UNIVERSITY OF CAPE COAST

ASSESSMENT OF RISK FROM LIQUEFIED PETROLEUM GAS (LPG) FILLING STATIONS IN ACCRA METROPOLIS AND IMPLICATIONS FOR LAND USE PLANNING

EMMANUEL ABEASHI MENSAH

2021

UNIVERSITY OF CAPE COAST

ASSESSMENT OF RISK FROM LIQUEFIED PETROLEUM GAS (LPG) FILLING STATIONS IN THE ACCRA METROPOLIS AND ITS IMPLICATIONS FOR LAND USE PLANNING

BY

EMMANUEL ABEASHI MENSAH

Thesis submitted to the Department of Geography and Regional Planning of the Faculty of Social Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Geography and Regional Planning

SEPTEMBER 2021

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:……….……… Date:………………

Name: Emmanuel Abeashi Mensah

Supervisors' Declaration

We hereby declare that the preparation and presentations of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:…………… Date:………………

Name: Prof. Albert Abane

Co-Supervisor's Signature:……………………Date:………………

Name: Prof. David Kofi Essumang

ABSTRACT

Densely populated areas in Ghana, including the Accra Metropolis have over a 14-year period (2007-2020) experienced at least 9 fire disaster events involving Liquefied Petroleum Gas stations. These accidents resulted in 35 fatalities and over 517 injuries and thus, the extent of vulnerability and risk from LPG hazards within the Accra metro and the approaches by which they can be addressed remain pertinent questions. Utilizing a pragmatist approach, a three phased study was conducted using primary data from observations, questionnaire surveys and in-depth interviews. The first phase utilized quantitative risk assessment approaches to determine the characteristics, levels of vulnerability and risk emanating from 10 LPG stations within the Accra Metro. The other two phase's analysed stakeholders' risk perceptions and risk management strategies. Hazard footprints varied per station and per hazard type. Maximum endpoint distance for the 2kW/m^2 thermal threshold occurred at 770 meters. Land use patterns in the risk zone were dominated by mixed use, residential and community services. Vulnerability and risk levels were far in excess of local and international standards. A poverty-risk nexus was found to be at play in the hazard zone and this reflected in low perceptions of socio-economic risk. Health and environmental risks were however negatively correlated with income. Personal risk management strategies were cognitive and ineffective. Safe technology and safe management, Land use planning and emergency response, and Alternative risk management strategies like the planned Cylinder recirculation model were the three dimensions of non-personal risk management strategies. Management of LPG risk in Ghana can be strengthened through the application of safe technology and safe management as well as risk informed land use planning.

KEY WORDS

Accra Metropolis

Liquefied Petroleum Gas Stations

Risk Assessment

Risk informed Land Use Planning

Vulnerability Assessment

ACKNOWLEDGEMENTS

My sincere thanks go to my supervisors Professor Albert Machistey Abane and Professor David Kofi Essumang for taking time to read my work and for the invaluable suggestions which were of immense help. I will forever be grateful for the confidence they reposed in me and for their patience and fatherly advice whenever I experienced difficulties. Special thanks also go to Professor Ben Ale, Dr. Adams Osman, Professor Adams Issahaku, Dr Francis Taale, Dr Charles Adongo, Kingsley Kanjin and Ebenezer Boateng for their help and support throughout my study. I am also grateful to my team of able field assistants including Akua Dankwaa, Abigail Amoah, Jennifer Donkoh, Edudzi Akpakli, Clement Amuquandoh and Jefferson Ikediuba. I also wish to thank personnel of the National Petroleum Authority, Environmental Protection Agency, Ghana National Fire Service and Accra Metropolitan Assembly for their support. Furthermore, I acknowledge the University of Cape Coast for their financial and material support. I am also indebted to my family especially my wife Margaret, for their immense moral support and patience throughout this journey. Finally, I give thanks to God almighty for making the sun to stand still, till the battle was won.

DEDICATION

To my mother, Mrs. Beatrice Edith Mensah

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ACRONYMS

AMA	–	Accra Metropolitan Area
ALARP	–	As Low As Reasonably Practicable
BLEVE	–	Boiling Liquid Evaporating Vapour Explosion
CRM	-	Cylinder Recirculation Model
DRM	–	Disaster Risk Management
DRR	–	Disaster Risk Reduction
IUGS	-	International Union of Geological Sciences
LPG	-	Liquefied Petroleum Gas
EPA	–	Environmental Protection Agency
NPA	–	National Petroleum Authority
RILUP	–	Risk Informed Land Use Planning
TCPD	-	Town and Country Planning Department
TDU	-	Thermal Dose Units
VCE	-	Vapour Cloud Explosion

CHAPTER ONE

INTRODUCTION

Background to the study

Industrial disasters have been the bane of public safety especially since the dawn of the industrial revolution and thus their control has become a focal point of public safety policy (Ale, 2005a). Historically, industrial accidents have proven to be generally retrogressive for public safety and human development due to the substantial number of fatalities, physical and psychological trauma, environmental and economic losses resulting from such disasters (Ale, 2005a). Since the early1600s a number of cities have witnessed industrial catastrophes, notable among them are the disasters which occurred in the Dutch cities of Delft and Leiden in 1654 and 1807, with death tolls of 1500 and 150 respectively in addition to 2000 injuries in respect of the Leiden incident. Similarly, in 1794 in Grenelle, France, an industrial disaster led to over 10,000 fatalities (Ale, 2005a).

The management of industrial hazards became necessary especially during the period of the industrial revolution in Europe. Although the industrial disasters witnessed during that era were significant events, the measures put in place to address the risk of such disasters from occurring, focused more on the application of safer technology than on the control of vulnerability to the industrial hazard. The exception was the Leiden explosion during the Napoleonic era which led to the classification of industries based on the level of hazard and subsequent classification into three classes: namely, those that could safely remain in cities without mitigation; those that could safely remain in cities only with mitigation; those which had to be located outside of cities. Thus, the emphasis of industrial risk control was effective on hazard control using a deterministic approach where buffer distances were also created to separate hazards from vulnerable populations as occurred in France before 2001 (Basta, 2009b).

However, in the post-World War II era, a series of industrial disasters including: Flixborough [UK, 1974]; Seveso [Italy, 1976] where about 37,000 people were exposed to Dioxin with immediate deaths of over 3,300 animals; Bhopal [India, 1984] with between 4000 and 20,000 estimated deaths; and Mexico City [Mexico, 1984] with about 550 fatalities and over 7000 injuries (Acquilla et al., 2005; Ale, 2005a; Arturson, 1987; Cozzani et al., 2006; Eckerman, 2011; Institution of Chemical Engineers, 2014; Sengupta, 2016; Sengupta et al., 2016; Xanten et al., 2014). These disasters led to a recognition of the external environment of industries as a crucial component in the management of industrial disasters (Ale, 2005a; C. Basta et al., 2008; Basta et al., 2007; Christou et al., 2011; M. D. Christou et al., 1999).

In developing countries also, industrial risks are high due to the proliferation of hazards for which little information exist regarding their magnitude, frequency and spatial extent (Akimoto, 2009). Abdolhamidzadeh et al. (2012), Bubbico & Marchini (2008) and Taveau, (2010) have argued that, chemical hazards, in particular, constitute greater risks especially within congested urban spaces. This growing risk, often manifests as industrial fires and explosions at chemical depots which has led to injuries, deaths and destruction of property. For instance, a recent vapour cloud explosion which occurred on the 15th of March, 2020 in Lagos Nigeria, led to over 200 injuries and 23 fatalities. The disaster also destroyed over 170 buildings including a secondary school and displaced over 500 persons (BBC Africa Eye, 2020).

Another LPG disaster occurred in the Western region of Ghana on the 9th of May 2017. This BLEVE incident injured over 100 individuals and also destroyed a factory and nearby buildings (GraphicOnline, 2017). Significantly though, not every risk situation may go through the process of developing into full scale disasters, but those that do, tend to affect many lives and resources at both local and regional scales.

The scramble for sparse land for industrial activities, residential and other land uses of economic benefit has resulted in the growth of organic cities, which brings about increased vulnerabilities as people and property are continually placed in close proximity to these major hazard establishments (MHEs) thereby increasing risk (Bubbico & Marchini, 2008; Civan, 2004; Pontiggia et al., 2011; Taveau, 2010; Turgut et al., 2013). This growing risk often manifests globally as industrial fires and explosions at chemical depots which lead to injuries, deaths and destruction of property (Bubbico & Marchini, 2008; Taveau, 2010; Abdolhamidzadeh, Che Hassan, Hamid, Badri, & Rashtchian, 2012).

Disaster risks from petrochemical substances such as Liquefied Petroleum Gas (LPG) have become a constant occurrence considering the expansion in the downstream chemical and petrochemical industries. This has raised a lot of concern for people due to the devastating accidents that have occurred through the storage and use of the chemical in the urban spaces, and at the same time impacted significantly on the prospects for further developments of the chemical industry. LPG accidents have occurred in Feyzin [France, 1966], Flixbourough [UK, 1974]; Beek [Netherlands, 1975], Los Alfaques [Spain, 1978] and in other countries resulting in a number of fatalities and injuries. These accidents also provide enough evidence of the potential risks associated with LPG and as such draw attention to the fact that, LPG installations have become a matter of concern and therefore much attention is required to deal with the risk it poses (Arturson, 1987; Oostendorp et al., 2016).

The recognition of vulnerability of the external environment as an integral part of industrial risk management by the European Commission in article 12 of the Seveso II Declaration represented a paradigm shift in industrial risk management. The directive's argument was that the Bhopal disaster, as well as other disasters, had demonstrated that the proximity of vulnerable populations and sensitive environments to chemical plants or other installations holding hazardous substances can be extremely important in determining the level of resulting damage if an accidental release occurs. Separating hazards from people and sensitive environments can thus provide critical protection if other methods of preventing accidents fail (Walker, 1995)

The basic philosophy underpinning the Seveso II declaration emphasizes the use of industrial risk assessment amongst other considerations as basis for land use planning decisions in neighbourhoods around industries. This paradigm shift in policy has brought about risk-informed land use practices which are being widely and cohesively implemented across European cities. Today, the use of risk information in land use planning has gained recognition both in general planning practice and in academia, and is commonly referred to as Risk Informed Land Use Planning (RILUP) (Christou et al., 1999).

RILUP is a cyclical disaster risk management strategy that involves the identification of all potential hazardous events associated with an industrial activity, followed by the modelling and quantification of the probabilities and consequences of all the hazards through an objective risk assessment process.

Evaluation of the risk through value laden cost benefit analysis then follows, after which decisions are made regarding the acceptability or otherwise of the risk. The process ends with risk monitoring and reverts once more to the identification of adverse events (Ale, 2009).

Thus, RILUP involves land use decision making which is primarily informed by the probable consequences of industrial hazards on surrounding human populations and environments. In RILUP, risk is conceptualised as a function of the probability of a hazard interacting with the consequences of that hazard that is, "*Risk =Probability * Consequences*" as postulated by Arnaud (1662) cited in (Ale, 2009) Ale that, the "*Fear of harm ought to be proportional not merely to the gravity of the harm, but also to the probability of the event*". Thus, risk may be represented as individual risk which is, the probability of fatality, injury or exposure to dangerous levels of a hazard to any given individual residing in the hazard zone. This may often be complemented with the societal risk, which is the total number of fatalities or injuries that society is likely to suffer.

Alternately, a consequence-based approach may be applied where only the severity of a worst-case scenario industrial hazard may be used as basis for land use decisions, effectively ignoring the likelihood of hazards especially when such information is hard to come by. Such an approach may be deterministic and in some cases involve stakeholder negotiated separation distances as was applicable in France before the AZF disaster in Toulouse in 2001 (Basta, 2009). To aid in the application of RILUP, risk criteria and the principle of keeping risk "as low as reasonably practicable" (ALARP) may be applied to determine if specific risks are acceptable or tolerable before land use decisions are taken to mitigate the risk (Basta, 2014;Christou et al., 2011).

Thus, RILUP assists in the management of industrial risk by reducing vulnerability to industrial hazards through the control of the exposure of elements such as people and property to the most probable chemical hazards. RILUP provides an intervention point for disaster managers to reduce the risk to industrial hazards. RILUP deeply resonates with current paradigms in disaster risk management such as the Sendai Framework for Action, which calls for the incorporation of risk information into every facet of human decision-making including land use planning. As land use planning and its related concept of spatial planning are both spatial strategies for controlling and catalysing development at all levels to ensure the sustainability of human settlements, society stands to benefit immensely from the enhancement of these spatial strategies through the infusion of risk information. The achievement of Sustainable Development Goal 11, regarding sustainable cities will be greatly aided by adopting RILUP as a means of addressing industrial risk.

The practice of RILUP is by no means a solitary approach to addressing industrial risk. According to the philosophy underpinning the "Seveso" directives, the application of safe technologies, safe management and emergency response must go hand in hand with land use planning, coupled with feed back to the public. (Christou et al., 2006) Thus, recognition is given to the effect that these other factors can have on the reduction of industrial risk and indeed on the implementation of industrial risk control. The application of Safe technologies has thus been proposed to help deal with industrial disasters which are built on the concept that the probability of an industrial disaster occurring is because of limitation of older, unwholesome and approved technology in an industrial setting. It advocates for industry players to adopt more safe, tested and durable technologies capable of preventing hazard occurrence.

For instance, the application of fire-resistant coasting's on pressure vessels, mounded or underground storage, high- or low-level alarms, water deluge systems and other technologies have been applied successfully in countries such as the Netherlands for the prevention of LPG hazards. (Castenfors & Svedin, 2001; World LPG Association, 2011; Xanten et al., 2014).

Interestingly, in most developing countries south of the Sahara, the application of safe technology is greatly undermined by the cost of safer technology, hence, industries tend to use antiquated technologies including 2nd hand equipment and these have undermined public safety.

In the area of safe management, the World Liquefied Petroleum Gas Association recommends that, safety management should be knowledge - based and should operate within a formal structure of policy and action plans and to this end, they emphasize hazard identification, evaluation, quantification and mitigation within a framework of laws, standards and codes as important aspects of safety management (World LPG Association, 2011). Across the European Union for example, industry regulators provide a strongly centralized risk management by way of regulatory codes, guidelines, binding consultative distances and advice for or against proposed land use changes to Planning Authorities. The risk advice, forms the basis for regulating developments in the neighbourhood of major hazardous industries based on the implications of the land use changes on individual and societal risk (Basta et al., 2007; Franks, 2004; Maddison, 1976). In the Netherlands, the Dutch Ministry for Housing and Spatial Planning through the Dutch National regulation known as the "*Besluit externe veiligheid inrichtingen"* (BEVI) offers a three-tier, multi-institutional system of RILUP which is operationalized through national, provincial and local planning agencies with binding thresholds of risk enshrined in law (Basta, 2009; Basta et al., 2007; Cozzani et al., 2006; Oostendorp et al., 2016; Xanten et al., 2014).

The promotion of RILUP as a strategy, calls for a concerted effort to include disaster risk reduction strategies at all levels of the planning process. Greiving and Fleischhauer (2006) argue that disaster risk analysis must contribute objective and scientific information to the incipient stage of the planning process where elements such as problem identification, goal formulation, analysis of existing conditions and estimation of impacts may benefit from such planning because, after a thorough discussion of the alternatives, there is the need to choose the best measures that fulfil the goal of the planning process. This decision-making phase is characterised by political and value laden decisions of various stakeholders, who decide whether to tolerate or alter a particular type of risk. Fallahi, Daneshpour and Ebrahimnia (2012) like Fallah, Mohamadi, and Nordfjærn (2018) also proposed the incorporation of scientific analysis with land use decision-making and implementation as well as coordination between different sectoral agencies. Thus, the points of intervention in the land use planning process remains a critical factor for the success of RILUP.

Prenger-Berninghoff and Greiving (2015) also point out that for a RILUP to be successful, local authorities and local people must be made to adhere to the plans developed by the spatial and sectoral planning authorities. Prenger-Berninghoff (2016) believes that lack of compliance from the stakeholders can possibly hinder the successful implementation of a land-use plan. Moreover, the Inter-Departmental Working Group on Land Use Planning-FAO (1993) asserts that, political will and ability to implement a land-use plan is a prerequisite for successful LUP and recommends that, there must be a consensus among stakeholders, regarding the need for changes in land-use or prohibition of unwanted changes in land-use. This, according to Wang (2012) calls for consensus between the government, professionals, and the community, regarding the meanings of risk, hazard, and vulnerability. In recognition of Wang's position, it may be argued that, public consultation should form an integral part of RILUP processes especially since it already forms an integral part of land use planning processes. Handling the effects of residual risk on the external environments involves weighing economic and social factors against the risk as decisions on acceptable levels of safety must be made jointly between industry, the authorities, and the local communities (Petts, 1988).

An examination of the status quo however reveals that, the stakeholder consultation during the RILUP process appears to be one-directional and the extent of the information shared, varies greatly. In practice, the RILUP process develops objective scientific knowledge as basis for decision making and considers land use decisions based on a strict or principle-based evaluation of the risk. In such situations, stakeholder consultation then takes the form of information to the public. Thus, in the United States, US Environmental Protection's Emergency Planning and Community Right-to-Know Act of 1986 and Dutch environmental regulations only ensure the rights of at-risk communities to know the level of exposure and vulnerability to dangerous chemical/industrial hazards through documents such as the Dutch *Risikoocarts* (risk maps) but do not necessarily involve them in the day to day assessments and evaluation of their risk nor in the choice of mitigating measures including land use modifications.

The security implications of sharing risk information with the general public have recently been cited as the reason for redacting sections of risk information in the Netherlands and the proscription of public access to industrial risk information in the UK (Basta et al., 2007).

In view of this, it can be argued then that, the unidirectional and constrained nature of public consultations in RILUP, could limit the chances of creating socially and politically acceptable land use changes especially where socio-economic considerations of stakeholders appear to be relevant in determining stakeholder risk perception and evaluation. In such situations, it is expected that the potential gains of RILUP may be significantly reduced because of inertia on the part of the public to accept risk informed land use prescriptions.

In Ghana, the management of land use patterns around hazardous sites has since pre-independence been regulated by a series of land use regulations and policies. The first of such regulations was the Town and Country Planning Ordinance of 1945 (Cap 84). Cap 84 provided for orderly and progressive development of human settlements to preserve and improve social amenities and serve as a management mechanism to ensure optimum efficiency and convenience in the use of land and land resources. Cap 84 was administered through the Town and Country Planning Department which had as its goal, the promotion of sustainable human settlement development based on principles of efficiency, orderliness, safety and healthy growth of communities (TCPD, 2021). Cap 84 had general provisions for prohibiting the use of land for building and non-building operations which were likely to cause danger or injury to health, or detriment to a neighbourhood. Under Cap 84, section 22, sub section 4, item (h), Cap 84 further proscribed compensation to land owners in the event that the Town and Country Planning Department intervenes to reverse such situation. Regarding stakeholder participation, the Cap 84 in its original form offered token power sharing with citizens. Until 1993, the Town and Country Planning Act of 1958 (Act 30) ensured that Town planning was centralized (TCPD, 2021). The assessment of the danger from a development was solely within the purview of a government minister and his technocrats and the process of town planning and industrial risk mitigation was also centralized. Stakeholder participation under Cap 84, therefore hovered between consultation and placation (Arnstein, 2019) because, even though there were provisions for feedback from concerned/affected parties within a stipulated time period, the minister and his technocrats retained the right to judge the legitimacy or feasibility of citizens concerns. Industrial risk was qualitatively determined and managed through this centralized and bureaucratic process.

With the passing of the local Government Act (Act 462) in 1993, Town and Country Planning was decentralized and devolved to district/Municipal/ Metropolitan level. Planning standards and zoning guidelines were still formulated at National level but were implemented at district/Municipal and Metropolitan level. The zoning guidelines developed at national level by the Town and Country Planning authority, designated specific industrial enclaves (or allowed for the rezoning of other uses to industrial use) where LPG stations and other hazardous facilities were to be sited. These guidelines were further influenced by recommendations from various agencies comprising the National Petroleum Authority, Ghana National Fire Service, Factories Inspectorate Department and the Environmental Protection Agency which specified generic buffer distances between LPG stations and public places (500 meters) and LPG and hot works (200 meters). Other state actors such as the Ghana Water Company, Electricity Company, Volta River Authority, Road and Highways Authority and National Security (NPA, 2010) also provide specific separation distances between LPG stations and their utility networks. However, to date there is poor coordination among the regulators.

The process for obtaining a development permit for any establishment including LPG stations begins with an application where the applicant supplies drawings of the proposed development and in addition to permits from the Ghana National Fire Service and the Environmental Protection Agency to the district assembly together with the appropriate fees. These will be vetted by the technical sub-committee of the Statutory Planning committee during which the risk of fires and explosions to the external environment will be qualitatively assessed on site. Barring any serious risk, approval will be given and by the Technical sub-committee and subsequently by the Statutory Planning Committee. The onus of risk identification therefore lies with the technical sub-committee which includes fire service and the national disaster management organization personnel. These personnel have no experience with the conduct of quantitative risk assessment although by the use of the deterministic distances they are able to qualitatively determine the levels of danger to surrounding properties. Thus, decisions on land use within hazardous areas was largely determined through qualitative assessment of the risk.

Statement of the problem

Ghana like other developing countries in the world, is faced with the problem of industrial risk as a result of the hazards imposed on society by industries operating in the city spaces and also as the result of increasing vulnerability of human populations which share their living spaces with such industries (Douti, Biyogue et al., 2019; Yirenkyi, 2016). Chemical installations dispensing Liquefied Petroleum Gas in particular have been at the centre of most industrial disasters in Ghana. The proliferation of LPG stations in Ghana, has occurred partly in response to the active promotion and adoption of LPG as a fuel of choice for commercial, industrial, transportation, agriculture, power generation and domestic use in mainly urban areas (Asante et al., 2018). This is because LPG is perceived as a relatively low emission replacement for dirty fuels such as traditional biomass (wood, charcoal, agricultural residues and animal waste), coal and kerosene.

The growth in LPG usage is also as a result of increased production of natural gas in Ghana and within the West African sub region and the promotion of LPG as an alternative fuel by successive governments. Locally, LPG has been heralded as a fuel which has less impact on global warming and thus has a major role to play in the achievement of Sustainable Development Goal 7, (Universal access to sustainable energy by 2030). In Ghana, the consumption of LPG has witnessed a significant increase of 62.7% over the last eight years (from 177,192 metric tons in 2010 to 288,329 metric tons in 2018) although consumption over the last three years appears to be somewhat stabilizing (NPA, 2020b). The net result of the increased demand for LPG in Ghana has brought about the proliferation of LPG filling stations across the country. Between 2014 and 2018 there was a 24.6% increase in the number of LPG filling stations across the country bringing the number of stations to 634 in 2018 and a further 659 in 2019 (NPA, 2020b; The Publisher, 2019).

In the Greater Accra region where the Accra Metropolitan Area (AMA) is located, there are 174 stations equivalent to 24% of the country's total number of stations. In the Accra Metropolitan Area itself, as at 2014 there were 24 (17.7%) stations. In 2018, the number of stations in the AMA was 22 but only 15 were active at the time of the study due to operational challenges such as mandatory shutdowns as a result of safety concerns (NPA, 2020b). The proliferation of LPG stations, has been highest in congested urban areas (Mensah, 2020) where due to high per capita demand of LPG for transport, domestic and commercial usage filling stations either increase their installed capacity beyond the industry average of 12 metric tonnes or discharge several times per week in order to meet public demand (NPA, 2020b). More than 77.4% of the 659 stations in Ghana were found by the National Petroleum Authority to be high risk (The Publisher, 2019) because of the growing number of LPG dispensing stations with demand driven storage capacities and operational frequency and poor regulatory compliance coupled with the high proximity to vulnerable urban population densities of over 1300 per square kilometre within the Accra Metro (World Population Review, 2021).

Table 1: Notable industrial LPG & Gasoline Fires in Ghana (2007-2019)

Year	Incident	Location	Chemical	Hazard	Fatalities	Injuries
2020	Mighty Gas Station	Ho	LPG	Flash fire/Jet fire	9	15
2019	Mambah Gas Station	Odorkor (Accra)	LPG	Flash fire/Jet fire	0	1
2019	Runnel Gas Station	Dawhenya (Greater Accra)	LPG	VCE	1	0
2018	Trinity Oil	Krofrom (Kumasi)	LPG	Jet fire	3	11
2018	Amoh Gas Station	Apenkwa (Accra)	LPG	Jet fire	0	3
2017	Mansco Gas	Atomic (Accra)	LPG	Jet fire/ BLEVE	7	192
2017	Olam Industries	(Takoradi)	LPG	Jet fire/BLEVE	0	132
2016	Louis Gas Station	Trade Fair (Accra)	LPG	Jet fire	12	23
2007	Engas Station	Asokwa (Kumasi)	LPG		3	140

Source: BBC, 2019;Donkor, 2014; GraphicOnline, 2017

The presence of over 510 high risk LPG stations in the urban space has since 2007 led to a number of disasters over the years with serious consequences for the safety of persons and properties in excess of one kilometre in the external environment of these chemical industries (Table 1)

Given the routine nature of the industrial chemical disasters, with the attendant fatalities, injuries and damage to property, it has become clear to all including Government of Ghana, that previous distance-based measures by Government agencies to deal with industrial risk have been inadequate. As a remedial measure, Government of Ghana through the National Petroleum Authority has currently crafted a "Cylinder recirculation model" which proposes relocation of high-risk LPG stations from the city to the outskirts of Accra, and converting their former locations within the city into distribution points rather than dispensing points. The proposed policy has been difficult to implement due to public opposition from LPG marketers and other stakeholders on economic and safety grounds. On safety grounds, opponents believe that, the arguments and decisions by NPA to relocate LPG are not cogent enough and might only reduce risk for a short time before it ultimately fails due to residential creep. The current rate of urbanization in the Accra Metropolis has fostered intense competition for land, therefore it is anticipated that, the urban sprawl will catch up with the relocated LPG bottling plants to once more, recreate conditions of risk.

More so, converting dispensing stations to distribution stations would not provide any additional safety to the external environment as, an incidence of fire at any proposed distribution station, would likely lead to worse hazardous conditions than existed under the previous arrangement due to the hundreds of potential missiles which may be precipitated by the hundreds of exploding LPG cylinders. Thus, the real issue is the poor management of land use patterns within the vicinity of industrial chemical plants which is to be blamed as many LPG stations once occupied low density areas but have subsequently been overrun by new developments. Resolving the risk posed by LPG stations in the Accra Metro, therefore, calls for a concerted effort to apply a bi-directional stakeholder consultation approach to RILUP where, land use decisions are made based on both objective risk assessments and stakeholder perceptions on risk. The need for a bi-directional stakeholder consultation approach to RILUP is necessitated by the introduction of Ghana's nascent Spatial Planning Act, Act 925 enacted in 2016. The act is expected to address spatial/land use planning challenges within towns and cities where planners have limited control over land use decisions. The limitation faced by planners is primarily due to the existing land tenure system which gives greater control over land use decisions to individuals, families, local chieftains and private sector.

Furthermore, objections by stakeholder to risk reducing measures put out by the Government of Ghana reinforce the view that, a typical one-directional approach to making land use decisions, with planners preparing supposed valuable land use solutions for citizens, will have limited chance of success because, a city or urban area is a network of individuals forming and creating spaces with different uses and their views are more important (Murgante & Borruso, 2015). It also remains imperative to review the current land use planning process in Ghana, to ascertain where in Land Use Planning framework, a stakeholder driven risk assessment and decision making can be integrated to control industrial LPG risk within the Metro. Such a study would provide answers to the following questions.

Research questions

The questions this study seek to ask are;

1. What are the characteristics of potential LPG fire hazards in the Accra Metropolitan Area?
2. Do vulnerability levels for land use types in Accra Metro conform to land use planning standards?
3. Does the level of risk for land use types in the Accra Metro conform to the land use planning standards?
4. How do stakeholders perceive risk related to LPG fire hazards in Accra Metro?

5. What risk reduction strategies do stakeholders employ to address LPG fire hazards in the Accra Metro?

Research objectives

The main objective of this thesis is to determine the risk posed by LPG stations and its implications for land use planning decisions in the Accra Metropolitan area.

The specific objectives are to:

1. Determine the characteristics of potential LPG fire hazards in the Accra Metropolitan Area
2. Assess level of vulnerability across various land use types in the LPG fire hazard zone.
3. Assess the level of risk from LPG fire hazards in the Accra metro for different land use types.
4. Analyse perceived risk of stakeholders with regards to LPG fire hazards in the Accra Metro.
5. Determine risk reduction strategies of stakeholders within LPG fire hazards zones in the Accra Metro.

Significance of the study

It is envisaged that, this study will provide site specific information on LPG fire hazards, vulnerabilities and risks within the Accra Metro to aid regulators develop guidelines on industrial and LPG fire risk mitigation. The study also provides insight into stakeholder risk perceptions and risk management strategies which can inform planning of hazard zones around LPG stations. It further provides a firm basis for a bottom-up approach to RILUP and help create socially and politically adjusted but tolerable risk standards especially for Land Use Planning authorities. This would go a long way to improve adherence to land use plans.

Finally, the study would identify weaknesses in the regulatory frameworks for LPG stations which hinder participatory risk assessments and risk control of LPG fire hazards and industrial fire risk in particular. It is hoped that the findings will stimulate discussions on industrial risks in general, by the media and other stakeholders focusing on risk tolerability and acceptability criteria and encourage a more effective public disaster risk management policy.

Limitations

In estimating the probability of hazardous events, the study relies on already established hazard frequencies from the United Kingdom's Health and Safety Executives failure frequency reports (HSE - U.K. Health and Safety Executive., 2017). This is as a result of the lack of a historical database on failure frequencies for LPG process equipment in Ghana. In addition, the modelling of the consequences of an LPG release does not account for terrain steering effects and thus assumes a flat terrain. Population data obtained for the study were limited to 2010 population estimates.

Delimitations

This study explores the character of industrial LPG risk in the Accra Metropolitan Area of Ghana. It unearths the frequency, severity and spatial extent of the LPG hazard and also identifies vulnerable human populations and activities within the catchment of the LPG hazard. It also examines the risk perceptions and risk management strategies of individuals exposed to the LPG risk and attempts to integrate their view into developing Land Use Planning options which are risk informed. It also addresses the conformance of risk levels to risk criteria from the UK health and safety executive (UK HSE). In doing so, the study departs from classical approaches to RILUP, by involving stakeholders in risk assessment and risk informed land use decision making resulting in a stakeholder adjusted risk informed land use planning. It applies a pragmatist philosophy and a sequential explanatory methodology in the study of industrial Risk by exploring the topic from both an objective probabilistic view and a subjective-constructivist view.

Finally, the study assesses and integrates measures for the mitigation of LPG hazards from both expert and lay perspectives which is essential for deriving sustainable solutions to LPG risk in urban areas.

Organisation of the study

This thesis is organised into ten (10) chapters. Chapter one outlines the introduction to the study. This chapter covers the background of the study, research problem, research questions and objectives, significance of the study and delimitation. Chapter Two is mainly about literature review conducted for the study. This section is grouped into two main categories. First theoretical issues concerning the concept of industrial disaster risk, risk perception, risk assessment and the land use planning processes. It also examines the philosophy underpinning the SEVESO directives and conceptual frameworks from Sengupta (2016) on the integration of risk information into land use planning processes and the role of stakeholder consultations.

The second part of the literature review is an empirical review where issues of industrial hazard occurrences around the world are discussed including the practical cases where stakeholder-based risk informed Land Use Planning is applied in Europe and North America. Chapter Three focuses on the methods employed to achieve the objectives of this study. The chapter covers issues such as research design, population, sampling methods of data collection, data processing and analysis and lastly ethical consideration.

The results of the study are presented and discussed in Chapters Four, Five, Six, Seven and Eight. Chapter Five covers results on the hazards associated with LPG filling stations in Accra Metropolis. Important aspects of the Chapter Four include the magnitude and spatial extent of the LPG hazard and land use patterns within the hazard zone. Chapter Five assesses levels of vulnerability to LPG fire hazards and also the conformance of the vulnerability levels to the UK Health and Safety Executive's (UK HSE) consequence-based risk criteria. Chapter six provides further information on location specific individual risk and potential loss of life indices. It also provides further information on the conformance of land uses in the hazard zone to the legal separation distance and to the UK HSE's probabilistic criteria.

Chapter Seven deals with the measurement of risk from stakeholders' perception and interrogates the socio-demographic and psychological factors which influence their risk perception. Chapter Eight analyses the personal and non-personal risk management strategies adopted by persons living and working in the hazard zone of LPG filling stations. The strategies examined include behavioural and cognitive responses to risk and the levels of support for safe technology, safe management, land use planning and emergency response.

Chapter nine presents the summary, conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter deals with the theoretical and empirical review of literature. The theoretical review looks at the concepts of disaster risk with focus on the hazards and vulnerability as components of risk. In addition, the chapter discusses the management of industrial disaster risk and gives attention to the role objective and subjective views of risk have on the management of risk. The chapter further examines the role of land use planning as a tool for mitigating risk. A conceptual framework which utilizes both objective and subjective views of risk as important elements of the risk management process and integrates land use planning into disaster risk management is outlined. An empirical review focuses on the historical occurrences and consequences of industrial fire hazards, as well as strategies employed across the globe to manage such hazards.

Industrial hazards

Industrial hazards are potentially damaging mechanical, electrical or chemical events and phenomena which occur as a result of the large scale application of technology in furtherance of economic production (Government of India, 2011). Industrial hazards are therefore a subset of technological hazards which tend to involve potentially damaging events emanating from the generalized use/misuse of technology. The difference between industrial hazards and technological hazards emanates from the scope of industrial hazards which focus on accidents relating to economically productive purposes (Pan American Health Organization, 2019).

The defining principle of any hazard lies in its potential destructive power which may only be realized in the face of vulnerable conditions. Industrial hazards have certain notable characteristics which define them and these include the following; a triggering factor, spatial dimensions, magnitude, frequency, duration, speed of onset and derived events.

Industrial hazards are triggered off by mainly human related errors which manifest and interact with other systemic errors and these errors may then be propagated through a system until it results in a disaster event. These errors include accidents, dangerous procedures, infrastructure deficiencies, and specific human activities that can cause death, injury, disease, or other health impacts, as well as jeopardize property, livelihood, and services, provoke socio-economic disorder, and environmental damage (Pan American Health Organization, 2019). The triggers can also be from natural sources such as lightning strike, floods, and seismic events. Conflicts and wars have also been one way industrial hazards have been triggered. United Nations Environment Programme (2019) explains that during conflicts, there may be deliberate action by warring parties to destroy industrial complexes in order to gain strategic advantage.

The magnitude of a hazard plays a big role in the realization of the concept given that, such hazards tend to occur on a large scale and affects hundreds of people. Van Westen et al. (2010) explains that the magnitude of hazards is the amount of energy released during a hazardous event. One important characteristic of hazards is its frequency of occurrence.

Van Westen (2010) defines frequency of occurrence as the number of events over a given period of time. Frequency of occurrence is a useful variable which helps in estimating the probability or chance of such hazards occurring. There is a relationship between the frequency and the magnitude of a hazard where events with higher frequency tend to have lower magnitude and though industrial hazards may not be as pervasive as natural hazards, their magnitude and economic consequences tend to be devastating (Galve, Remondo & Gutierrez, 2011). Industrial hazards also have spatial distribution which exemplify their reach and provides a good indicator of exposure of various elements in space to the potential force of the hazard. Prenger-Berninghoff & Greiving (2015) explain that knowing the spatial extent of an industrial hazard provides the bases for risk-based planning. With that, planners will be able to know areas likely to be affected and make necessary land use interventions. It can also serve as the basis for identifying persons likely to be at risk and stakeholders for inclusive planning.

Other defining characteristics of industrial hazard may include its duration and potential domino effects. Duration of industrial hazards considers the time from when the event is triggered to the time when the magnitude subsides significantly such that, it can no longer cause harm (Van Westen et al., 2010). However, the longer the duration the greater the impact of the industrial hazard while shorter durations can have less impact. This is however, not always the case as different types of industrial hazards can produce different levels of duration and effects. Lowesmith et al.,(2007) have described the duration and effect for several industrial hazards such as flash fire, Jet fire, and pool fire in relation to LPG.

Another component of the industrial hazards is the speed of onset. Industrial hazards tend to have higher speed of onsets given that, the time span from when they are triggered to the time when they have maximum impact is relatively short compared to most natural hazards. The speed of onset for industrial hazards can range from just a few seconds to several days. This has implications for early warning, response time, and evacuations. However, different types of industrial hazards have different onset times and durations (Gerrard & Petley, 2013)

Types of industrial hazards

Boiling Liquid Expanding Vapour Explosion (BLEVE)

A BLEVE is a sudden catastrophic vessel failure, usually due to fire impingement on an LPG vessel, leading to a major fireball and some blast overpressure (Roberts, 2000). The likelihood of such events for fully mounded LPG tanks is generally considered to be negligible, although it could still occur for LPG road tankers (Atkins, 2007). BLEVEs typically occur in closed storage tanks that contain a liquefied gas, usually a gas that has been liquefied under pressure. Propane is an example of a chemical that has been involved in many BLEVE accidents. Most propane tanks at service stations contain liquid propane. These tanks are neither insulated nor refrigerated, so the tank contents are at ambient temperature. Since the ambient temperature is almost always significantly above propane's boiling point of -43.7°F, the tanks are highly pressurized (Martín et al, 1977).

A common B trigger for BLEVE happens when a container of liquefied gas is heated by fire, increasing the pressure within the container until the tank ruptures and fails. When the container fails, the chemical is released in an explosion. If the chemical is above its boiling point when the container fails, some or all of the liquid will flash boil, that is, instantaneously become a gas

(Tauseef, Abbasi & Abbasi, 2010). If the chemical is flammable, a burning gas cloud called a fireball may occur if a significant amount of the chemical flash boils (See Plate 1). Other potential BLEVE hazards include overpressure, hazardous fragments, smoke, and toxic by-products from the fire (Seattle & Washington, 2007)

Plate 1: BLEVE event in Accra. 6th October 2017.
Source: Joy News Online, 2017.

The magnitude of a BLEVE depends on the temperature of the tank, internal pressure of the tank and quantity of fuel. Although tanks holding liquefied gas are designed to withstand high pressures but for propane the internal tank pressure under normal storage conditions is already high enough that 100% of the released chemical would form a fireball; no pool fire would form. The duration of BLEVE can range from 10-15 seconds and will release very high levels of thermal radiation in all directions (Birk, 1996).. Typically, within the 10-15seconds of the onset the worst effects of the hazard would have occurred covering areas within its reach. The reach or the spatial extent is linked to the volume of fuel and size of the tank. The derived events from a BLEVE include hazardous fragments or missiles which may cause injuries and fatalities through direct impact with humans. The fragments may also spread the fire into neighbouring land uses.

Jet fire

A Jet fire occurs when a flammable liquid or gas is ignited after its release from a pressurized, punctured vessel or pipe (American Institute of Chemical Engineers. Center for Chemical Process Safety, 2010). With Jet fire once flammable liquids or gas are released their occurrences is supported by naked fires within the environment they are released. The pressure of release generates a long flame, which is stable under most conditions (American Institute of Chemical Engineers. Center for Chemical Process Safety, 2010). A flash flame may take the form of Jet flame on reaching the spill point. Mogi and Horiguchi (2009) explain that the release rate and the capacity of the source determine the duration of the Jet fire.

Also, Gómez-Mares, Muñoz and Casal (2010) assert that the flame length from Jet fires increases directly with flow rate. They further explain that, when there is a typically pressurized release of 8kg/s, Jet fires would have a length of 35 m. They further point out that, that there are instances when the 35m flame length can be exceeded or reduced as the due to the effects of crosswinds. The aforementioned researchers also put it that, an increase in the crosswind velocity increases the flame length while the opposite can occur.

Plate 2: Jet fire, Ho, 1st November, 2020
Source: https://news.payperlez.com, 2021

Pitblado (2007) argues that Jet fires tend to have a longer duration period as compared with BLEVEs. Indeed, Drysdale (2011) explains that, Jet fire can continue to burn for as long as the release of gas is not isolated, and the prolonged thermal radiation (or flame impingement) can lead to significant risks, although the impact tends to be relatively local. Plate 2 shows a Jet fire which occurred at Ho in the Volta region of Ghana on 1st November, 2020.

Flash fires

A flash fire is the non-explosive combustion of a vapour cloud resulting from the release of a flammable material in the open air. The speed of burning is a function of the concentration of the flammable component in the cloud and also the wind speed (Hirst, 1989). If this cloud then finds a source of ignition, the area covered by the vapour cloud will burn rapidly as a flash fire, with significant risks to all those within the flash fire envelope (Atkins, 2007). Within a few second of ignition the flame spreads both upwind and downwind of the ignition source. Beyler (2016) explains that initially the flame is contained within the cloud due to premixed burning of the regions within the flammable limits. Subsequently however, the flame extends in the form of a fire plume above the cloud. The downwind edge of the flame starts to move towards the spill point after consuming the flammable vapour downwind of the ignition source. The trigger between flash fire and Jet fire are similar. However, flash fires can also be caused by overfilling of the tank, faulty valves and tank being impacted by an external force causing a leakage.

Plate 3: Flash fire at a test site
Source: Process Engineering Channel, YouTube, 2015.

Typical flame propagation speeds are of the order of 4 m/s (Hirst, 1989). According to Palacios, Muñoz, Darbra and Casal (2012), the difference between a flash fire and a jet fire is that the latter contacts fire within a few seconds when there is a larger leakage, whereas the former usually spreads for a while before the gas contacts fire when its concentration is between the upper and lower flammability levels. The upper flammability level occurs when the gas is too concentrated within a given area. That is when the ratio of gas to air is too high while the lower flammability level refers to a situation where *the ratio of gas to* *air is too low*. Combustion burning of leaked gas occurs within the upper and lower flammability levels (Britter, 1989).

On the other hand, he further explains that lower flammability level occurs.

Vapour Cloud Explosion

This is similar to a flash fire, except that if the vapour cloud is in a partially confined area, then the ignition of the cloud could also lead to a vapour cloud explosion (VCE), generating significant levels of blast overpressure, which would present a risk to people beyond the flash fire envelope (Atkins, 2007). When a flammable chemical is released into the atmosphere, it forms a vapour cloud that will disperse as it travels downwind. Eckhoff (2005) observes that if the cloud encounters an ignition source, the parts of the cloud where the concentration is within the flammable range (between the Lower and Upper Explosive Limits) will burn.

Shepherd and Lee (1992) explain further that the speed at which the flame front moves through the cloud determines whether it is a deflagration or a detonation. In some situations, the cloud will burn so fast that it creates an explosive force (blast wave) which can cause damage to windows, doors and buildings. The blast wave makes the effects much more severe because there is the thermal radiation as well as blast over pressure. Tauseef, Rashtchian, and Abbasi (2011) stipulate that the severity of a vapour cloud explosion depends on the chemical, the cloud size at the time of ignition, the type of ignition and the congestion level inside the cloud. If the leakage is able to form a bigger cloud size all elements within that reach are at risk. Plate 4 shows an LPG gas leakage which occurred on the 15th of March in Abule Ado, a suburb of Lagos where LPG from an underground pipeline leaked. The gas escaped for approximately 5 minutes before it ignited and exploded.

Plate 4: LPG Leakage at Abule Ado, Lagos, Nigeria on 15th March 2020
Source: BBC Africa Eye News (2020)

Lamb and Verlinde (2011) explain that the cloud size increases in relations to the volume or the amount of gas being released into the atmosphere. If the time of ignition is immediate then a Jet fire occurs but the longer it delays the less chance, there will be of a severe VCE explosion occurring. The type of ignition may also influence the rapidity with which the flame front moves through the vapour cloud. Eckhoff and Thomassen (1994) postulate that higher energy ignition sources can lead to a more severe explosion than do lower energy sources.

Plate 5: After effects of a vapour cloud explosion in Lagos, Nigeria. 16th March, 2020.
Source: AFP TV, 2020.

Plate 5 shows the after effects of the vapour cloud explosion that occurred in Lagos, Nigeria which destroyed over 50 properties at Abule Ado in Lagos. The blast also levelled a secondary school and surrounding properties and killed 23 people and injured over 500 (See Plate 5) Lastly, congestion level impacts the severity of VCE. This impact is related to physical congestion of the area, such that areas with more physical structures which create turbulence but do not impede the spread of a cloud are more likely to experience severe VCE. On the other hand, areas with more physical developments increase the mixing of leaked gas with ambient air which reduces the severity levels.

Pool fire

Any release of fuel may form a liquid pool on the ground. If the release finds a source of ignition, then a pool fire will be formed (See Plate 5). A pool fire occurs on ignition of an accumulation of liquid as a pool on the ground or on water or other liquid (International Labour organization, 1996). A steadily burning fire is rapidly achieved as the vapour to sustain the fire is provided by evaporation of liquid by heat from the flames. The maximum burning rate is a function of the net heat of combustion and heat required for its vaporization.

Plate 6: Pool fire due to a crashed fuel tanker. Lagos-Ibadan express (28th June, 2018)
Source: ChannelsTV.com, 2021

Generally, heat radiation dominates the burning rate for flame greater than 1m diameter (Gore et al., 2006). Pitblado (2007) explains that heat from the pool fire may weaken a leaking tank and cause it to fail completely which may cause a BLEVE, which pose a greater threat than a pool fire because of fragments from the BLEVE.

Elements at risk to industrial hazards

All objects, persons, animals, activities and processes that may be adversely affected by hazardous phenomena, in a particular area, either directly or indirectly are referred to as elements at risk (Van Westen et al., 2010). There are various categorisations for grouping the elements at risk to industrial hazards or any other hazards. Van Westen et al., (2010) claim that, the classification of elements at risk is dependent on the country, the setting (urban, rural, etc.) the objectives of the risk assessment, the scale, available resources etc. (Cheng et al., 2015). On the contrary, Ma et al.,(2015) grouped elements at risk in her research into human targets, environmental and asset targets. The Asian Disaster Preparedness Centre (ADPC) cited in (Van Westen et al., 2010) also groups elements at risk into physical, social, economic and environmental.

In the United States of America, Hazus which is a nationally standardized risk modelling methodology, classifies elements at risk in a detail but is specific to the USA. The HAZUS classification scheme looks at general building stock, essential facilities, hazardous material facilities, high potential loss facilities, transportation lifeline systems, utility lifeline and demographics. Villagran De Leon (2006) adopts a sectoral approach and classifies the elements at risk into housing, basic lifelines, health, education, agriculture, energy, infrastructure, commerce, industry, finance and telecommunications. Their sectoral approach is targeted at assigning responsibilities to sectors which are in charge of specific elements that will be affected during a disaster.

However, in most industrial risk studies, attention is focused on tangible elements rather than intangible elements such as social and political systems of governance and cultural values. The tangible elements most studies tend to focus on are buildings, basic lifelines, infrastructure and population. Also in some cases, industrial risk assessors take into consideration the spatial scale at which to collect the elements at risk. However, the scale approach has challenges when mapping at community level because the amount of details to be captured is high and more laborious than at a small scale which considers a larger area and less details.

Van Westen et al., (2010) argues that any survey of elements at risk will always be incomplete, and therefore a risk assessment study nearly always generalises by focusing on specific groups of elements at risk. The argument by Van Westen et al., (2010) on the incomplete nature of mapping elements at risk means that more focus should be given to the nature of the hazard in the determination of which elements to consider. This is because different elements at risk have varying levels of vulnerability to a given hazard.

Although the type of hazard should be considered in developing elements at risk, elements at risk inventory is also constrained by availability of data, data reliability and the cost involved in making an inventory of the elements (Sengupta, 2016). Cost of inventorying elements at risk is influenced by the scale at which the inventory is to be collected. For scale, HAZUS elements at risk looks at collecting information at the census tract or blocks by aggregating the number of buildings and occupancy class (Moreland, 2018). Constrained by availability of comprehensive data for elements at risk at the census tract in India, Sengupta (2016) opted for individual level by collecting elements at risk information for each single structure within industrial hazard zone. Data for elements at risk inventory is a challenge for developing countries as the data base for building footprints and people within elements might not exist hence the researcher has to develop his/her own database. In this research much attention is given to availability of data and the cost and scale to map the elements at risk. Sengupta (2016) asserts that for quantification purposes elements at risk inventory moves beyond the classification scheme to adopt the scale to map a set of measurable attributes related to elements at risk and their surroundings should be identified. Information about the elements at risk is useful in the generation and estimation of vulnerability of the elements at risk.

Vulnerability of elements at risk to industrial hazards

Vulnerability is a concept with diverse meanings and conceptualisations and is noted for having a vague and imprecise meaning. Birkmann (2005) outlines about five different concepts of vulnerability (Figure 1).

