGM. a) Propane, b) Butane, c) LPG.

It is fundamental to mention that, when large volumes of a flammable hazardous substance is stored, the possibility that a fraction of the mass available inside the container generating a pool fire increases; therefore, the thermal radiation increases in the immediate intervention zone (Fema *et al.*, 1989). Figure 5, indicates the simulations performed with ALOHA software, showing that the radius of influence is close to those obtained by the empirical equations used so far.

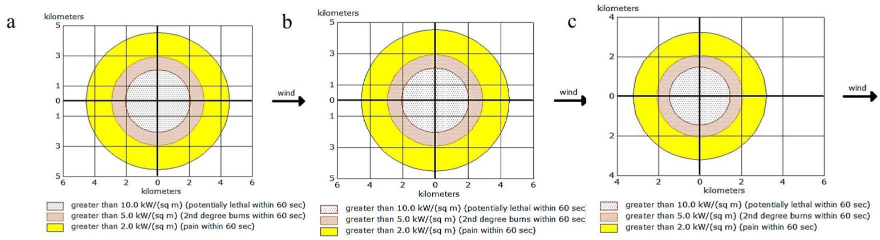

Figure 5. Simulations to obtain influence radius due to an explosion by BLEVE by product in the CGM. a) Propane, b) Butane, c) LPG.

Equations (9), (10), (11) and (12) have been used to assess the vulnerability of the exposed population. The results indicate that in the event of a BLEVE event for propane tanks, people within a 2000 m radius can suffer third degree burns and even death. The radius of secondary influence is estimated at 3,500 m, where second-degree burns are guaranteed and up to 5,000 m a spectator is expected to suffer first-degree burns, depending on the exposure time and even the clothing of the observers, the impact can become imperceptible.

Table 2. Estimation of the vulnerability of people due to a BLEVE accident in the CGM

Content	*Horizontal distance (m)*	*Received irradiationI (kW/m²)*	*Probit evaluation 1st degree burns*		*Probit evaluation 2nd degree burns*		*Probit Evaluation 3rd degree burns*		*Mortality*	
Propane	2000	29	14.1	99%	10.8	99%	9.3	99%	7.3	99%
	3500	11	10.4	99%	7.0	98%	6.2	89%	4.1	18%
	5000	6	7.6	99%	4.3	25%	3.9	14%	1.8	0%
Butane	2000	20	12.1	99%	8.8	99%	7.7	99%	5.6	72%
	2700	10	9.2	99%	5.9	84%	5.2	58%	3.1	3%
	4000	7	7.5	99%	3.8	12%	3.6	8%	1.4	0%
GLP	700	30	13	99%	10.2	99%	8.2	99%	7.5	99%
	1000	12	11.5	99%	8.2	99%	7.2	99%	4.2	22%
	2000	7	6.7	96%	3.4	5%	3.1	3%	1.0	0%

With this last evaluation, the radius of influence are estimated by relating the results obtained through the equations presented, the simulations of the ALOHA software and the maximum radiation thresholds proposed in the work performed by WS Atkins Safety & Reliability for the Health and Safety Executive of the United Kingdom. Kingdom, which is based on the Probit method proposed by TNO and suggested as the basis for this analysis (TNO, 1997; Rew, 1997; Prugh, 1994; Prugh, 1991; NTP 293, 2001).

Table 3, lists the results associated with an operating capacity of 100% of the capacity of each tank. After the sudden release of the gases, in the case of propane, a diameter of the fireball of around 2000 m and a duration of 64 s would be obtained. This gives an idea of the extent of an explosion at the CGM without considering chain reactions.

Table 3. Delimitation of areas of influence in the event of an explosion by BLEVE in the CGM

Radius of influence	*Irradiation dose received* $\left[\frac{kW}{m^2}\right]^{\frac{4}{3}}$	*Propane Radius (m)*	*Butane Radius (m)*	*GLP Radius (m)*	*Probit vulnerability assessed*
Red zone	3000	2000	2000	700	Death / 3rd degree burns
Orange zone	2000	3500	2700	1000	2nd degree burns
Yellow Zone	600	5000	4000	2000	1st degree burns

The radius of influence is identified as red zone of greatest influence, with risk of death, than the medium zone of influence or orange zone, with risk of suffering second degree burns and finally, the smallest radius of influence, being the yellow zone. This vulnerability is subject to the characteristics of the clothing of the exposed persons, in addition to the exposure time. Due to the nature of BLEVE explosions, the exposure time is close to the duration of the fireball, which for propane and butane is around a minute and for LPG 34 seconds. The estimation of the radiation received by an exposed person who is within the defined areas of influence, gives us an appreciation of the magnitude of the damage that the appearance of BLEVE can cause in any of the containers that are inside the CGM. Below are the areas of influence represented in satellite images.