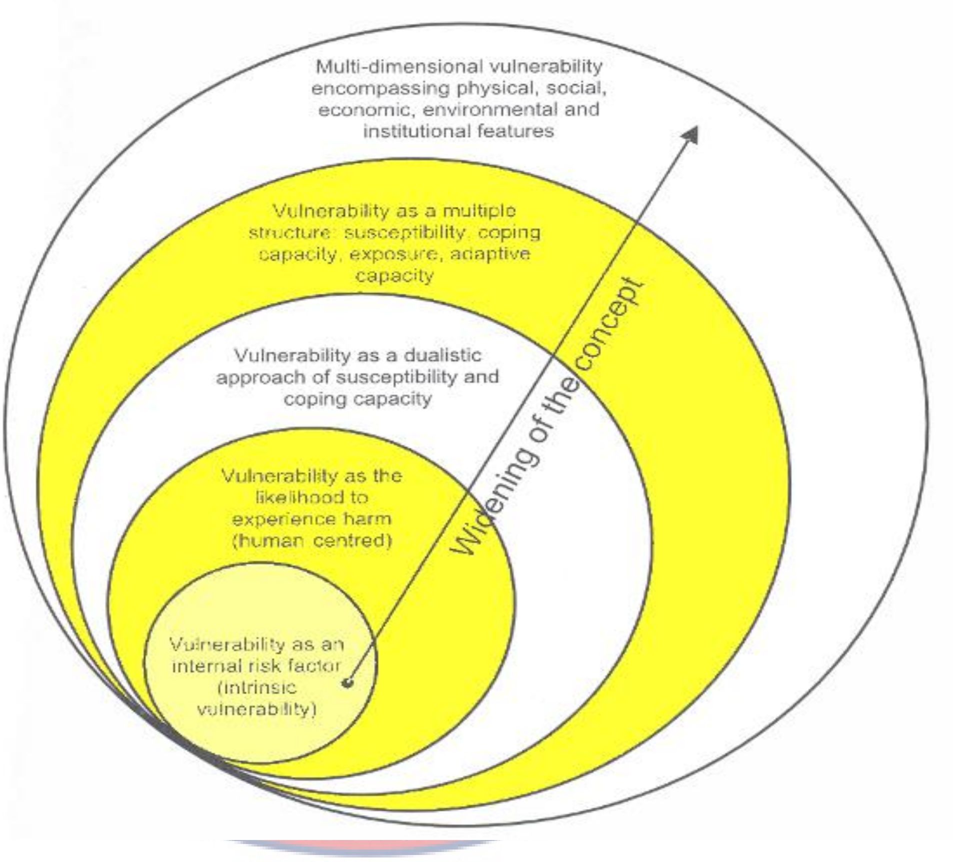

Figure 1: Concept of vulnerability
Source: Birkmann, 2005

The first concept looks at vulnerability as an internal risk factor. Pelling (2003) explains that vulnerability refers to exposure to risk and the inability to avoid or absorb potential harm. The definition by Pelling (2003) falls within the dualist approach of vulnerability. Bohle (2001) cited in (Van Westen et al.,

2010) is also known for his dualist concept of vulnerability by diving vulnerability into a double structure with an external component which looks at the exposure to hazards and an internal component which focuses on coping. Niekerk (2005) cited in (Van Westen et al., 2010), also concurs that vulnerability is the extent to which a community will degrade when subjected to a specified set of hazardous conditions and further argues that, vulnerability consists of exposure and coping capacity. Twigg & Benson - ProVention Consortium, (2007) defined vulnerability as exposure, resistance and resilience. In this definition exposure looks at the properties and population elements which may be at risk of damage (Messner & Meyer, 2006). Resistance as the measures taken to prevent, avoid or reduce loss while resilience as the ability to recover prior state or achieve desired post-disaster state. This definition by Prevention Consortium falls within the multi-structure concept of vulnerability.

The United Nations Office for Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction, 2017a) takes a multi-dimensional approach to the study of vulnerability by envisaging vulnerability as conditions which are determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Physical factors which can make an element at risk vulnerable to industrial hazards includes the type of buildings, type of construction material, number of floors, spacing between buildings, infiltration capacity, distance from highly vulnerable buildings and others specific to industrial hazards. Masozera, Bailey, and Kerchner (2007) argue that social and economic conditions are typically attributes of human populations which may predispose them to various levels of harm and include levels of poverty and social exclusion, gender disparities among others.

Per the concept of vulnerability shared by the (United Nations Office for Disaster Risk Reduction, 2017a) they outline several characteristics of vulnerability. Four main characteristics of vulnerability are outlined including multi-dimensional, dynamic, site-specific and intrinsic nature of vulnerability. The multi-dimensional characteristic of vulnerability rather focuses on the physical, social, economic, environmental, institutional, and human factors which create conditions of vulnerability whilst the dynamic nature of vulnerability explains that vulnerability is not static but always evolving or changing in time (Ribot, 2013). This is because the conditions which determines vulnerability are in themselves not static therefore, vulnerability cannot be expected to be static. The dynamic nature of vulnerability makes room for either improving or worsening one's vulnerability to a hazard. Also, because land uses are in constant change vulnerability of elements at risk changes with it. However, different areas experience different levels of vulnerability. This could be influenced by the location of the elements at risk to the hazard (Ribot, 2013). In addition, because the hazard has the probability of occurrence in space the exposure of elements at risk to the hazard is premised on this probability thus every location may offer different levels of exposure or susceptibility. Space is a dynamic entity as similar elements at risk can cluster at a particular area hence different levels of vulnerability occur in space.

The last set of characteristics of vulnerability which is about the intrinsic nature of the concept. Intrinsic aspect of vulnerability is dependent on the nature of the element at risk and its properties. For example, vulnerability of structures to industrial hazards are determined by the type of material the structure is made of and, for human populations, the socio-economic status of people has direct effect on vulnerability. Morduch (1994) explains that persons with low income are more likely to be vulnerable as they will have low coping capacity compared to high income households.

Industrial risk and disasters

Risk is a part of everyday activity of man. Beck (1992) and Ale (Ale, 2005a, 2009) affirm that, no one is immune to risk as risk is global and is shared by all. The word risk connotes different meaning. Arnaud (1667) cited in Ale, (2009) defines risk as a probable occurrence of a hazard and its expected harmful consequences. In this definition risk is conceived as a function of hazard and vulnerability. This notion of risk has persisted for many years. In the same vein, United Nations Office for Disaster Risk Reduction (2017b) defines risk as a combination between the hazard and the vulnerability. Kapucu and Ozerdem (2013) also explains risk as the likelihood, or more formally the probability, that a particular level of loss will be sustained by a given series of elements as a result of a given level of hazard. In this definition risk is viewed as a function of elements at risk, hazard and vulnerability.

Villagran de Leon (2006) argues that, risk is a combination of two factors that is hazards which interact with vulnerable conditions and coping capacity of the elements at risk. They further explain that, risk is a process which increases as time elapses due to various social processes as opposed to static notion of risk by Arnaud (1667). The concept of risk is also linked with the widening concept of vulnerability and as different scholars define vulnerability differently the function of risk also changes accordingly.

However, one entity which is constant in all the definitions is the concept of hazard while vulnerability notion changes. From Schmidt-Thomé's (2006) notion of risk, industrial risk can be defined as interaction between industrial hazards and vulnerable elements with the potential to exceed the ability of the vulnerable elements to cope with the hazard. Industrial risk is a subset of technological risk, and is present wherever systems are operating in which technology and people interact for economically productive purposes. Industrial risk in societies become preeminent with the technological advancement and development of industries within urban landscapes. Initially, the concept of industrial risk was mainly limited to workers within industrial complexes. But in both new and post-industrial societies the concept of industrial risk broadened to include not only the occupational health and safety of industrial workers, but also the safety of people and property in the external environment of an industrial site (Ale, 2009). Basta, (2009a) emphasizes that, in post-industrial Europe, industries in cities have posed challenges to people with the potential to cause death, harm and even affect health.

Van Westen et al. (2010) observes that, the manifestation of industrial risk is what can be termed an industrial disaster which has the ability to actually bring harm to society (Figure 2). Industrial disasters usually occur when the risk actualises by exceeding the capacity of elements at risk to respond to industrial hazards.

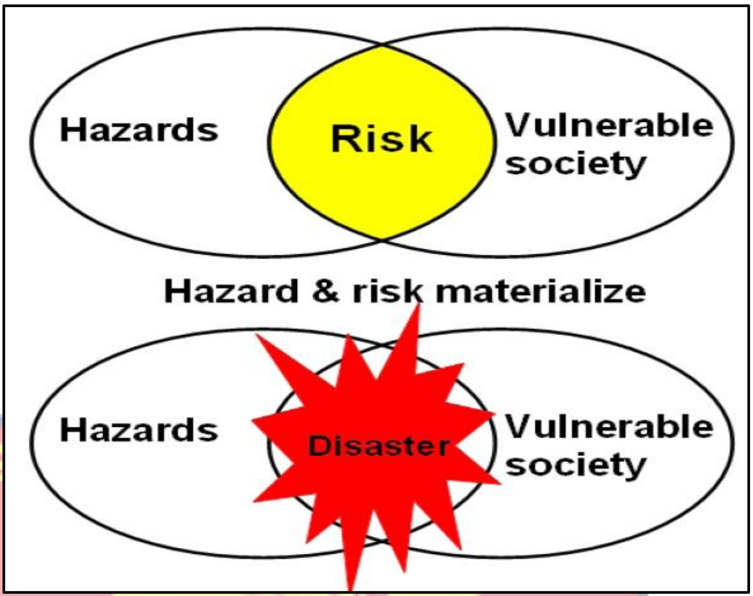

Figure 2: The concept of risk and disaster
Source: Van Westen et al, 2011

Thus, industrial disasters are actual loss events which disrupt the normal productive function of industries and lead to economic and human losses or injuries both on the industrial site and in the environment external to these industries. Although this criterion appears to provide some clarity to the definition of disasters, it does not necessarily lead to a convergence because there is no agreement regarding the extent of loss that may qualify an event as a disaster. It may suffice to say that, such losses are expected to be of industrial scale, that is, on a large scale. The spectrum of disasters may therefore be seen as transcending from mere accidents to catastrophes which may involve thousands of people such as the Bhopal industrial accident in India (Acquilla et al., 2005; Ale, 2005a; Arturson, 1987; Cozzani et al., 2006; Sengupta, 2016; Sengupta et al., 2016; Xanten et al., 2014).

Management of industrial disaster risks

The origin of modern risk management was precipitated by some industrial accidents which occurred in Europe after the Second World War (Ale, 2005a). Industrial risk management is the application of disaster risk reduction policies and strategies to prevent new industrial disaster risk, reduce existing industrial disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses (United Nations Office for Disaster Risk Reduction, 2017a). Accordingly, the United Nations Office for Disaster Risk Reduction (2017a), categorizes industrial risk management into three main types namely, prospective disaster risk management, corrective disaster risk management and compensatory disaster risk management, also called residual risk management. The management of industrial fire risks in the petro-chemical industries tends to be largely prospective as it seeks to anticipate and control future risks of industrial fires, toxic releases and explosions through complex modelling of hazardous scenarios in a quantitative risk assessment and the application of safe technology, safe management, and procedures to curb the risk.

Industrial risk management of petro-chemical industries also tends to be corrective when it identifies and ameliorates existing risk through the retrofitting of critical infrastructure or the relocation of exposed populations or assets through safe technology and land use planning. Industrial risk may also be managed using a compensatory approach where a mix of risk transfer and risk financing options like insurance and reinsurance may be used to cater for residual risk brought on by industrial activity. Disaster preparedness, planning, and emergency response may also be applied to build the capacity of individuals and communities in the face of residual risk that cannot be effectively reduced.

IUGS (1997) differentiates disaster risk management into two main components that is, assessment of risk and control of risk. However, there exist other approaches which basically treat risk assessment separately from management of risk. Greiving and Fleischhauer (2006) suggest that, it is crucial to separate risk assessment from risk management as the former on the one hand is a scientific, factual assessment of risks while the latter refers to normative decisions for managing risks. They further categorize risk management activities into four control measures namely mitigation, preparedness, response and recovery. This categorization is a re-echo of a similar categorization by Alexander (2002). Whichever approach one takes, all scholars admit that, risk management begins with assessment of risk.

Industrial risk assessment

The United Nations Office for Disaster Risk Reduction, (2017a) defines risk assessment as either a qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend.

In the main, industrial risk assessment primarily constitutes a scientifically-led process which is based on empirical data and scientific findings which form the basis for weighing up processes and decisions for risk management measures (Kalliopi et al, 2011).

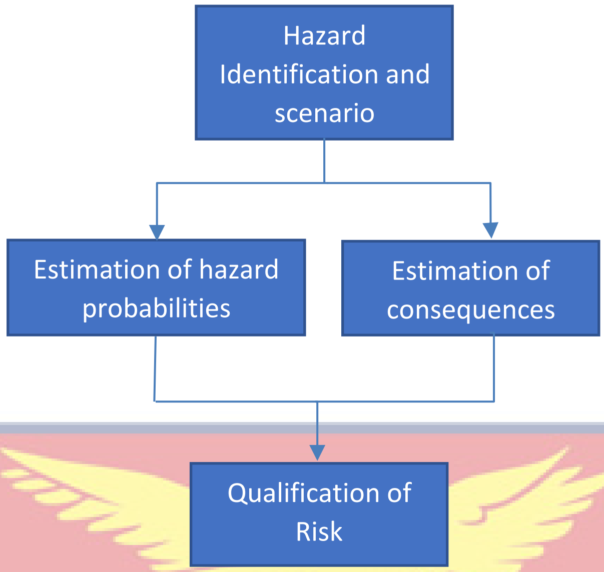

Figure 3: Process of industrial risk assessment
Source: Ale, 2005

As shown in Figure 3, disaster risk assessment includes: the identification of hazards and hazard scenarios; a review of the technical characteristics of hazards such as their location, magnitude, frequency and probability; and the analysis of exposure and vulnerability to the hazard including any expected physical, environmental and economic consequences. The process terminates with the subjective evaluation and qualification of the identified risk per applicable risk criteria.

To sum up, results of risk assessments are statements about the acceptability or otherwise of the likelihood of potentially damaging effects (Ale, 2005a; Hollenstein, 2005). Industrial risk assessment can be categorized into two main approaches which are either qualitative or quantitative. Qualitative risk utilizes tools to derive data on the potential hazards through the use of a check list and index-based methods and evaluates the results of the risk analysis using risk matrices. Risk matrices relate the likelihood of the hazard to the severity of the consequence of a hazard but in doing so, they do not explicitly quantify the probability of a hazard and the severity of the consequences in absolute terms. Quantitative risk approaches on the other hand may take two forms: either a consequence-based assessment or a purely probabilistic risk-based assessment.

Consequence based approaches utilize a system of quantitative models to determine the consequences of a hazard based on based the magnitude and spatial distribution of the hazard. Christou, Gyenes and Struckl (2011) explain that, this approach is based on the assessment of consequences of credible (or conceivable) accidents, without explicitly quantifying the likelihood of these accidents. Consequence based approaches tend to circumvent the quantification of the frequencies of occurrence of the potential accidents and the related uncertainties (Abrahamsson, 2002). The basic concept of the consequence-based approach is the existence of one or more worst credible scenarios, which are defined using expert judgement, historical data and qualitative information.

Risk-based approaches on the other hand, treats risk as a combination of the consequences derived from the range of possible accident scenarios, and the likelihood of these accidents (Ale, 2005b). Generally, a risk-based approach consists of five parts identification of hazards, calculation of the probability of occurrence of the potential accidents, estimation of the extent of consequences of the accidents and their probability, integration into overall risk indices that may include both individual and societal. Finally, the outcome is compared with risk acceptance criteria to determine the acceptability or otherwise of the calculated risk.

The main types of industrial risk assessment discussed here, are often technical and mostly undertaken by risk assessors who may not be living within the risk zones they are assessing. Kasperson et al., (1988), Petts (1988) and Beck

(1992) argue for the integration of social perceptions into the technical analysis of risk for effective risk management. To facilitate this, Petts (1988) further argues that risks need to be assessed and discussed publicly in an effective and rational manner. This concept of involving individual and societally perceived risk is studied as the concept of risk perception. Slovic (2016) supports the notion of socially constructed risk by arguing that risk is not only a calculation to be undertaken by technocrats but also a complex amalgam of emotions, interests and values by people living in the hazard zone. Although technical and social risks are needed, Petts (1988) explains that the biggest challenges is how to base development decisions on both technical assessment and societal perception of the risk.

Risk perception

Risk perception is the subjective assessment of the probability of a specified type of accident happening and how concerned we are with the consequences (Rundmo et al., 2004). According to Weinstein (1989), perception of risk is a social and cultural construct which transcends the individual, and is based on values, symbols, history, and ideology. Micic (2016) also asserts that, risk perception can be seen as a generic term but we will accept that it relates to individual's beliefs, attitudes, judgments, and feelings in addition to their cultural and social disposition. This means that risk as perceived by people will differ depending on their social and cultural background. Understanding risk perceptions and their underlying processes is thus important in order to learn more about the way people interpret and respond to hazardous emergency events Knuth (2014).

Several scholars have all argued for inclusion of perceived risk in the assessment of technological/industrial risk Kasperson et al., (1988), Petts (1988), Beck (Beck, 1992), Slovic (2016) and Sadiq et al., (2019). However, evaluating and assessing perceived risk is riddled with numerous challenges. This is because of the social and cultural background of people which differ significantly. This is what has generated several approaches in the assessment of perceived risk. According to Wahlberg (2001) risk perception (RP) can be studied based on the following approaches: the psychometric approach, the basic risk perception model (Sjöberg, 1993), and cultural theory (Douglas & Wildavsky, 1982).

Determinants of individual risk perception

Perceived risk can be determined by a number of factors. Generally, perceived risk is influenced by socio-economic and psychological factors which lead to observable variations in risk perception. The influence of these factors on risk perception are important for establishing theoretical models of risk (Hitchcock, 2001). Regarding the role of gender on risk perception, Slovic (1987) , in multiple studies found that, women tend to frequently rate environmental and health risk as moderate or high risk compared to their male counterparts. Davidson and Freudenburg (1996) also posit that, gender differences in risk perception cannot be attributed to differences in knowledge alone as health and safety concerns are greater among females than males.

Socioeconomic Status

A main characteristic in people's perception is that of their socioeconomic status, often referred to as SES, a challenging and rather debatable issue to conceptualize (Luloff, 2011). Socioeconomic status (SES) is a broad concept that includes such factors as educational attainment, occupation, income, wealth, and deprivation. Socioeconomic status (SES) is a composite measure of an individual's economic and sociological standing. It is a complex assessment measured in a variety of ways that account for a person's work experience and economic and social position in relation to others, based on income, education, and occupation. Socioeconomic status has been a powerful determinant of risk perception. According to Baker et al., (2013), generally, in sociology SES is viewed as a latent construct and is measured using a composite measure of education, income, and occupation or some variation of these three indicators. While these three indicators represent the most widely accepted measures of SES, it is sometimes defined subjectively in terms of wealth, home ownership, or as neighbourhood disadvantage. Kusama et al., (2018) suggests that, income and education are directly related to anxiety and risk aversion such that, lower income and educational groups tend to exhibit lower anxiety and risk aversive behaviours whilst income groups and higher education students tend to show the most risk aversive behaviours.

Inglehart's theory, which is centred upon Maslow's hierarchy of needs (food, shelter and safety) (Maslow, 1943; Neher, 1991a) also argues that the poor whose basic daily needs are not fulfilled fail to be concerned about their safety and the protection of the environment. As members of society become more affluent, they strive for better economic goals, termed to be "post-materialist" values that may include political freedom, individual self-fulfilment and environmental protection (Abramson & Inglehart, 1995). The United Nations International Strategy for Risk Reduction (UNISDR) in the Global Assessment Report(GAR) on disaster risk reduction for 2015, (UNISDR, 2015) emphasised the link between poverty and risk. It argued that, a poverty-risk nexus exists and show how global inequalities create underlying risk drivers such as, declining ecosystems, weak social protections, vulnerable rural livelihood and increased exposure to major hazards. They further indicate that, risk drivers in turn create multi-dimensional poverty which forces individuals to face every day risk such as food insecurity, ill health, crime, lack of sanitation and poor access to social services. The continuous nature of the everyday risk, lead to the intensification and extensification of risk as poor people are exposed to frequent low severity and infrequent high severity hazards. The outcome of such a situation would be more disaster losses and increased poverty outcomes, which reinforce the multidimensional poverty status of individuals.

Proximity and risk perception

It is expected that there would be a distance decay factor in the assessment of risk perception. Proximity to hazardous facilities should yield higher levels of perceived risk whiles distances further away from a hazard will yield less perceived risk.

Disaster risk control

According to Christou et al., (1999), industrial risk control on the part of agencies mandated to ensure public safety may involve use of a multi-level safety concept based on the philosophy of the SEVESO II direction on major accident hazard control. Elements of the multi-level system include the utilization of safe technology in industrial plants with the aim of ensuring that risk from the plants are reduced to their barest minimum. The application of safe technology, however does not exist in a vacuum but rather occurs within a framework of safe management practices as suggested by Christou et al. (1999).

Land use planning and emergency response are also elements within the multi-level safety concept of the directive which are purposed at addressing the residual risk from industrial chemical hazards (Christou & Porter, 1999).

Potential victims of industrial chemical hazards and other stakeholders may adopt either cognitive or behavioural strategies as risk control measures. Cognitive strategies generally involve non-action related measures taken by people exposed to risk with the sole purpose of assuaging their fears. Such measures are usually based on superior reasoning or an appeal to pity or appeal to a superior being without actually involving any further actions on the part of the exposed individual or community. Skinner and Zimmer-Gembeck (2016) and Aldwin and Yancura (2004) have argued that, while cognitive risk reduction strategies may not involve actual remediate actions, they provide a mental shield to those who utilize such strategies.

Behavioural risk control on the other hand involves remedial actions such as building one's capacity to cope with hazardous conditions from an industrial hazard through the use of firefighting equipment and techniques. Van Westen et al.,(2010) explains that, behavioural risk control strategies include risk avoidance, risk mitigation, risk transference and risk retention all of which are aimed at reducing the risk to people and property. Risk avoidance, argue generally involves modification of a hazard in order to avoid the potential harm that may be caused. In the case of an industrial hazard, this may involve removing harmful chemicals from populated centres or making sure that volatile chemicals do not come into contact with naked flames. Regarding risk mitigation, Greiving & Fleischhauer, (2006) explain that, this usually involves, modification of the extent of the susceptibility to hazard damage and disruption.

Generally, that means removing vulnerable populations from harm's way through evacuations or by building the coping capacity of exposed populations through livelihood improvements and awareness creation.

Transfer of risk as explained by United Nations Office for Disaster Risk Reduction (2017a) involves outsourcing of the impacts of risk mostly through insurance to capable third parties. They argue that, this can significantly improve the recovery of affected persons and communities in the event of a disaster. Transference may be partial or complete where the risk is shared with collaborators within the same industrial domain. Retention and sharing of risk of risk has been explained by Van Westen et al. (2010) as involving the management of residual risk through budgeting. This approach to risk management relies on the fact that some levels of risk must be tolerated or accepted with society and by individuals as such residual risk may be accepted and budgeted for. Considering all the strategies available to people at risk, mitigation can be considered to be long term and anticipatory while the rest are reactive. The anticipatory nature of mitigation gives it a greater chance to help control disaster risk with much more efficiency.

Risk control measures for industrial chemical hazards may also be in the form of engineered solutions such as bunkering and erection of barriers etc. They may also be in the form of risk informed land use planning (RILUP) and awareness creation. Van Western et al., (2010) observe that, the former are a structural measure, while the latter measures are non-structural measures. Although structural measures provide some degree of protection, non-structural measures such as RILUP have overtime demonstrated the ability to mitigate residual risk by reducing vulnerability to industrial chemical hazards.

Risk informed land use planning emerged in response to the recognition of vulnerability of the external environment as an integral part of industrial risk management by the European Commission in the Seveso II Declaration. The Seveso II Declaration contends that, proximity of vulnerable populations and sensitive environments to chemical plants or other installations holding hazardous substances, can be highly significant in determining the level of resulting damage, if an accidental release takes place. It is thus, important to separate hazards from people through land use planning (Walker, 1995 as cited in Basta 2009a).

Although traditional land use planning aims at achieving comfort, convenience and health, it generally lacks the capacity to assess risk and therefore requires inter-sectoral support and coordination to develop and infuse risk information into the land use planning process (Greiving & Fleischhauer, 2006). Infusion of risk information into land use planning processes provides a basis for making land use decisions which are based not only on the economic potential of the land but also on the potential risk to users of the land. Broadening the basis for land use decisions to include risk, helps to drive risk reduction strategies that effectively reduce vulnerability and build resilience. The Sendai framework on risk reduction prioritises the assessment and integration of risk information in every facet of human development. To forestall the disastrous consequences of chemical hazards on human development, there is the need to integrate risk assessment into land use planning and development planning in order to reduce risk. Given the possibility of marginalized groups to become more exposed to chemical hazards there is the need to consider efficient use of land while reducing the risk to marginalized populations.

Approaches to risk informed land use planning

The methodological approach to the LUP evaluations differs from country to country. The main difference is in how to assess the compatibility between hazardous establishments and urban surroundings in terms of the variables which are considered for the assessment of compatibility between establishments and surroundings (Basta et al., 2007). In defining a compatible location of a target T with respect to the Effects, it is formalized as:

C1=f (Pe, Efe)

C1=f (Efe), where C1=compatibility of the target T, P=Probability of the event, and Efe=effects of the event.

C1= f (Pe, Me) *V1

C1= f (Me)*V1, where Me=Magnitude of the event, and V1=vulnerability of the target.

Owing to historical, cultural, administrative, legislative and other reasons, the risk assessment methods applied to support land use planning decisions vary significantly. According to (Christou & Papadakis, 1998), the existing methodologies can be divided into the following four categories:

- Deterministic approaches with implicit judgement of risk
- Consequence-based approach
- Risk-based (or probabilistic) approach
- Semi-quantitative approaches

Deterministic approaches with implicit judgement of risk

The most straight-forward approach is to use pre-defined (deterministic) separation distances, the size of which varies according to the type of hazardous substances present in the Seveso establishment (Christou et al., 2011).

These distances derive from implicit judgement of risk, based on the appraisal of typical accident scenarios. The method is based on three elements: first, a target is set for the establishment to operate if possible, without imposing any risk to the population outside the fence. Second, “State of the art” technology is applied at the source and additional safety measures are taken in order to restrict the consequences within the fence should an accident happen. Finally, a “gradual” land-use zoning systems exists, that avoids neighbouring incompatible land uses (i.e., an industrial zone is followed by a mixed zone or agricultural area and not by a residential zone).

Consequence-based approach

The Consequence-based approach is simply an assessment of consequences of credible (or conceivable) accidents, without explicitly quantifying the likelihood of these accidents. This way the approach circumvents having to quantify the frequencies of occurrence of the potential accidents and the related uncertainties. Two distances or zones are defined (Figure 4): An internal zone (Z1) corresponding to the beginning of “lethal effects” where no urban development is allowed, and an external zone (Z2) corresponding to the beginning of “irreversible” effects, where no sensitive population with high densities are allowed (Figure 4).

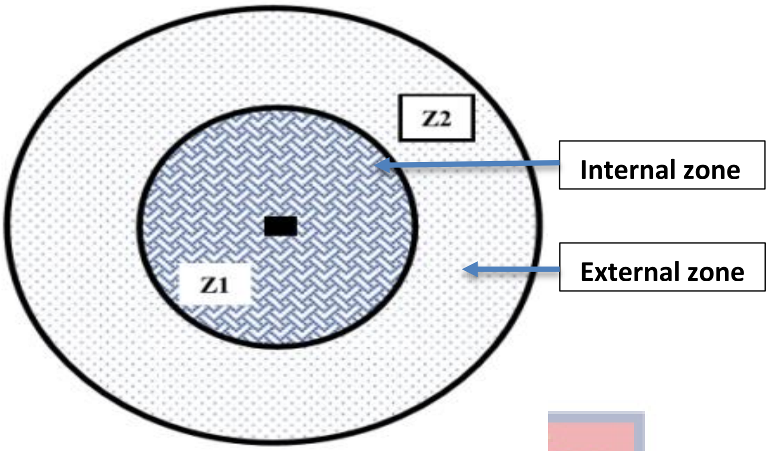

Figure 4: Land use restriction zones: A consequence-based approach
Source: Christou et al, 2011

The basic concept of the consequence-based approach is the existence of one or more worst credible scenarios, which are defined using expert judgement, historical data and qualitative information. The basic idea is that if measures exist sufficient to protect the population from the worst accident, sufficient protection will also be given for any less serious incident.

Risk based (probabilistic) approach

This approach, determines the likelihood of an event's occurrence in addition to determining its consequences. Generally, the risk-based approach begins with identification of the potential hazards. Knowledge of the potential hazard informs decisions to estimate the probability and consequence of the hazards. Next, the impact of the hazard on either an individual or the society is estimated. Finally, decisions are taken after estimated individual and societal risk values are compared with acceptance criteria. The risk criteria, is expressed in terms of probability of injuries or fatalities per location for any given individual within the risk zone. These probabilities are often shown as risk contours or in the form of F-N curves which show fatality rates against probabilities.

After the individual risk contours are estimated the decision on acceptable levels of risk for various types of land use is guided by risk acceptability criteria in the form of probability of injury or fatality thresholds.

Hybrid (Semi-quantitative) approach

This approach is a combination of both the consequence-based and risk-based approaches. Quantitative analysis is accompanied by a qualitative decision-making process. Generally, the risk posed by a hazardous installation to a society is dependent on a number of factors. These factors include the relevant scenarios, their frequency, the kinetics of each scenario, the intensity of the dangerous phenomena, the vulnerability of the area as well as the population affected (Christou & Porter, 1999). In quantitative terms, each of these parameters can be assigned an exact value. Conversely, in semi-quantitative terms, each of these parameters can be described by assigning them a range of values. In the decision-making process, a set of combination rules can be applied to inform the acceptability of a particular risk. The decision is preceded by an analysis of each of the elements (Christou et al., 2011; Török et al., 2019).

With this approach a matrix of risk acceptability approach is used to combine gravity and likelihood of the risks (Török et al., 2019). Gravity levels are classified based on severity and may include categories such as disastrous, catastrophic, major, serious, and moderate (Taveau, 2010) while probability levels are assigned based on hazard frequency.

Various combinations of severity and likelihood are used in demarcating management zones and various risk reduction strategies are then adopted for each of the management zones **(Table 2)**.

Table 2: Matrix for risk acceptability

	LIKELIHOOD				
GRAVITY	E	D	C	B	A
Disastrous					
Catastrophic					
Major					
Serious					
Moderate					

Source: Taveau, 2010

For example, the areas marked in Red, have unacceptable risk and are not recommended for any other development apart from industrial use. For developments in the orange zone, a limit may be used for only land uses which have low population and building densities for example agriculture. The yellow zone represents a tolerable region where general land use types may be placed while the green zone represents a broadly acceptable region where highly vulnerable developments such as nurseries and hospitals may be developed.

Both the consequence and the risk-based approaches utilize the risk management concept of "As Low as Reasonably Practicable" (ALARP).

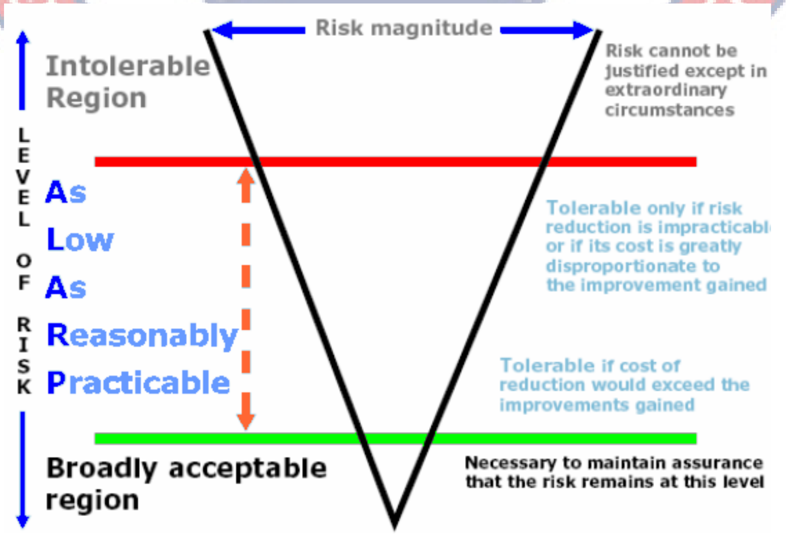

Figure 5: The concept of ALARP
Source: Van Western, 2011

As depicted in Figure 5, the concept of risk criteria is used in the determination of risk acceptability and tolerability. The risk criteria come in three main forms. The first criterion is acceptable risk which is, the type of risk that society considers to be insignificant and adequately controlled (Zhou et al., 2014). The second criterion is tolerable, which is risk that must be tolerated even though it is outside the region of acceptability. Such tolerable risk exists because, further attempts at risk reduction are impracticable and yield insignificant results or produce cost which are greatly disproportionate to improvement gained.

However, efforts must be made to maintain the risk in this region as low as reasonably practicable (ALARP). Thus, there is the need for continuous monitoring to ensure that, risk levels stay within the zone. The third form of the risk criteria is unacceptable risk where the risk levels generally exceed the coping capacity of society and creates serious disruptions to the way society functions.

Theoretical framework

There are debates about the concept of risk as observed by Slovik and Powers (as cited in Williamson & Weyman, 2005). Thompson and Dean (as cited in Williamson & Weyman, 2005) observe that, conceptions of risk lie on a continuum between probabilistic and contextualist models. Thus, realist construe risks as quantifiable and unbiased attributes of the environment which can be deduced through empirical investigation. They depict risk as being composed of hazard probability interacting with the consequences of a hazard and this approach is often viewed as scientific. Contrastingly, a constructionist perspective of risk is relative because it reflects the values and social structure of a divergent society and finds expression through risk perception. Figure 6, shows the different perspectives of risk and the levels of social organization associated with each perspective.

Realism and Rational Actor models of risk:

Within the social sciences, epistemological approaches to risk which are rooted in realism view risk as human behaviours based on the outcome of rational choice. Starr (1969) posited that, individuals' acceptability of risk is contingent on finding an equilibrium between a risk and the benefit derived from that risk. Starr's views have their basis in utilitarian economic theories which emphasize rational decision making using a cost benefit approach.

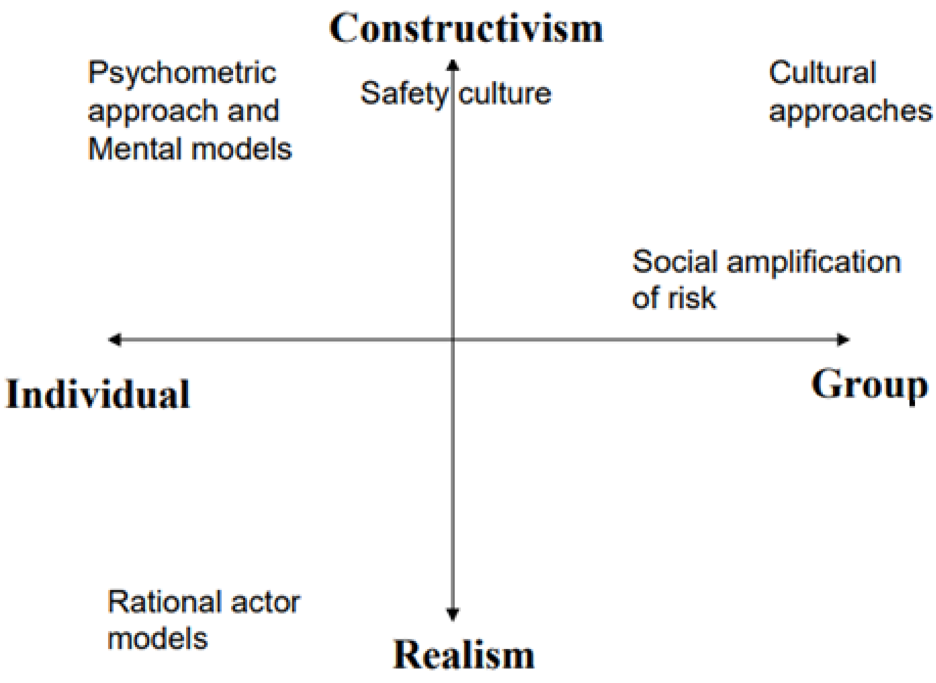

Figure 6: Theoretical Perspectives on risk
Source: Renn (1998)

Rational Actor models

Behavioural decision theory examines risk from an economic perspective where risk taking behaviour is utilitarian and based on rational decision making.

Starr (1969) introduced the concept of 'revealed preferences' where the equilibrium between a risk and the benefit to society reflects the acceptability of that risk. This in essence requires a cost benefit analysis term with respect to the risk behaviour. It has also been observed that non-rational decision making can occur leading to an over estimation or underestimation of risk (Weyman & Kelly, 1999).

Value expectancy theory also utilizes a similar approach to the behavioural decision theory but focuses on the reasons why people are motivated to protect themselves in relation to their understanding of risk and perception of vulnerability. According to Weinstein (1993, as cited in Weyman & Kelly, 1999) the motivation of individuals to protect themselves is based on the perceived likelihood and consequences of an event as well as the desire to minimise the negative consequences of an anticipated event. This often requires weighting the benefits of self-protective behaviour against the costs of such behaviour.

Psychometric paradigm

Psychometric approach to the assessment of risk perception is the most utilized paradigm in risk perception research. It was developed by Fischhoff et al.(1978, as cited in Sjöberg et al., 2004) by utilising questionnaires and factor-analytic procedures to extract a number of primary and secondary dimensions of risk perception.

The assumptions of the psychometric approach are that human risk perception is multidimensional and can be measured by developing scales 'that reflect characteristics of risks that are important in shaping human (risk) perception'. The weakness of this approach is that, the number of dimensions of risk perception extracted in psychometric research differs from researcher to researcher. But the most widely used dimensions are either eight or five (Morgan et al, 1994). The common dimensions usually considered are controllability of risk, voluntariness of risk, severity of risk and novelty of risk. The differences in dimensions have implications for the interpretation of risk. Sjoberg et al., (2004) however assert that, data from the psychometric approach can explain at most 20-25% of the variance of perceived risk and risk tolerance and that the strong explanatory power claimed for the model is based on misleading data analysis.

The basic risk perception model (BRPM) postulated by Sjoberg (1993) is a less well-known alternative to the psychometric approach. It incorporates and expands on the psychometric dimensions and explains more variance in risk perception (Sjöberg, 1998). It does this mainly by adding the factors of attitude, risk sensitivity, and specific fear, and sometimes trust and moral value (Sjöberg, 1998). It would seem that the dimensions extracted in this kind of research are a bit more stable from study to study than those of the psychometric approach. The method used in research on this approach is similar to that of the psychometric, i.e., questionnaires, factor and regression analyses. The samples used are, however, much larger and more representative of the general population. Another important difference is that in the statistical analyses, the individual is used as the unit of analysis, not the mean of responses (Sjöberg, 1992). In this approach the individual is the focus rather than the psychometric factors as used in the psychometric approach.

With cultural theory approach, perceived risk is studied in relation to cultural adherence and social learning. Oltedal et al., (2004) explain that, depending on whether one is socially participating and which groups one belongs to, one will focus on different kinds of risks. By this, it can be said that fear is a choice and that the amount of fear to carry is dependent on the individual. According to Wildavsky and Douglas (1990, as cited in Oltedal et al., 2004) the cultural theory of risk is able to predict and explain what kind of people will perceive which potential hazards will be dangerous. A critic of cultural theory is that it has not produced strong research of high-quality giving support to the hypothesized explanations (Boholm, 1996). Raynes (1992, as cited in Oltedal et al., 2004) and Sjöberg (2004) argue that empirical support for this theory has been surprisingly meagre.

In spite of this difficulty, there is strong recognition of the need for social explanations of risk perception. The Royal Society report (Pidgeon, 1998) concludes that cultural variables play an important part in how people understand risk, and that 'differences in public evaluations of risk might consider the social and cultural context in which those exposed to a risk are located.'

Conceptual framework

A framework on risk management proposed by The European Commission is one of the frameworks which was adopted and later adapted for use by the present research.

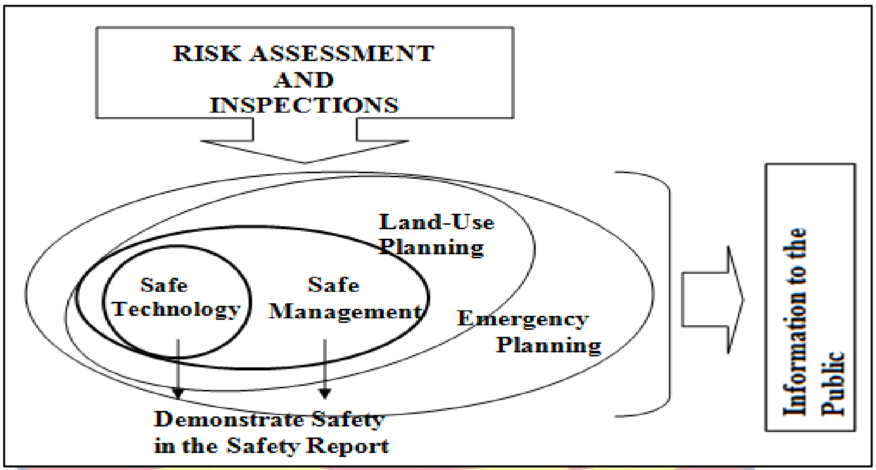

Figure 7: The philosophy of the Seveso II Directive
Source: Adapted from Christou et al., (2006)

The framework utilizes a multi-level safety concept built for the Seveso II Directive which is aimed at the prevention and limitation of major accidents and their consequences. The framework is an improvement on the provisions contained within the SEVESO I directive (Figure 7). According to Christou et al.,(2006), the framework encapsulates the philosophy of the SEVESO II directive which seeks to achieve safety for all persons in the vicinity of a major hazardous installation. It integrates risk assessment, safe technology, safe management, land use planning and emergency response to achieve its objective. Safe technology is enabled through safe management to reduce identified risk and residual risk is addressed through land use planning and emergency response. Feedback is given to the general public. A critique of the model is that, the information to the public is one way with no information from stakeholders feeding back into the process.

A similar framework adopted for the current study is based on work by Sengupta (2016) which addresses the management of major industrial risk (Figure 8). The risk assessment phase also involves two distinct processes of risk estimation and risk evaluation. Risk estimation is a scientific and technical process whereas risk evaluation is a subjective and political process involving the judgement of the significance of risk using risk criteria. The treatment and control of risk also involves the improvement of plant safety and the deployment of offsite safeguards and mitigation measures. Other elements of the risk control are land use planning and emergency response planning. Communication and consultation take place with stakeholders in order to inform the risk assessment and treatment process. Monitoring and review of the process also takes place.

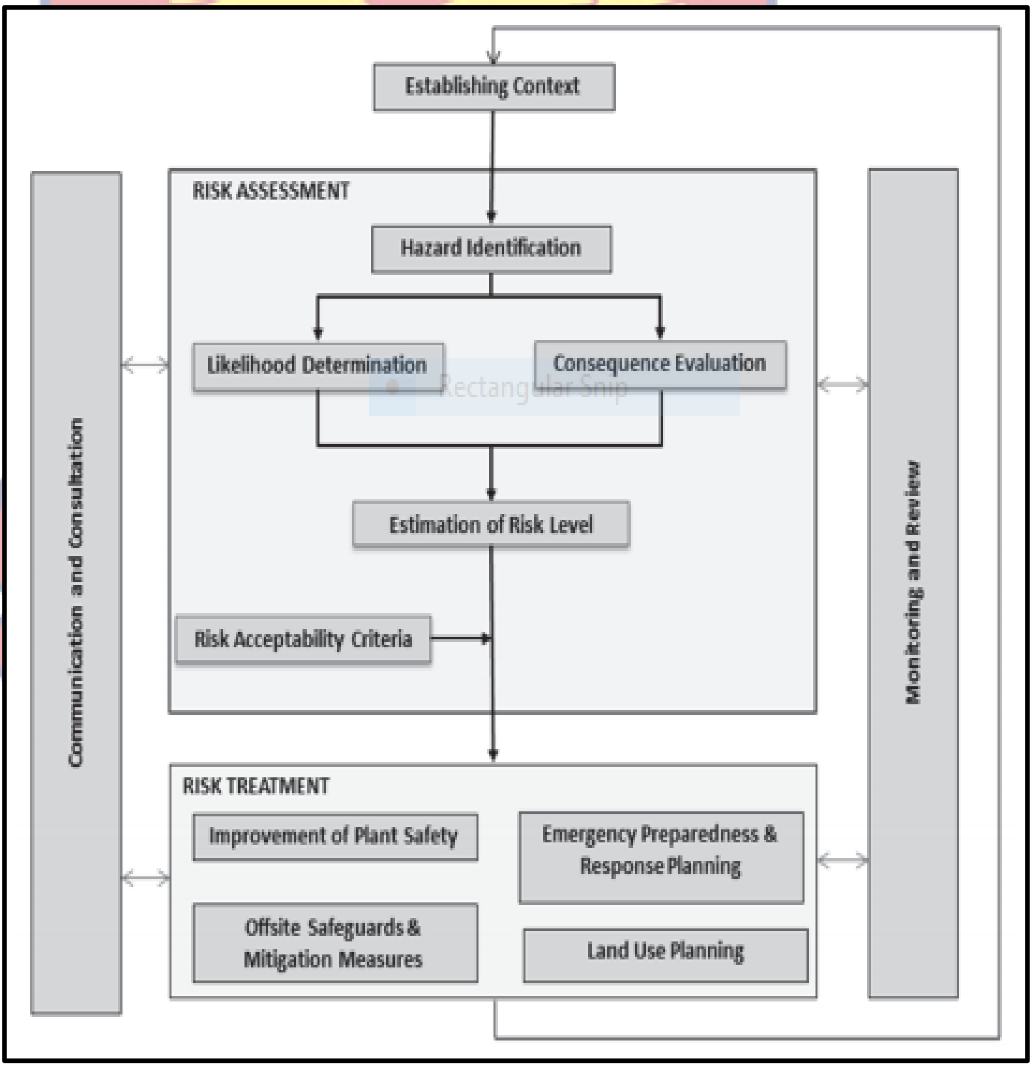

Figure 8: Industrial risk management
Source: Sengupta, 2016

Industrial risk management frameworks adapted for the work

The frameworks by Christou & Papadakis (1998) and Sengupta (2016) on industrial risk management were adapted for the current study. Christou's frame work highlights the philosophy of the SEVESO II declaration on major accident hazard control but has been modified to include two-way risk communication and consultation with stakeholders as shown in Figure 9. The risk treatment and control components of risk management has also been highlighted.

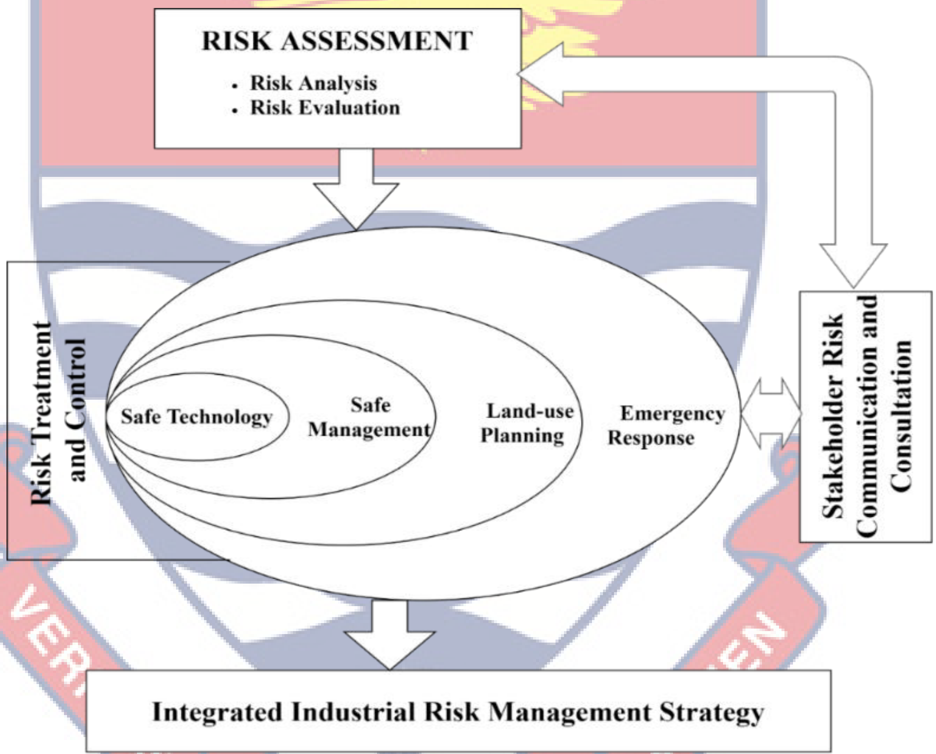

Figure 9: Stakeholder driven risk informed land use planning
Source: Christou (1999)

Sengupta's framework on industrial risk management has been enhanced by incorporating a distinction between the risk analysis and risk evaluation stages of an assessment (Figure 10). The explicit distinction of these two stages allows for focus on risk evaluation as a distinct process which can be addressed through stakeholder risk consultations. The elements within risk treatment and control benefit from the assessment of risk and have been modified to reflect the contributions of cognitive and behavioural risk management strategies which are employed by stakeholders in order to assess and control industrial risk. Behavioural risk control measures reflect positive actions undertaken to control risk and may include efforts to avoid, mitigate, transfer or retain risk. Such measures in the case of industrial risk, may find expression through the application of safe technologies, safe management, risk informed land use planning and emergency response planning. These risk reduction strategies also reflect wholly, the philosophy of the SEVESO II declaration on major accident hazard control. These risk control measures further benefit from a thorough understanding of how institutional arrangements, policies and regulations influence the assessment and control of industrial risk.

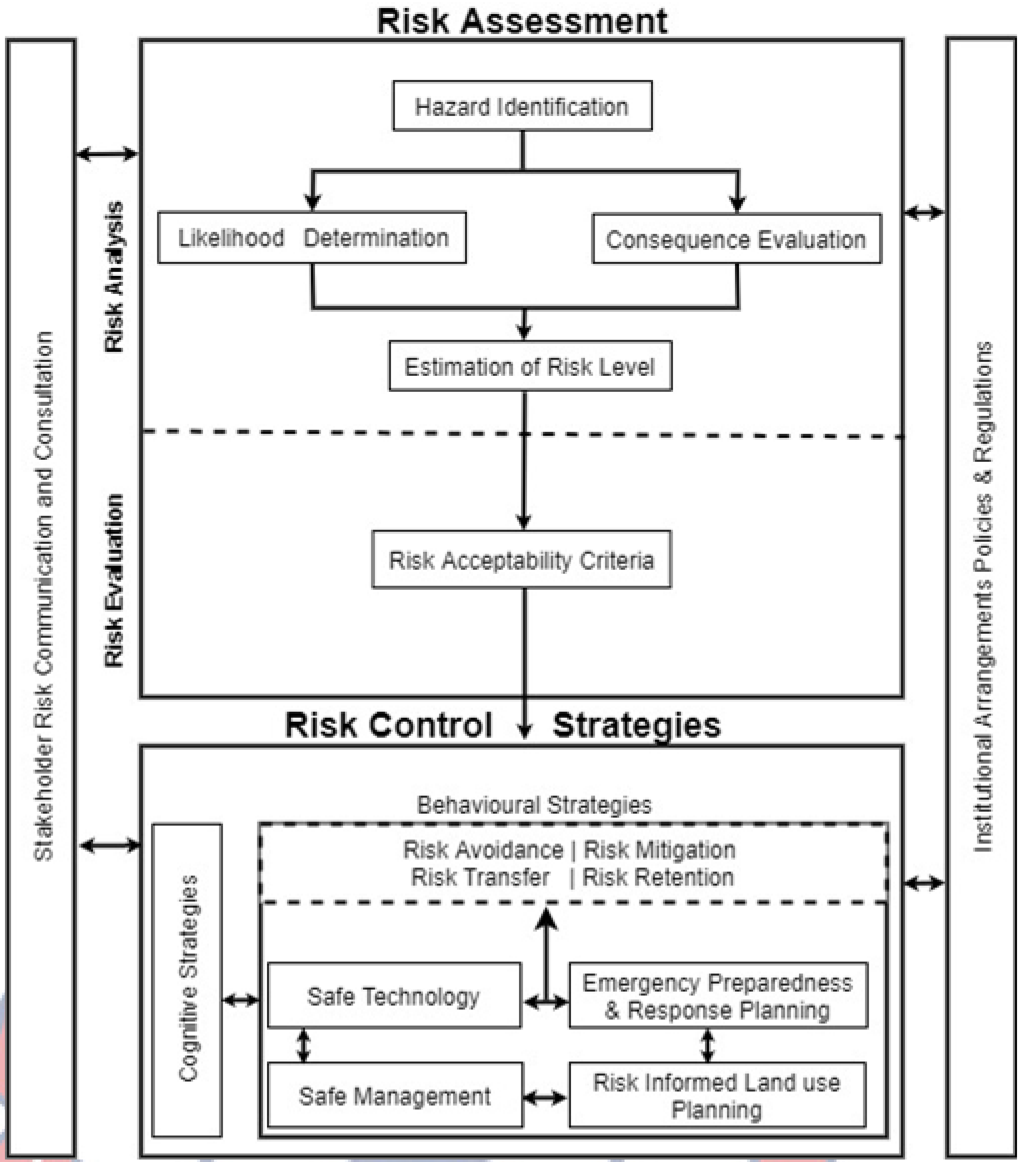

Figure 10: Mitigation of industrial disaster risk
Source: Adapted from Sengupta (2016)

Within the Ghanaian setting, efforts aimed at addressing the risk from LPG stations have primarily focused on introducing safer technologies such as water cooling and deluge systems, automatic gas leak detectors, colour coded vapour and liquid lines, temperature and pressure gauges. Land use planning has however seen less effort because of the already urbanized nature of these environments. Emergency response planning has also seen improvement with contingency plans being developed for counteracting LPG incidents within the metro.

Efforts on safe management have also led to enhanced training on the operation of LPG plants with focus on discharging of LPG products as these have been identified as major causal factors for LPG accidents in Ghana. (EPA, 2007).

Systematic Methods for LPG risk informed Land Use Planning

The Case of United Kingdom

Advices related to toxic releases are performed according to the risk-oriented approach and require a QRA, while in the case of thermal radiation and explosions the consequence-oriented approach is adopted. In the former case, safety distances are assessed against the probability to receive at least a dangerous dose; in the latter one, safety distances are assessed against the receipt of prescribed thermal dose units. The criteria used to determine the likelihood of the two incurring these effects are based on both the individual and the societal risk in the form of a location specific individual risk index (LSIR) and a potential loss of life index (PLL) respectively.

Location specific Individual risk refers to the risk for any individual at a specified location. It refers to a location, and does not refer to any specific person. The risk criterion assumes that an individual (any one, not a specific person) would be at the given location for 24 hours per day, 365 days per year. The basic assumption underlying location specific individual risk is that, it is the risk to members of the public who are present at a given location and who cannot escape from the location, when exposed to the hazard. This assumption may be reasonable for residential areas, but not for other land uses, where the location occupancy would be less than hundred percent or there are vulnerable members of population who cannot escape without assistance (aged care or child care centres, hospitals etc.). In order to accommodate this, the risk criterion is increased for locations with lower occupancy, compared to residential areas, and reduced for sensitive land uses. The risk is still calculated as peak individual risk. Hence, the individual risk (IR) is the total risk from all possible events or incidents that can impact on an individual at a specific location (x, y) from a particular operation. This can be given by:

LSIR (x, y, i) = [Probability of incidence * Conditional Probability of the scenario * Probability of fatality]

Societal risk expresses the relationship between the frequency of a hazard and the number of people suffering from a specified level of harm. Societal risk attempts to address the issue of multiple fatalities or injuries. It is useful in assessing situations where there is a chance that, multiple fatalities from an industrial hazard may occur and where individual risk alone may not be sufficient to adequately represent the situation. For example, it occurs in situations where a large number of people may be exposed for a short period such as in public open spaces or communities, or in transport situations where exposure time is brief and population densities vary along the route. Sengupta (2016) argues that, compared to the LSIR, societal risk becomes can be zero even when LSIR is high due to the absence of people within a specific part of the hazard zone. Cameron and Raman (2012) argue that, the feeling of dread often associated with multiple fatality incidents far exceeds that of single fatality incidents and thus societal perception of risk and risk aversion.

Many different measures exist for computing societal risk. However, for the purposes of this research, societal risk is computed using the Potential

Loss-of-Life (PLL) index. The PLL was selected because it can be mapped to show variations in societal risk across a study area.

PLL is computed as follows.

PLL (x, y) = [IR (x, y)* NP (x, y)]

Where: - PLL(x, y) is the Potential Loss of Life at a geographical location (x,y);

- IR(x, y) is the individual risk at location (x, y);

- NP (x, y) is the number of people at a geographical location (x, y).

In order to maintain a judgmental approach and to evaluate every risky situation in its particular aspects, the calculation of societal risk results from the integration of the individual risk figure with additional population data. The same judgmental approach is applied to define generic precautionary distances in all cases in which a full assessment is not realizable. The risk calculations define "consultation zones", i.e., areas where the risk from a major accident can be relevant and for that reason a full assessment is required before authorizing a certain urban development (Figure 11).

The scope of this successive accurate analysis is the individualization of the "consulting zones", more or less compatible with the presence of more or less vulnerable urban populations. One decisive element of the analysis is the vulnerability analysis, where the population, the buildings and infrastructure (generally: the targets) are classified using specific indicators. Age of residents, their daily permanence inside buildings and structural characteristics of buildings are the main indicators by which four classes of decreasing vulnerability (A, B, C and D) are determined. The deriving evaluation of compatibility can be seen as a full integration of the three variables of frequency, damage and vulnerability. Generally, the three-zone hazard/risk maps and a matrix approach to the zones and to the classification of types of developments allow ready access to Health and Safety Executives methodology by planners. The clarity and transparency of the advice and information from HSE have facilitated the wide acceptance of risk information by Planning Authorities.

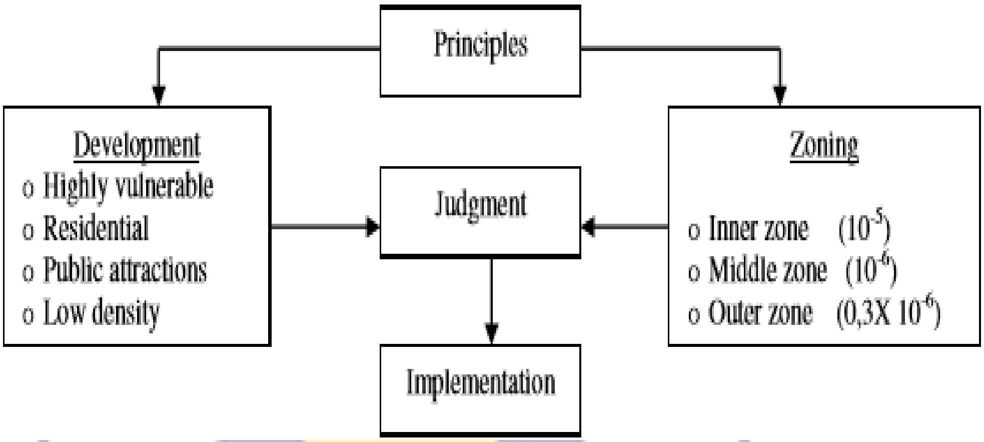

Figure 11: The UK standard method for major accident risk prevention
Source: Christou & Porter, 1999

The decision matrix

The HSE decision matrix which guides land use planning in the hazard zone, considers the consultation zones that land uses fall into and the sensitivity level of the land use. Table 3 summarizes the decision matrix which is applied during land use planning.

Table 3: HSE's Decision Matrix

Level of Sensitivity	Development in inner zone	Development in middle zone	Development in outer zone
1	DAA	DAA	DAA
2	AA	DAA	DAA
3	AA	AA	DAA
4	AA	AA	AA

DAA = **D**o not **A**dvise **A**gainst development
AA = **A**dvise **A**gainst development
Source: UK HSE

From the matrix in Table 3, decisions are moderated by the consultation zone and the sensitivity level of the land use. Decisions may be DAA (**D**o not **A**dvise **A**gainst development or AA (**A**dvise **A**gainst development).

The Case of France

In France, major accidents are described according to three parameters. Probability is assessed against class of probability according to a national scale of five categories from A (> 10-2/year) to E (<10-5/year) (Table 4);

- Intensity (or magnitude): this is determined by calculation of the effect distances, which are assessed against national effects thresholds;
- Severity of effects: this is established assessing the number of potential victims within the mentioned effects distances. The impact is hence classified depending on the number of victims for each type of effect. National regulation provides five categories of effects. Once major accidents are characterized according to probability and impact classes, relevant planning decisions are taken according to a national acceptability matrix. "NON" areas are areas for which the risk is deemed too high: the installation cannot be authorized in its current state. Blank areas are acceptable areas for which authorization can be given. An intermediate area ("MMR" areas) are the areas in which authorization is given after verification that cost-acceptable risk control measures have been put in place.

Table 4: The French risk matrix

	LIKELIHOOD				
GRAVITY	A	B	C	D	E
Disastrous	NON	NON	NON	NON	MMR
Catastrophic	NON	NON	NON	MMR	MMR
Major	NON	NON	MMR	MMR	MMR
Serious	NON	MMR	MMR		
Moderate	MMR				

Source: Christou & Porter, 1999

A set of zoning principles are also set out in the national PPRT guide. Principles are related to the alert (*Fr. aléas*) levels, which are derived from the combination of severity and cumulative probability. Local Authorities elaborate technological risk prevention plans (PPRT), which are basically limiting the areas within which restrictions can be imposed on existing and future buildings, among which the expropriation of existing buildings and constructions in the areas exposed to very hazardous risks can be regarded as the most innovative introduction of the recent policy developments. The severity of accidents is classified according to national endpoint values. In this regard, the French approach is based on binding thresholds, which in no case can be exceeded.

The Case of Germany

The German Guidance "SFK/TAA-GS-1" gives recommendations for separation distances between establishments under the German Major Accidents Ordinance (Germ. *Störfall Verordnung*) and areas requiring protection within the framework of Land-Use Planning. The policies according to Article 12, paragraph 1 of the Seveso II Directive is defined in Germany in the mentioned Federal Building Code (Germ. *BauGB*) together with the associated Federal Land Use Ordinance (Germ. *BauNVO*) and in Section 50 of the Federal Pollution Protection Act (Germ. *BImSchG*). The consideration of appropriate separation distances should enable the effects of major accidents in establishments on neighbouring sensitive objects to be avoided as far as possible. The separation distance recommendations are only related to people as the subject to be protected, they are not suitable for the assessment of current mixed situations (existing buildings), for the licensing procedure under "*BImSchG"* or as the basis for the external emergency planning.

German major accident policy and legislation have, up until now, only considered a deterministic approach which is "consequence based"; furthermore, establishments which fall under the requirements of the Seveso II Directive are required to be designed and operated according to the "state of the art in safety technology". The application of this principle should imply that the risks of effects of an accident outside of the establishment are negligible. In exceptional cases different tools are applied. The general used "consequence – based" approach refers to pre-selected "worst credible" or "representative" scenarios. With respect to fertilizers (ammonium nitrate) and explosives generic approaches are occasionally used, while in the case of LPG applicable standard scenarios (like the BLEVE) are adopted. In any case, the evaluation that moves from the 'worst credible scenario" is based on:

- the maximum permitted amount of substance, its temperature and pressure, and
- the vulnerability of the surrounding environment.

Regarding the effects, the criteria adopted to define the compatibility are:

- Injuries or fatalities of a large number of people,

- Material damage, and
- Individual/societal risk (only in exceptional cases).

The SFK/TAA-Recommendations are guidance and the prescribed endpoints should be considered as target-criteria. The application is left to the individual State which, where justified, may adopt other values. The tolerability of risks under the German Major Accident Ordinance is governed by the concept that “establishments may only carry out their hazardous activities if they are able to demonstrate that hazardous effects from an accident may be reasonably excluded”. This is based on technical regulation and expert judgments.

The Case of Ghana

Assessment and management of industrial risk in Ghana within the context of the downstream petrochemical has been the responsibility of a number of institutions including the following: Land use and Spatial Planning Authority; Ghana National Fire Service (GNFS); The Environmental Protection Agency; Ghana Civil Aviation Authority; Ghana Water Company; Electricity company and with the National Petroleum and Authority which acts as the principal investigator. These agencies operate through an inter-agency advisory committee which provides deterministic buffer distances and other guidelines for the assessment of industrial risk. The Deterministic distances are based on are generic separation distances derived from the emergency response guide (US Department of Transport, 2020) and similar publications. These separation distances are documented by the National Petroleum Authority in their Guidelines for the installation and management of LPG filling Stations (NPA, 2015). The separation distances are varied and include the following: the separation distance between neighbouring stations which has oscillated between minimum of 300 meters and a maximum of 1 kilometre over the years); separation distances between stations and public places such as churches (100 to 500 meters over the years and separation from hot works and naked flames (30 - 200 meters). The specified distances are used by all members of the inter-agency committee in assessing and regulating risk. The zoning status of a potential development is also cross checked to ensure that it complies with industrial zoning regulations as specified in the zoning guidelines (Ministry Of Environment Science And Technology & Department of Town And Country Planning, 2011). The environmental protection agency and the GNFS also conduct checks waste management and occupational health and safety requirements. Subsequent to this, the relevant local government agency will consider the application during meetings by the statutory planning committee meetings in order to approve or disapprove the development.

In 2019, the inter-agency committee conducted a qualitative risk assessment which took into consideration the siting, engineering materials and fabrication, equipment conditions, safety management systems, staff and facility management, materials and fabrication of the LPG stations. Each of the five categories accounted for 20% of the total score and facilities that scored below 40% were regarded as low risk. Facilities which scored 40 to 60% were regarded as medium risk and those which scored greater than 60% were regarded as high risk facilities. Furthermore, a 20 ton limit was placed on the quantity of LPG that could be stored on site. This represented a more comprehensive approach to the assessment of LPG risk. However, the focus was still on the industrial facilities and as yet the deterministic separation distances and zoning compliance remain the major criteria for making decisions on the approval of developments around industrial sites (Armah, 2020).

Chapter summary

The existing literature on risk assessment and land use planning is relevant to the current research in a number of ways. Firstly, it informed the choice of BLEVE's and Jet fire from bulk road vehicles as hazard scenarios. According to Tauseef and Abaasi (2010), BLEVEs are the most catastrophic type of LPG fire hazard because they generate super-heated fireballs, blast overpressure and missiles all of which are leading causes of fatality. Jet fires from bulk road vehicles are also the most frequent causes of LPG fire hazards in Ghana. According to the EPA and NPA (2020) over 90% of all LPG fire hazard incidents involved Jet fires. In addition, due to their focused nature, Jet fires also produce very intense streams of thermal radiation that is able to cause severe damage where vulnerable elements exist. Secondly, the literature influenced the consequence and probabilistic risk assessment methodologies employed for the current study. It emerged that, consequence and probabilistic approaches to risk informed land use planning offer safety benefits which are superior to the deterministic approach currently used in Ghana. Unlike the uniform deterministic approach, consequence and probabilistic approaches offer safety managers vulnerability and risk information which address worst case or most probable scenarios which are well tailored to specific site conditions. The literature also informed the study's adoption of the UK health and safety executives risk informed land use planning methodology over that of other countries. The UK HSE risk methodology combines the superior safety benefits of consequence and probabilistic risk assessments with the sensitivity levels of different land uses to inform land use planning decisions and is applicable to Ghana with some degree of modifications. The approach by countries such as the Netherlands and France also offer safety benefits but are methodologically more difficult to implement. The literature also provides a suitable conceptual frame work which is used as basis for discussing the role of stakeholders and regulatory frameworks in risk informed land use planning.

CHAPTER THREE

RESEARCH METHODS

Introduction

This chapter outlines the methodology employed in this study. After a brief description of the study area, the study examines the research philosophy, research design, target population, sampling, data collection instruments, and analysis and ethical considerations. The outline of the study area provides a descriptive account of Greater Accra from its geographic location, population, and development. The research philosophy explains the research paradigm adopted and its influence on the research design. The target population gives an account of the people the study envisaged to interview while the sampling dealt with the calculation used to arrive at the target population covered in the field exercises. Data collection instruments employed in soliciting information from the sampled population and other observatory data are also discussed while the methods used in modelling the LPG fire hazards are also explained. Lastly, the chapter gives an account of the ethical issues related to the study.

Study area

The study focused on spatial land use with regards to the sitting of liquefied Petroleum Gas stations in the Accra Metropolitan Assembly. Accra Metropolitan Assembly (AMA) lies on latitude 5^0 32' 59.99" N and longitude 0^0 12' 60.00" E. It is bounded to the north by Ga West Municipal, east by Ga South Municipal, west by La Dadekotopon Municipal and south by the Gulf of Guinea (Figure 12). The area was first established in 1877 to serve as the national capital for the Gold Coast and subsequently for Ghana (Spio, 2011). The metropolis has a total area of one hundred and thirty-nine square kilometres (139.694 km^2).

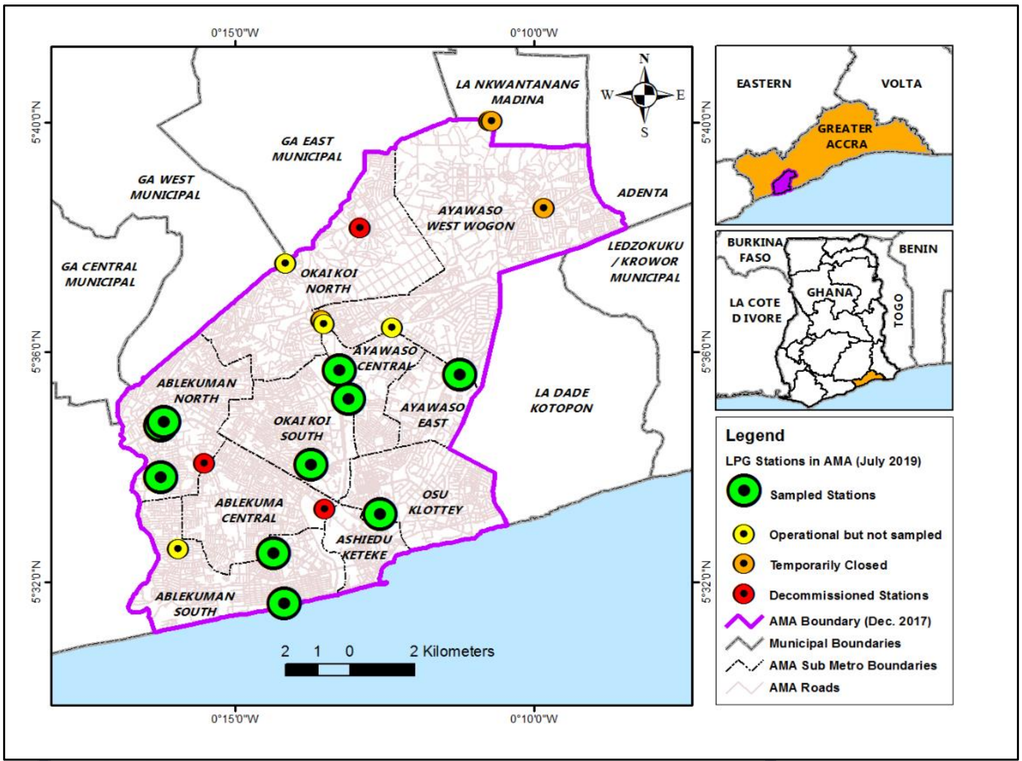

Figure 12: Map of Accra Metropolitan Area
Source: Authors Construct, 2019

As at December 2017, the metropolis had 10 sub-metropolitan areas namely Ablekuma South, Ablekuma Central, Ablekuma North, Aseidu Keteke, Osu Klottey, Okai Koi South, Okai North, Ayawaso Central, Ayawaso East and Ayawaso West. The metropolis previously had more sub-metropolitan areas including Tema, La Dade Kotopon, Ledzokuku Krowor, among others. But as these sub-metropolises increased in population, they broke away to form independent districts.

Climate

The study area is within the dry equatorial climatic zone of Ghana. It has a bi-modal rainfall (April to July and September to November) and a dry season from December to February within the year. The average annual rainfall for the metro is between 787mm and 1200mm (Ghana Meteorological Agency, 2018). June is the month with the most rain with an average precipitation of 193mm. It also has the highest number of rainfall days spanning more than 10 days while January has least rainfall of 16mm with an average of one day of rainfall. The harmattan months of January to mid-April have maximum temperatures averaging 32^{0}C as compared to July, June and August. Relative humidity in the area is very high, averaging 75% to 85% (Ghana Meteorological Agency, 2018).

Drainage

The metropolis is drained by four catchments; namely, Densu, Korle-Chemu, Kpeshie and Songo-Mokwe catchment (Accra Metropolitan Assembly, 2006). Densu catchment is the biggest in the metropolis located in the western and south-west part of the metro. It encompasses the Weija dam, communities such as Mallam, Dansoman, Kwashieman, McCarthy Hill, Mpoase and parts of Awoshie. Densu is the major river in the catchment with Pompon, Kuia, Adaiso and Dobro as tributaries. Korle- Chemu is drained by Odaw, Onyasia, Dakobi and Ado rivers with the popular Korle and parts of the Chemu Lagoon. Rivers in the metropolis have their endpoint into lagoons which have a closed-end to the sea.

Relief and Geology

The average altitude of Accra is 20 meters with very few areas reaching a height of 70 meters. The metropolis is underlined by two geological types from different eras. The lower part of the metro (thus about 5km inland from the sea) is of predominantly sandstones, grit and shale of the Accraian (Mid-Devonian) era (Minerals Commission Ghana, 2011). These geology types explain sediment deposition effects of rivers in the area which allows easy infiltration and formation of aquifers and high-water tables. High water tables are contributory and enhancing agents in the formation of floods with little rainfall. Phylitte, quartz and schist geologies are dominant the upper part of the metropolis and are of the Dahomeyan era. The western part of the metropolis is characterised by plinthosols which have low depth and are comprised of deposits from the Densu River. The rest of the metropolis has an acrisol soil type.

Vegetation

Accra lies within two vegetative covers of Ghana, the strand/mangrove and coastal grassland. The strand/mangrove is found close to the sea and it moves inland to about 2.5 km. This vegetation type is usually confined to borders of lagoons and rivers in the metro. Patches of grass and shrubs form the larger vegetation cover, lacking any major dense vegetation. This cover is highly influenced by the combination of temperature, rainfall, geology and soil types in the study area. Unfortunately, a large part of the shrubs and patches have all been cut for physical development.

Population

In terms of population, Accra Metropolis host about 1,665,086 people living within the metropolis per the World Population Review (World Population Review, 2021). Out of this figure, the males constitute 48.1%, while the females dominate with 51.9%. The metropolis keeps attracting thousands of migrants from all parts of the country. It is currently estimated that the population of AMA grows by 2.14% annually since the 2010 population census (World Population Review, 2021). The Ghana Statistical Service has therefore projected the population of the metropolis at 2 million with a commuting population of about 4 million on a daily basis.

Socio-Economic Activities

The high number of commuting populations in the study area can be attributed to the fact that, Accra Metropolitan Area serves as the main socio-economic centre of Ghana. The metropolis is dotted with several major businesses from service providers, manufacturing, oil companies, financial institutions, and telecommunication, tourism, education and health institutions serviced by an intricate network of roads (Abane, 2011). Its strategic location, large population, availability of governmental offices and financial sectors makes it the most preferred for business and migrants. In addition, the pool of vibrant economic activities, population/market, closeness to Tema harbour and refinery have propelled the growth and development of several LPG gas stations in the metropolis. The current number of LPG stations in the metropolis is about 15 all sited within heavily developed residential and commercial zones. Yirenkyi (2017) have written about the hazards of citing fuel service and Gas filling stations in heavily populated areas as that tends to expose the vulnerable populations to the risk severe thermal radiation, blast overpressure which may result in injuries and fatalities.

Study design

Philosophy

The study adopted the pragmatist philosophy in explaining the concept of industrial risk and its implications for land use planning. According to Pierce (as cited in Legg & Hookway, 2019), pragmatism offers at once loyalty to facts and adherence to tough-minded epistemic standards without limiting the adoption of subjective world views to which the tender-minded may aspire. Therefore in the quest for answers on mitigation of industrial risk through land use planning, it is pertinent to recognize that while traditional approaches to risk-informed land use planning are essentially the product of empirical and logical processes, the concept of risk has highly subjective components as recognized by Kasperson et al., (1988). Therefore, subjective construction of risk and risk adaptations would also be required to lay to rest the unending arguments of how much industrial risk exist from LPG sites in the city of Accra and what should be the land use planning implications of the identified risk. Both positivist and interpretivist ontologies would have significant roles to play in explaining the concept of disaster risk given that, risk has deeply embedded roots in probability theory and is also subjectively constructed through social and cultural norms.

Pragmatism aims at clarifying the concepts based on their consequences as such, this research would benefit from the pragmatist viewpoint by also viewing the implications of risk to individuals and society as the attribute that brings clarity to the concept of industrial risk. This would enable a higher ('third') grade of clarity to how the concept is employed in practice(Legg & Hookway, 2019). A pragmatist's viewpoint would also promote a more democratic but factual view of reality which would be imperative for any attempt at prescribing a solution to the intractable problem of industrial LPG fire hazards in urban areas.

Following from the pragmatist research philosophy a variation of the mixed method sequential explanatory research design was adopted for the study. According to Creswell (2013), mixed-method sequential explanatory research designs firstly employ quantitative research techniques to objectively inquire on a problem and then follow up with qualitative methods while providing other interpretive approaches to expatiate on issues identified by the quantitative techniques. The adoption of mixed-method is based on the complementary role qualitative and quantitative methods play. Creswell et al., (2004) argue that, the logic for mixing qualitative and quantitative is that, neither is sufficient in themselves to capture the trends and details.

The first phase of this study addresses the issue of LPG risk from a purely realist perspective and thus utilises a risk-based approach to model the extent of vulnerability of land uses and human populations to potential LPG fire hazards. The second phase involves both a combined quantitative and qualitative evaluation of vulnerability to LPG fire hazards using data from a cross-sectional survey and in-depth interviews. This phase also explores risk management strategies of vulnerable persons living or working within potential LPG fire hazard zones.

The quantitative method applied in the risk assessment was undertaken with the goal of providing an objective way of capturing the nature of the risk to individuals residing or working within the potential hazard zone of the LPG filling stations while the cross-sectional survey and qualitative inquiry deepened knowledge on the nature of the risk through the collective experiences of stakeholders who provided a means to reconcile implications of the risk with the nature of the risk itself. Stakeholder perceptions of risks and the reality they represent are mutually reinforcing and full of inferences that cannot be separated from the external world (Legg & Hookway, 2019)

Target population

The target population of the study included individual LPG filling stations within the Accra Metro as well as residents and working populations within the hazard zone of LPG filling stations. Physical Planners, officers from the Ghana Fire Service, the Environmental Protection Agency, the Factories Inspectorate Division, the National Petroleum Authority, and the Land Use and Spatial Planning Authority were also included in the study's target group of regulators and managers of LPG stations. The unit of analyses for the risk assessment was land use in the vicinity of LPG filling stations and individual respondents within the potential hazard zone of the LPG sites.

Sampling

Sampling of subjects was in multiple stages. The sampling frame for the LPG sites within the study area was 15 active LPG filling stations. The fifteen stations were put into four spatial clusters. The clustering of the stations was to address the potential domino effect that a fire at one station could have on neighbouring stations thereby multiplying the effects and consequences. Three out of the four clusters were randomly selected for the study. The three clusters selected for the risk assessment had a total of 10 LPG stations which were representative of LPG stations in the AMA and were thus, included in the study. The combined population of the 10 sites was estimated from the 2010 population and housing census to be 141,194 for Jet fire hazard zones and 321,120 for BLEVE hazard zones (GSS, 2010). For the cross-sectional survey of persons living and working within the hazard zone of the 10 LPG sites, the required sample size for the study was established using Cochran’s (1977) formula for sampling from known populations

$$ss = \frac{Z^2 pq}{e^2} \quad \text{Where } q = (1\text{-}p)$$

$$ss = \frac{1.96^2\,(0.5(1-0.5))}{0.4^2}$$

$$ss = \frac{(3.8416(0.5)(0.5))}{0.05^2}$$

$$ss = \frac{(3.8416(0.25))}{0.0016}$$

$$n = 600$$

$$\frac{ss}{1 + \frac{ss - 1}{population}}$$

$$new\ sample = \frac{600}{1 + \frac{600 - 1}{321{,}120}}$$

=599

Cochran's formula establishes the sample size based on confidence levels and confidence intervals or margins of error and the population size. The confidence interval specifies the certainty of the results whiles the margin of error shows the range within which the results may lie. In the formula, (n) is the desired sample size and (z) is the z score of the confidence level which in this case was set at 1.96 for the 95% confidence level. The proportion of the population with the desired characteristic is represented by (p) and was set at 50% since this was also unknown. A margin of error of 4% was adopted for the study.

Furthermore, the correction for a finite population was applied where the larger BLEVE population was used. A sample size of 599 was derived and this was rounded up to the nearest 100 to arrive at a sample size of 600. The sample size of 600 was equally allocated to the 10 LPG stations selected earlier in the study thus, 60 respondents were randomly sampled from each site by visiting 60 randomly selected structures and interviewing the first adult encountered. An equal number of respondents were selected from each to facilitate comparism. Based on the modelled magnitude of the thermal radiation from potential LPG fire hazards, a potentially lethal zone where the magnitude of the thermal radiation exceeded $10kw/m^2$ and a non-lethal zone with thermal radiation below $10kw/m^2$ was established following Croce & Mudan (1986). The division facilitated the expression of the hazard potential and also provided a basis for equally dividing the sixty respondents between these two zones. The equal division of the sample population for each selected LPG station into lethal and non-lethal zones was to understand the influence of proximity on risk perception.

For the qualitative study, 33 people were purposively sampled. These included ten (10) operators of LPG filling stations and three (3) regulators from the National Petroleum Authority, Environmental Protection Agency and the Land Use and Spatial Planning Authority. Twenty (20) opinion leaders two (2) from each site were also selected and separately interviewed.

Data collection and instruments

Data used for this study were derived from both primary and secondary data sources. For each LPG filling station, the exact location of the station was obtained using GPS receivers. Additionally, the number of LPG tanks and their dimensions, capacity, type of chemical stored as well as data on environmental factors such as landscape type, type of buildings in the vicinity were all obtained using checklists. The land use types and intensity of use within the limits of potential LPG fire hazard zones were also obtained using GPS field surveys and hard copy aerial images of the areas in question. Secondary data on meteorological conditions such as temperature, relative humidity, and wind speed and wind direction were obtained from the Ghana Meteorological Agency. Failure frequency data for BLEVE and Jet fires was adopted from the UK Health and Safety Executive (2017). For BLEVE hazards a value of 1×10^{-5} was selected while 1×10^{-6} was used for Jet fires.

Following the collection of data for the hazard and physical vulnerability assessment, risk perceptions and management strategies of stakeholders were solicited from people living and working within the modelled LPG fire hazard zones with the help of a questionnaire. The questionnaires were digitally/electronically deployed on smartphones with the help of KobotoolBox software. The questionnaire was structured into four sections. The first section collected data on the socio-demographic characteristics of the respondents. The second section covered the dimensions of perceived risk comprising economic, social, health, environment and security issues. The third section of the instrument contained factors influencing perceived risk while the fourth and final section covered risk management strategies of stakeholders. In addition, the data was supported by interviews undertaken with managers of LPG filling stations and regulators who included the National Petroleum Authority and the Land Use and Spatial Planning Authority.

The interview guide for the LPG operators and persons within the vicinity of the station, sought to find out how much LPG fire risk each of these stakeholders perceived and what their risk management strategies were. It was for the purpose of extending the initial survey and providing further information on risk within the hazard zone around the LPG station. In the case of the regulators, emphasis was on risk management strategies being applied to halt LPG fire hazards and the specific role of land use planning in this process.

Data processing and analysis

Data processing and analysis was undertaken for each objective of the study. The connections between each of the major components of the analysis are provided in Figure 13.

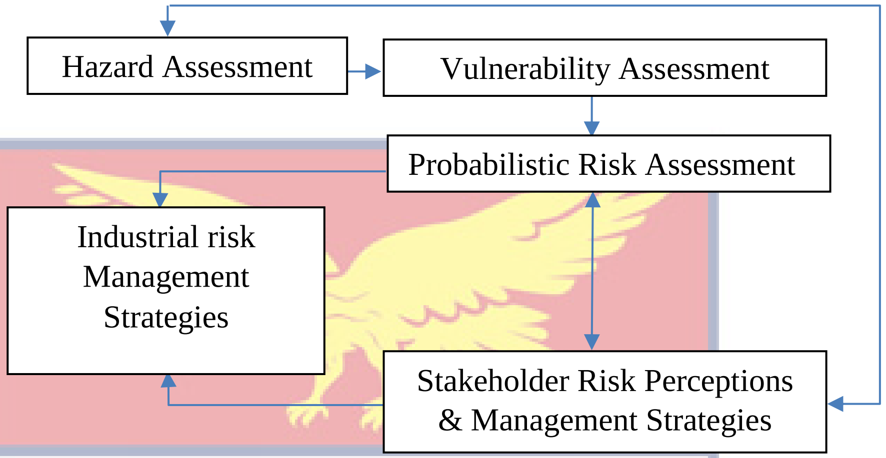

Figure 13: Flow chart of the analytical process
Source: Authors construct, 2020

Objective one sought to model the characteristics of the magnitude and spatial extent of potential LPG fire hazards and the distribution of land uses in the hazard zones. The dense gas dispersion model [DEGADIS] (Havens & Spicer, 1985) and selected fire models from the American Institute of Chemical Engineers(1994) and Chamberlain (1987), embedded within the Areal Locations of Hazardous Atmospheres (ALOHA) version 5.43 software from the United States Environmental Protection Agency was used to model the spatial extent and thermal radiation loads for both BLEVE's and Jet fires. Meteorological conditions used for the modelling were averaged from November to February to obtain a dry season estimated mean as fire were more likely to spread under such dry conditions.

Levels of concern (hazard thresholds) used in the hazard analysis, were adopted from the work of Croce & Mudan (1986) where 60 seconds of exposure to LPG fire hazards produces thermal radiation loads between 2.1 and 5 kW/m^2 cause pain and between 5.1 and 10 kW/m^2 cause 2nd degree burns and greater than 10 kW/m^2 can be lethal. Endpoint distances, fireball radius, for the three hazard thresholds as well as burn rate levels were estimated. In order to obtain an areal distribution of the levels of thermal radiation within the hazard zone, the hazard thresholds were generated at 1 kW/m^2 intervals and these were exported into KMZ format using Marplot version 5.11. The hazard thresholds in the form of vector polygon were processed into point data within the ArcGIS Pro version 2.6 Platform using Python 3x code. The point estimates representing the thermal hazard thresholds were then interpolated after log transformation using Empirical Bayesian Kriging interpolation functions with the De-Trended K-Bessel semi-variogram model. This data was then transferred to the land use data through the use of a spatial join and averaging function in the ArcGIS Pro platform as mean thermal radiation per land use (I).

Objective two utilized a consequence-based approach and GIS functions to assess vulnerability to LPG fire hazards. The duration of exposure (t) was computed for each land use type in all the 10 LPG sites. For the BLEVE hazard, the duration of exposure was equal to the burn duration of the hazard due to the relatively short durations of BLEVE hazards. For Jet fire hazards, the time of exposure was computed as the time to reach a safe zone which was equated to the minimum distance from a given location to a building with at floor space of least $10m^2$. To achieve this, the system of equations elicited from Baixos. et al., (1992a) were applied in the ArcGIS Pro using python code.

$\Delta t = (t_r + t_v)$...........Equation (1)

Where,

Δ t: Total exposure duration

u: Escape speed [m/s](=4m/s)

t_r: reaction time [s](=5s)

x : Escape distance (Shortest distance to buildings with minimum floor space of 10m^2)

t_v: escape time $= \frac{x}{u}$

Secondly, in fulfilment of objective two, thermal dose units (TDU) were also calculated for each land use type and for all 10 LPG sites using the previously estimated total exposure duration (Δ t) and the mean thermal radiation per land use (I) as shown in Equation 2. TDU is a measure of exposure to thermal radiation and it provides an indication of the levels of vulnerability of individuals exposed to LPG fire hazards (Spouge, 1999).

Thermal Dose Unit (TDU) = I (KW/m^2) $^{4/3}$ * t………………… Equation (2)

- where (I) is the intensity of thermal radiation
- and (Δ t) is the duration of exposure to thermal radiation.

The thermal dose units were interpreted using recommended values from DNV / Statoil (2001 as cited in HSE - U.K. Health and Safety Executive., 2010) as shown in Table 5.

Table 5: Thermal dose units and its effects on human beings

Effect	Thermal dose ($s*[kW/m^2]^{4/3}$)	Comments
Pain	108 – 127 85 - 129	bare skin
Significant injury Level/First degree burns	600 - 800 250 – 350 210 – 700	bare skin
Second degree burns/ 1% lethality level for average clothing	900 – 1300 500 – 3000	bare skin
Third degree burns/ 50% lethality level for average clothing	2000 – 3000	bare skin

Source: DNV / Statoil, 2001

One-way Analysis of variance test available in SPSS was used to examine differences in TDU values for each land use type. The effect of proximity on TDU values was also analysed. Table 5 shows a list of critical TDU values for estimating vulnerability.

Additionally, statistical models in the form of Probit functions as depicted in Equation 3 were used to determine the relationship between thermal radiation from LPG fires and the expected fatalities within the general population. The Probit models require only the TDU as a parameter.

Y= -12.8 + 2.56 ln (TDU)……… Fatality: Equation (3) Tsao & Perry (1979)

Where,

- Y= Probit value
- TDU = Thermal dose units

The Probit equation on lethality was adopted from the Probit function proposed by Tsao & Perry (1979 as cited in HSE - U.K. Health and Safety Executive., 2010) to provide a pessimistic estimation of vulnerability in line with the philosophy of consequence-based risk.

The levels of vulnerability per land use were assessed using consequence-based risk criteria from the HSE - UK Health and Safety executive (2015). Land use planning decisions were either advised against or not advised against based on the criteria. Sensitivity analysis was also conducted to detect changes in the vulnerability levels for each land use. This was done by making changes to the sensitivity levels of some land use types.

The third objective was achieved by the use of a probabilistic risk approach and criteria also from the HSE-UK Health and Safety Executive (HSE - U.K. Health and Safety Executive., 2010b, 2015) to assess levels of risk per land use. Specifically, individual risk in the form of a location specific individual risk (LSIR) index were computed according to the formula and definitions by Ale (2002), Cameron and Raman (2005) and Sengupta, (2016) The LSIR was estimated by multiplying the frequency of the BLEVE and Jet fire hazard scenarios by the probability of their consequence (Probit values) as shown in Equation 4.

LSIR (x, y, i) = [Probability of incidence * Conditional Probability of the scenario * Probability of fatality (Probit value)]………. Equation (4)

The land uses were then categorized into four classes of sensitivity according to the UK Health and Safety Executives' classification scheme. Land use types were evaluated based on their given LSIR values and their land use sensitivity and their PLL values. The decision was limited to "advice against" or "do not advice against" based on the existing criteria.

The fourth and fifth objectives of the study which covered the risk perceptions and risk management strategies of individuals collated during the cross-sectional survey and in-depth interviews, provided deeper insight into the issue of vulnerability to LPG fire hazards and the role land use planning plays in managing the risk. To achieve this, the survey data was initially processed to correct for logical inconsistencies and the reliability of the instrument was also checked using the Cronbach's alpha statistic. Descriptive statistics were run in the IBM Statistical Software Package SPSS version 25 to provide an overview of respondents' socio demographic characteristics. Owing to the multidimensional nature of the perceived risk, factor analysis was performed on the data after the Kaiser Meyer Olkin, Bartlett test of Sphericity and the Cronbach Alpha test all gave an indication of the suitability of the data for dimension reduction. Inferential statistics specifically, binary logistic regression analysis was performed on the reduced dimensions to determine the functional relationship between factors such as proximity, socio-economic status, property ownership, etc to determine their influence on each dimension of risk perception. The odds ratios for each of these variables was reported. This was done in order to provide additional insight into the vulnerability to LPG fire hazards. The risk management strategies for personal and non-personal risk management strategies were also statistically analysed.

For non-personal risk, frequency and bar charts were used while non-personal risk was factor analysed to derive dimensions of non-personal risk management strategies. Chi-square tests were also used to determine if significant association existed between perceived risk and choice of risk and risk management strategy.

Qualitative risk perceptions derived through in-depth interviews were also transcribed and analysed thematically in order to extend the insights gained on risk perception of respondents. The themes covered included their risk management practices and the specific roles land use planning plays in reducing risk. Verbal quotations from the themes were used to support descriptive and inferential results from the earlier questionnaire survey.

Ethical considerations

Ethical considerations were taken into account before embarking on the data collection in order not to cause discomfort to respondents. The first ethical issue considered before administering any of the instruments used in the study was to obtain the consent of respondents. The purpose of the research was explained and consent of each respondent and consent obtained before administering the instrument. Selected respondents who declined to answer any of the instruments used in this research either from the onset or midway were given the opportunity to gracefully exit and where partial data sets had been accumulated, these were subsequently discarded and the respondent was replaced.

Also, the research considered the anonymity of respondents where all respondents were given unique identifiers rather than names. This was to prevent the direct tracing of responses to respondents. Officials of LPG stations were given the opportunity to consent to data collection on their operations. In most instances copies of the researcher's introductory letter were accepted and filed in the company records. Additionally, each respondent was interviewed alone without the presence of other people who could potentially influence responses. In a few cases where this was not possible, the researcher stressed on the need for the respondent to answer questions without prior consultations and only responses from the selected respondents were recorded.

Chapter summary

The chapter describes the methodology employed in achieving the objectives set by this thesis. The chapter was grouped into explaining the study area, research designs, target population, sampling approach, data collection techniques, data analysis and ethical issues considered before the work was undertaken. The study area placed Accra Metropolis into context by describing its geographic location, administrative areas, and physical conditions including climate, landform and drainage. It also explained the socio-economic dimensions of the study area and the proliferation of LPG stations. The research employed a pragmatist philosophy which informed the adoption of a mixed sequential explanatory where both qualitative and quantitative approaches were used in data collection and analysis. The target population comprised LPG filling stations and persons living and working at and around LPG stations as well as regulators from Land Use and Spatial Planning Authority and the National Petroleum Authority.

A statistically relevant sample was generated after applying a mathematical formula to the population and with the help of questionnaires and observation checklist and interview guides, data were collected from the sampled population. Lastly, LPG hazard zone modelling was undertaken with field data where vulnerability and risk to human populations from potential LPG fire hazards were estimated using Geographic Information Systems and statistical models. Subjective views of risk were also derived from the survey and interviews to explain issues raised. Risk management strategies were also analysed with a focus on how land use planning can be utilized as a risk reducing measure. Finally, the chapter explained the ethical issues considered.

CHAPTER FOUR

CHARACTERISTICS OF LIQUEFIED PETROLEUM GAS FIRE HAZARDS IN THE ACCRA METROPOLIS

Introduction

This chapter models two common types of LPG fire hazard which have occurred in Ghana using data from LPG stations in the Accra Metropolitan Area. The hazards modelled were boiling liquid evaporating vapour explosions (BLEVE) and Jet fires. The data used in modelling these fire hazards included LPG chemical data, infrastructure data, meteorological data and environmental data. The two main types of fire hazards are compared across the ten LPG sites using parameters such as magnitudes of their thermal load in the event of an accident and the endpoint distances for critical thermal thresholds. The effect of distance on the thermal loads at all 10 locations are also examined.

Site, storage situation and weather conditions at LPG Stations

The study identified 15 active LPG stations in Accra metropolitan area. Out of this number 10 were selected and used for the study. The stations were located in: Alajo, Avenor, Awudome, Dansoman, Chorkor, Kawkudi, Mamprobi, Odorkor and Tudu (Figure 14).

All of these communities had one LPG station except Odorkor which had two.

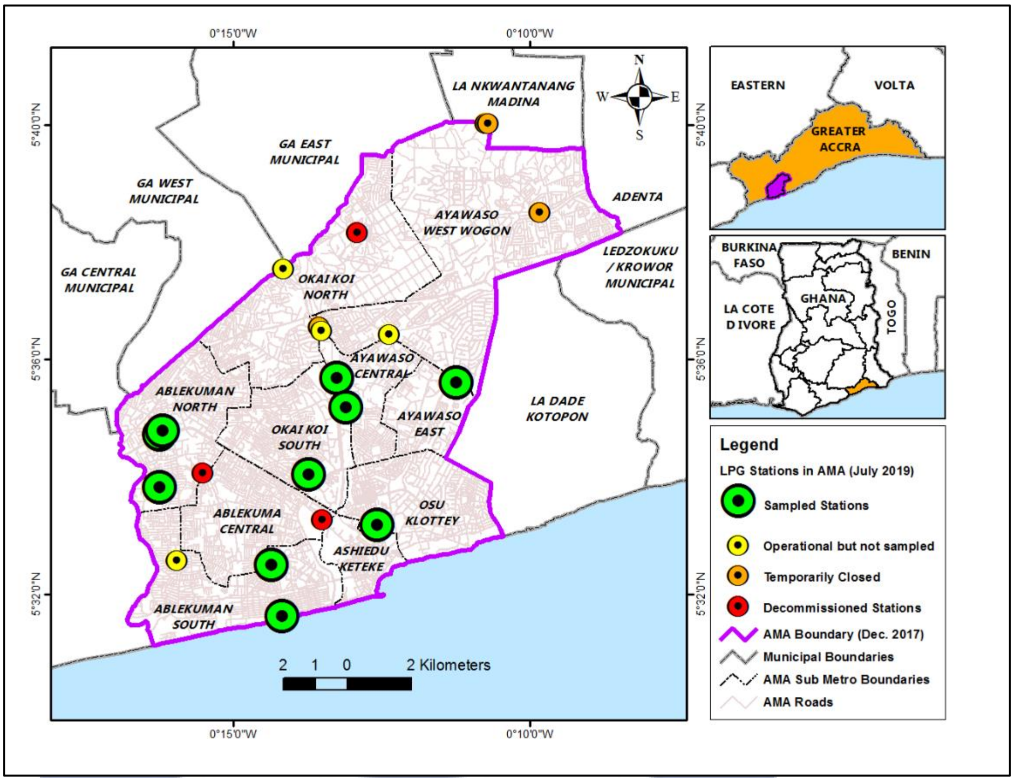

Figure 14: Spatial distribution of LPG stations in Accra Metropolis
Source: Field work, 2019

In Ghana LPG is a mixture composed primarily of propane and butane in the proportion of 20% propane and 80% butane. In the Accra Metro, majority of the stations stored their LPG product in pressurized cylindrical vessels of various capacities mounted on concrete pillars. The LPG stations had different tank dimensions and storage capacities (Table 6).

For the dimension, the minimum length was 7.3m for the Chorkor and Awudome LPG stations and a maximum length of 16.1 for the Avenor LPG station (Table 6). In terms of width the range was between 1.8m and 2.4m in diameter. The capacity of LPG vessels in the study area ranged from a low of 8.79 tonnes to a high of 23.4 tonnes. The mean tank capacity was 16.9 tonnes with five LPG stations (Chorkor, Alajo, Dansoman, Odorkor A and Tudu) having their tanks below this level. The Kawkudi LPG station had the largest tank size of 23.4 tonnes.