In figure 6, it is observed that the population of Monteverde located at ≈1200 m from the CGM (measured linearly from the nearest tank), is within the zone of greatest influence that reaches a radius of 2000 m that corresponds to the diameter reached by the fireball. In the case of propane and butane; figures 6 and 7 respectively. The populated area of both communes is shaded, the rest corresponds to land used mainly for agriculture and shrimp farms. Within this zone the chances of survival are low due to direct contact with fire and oxygen deficiency (Pietersen, 1990). The maps have also indicated the beach area, which is a tourist destination with an unestimated floating population.

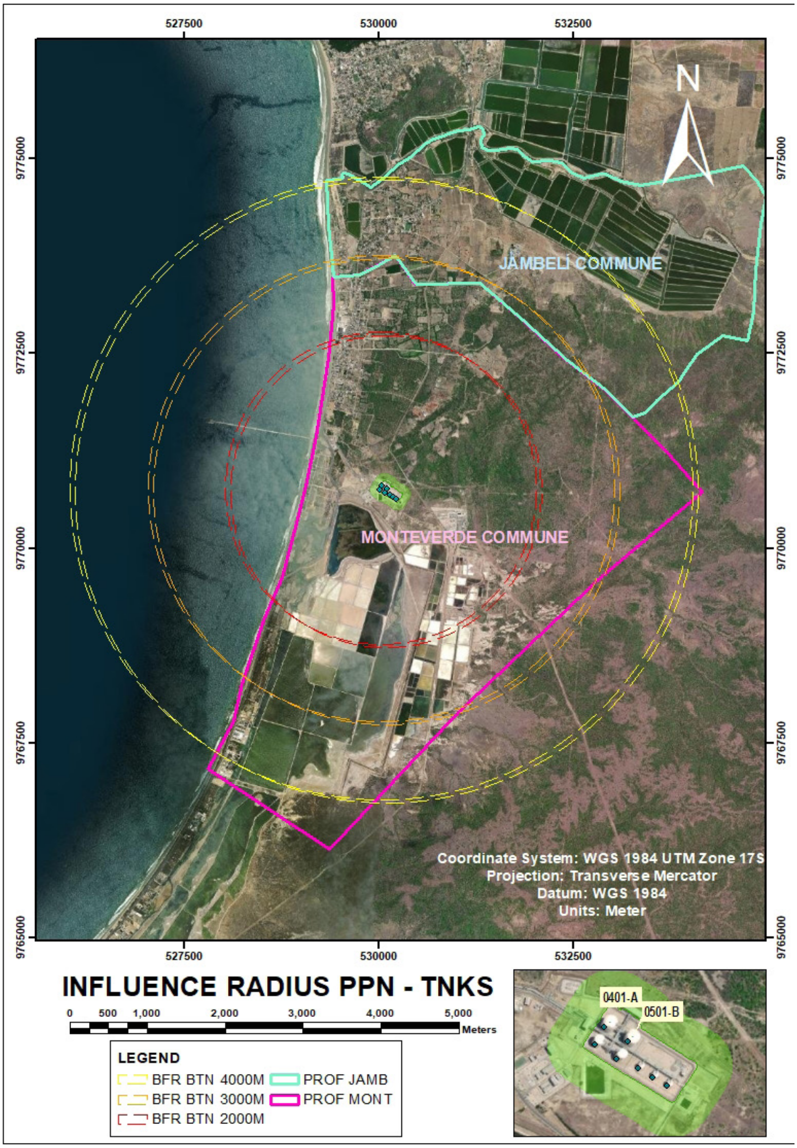

Figure 6. Maximum radius of influence generated by the explosion of one of the CGM propane tanks at 100% of its nominal capacity.

Figure 7. Maximum radius of influence generated by the explosion of one of the CGM butane tanks at 100% of its nominal capacity.

Figure 8, shows the buffers calculated for the three LPG spheres, resulting in the smaller radius of influence reaching 700 meters around the spheres.