Table 6: Tank capacity of LPG vessel at the sampled stations

Location	Length(M)	Diameter(M)	85% of Tank Capacity (Metric Tons)
Chorkor	7.3	1.8	8.79
Alajo	10.9	1.8	13.2
Dansoman	8.2	2.1	13.5
Odorkor A	8.5	2.1	14
Tudu	10.0	2.1	16.4
Odorkor B	11.9	2.1	19.4
Avenor	16.1	1.8	19.5
Awudome	7.3	2.7	19.8
Mamprobi	9.7	2.4	20.8
Kawkudi	10.9	2.4	23.4
Total	-	-	**168.79**

Source: Field work, 2019

The meteorological conditions used in modelling the LPG fire hazards were averaged from a three-year period spanning 2016-2018 (GMET, 2018). The parameters averaged included wind speed, wind direction, atmospheric temperature, relative humidity and cloud cover (Table 7). Data for only the dry season (November – February) was used as fires were most likely to spread faster due to the dry conditions which prevail during that period.

Wind speed averaged 3.7 meters/second which on the Beaufort scale represents a light to gentle breeze. Wind direction was primarily south and mean monthly temperature was 29°c. Relative humidity was 76% whiles cloud cover was approximately 32% (Table 7).

Table 7: Meteorological conditions used for modelling LPG fire hazards

Meteorological Variables		Average dry season
	2016	3.9
Wind speed (m/s)	2017	3.3
	2018	3.9
Average		3.7
	2016	190.4
Wind direction (°)	2017	100.6
	2018	220.4
Average		170.5
	2016	29.5
Mean Monthly Temperature (°c)	2017	28.8
	2018	29.2
Average		29.2
	2016	72.3
Relative humidity %	2017	79.0
	2018	78.5
Average		76.6
Cloud cover %		32%

Source: Ghana Meteorological Agency, 2019

Simulation of LPG BLEVE hazards in the Accra Metropolis

A BLEVE hazard was simulated for the 10 LPG stations using parameters outlined in Tables 1 and 2. The BLEVE scenario was modelled with parameters similar to the catastrophic LPG BLEVE incident which occurred on 7th October, 2017. The percentage of Tank Mass in Fireball is modelled as 100%.

Burn duration and magnitude of LPG BLEVE hazards

The BLEVE hazards recorded burn durations of between 9 and 11 seconds. Alajo, Chorkor and Dansoman recorded burn durations of 9 seconds while Kawkudi and Mamprobi recorded burn durations of 11 seconds. The magnitude of the thermal radiation emitted from the LPG hazards varied by the type of LPG hazard. For BLEVE hazards, the highest magnitude of thermal radiation was 96.2 kW/m^2 and this was recorded at Tudu. Chorkor had the lowest peak thermal radiation of 80.2 kW/m^2. Avenor had the highest mean thermal radiation of 23.8 kW/m^2 compared to Awudome, Mamprobi, Odorkor A and Odorkor B and Tudu all of which had a mean thermal radiation of 5.3 kW/m^2 (Table 8).

Table 8: Magnitude of thermal radiation from BLEVE hazards

Location	Burn Duration	Minimum	Maximum	Mean	Std Deviation
Alajo	9	1.0	88.1	5.5	10.8
Avenor	10	1.0	89.4	23.8	21.0
Awudome	10	1.0	90.6	5.3	11.1
Chorkor	9	1.0	80.2	6.5	13.1
Dansoman	9	1.0	92.1	5.4	11.1
Kawkudi	11	1.0	89.2	5.8	11.4
Mamprobi	11	1.0	90.1	5.3	11.0
Odorkor A	10	1.0	95.2	5.3	11.1
Odorkor B	10	1.0	96.2	5.3	11.0
Tudu	10	1.0	94.4	5.3	11.1

Source: Field work, 2019

Endpoint distances and areal extent for the simulated BLEVE hazard

End point distances for thermal radiation emanating from BLEVE hazards are presented in this section. The endpoint distances indicate the distance at which four critical thermal thresholds are exceeded. The thresholds include a fireball diameter, 10 kw/m^2, 5 kw/m^2 and 2 kw/m^2 thermal thresholds.

After a 60 second exposure, the greater than 10 kW/m^2 thermal loads is known to cause fatalities, while the 5.1 - 10 kW/m^2 cause 2nd degree burns after the same period. The 2.1 - 5 kw/m^2 also causes pain after 60 seconds whiles up to 2 kw/m^2 is generally considered safe. The fire ball diameter has the highest record of thermal radiation in the region of 96 kW/m^2 and is a significant indicator of lethality. Chorkor had the smallest diameter of 116 whilst Kawkudi had 161 meters. Avenor, Awudome, Odorkor B and Mamprobi all had fireball diameters above the mean fireball diameter of 143 meters. A Kruskal Wallis test indicated that, there were statistically significant differences in the recorded diameters of fireballs across the 10 LPG Stations $\chi 2$ (9, n = 75) = 74, p =0 .001.

The relationship between fireball diameter and tank volume was investigated using Spearman's rho correlation coefficient due to the skewed nature of the fireball diameters. The result showed a strong, positive correlation between the two variables, r = 0.996, n = 75, $p < 0.001$, with high tank volumes being strongly associated with large fireball diameters.

Chorkor had the shortest endpoint distance of 257 meters as measured from the location of the LPG vessel. The initial 116 meters of this distance places an individual within the fireball radius of the BLEVE hazard. Kawkudi recorded the farthest endpoint distance of 350 meters for the 10 KW thermal threshold. For the 5kW threshold, Chorkor again had the least endpoint distance of 363 meters from the station whilst Kawkudi recorded an endpoint distance of 495 meters. The 2kW threshold also ended at a minimum distance of 565 meters and a maximum distance of 770 meters (Table 4). The areal extent of the BLEVE hazards varied from location to location.

Chorkor had the smallest BLEVE hazard zone approximately 6.8% of the total BLEVE hazard area compared to Kawkudi which had approximately twice the area (13.1%) of the Chorkor hazard zone (Table 9).

Table 9: End endpoint distances for BLEVE of stationary LPG vessel

Location	Fireball Diameter	10kw/m^2	5kw/m^2	2 kw/m^2	Tank Capacity (85% -Mt. Tonnes)
Chorkor	116	257	363	565	8.79
Alajo	133	292	413	643	13.2
Dansoman	134	294	416	647	13.5
Odorkor A	135	298	420	655	14
Tudu	143	313	442	688	16.4
Odorkor B	151	330	466	726	19.4
Avenor	151	331	467	727	19.5
Awudome	152	332	469	730	19.8
Mamprobi	154	338	476	742	20.8
Kawkudi	161	350	495	770	23.4
Average	143	313	443	689	

Source: Field work, 2019

A pictorial representation of the mean and maximum endpoint distances and their relationship with the required separation distances between LPG stations and hot works and LPG stations and public places is shown in Figure 2.

In the diagram, the minimum and maximum fireball radii are contained within the required separation distance for hot works and public places which are 200 and 500 meters respectively (Figure 15).

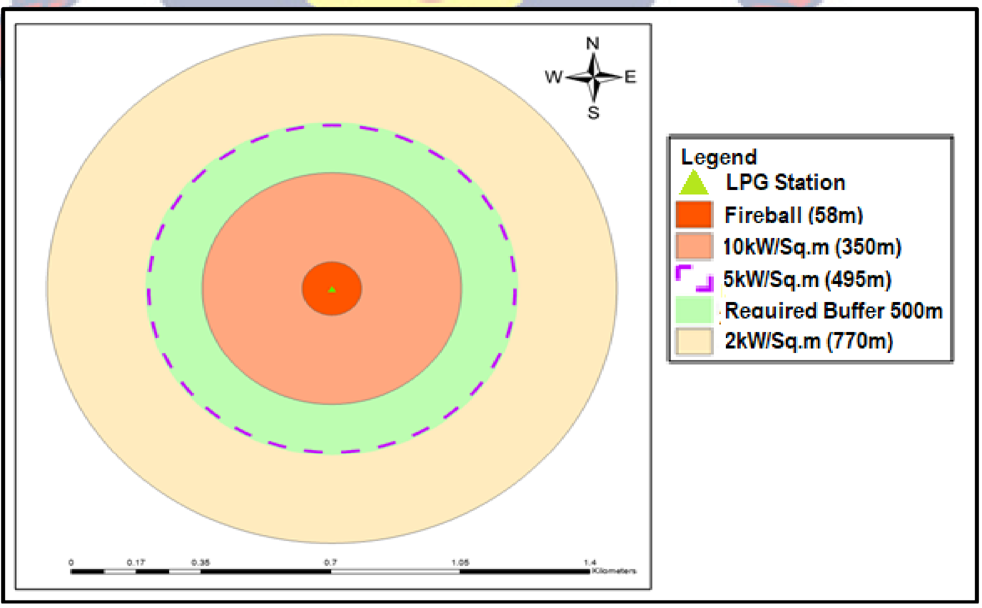

Figure 15: BLEVE hazard endpoint distances and the 500-meter required separation distance.
Source: Field work, 2019

Odorkor B, Avenor, and Mamprobi had hazard zones which were 1.6 times larger than that of Chorkor (Table 10). For Kawkudi, the area of the fire ball was twice that of Chorkor however, for the 10 kW/m^2 zone, Mamprobi had the largest area. Within the 5 kW/m^2 area, Kawkudi again recorded the largest area of approximately 38.5 hectares. The same pattern was repeated for the 2kW zone. Proportionally, at Chorkor, the fireball hazard zone has the smallest areal coverage whilst the 10,5,2 kW/m^2 hazard zones are about 17.9,18.7 and 53.5 times larger than the fireball zone respectively. For Kawkudi, the 10kW, 5kW, 2kW and 1 kW hazard zones were 15.2, 19.3, 54.6 and 96.9 times larger than the fireball zone respectively (Table 10).

Table 10: Areal extent of BLEVE hazard zones in Accra Metro.

LOCATION	FIRE BALL	10KW	5KW	2KW	1KW	Total	%
Chorkor	1.1	19.7	20.6	58.8	94.2	194.4	6.8
Alajo	1.4	23.6	24.5	67.5	101.8	218.8	7.7
Dansoman	1.4	25.7	27.2	77.1	123.4	254.9	9.0
Odorkor A	1.4	26.4	27.5	79.3	125.9	260.5	9.2
Tudu	1.6	29.2	30.6	87.3	139.5	288.1	10.1
Odorkor B	1.8	32.4	34.0	97.3	148.5	313.9	11.0
Avenor	1.8	32.6	34.1	97.5	148.0	313.9	11.0
Awudome	1.8	32.8	34.5	98.2	146.6	313.9	11.0
Mamprobi	1.9	34.0	35.3	101.7	141.1	313.9	11.0
Kawkudi	2.0	30.3	38.5	109.2	193.7	373.8	13.1
Total	16.2	286.7	306.6	874.0	1362.8	2846.3	100.0

Source: Field work, 2019

Relationship between distance and thermal radiation: BLEVE hazards.

It was observed that, distance from the LPG station had an inverse relationship with the magnitude of thermal radiation from the LPG hazard. For BLEVE hazards, a unit increase in distance from the station resulted in a decrease of between 0.391 and 0.664 kW/m^2 as shown in Table 11.

Table 11: Thermal loads and distance from BLEVE hazards.

Location	Coefficient (β) Thermal Radiation (kW/m^2)	Std. Error	t-value	P-value	R^2
Alajo	-0.468	0.000	-2364.223	0.000	0.95
Avenor	-0.664	0.001	-519.565	0.000	0.98
Awudome	-0.417	0.000	-2473.005	0.000	0.94
Chorkor	-0.532	0.000	-1634.926	0.000	0.95
Dansoman	-0.481	0.000	-2276.820	0.000	0.94
Kawkudi	-0.391	0.000	-2578.728	0.000	0.94
Mamprobi	-0.410	0.000	-2552.440	0.000	0.94
Odorkor A	-0.468	0.000	-2207.716	0.000	0.93
Odorkor B	-0.420	0.000	-2491.664	0.000	0.94
Tudu	-0.445	0.000	-2325.682	0.000	0.94

Source: Field work, 2019

Distance from the LPG stations explained between 93 and 98% of the variation in thermal radiation for BLEVE hazards.

As shown in Figure 16, for the Chorkor LPG Station, at a distance of zero meters, the thermal radiation was approximately 80.2 kW/m^2. Again, for Chorkor, at distances of 100,200, 300 and 500 meters the thermal radiation levels were 49, 17, 8.9 and 1.25 kW/m^2 whiles Odorkor B recorded 51.7, 22.5, 11.3 and 2.54 kw/m^2 *for* the same distances.

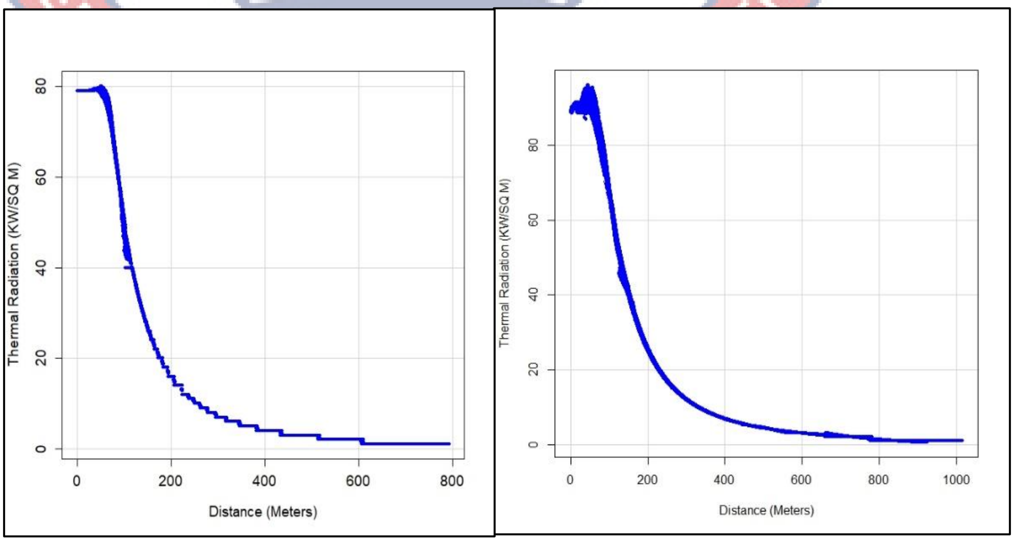

Figure 16: Thermal radiation loads per distance at the Chorkor and Odorkor B LPG station.
Source: Field work, 2019

Simulation of Jet fire from bulk road vehicle

A Jet fire from a bulk road vehicle with vessel capacity 1709 cubic feet (48,393.5 litres) of LPG contained in an 8-foot diameter and 40-feet length tank was simulated. The Jet fire is modelled as a result of instantaneous ignition of LPG gas which escapes from a 1-foot manhole found on most LPG bulk road tankers This scenario may occur as a result poorly secured or missing manhole cover bolt as occurred in the Louis Gas station disaster which claimed 12 lives in December 2016 near the Trade fair site in Accra.

Burn duration and magnitude of thermal radiation for a simulated LPG Jet fire hazard

The simulated Jet fire lasted for a total of 40 seconds with a maximum burn rate of about 1,360 kilograms/sec. The Jet fire emitted a flame with a maximum length of approximately 153 meters (502 feet) and the total amount of gas burned in the Jet fire was 22,329 kilograms. The deficit of 3.67 tons would burn as a pool fire. The thermal radiation for Jet hazards ranged from a minimum of 1 to a maximum of 63.4 kW/m^2. Twenty-five percent (25%) of the thermal load was 1 kW or lower while 50% of the values were 2.1 kW/m^2 or lower. The mean value of 3.89 was higher than the median giving an indication of a positively skewed distribution.

Flame Length, Endpoint distances and Areal extent for the Jet fire hazards.

The flame length reported for the Jet fire was 153 meters and the maximum amount of thermal radiation was 63 kW/m^2. End point distances for the 10 kW/m^2 threshold was 204 meters (669.2 feet). The 5-kW threshold extended to 299 meters (981 feet) while the 2 kW/m^2 threshold ended at 471 meters (1545.2 feet).

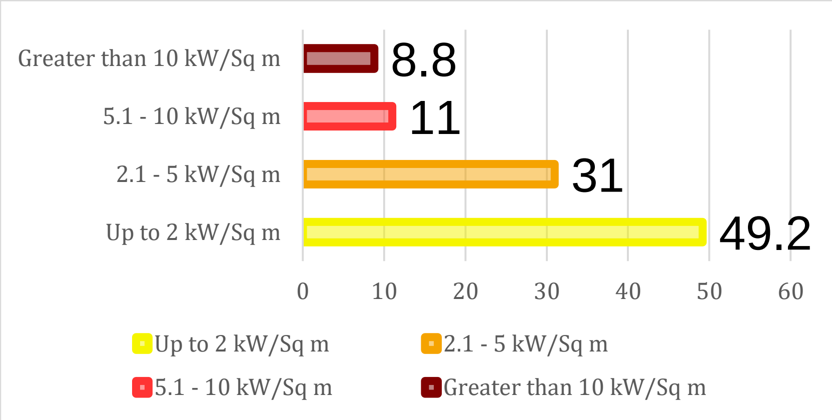

Figure 17: Areal extent for Jet fire hazards in the Accra Metro.
Source: Field work, 2019

The greater than 10 kW/m^2 hazard threshold covered the smallest and inner-most portion of the hazard zone. It accounted for less than 9% of the area influenced by the simulated Jet fire. At 11%, the 5.1 to 10 kW/m^2 hazard threshold occupied a slightly larger area portion of the hazard zone immediately adjacent to the 10 kW/m^2 hazard zone (Figure 17). Thermal radiation in the range of 2.1 to 5 kW/m^2 hazard threshold covered approximately 3-times the area of the initial zones.

It was also observed that a 1-meter increase in distance from the Jet fire will lead to a decrease of 0.269 kW/m^2 in thermal load.

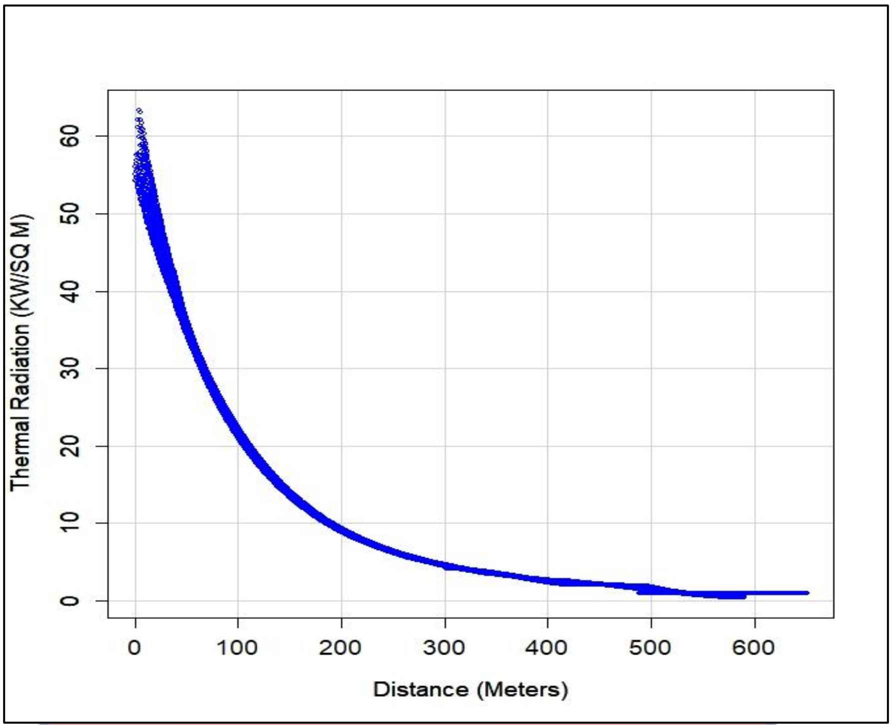

Figure 18: Thermal radiation from Jet fires relative to distance
Source: Field work, 2019

As shown in Figure 18, at a distance of zero meters from the LPG station, a thermal radiation value of over 60 kW/m^2 was obtained. At 100, 200, 300 and 500 meters, thermal radiation values of 23, 9.4 5.6 and 1 kW/m^2 were recorded.

Land use patterns and proximity to the BLEVE hazard zones.

The land use patterns within the various BLEVE hazard zones indicated that, the industrial base within the hazard zone was small compared to other land uses. Hazard zones which were nearer the LPG station had a larger industrial base than those further away from the station. This partly occurs because of encroachment on industrial land uses (Figure 19).

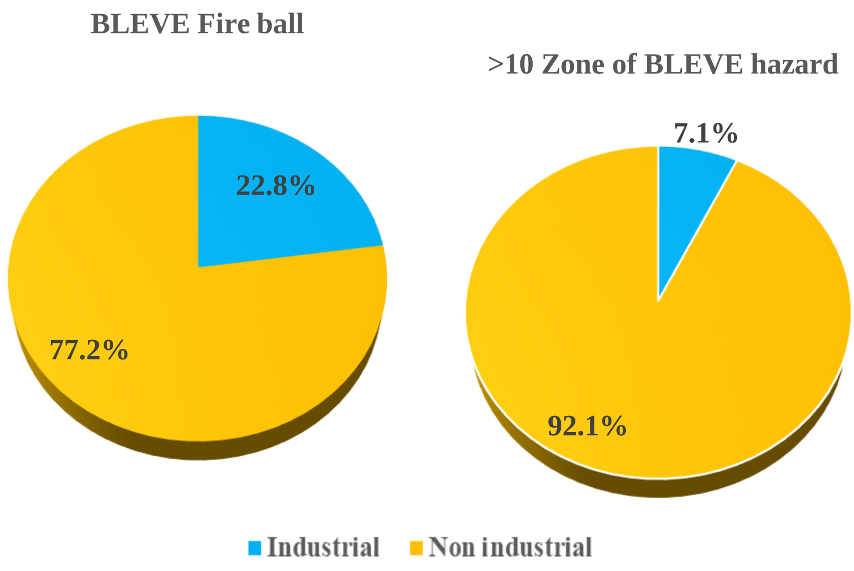

Figure 19: Industrial versus non-industrial land uses in the BLEVE hazard zone
Source: Field work, 2019

A disturbing observation was that, about 31.4% of the total land area in the fireball radii of potential BLEVE hazards was occupied by mixed use (commercial/residential – 15.8%), residential (10%) and commercial land uses (7.5%) part of which were virtually at the centre of the fireball (Appendix A). For the > 10 kW/m^2 hazard zone, the land use patterns were also similar to the other zone where land uses other than industrial dominated the zone (Figure 19). In the case of the 5.1 to 10 kW/m^2 hazard zone, land uses other than industrial again dominated the zone (Appendix A).

In some locations, the 5 to 10 kW/m2 hazard zone had land uses such residential, transport and vacant lands being as close as 250 meters to an LPG station (Appendix A) and Plate 6.

Plate 7: Conflicting Land use patterns in the Odorkor LPG hazard zones. Source: Fieldwork, 2019

For the 2.1 to 5 kW/m^2 zone, the same pattern emerged with industrial land uses accounting for only 7.3% of the space in this zone. Altogether, these land uses, were 345 meters to an LPG station (Appendix A). In the 1-2 kW/m^2 safe zone, industrial uses were slightly higher but did not dominate the zone. The community services, industrial, mixed us, residential, transport and utilities in this zone were approximately 513-515 meters away from the nearest LPG station (Appendix A). For Jet fires, industrial land uses also formed a comparatively smaller portion land area. Approximately 82.8% of all uses in the Jet fire hazard comprised non-industrial uses at varying distances to LPG stations (Appendix B) and Figure 20 and Plate 7.

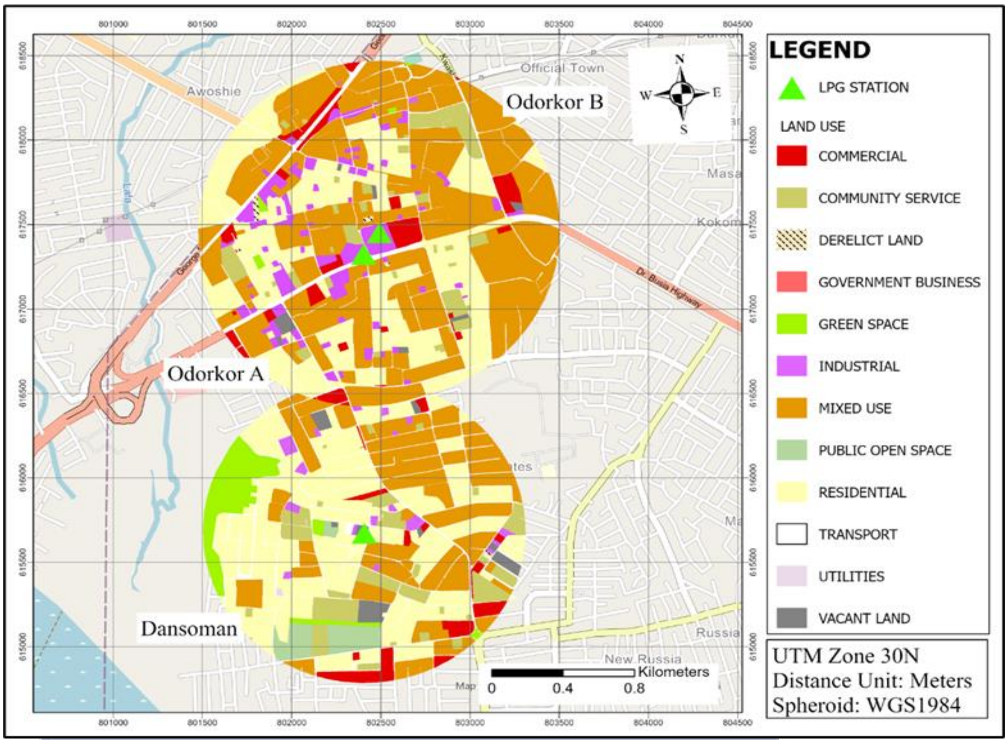

Figure 20: Land use patterns in the LPG hazard zone.
Source: Fieldwork, 2019

Plate 8: Conflicting Land use patterns at Avenor, Accra.
Source: Fieldwork, 2019

Discussion

Although the burn durations for both BLEVE and Jet fire hazards were under 1 minute, their durations were well within acceptable limits as indicated by the American Institute of Chemical Engineers (2010). Birk (1996) also asserts that, BLEVE hazards are usually of short duration lasting between only 10-15 seconds. Thus, the burn duration of the simulated BLEVE hazards which ranged between 9 and 11 seconds was not abnormal. The duration of the Jet fire hazard, at 40 seconds, was higher than that of the BLEVE. This was expected as Pitblado (2011), has argued that, Jet fires tend to have a longer duration period compared to BLEVEs. Drysdale (Drysdale, 2011) also explains that, Jet fires can continue to burn for as long as the release of gas is not isolated. In the case of the simulated Jet fire, the high release rate of 1,360 kilograms/sec meant that the duration of the Jet fire would be significantly shorter although not as short as that of the BLEVE hazard.

This study's estimates of thermal flux from BLEVE hazards was consistent with estimates provided by the Emergency Response Guide documentation on BLEVE hazards (United State Department of Transport, 2016) The fire ball radius for Chorkor which has a tank capacity of 8.7 metric tonnes was 58 meters while the Emergency Response Guide documentation estimated a fireball radius of 62 for a tank size of 10.9 metric tonnes. At a distance of 100 meters downwind and 80 meters crosswind produced results similar to those recorded by Zhang & Liang (2013) in their analysis of thermal fluxes from BLEVE hazards.

The fireball diameters for Odorkor B, Avenor and Awudome which ranged from 151-152 meters were slightly less than the fireball diameter of

159.28 meters reported by Zhang & Liang (2013) for similar quantities of LNG in a BLEVE scenario. Dhurandher et al (2015) also reported a fireball diameter of 169 meters for 48.75 m^3 (48,750 litres) of LPG while the current findings recorded a fireball diameter of 161 meters for 43.48 m^3. From the previous discussion, it can be noted that, all the fire ball radii were below the 500 meters required separation distance between public facilities and LPG stations.

The implication of this is that, adherence to the 500-meter buffer distance can offer real protection to the surrounding land uses and populations. It is worth noting that, per the regulatory requirements there is no specified distance between residential land uses and LPG stations although there has been a moratorium on the establishment of new LPG stations especially in residential areas since 2018 (NPA, 2020a).

Generally, Zhang & Liang's (2013) analysis of the relationship between distance and thermal loads were also similar to the findings on the effect of distance on thermal radiation from LPG BLEVE hazards for the Odorkor B LPG station as shown in Figure 3. At a distance of 100,200, 300 and 500 meters the c reported 52, 19.8, 9.8 and 5 kw/m^2 whilst the findings of this research were 51.7, 22.5, 11.3 and 1.25 kw/m^2 for the same distances.

The relationship between distance and thermal radiation values for Kawkudi also showed results similar to those observed by Dhurandher et al (2015). In their report, thermal radiation values at 100, 200, and 300 meters were indicated respectively as 45, 24.09, 13.6kw/m^2 whilst the current research reported 48.9, 23.4, and 12.2kw/m^2 at the same distances respectively. The maximum thermal radiation values were however lower than those reported by both Zhang & Liang (2013) and Dhurandher et al (2015).

The study also indicated that the maximum endpoint distances for all the hazards zones were recorded at Kawkudi. For 10kw/m^2 hazard zone, the maximum endpoint distance was 350 meters and 495 meters for 5kw/m^2 hazard zone. For 2kw/m^2 the maximum endpoint distance was 770 meters. These results are similar to those reported by Dhurandher et al (2015) who observed a 360 meter endpoint distance for 10kw/m^2 and 550 meters for 5kw/m^2 respectively.

Given the observed maximum end point distances, it can be concluded that, the 500-meter buffer distance between public place and LPG stations may in some cases not provide adequate protection from BLEVE events when thermal loads are below 5kW/m^2. This observation is consistent with recommendations by the US Department of Transport published in the Emergency response guide for the year 2020. The Emergency response guide recommended an 800-meter separation distance between LPG incidents and human populations (US Department of Transport, 2020) .

Endpoint distances obtained from the Jet fire for the 2, 5 and 10 kw/m^2 thermal radiation thresholds had relatively shorter endpoints compared to the BLEVE hazard. However, with a longer duration and a maximum flame length of 153 meters, Jet fires tend to be very hazardous. Field observations by this research from a similar LPG Jet fire accident which occurred near the Trade Fair site in Accra on December 22, 2016 showed that, the fire travelled south east for at least 220 meters into the Trade Fair site and 260 meters north east past the La Dade Kotokpone Municipal Assembly and 230 meters south west towards the Giffard Road. Thus, the results are consistent with other LPG Jet fire accidents which have occurred in the past. It can be concluded that, the 500-

meter separation distance between public places and LPG stations can potentially provide adequate protection from Jet fire hazards.

LPG hazards simulated for this research have significant implications for LPG hazard management in Ghana. The fireball diameters from the simulated BLEVE's varied significantly across locations and were directly influenced by the volume of fuel stored at each location. However, the BLEVE fireball diameters up to the 5 kw/m^2 zones and the Jet fire flame lengths up to the 2 kw/m^2 were well within the 500-meter separation distance that is required between existing public places and LPG stations. As such the current required separation distance of 500 meters, can protect the public from the fireball of BLEVE hazards where thermal fluxes can reach 350 kw/m^2.

The lower magnitudes of Jet fire thermal radiation, in no way reduces their severity as the longer burn duration and the focused nature of the flame was such that it posed a danger to other LPG vessels in the vicinity by imposing BLEVE conditions on them. Additionally, since the quantity of fuel stored on-site directly influences the spatial extent of the hazard, regulating the LPG storage capacities may help to reduce the spatial extent and magnitudes of the hazard.

Per zoning policies in Ghana which guide spatial planning, LPG stations to be located in any of four categories of land use namely, service industrial, light industrial, general industrial and heavy industrial zones. However, the hazardous area (>2kw/m^2) which forms approximately 48.2 – 53.3% of area around the station was dominated by mixed uses which comprised informal businesses such as retail shops and food vending and residential units. Other residential land uses as well as community services such as schools, hospitals, religious centres among others were also found in this zone. For Jet fire hazards public and residential land uses occurred within the required 500-meter separation distance while for BLEVE hazards conflicted land uses occurred within all zones especially the >5kw/m^2 which was less than the 500 meters required separation distance. Thus, these land use patterns and their proximity to the LPG stations exacerbate the danger that LPG stations in the Accra Metro pose to the public by exposing them to dangers well above the required levels.

Given the proximity of these conflicting land uses to the LPG stations, they could also serve as potential sources of ignition in the event of an LPG leakage due to the prevalence of naked flames for welding and food preparation. Previous LPG leakage events which have occurred in Ghana, attracted fire from the immediate environment (Environmental Protection Agency, 2007). In addition, with the observation that, the farther the distance from an LPG station the lesser the magnitude of the thermal radiation, improvements in safety may be gained by keeping sensitive land uses farther away from the station.

Per the conceptual framework on risk informed land use planning, hazard assessments form an important part of a risk assessment. By providing information on the nature of LPG hazards further interrogation of the consequences of the hazard can be determined through consequence analysis. Disaster prevention and mitigation actions can also be initiated to control LPG hazard. The application of safe technologies such as partial and full mounding of LPG vessels, application of passive fire protection and the installation of water deluge and sprinkler systems have been proven to be effective LPG hazard controls (World LPG Association, 2011). In Ghana however, the application of safe technology has included the use of water sprinklers, gas detectors, emergency shut off valves but has not included the partial or full mounding as an approach. Thus, more room for hazard control through these technologies exist. Hazard control through the application of application of safe management has also seen some improvement with the initiation of certification for LPG station attendants and managers.

Chapter Summary

This Chapter focused on the determination of the magnitude, spatial extent and duration of LPG fire and explosion hazards in the Accra Metro. The characteristics were derived based on typical dry weather conditions. The analysis indicated that, BLEVE hazards had a greater magnitude and spatial extent than Jet fires and both varied from station to station due to differences in the quantity of LPG stored on site. The spatial extent of BLEVE hazards in all cases was beyond the required 500-meter separation distance between LPG stations and public facilities. All jet fire hazard zones were however less than the buffer distance. The land use patterns in the zone were also dominated by mixed use (commercial/residential), residential, commercial and community services with a small industrial base contrary to zoning regulations. for LPG sites.

CHAPTER FIVE

HUMAN VULNERABILITY TO LIQUEFIED PETROLEUM GAS FIRE HAZARDS IN ACCRA METROPOLIS

Introduction

This chapter presents the results of a human vulnerability assessment estimated using relevant indices such the Thermal Dose Unit (TDU) probability of fatality model and a Tsao & Perry (1979) cited in (HSE - U.K. Health and Safety Executive., 2010a). An assessment of the influence of variables such as exposure duration and thermal radiation levels on the vulnerability levels measured using the TDU is also presented. Furthermore, analysis of the relationship between land use type and vulnerability to LPG fire hazards is presented together with an estimation of the moderating influence of proximity on this relationship.

Human vulnerability to thermal radiation from LPG fire hazards

It is observed from Table 12 that, individuals within the modelled LPG fire hazard zones would be exposed to thermal radiation doses ranging from 1 to 96.2 kW/m^2 for BLEVE hazards and 1 to 63.4 kW/m^2 for a Jet fire from a bulk road vehicle in the event of an accident occurring during discharging. The mean thermal radiation for all hazards was in the 3.94 to 5.4 kW/m^2 range where it is expected that, pain will occur within 15-20 seconds and 2nd degree burns within 60 seconds. The maximum values for all the hazard scenarios exceeded 25 kW/m^2 where it is expected that, there will be a significant chance of fatality for instantaneous exposure. At these maximum thermal loads, it is also expected that, spontaneous ignition of wood will occur after long exposure and unprotected steel will reach thermal stress temperatures that can cause failure.

Table 12: Thermal radiation per hazard scenario

Hazards	Min	1^{ST} Qu.	Median	Mean	3^{rd} Qu.	Max
Jet fire of bulk road vehicle	1	1	2	3.94	4.0	63.4
BLEVE of stationary vessel	1	1	2	5.4	4.3	96.2

Source: Field work, 2019

2<TR< =5kW/m^2. Minimum to cause pain within 60 seconds.

5<TR<=10 kW/m^2. Pain in 15-20 seconds and 2nd degree burns within 60 seconds.

10.0 <TR< =25 kW/m^2.Potentially lethal within 60 sec

TR>25 kW/m^2 - Significant chance of fatality for instantaneous exposure and spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures that can cause failure.

Exposure duration

Exposure duration influences the extent of vulnerability to LPG fire hazards by limiting how much thermal radiation would be absorbed within a hazard area. In this study, exposure duration for Jet fires was computed from escape distance, escape time and reaction time. Escape distance was defined as the distance between a given location and existing buildings with floor space greater than 9m^2 and escape time as escape distance divided by an escape speed of 4 meters/sec. Exposure duration was computed as escape time plus reaction time of five seconds (Green book). For BLEVE hazards, exposure duration was equivalent to the burn duration of the BLEVE as recommended by the American

Institute of Chemical Engineers (2002). Most locations within the Jet fire hazard zone were close to a building. At least 25% of all locations in the Jet fire hazard zone were within 3.9 meters of a building whilst the mean escape distance was 10.3 meters indicating a positive skew. About 75% of all locations were also within 11.9 meters of a building. However, there were many outliers as indicated by the minimum value of 0 and the maximum value of 206.7 meters (Table 13).

Escape time ranged from 0 second for those already in a building to 51 seconds for that outdoors. The mean escape time was however less than 3 seconds. Exposure duration for the Jet fire hazard scenario, ranged from 5 to 56.7 seconds with a mean time of 7.6 seconds (Table 13). At least 75% of the Jet fire hazard zone had exposure durations of not more than 8 seconds. BLEVE exposure duration ranged from 9 to 11 seconds with average exposure duration of 10 seconds. Up to 75% of all locations within the BLEVE hazard zone had up to 10 seconds of exposure durations (Table 13).

Table 13: Exposure duration for two hazard scenarios

Hazard Exposure Parameters	Min	1st Qu.	Median	Mean	3rd Qu.	Max
Jet fire Escape Distance (meters)	0.0	0	3.9	10.3	11.9	206.7
Jet fire Escape Time (seconds)	0.0	0	1.0	2.6	3	51.7
Jet fire Exposure duration (seconds)	5.0	5	6.0	7.6	8	56.7
BLEVE Exposure duration (seconds)	9	10	10	10	10	11

Source: Field work, 2019

Thermal Dose Units

Human vulnerability to filling station fire hazards includes 1st, 2nd and 3rd degree burns. The last two carry significant chances of fatality depending on factors such as exposure duration, intensity of thermal radiation and the percentage of exposed bare skin. Together, these three factors enable the computation of a Thermal Dose Unit which can be used to estimate the degree of human vulnerability to fire hazards. The TDU is a received thermal radiation dose which is computed as:

$$TDU = (I)^{4/3} * t \quad \text{……………………. Equation (6)}$$

Where,

I = Intensity of thermal radiation

t = Exposure duration

Thermal dose units were computed for the two hazard scenarios based on exposure duration and thermal radiation. The results showed that, the minimum TDU values recorded were 1.2 and 2.5 for Jet fires and BLEVE respectively. Both of these TDU values were below the pain threshold. At least 25% of all hazard scenarios also had TDU values below the pain threshold the mean TDU of the BLEVE was sufficient to cause 1st degree burns whilst that of the Jet fire could only cause pain (Table 14).

Table 14: Thermal dose units per hazard scenario.

Hazards	Min	1st Qu.	Median	Mean	3rd Qu.	Max
Jet fire of bulk road vehicle	1.2	6.3	15.7	68.3	46.6	3925
BLEVE of stationary vessel	2.5	11	26.4	143	69.8	4446

Source: Field work, 2019
* Pain 85 - 129 TDU
1st degree burns 130 - 800 TDU
2nd degree burns and 1% lethal threshold ranges from 900 - 1800 TDU
3rd degree burns and 50% lethal threshold ranges from 1800 - 3200 TDU
100% lethal threshold exceeds 3200 TDU

At least 75% of all hazards had TDU values which were below the pain threshold. However, both the Jet fire and BLEVE hazard had maximum TDU values that were well above the 100% fatality threshold (Table 14).

As shown in Figure 21, the thermal dose unit foot prints from Jet fires cover substantial parts of the Accra Metro. The thermal dose unit foot prints consist of the following areas: places in yellow indicate which area below the pain threshold; places in light orange cover the pain threshold and places in deep orange are points where victims could suffer from 1st degree burns.

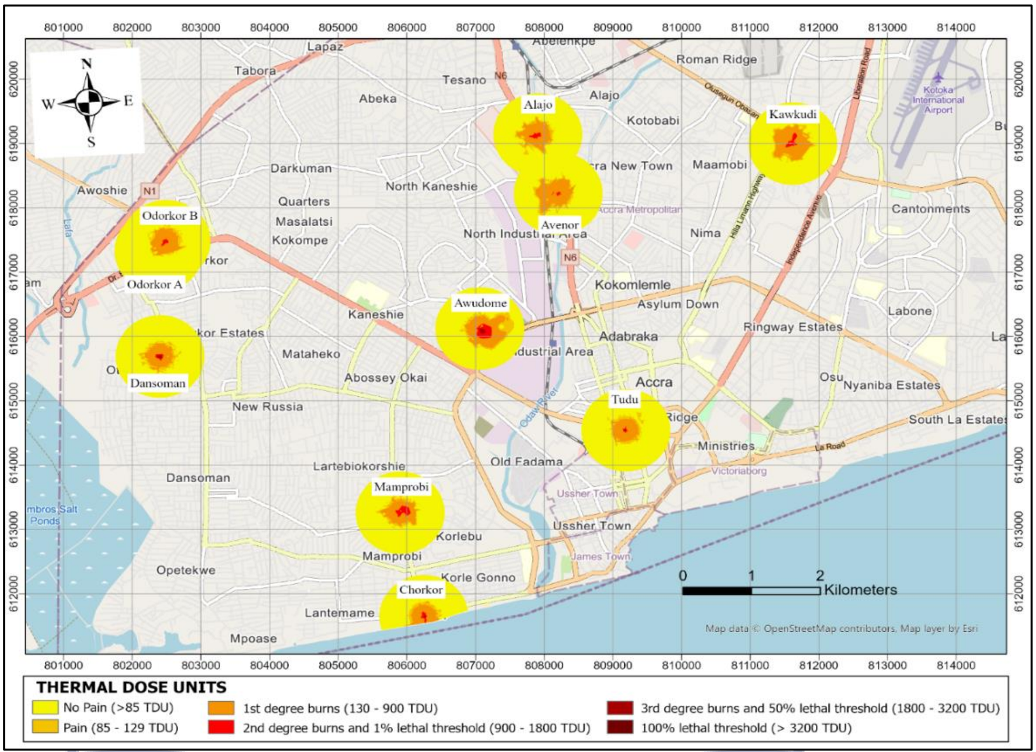

Figure 21: Magnitude and Spatial extent of Thermal Dose Units from Jet fire hazards
Source: Field work, 2019

All places in red are where victims could have 2nd degree burns. Awudome, Dansoman, Tudu and Chorkor have part of their inner zones potentially inflicting 3^{rd} degree burns on victims.

The Kawkudi TDU foot print will impose pain and first degree burns on human populations at the 37 Military Hospital and the Accra Girls Senior High school which has boarding facilities. Persons in the vicinity of the National Mosque which is located south west of the Kawkudi hazard zone would also be subjected to pain and first-degree burns (Figure 22).

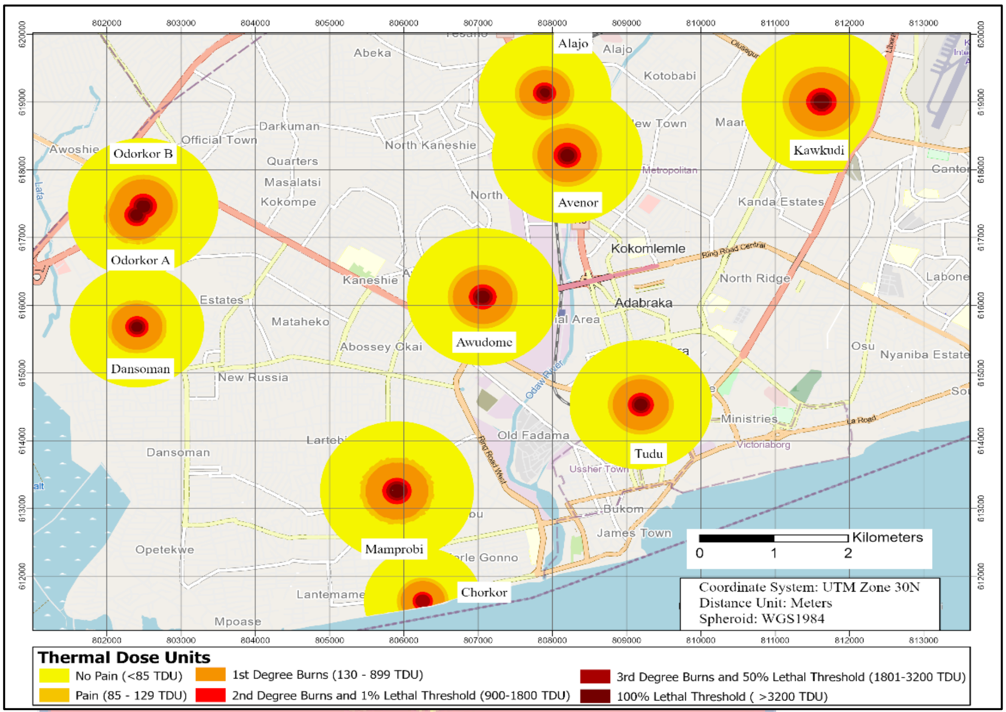

Figure 22: Magnitude and Spatial extent of Thermal Dose Units from BLEVE fire hazards
Source: Field work, 2019

Vulnerability Levels across land use types in the Jet fire hazard zones.

The mean TDU for land use types in the Jet fire hazard zone fell into two groups. The first group of land uses comprising 85.4% of all land uses (mixed use, commercial, community service, government business, residential and transport) had mean TDU values below the pain threshold. The second group comprising 14.6% (derelict land, greenspaces, industrial, public open spaces and utilities) also had mean TDU values which would potentially expose human populations to first degree burns (Table 15). The thermal Dose Unit values recorded were not normally distributed hence, a Kruskal Wallis test was conducted to test whether the median of TDU values differed across land use types in the Jet fire hazard zone. The results indicated that, TDU median values were significantly different across land use types ($H (11) = 288804.127, P < 0.00$).

Table 15: Land use types and vulnerability to Jet fires

Land use	% Area	Min	1st Qu.	Median	Mean	3rd Qu.	Max
Commercial	6.8	1.2	5.4	12.9	51.1	37.3	1920.9
Community Service	14.1	1.2	8.1	19.4	63.2	56.2	1518.2
Derelict Land	0.3	1.9	14.0	105.9	203.9	297.2	986.3
Government Business	3.4	1.2	7.9	23.0	57.1	53.1	969.0
Green Space	2.5	1.3	10.2	33.8	196.3	201.0	1795.8
Industrial	6.9	1.3	7.3	21.5	156.3	134.1	3925.3
Mixed Use	25.0	1.2	5.4	13.7	40.7	36.1	1572.1
Public open space	1.1	1.3	7.5	14.4	167.0	254.0	1566.0
Residential	28.2	1.2	5.6	13.0	34.8	29.7	1466.0
Transport	7.9	1.3	7.8	18.1	74.3	53.3	2285.2
Utilities	3.0	1.3	39.4	109.5	292.8	333.4	2199.8
Vacant Land	0.8	1.4	13.1	41.1	162.4	248.5	3499.3

Source: Field work, 2019

Table 15 shows differences in the median TDU values per land use type. Land uses which did not differ statistically and those which were marginally different, can be assumed to have similar exposure durations and thermal radiation. Those with larger differences do not share similar exposure durations or thermal radiation.

Vulnerability Levels across land use types in BLEVE hazards zone.

The mean TDU for land use types in the BLEVE hazard zone fell into two groups. The first group of land uses comprising commercial, community service, derelict land, government business, green spaces, industrial, public open space, transport, utilities and vacant land (43.3%) all had mean TDU values in the first-degree burns category while residential and mixed land uses which comprised 56.7% were in the pain threshold (Table 16).

Table 16: Land use types and vulnerability to BLEVE's (TDU)

Land use	% Area	Min	1st Qu.	Med.	Mean	3rd Qu.	Max
Commercial	7.3	2.6	10.0	25.2	129.7	61.7	4334.5
Community service	9.9	2.7	22.7	47.6	181.1	124.2	4436.9
Derelict land	0.2	3.8	15.5	30.5	559.3	616.0	3912.5
Government business	3.5	2.5	10.0	27.7	133.0	119.9	3036.3
Green space	2.3	3.2	11.0	27.7	348.5	119.2	4444.2
Industrial	8.6	3.6	10.0	21.1	259.3	56.2	4405.9
Mixed use	28.8	2.5	10.0	22.7	104.1	56.0	4446.0
Public open space	1.4	2.5	11.0	25.2	259.5	47.6	4382.9
Residential	27.9	2.7	11.0	26.1	87.5	64.4	4266.8
Transport	7.8	2.5	11.0	27.7	150.5	76.1	4443.9
Utilities	1.5	9.0	62.7	142.8	479.9	452.2	4070.9
Vacant land	0.8	2.8	15.8	27.7	295.5	75.5	4295.9

Source: Field work, 2019

All land uses in the BLEVE hazard zone had minimum, first quartile and median TDU values below the pain threshold except for Utilities whose median TDU value was indicative of first-degree burns (Table 17). Another Kruskal Wallis test was conducted to test whether the median TDU values for BLEVE hazards differed across land use types. The results indicated that, median TDU values differed significantly across land use types in the BLEVE hazard zone ($H(11) = 370384.786$, $P < 0.00$).

Chance of fatality associated with BLEVE and Jet fire hazards.

The percentage fatality presented in Table 17 indicate the chance of fatality from a given hazard based on the thermal dose units and a Probit value generated from Tsao & Perry (1979) cited in (HSE - U.K. Health and Safety Executive., 2010a) Dose – Response model ($Y = -12.8 + 2.56 \ln V$) where V= Thermal dose units. About 93% of the hazard zone of BLEVE hazards had zero fatality estimates compared to Jet fires which had 96% of its area recording zero fatality rates.

Table 17: Percentage fatality for the three hazard scenarios

	BLEVE (Stationary vessel)	Jet fire (Bulk road vehicle)
Percentage fatality	% Area	% Area
Zero fatality	93.4	96.1
1 - 10% fatality rate	1.9	1.6
11 - 20% fatality rate	0.6	1.1
21 - 30% fatality rate	0.4	0
31 - 40% fatality rate	0.3	0
41 - 50% fatality rate	0.3	0.7
51 - 60% fatality rate	0.3	0
61 - 70% fatality rate	0.3	0
71 - 80% fatality rate	0.3	0
81 - 90% fatality rate	0.4	0.4
91 - 99.9% fatality rate	1.9	0.1
Total	100.0	100

Source: Field work, 2019

Thus, BLEVE hazards had potentially greater consequence than Jet fires. The large non-fatal areas suggest that, fatality due to LPG fire hazards are concentrated in just a few parts of the study area.

Areas with between 1-10% fatality rates covered only 1.9% and 1.6 % of the BLEVE and Jet fire hazard zones respectfully. Areas with up to 50% fatality rates occupied up to 3.5% and 3.4% of the BLEVE and Jet fire hazard area respectively. Areas with greater than 50% fatality rates covered approximately 3.2 and 0.5% of the study area for BLEVE and Jet fires of bulk road vehicles respectively. This suggests that, vulnerability levels for BLEVE hazards tend to have a greater spatial foot print than Jet fires even when their hazard magnitudes are similar to Jet fires.

Vulnerability based Distance criteria for LPG Stations placement in the Accra Metro

The consequence-based consultation distances serve as a criterion for screening and permitting of developments in the vicinity of a major hazardous facility such as a Gas station. In this study, the vicinity of the LPG stations was categorized into three zones based on the potential consequences of their TDU value on human populations.

An inner zone with where TDU levels can potentially cause 50% fatalities and above, a middle zone where TDU levels could cause 1-49% fatalities and an outer zone where TDU levels could lead to less than 1% fatality rates were designated for all locations. The results indicate that, for Jet fires, the mean consultation distances were below 100 meters (Figure 23). Maximum consultation distance for the inner zone for all locations was below 200 meters with the exception of Awudome where the consultation distance was marginally higher than 200 meters (Figure 23).

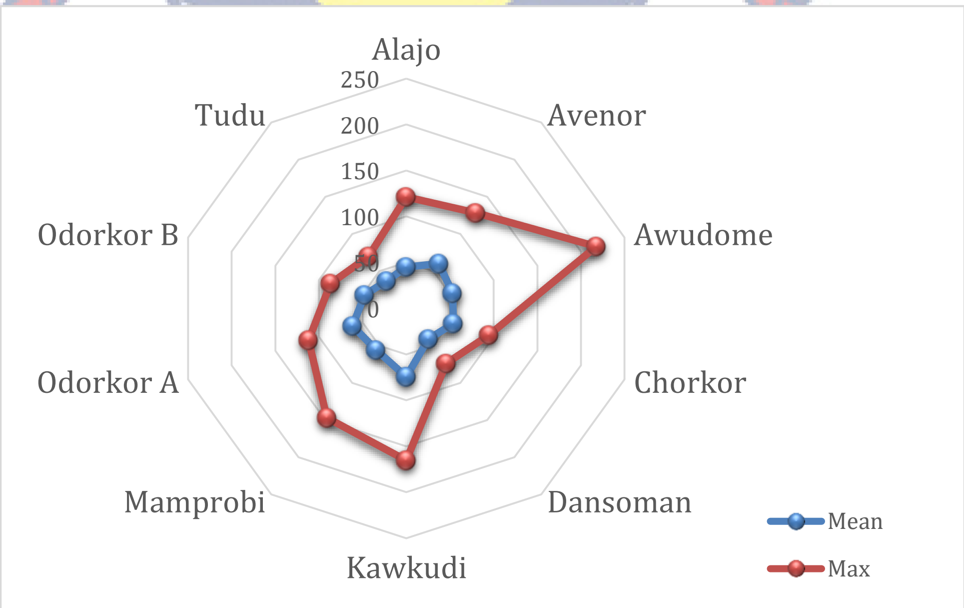

Figure 23: Consultation distances for the Inner zone of Jet fire
Source: Field work, 2019

For the middle zone of the Jet fire hazard, all mean consultation distances were below 200 meters with the exception of Kawkudi, Avenor and Awudome (Figure 24). A maximum consultation distance of 279.1 meters was recorded at Awudome

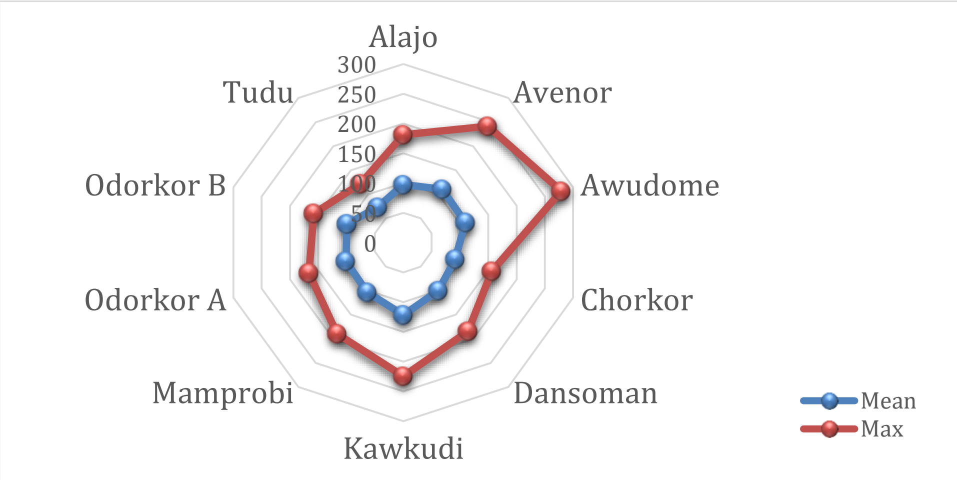

Figure 24: Consultation distances for the Middle zone of Jet fire
Source: Field work, 2019

Figure 25, shows the consultation distances for outer zone of the Jet fire hazards. The mean consultation distances of all the 10 locations were below 500 meters.

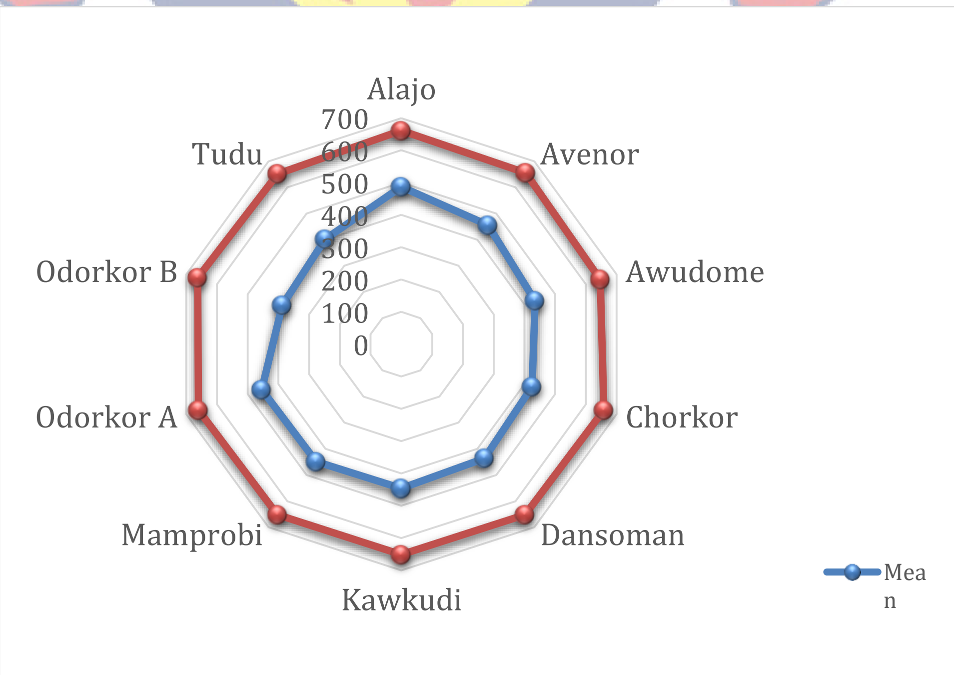

Figure 25: Consultation distances for the outer zone of Jet fire
Source: Field work, 2019

The maximum consultation distances for all the 10 locations were above 600 meters. The highest consultation distance of 663.2 meters was recorded at Odorkor B (Figure 25).

Figure 26 shows the inner, middle and outer consultation zones for Jet fire hazards. The yellow area which is the outer zone with less than 1 % fatality covers substantial number of buildings and structures. The Middle and Inner zones with orange and brown colours also had buildings and other structures as well as infrastructure such as major roads. It can be observed that, even though the zones appear to be concentric, the exposure duration and other factors involved in the estimation of the fatality rates lead to the amorphous shape of each zone. The outer zone is larger due to the effect of distance decay while the middle and inner zones tend to be much smaller.

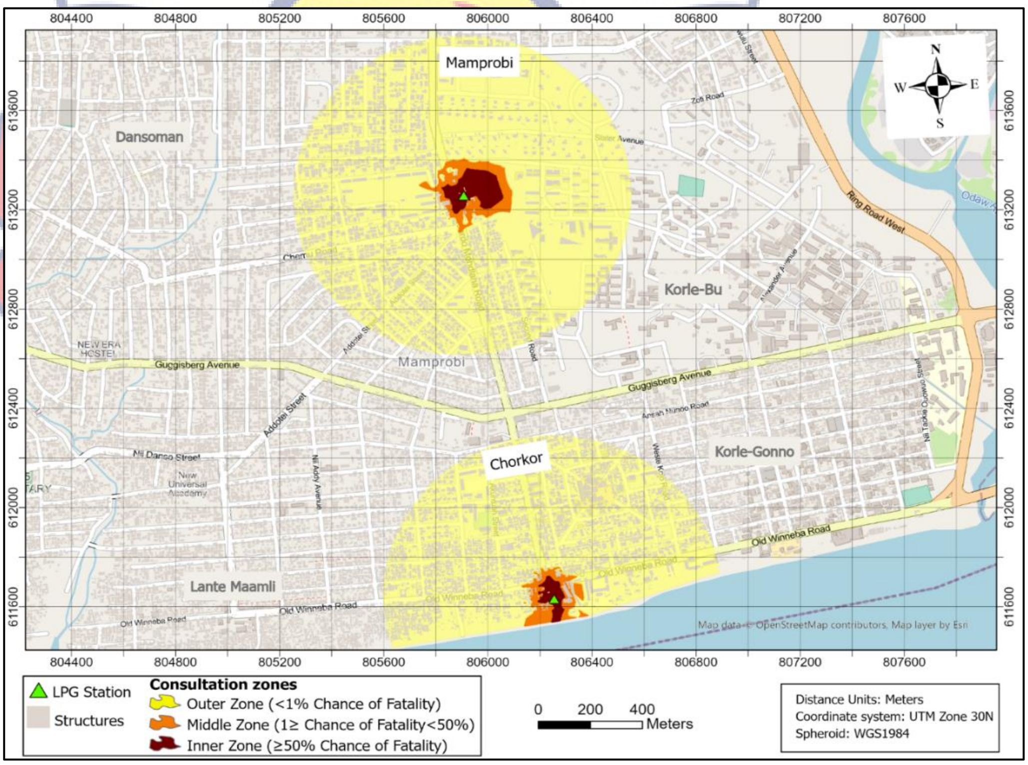

Figure 26: Consultation zones for Jet fire hazards based on the UK HSE consequence-based criteria.
Source: Field work, 2019

In the inner zone of BLEVE hazards, both the mean and maximum consultation distances for all 10 locations were below 200 meters, with Kawkudi recording the highest maximum consultation distance of 191.5 meters (Figure 27).

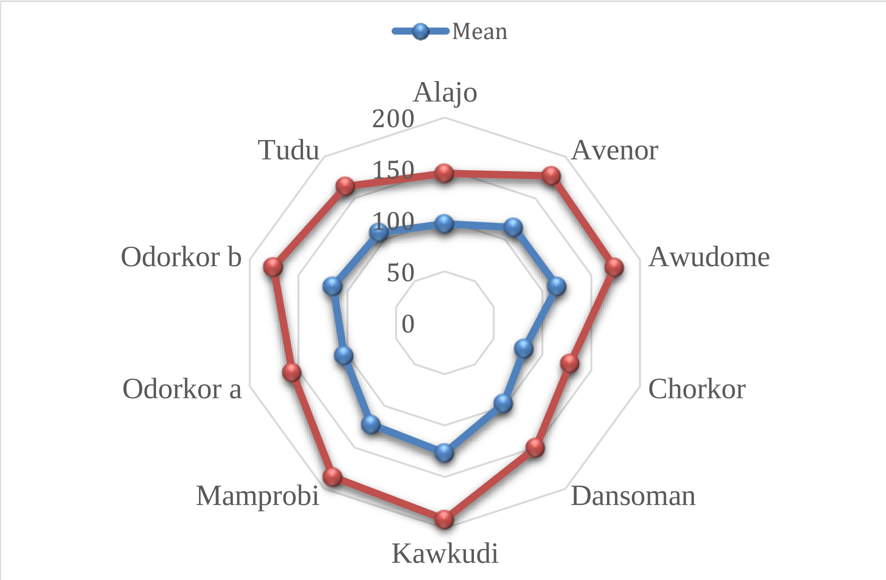

Figure 27: Consultation distances for the Inner zone of BLEVE hazard
Source: Field work, 2019

For the middle zone of BLEVE hazards, Figure 28 shows that, six stations had a mean consultation distance above 200 meters but less than 500 meters.

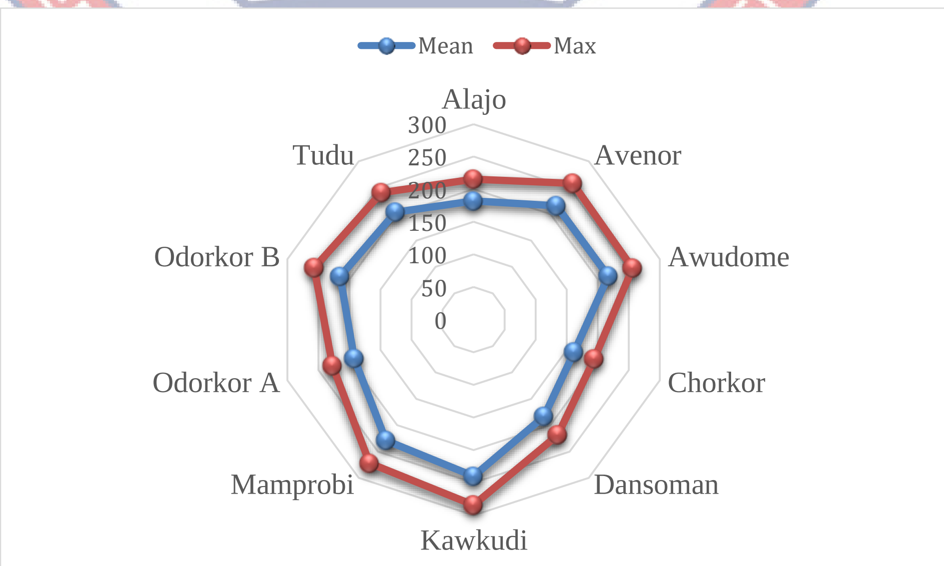

Figure 28: Consultation distances for the Middle zone BLEVE
Source: Field work, 2019

The maximum consultation distances for all the 10 LPG locations were also above 200 meters with the exception of Chorkor which had 194.2 meters. The farthermost consultation distance in this zone (284 meters) was recorded at Kawkudi while the shortest consultation distance within the middle zone was recorded at Chorkor (194.2 meters).

The outer zone of BLEVE hazards had mean consultation distances of between 543 meters and 724.6 meters. The maximum consultation distances were between 792 meters and 1074 meters (Table 18).

Table 18: Consultation distances for the outer zone - BLEVE hazards

Location	Mean (m)	Max (m)
Alajo	623.2	897.5
Avenor	707.7	1017.2
Awudome	711.0	1019.7
Chorkor	543.9	792.7
Dansoman	627.7	904.2
Kawkudi	724.9	1074.7
Mamprobi	724.6	1035.8
Odorkor A	636.7	914.9
Odorkor B	706.4	1015.5
Tudu	669.8	960.7

Source: Field work, 2019

The inner, middle and outer zones of the BLEVE hazard are shown in brown, orange and yellow respectively. The yellow outer zone of the BLEVE was larger than that of the Jet fire hazards and also had a more regular shape. The outer consultation zone for Mamprobi covered major parts of the Korle-bu Teaching Hospital and other residential areas (Figure 29). For Chorkor, major parts of the fishing community and surrounding areas were also found in the inner zone.

The circular nature of the consultation zones for BLEVE hazards, was due to the fact that, fire balls that develop during a BLEVE are not influenced much by prevailing wind conditions because of their short durations. The uniformity of the exposure duration at each location also explains the circular nature of the zone (Figure 29).

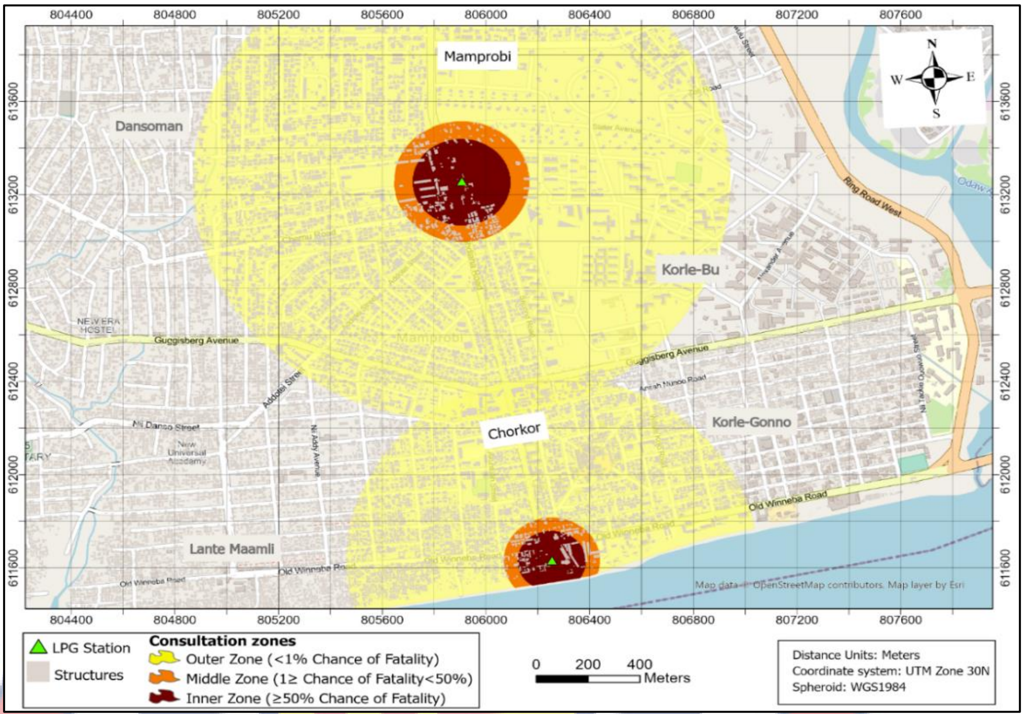

Figure 29: Consultation zones for BLEVE hazards based on the UK HSE consequence-based criteria.
Source: Field work, 2019

Land use patterns in the UK Health and Safety Executives' vulnerability (UK HSE) consultation zones.

Vulnerability based assessment takes into consideration the physical extent and severity of hazards but does not consider the frequency of such hazards. Per the UK HSE's approach to consequence-based assessments, consultation distances for three different levels of hazard severity are considered. The first consultation distance known as the outer zone, is defined by a hazard severity significantly lower than a dangerous dose where a dangerous dose is defined as thermal radiation with fatality rates of at least 1%.

A second consultation distance usually termed a middle zone, is based on a dangerous dose or hazard severity levels which can sustain fatality rates of at least 1%. A third consultation distance termed an inner zone is based on hazard severity levels which are significantly above the dangerous dose. For the inner zone this means it is an area with fatality rates of at least 50%. Overall, industrial land uses form only a small portion of the inner, middle and outer zones. In each zone, some non-industrial land uses which dominated the zone were compatible with industrial use while other uses such as residential were not.

Plate 9: Land uses in the LPG hazard zone, Awudome Estates, Accra.
Source: Fieldwork, 2019

Although, in the Jet fire inner zone, industrial uses occupied approximately 1/3 (29.3%) of the zone, other potential complementary land uses such as utilities (27.8%) and green spaces (17%) also had significant coverage area within the zone (Plate 8 and 9). Compared to Jet fires, the inner zone of BLEVE hazards had a smaller industrial base (20%) due to its relatively larger spatial extent

(Plate 8, 9 and 10). Community service, mixed use and residential were the other significant land uses in the zone (Table 19, Plate 9 and Figure 30).

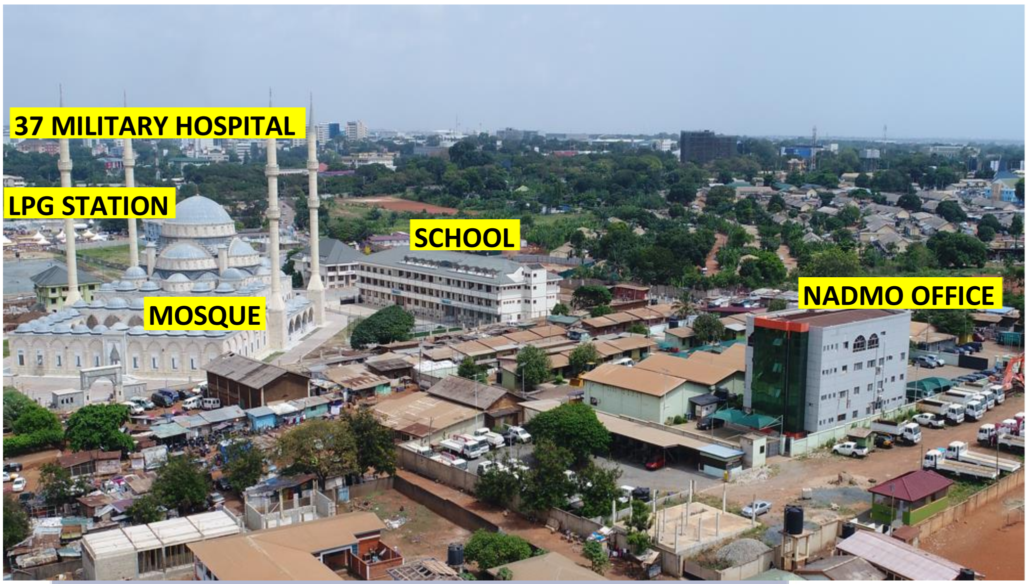

Plate 10 : Multi-storey residential units within the inner LPG hazard zone
Source: Fieldwork, 2019

Plate 11: Community Services within the LPG hazard zone
Source: Fieldwork, 2019

The industrial base in the middle vulnerability zone of Jet fires was not significantly large (18.4%). The rest of the zone was made up of a mixture of land uses some of which were compatible and others incompatible with industrial use (Table 19).

Table 19: Land use patterns in Vulnerability Zones for Jet fire and BLEVE

Land use	Jet fire			BLEVE		
	Inner Zone	Middle Zone	Outer Zone	Inner Zone	Middle Zone	Outer Zone
	%Area	% Area	%Area	%Area	%Area	%Area
Commercial	3.3	4.4	6.9	7.1	4.6	7.5
Community Service	3.3	14.1	14.3	11.5	14.9	9.7
Derelict land	0.6	1.8	0.2	1.2	0.8	0.2
Government business	0.4	2.7	3.4	2.8	5.5	3.4
Greenspace	17	8.9	2.1	7.4	3.5	2.1
Industrial	29.3	18.4	6.4	20	8.5	8.3
Mixed use	3.2	11.9	25.5	16.7	26.6	29.2
Public open space	3.9	4.1	1	3.5	2.1	1.3
Residential	1.6	10.5	29	11.5	19.1	28.7
Transport	7.6	8.9	7.9	8.7	8	7.8
Utilities	27.8	12.3	2.3	7	5.4	0.3
Vacant land	1.8	1.3	0.7	2.5	1.3	0.7
Total	100	100		100	100	100

Source: Field work, 2019

For BLEVE hazards, their middle zones were made up of a relatively smaller proportion (8.5%) of industrial uses. Other land uses in the BLEVE middle zone were not necessarily compatible with industrial use.

The outer vulnerability zone for Jet fires was largely occupied by community services (14.3%), mixed use (25.5%), residential (29%), and commercial services (6.9%) which together constituted approximately 76% of the total land area in this zone (Table 19). A very large proportion (83.4%) of land within the outer zone of BLEVE hazards was made up of commercial land use (7.5%), community services (9.7%), mixed use (29.2%) and residential (28.7%) use most of which were incompatible with industrial use (Figure 30).

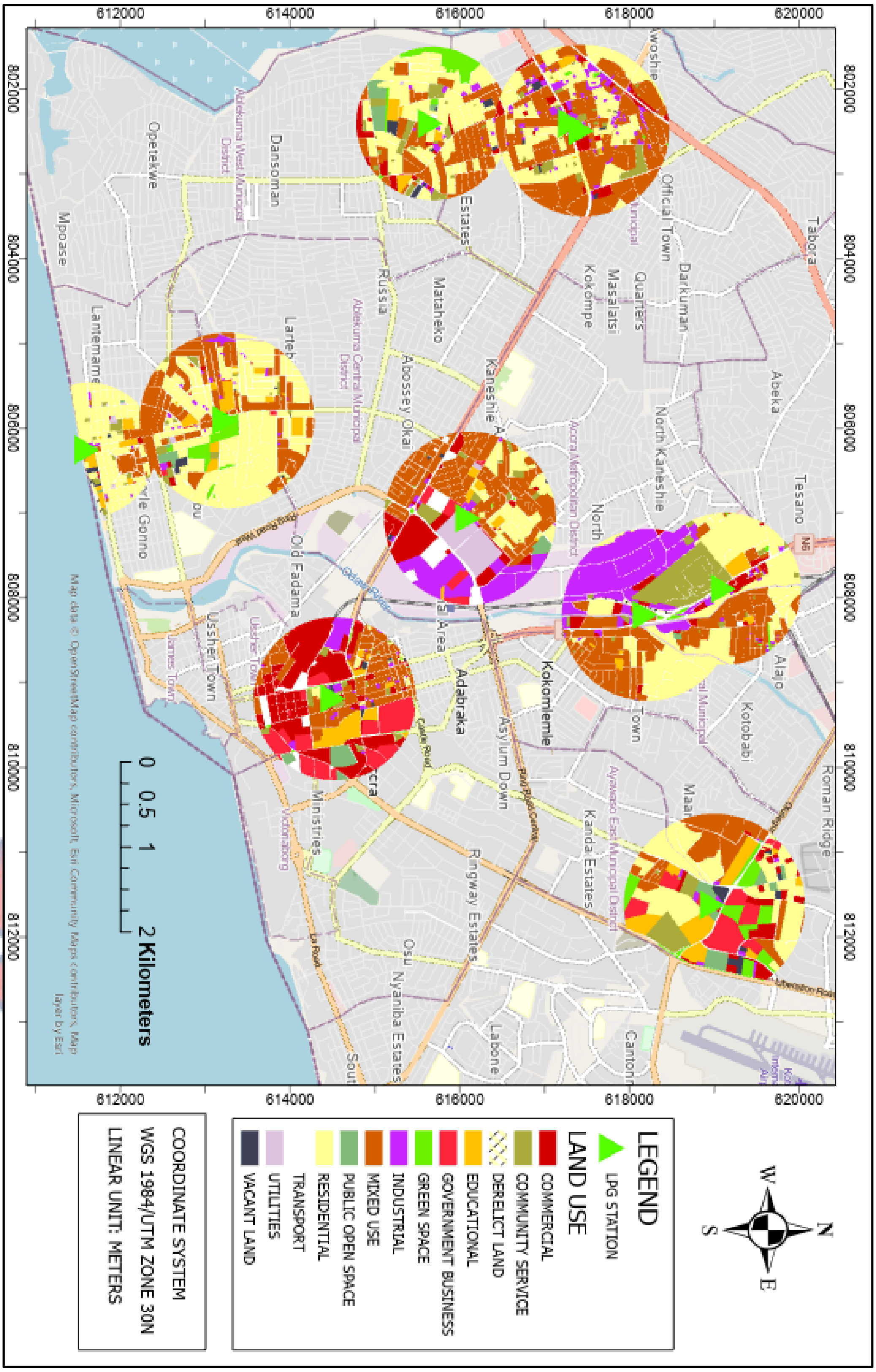

Figure 30: Land use map of the inner, middle and outer zone
Source: Field work, 2019

Sensitivity levels for land uses around LPG filling stations in the Accra Metro.

The land use types were categorised into sensitivity levels based on the four level UK HSE land use sensitivity criteria. Level 1 covered land for use by working populations where higher levels of protection and organization are expected due to the indoor nature of the activities and the higher levels of emergency preparedness required Level 2 consisted of land for use by the general public and captured the residential, retail and transport activity areas as well as guest houses and areas where community services are rendered. Level 3 consisted of land for use by vulnerable people such as healthcare services, basic and secondary education and other services where minors or elderly groups may be present Level 4 covered land for use by large outdoor populations (usually greater than 1000) (Appendix C).

Effects of Land Use and Spatial Planning Authority's framework on sensitivity levels of land uses around LPG filling stations in Accra Metro.

Vacant and derelict lands, green spaces, utilities land uses which were previously in sensitivity level 2 based on the UK HSE classification were all recoded into the sensitivity level 1. This was because these land uses according to the Land Use and Spatial Planning Authority (LUSPA) zoning framework LUSPA (2016) were more compatible with industrial land uses which dominated the sensitivity level one category. Government and formal businesses were also moved from sensitivity level 1 to level 2. This was because it was determined that these land uses were generally accessible to the general public including hawkers and trades men (Appendix D).

Land use advice based on HSE sensitivity and vulnerability criteria.

Application of the UK HSE sensitivity levels and vulnerability criteria suggested that, approximately 90% and 98% respectively of land uses in the inner zone of BLEVE and Jet fire hazards in the Accra metro must be reconsidered in terms of safety (Figure 31) and (Appendices E and H). For BLEVE hazards, the only allowed uses were formal business, general industrial and government business.

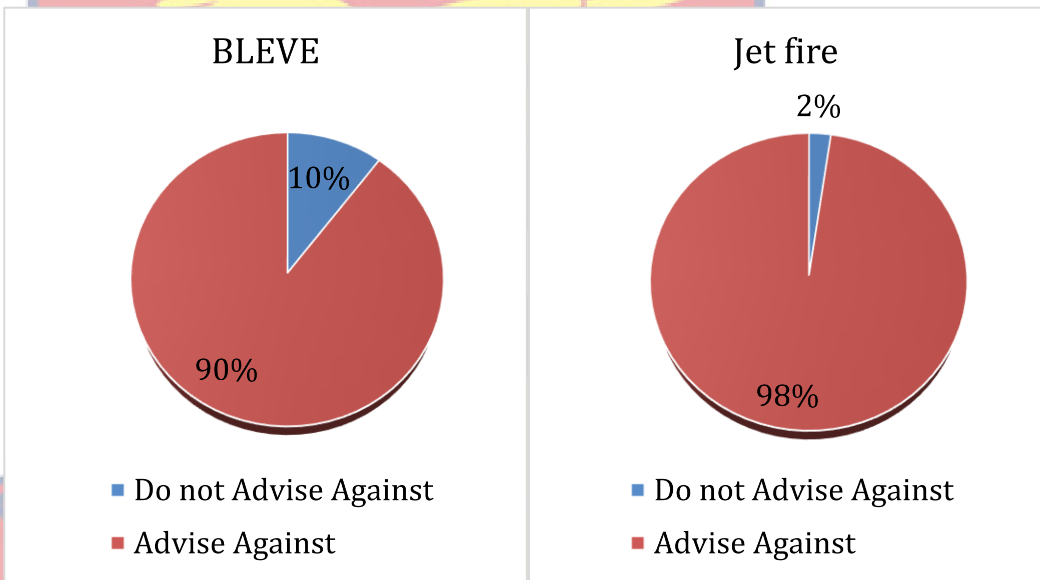

Figure 31: Land use decisions in the inner zone of BLEVE and Jet fire hazards.
Source: Field work, 2019

Out of these, formal business constituted the largest proportion (64.1%) of land uses that should be allowed in the inner zone.

In the case of the Jet fire hazard, government and formal businesses were the only uses allowed in the inner zone. Again, formal businesses constituted the largest proportions of the allowed land uses. All other land uses within the inner zone were proscribed (Figure 31 and Appendix E).

In the middle zone, land uses which were advised against formed a smaller proportion of all land use types with approximately 14% and 12.3% for BLEVE and Jet fires respectively (Figure 32, Appendix F and I).

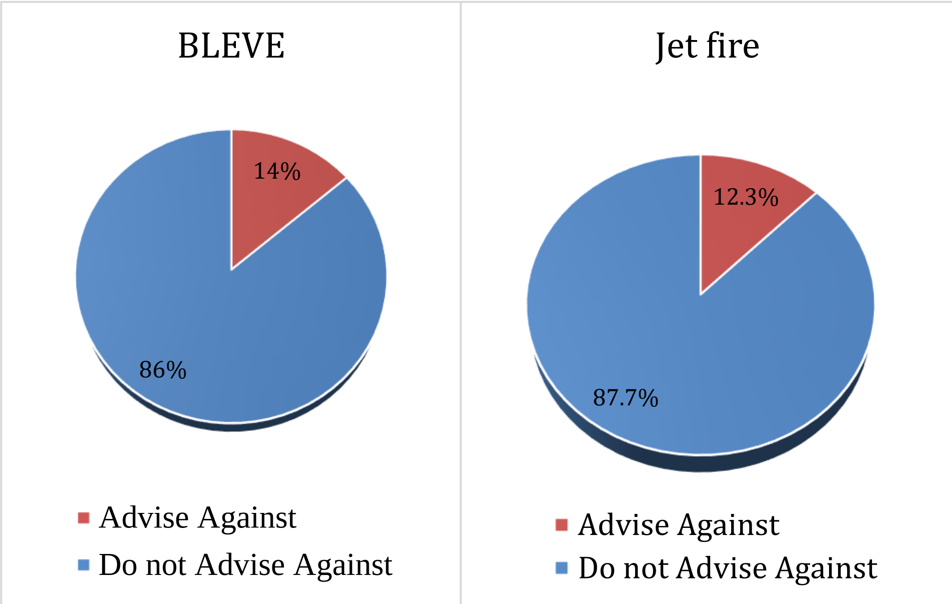

Figure 32: Land use advice for the middle BLEVE and Jet fire zones.
Source: Field work, 2019

Specifically, for Jet fire hazards, community services such as basic education (27.5%), informal business such as open markets (0.4%), health facilities (2%), high density residential (2.1%) and slums (34.7%) as well as open spaces in communities (33.4%) were advised against. All other land uses were not advised against (Appendix F). Land uses within the middle zone of the BLEVE hazard which were advised against included basic education, informal business, public open space, residential high density, residential slum, secondary education, tertiary education. Among these land uses, basic education, residential high density, residential slum and tertiary education formed a larger proportion of about 87.2 of the land areas (Appendix I).

In the outer zone of both BLEVE and Jet fire hazard, land uses that were advised against constituted an even smaller proportion of approximately 5% of land uses in BLEVE hazards and 6% of land uses for Jet fire hazards (Figure 33).

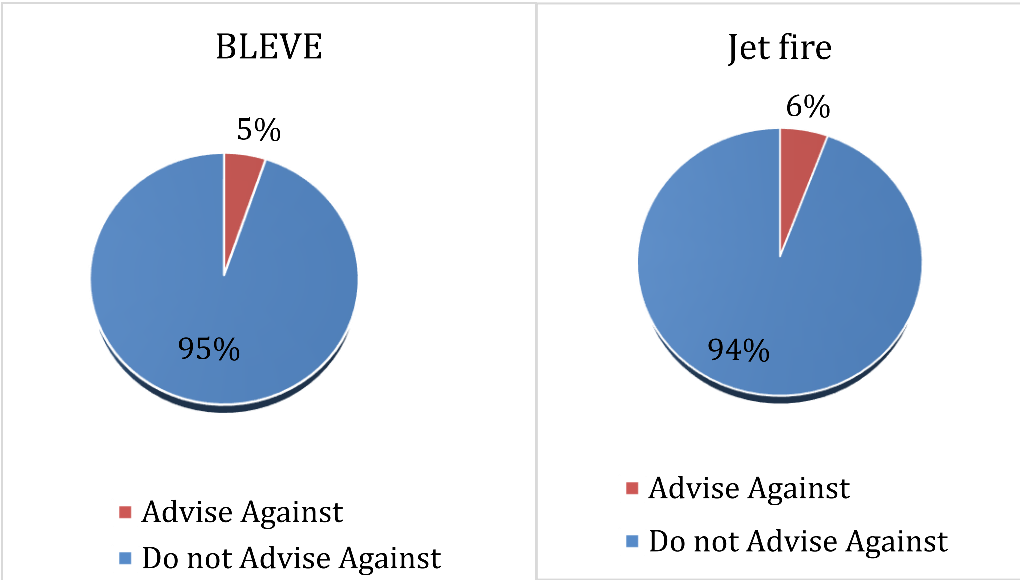

Figure 33: Land use decisions in the outer zone of BLEVE and Jet fire hazards.
Source: Field work, 2019

It is also clear from Appendix G that, only three of the land uses within the outer zone of Jet fire hazards were advised against. These land uses were public open space, informal business, and tertiary education. Among this category of land uses, informal business and tertiary education covered a larger proportion (82.2%). The same category of land uses was also advised against for BLEVE hazards with informal businesses occupying a larger proportion of land area for both hazard types (Appendix I).

Land use advice based on modified sensitivity and UK HSE vulnerability criteria.

Application of the UK Health and Safety Executive's framework indicated that, 62% and 24% of the land uses in the inner zone of the BLEVE and Jet fire hazards were advised against based on the revised sensitivity levels and vulnerability criteria (Figure 34). Land uses in the inner zone of the BLEVE which were advised against included mixed use (24.3%), roadways (13.2%), formal business (10%) and basic education (5.5%). For land uses in the inner zone of Jet fires which were advised against were similar to that of the BLEVE but with differences in configuration (Appendix K and N).

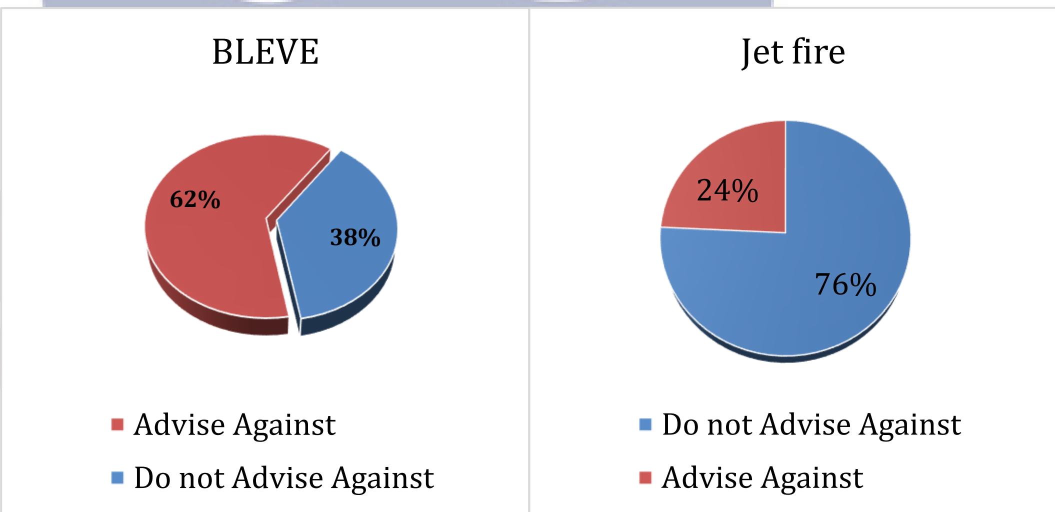

Figure 34: Land use decisions in the inner zone of BLEVE and Jet fire hazards.
Source: Field work, 2019

For the middle zone, 14% of the land uses in the BLEVE hazard zone were advised against as compared to 12% for Jet fires hazards (Figure 35). For BLEVE hazards, land uses such as basic education, informal business, public open space, residential high density, residential slum, secondary education, and tertiary education were advised against in the middle zone.

Among these land uses, basic education and residential land uses constituted a larger proportion (74.2%) of the land area within this zone. Comparatively, the middle zone of Jet fire hazards had land use patterns similar to that of BLEVE's with health care facilities being the only addition to those uses advised against (Appendix L and O).

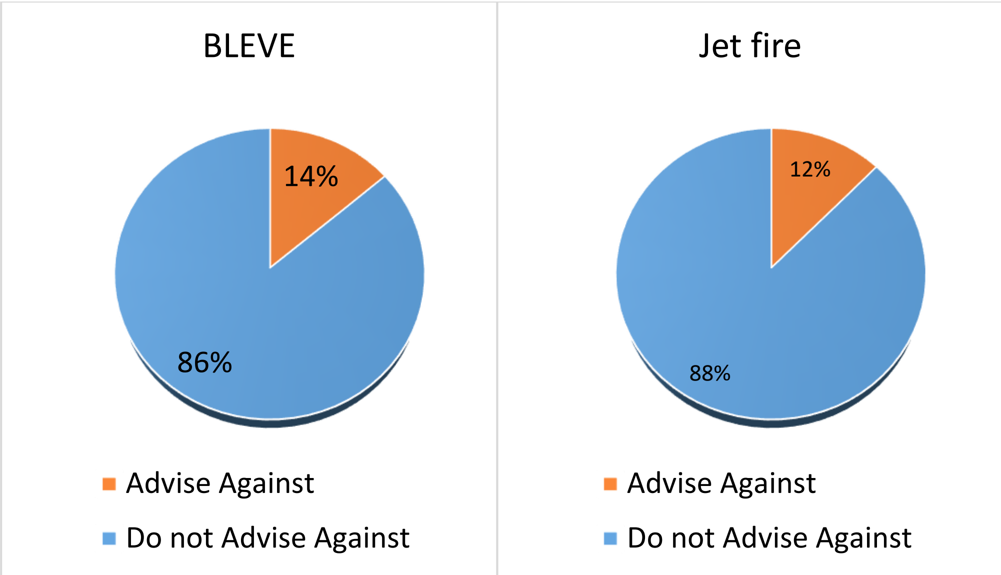

Figure 35: Land use decisions in the middle zone of BLEVE and Jet fire hazards.
Source: Field work, 2019

Based on the revised sensitivity classes, land uses in the outer zone of LPG hazards showed that, only 5% and 6% respectively of these uses were advised against for BLEVE and Jet fire hazards (Figure 36). For BLEVE hazards, land uses advised against were informal business, public open spaces and tertiary educational centres with informal business forming the largest proportion of about 49.6% (Appendix P). Comparatively, Jet fires also had the same land use types being advised against. However, in the case of Jet fires, informal business (44.2%) and tertiary educational centres (38%) formed the biggest proportion of land uses (Appendix M).

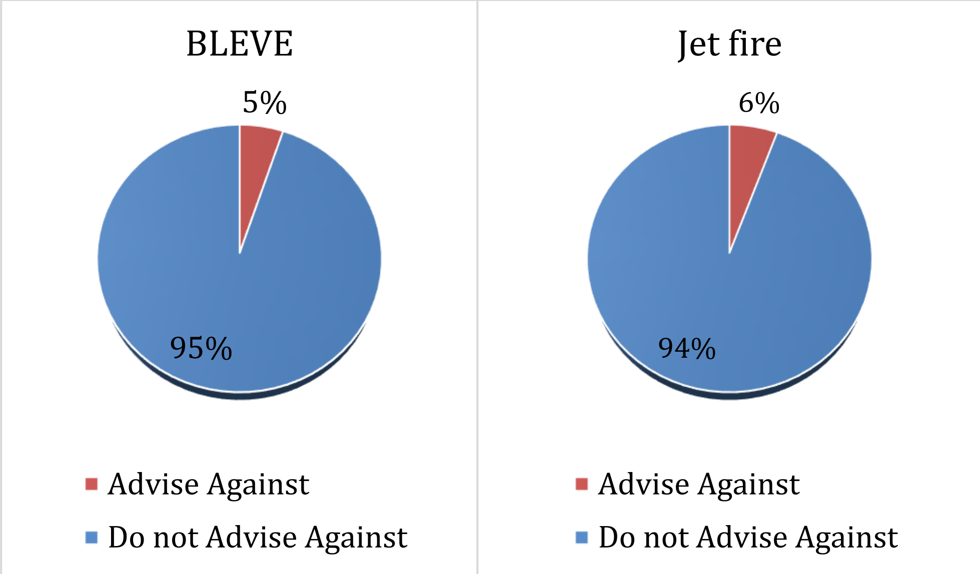

Figure 36: Land use decisions in the outer zone of BLEVE and Jet fire hazards.
Source: Field work, 2019

Modification of the UK HSE sensitivity criteria too yielded a reduction in land uses advised against. In the inner zone, there was -31.1 % decrease for BLEVE hazards whiles Jet fire hazards had a -75% decrease.

Discussion

BLEVE hazards have thermal radiation levels which are generally higher than that of the Jet fire. This implies that, BLEVE may have higher levels of vulnerability than Jet fires given their hazard levels alone. However, it is important to note that, the maximum thermal radiation value for both hazard types have the capacity to cause instantaneous fatalities given their magnitude alone. The Dutch Guidelines for quantitative risk assessment - Green Book (Haag et al., 2001), recognizes that, BLEVE hazard are the most severe forms of LPG hazards due to the thermal radiation levels and the blast overpressure.

Exposure duration for BLEVE hazards did not exceed 11 seconds. This was because, BLEVE exposure durations were pegged to the duration of BLEVE fire hazards which usually last 10-15 seconds (Venart, 1998). The

Green book further argues that, most people need a reaction time of 5 seconds in other to respond to fire hazards, therefore BLEVE's in particular leave very little time for any form of effective shelter seeking behaviour. Jet fire exposure duration were significantly higher than that of the BLEVEs' because, their exposure durations are estimated based on the assumption that, shelter seeking behaviours play a role and therefore escape speeds and the distance to shelter matter. According to the Green book, exposure duration of less than 30 seconds is the norm with 30-60 seconds being pessimistic. In the Mexico City catastrophe in 1984, exposure duration was estimated to be less than 60 seconds but, in this study, up to 75% of the exposure duration values for Jet fire were below 10 seconds with only a very small portion being 30-56 seconds. Thus, exposure durations were not overly pessimistic.

Up to 75% of thermal dose units associated with the Jet fires had estimates which placed them into the pain threshold. The maximum values for the TDU were however in the 100% fatality range. TDU values recorded for Jet fires indicated that, statistically significant differences exist in TDU values for different land use types in the hazard zone. About 75% of the most economically active and densely populated land uses such as commercial, community service, government business, mixed use, residential and transport were not exposed to significant injuries or fatalities. Other land uses which were not densely populated such as vacant and derelict lands and utilities had higher TDU estimates with consequent 1st degree burns. The difference was mainly due to their inability to offer shelter from thermal hazards (Baixos. et al., 1992b). About 25% of these land uses also had values in the 2nd degree burn threshold.

For BLEVE hazards similar patterns in the TDU estimates were observed although the consequences were a level higher than that of the Jet fire. This stemmed from the fact that, BLEVE hazards had higher levels of thermal radiation which is a key component in the estimation of the TDU (American Institute of Chemical Engineers, 1994). Percentage fatality estimates indicated that, BLEVE hazards generate higher levels of fatality than Jet fires. However, the focused nature of Jet fires and their longer burn durations make them equally a dangerous phenomenon. Data from previous LPG fires in Ghana indicate that, the most fatal LPG accidents in Ghana include the Kwehu Fodua LPG tanker crash which occurred in the Eastern region and led to a Jet fire resulting in the loss of 27 lives (Donkor, 2014). The Louis Gas station incident which occurred near the Trade Fair Site (Trade Fair Jet fire) also claimed 12 lives compared to the 7 deaths from the Atomic Junction Gas BLEVE event (BBC, 2019).

Consequence based risk estimates indicated that, for the inner zone of both BLEVE and Jet fires, all locations except one had consultation distances which were below the current 500-meter separation distance required by local planning authorities and other state agencies (NPA, 2020a). In practice this means that, in all cases, if properly enforced, the 500-meter required separation distance can lower exposure to thermal radiation resulting in a less than 50% chance of fatality to persons beyond this limit. It is important to note however that, in practice, none of the 10 LPG stations actually had a 500-meter separation distance between it and other incompatible land uses. The land uses within the consequence-based risk zones were also largely incompatible with the land use requirements of LPG stations as they included hot works, public spaces and residential areas with vulnerable populations. For instance, residential land use in the inner zone formed 1.6% and 11.5% of the total land area for Jet fires and BLEVE's respectively whiles in the middle zone it constituted 10.5% and 19.5% for Jet fires and BLEVE hazards respectively.