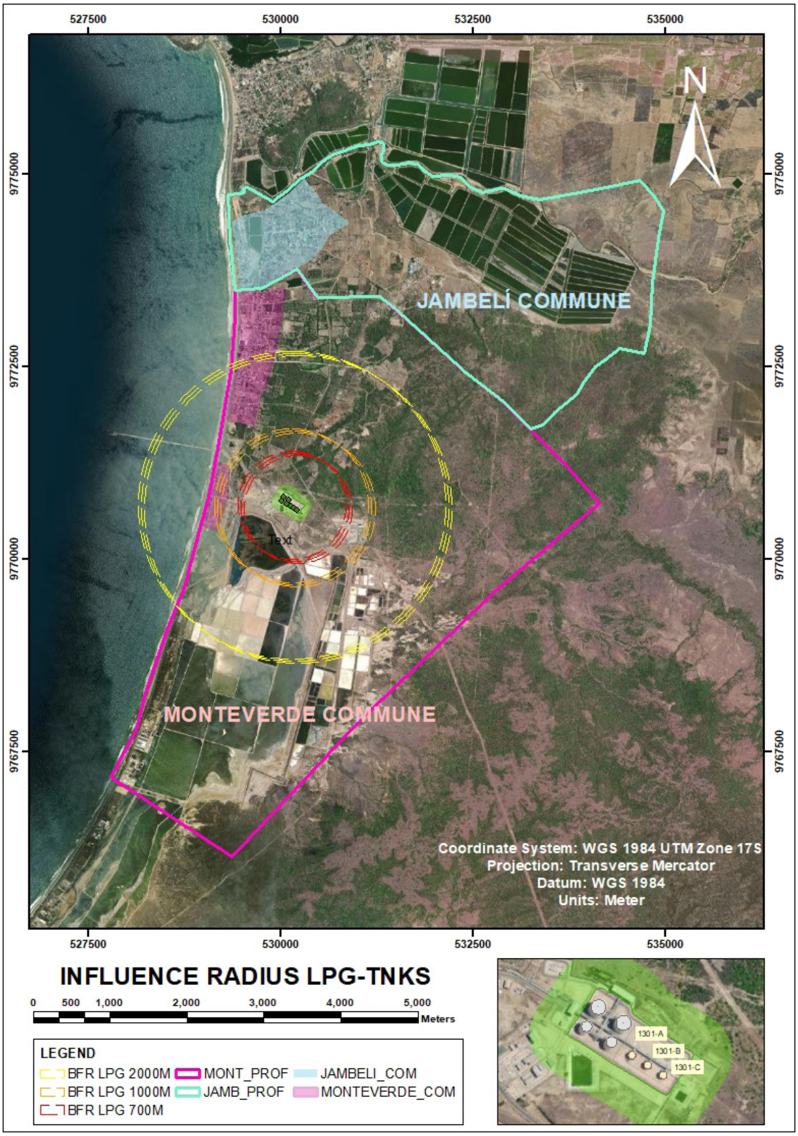

Figure 8. Maximum radius of influence generated by the explosion of one of the LPG tanks of the CGM at 100% of its nominal capacity.

This analysis indicates that in case of a BLEVE explosion, the entire Monteverde community could be affected by the radiation generated. It is important to mention that the calculations presented have been made considering ideal terrain and wind conditions. However, it should be mentioned that there is a small elevation of approximately 21 meters between the MGC and the community of Monteverde, whose attenuation effects must be estimated in a subsequent analysis.

Due to the large amount of gas that it can store, the CGM becomes a source with a high risk potential. Just to make a comparison, the disaster that occurred at the San Juan de Ixhuatepec terminal in Mexico in 1985 was due to the explosion of a 2,400 m^3 capacity sphere, generating a chain reaction to other units with less storage capacity. Inside the station, the explosions reached a radius of seven blocks in all directions and the fragments of the tanks were found up to 1,200 meters away. The heat was such that it even caused the explosion of the domestic gas tanks in the houses of the sector. (López et al, 2012; Pietersen, 1988; Tauseef, 2010). The capacity of the LPG plant in San Juan de Ixhuatepec at the time of the disaster was approximately 11,000 m^3, a volume that corresponds to 10% of the nominal storage capacity in the CGM (Pietersen, 1988).

The current operational capacity (as of the year of publication, 2022) of the CGM is around 40% of its nominal capacity, and there are no human settlements around the limits of the CGM. However, experience indicates that illegal housing settlements usually develop after the construction of facilities or industrial complexes, which places the CGM in an ideal situation to establish risk studies and establish policies that safeguard the security of the population.

4. Conclusions

The estimation of the affected radius was performed using several methods, among them the one proposed by TNO, in which the vulnerability of the population exposed to thermal radiation is analyzed. With this it was possible to define that the radius of intervention, or called red zone, is 2,000 m for propane and butane as well as 700 m for LPG. The orange zone, or medium alert, reaches 3,500, 2,700, and 1,000 for propane, butane, and LPG, respectively. And finally, the yellow or low alert zone reaches 5,000, 4,000, 1,500 for propane, butane and LPG, respectively.

The mortality will be 99.9% for the BLEVE explosion of the Propane and Butane tanks within a radius that reaches 2,000 m, directly affecting the Monteverde commune with an estimated population of 1,200 people according to the last population census and housing, under ideal ground conditions and at its maximum operational capacity.

The Probit evaluation method allows estimating the vulnerability to which people from the communities near the CGM are close. It was obtained that in the previously defined red zones there will be 3rd degree burns and death. For the orange zones, it has been estimated that the probability of suffering second degree burns is high, this depends on the exposure time and the type of clothing worn by the inhabitants, since it is a coastal zone, it is estimated at more than 30% of the exposed body surface and light clothing. Finally, in the yellow zones, there is a high probability of suffering first degree burns, again with the clothing conditions previously exposed.

BLEVE explosions are sudden, the CGM has large volumes of flammable substances stored, which can cause the formation of pool fires and increase thermal radiation in the intervention areas close to the point of explosion.

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