Yirenkyi (2016) and Douti, Biyogue et al (2019) have also reported on issues of poor siting of LPG and Gasoline filling stations in Ghana and argued that, the close proximity (less than 30 - 50 meters) of filling stations to residential and other land uses pose a serious health and safety risk to residents. Essentially therefore, it is clear that LPG and fuel service stations in Ghana are not located in dedicated industrial zones but rather in areas with diverse and often conflicting uses. The current research even extends this argument by suggesting that, although some degree of non-conformance to industrial land use patterns exist near LPG stations, generally, the level of non-conformance increases with distance from the LPG station as observed in the middle and outer zones around these stations.

Assessment of the levels of vulnerability indicated that, depending on their location and sensitivity levels, some land uses were being exposed to excessive chance of fatality while others were not. This is because land uses in the inner zone, which were approximately 200 meters or less away from an LPG fire hazard exposed people to above 50% chance of fatality. Application of the UK HSE risk framework on land use patterns suggest that, between 90 and 98% of all land uses in the inner zone of LPG stations involved developments which should have been advised against, especially in cases where the stations predate these developments. The middle zone which was between 200 and 300 meters and therefore land uses in that zone are subject to dangerous doses of thermal radiation and greater than 1% chance of fatality which according to the UK HSE criteria is too high. Land uses in this zone also include those which have vulnerable populations or involve hot works such as educational (including boarding schools) and health facilities, residential, mixed use (commercial/residential) and service industries. Approximately 12-14% of land uses in the middle zone were advised against compared to the 98 and 90% indicating a percentage decrease of -87.8% and -84.4% in poorly situated land uses between the inner and middle zones.

The outer zone was a less vulnerable location for all land uses except for those which involved large scale human activities such as open markets, tertiary institutions and public open spaces where communities often gather for funerals and other social activities. Land uses in that category constituted only 5 to 6% of the land uses in the outer zone. These land uses were approximately 600 meters away from the station in the case of Jet fires and over 1000 meters for BLEVE hazards. Modification of the UK HSE land use sensitivity criteria showed that by accommodating only land uses compatible with industrial zones a marked reduction in vulnerability to LPG fire hazards can be achieved.

These findings were confirmed by results from a qualitative risk assessment conducted by a team of regulators from the National Petroleum Authority, Environmental Protection Agency, Ghana National Fire Service, Factory Inspectorate Directorate, and Ghana Atomic Energy Commission in 2019. The results from the assessment initially indicated that, 99% of existing LPG retail outlets were high risk based on the location of the stations, engineering, equipment conditions, safety management systems, staff and facility management, materials and fabrication of the LPG stations. Following a ministerial review, 510 out of 659 stations representing 77.4% of the LPG stations in Ghana were still classified as high risk while 17.5% were medium risk and 5.2% low risk (The Publisher, 2019)

Chapter summary

In summary, fewer areas were vulnerable to LPG hazards compared to the larger spatial foot print of the LPG hazard. Majority of the land uses in the Jet fire hazard zones were below the pain threshold while the BLEVE hazards had more than half of its area exposed to at least 1st degree burns. Both BLEVE and Jet fire hazards had more than 90% of their land uses recording zero fatalities based on a Tsao and Perry 1979 as cited in UK Health and Safety Executive, 2010) model.

Variations in vulnerability levels were dependent on the magnitude of the hazards at each location and also the exposure duration. Thus, the levels varied significantly across land use types with public open spaces and vacant lands in close proximity to LPG stations being more vulnerable. More than 90% of all land uses in the inner (>50% fatality) vulnerability zones of both BLEVE and Jet fire hazards were too exposed and susceptible to be allowed within the zone based on the UK Health and Safety executive's standards. Vulnerability levels were more tolerable based on local planning standards.

CHAPTER SIX

RISK ASSOCIATED WITH LIQUEFIED PETROLEUM GAS FIRE HAZARDS IN THE ACCRA METROPOLIS

Introduction

In this chapter, a probabilistic approach is adopted to estimate the risk of fatality resulting from LPG fire hazards for each land use type in the hazard zone. The approach combines known failure frequencies from existing literature with the consequences of LPG fire hazards in order to estimate individual risk using the Location Specific Individual Risk (LSIR) index. The estimated LSIR indices were then used as basis for evaluating the level of risk to land use types in the hazard zone by applying the UK Health and Safety Executive's risk criteria and land use sensitivity framework. The outcome of the evaluation provides sound basis for risk informed land use planning in the vicinity of LPG stations in the Accra Metro and other areas in Ghana.

Location specific individual risks were estimated for each land use type by adopting an LPG vessel failure frequency of $1 x 10^{-5}$ for BLEVE hazards and an LPG Bulk road vehicle accident frequency of $1 x 10^{-6}$ as published in the UK HSE failure frequency report (HSE - U.K. Health and Safety Executive., 2017). These failure frequencies were then multiplied with the probability of fatality from LPG fire hazards which had previously been estimated using a Tsao & Perry (1979 as cited in HSE - U.K. Health and Safety Executive., 2010)

Dose – Response model: $Y = -12.8 + 2.56 \text{ Ln (TDU)}$

Where,

Y= Probit value representing likelihood of fatality

TDU = Thermal dose units.

Location Specific Individual Risk thresholds published by the UK Health and Safety Executive were used to categorize the risk into three distinct zones. The three zones comprise an Inner zone (IZ), middle zone (MZ) and outer zone (OZ). The inner zone has a 10 chance per million (10 CPM) of fatality (equivalent to 1 chance of fatality per 100,000 population) while the middle zone has a 1 chance per million (1 CPM) of fatality (equivalent to 0.1 chance of fatality per 100,000 population). The outer zone has 0.3 chances of fatality per million (equivalent to 0.03 chance of fatality per 100,000 population). The consultation zones serve as the boundaries for evaluating proposed developments during land use planning. The physical distance to each of the thresholds was obtained using spatial analysis functions and the suitability of each land use type was evaluated based on its LSIR index and the sensitivity of the land use. Potential loss of life (PLL) estimates (estimates of societal risk) was also obtained by multiplying the LSIR values with population estimates of each land use.

Relative Proportions and the endpoint distances for LPG risk zones

BLEVE hazards recorded a coverage area of 75.9% compared to 22.6% for the inner zone and the middle zone respectively. The middle risk zone was also larger than the outer zone which had a coverage area of only 1.5% (Figure 37).

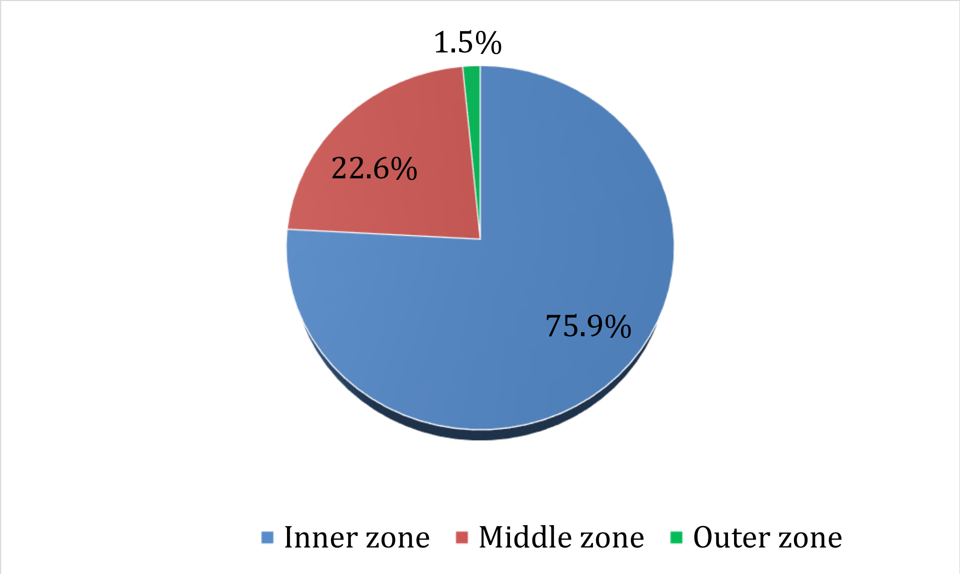

Figure 37: Coverage of the inner, middle and outer BLEVE risk zone
Source: Field work, 2019

Consultation distances derived for different filling stations in the study are shown in Table 20. The maximum consultation distance for the inner zone of BLEVE hazards ranged from 249.8 meters (Chorkor) to 360.5 meters (Kawkudi). With regards to the middle zone the maximum distance of this zone ranged from 279.7 to 402.6 meters (Kawkudi). The outer zone for BLEVE hazards ranged from 279.9 to 406.1 meters. The variation in consultation distance was due to differences in the quantities of gas stored at each location

Lastly, the minimum distance for places with no risk of fatality occurred at various ranges. The minimum distance at which this occurred was 277.1 meters at Chorkor and the maximum distance at which zero location specific individual risk occurred was 402.9 meters at Kawkudi (Table 20).

Table 20: Consultation distances for simulated BLEVE hazards

Risk criteria (UK. Health and Safety Executive)	Location	Tank Volume (m^3)	Min Distance (Meters)	Mean Distance (Meters)	Max Distance (Meters)
Inner zone (LSIR >=10 chances of fatality per million of the population)	Alajo	24.5	0	184.7	278.7
	Avenor	36.3	0	217.9	331.8
	Awudome	36.8	0	218.9	330.1
	Chorkor	16.3	0	155.5	249.8
	Dansoman	25.0	0	186.1	282
	Kawkudi	43.5	0	239.1	360.5
	Mamprobi	38.7	0	233.9	354.1
	Odorkor A	26.0	0	193.2	291.9
	Odorkor B	36.1	0	217.4	330.6
	Tudu	30.5	0	206.1	310.8
Middle zone (LSIR >= 1 chance per million but < 10 chances of fatality per million of the population)	Alajo	24.5	276.4	298.1	318.7
	Avenor	36.3	321.3	351.4	379.1
	Awudome	36.8	327.5	353.1	377.7
	Chorkor	16.3	247.2	263.6	279.7
	Dansoman	25.0	275.6	300.2	322.6
	Kawkudi	43.5	357.8	382.4	402.6
	Mamprobi	38.7	345.4	373.4	399.5
	Odorkor A	26.0	288.7	317.3	344.7
	Odorkor B	36.1	322.8	350.4	377.4
	Tudu	30.5	308.1	332.2	355.6
Outer zone (LSIR >=0.3 chances per million but < 1 chance of fatality per million of the population	Alajo	24.5	316.5	319.2	321.9
	Avenor	36.3	368.4	376.3	382.9
	Awudome	36.8	374.8	378.2	381.5
	Chorkor	16.3	276.8	278.2	279.9
	Dansoman	25.0	315.8	321.4	325.7
	Mamprobi	38.7	381.2	395.3	406.1
	Odorkor B	36.1	369.2	375.1	381.2
	Tudu	30.5	351.9	355.7	359.2
Zero LSIR	Alajo	24.5	321.0	652.4	897.5
	Avenor	36.3	373.9	742.9	1017.2
	Awudome	36.8	380.3	746.4	1019.7
	Chorkor	16.3	277.1	569.9	792.7
	Dansoman	25.0	319.0	657.1	904.2
	Kawkudi	43.5	402.9	762.4	1074.7
	Mamprobi	38.7	383.5	762.3	1035.8
	Odorkor A	26.0	341.0	669.4	914.9
	Odorkor B	36.1	374.4	741.4	1015.5
	Tudu	30.5	356.3	703.1	960.7

Source: Field Work, 2019

For Jet fire hazards, no inner zone was found as the LSIR values did not reach 10 chances per million or 1 chance per 100,000. Figure 38 presents the consultation distances at which the middle zone occurs for different locations in the study area. The mean distances for the middle zone were all below the 500-meter required separation distance between LPG stations and public places. The maximum distances recorded for the middle zone however, saw three stations namely Avenor, Awudome and Kawkudi exceeding a 300-meter range. All other stations also had middle zone endpoints which were below 300 meters but were still within the 500-meter required separation distance.

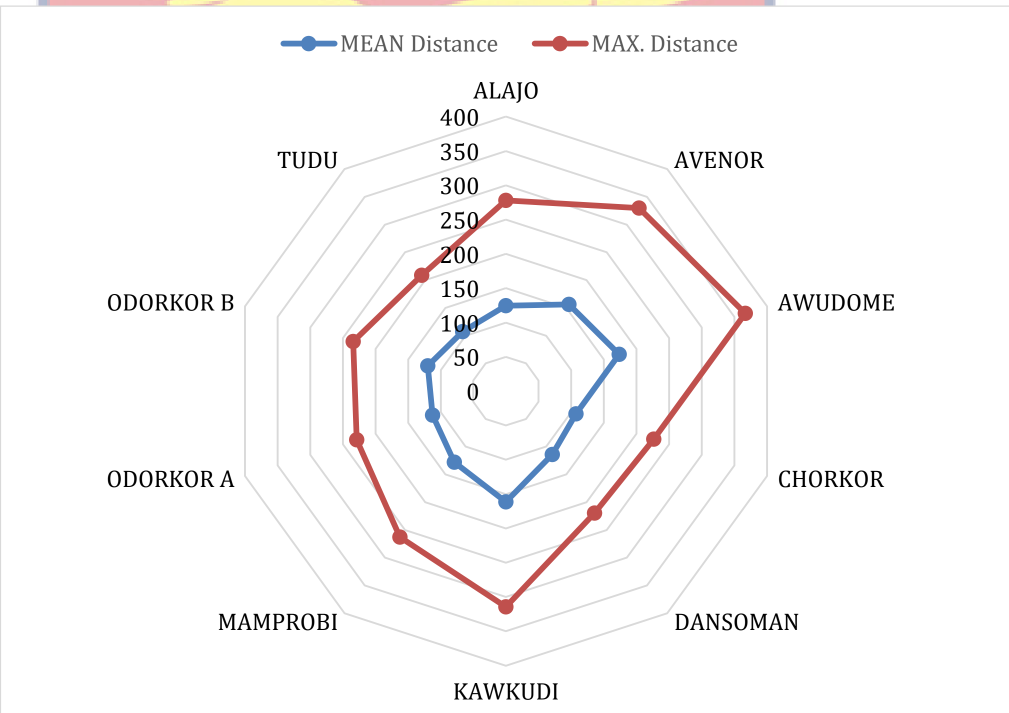

Figure 38: Consultation distances for LSIR middle zone: Jet fire hazards. Source: Field Work, 2019.

The spatial extent of the Jet fire hazard zones is shown in Figure 39. The orange-coloured areas show the extent of the middle zone. The light-yellow shows areas with negligible LSIR values.

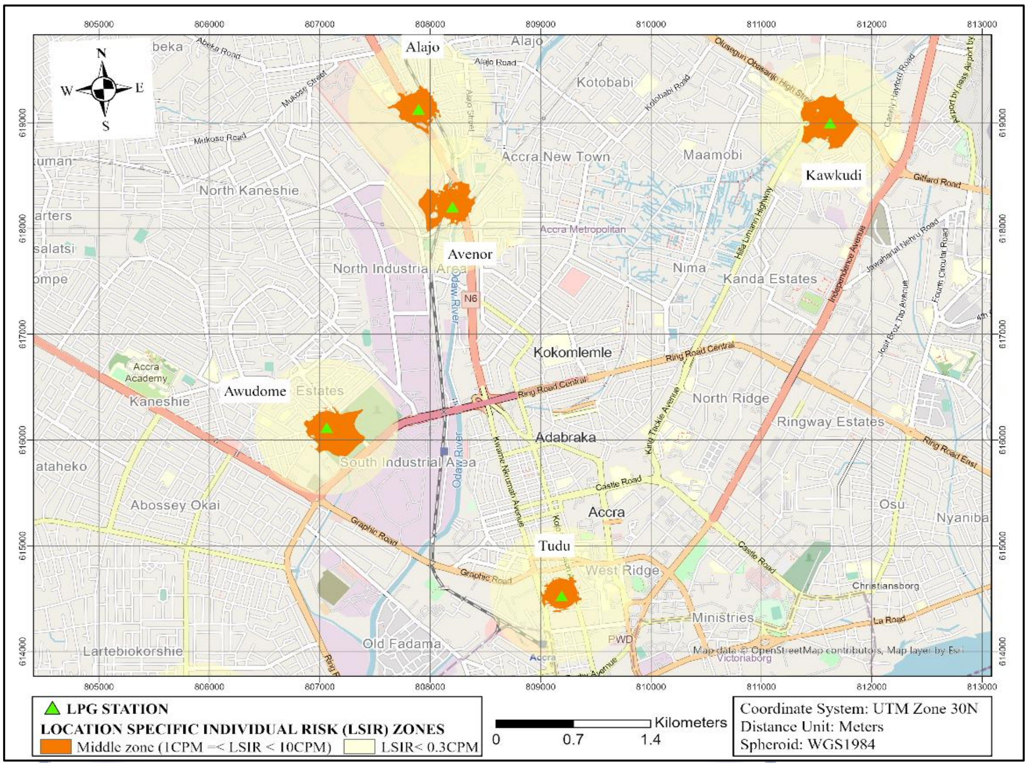

Figure 39: Spatial extent of Jet fire hazard zones
Source: Field Work, 2019

Land use patterns in the inner, middle and outer LSIR risk zones of BLEVE hazards.

Tables 17 and 18 in Appendix C show the percentage area for land uses that fall within each LSIR zone for all locations. In the inner zone where the chance of fatality is 10 chances per million, mixed land use (commercial and residential) had the highest land area of approximately 22%. This indicates that, mixed land use comprising conjoined commercial and residential uses are more exposed to the risk of fatality from LPG BLEVE hazards compared to other land uses within the inner risk zone. Residential land uses also occupied 19% or approximately 1/5th of the areas within the inner zone. This indicates that, a significant number of persons living within the inner zone would be exposed to 1 chance in 100,000 or 10 chances per million of fatality. Within the residential land use type, multi-storey and institutional residences had the highest coverage area. Altogether commercial, community services, residential and mixed use occupied 57.3% of the inner zone compared to 10.6% for industrial use.

For the middle zone, where there is a 1 chance of fatality per million (0.1 chance per 100.000), approximately 1/4th (24.5%) of the area was also occupied by mixed land uses comprising conjoined commercial and residential uses especially at the edge of major streets. In addition, about 27.2% of the area was being utilized for various categories of residential land uses with medium density, multi-storey and institutional residences having higher proportions. Community services in this zone also constituted about 16% of the land area (Appendix Q). Altogether, the residential, commercial, mixed use and community services occupied about 67.7% of the BLEVE middle zone compared to 11.3% for industrial use.

The outer zone had about 23.5% being covered by commercial/residential land uses. Residential areas of various types also occupied an additional 28.3% of the outer zone (Appendix R).

Land use patterns in the LPG Jet fire risk zones.

Land use patterns in the middle LSIR zone comprised only a small proportion of industrial use while other uses such as residential (11.7%), mixed use constituted approximately (10.9%), Community services (16.5%) made up the 39.1% of all land uses (Appendix S). Altogether, these land use constituted approximately 38.9% of the land uses in the Jet fire middle zone while industrial made up only 7.2%.

Risks Sensitivity Levels

The land use types were categorised into sensitivity levels based on the four level UK HSE land use sensitivity criteria. These levels are; level 1- land for use by working populations where higher levels of protection and organization are expected due to the indoor nature of the activities and the higher levels of emergency preparedness which are enforced at this level.

Level 2, land for use by the general public which captures the residential, retail and transport activity areas used by the general public. This level also captures guest houses and areas where community services are rendered.

Level 3, land for use by vulnerable people captures areas where healthcare, basic and secondary education and other services where minors or elderly and other vulnerable groups may be present. Level 4, land for use by dense large outdoor populations covering large open areas.

Sensitivity levels of land uses within BLEVE hazard zones.

For BLEVE hazard zones land use sensitivity level 2 which is land use meant for the general public was dominant at 70.2%. This was followed by level one which is meant for restricted groups such as formal and industrial workers who are very well organized with reference to safety. Level 3 and 4 followed in that order as shown in figure 40.

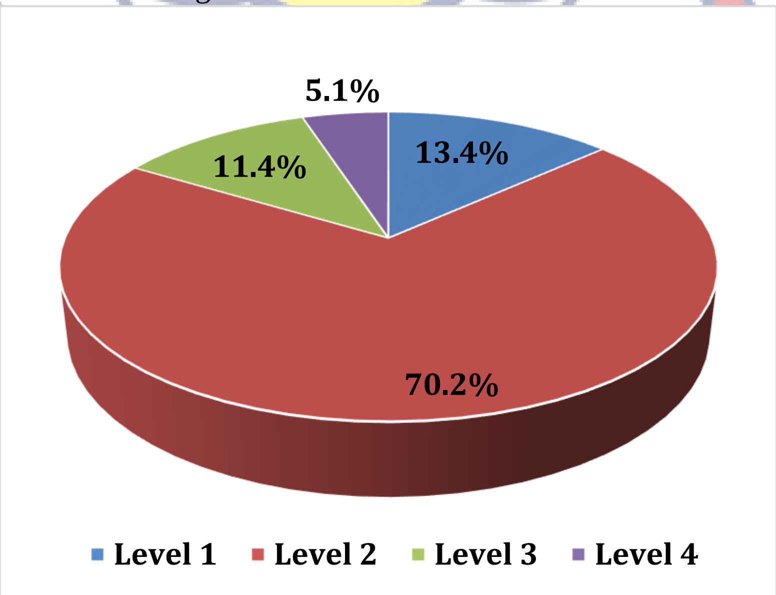

Figure 40: Land use per sensitivity level based on UK HSE guidelines
Source: Field Work, 2019

For level 1, which had general industrial (39%) and formal business (36.9%) constituted the largest proportions. A smaller proportion (26%) of the land use around LPG stations with this level of sensitivity was for government business (Appendix T).

For sensitivity level 2, 39% of the land use by the general public is mixed (commercial and residential) whilst 28% area was for residential land use. Another 10% of the land use at this level was for transport terminals and roadways (Appendix U). Considering sensitivity level 3, more than half (72%) of the land use activities captured at this level were residential high density and residential slum. Cumulatively, basic education and health formed 24% of land use types captured at this level. These groups are expected to have higher levels of vulnerability due to age, ill health and high population density (Appendix V). With respect to level 4, a higher proportion (47.8%) of the land used by large outdoor populations was for informal business such as open markets. Another 28% of the land area was used by large outdoor populations as public open space land (open spaces within communities). These areas were deemed to have a higher sensitivity to LPG hazards due to the cumulative societal risk resulting from the presence of very high number of people outdoors (Appendix V).

Sensitivity levels for Jet fire.

Land uses within the Jet fire hazard zones and their levels of sensitivity are shown in figure 41. Again, land use in level 2- land for public use dominated the Jet fire hazard zone. However, unlike the BLEVE, where public use spaces were the most dominant sensitivity level, for Jet fires, land uses in the vulnerable level 3 were the second most dominant. Land uses with very large human populations were last in both cases (Figure 41)

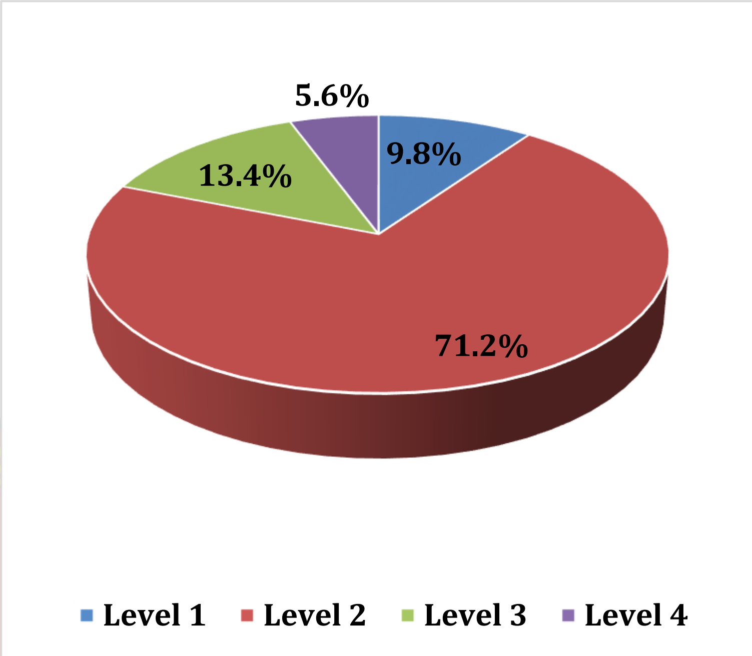

Figure 41: Sensitivity levels for land uses in Jet fire zones based on the UK HSE classification
Source: Field Work, 2019

For sensitivity level 1, formal business (44.4%) constituted a large proportion of the land area. Government business covered almost (34.5%) of the land area within this level (Appendix W). For level 2, mixed use commercial residential and roadways together constituted approximately 44% proportions of the total area. Mixed use (commercial/residential) alone accounted for approximately 34% of the total land area within this level. Residential land uses collectively constituted 27.3% of the land area within sensitivity level 2. Land uses such as derelict land, library, linear green space, major drain, major hazardous establishment, Community centre, mixed use community service, public toilet, Railways, and Refuse disposal all together constituted approximately 4% of the total land area of level 2 (Appendix X).

Residential high density (32.1%), residential slum (33.2%) and basic education (24.3%), together accounted for the largest proportion of the land area within sensitivity level 3. Informal business and tertiary education accounted for approximately 80% of the land area of sensitivity level 4 (Appendix Y).

Land use Decisions of the Study Area Based on the UK's Health and Safety Executive's Location specific individual Risk and Land use sensitivity Criteria

Land use decisions were analysed based on their location specific individual risk and their sensitivity levels. Some of the land uses within the inner, middle and outer risk zones were advised against based on the UK HSE criteria. This is because Ghana lacks a risk-based criterion for making land use decisions. Approximately 89% of all land use types in the inner zone of BLEVE hazards were advised against (Figure 42). Mixed use (commercial/residential) constituted the largest proportion (25%) of land use which was advised against within the inner BLEVE hazard zone. Residential land uses also constituted about 21.7% while community services made up 17.7% of all land use types in the BLEVE inner zone.

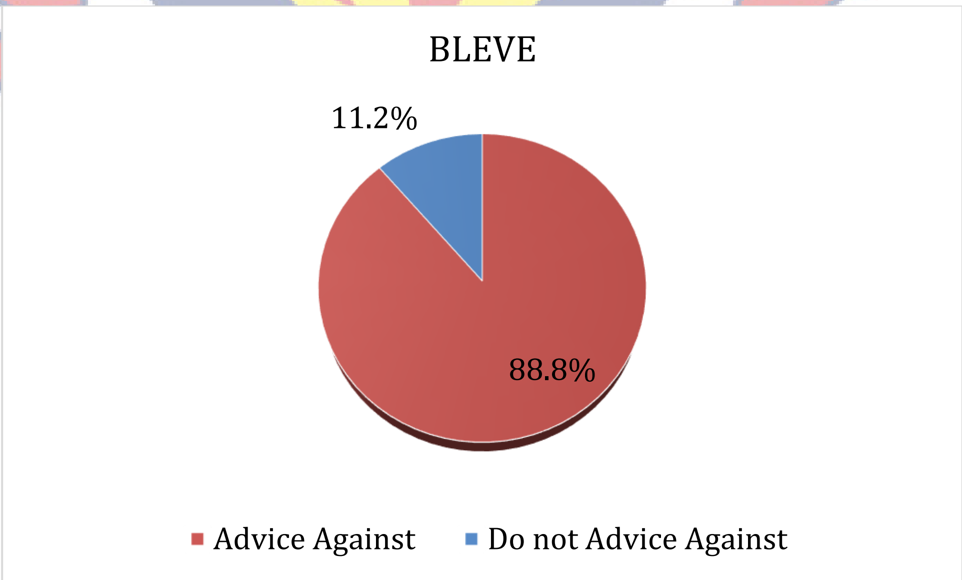

Figure 42: Land use decisions for inner zone of BLEVE hazards
Source: Field Work, 2019

In all, mixed use, commercial, residential and community services constituted a dominant proportion (65%) of all land uses in the BLEVE inner zone which should be advised against in the interest of public safety. Comparatively industrial land uses constituted only 11.1% of the land uses which were not recommended within the inner zone based on the UK HSE risk criteria (Appendix Z).

Compared to the inner zone, only a small proportion of land uses in the middle zone of both LPG fire hazards were to be prohibited. Within the advice against category, BLEVE hazards recorded slightly higher proportions compared to the middle zone of Jet fires (Figure 43). Specifically, in the middle zone of BLEVE hazards, educational services (48.6%) and high density and slum residential areas (43.9%) constituted the largest proportion (92.5%) of all land uses which were advised against in the interest of public safety.

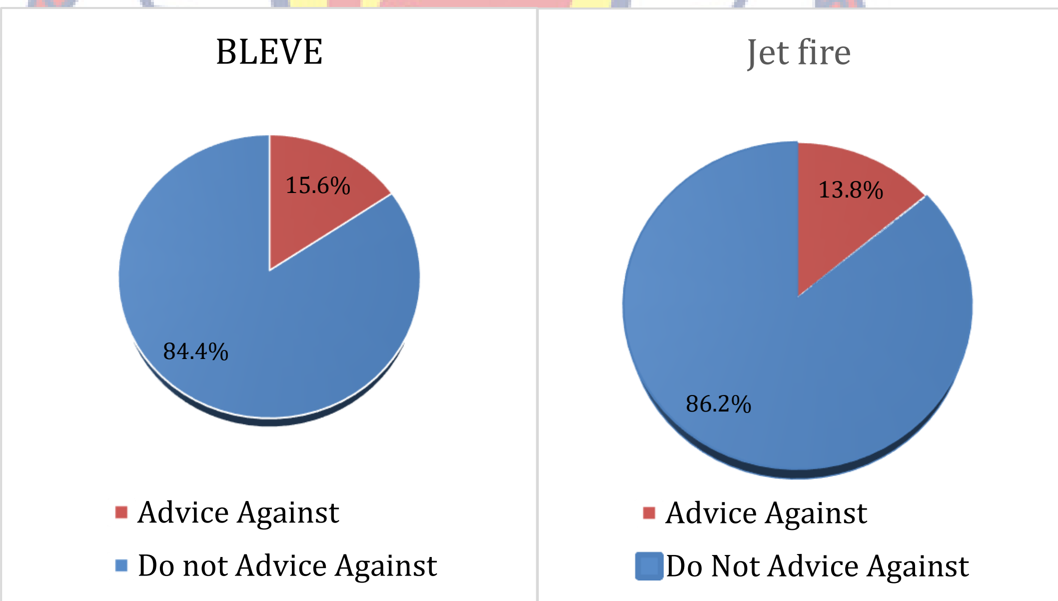

Figure 43: Land use decisions for middle zone of BLEVE hazards
Source: Field Work, 2019

Altogether, residential, commercial, mixed use and educational services constituted 95.9% of all land uses in the BLEVE middle zone which were to be reconsidered due to safety reasons (Appendix A1).

For Jet fire hazards, land use types which were advised against in the LSIR middle zone were mostly educational services (35.3 %), high density and slum residential areas (32.7%) and public open spaces (29.3%). All together, these land uses formed approximately 97.3% of all land uses deemed unsuitable for the Jet fire middle risk zone (Appendix A2).

Land use Decisions Based on the UK's Health and Safety Executive's Location specific individual Risk and a modified land use sensitivity Criteria

For land uses in the inner BLEVE zone changes in the sensitivity resulted in only a marginal reduction in the land uses recommended for prohibition (Figure 44). Within the inner zone, mixed land use (Commercial/Residential) had the highest coverage area of about 26%. This was followed by residential uses at 22.6%, community services (18.4%) and commercial services (7.1%). Together, these land uses constituted 74.2% terminals of the entire inner zone. (Appendix A3).

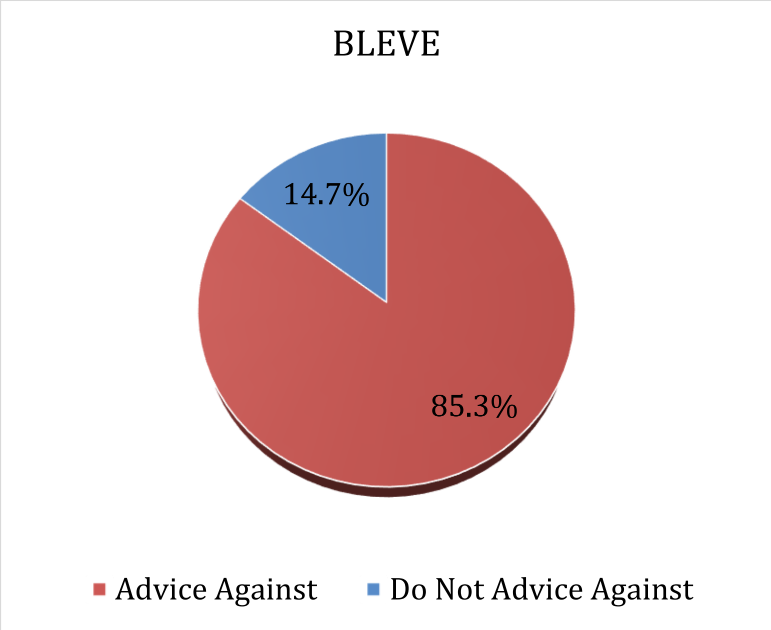

Figure 44: Land use decisions for inner zone using modified sensitivity
Source: Field Work, 2019

Land use patterns in the middle zones of both BLEVE and Jet fire hazards did not record any changes to the land use decisions under the modified sensitivity levels.

Discussion

The end point distance for the inner zone of BLEVE hazards was 360.5 meters and that of the middle and outer zone were about 406.1 meters and 402.6 meters respectively. This meant that all the zones effectively ended within the 500 meters' buffer required for such facilities. In effect the 500-meter legal separation distance would be effective as a protection mechanism against most of the risk associated with BLEVE hazards. Persons found within the required 500-meter separation distance would still be exposed to between 1 chance in 100,000 and 0.3 chances in 1,000,000 risks of fatality. (HSE - U.K. Health and Safety Executive., 2015). The inadequacy of the 500-meter separation distance is further proven by the 800-meter precautionary safety distance for LPG hazards recommended by the US Department of Transport in their Emergency Response Guide for the year 2020 (US Department of Transport, 2020).

There were differences in the consultation distances among all the 10-locations due to the variation in the volume of LPG stored at each location. The maximum distance at which LSIR of BLEVE hazard was negligible was about 403 meters for all locations. At a distance of approximately 404 meters and beyond, location specific individual risk was zero. However, because the distance at which zero LSIR was recorded varied among locations, it implied that, the risk of fatality from LPG fire hazards cannot be addressed through the application of generic safety distances. In the case of BLEVE hazards in Accra metro however, some degree of risk reduction may be implemented for distances beyond 405 meters.

Jet fire hazards recorded only a middle zone with maximum consultation distances in some cases up to 370 meters. This means that, for LPG Jet fires hazards in the Accra metro, significant fire risk reduction may be gained beyond a 370-meter buffer distance. Persons below this limit however, would be exposed to at least 1 chance in 100,000 and 0.3 chances in a 1,000,000 risk of dying from a Jet fire incident. The 500-meter legal separation distance therefore offers adequate protection from potential LPG Jet fire hazards in the Accra Metro.

The highest proportion of land area within the inner LSIR zone of LPG BLEVE fire hazards was mixed used (commercial and residential) and residential land use. This implied that, a larger number of people living in these land uses in the inner zone would be exposed to 1 chance in 100,000 of fatality. The middle zone and outer zone also exhibited similar land use patterns with mixed use (commercial and residential) and residential land use occupying larger proportion among all land uses in these zones. The trend of land use pattern within Jet fire hazard was also similar to that of BLEVE hazards as residential land use constituted the highest percentage of land area compared to other land uses within the BLEVE middle zone. This meant that, such land uses would also be exposed to significant risk. Land use such as formal business, general industrial, and government business were not advised against within the LSIR inner zone of BLEVE hazard using the UK HSE framework using the modified sensitivity criteria.

Chapter summary

The levels of risk from BLEVE hazards were greater compared to the risk from jet fires. The end point distances for the risk zone varied between stations and did not have a consistent shape. In the case of the BLEVE hazards, significant risks existed up to 406 meters compared to the risk from Jet fires which was lower at 366 meters. However, all the significant risk, occurred well within the required 500-meter separation distance between LPG stations and public places. Land use patterns in the risk zones were also similar to those in the hazard and vulnerability zones where sensitive land uses such as mixed and residential uses dominated. The industrial based was however much larger in the risk zone and in the case of the of the Jet fires, it amounted to at least a third of the area. More than 90% of all land uses in the inner risk zone of BLEVE's were determined to be in the advice against category because of their levels of sensitivity. These land use developments far exceeded the UK Health and Safety executives acceptable risk criteria of $1 * 10^{-6}$ for normal developments and $0.3 * 10^{-6}$ for sensitive developments such as schools and hospitals. Majority of land uses in the inner and middle zone also fell in to the prohibited category based on local zoning regulations and planning standards.

CHAPTER SEVEN

RISK PERCEPTION OF PEOPLE RESIDING AND WORKING AROUND LIQUEFIED PETROLEUM GAS STATIONS IN THE ACCRA METROPOLIS

Introduction

This chapter presents the results of a survey of persons living and working within the hazard zone around LPG filing stations in the Accra Metropolis. The socio-demographic and economic characteristics of the respondents as well as their perceptions of risks are presented and discussed. The influence of proximity, sex, and socioeconomic status on risk perceptions of respondents are also presented and discussed.

Socio- Demographic background of Respondents

Sex Composition

The majority of the 600 sampled respondents were male (68.7%). This was more than twice the percentage of female respondents who were about 31.3%.

Age Distribution

The majority of the respondents (93%) living and working around LPG stations were below the age of 60. At least 84.7% of the respondents were less than 50 years old. The age distribution of respondents was disaggregated by sex and it was observed that the mean age of females (33 years) was lower than that of the males (35 years). There were some outliers in the ages of both males and females. Males recorded 85 years as its oldest age whiles females recorded 74 years. It is therefore evident that, the respondents interviewed were from a youthful population composed of young males and even younger females (Table 21).

Table 21: Age distribution of respondents.

Age Category	Frequency	Percent
Less than 20 years	26	4.3
20 - 29 years	218	36.3
30 - 39 years	173	28.8
40 - 49 years	92	15.3
50 - 59 years	50	8.3
60 - 69 years	33	5.5
70+ years	8	1.3
Total	600	100.0

Source: Field work, 2019

Table 22 shows the marital status of respondents. Majority of them were single and had never married. This constituted approximately 50% of respondents. There was only a slight difference (5%) between singles and married people in terms of their relative percentages. Less than 6% of the respondents claimed to be divorced or widowed.

Table 22: Marital Status of Respondents

Marital Status	Frequency	Valid Percent
Never Married	297	49.5%
Married	268	44.7%
Ever Married	35	5.8%
Total	600	100%

Source: Field work, 2019

Educational Background

Regarding the educational background of the respondents, 39.7% (238) had completed secondary school and 33.8% (203) had some form of basic education. A smaller percentage had tertiary education (17.5%) whilst about 9%

had not attained any form of education. In Figure 45, the educational background of respondents is disaggregated by sex of respondent.

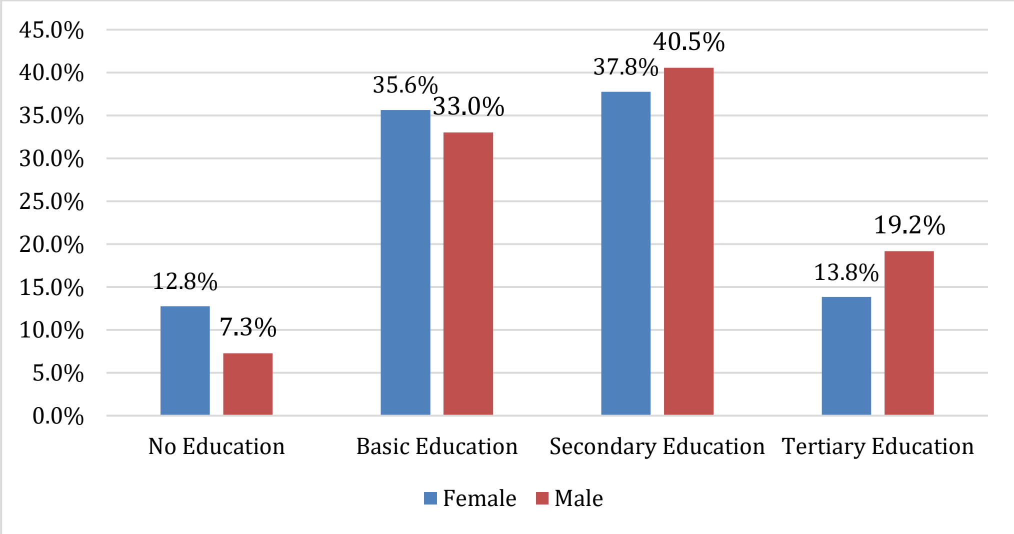

Figure 45: Educational status of respondents
Source: Field work, 2019

It was observed that amongst respondents in the hazard zone of LPG stations, males were better educated than females.

Employment Status

Considering the employment status of the respondents, (Table 23) indicates that, a larger number of the respondents were employed.

Table 23: Employment status of respondents

Employment Status	Frequency	Valid Percent
Employed	572	85.3%
Unemployed	88	14.7%
Total	600	100%

Source: Field work, 2019

To further understand the employment status of the respondents, their occupations were analysed. Out of the total number of people employed (572), majority of them (34.8%) were working in the technical or industrial sector, 21.8% were found in the administrative or service sector and 27.5% of them were into different forms of trading. A small percentage of the employed respondents were farmers (0.3%) and students (1.0%). The occupation of respondents was further disaggregated by sex as shown in Figure 46. The results showed that, majority of females were involved in various forms of trading, whilst most men were found in technical or industrial sectors. The number of males found in the administrative or service sector was approximately 7% higher than females found in the same sector.

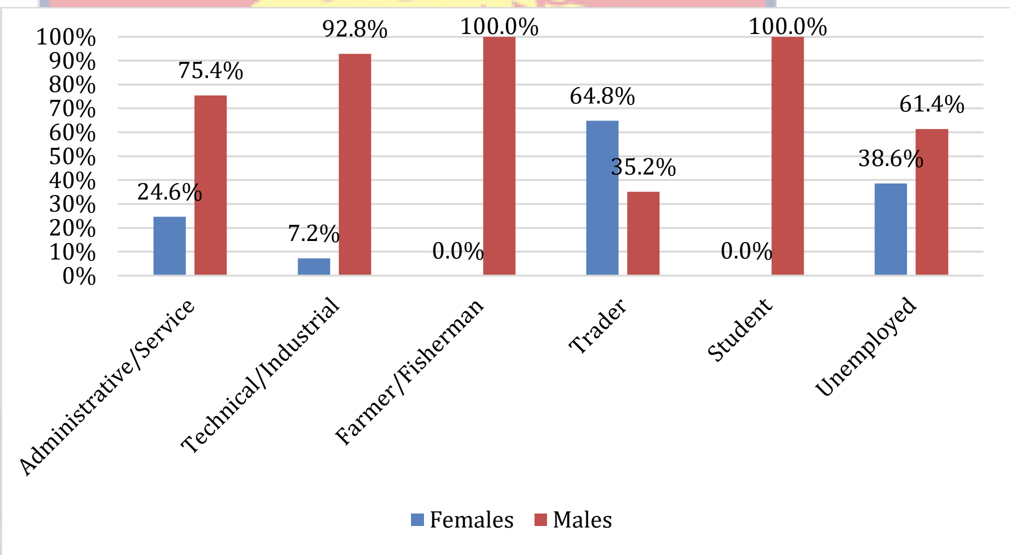

Figure 46: Occupation of Respondents
Source: Field work, 2019

The analysis of income for male and female respondents is shown in Figure 47. It is seen that, males had higher incomes than females in the GHC 500 – 1000 and more than GHC 1000 income brackets. Females dominated the lower and no income brackets.

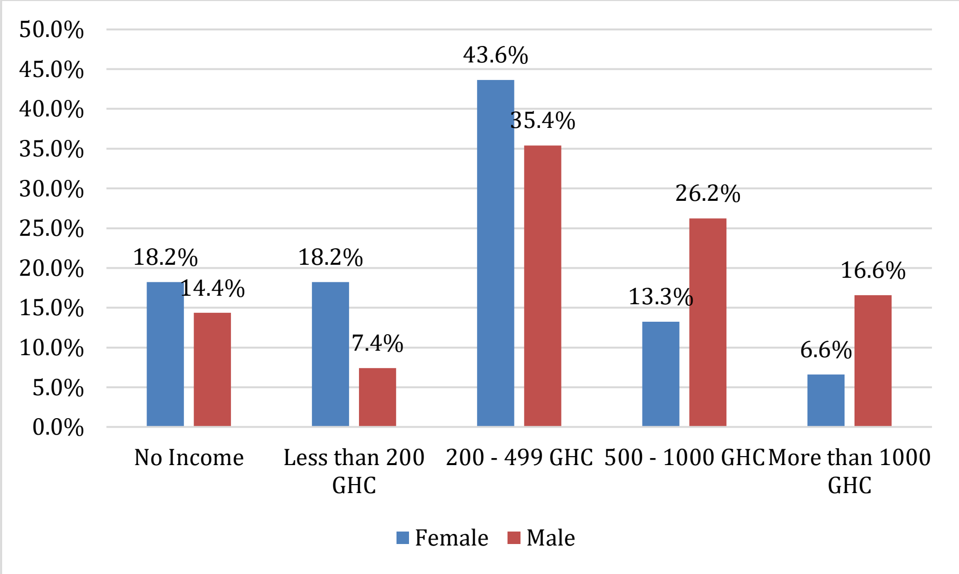

Figure 47: Income Bracket for Male and Female Respondents
Source: Field work, 2019

Proximity to the Station

Based on the sample size, 50% of the respondents interviewed were within 350 meters close to the gas filling station while 50% were farther away from the station. Approximately 51.6% of respondents in the inner part of the hazard zone were female compared to 49.3% who were male. In the outer zone, 48.4% were females whilst 50.7% were males.

Numbers of Years Spent in the Area and number of hours of work

It was determined from the survey that, approximately 25% of respondents had spent at least two years living and working near an LPG station. Fifty percent had spent at least five years and 75 % had spent at least 10 years. There was no difference between majority (95%) of males and females as to the number of years spent living and working around the station (Table 24).

Table 24: Number of hours and years spent around LPG stations

	Females	Males	Both	Females	Males	Both
Percentiles	Hours per day			Years spent		
10	1	1	1	1	1	1
25	1	1	1	2	2	2
50	2	2	2	5	5	5
75	7	6	6	10	10	10
90	8	8	8	20	20	20
95	9	9	9	27	30	30

Source: Field work, 2019

However, amongst persons who had stayed in the area for more than 26 years; males had a 3-year lead on females. This group however, constituted only 5% of all respondents.

As to the number of hours averagely spent each day living or working near the station, 25% spent at least one hour, 50 % spent up to 2 hours and 75 % spent up to 6 hours (Table 24). It was observed that, there were no large differences between number of hours spent by males and females who live and work near LPG filling stations.

Property Ownership

Respondents were further interviewed to understand the number of females and males who owned properties around the gas filling stations. Approximately 65% of both male and female respondents did not own any properties around the gas stations (Table 25).

Table 25: Property ownership status of respondents

		Female		Male	
		Freq.	%	Freq.	%
Own property near	No	108	57.4%	268	65.0%
the LPG station	Yes	80	42.6%	144	35.0%

Source: Field work, 2019

Risk perception of persons in the hazard zone of LPG stations

Responses to the type and level of risk perceived by subjects is presented in this section. To understand respondents' risk perception, various questions were asked on economic, social, environmental, health and security risk emanating from LPG stations. From the answers provided by the respondents some risk perceptions were formed. Generally, most respondents perceived minor risks compared to those who perceived major risk. Among those who perceived risk from LPG, health risk was rated higher than all other risk categories. This was followed by environmental, social, security and lastly economic risk. The results indicate that, respondents are more aware of the health, environmental and social consequences they may suffer as a result of the existence of an LPG station in the area than they are of the economic risk (Table 26).

Table 26: Risk Perception of Respondents

Type of Risk	Likelihood of serious consequences from LPG fire hazards	
	More likely	Not likely
Health	57.5%	42.5%
Environmental	41.6%	58.4%
Social	41.3%	58.7%
Security	41.0%	59.0%
Economics	35.5%	64.5%

Source: Field work, 2019

Dimensions of Risk Perceptions

To ascertain if there was an underlying structure in risk perception, twenty-nine (29) variables were subjected to principal component analysis (PCA). Prior to conducting the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix showed that, many of the coefficients were above 0.5. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy statistic was 0.944 which exceeded the recommended value of 0.6 (Kaiser, 1974) and Bartlett's Test of Sphericity (Bartlett, 1954) reached statistical significance at $p<0.01$, supporting the factorability of the correlation matrix. Inter item correlation was further confirmed by the results of the Cronbach's Alpha statistic of 0.960 which indicated strong positive correlation (Table 27).

Table 27: Suitability of the risk perception data for factor analysis

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.944
Bartlett's Test of Sphericity	Approx. Chi-Square	14599.225
	df	406
	Sig.	.000

Source: Field work, 2019

PCA revealed the presence of five components with eigenvalues exceeding 1. The five components explained 47.1%, 9.7%, 5.5%, 4.7% and 3.9% of the variance respectively. Examination of the scree plot showed a clear break after the second component. Using Catell's (1966) scree test, two components were maintained for further investigation. The two-component solution explained a total of 56.8% of the variance, with Component 1 contributing 47% and Component 2 contributing 9.7%. Due to potential correlation between the factors, and to help in the interpretation, the two factors were rotated using the Oblimin rotation as it is more suitable for factors which are correlated.

Table 28: Dimensions of risk perception

Factor 1	Loading	Factor 2	Loading
Experience land use conflict	0.903	Lose investments	0.875
Experience poor sanitation	0.856	Pay higher premiums	0.849
Experience food contamination	0.814	Lose access to credit	0.817
Experience noise	0.801	Lose access to your professional groups	0.804
Experience littering and improper waste disposal	0.778	Lose your savings	0.786
Experience water contamination	0.76	Lose access to your license to operate	0.68
Be targeted by criminals	0.745	Become unemployed	0.643
Become stressed	0.723	Lose your business	0.591
Become overly anxious	0.718	Lose your family members	0.566
Become fearful	0.693	Lose social/religious groups	0.564
Experience civil unrest	0.675	Lose your home	0.541
Experience violent conflicts	0.672		
Destruction of buildings	0.637		
Offensive odour	0.628		
Suffer health problems	0.508		

Source: Field work, 2019

The rotated solution revealed the presence of simple structure, with both factors showing a number of strong loadings. Fifteen (15) out of 29 variables loaded above 0.5 on factor 1 and 11 out of 29 loaded above 0.5 on factor 2. No variable loaded on both factors as shown in Table 44. The correlation of the items in each component was strong as shown by the Cronbach's alpha of 0.920 for the socio-economic risk component and 0.952 for the health-environment-security component. There was also strong positive correlation between the two factors (r = 0.561) which justifies the use of the direct Oblimin rotation method (Table 28).

Influence of proximity, sex and socio-economic status on perceived socio-economic risk from LPG hazards

As expected, there were far more respondents who perceived major socio-economic risk within the inner-lethal zone compared to the outer non-lethal zone (Figure 48).

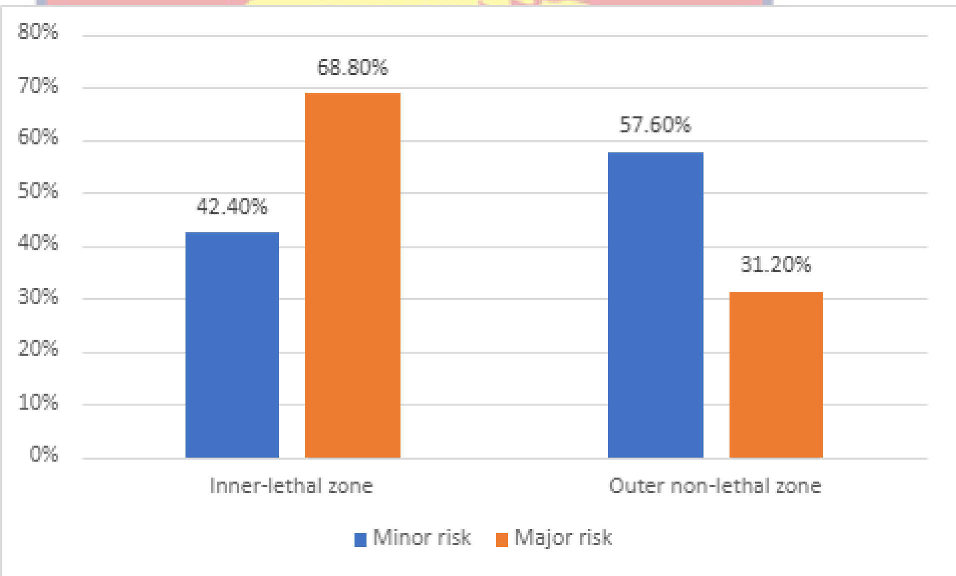

Figure 48: Effects of proximity to LPG stations on perceived socio-economic risk from LPG hazards
Source: Field work, 2019

Hence, the greater the proximity the more socio-economic risk that was perceived. The converse is true in the outer zone where distance decay leads to a reduction in the magnitude of risk perceived. Chi-square test of the association between proximity levels and risk perception suggest that, there exist a statistically significant relationship between them χ^2 (1, N = 600) = 37.2, $p < 0.001$. Cross tabulation of socio-economic risk with the sex of respondents also showed that, there were very little differences between the levels of socio-economic risk perceived by males and females (Table 29).

Table 29: Association between sex and perceived socio-economic risk

	Female		Male	
	Freq.	%	Freq.	%
Minor Perceived Risk	130	69.1%	285	69.2%
Major Perceived Risk	58	30.9%	127	30.8%
Total	188	100.0%	412	100.0%

Source: Field work, 2019

A Chi-square test further proved that, there was no significant relationship between the sex of respondents and their perceived socio-economic risk, $\chi2$ (1, N = 600) = 0.00, p < 0.995.

Table 30: Relationship between income levels and perceived risk

	No Income		Less than 200 GHC		200 - 499 GHC		500 - 999 GHC		1000 GHC Plus	
	Freq	%	Fre q	%	Freq	%	Freq	%	Freq .	%
Perceived Minor Risk	82	90.1	48	76.2	145	65.3	87	66.9	53	67.1
Perceived Major Risk	9	9.9	15	23.8	77	34.7	43	33.1	26	32.9
	91	100	63	100	222	100	130	100	79	100

Source: Field work, 2019

Cross tabulation of income and perceived socio-economic risk (Table 30) also suggest that, risk perception increases as income levels increase. However, at the highest income levels, the magnitude of risk perception reduces slightly but still remains higher than that of low-income earners. Chi-square test of the association between income levels and the magnitude of perceived socio-economic risk suggest that, there exist a statistically significant relationship between them χ^2 (4, N = 585) = 22.0, p < 0.001. Cross tabulation of property ownership and perceived socio-economic risk showed that, most of the people who perceived major socio-economic risk were persons who owned properties near the station (Table 31).

Table 31: Association between property ownership and perceived socio-economic risk

	No		Yes	
	Freq.	%	Freq.	%
Perceived Minor Risk	292	77.7%	123	54.9%
Perceived Major Risk	84	22.3%	101	45.1%
Total	376	100.0%	224	100.0%

Source: Field work, 2019

Chi-square test of the association between property ownership and the magnitude of perceived socio-economic risk indicated that, there exist a statistically significant relationship between these variables χ^2 (1, N = 600) =34.063, p < 0.000.

Regression Analysis

Binary logistic regression was performed to assess the impact of a number of factors on the likelihood that respondents would perceive major personal risk from LPG filling stations in their locality.

A model containing three independent variables (proximity to LPG stations, income and property ownership) was considered. The sex of respondents was not included because it had no significant association with perceived socio-economic risk. Due to multi-collinearity concerns, separate models involving proximity and income levels and proximity and property ownership were used to ascertain the effect of each set of independent variables on the perceived risk. The effect of proximity and income levels on the magnitude of perceived socio-economic risk was statistically significant, $\chi2$ (5, N = 585) = 60.346, $p < 0.001$(Table 32). This indicated that, the model was able to distinguish between the magnitude of perceived socio-economic risk of respondents within the lethal hazard zone and those beyond as well as for persons with different income levels. The model as a whole explained between 9.8% (Cox and Snell R square) and 14% (Nagelkerke R squared) of the variance in risk perception and correctly classified 70.9% of cases. As shown in Table 32, both independent variables (proximity and income levels) were statistically significant contributors to the model. Proximity to LPG stations recorded an odds ratio of 3.1(1/0.3) indicating that a unit decrease in proximity would lead to a 3-fold likelihood of perceiving major socio-economic risks (Table 32). The model also indicated that, compared to the no income group of respondents, generally, high income levels lead to a higher probability of perceiving socio-economic risk. Respondents who earned less than 200 GH¢ were only 2.4 times likely to perceive major risk than those in the no income group. Comparatively, respondents in the 200 – 500 GH ¢ category were 4.5 times more likely to perceive major socio-economic risk while those who earned between 500 – 1000 GH¢ were 4.6 times as likely to perceive major socio-economic risk. Those with the highest income levels (above 1000 GH¢) also recorded a high odds ratio of 4.0 even though this was slightly lower than that of the preceding two categories of income earners (Table 32).

Table 32: Effect of proximity and income on perceived socio-economic risk

	B	S.E.	Wald	df	Sig.	Exp (B)
Proximity-Inner-lethal zone (Reference)						
Proximity (Outer non-lethal zone)	-1.13	0.20	32.79	1	0.000	0.322
No income (Reference)			18.62	4	0.001	
<200 Gh ¢	0.89	0.47	3.61	1	0.057	2.435
200–499 GH¢	1.50	0.39	15.23	1	0.000	4.492
500–999 GH¢	1.54	0.41	14.40	1	0.000	4.662
1000GH¢ plus	1.38	0.43	10.17	1	0.001	3.988
Constant	-1.65	0.36	20.52	1	0.000	0.192

Source: Field work, 2019

Proximity and property ownership were also significant predictors of perceived socio-economic risk, $\chi2$ (2, N = 600) = 84.783, $p < 0.001$. The model was able to differentiate between the magnitude of perceived socio-economic risk of respondents within the inner-lethal hazard zone and those beyond as well as for persons who either owned properties within the hazard zone or those who did not. The model as a whole explained between 13.2% (Cox and Snell R square) and 18.8 % (Nagelkerke R squared) of the variance in risk perception and correctly classified 74.8% of cases. As shown in Table 33, both of the independent variables (proximity and property ownership) contributed significantly to the model.

Table 33: Effect of proximity and property ownership on perceived socio-economic risk

	B	S.E	Wald	df	Sig	Exp (B)
Proximity-Inner-lethal zone (Reference)						
Proximity (outer zone)	-1.14	0.2	32.41	1	0.00	0.32
No property near the LPG station (Reference)						
Property owned near the LPG station	1.35	0.2	47.74	1	0.00	3.87
Constant	-0.99	0.15	42.46	1	0.00	0.37

Source: Field work, 2019

Proximity to LPG stations again recorded an odds ratio of 3.1(1/0.32) indicating that a unit decrease in proximity would lead to a 3 times likelihood of perceiving socio-economic risks.

Property owners had a greater chance (3.87 odds ratio) of perceiving risk compared to respondents who did not own properties near the LPG station (Table 33).

The influence of proximity, income and property ownership on the health-environment-security dimensions of LPG disaster risk

The proportion of respondents who perceived major health-environment-security risk was greater than those who did not. Within the inner-lethal zone, those who perceived major risk were greater than those who were outside the lethal zone. This suggest that, proximity was a good predictor of the magnitude of health-environment-security risk perceived around LPG stations (Figure 49).

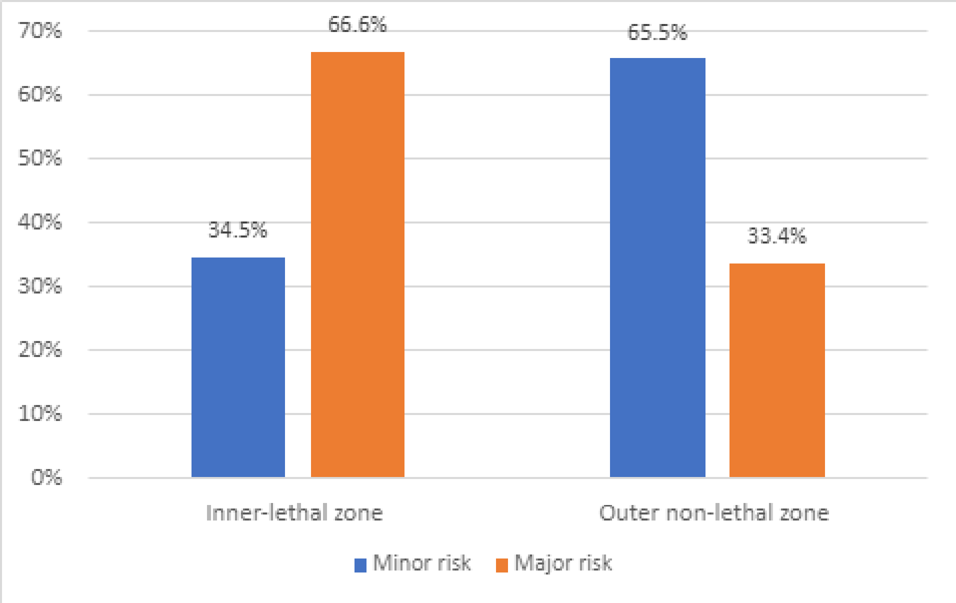

Figure 49: Effect of proximity on the perceived Health-Environment-Security Risk
Source: Fieldwork, 2019

A Chi-square test was once again run to verify the association between proximity levels and perceived health-environment-security risk. This was to provide an indication of whether or not proximity influences risk perceptions. From the Chi-square result, χ^2 (1, N = 600) = 79.1, p < 0.000, there was significant association between perceived health-environment-security risks and proximity levels. Cross tabulation of the sex of respondents against the perceived health-environment-security risks indicated that, there was only a marginal difference between the sexes relative to their perceived health-environment-security risks (Table 34).

Table 34: Sex and perceived health-environment-security risks.

	Female		Male	
	Freq.	%	Freq.	%
Perceived Minor Risk	90	47.9	199	48.3
Perceived Major Risk	98	52.1	213	51.7
Total	188	100	412	100

Source: Field work, 2019

A Chi-square test to verify the association between sex and perceived health-environment-security risk indicated that, χ^2 (1, N = 600) =0.009, p < 0.922, perceived health-environment-security risks of respondents were not dependent on their sex.

Cross-tabulation of income levels with perceived risk in Table 35 suggest that, compared to the no income group, higher income groups consistently reduced their perceptions of health-environment-security risks as their income levels increased. Lower income earners perceived more health-environment-security risks. A Chi-square test was run to verify the association between perceived health-environment-security risk and income levels. From the Chi-square result, χ^2 (4, N = 585) = 8.436, p < 0.77, a significant value of 0.77 was attained which is larger than the alpha value of .05. Therefore, it can be said that, there was no significant association between perceived health-environment-security risks and levels of income respectively.

Table 35: Relationship between income levels and perceived risk

	No Income		Less than 200 GHC		200 - 500 GHC		500 - 1000 GHC		More than 1000 GHC	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
No Perceived Risk	53	58	24	38	111	50	66	51	47	60
Perceived Risk	38	42	39	62	111	50	64	49	32	40
Total	91	100	63	100	222	100	130	100	79	100

Source: Field work, 2019

Cross-tabulation of property ownership with perceived health-environment-security risks in Table 36 suggest that, there were more property owners who perceived major risk compared to property owners who perceived minor risk. People who did not own properties were less likely to perceive risk.

A Chi-square test of the result indicated that, property ownership significantly determines people's perceived health-environment-security risk χ^2 (1, N = 600) = 18.89, p < 0.000.

Table 36: Property ownership and perceived health-environment-security risks

	No Property		Own Property	
	Freq	%	Freq	%
No Perceived Risk	220	58.5	90	40.2
Perceived Risk	156	41.5	134	59.8
Total	376	100	224	100

Source: Field work, 2019

The data was further subjected to a binary logistic regression analysis. The outcome indicated that, proximity and income levels were statistically significant predictors of perceived risk ($\chi 2$ (5, N = 585) = 68.668, p < 0.001). The regression model was able to differentiate between health-environment-security risk perception of respondents within and outside the lethal hazard zone and for people with different income levels. The model as a whole explained between 11.1% (Cox and Snell R square) and 14.8% (Nagelkerke R squared) of the variance in risk perception and correctly classified 66% of cases.

Proximity and income levels were statistically significant contributors to the model as shown in Table 37. The model indicated that, compared to the no income group of respondents, generally, higher income levels lead to a lower probability of perceiving major health-environment-security risk. Respondents who earned less than 200 GH¢ were 1.93 times more likely to perceived major risk than the no income group.

Table 37: Effect of proximity and income levels on perceived health-environment-security risk

	B	S.E.	Wald	df	Sig.	Exp(B)
Proximity-Inner-lethal zone (Reference)						
Proximity-Outer-lethal zone	-1.34	0.178	56.840	1	0.000	0.262
No income (Reference)			7.738	4	0.102	
<200 Gh ¢	0.66	0.354	3.455	1	0.063	1.930
200 – 500 GH ¢	0.18	0.266	0.463	1	0.496	1.198
500 – 1000 GH¢	0.285	0.291	0.962	1	0.327	1.330
Above 1000 GH¢	-0.29	0.331	0.763	1	0.383	0.749
Constant	0.45	0.246	3.343	1	0.067	1.568

Source: Field work, 2019

Compared to the no-income group, respondents in the less than 200 GH ¢ category had the highest odds ratio of 1.93 meaning they had the highest likelihood of perceiving major health-environment-security risks while those who earned highest income levels (above 1000 GH¢) recorded the lowest odds ratio of 0.749. This downward trend in the odds of higher income earners indicated that, health-environment-security risk from LPG hazards were of little concern to high income earners compared to low- and no-income earners. Further analysis however showed that, majority of the high-income earners did not reside in the hazard zone and therefore had limited exposure to the risk (Table 38).

Table 38: Residential status and income of respondents

	Not Resident		Resident	
	Count	%	Count	%
No Income	29	10.5%	62	20.1%
Less than 200 GHC	26	9.4%	37	12.0%
200 - 500 GHC	112	40.4%	110	35.7%
500 - 1000 GHC	72	26.0%	58	18.8%
More than 1000 GHC	38	13.7%	41	13.3%
Total	277	100.0%	308	100.0%

Source: Field work, 2019

Proximity and property ownership were also significant predictors of perceived health-environment-security risk, $\chi 2$ (2, N=600) = 80.729, $p < 0.001$. The model distinguished between perceived health-environment-security risk of respondents within the lethal hazard zone and those beyond as well as for both property and non-property owners within the hazard zone. In general, the model explained between 12.6% (Cox and Snell R square) and 16.8% (Nagelkerke R squared) of the variance in risk perception and correctly classified 66% of cases. Significant contributions were made to the model by both proximity and property ownership (Table 39).

Table 39: Effects of proximity and property ownership on perceived risk

	B	S.E.	Wald	df	Sig.	Exp (B)
Proximity (Outer zone)	-1.3	0.18	58.3	1	0.0	0.26
Do you own any property near the LPG station (Yes)	0.8	0.18	17.7	1	0.000	2.15
Constant	0.3	0.14	5.15	1	0.023	1.36

Source: Field work, 2019

Proximity to LPG stations again recorded an odds ratio of 3.9 (1/0.26) which indicates that, a unit decrease in proximity would lead to almost 4-fold increase in the probability of perceiving major health-environment-security risk. Property owners also had a greater chance (2.15 odds ratio) of perceiving risk compared to respondents who did not own properties near the LPG station (Table 39).

Psychological factors and risk perception

Risk perceptions of people living and working in the vicinity of LPG filling stations in the Accra Metro were subjected to in-depth interviews. Twenty persons consisting of 10 males and 10 females were interviewed. The ages ranged between 23 and 52 years. Major themes used in the interviews were derived from the psychometric paradigm of risk perception (Rundmo & Moen, 2006). The themes used are shown in (Table 40).

Table 40: Themes used in evaluation of the effect of psychological factors on risk perception.

Item no.	Themes Used in In-depth Interviews on risk from LPG stations
1	Whether the risk was caused by human error
2	Whether people face this risk voluntarily
3	Ability to personally control the risks
4	Propinquity (How personal is the risk)
5	Whether the risks were known precisely by the exposed person
6	Novelty of the risk
7	Extent to which the risks is known to science
8	Publicity of the risk
9	Whether death occurs immediately
10	Whether the risk was chronic or catastrophic
11	Whether the risk was common or dreaded
12	Severity of consequences
13	Whether the risk impacts children
14	Risk-benefit trade-off
15	Trust

Source: Field work, 2019

Source of LPG Risk, voluntariness of risk, and Ability to control risk

Most of the respondents from the interviews indicated that human error was the main source of risk from LPG stations. They explained that, many of the personnel handling operations at LPG stations are poorly trained and not motivated enough to respond to emergency situations that arise during their work. As such they may make errors which could lead to accidents and even when there is a leakage, they may be the first to run away instead of staying to deal with the problem. Three remarks from two males and a female are indicated below

> *The machines themselves cannot cause a disaster; it is the human beings who mishandle the machines that brings about the problem* (A 24-year-old male Chorkor resident).

> *The attendants mostly do not care about the regulations because they are focused on making money. Many times, they even over fill*

cylinders provided you are ready to pay the required amount (A 27-year-old female resident).

When they are filling their main tanks, because of money they try to over fill it, which causes the gas to shoot high into the air making us to run in all directions (A 42-year-old male non-resident).

On the voluntariness of risk, many of the respondents interviewed indicated that they live in the area and had been living there for a long time. Thus, the stations came to meet them and so they do not really know whether or not they can escape the risk because that was their home. Other respondents indicated that it was their place of work and since jobs are hard to come by there was nothing they could do. Simply put, they lack the capacity to negotiate the level of risk that they face. A 52-year-old male non-resident security man who had worked with a state agency in Tudu for over 20 years narrated how a major leakage occurred in the area. In spite of that, he has continued with his job at the same location for many years since the incident. A 38-year-old non-resident and mobile money vender in Odorkor also narrated an incident where fire broke out in a gas filling station near his shop. In spite of this, he has also maintained his location doing brisk business at the time of the interaction. According to the respondents, subsistence is the main reason why they feel they have no choice when it comes to the risk from LPG hazards.

The ability to control risk was a challenge for many of the people interviewed. Generally, their responses were in two main categories: First, most interviewees expressed an opinion which was adequately captured by a 32-year-old female resident who claimed; *I am helpless. I can do nothing.* A 43-year-old male resident also remarked that, *it will not happen here. I pray, so even if* *it happens, it would not affect me*. Other views expressed were much more behavioural such as the following; *I will run, I will not light a fire, etc.*

Propinquity, novelty and precision of knowledge on LPG risk

Many views were expressed concerning how personal the risk was to respondents interviewed. Many of the respondents felt that the risk was close to them given their proximity to the station. The risk of an LPG disaster was not new to most respondents as they had seen on television the extent of damage from LPG disasters which had occurred. Many of them could refer to the Atomic Junction LPG disaster incident and the Fuel station fire which occurred at the Kwame Nkrumah Interchange, Accra in 2015.

A few of those interviewed claimed that LPG disaster risk is a new phenomenon as such they do not have any idea about it. Some of the respondents had precise knowledge of the risk of LPG disasters. This was evidenced by some statements that respondents made on the issue including these two:

> *I cannot tell how likely an LPG disaster might be because I do not work at the station* (A 19-year-old male resident)
>
> *An LPG fire cannot affect me because I will run and escape from the area* (A 24-year-old male resident mechanic).

Despite this claim made by the mechanic, it was observed that, his place of work was immediately next to an LPG station. Thus, his ability to escape in the event of a fire hazard was improbable. The second respondent's inability to realize the sheer impossibility of out-running a gas fire when in such close proximity to the source of the fire reinforces the notion that, respondents had very limited knowledge of LPG fire hazards.

Scientific knowledge on risk and public concern

Most respondents contend that government knows about the risk associated with LPG hazards. A 36-year-old male non-resident asserted that;

Governments attempt to solve the risk of LPG disasters through the cylinder recirculation model proves that they are well aware of the risk

Another 45-year-old male resident said that: *This station has been shut down by Government before so they are well aware of the risk*

Fatality potential, immediacy, severity, impacts on children and fear factor

On the issue of the fatality potential all the interviewees agreed that LPG hazards can kill. Many indicated in their submissions that LPG incidents they have heard about always involved fatalities and that the burns alone can kill.

> *People have died through LPG accidents and so it is possible it can kill people here* (A 51-year-old female resident).
>
> *It takes only a split second for LPG to catch fire and there are many people here so it can certainly kill* (A 52-year-old male Odorkor resident).

This notion affirms the argument that, LPG hazards have immediate consequences which are almost certainly fatal and catastrophic rather than chronic. This means that LPG hazards can kill many people including children in a split second. Indeed, some of the respondents further suggested that, they harboured fear of LPG hazards given the seriousness of its outcomes. Opposite the Chorkor LPG filling station, a lady aged 43 made this claim, “At times I can even smell the gas and so I close the doors to the shop. It is very frightening”

All two persons interviewed at Avenor expressed fear of not only the LPG but also of the LPG station operators as there had been many confrontations with residents regarding the presence of the LPG station within the community.

One female community member who was initially approached for an interview declined but said;

> *Please go behind the house, away from the view of the station. There are people there who would talk to you. Over here no one will speak with you because we are all afraid.*

Some interviewees argued for the economic benefits of LPG and their views can be summed up by the statement made by a 36-year-old female interviewee who asserted that; *someone has setup his business and has employed people and is serving the community. Why should he stop?* Another 29-year-old male resident also stated that; *LPG must be tolerated within the community as it was bringing benefits to many people. There is no market outside of the community so we must live with it.*

Discussion

Generally, the data showed that, majority (2/3) of the people around LPG stations are young Christian males who are engaged in some form of technical or industrial type (blue collar) of jobs. A substantial number of females also engage in retail trade around the stations. At least a third of the two groups have some basic education with another one third having secondary education. Approximately half of the persons living around the stations are married with the other half unmarried. Many of the people also earned between 200-499 Gh¢ with a smaller proportion reporting no income or high incomes (above 1000 GH¢). The socio-demographic profile, is consistent with the general socio-demographic characteristics of the Accra Metro where a large number of the populace are young migrant workers with low wages.

About half of the population have spent at least five years living and working in the area. However, the median number of hours spent per day was two hours, indicating that, most persons in the area do not actually spend all their working hours there. This may be due to the nomadic nature of the retail trade which usually involves hawking rather than selling at fixed locations. Those who spend slightly longer hours may be more involved with the technical industrial activates which tend to be more stationary. This is supported by the fact that, only 42% of respondents said that they owned some form of property in the area meaning they had fewer economic ties with the area even though a majority of them lived in the area. It is common knowledge that in urban areas like Accra people travel long distances from their homes in order to seek a livelihood. Thus, most people do not work near their homes. The socio-demographic characteristics around the LPG sites are also not very different from what exist in part of the United State where hazardous facilities are primarily found in low-income areas with low level of education. Kearney and Kiros (2009) confirmed this in their research where blue colour workers were 2.689 times more likely to be located near hazardous sites than those with white colour occupation. Kearney and Kiros (2009) also found that more educated people are less likely to be located near hazardous areas.

The findings also indicated that, most people perceive minor risk compared to those who saw a major threat. However, amongst those who perceived a major risk, the health, environment and social risks were of more concern than security and economic risk emanating from the operation of LPG stations. This suggests that, most of the respondents are more concerned about the effect of the LPG fire hazards on their person and environment than on their assets. Dimensions of risk which also emerged from the study included socio-economic risk and health-environment-security risk. These two dimensions suggest that, socio-economic status may be important in moderating risk perceptions. Further analysis confirmed that, perception of socio-economic risk from LPG stations are moderated by property ownership and income status. Higher incomes generally increase the level of perceived socio-economic risk. This was also true for property ownership suggesting that, people with low socio-economic status are more concerned with their subsistence and have very little to lose economically in case of an LPG disaster. This is consistent with findings by Kusama et al.,(2018), Abramson & Inglehart (1995) where independently they observed that, people who were well educated and who earned a high income were more risk averse than lower income earners who were poorly educated. Maslow's hierarchy of needs (1948 as cited in (Neher, 1991b) provides further evidence of the importance of socio-economic status as a moderator of risk perception. It asserts that, individuals would attend to their basic needs of food and shelter before responding to higher order needs like safety and belongings. This reinforces the notion that, individuals care more about their basic need than an LPG fire risk which they do not precisely know as indicated by the results of the qualitative risk perceptions.

Behavioural decision theories also provide some insight into the risk perception and risk acceptability of individuals living and working around LPG stations. The behaviour of some of the respondents appeared to be rational based on their analysis of the cost and benefits of living and working around an industrial site. In their eyes, the socio-economic benefits of living and working around a hazardous industrial site, far outweighs the socio-economic risk. However, Williamson and Weyman (Williamson & Weyman, 2005a) also argue that the use of heuristics in assessing risk may lead to biases and errors in rational decision making which, may expose individuals to higher forms of risk. This appears to be the case as the respondents place socio-economic benefits far above socio-economic cost because they lack a full appreciation of the dangers of LPG fire hazards and thus underestimate the danger. This could further be explained by the fact that majority of the people living and working in Accra are migrants who came to look for greener pastures and thus place their livelihood issue well above any other concerns. The Poverty-Risk nexus by UNISDR (UNISDR, 2015), throws more light on the linkage between poverty and risk by explaining that, globalisation has created underlying risk factors especially in rural areas that promote rural urban migration. Such migrants invariably add to the multi-dimensionally poor in cities such as Accra. These migrants are faced with everyday risk of diseases, crime and food insecurity in their quest to survive within Accra. This situation leads to exposure to frequent low risk such as environmental pollution and crime around LPG as well as infrequent high risk such as the 9 BLEVE hazards, Jet fires and vapour cloud explosions which have occurred in Ghana. The physical and material losses which they experience and the inadequacy or lack of financial and material compensation which eventually worsens their poverty situation (www.ghanaweb.com, 2018).

Health-environment-security risks on the other hand responded negatively to socio-economic status. The implication of this is that higher income earners and property owners are less likely to worry about their health-environment–security risk than those with lower socio-economic status. Although respondents also indicated in the qualitative study that, they felt personally at risk, it was realized that, majority of those with higher incomes are not residents and therefore have limited exposure to health-environment and security risk. In the case of health environment and security risks, individuals who perceived minor risk did not consider the societal risk but focused only on individual risk and since they did not live within the vicinity of the hazard, they did not perceive any risk to themselves.

The risk perceptions expressed in this study during the in-depth interviews also confirmed arguments by Slovic (2016), Sjoberg (2000) and Williamson and Weyman (Williamson & Weyman, 2005a) that dread stemming from the severity of a risk and uncertainty/lack of familiarity plays a role in shaping risk perceptions. Respondents agreed on the possibility of an immediate and catastrophic nature of LPG fire hazard but could not provide precise information about the likelihood and severity of such incidents.

Finally, proximity to LPG stations has been an issue under contention for so many years and the results of this study add to the argument that, proximity to LPG hazards has a strong influence on individual's perceived risk. From the results, location within the potentially lethal inner zone influences an individual's perception of risk irrespective of the dimension. In this regard, it can be stated that, living within a distance of less than 350 meters from an LPG filling station could lead to strong perception of risk while distances greater than 350 meters lead to reduction in perceived risk.

Chapter summary

There was a dominant male population with a mean age of 35 years who were primarily engaged in blue collar jobs and a comparatively smaller and younger female population engaged in retail trade. Although most were married with children, they were low-income earners with mostly secondary education. The risk that these groups of persons faced was split along two dimensions namely: socio-economic risk and Health-Environment-Security risk. Low-income earners were more likely to perceive major socio-economic risk compared to high income earners who also owned property. Low-income earners perceived higher personal and environmental risk compared to high income earners because they only few of them actually lived in the hazard zone. Distance from the station was also negatively correlated with perceived risk. Psychological attributes of LPG disasters such as the catastrophic, immediate and involuntary nature of LPG also contributes to the perception`

CHAPTER EIGHT

RISK MANAGEMENT STRATEGIES OF RESPONDENTS

Introduction

This chapter presents the views from respondents on how the risk associated with LPG stations can be managed. The results include personal and non-personal risk management strategies that are deployed or expected to be deployed to reduce the risks from LPG hazards. The risk management strategies are discussed with reference to behavioural decision and value expectancy theories.

Personal risk management strategies

As part of the management strategies, suggestions were sought from the respondents on whether risks from LPG stations close to them ought to be reduced or not. The results indicate that, 98% supported a suggestion that, the risk from LPG stations should be reduced (Figure 50).

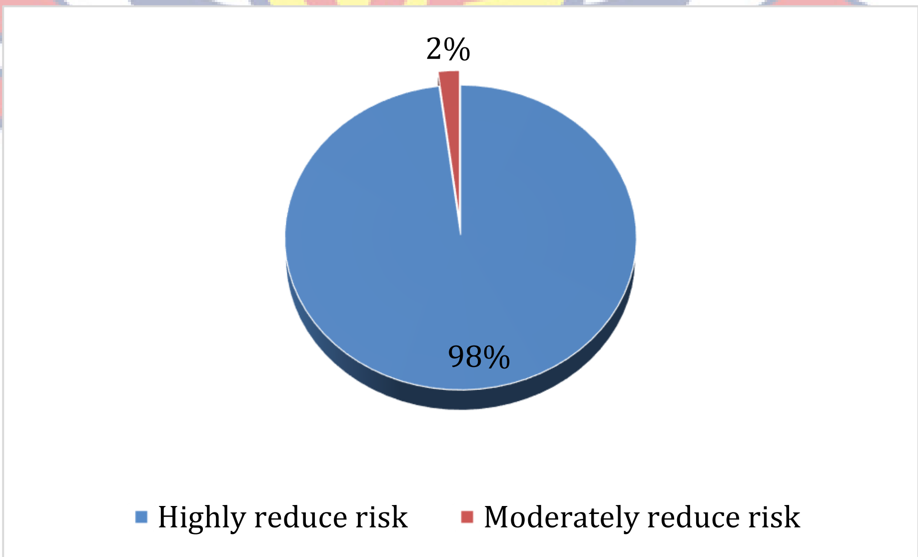

Figure 50: Perceptions on risk reduction
Source: Field work, 2019

As part of risk reduction, the respondents were also asked to rank on a scale of 1 to 5, how much the risk from LPG hazards should be reduced with 1 representing very small reduction and 5 very large reduction. The result from Table 41 shows that, a large percentage (86.7%) of respondents strongly wanted the risks from LPG stations to be very much reduced. Few of the respondents (0.3%) also wanted the risks from LPG stations to be reduced but not very much.

Table 41: Extent of reduction in risk of LPG disasters

Ranks of reduced LPG disaster	Frequency	Percent
1 – Very small reduction	2	0.3
2 – Small reduction	12	2.0
3 – Moderate reduction	30	5.1
4 – Large reduction	34	5.8
5 - Very large reduction	508	86.7
Total	586	100

Source: Field work, 2019

Respondents were asked to indicate which agency should be responsible for risks reduction. Figure 51 shows that, 37% of the respondents think that reduction of the risk from the LPG Stations is the responsibility of the government. About 25 % of the respondents however placed it at the doorstep of owners of the LPG stations. The views of this category of respondents may be linked to the claim that LPG stations are not properly managed by the owners which could lead to hazards. Some respondents (about 19%) also indicated that risks from LPG hazard should be a public concern and should be reduced by everybody.

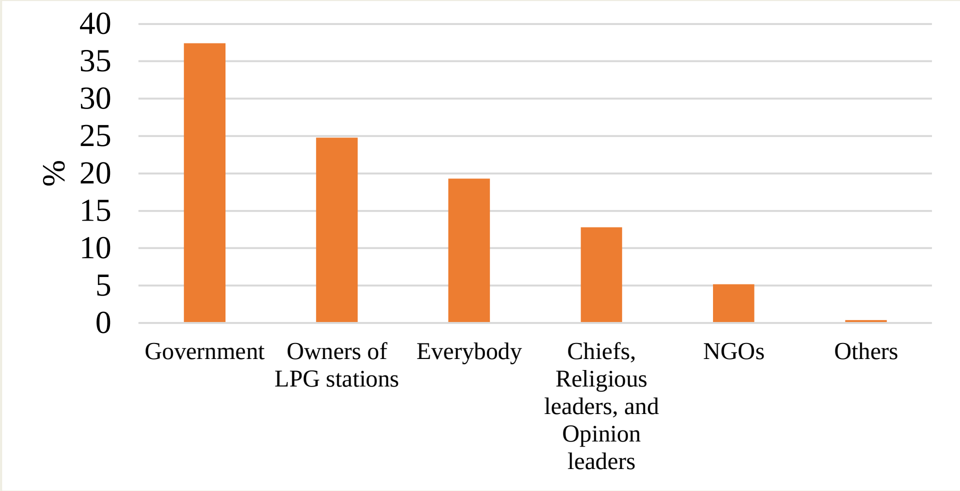

Figure 51: Responsibility for reduction of risk from LPG stations.
Source: Field work, 2019

The personal risk management strategies were categorized into three namely cognitive responses, behavioural responses, and a combination of both cognitive and behavioural responses. Figure 52 indicates that, most of the responses were basically cognitive, followed by behavioural strategies with a few being a combination of both cognitive and behavioural strategies.

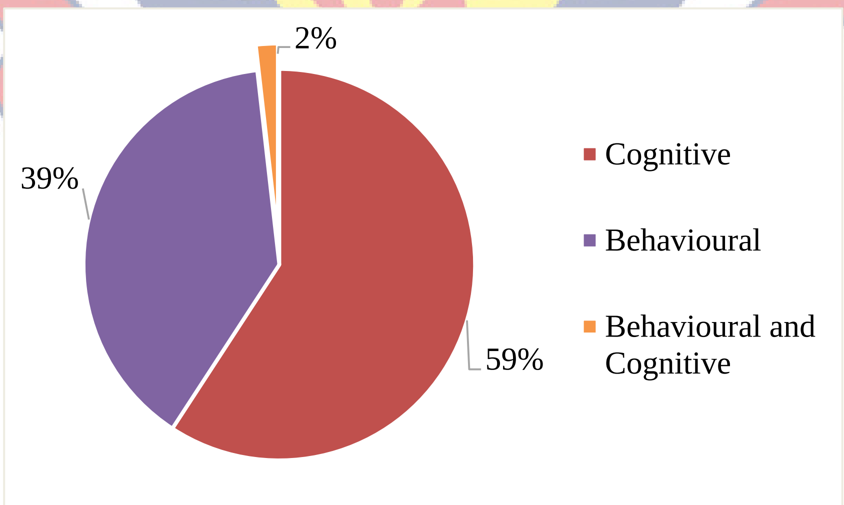

Figure 52: Categories of responses on risks management strategies by respondents
Source: Field work, 2019

Behavioural responses

Behavioural responses are the physical actions that respondents would take to reduce or manage the risk from the LPG hazards. These responses were grouped into four themes such as risk avoidance, risk mitigation, risk transfer and risk financing (risk retention). As Figure 53 shows a majority of the behavioural responses were on risk mitigation (49%) and risk avoidance (44%). Only a few of the responses were on risk transfer and risk financing.

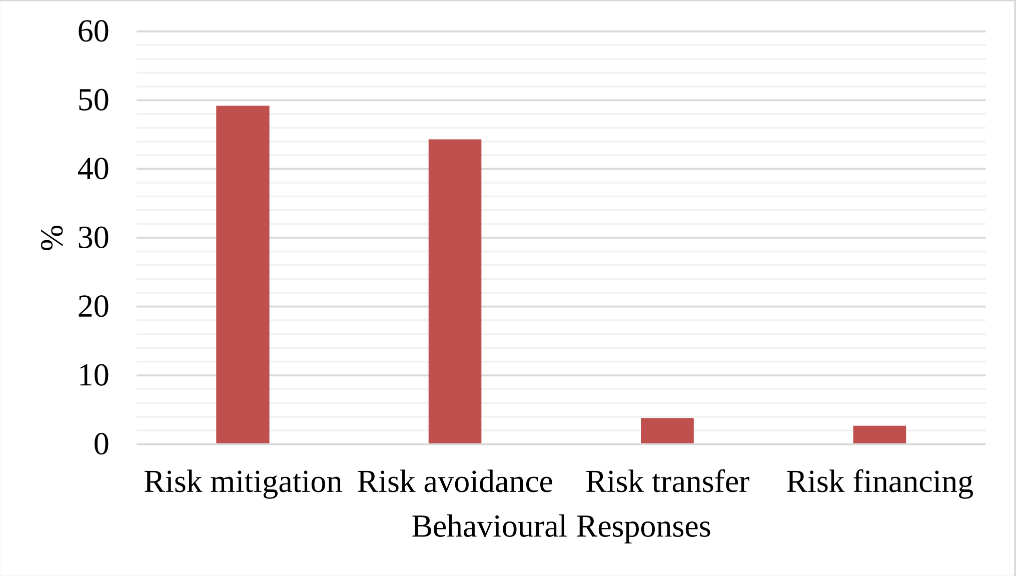

Figure 53: Behavioural responses on risk managements by respondents
Source: Field work, 2019

Specifically, respondents who adopted risk avoidance indicated that they deliberately avoid spending time in the immediate vicinity of the station or avoid lighting fires or using naked flames near the station. Others also indicated that they had no properties or valuables in the hazard zone and would therefore be spared from serious economic losses in the event of a fire. Others suggested that, they would relocate when they have the means to do so. For those who selected mitigation strategies, they indicated that they would run or call the fire service in case of fire. Other mitigation measures included purchasing fire extinguishers to protect their homes and properties. Respondents who adopted risk transfer also indicated that they either had fire insurance or depended on others to transact business in the vicinity of the station. For those who retained the risk, they suggested that they had adequate resources to rebuild in the event of a fire and could therefore not be distracted from pursuing their economic activities.

Cognitive Response

Cognitive strategies are non-physical actions or mental actions/views which respondents use to manage risk from LPG stations. Table 42 indicates that more than half of the respondents (58.3%) seem helpless and cannot do anything to manage the risks. Another 22.7 % of respondents also believed that another agency should do something about the risk. Faith in divine protection was also adopted by about 14 % of respondents who had a cognitive response strategy. Some 3.5 % of respondents also believed that a disaster would not take place or even if it did, they would not be directly affected; a claim relating to the “positive self, negative other” principle (Van Dijk, 1993).

Table 42: Cognitive responses on risk managements by respondents

Cognitive Response	Freq.	Percent
I am helpless. I cannot do anything about the risk	218	58.3
I believe another agency should do something about it	85	22.7
I pray for the disaster not to happen	34	9.1
I pray for God to protect me even if it happens.	17	4.5
I believe that, there will be no disaster	10	2.7
I believe if a disaster happens it would not affect me.	3	0.8
I believe I would not be affected because I am far away from the Gas station	7	1.9
Total	374	100

Source: Field work, 2019

Issues of proximity was another concern that came out as a cognitive response. Some 2% of the respondents argued that they were too far away from the LPG stations and will therefore not experience any risk from LPG hazards.

Effect of risks perception on risk management strategies

The risk perception of respondents was used to determine the strategies adopted to manage the perceived risk. The risk perception was categorized into very minor risk, minor risk, major risk, and catastrophic risk. The management strategies were also grouped into cognitive, behavioural, and both cognitive and behavioural. Cognitive strategy was used as a reference category for a multinomial logistic regression. From Table 43, it can be observed that respondents who perceived major risk were 1.861 times more likely to adopt a behavioural rather than cognitive risk management strategy.

Table 43: Effect of risks perception on risk management strategies

		B	SE	Wald	df	Sig	Exp(B)
Behavioural	Intercept	-0.84	0.25	11.18	1	0.00	
	Very minor risk	-0.13	0.49	0.07	1	0.79	0.88
	Minor Risk	0.43	0.30	2.07	1	0.15	1.54
	Major risk	0.62	0.28	5.06	1	0.03	1.86
	Extremely major risk	0^b			0		
Behavioural and Cognitive	Intercept	-3.28	0.72	20.70	1	0.00	
	Very minor risk	-18.38	0.00		1		0.00
	Minor Risk	-1.26	1.24	1.03	1	0.31	0.29
	Major risk`	0.28	0.81	0.12	1	0.73	1.32
	Extremely major risk	0^b			0		

Source: Field work, 2019

Comparatively, those who observed very minor risk were less likely to adopt a behavioural risk management strategy even though, the results were not significant.

Perception on effectiveness of personal risk management strategy

Respondents provided their perceptions on how effective they thought their risk management strategies would be in the event of a disaster. These perceptions were compared with the cognitive, behavioural, and the combination of both strategies as shown in Figure 54. The result indicated that, generally, less than 50% of respondents who hope to employ some form of personal risk management perceived their strategies to be effective. The highest returns were mainly those who adopted behavioural strategies. Those who perceived their strategies to be ineffective were mainly, those who adopted cognitive risk management strategies.

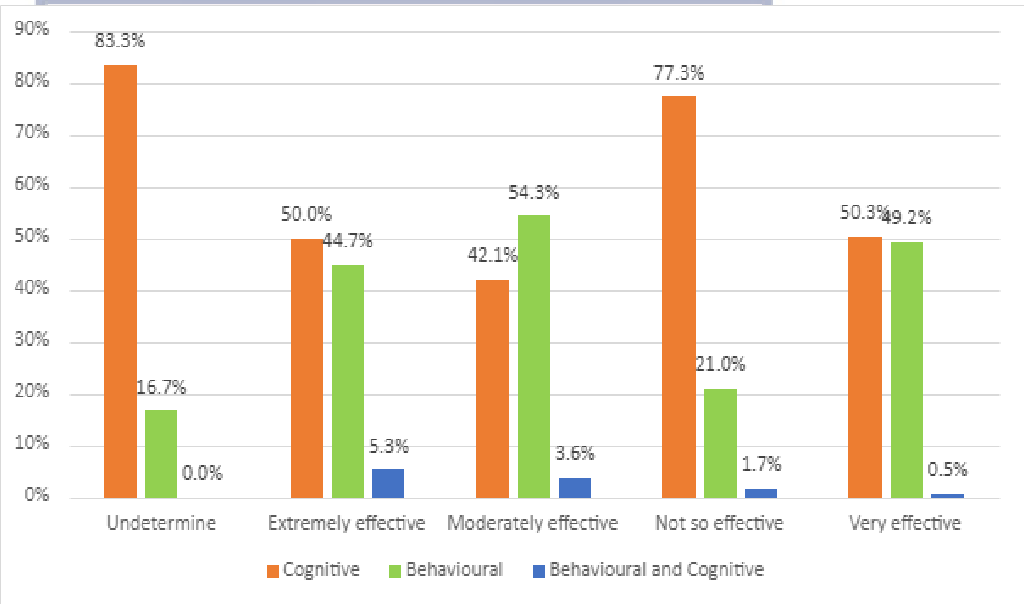

Figure 54: Effectiveness of risk management strategy
Source: Field work, 2019

Non-Personal Risk Management Strategies

With respect to the use of alternative risk management strategies, it can be observed that, majority of respondents (92.4%) support the use of safer technology at LPG stations to help reduce LPG hazards. It was also clear that, there was a general lack of support from respondents for the use of alternative fuels such as charcoal. However, approximately 62.3% of respondents also offered moderate to complete support for reduction in the quantity of gas stored at LPG station to help reduce or manage risk from the LPG hazards (Table 44).

Table 44: Level of support for Safe technology and alternative risk mitigation strategies

	Introduce safer technology at LPG Stations		Reduce the quantity of gas stored at LPG stations		Promote the use of charcoal instead of LPG		Practice Cylinder recirculation model	
Level of Support	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not in Support	19	3.2	134	22.3	244	41.2	167	27.8
Little Support	32	5.3	92	15.3	112	19	75	12.5
Moderately Support	114	19.2	116	19.3	90	15.2	96	16
Completely Support	429	72.2	258	43	146	24.7	262	43.7
Total	594	100	600	100	592	100	600	100

Source: Field work, 2019

Further, about 60% of the respondents offered moderate but highly significant support (χ^2 (3, N = 59) = 20.861, p < 0.000) for the Government's cylinder recirculation model as an LPG risk management strategy. Majority (>90%) of respondents offered little to moderate support for alternative strategies such as the Cylinder Recirculation Model irrespective of their levels of perceived risk (Appendix A4).

From Table 45, it is observed that, in respect of safe management as a strategy for risk reduction, about 80.7% of the respondents completely supported strict management of the LPG filling stations to minimize risk from the LPG hazard. A larger proportion of the respondents also completely supported the idea that more checks be done at the LPG stations as a risk management strategy. There was also complete support (82.8%) for improvement in knowledge and skills of personnel working at LPG filling stations as a risk management strategy. In addition, 82.5% of the respondents completely supported the idea that, there should be education on safety for the general public. Generally, support for the use of safer technologies and management regimes in LPG fire hazard control was high among respondents.

Table 45: Level of support for Safe management as an LPG hazard mitigation strategy

	Ensure strict management at LPG filling stations		Undertake more checks at LPG stations		Improve the knowledge and skills of the personnel at LPG filling stations.		Educate the general public on safety	
Level of Support	Freq.	%	Freq.	%	Freq.	%	Freq.	Percent
Not in Support	8	1.3	9	1.5	16	2.7	5	0.8
Little Support	23	3.9	18	3	23	3.9	20	3.4
Moderately Support	85	14.2	75	12.6	89	14.8	79	13.3
Completely Support	484	80.7	492	82.8	472	78.7	489	82.5
Total	600	100	594	100	600	100	593	100

Source: Field work, 2019

A Chi-square test further indicated that, there was a statistically significant association between levels of perceived risks and support for the use of safe technology and safe management $\chi 2$ (3, N = 586) = 13.144, p < 0.004 (Appendix A5)

With respect to land use planning as a risk reduction strategy, many respondents (60.9%) did not support the idea of relocating everyone living close to LPG filling stations, however, a small majority (54.4%) offered moderate to complete support for the removal of schools and public facilities from the vicinity of LPG stations (Table 46).

Table 46: Level of support for land use planning as an LPG hazard mitigation strategy

Level of Support	Relocate everyone		Relocate LPG stations		Relocate community services		Retain stations and budget for the risk	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not in Support	301	50.2	67	11.2	194	32.4	307	51.8
Little Support	64	10.7	44	7.3	79	13.2	58	9.8
Moderately Support	66	11	66	11.1	59	9.8	67	11.3
Completely Support	169	28.2	420	70.4	267	44.6	161	27.2
Total	600	100	597	100	599	100	593	100

Source: Field work, 2019

A majority of respondent (70%) rather offered complete support for the relocation of LPG stations to uninhibited areas. About 61.6% of respondents also offered little or no support for the retention of LPG stations at their present locations, even in lieu of compensation in the event of an accident (Table 46). It was also observed that, there was limited support for land use planning as a strategy for mitigating LPG hazards irrespective of the levels of perceived risk (Appendix A6).

About 77.7% of respondents were also in support of government procuring more ambulances and fire trucks and personnel to support emergency response in the event of LPG fire hazards (Table 47).

Table 47: Level of support for emergency response as an LPG hazard mitigation strategy

	Get more ambulances and fire trucks and personnel	
Level of Support	Freq.	%
Not in Support	80	13.3
Little Support	54	9
Moderately Support	123	20.5
Completely Support	343	57.2
Total	600	100

Source: Field work, 2019

Confirmatory Factor Analysis of Risk Management Strategies

Confirmatory Factor Analysis (CFA) using the principal axis factoring method was conducted using the 13 non-personal LPG risk management strategies suggested by respondents. The 13 variables were expected to conform to the industrial risk management framework put forward by the European Commission in the SEVESO II directive. The framework suggests that, industrial risk management strategies entail the following; Safe technology, safe management, land use planning and emergency response.

Prior to the CFA, the suitability of the suggested items for factor analysis was assessed and the returns showed that, many coefficients were above 0.5. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy statistic was 0.801 which is greater than the recommended value of 0.6 (Kaiser, 1974) and Bartlett's Test of Sphericity (Bartlett, 1954) reached statistical significance $p<0.001$, supporting the factorability of the correlation matrix. PCA of the variables with Oblimin rotation due to potential correlations amongst the factors showed the presence of three components with eigenvalues greater than 1. The three-component solution explained a total of 51.36% of the variance, with

Component 1 contributing 27.3%, Component 2 contributing 14.1% and component 3 contributing 9.9%.

Table 48: Factor analysis of management strategies of risk from LPG hazard

	Components			Communalities
	1	2	3	Initial
Undertake more checks at LPG stations	**0.838**	0.188	0.107	0.704
Improve the knowledge and skill of the personnel working at LPG filling stations.	**0.813**	0.048	0.038	.673
Ensure strict management at LPG filling stations	**0.802**	0.195	0.040	0.647
Introduce safer technology at LPG Stations	**0.775**	0.165	0.144	0.606
Educate the general public on safety	**0.745**	0.171	0.058	0.557
Remove schools and other services which attract large number of people from the neighbourhood of LPG stations.	0.173	**0.696**	-0.097	0.419
Maintain LPG station but pay compensation to victims	-0.005	**0.675**	0.119	0.478
Relocate everyone living close to LPG filling stations	0.057	**0.651**	0.147	0.435
Get more ambulances and fire trucks and personnel	0.289	**0.600**	-0.033	0.405
Reduce the quantity of gas stored at LPG stations	0.274	0.451	0.286	0.291
Sell already filled gas cylinders at LPG stations (Cylinder re circulation)	0.122	0.326	**0.590**	.419
Promote the use of alternative fuel like charcoal instead of LPG	-0.075	0.021	**0.664**	0.460
Relocate LPG stations to uninhabited areas	0.188	-0.072	**0.664**	0.486

Source: Field work, 2019

Table 48 shows that, 12 of variables loaded above 0.5 with none of the variables loading on more than one factor. With respect to factor one, five (5) were above 0.5, while factor 2 had four (4) variables loading above 0.5. The third factor, had three (3) items loading above 0.5. For loading 1 and 2, their Cronbach's Alpha statistics were 0.853, 0.560 which indicate strong and moderate correlation between the variables. The third factor however had lower correlation between the items.

Factor one corresponded with safe technology and safe management while factor two corresponded with safe technology and safe management and factor three corresponded with unorthodox risk management strategies such as the use of charcoal, removal of all LPG stations and the proposed cylinder recirculation model.

Views on strategies recommended by respondents for management of LPG risk

Each respondent interviewed was asked to suggest other risk management strategies beyond what was captured in the survey in order to have a broader response on LPG risk mitigation strategies. Their responses were categorized into themes such as safe technology and management, land use planning, emergency response and alternative strategies (such as the Cylinder recirculation model) in order to explain further the results of the factor analysis.

On the issue of safe technology and safe management, some of the respondents believed that, the risk from LPG hazards were results from poor quality equipment used and also negligence and cowardice on the part of poorly trained LPG station managers and attendants. They indicated the need to use quality equipment and to train personnel of Gas filling stations. Several LPG station managers indicated that the pumps used in LPG plants tend to be very unreliable and are a major source of leakages and electrical faults that could cause a fire. A 45-year-old male station manager stated thus; *I have changed my pump twice this year alone but hopefully the current one will last for some time.* They also indicated that leakages tend to occur on the vapour and liquid lines, often requiring maintenance. Some respondents also claimed that, proper engineering of LPG stations and equipment could help in preventing LPG hazards and its associated risks. Some suggested that, there should be construction of walls around LPG stations while others argued that, LPG filling tanks should be buried underground in order to prevent explosion. On the issue of management, an LPG station operator (male, 43 years old), noted that:

> *An operator must show courage in the face of an LPG fire because failure to shut down the flow of gas would result in a catastrophe*

Another 35-year-old male station manager observed that:

> *We experienced a fire here at our station when a mentally deranged man set fire near the station. Even though the gas caught fire and was shooting high into the air which caused passers-by and vehicles to flee, we were able to control it by quickly shutting down the valves. Fortunately, only the man who set the fire got hurt*

Some station managers blamed the high employee turnover rates for the poor level of technical proficiency. Some station attendants also indicated that, they had either Junior High school education or did not complete senior high school and that this was common amongst employees. An Environmental Protection Agency official stated that;

After the Trade Fair LPG accident in 2016 where an LPG bulk road vehicle lost its manhole cover due to over pressurisation and a weakly secured cover, we interviewed those concerned and came to the realization that, those involved in the LPG industry are poorly trained right up from the managers all the way to pump attendants. Those in charge of loading the vehicle at Atuabo were not qualified and neither were the mechanics who had earlier worked on the manhole cover. The driver of the vehicle was also poorly trained and so even though he noticed that the vessel was sweating, he did not know what to make of it.

This management challenge is as a result of poor remuneration and conditions of service offered to station attendants. Therefore, there are actually very few technically qualified persons working in the LPG industry.

He further stated that,

The regulators have begun a safety training programme for all LPG station managers and operators as well as the drivers of the bulk road vehicles and this training will lead to certification. So very soon without being certified by the regulators you cannot work in the LPG industry.

Other respondents also expressed their views on the use of land use planning as a means of addressing LPG hazards. The responses from most of them suggest that, relocating LPG stations from neighbourhoods is necessary to protect people living within the LPG hazard zones. They also noted that there were conflicts between the community and the LPG station. This was due to the fact that some station had imposed themselves on the community and were a major source of hazard anytime their pressure relief valves vent LPG into the air. Below are views from different respondents.

> *The LPG station should be removed from this place totally* (A 29-year-old female)
>
> *The LPG is dangerous; therefore, it must be situated outside populated areas.* (A 37-year-old male)
>
> *The LPG station should be located far from this neighbourhood and there must be regular checks on the LPG stations* (A 22-year-old female)
>
> *Remove the stations. They're just one entity versus the entire community* (A 34-year-old female).

Despite the concern by most of the respondents that LPG stations should be relocated from neighbourhoods to help manage the risk, some respondents also argued that, the LPG stations should be retained for the purpose that they provide economic benefits to the people living around it. A few other respondents were of the view that current land uses around LPG stations should also not be changed because the owners had invested quite heavily in their business.

One of the respondents, a 36-year-old female stated that;

> *People have invested heavily in economic ventures both at the station and around it. Why do you want to spoil their business?*

A physical planner with the Accra Metropolitan Assembly indicated that;

> *Many of the stations were in violation of the statutory land use regulations and that were working to resolve that.*

The planner further indicated that;

we are doing our best given the fact that the city is already developed.

An official from the National Petroleum Authority remarked that,

Some LPG stations are established years ago in remote areas which have surrounded by greenspaces and non-residential uses but, because the LPG business usually brings electricity and water to these areas, they tend to attract other economic activities and even residencies which then creates the high-risk environment that can be observed in many places.

The official however admitted that there were instances where stations were operating illegally and that steps were being taken to make them compliant. He stated that;

we do not close down LPG stations permanently. We close them down until they comply with regulations and then they re-open.

On the issue of emergency response, a 34-year-old Station manager had this to say;

Fire service personnel are supposed to be present during discharging of the LPG product but they do not turn up and even when they show up its just one person, what can he do?

Fire hydrants should be made available at LPG filling stations to facilitate firefighting (A 28 –year old male)

These observations underscored the need for a concerted effort in emergency response planning in order to address LPG fire hazard issues within communities which host such facilities.

Discussion

The current findings which suggest that majority of respondents want Government and LPG station owners to address fire safety issues associated with LPG retailing plants reflects to a large extent, public sentiments on the operations of LPG Plants especially in communities which are host to such industries. Reports from the Environmental Protection Agency and the Ghana National Fire Service show5 that, public concern for fire safety is very high and this was also evident in the interviews conducted in the study communities. In many of the 10 communities used in the study, there were a lot of disagreements between the station operators and their immediate neighbours. Many persons interviewed declined and those who spoke did so only when they were out of sight of the station operators. Many respondents living and working in the hazard zone also felt powerless in the face of the fire safety hazards within their communities as was evidenced by the large number of respondents who employed a cognitive response strategy. Aldwin & Yancura (2004) and Skinner & Zimmer-Gembeck (2016) have argued that, while cognitive risk reduction strategies may not involve actual remedial actions, they nevertheless provide a mental shield to those who utilize such strategies. The approximately 39% of the respondents who employed behavioural strategies relied mostly on mitigation through flight from the hazard area. A few also indicated that they would take fire control measures like putting out naked fires and calling the Fire Service in the event of a fire. Although Reim, et al., (2016) argue that, behavioural risk control strategies involve the utilization of various strategies such as risk avoidance, risk mitigation, risk transference and risk retention, very few persons said they would employ risk transfer and retention. This finding is confirmed by the MunichRe (2019) report on disasters that state that, developing countries in Africa have extremely low rates of disaster risk transfer/insurance. Eight in ten respondents were of the view that their risk management strategies were not so effective even in cases where behavioural strategies were being employed.

The observations made by the current research that, respondents who perceived major risk were more likely to adopt a behavioural rather than cognitive risk management strategy was in agreement with the Value Expectancy theory. Weinstein (1993 as cited in Weyman & Kelly, 1999) observe that, one of the main characteristics of the Value Expectancy theory is that, it can explain the protective strategies that individuals adopt based on their perception of risk. This means that, those who realize actual dangers with LPG stations are more likely to choose a behavioural strategy which is more effective in reducing the risk of LPG fire hazards. Comparatively, those who observed very minor risk would more likely adopt a cognitive risk management strategy which was rated by respondents as being less effective.

Most respondents indicated high levels of support for the use of safer technologies at LPG filling stations. Interviews conducted showed that, some respondents wanted LPG vessels to be buried and fire hydrants provided at each station in order to address the issue of safety. The World LPG Association (2011) concurs with this assertion and has argued that, safe technology can be used to help deal with industrial disasters emanating from the use of older, unwholesome and unapproved technology in an industrial setting. They further observe that, industry players should adopt safe, tested and durable technologies for example, the application of fire-resistant coasting on pressure vessels, mounded or underground storage, high- or low-level alarms, water deluge systems and other technologies which have been applied successfully in countries such as the Netherlands (Castenfors & Svedin, 2001; World LP Gas Association, 2011; Xanten et al., 2014). Recent studies on risk associated with LPG stations in Ghana found that among other things, the quality of the LPG installations contributed significantly to risk and undermine public safety (Environmental Protection Agency, 2007). Safe technology was also perceived by both risk aware and risk averse respondents as a useful tool for the mitigation of LPG fire risk. Respondents who were risk aware however had more dominant support for the use of safe technology due to the higher level of risk perception. The large support for safe technology could also be interpreted as a compensatory defence mechanism especially by those who indicated that they had no effective way of personally addressing the risk associated with LPG fire hazards.

Safe management practices were also highly endorsed by majority of respondents irrespective of their levels of perceived risk. These practices included strict adherence to regulations, regular monitoring and improvement of the knowledge and skills of LPG operators and safety education for the general public. These findings were further buttressed by the qualitative responses which suggested that, there is a general absence of a safety culture within the ranks of LPG industry operators. Following the recent spate of LPG accidents in Ghana, the Environmental Protection Agency, National Petroleum Authority and the Ghana National Fire Service have embarked on more rigorous monitoring and evaluation of LPG stations as well as training of LPG station managers and attendants in order to improve on the safety culture within the industry. A certification programme for managers and attendants is also being rolled out in order to address the lack of skilled personnel within the industry. These observations and industry developments are consistent with the views of the World Liquefied Petroleum Gas Association which has argued that, safety management of LPG risk must operate within a framework of laws, standards and codes which are important aspects of safety management (World LPG Association, 2011).

Safe technology and safe management were also found to be the most important set of strategies capable of reducing the risk of LPG fire hazards in the Accra Metro. This was evidenced by the high factor loadings which safe technology and safe management had with component one of a confirmatory factor analysis where they explained 27% of the variance. The loading of variables associated with both safe technology and safe management on component one of the confirmatory factor analyses suggests that, both factors were seen by respondents as inextricably linked and the first line of defence against LPG fire hazards in the Accra Metro. This finding is also consistent with the philosophy of the European Commission's SEVESO II policy framework on industrial risk mitigation which also emphasizes a similar approach (Amendola, 1998).

Land use planning and emergency response also received varied levels of support by respondents. Most of the respondents highly endorsed the relocation of LPG stations to uninhibited areas. This was a major concern to the respondents as many of them were of the view that, LPG stations should be relocated irrespective of a station's capacity to engage in risk transfer or retention. These views project the idea of locally unwanted land uses (LULU) and the Not in my backyard (NIMBY) controversies and further illustrate the difficulties that frequently occur when a hazardous project significantly changes its environment (Qonono, 2019; Sengupta et al., 2016).

Confirmatory factor analysis indicated that, land use planning and emergency response were the second most important factors to consider in the mitigation of LPG fire hazards. Although this strategy has some public support, it was marginal. This suggest that, while the public is concerned with land use conflicts resulting in residual risk to the external environment of LPG stations, about one third still have reservations regarding the complete removal of the station or removal of public facilities which may be at risk. These reservations are due to concerns about the economic losses and the inconvenience / cost they may create. Similarities exist between framework for industrial risk mitigation by the European Commission and what is proposed by the respondents however, where emergency response is seen as the final arbiter between at risk populations and a hazard, within the Ghanaian context emergency response and land use planning are seen as conterminous factors relative to LPG station fire hazard mitigation.

Alternative risk strategies such as the Cylinder recirculation model, the use of charcoal and the complete relocation of LPG stations made up the third component of strategies identified during the confirmatory factor analysis. These factors explained only about 10 percent (9.9%) of the variance in the non-personal mitigation strategies. As alternative strategies, they recorded lower levels of support and could be perceived as generally not acceptable to the populace. Among these strategies, the Cylinder recirculation model had better support than the other two even though support for it was moderate. These findings are consistent with media reports on the resistance to the Ghana Government's Cylinder recirculation policy by industry players and sections of the general public because of perceived potential economic losses. It is worth noting that, the lack of support for alternative fuels was also consistent with the findings of the World LP gas association (2011) which concludes that LPG is by far superior to Charcoal and electric power and is therefore unlikely to be jettisoned by users in spite of the safety issues associated with its use.

Chapter Summary

This chapter examined the issue of mitigation of LPG fire hazards in the Accra metro. It was determined that personal strategies employed by individuals living in the hazard zone were predominantly cognitive as opposed to behavioural. Non-personal strategies advocated for were the application of safe technologies and safe management practices such as mounding or burying of the tank and provision of water deluge systems, staff training and certification and application of frequent and strict monitoring programmes. The use of land use planning was also seen to be beneficial but marginally so especially in the already built environment. Emergency response was seen as equally important in addressing issues of LPG fire hazards. The use of alternative strategies such as the Cylinder recirculation model garnered moderate support but would require extra public sensitization and assurance of its economic and safety benefits. It was also concluded that, in spite of the safety issues, LPG is the most preferred fuel by households and the availability should not be compromised.

CHAPTER NINE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter summarizes the key findings of the research in order to provide evidence-based views on the risk from LPG stations and how such risk may impact on land use planning. The chapter presents both objective and subjective views of LPG station fire risks and risk management strategies as captured in chapters' four to eight respectively. It also makes relevant recommendations based on the key findings.

Summary

LPG station fire hazards differed significantly between locations with vessel capacity and hazard type being the main determinants of the hazard severity.

The most lethal aspects of potential LPG station hazards in Accra Metro would occur well within the required separation distance of 500 meters for public spaces, despite the fact that the hazards themselves extend up to 770 meters away from the station, exposing significant portions of the area to pain and first-degree burns.

In spite of the fact that, LPG hazards are spread out over large areas, only about 25% of locations around an LPG station really showed significant levels of vulnerability based on the potential magnitude of Thermal Dose Units that people in the hazard zone would face. Prediction of vulnerability using a statistical model from Tsao & Perry (1979) also indicated that, about 93.4% and 96.1% of all locations in BLEVE and Jet fire hazard zones would not suffer fatalities.

There was also a general lack of adherence to the land use regulations for in the vicinity of LPG filling stations within the Accra Metropolitan area and this increases risk and vulnerability levels. Given the general lack of adherence, it was determined that and based on guidelines from the UK health and Safety Executive's consequence based and probabilistic risk criteria, more than 90% of all land uses in the inner zone of BLEVE and Jet fire hazards ought to be examined if the LPG stations are to remain in place. However, from the perspective of Ghana's prescribed 500-meter protective zone and industrial zoning regulations, only 62% and 24% of all land uses in the inner vulnerability zones of BLEVE hazards and Jet fire's need to be re-examined. In the middle zone where there is a greater than 1 chance in a million risk of fatality, only 15% of all land uses need to be re-examined in the interest of public safety.

Evidence from the survey suggests that, there is a high level of vulnerability to LPG fire hazards due to poor risk perception among people living and working around LPG stations. This poor perception of risk is hinged on a poverty-risk nexus which is self-propagating. This is because, socio-economic status had a major influence on perceived risk. Low-income earners were less likely to perceive socio-economic risk compared to high income earners and property owners were four times more likely to perceive major socio-economic risk. Conversely, low-income earners perceived more personal health risk compared to high income earners.

The immediacy and certainty, personal and often and catastrophic nature of LPG disasters plays a key role in individuals' perception of risk from LPG stations. It was also believed that the risk from LPG hazards is well known to Government but is poorly attended to.

With respect to risk mitigation, although majority wanted LPG hazards addressed, it was observed that, individuals felt quite powerless to personally address LPG hazards while LPG industry regulators also felt that they were doing their best under the prevailing regulatory conditions.

Within the context of this study three dimensions of non-personal risk mitigation strategies emerged. These were as follows: safe technology and classical safe management approaches; land use planning and emergency response; and unconventional risk management strategies. Unconventional risk management strategies which included the recent Cylinder recirculation model policy had moderate levels of support from respondents. On the contrary, respondents emphasized safer technologies and management as a better way of reducing human errors which were perceived as the major causative factor in all LPG disasters recorded in the Accra metropolis.

Conclusions

With respect to the first objective, it emerged that, potential BLEVE hazards posed a greater danger to persons within the metro than Jet fires and that the magnitude and spatial extent of these hazards varied significantly between LPG stations due to differences in vessel capacities. Potential thermal radiation loads in the Accra metro were also high and extended well beyond the required 500-metre separation distance between stations and public places. Consequently, the use of a single deterministic separation distance as a safety measure is problematic. Consultation distances derived from individual risk assessments may be required.

With regards to the second and third objectives, it can be concluded that, whether based on the local or international standards, there is a high degree of vulnerability and risk of fatality and 2nd degree burns in the immediate environment (up to 500 meters) around LPG filling stations. This is due to the high degree of non-adherence to land use regulations which places sensitive land uses within reach of severe LPG hazards. This suggest that land use reforms may be required. Given the already urbanized nature of the affected areas, land use reforms around pre-existing LPG filling stations may be difficult and the socio-economic implications of such reforms need to be considered.

On the fourth objective, it was concluded that, the hazard zone around LPG stations in the Accra metropolis are dominated by groups of low-income earners who place their everyday economic interest well above any safety concerns, Thus, managing the risk at LPG stations would require policies which are sensitive to the socio-economic dimensions of the risk as this can exacerbate or minimize levels of vulnerability and risk.

On the fifth objective, it was concluded that, people exposed to LPG hazards generally feel powerless to address the safety concerns personally and rely to a large extent on cognitive strategies and governmental efforts to address such safety concerns. Furthermore, there are three dimensions of non-personal LPG hazard mitigation strategies which are preferred within the Accra metro in contrast to the four known dimensions from literature. However, these preclude alternative risk reduction strategies such as the Cylinder recirculation model, the use of alternative fuels and the complete relocation of LPG stations from urban spaces.

Finally, it is concluded that, industrial LPG risks remain high and would require a comprehensive and consultative safety policy and risk based land use management framework adapted to the local conditions in order to address such challenges.

Recommendations

In view of the findings of this study the following recommendations are suggested.

The quantity of LPG kept at kept at an LPG Station must be well regulated to keep the risk to the external environment within acceptable levels since this is the one of most important determinants of the magnitude of LPG hazards.

LPG industry regulators must discontinue the use of a universal deterministic buffer distance as a planning tool and replace it with a consequence or risk-based approaches due to the varied nature of LPG hazards at each site. In addition, locally relevant risk criteria would be required and together these would provide a better framework for land use decision making in the hazard zone.

The Accra metropolitan assembly must find alternative sites and economically viable livelihoods for low-income groups currently located within the hazard zone of LPG stations/proposed distribution centers in order to decrease their vulnerability and risk to LPG hazards.

LPG industry regulators must also continue to pursue the use of safe technologies (such as burying the LPG vessels) and safe management practices (including the use of only qualified personnel) within the LPG industry. Government must also reconsider its Cylinder recirculation model by addressing questions on value addition and safety of investment and more importantly safety of the external environment around LPG facilities.

Governments Cylinder recirculation model must be reexamined with a view to improving of the value chain and safety implications on the external environment of LPG facilities.

Finally, a comprehensive and consultative safety policy and risk based land use management framework adapted to the local conditions would be needed to address the risk of LPG disasters and industrial risk as a whole.

REFERENCES

Abane, A. (2011). Travel behaviour in Ghana: Empirical observations from four metropolitan areas. *Journal of Transport Geography*, *19*(2), 313–322.

Abdolhamidzadeh, B., Rosmani, C., Hassan, C., Diana, M., Farrokhmehr, S., Badri, N., & Rashtchian, D. (2012). Anatomy of a domino accident : Roots , triggers and lessons learnt. *Process Safety and Environmental Protection*, *90*(5), 424–429. https://doi.org/10.1016/j.psep.2012.04.003

Abrahamsson, M. (2002). Uncertainty in quantitative risk analysis-characterisation and methods of treatment. *Fire Safety Engineering and Systems Safety*, 88. http://lup.lub.lu.se/record/642153

Abramson, P. R., & Inglehart, R. (1995). *Value Change in Global Perspective*. University of Michigan Press.

Acquilla, S., Bertell, R., Dhara, V. R., & Tognoni, G. (2005). Aftermath of the world's worst chemical disaster: Bhopal, December 1984. *Journal of Loss Prevention in the Process Industries*, *18*(4–6), 268–273. https://doi.org/10.1016/j.jlp.2005.06.008

Af Wåhlberg, A. E., Research, R., & Af Wåhlberg, A. E. (2001). The theoretical features of some current approaches to risk perception. *Journal of Risk Research*, *4*(3), 237–250. https://doi.org/10.1080/13669870152023791

Akimoto, F. (2009). The birth of "land use planning" in American urban planning. *Planning Perspectives*, *24*(4), 457–483. https://doi.org/10.1080/02665430903145705

Aldwin, C. M., & Yancura, L. A. (2004). Coping. *Encyclopedia of Applied Psychology, Three-Volume Set*, *1*, 507–510. https://doi.org/10.1016/B0-12-657410-3/00126-4

Ale, B. J. M. (2005a). Living with risk: A management question. *Reliability Engineering and System Safety*, *90*(2–3), 196–205. https://doi.org/10.1016/j.ress.2004.10.015

Ale, B. J. M. (2005b). *Tolerable or Acceptable : A Comparison of Risk Regulation in the United Kingdom and in the Netherlands*. *May 2005*. https://doi.org/10.1111/j.1539-6924.2005.00585.x

Ale, B. J. M. (2009). *Risk: an introduction:The Concept of risk, danger,and chance* (1st ed.). Routledge. http://www.ghbook.ir/index.php?name =فرهنگ و رسانه های نوین&option=com_dbook&task= readonline&book_ id=13650&page=73&chkhashk=ED9C9491B4&Itemid=218&lang=fa &tmpl=component

Armah, J. (2020, July 10). Chief Inspector. (E. Mensah, Interviewer)

Amendola, A. (1998). I.1 - Approaches to Risk Analysis in the European Union. In C. Kirchsteiger, M. D. Christou, & G. A. B. T.-I. S. S. Papadakis (Eds.), *Risk assessment and management in the context of the seveso II directive* (Vol. 6, pp. 3–26). Elsevier. https://doi.org/https://doi.org/10 .1016/S0921-9110(98)80007-4

American Institute of Chemical Engineers. Center for Chemical Process Safety, & P. (2010). *Guidelines for process safety metrics / Center for Chemical Process Safety*. Hoboken, N.J. : Wiley ; New York : Center for Chemical Process Safety.

American Institute of Chemical Engineers. (1994). Guidelines for evaluating the characteristics of vapor cloud explosions, flash fires, and BLEVEs. In *Guidelines for Evaluating the Characteristics of Vapor Cloud*

Explosions, Flash Fires, and BLEVEs. Center for Chemical Process Safety of the American Institute of Chemical Engineers. https://doi.org/10.1002/9780470938157

Arnstein, S. R. (2019). A Ladder of Citizen Participation. *Journal of the American Planning Association*, *85*(1), 24–34. https://doi.org/10.1080/01944363.2018.1559388

Arturson, G. (1987). The tragedy of San Juanico-the most severe LPG disaster in history. *Burns*, *13*(2), 87–102. https://doi.org/10.1016/0305-4179(87)90096-9

Asante, K. P., Afari-Asiedu, S., Abdulai, M. A., Dalaba, M. A., Carrión, D., Dickinson, K. L., Abeka, A. N., Sarpong, K., & Jack, D. W. (2018). Ghana's rural liquefied petroleum gas program scale up: A case study. *Energy for Sustainable Development*. https://doi.org/10.1016/j.esd.2018.06.010

ATKINS. (2007). *Initial Assessment of Vapour Cloud Explosion Risks Associated with the La Collette Fuel Depot Initial Assessment of Vapour Cloud Explosion Risks Associated with the La Collette Fuel*. *03*, 1–53.

Baixos., P., Stoffen., C. P. van R. door G., Baixos., P., & Arbeid., D.-G. van de. (1992a). *Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials [Green book]*. Directorate-General of Labour of the Ministry of Social Affaires and Employment. http://www.bib.ub.edu/fileadmin/fdocs/greenbook.pdf

Baixos., P., Stoffen., C. P. van R. door G., Baixos., P., & Arbeid., D.-G. van de.

(1992b). *Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials [Green book]*. Directorate-General of Labour of the Ministry of Social Affaires and Employment.

Baker, J., Bouchlaghem, D., & Emmitt, S. (2013). Categorisation of fi re safety management : Results of a Delphi Panel. *Fire Safety Journal*, *59*, 37–46. https://doi.org/10.1016/j.firesaf.2013.03.005

Bartlett, M. S. (1954). A Note on the Multiplying Factors for Various Chi Square Approximationse. *Journal of the Royal Statistical Society*, *16*, 296–298.

Basta, C. (2009a). *Risk , Territory and Society : Challenge for a Joint European Regulation.* Delft University of Technology.

Basta, C. (2009b). *Risk , Territory and Society : Challenge for a Joint European Regulation door*.

Basta, C. (2014). Siting risky facilities: Probabilism, determinism and beyond. *Planning Theory*, *13*(1), 44–64. https://doi.org/10.1177/14730952134 79579

Basta, C., Christou, M., Struckl, M., & Ale, B. (2008). Translating the risk of major accidents into opportune safety distances from dangerous establishments: Recent developments of the European regulation as deriving from selected national practices. *9th International Conference on Probabilistic Safety Assessment and Management 2008, PSAM 2008*, *2*(January), 1638–1645.

Basta, C., Neuvel, J. M. M., Zlatanova, S., & Ale, B. (2007). Risk-maps informing land-use planning processes. A survey on the Netherlands and the United Kingdom recent developments. *Journal of Hazardous Materials*, *145*(1–2), 241–249. https://doi.org/10.1016/j.jhazmat.2006.11.032

BBC. (2019). *Ghana's capital rocked by huge gas blasts*. https://www.bbc.com/news/world-africa-41541001

BBC Africa Eye. (2020). *Lagos Inferno*. BBC World News. https://www.bbc.co.uk/programmes/m000nc5w

Beck, U. (1992). *Risk society: Towards a new modernity. Sage Publications.* Sage Publications, Incorporated.

Beyler, C. L. (2016). SFPE handbook of fire protection engineering. In *SFPE Handbook of Fire Protection Engineering, Fifth Edition* (Fifth edit). https://doi.org/10.1007/978-1-4939-2565-0

Birk, A. M. (1996). Hazards from propane BLEVEs: An update and proposal for emergency responders. *Journal of Loss Prevention in the Process Industries*, *9*(2), 173–181.

Birkmann, J. (2005). Danger need not spell disaster But how vulnerable are we? *United Nations University*, *1*, 1–8.

Boholm, Å. (1996). Risk perception and social anthropology: Critique of cultural theory. *Ethnos*, *61*(1–2), 64–84. https://doi.org/10.1080/00141844.1996.9981528

Britter, R. E. (1989). Atmospheric Dispersion of Dense Gases. *Nature*, *51*(1321), 396. https://doi.org/10.1086/125967

Bubbico, R., & Marchini, M. (2008). *Assessment of an explosive LPG release accident : A case study*. *155*, 558–565. https://doi.org/10.1016/j.jhazmat.2007.11.097

Castenfors, K., & Svedin, L. (2001). Crisis communication: Learning from the 1998 LPG near miss in Stockholm. *Journal of Hazardous Materials*, *88*(2–3), 235–254. https://doi.org/10.1016/S0304-3894(01)00269-2

Catell, R. B. (1966). The scree test for number of factors. *Multivariate Behavioral Research*, *1*, 245–76.

Chamberlain, G. A. (1987). Developments in Design Methods for Predicting Thermal-Radiation from Flares. *Chemical Engineering Research & Design*, *65*(4), 299–309.

Cheng, L., Li, S., Ma, L., Li, M., & Ma, X. (2015). Fire spread simulation using GIS: Aiming at urban natural gas pipeline. *Safety Science*, *75*. https://doi.org/10.1016/j.ssci.2015.01.002

Christou & Papadakis. (1998). *Risk Assessment and Management in the Context of the Seveso II Directive*.

Christou, M. D., Amendola, A., & Smeder, M. (1999). The control of major accident hazards: The land-use planning issue. *Journal of Hazardous Materials*, *65*(1–2), 151–178. https://doi.org/10.1016/S0304-3894(98)00261-1

Christou, M., Gyenes, Z., & Struckl, M. (2011). Risk assessment in support to land-use planning in Europe : Towards more consistent decisions. *Journal of Loss Prevention in the Process Industries*, *24*(3), 219–226. https://doi.org/10.1016/j.jlp.2010.10.001

Christou, M., Struckl, M., & Biermann, T. (2006). *Land Use Planning Guidelines in the Context of Article 12 of the Seveso II Directive 96/82/EC as Amended by Directive 105/2003/EC*. European Commission.

Christou, Struckl, M., & Biermann, T. (2006). *Landuse Planning Guidance in the Context of Article 12 of the SEVESO II Directive 96/82/EC as Amended By Directive 105/2003/EC*. European Commission:Joint Research Centre.

Civan, F. (2004). *Natural Gas Transportation and Storage*. *4*, 273–282.

Cochran, W. G. (1977). *Sampling techniques*. John Wiley & Sons.

Cozzani, V., Bandini, R., Basta, C., & Christou, M. D. (2006). Application of land-use planning criteria for the control of major accident hazards: A case-study. *Journal of Hazardous Materials*, *136*(2), 170–180. https://doi.org/10.1016/j.jhazmat.2005.12.031

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications, Incorporated.

Creswell, J. W., Fetters, M. D., & Ivankova, N. V. (2004). Designing A Mixed Methods Study In Primary Care. *Annals Of Family Medicine*, *2*(1). https://doi.org/10.1370/afm.104

Croce, P. A., & Mudan, K. S. (1986). Calculating impacts for large open hydrocarbon fires. *Fire Safety Journal*, *11*(1–2), 99–112. https://doi.org/10.1016/0379-7112(86)90055-X

Davidson, D. J., & Freudenburg, W. R. (1996). Gender and Environmental Risk Concerns. *Environment and Behavior*, *28*(3), 302–339. https://doi.org/10.1177/0013916596283003

Dhurandher, B. K., Kumar, R., & Dhiman, A. (2015). Impact Assessment of Thermal Radiation Hazard from LPG Fireball. *Procedia Earth and Planetary Science*, *11*, 499–506. https://doi.org/10.1016/j.proeps.2015.06.050

Donkor, K. B. (2014, January 17). Ghana's capital rocked by huge gas blasts. *Daily Graphic*. https://www.graphic.com.gh/news/general-news/five-more-die-in-kwahu-fodoa-gas-explosion.html

DOUGLAS, M., & WILDAVSKY, A. (1982). *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*.

Douti, Biyogue, N., Abanyie, Samuel, K., & Ampofo, Steve, E. (2019). Spatial distribution and operations of petrol stations in the Kassena-Nankana district (Ghana) and associated health and safety hazards. *Journal of Toxicology and Environmental Health Sciences*, *11*(5), 50–61. https://doi.org/10.5897/jtehs2018.0420

Drysdale, D. (2011). An introduction to fire dynamics. In *Combustion and Flame* (Third Edit, Vol. 66, Issue 1). A John Wiley & Sons, Ltd., Publication. https://doi.org/10.1016/0010-2180(86)90037-4

Eckerman, I. (2011). Bhopal Gas Catastrophe 1984: Causes and Consequences. In *Encyclopedia of Environmental Health* (Issue June). Elsevier Inc. https://doi.org/10.1016/b978-0-444-52272-6.00359-7

Eckhoff, R. K. (2005). Current status and expected future trends in dust explosion research. *Journal of Loss Prevention in the Process Industries*, *18*(4–6), 225–237. https://doi.org/10.1016/j.jlp.2005.06.012

Eckhoff, R. K., & Thomassen, O. (1994). Possible sources of ignition of potential explosive gas atmospheres on offshore process installations. *Journal of Loss Prevention in the Process Industries*, *7*(4), 281–294. https://doi.org/10.1016/0950-4230(94)80041-3

EPA. (2007). *Environmental Protection Agency - Ghana National Implementation Plan of the Stockholm Convention on Persistent Organic Pollutants*. *December*, 2–267.

F. Martín, C. Saiz-Jimenez, A. C. (1977). Pyrolysis-Gas Chromatography-Mass Spectrometry of Soil Humic Fractions: I. The Low Boiling Point Compounds. *Soil Science Society of America Journal*, *41*, 1114–1118.

Fallah Zavareh, M., Mohamadi Hezaveh, A., & Nordfjærn, T. (2018). Intention to use bicycle helmet as explained by the Health Belief Model, comparative optimism and risk perception in an Iranian sample. *Transportation Research Part F: Traffic Psychology and Behaviour*, *54*(2018), 248–263. https://doi.org/10.1016/j.trf.2018.02.003

Fallahi, A., Daneshpour, Z. A., & Vahideh, E. (2012). Integrating disaster management and metropolitan planning in Tehran. In S. Manfred, P. Vasily V, Z. Peter, & E. Pietro (Eds.), *REAL CORP 2012: Re-mixing the city-towards sustainability and resilience?*

Franks, A. (2004). *A Review of HSE's Risk Analysis and Protection-Based Analysis Approaches for Land-Use Planning*. *September*. http://www.hse.gov.uk/research/rrhtm/

Gerrard, C. M., & Petley, D. N. (2013). A risk society? Environmental hazards, risk and resilience in the later Middle Ages in Europe. *Natural Hazards*, *69*(1), 1051–1079. https://doi.org/10.1007/s11069-013-0750-7

Ghana, M. C. (2011). *(Minerals Commission Ghana, 2011).*

Gómez-Mares, M., Muñoz, M., & Casal, J. (2010). Radiant heat from propane jet fires. *Experimental Thermal and Fluid Science*, *34*(3), 323–329. https://doi.org/10.1016/j.expthermflusci.2009.10.024

Gore, J., Klassen, M., Hamins, A., & Kashiwagi, T. (2006). Fuel property effects on burning rate and radiative transfer from liquid pool flames. *Fire Safety Science: Proceedings of the Third International Symposium*, 395–404. https://doi.org/10.4324/9780203973493

Government of India. (2011). *Disaster Management in India*.

GraphicOnline. (2017). *Explosion at Takoradi leaves more than 100 injured*. News and Headlines. https://www.graphic.com.gh/news/general-news/explosion-at-takoradi-leaves-several-injured.html

Greiving, S., & Fleischhauer, M. (2006). Spatial planning response towards natural and technological hazards. In P. Schmidt-Thomé (Ed.), *Natural and technological hazards and risks affecting the spatial development of European Regions. Geological Survey of Finland, Special Paper 42* (pp. 109–123).

Haag, P. A. M., Ale, B., & Post, J. (2001). Guideline for quantitative risk assessment in the Netherlands. *Proceedings 10th International Symposium on Loss Prevention and Safety Promotion in the Process Industries*, *2*, 1429–1438.

Havens, J. A., & Spicer, T. O. (1985). *Development of an Atmospheric Dispersion Model for Heavier-Than-Air Gas Mixtures.* (Vol. 1).

Hirst, R. (1989). *Underdown's Practical Fire Precautions*. Gower Technical.

Hitchcock, J. (2001). Gender Differences in Risk Perception: Broadening the Contexts. *RISK: Health, Safety & Environment (1990-2002)*, *12*(3), 4.

Hollenstein, K. (2005). Reconsidering the risk assessment concept: Standardizing the impact description as a building block for vulnerability assessment. *Natural Hazards and Earth System Sciences*, *5*(3), 301–307. https://doi.org/10.5194/nhess-5-301-2005

HSE - U.K. Health and Safety Executive. (2010a). *Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment*. https://www.hse.gov.uk/foi/internalops/hid_circs/technical_osd/spc_tech_osd_30/spctecosd30.pdf

HSE - U.K. Health and Safety Executive. (2010b). *Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment*.

HSE - U.K. Health and Safety Executive. (2015). *Land-use planning methodology in the UK*. HSE Land Use Planning - HSE's Land Use Planning Methodology. https://www.hse.gov.uk/landuseplanning/methodology.htm

HSE - U.K. Health and Safety Executive. (2017). Failure Rate and Event Data for use within Risk Assessments. In *Health & Safety Executive Offshore Safety Division* (Vol. 1, Issue 1).

Institute for Systems Informatics and Safety. (1999). *Guidance On Land Use Planning As Required By Council Directive 96/82/EC (SEVESO II)* (M. D. Christou & S. Porter (eds.)). http://www.straz.gov.pl/page/file.php?id=31898

Institution of Chemical Engineers. (2014). Remembering Bhopal – 30 years on. In *Loss Prevention Bulletin* (Issue 240).

Inter-Departmental Working Group on Land Use Planning(FAO). (1993). Guidelines for land-use planning. In *FAO Development Series* (Issue 1). Food and Agriculture Organization of the United Nations.

Jorge Pedro Galve, Juan Remondo, F. G. (2011). Improving sinkhole hazard models incorporating magnitude–frequency relationships and nearest neighbor analysis. *Geomorphology*, *134*, 157–170.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, *39*, 31–36.

Kalliopi Sapountzaki, Sylvia Wanczura, Gabriella Casertano, Stefan Greiving, G. X. & F. F. F. (2011). Disconnected policies and actors and the missing role of spatial planning throughout the risk management cycle. *Natural Hazards*, *59*, 1445–1474.

Kapucu, N., & Ozerdem, A. (2013). Hazards, Vulnerability, and Disaster Risk. *Managing Emergencies and Crises*, 11–35. http://samples.jbpub.com /9780763781552/81552_CH02_FINAL.pdf

Kasperson, R. E., Brown, H., Emel, J., Goble, R., Kasperson, J., Ratick, S., Renn, O., & Slovic, P. (1988). The Social Amplification of Risk: A Conceptual Framework. *Risk Analysis*, *8*(2), 177–187.

Kearney, G., & Kiros, G. E. (2009). Spatial evaluation of socio demographics surrounding National Priorities List sites in Florida using a distance-based approach. *International Journal of Health Geographics*, *8*(1), 1–10. https://doi.org/10.1186/1476-072X-8-33

Knuth, D., Kehl, D., Hulse, L., & Schmidt, S. (2014). Risk Perception, Experience, and Objective Risk: A Cross-National Study with European Emergency Survivors. *Risk Analysis*, *34*(7), 1286–1298. https://doi.org /10.1111/risa.12157

Kusama, T., Aida, J., Tsuboya, T., Sugiyama, K., Yamamoto, T., Igarashi, A., & Osaka, K. (2018). The association between socioeconomic status and reactions to radiation exposure: a cross-sectional study after the Fukushima Daiichi nuclear power station accident. *PloS One*, *13*(10), e0205531–e0205531. https://doi.org/10.1371/journal.pone.0205531

Lamb, D., & Verlinde, J. (2011). Physics and Chemistry of Clouds. In *Paper Knowledge . Toward a Media History of Documents*. Cambridge University Press.

Legg, C., & Hookway, C. (2019). Pragmatism. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 201). Metaphysics Research Lab, Stanford University.

León, J. C. V. De. (2006). *Vulnerability: A Conceptional and Methodological Review*. UNU Institute for Environment and Human Security (UNU-EHS).

Lowesmith, B. J., Hankinson, G., Acton, M. R., & Chamberlain, G. (2007). An overview of the nature of hydrocarbon jet fire hazards in the oil and gas industry and a simplified approach to assessing the hazards. *Process Safety and Environmental Protection*, *85*(3 B), 207–220. https://doi.org/10.1205/psep06038

Luloff, G. L. T. &A. E. (2011). Position on Environmental Issues and Engagement in Proenvironmental Behaviors. *Society & Natural Resources*, *15*, 471–482.

LUSPA. (2016). *LAND USE AND SPATIAL PLANNING ACT, 2016*. *Act 925*, 1–106.

Ma, S., Zhang, S., Yu, C., Zheng, H., Song, G., Semakula, H. M., & Chai, Y. (2015). Assessing Major Accident Risks to Support Land-Use Planning Using a Severity-Vulnerability Combination Method: A Case Study in Dagushan Peninsula, China. *Risk Analysis*, *35*(8), 1503–1519. https://doi.org/10.1111/risa.12351

Maddison, T. O. M. (1976). *the Uk Approach To Land Use Planning in the Vicinity of Chemical*. 1–18.

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, *50*(4), 370–396. https://doi.org/10.1037/h0054346

Masozera, M., Bailey, M., & Kerchner, C. (2007). Distribution of impacts of natural disasters across income groups: A case study of New Orleans. *Ecological Economics*, *63*(2–3), 299–306. https://doi.org/10.1016/j.ecolecon.2006.06.013

Mensah, R. (2020). Gas filling stations in urban areas in Ghana. Effects and consequences. In *Landscape Conservation*. GRIN Verlag.

Messner Frank, & Meyer, V. (2006). Flood Damage , Vulnerability and Risk Perception – Challenges for Flood Damage. *Environmental Research*, 149–167.

Micic, T. (2016). Risk reality vs risk perception. *Journal of Risk Research*, *19*(10), 1261–1274. https://doi.org/10.1080/13669877.2015.1121900

Ministry Of Environment Science And Technology, & Department of Town And Country Planning. (2011). *Zoning Guidelines and Planning Standards*.

Mogi, T., & Horiguchi, S. (2009). Explosion and detonation characteristics of dimethyl ether. *Journal of Hazardous Materials*, *164*(1), 114–119. https://doi.org/10.1016/j.jhazmat.2008.07.133

Morduch, J. (1994). Poverty and vulnerability. *The American Economic Review*, *2*(84), 221–225.

Moreland, C. of. (2018). *EMERGENCY, MUNICIPAL MANAGEMENT PLAN*.

Morgan, D. G. M. P. S. M. G. (1994). Perception of Risks From Electromagnetic Fields: A Psychometric Evaluation of a Risk-Communication Approach. *Risk Analysis*, *14*(5), 815–828.

MunichRe. (2019). *NatCatService*. NatCatService. www.munichre.com/touch/%0Anaturalhazards

Murgante, B., & Borruso, G. (2015). Smart Cities in a Smart World. In S. T. Rassia & P. M. Pardalos (Eds.), *Future City Architecture for Optimal Living* (pp. 241–269). Springer Optimization and Its Applications. https://doi.org/10.1007/978-3-319-15030-7

Neher, A. (1991a). Maslow's Theory of Motivation: A Critique. *Journal of Humanistic Psychology*, *31*(3), 89–112. https://doi.org/10.1177/0022167891313010

Neher, A. (1991b). Maslow's Theory of Motivation: A Critique. *Journal of Humanistic Psychology*, *31*(3), 89–112. https://doi.org/10.1177/0022167891313010

NPA. (2015). *Guidelines for LPG Insatllation for LPG Stations*.

NPA. (2020a). *Amendments to the guidelines for siting petroleum products retail outlets* (NPA/IML/OMC/01/12).

NPA. (2020b). *Regional Consumption (2010 - 2020)*. Acts,LI's,Templates & Statistics. http://www.npa.gov.gh/download-media/industry-data/ downloads

Oltedal, S., Moen, B.-E., Klempe, H., & Rundmo, T. (2004). *Explaining risk perception. An evaluation of cultural theory Rotunde* (T. Rundmo (ed.)). Rotunde publikasjoner.

Oostendorp, Y., Lemkowitz, S., Zwaard, W., van Gulijk, C., & Swuste, P. (2016). Introduction of the concept of risk within safety science in The Netherlands focussing on the years 1970-1990. *Safety Science*, *85*, 205–219. https://doi.org/10.1016/j.ssci.2016.01.013

Palacios, A., Muñoz, M., Darbra, R. M., & Casal, J. (2012). Thermal radiation from vertical jet fires. *Fire Safety Journal*, *51*, 93–101. https://doi.org/10.1016/j.firesaf.2012.03.006

Pan American Health Organization. (2019). *Hazards and their impact on health*. General Concepts. http://www.saludydesastres.info/index.php?option=com_content&view=article&id=330:3-3-technological-hazards&catid=114&Itemid=1026&lang=en

Pelling, M. (2003). Natural disasters and development in a globalizing world. In *Natural Disasters and Development in a Globalizing World*. https://doi.org/10.4324/9780203402375

Petts, J. (1988). *Major hazards control: the local community and risk decisions*. *110*, 507–523.

Pidgeon, N. (1998). Risk assessment, risk values and the social science programme: Why we do need risk perception research. *Reliability Engineering and System Safety*, *59*(1), 5–15. https://doi.org/10.1016

/S0951-8320(97)00114-2

Pitblado, R. (2007). Potential for BLEVE associated with marine LNG vessel fires. *Journal of Hazardous Materials*, *140*(3), 527–534. https://doi.org/10.1016/j.jhazmat.2006.10.021

Pitblado, R. (2011). Journal of Loss Prevention in the Process Industries Global process industry initiatives to reduce major accident hazards. *Journal of Loss Prevention in the Process Industries*, *24*(1), 57–62. https://doi.org/10.1016/j.jlp.2010.08.006

Pontiggia, M., Landucci, G., Busini, V., Derudi, M., Alba, M., Scaioni, M., Bonvicini, S., Cozzani, V., & Rota, R. (2011). CFD model simulation of LPG dispersion in urban areas. *Atmospheric Environment*, *45*(24), 3913–3923. https://doi.org/10.1016/j.atmosenv.2011.04.071

Prenger-Berninghoff, K. (2016). *The use of risk information in Strategic Environmental Assessment and spatial planning* (Issue September). TU Dortmund University.

Prenger-Berninghoff, K., & Greiving, S. (2015). The Use of Risk Information in Spatial Planning in Europe: Examples from Case Study Sites in Italy and Romania with a Focus on Flood and Landslide Hazards. In Giorgio Lollino, A. Manconi, F. Guzzetti, M. Culshaw, P. Bobrowsky, & Fabio Luino (Eds.), *Engineering Geology for Society and Territory - Volume 5* (5th ed., pp. 737–741). Springer International Publishing. https://doi.org/10.1007/978-3-319-09048-1_143

Qonono, K. (2019). *Analysis of the fire hazard posed by petrol stations in Stellenbosch and the extent to which planning acknowledges risk*. *April*, 1–107.

Reim, W., Parida, V., & Sjödin, D. R. (2016). Risk Management for Product-Service Systems Operation. *International Journal of Operations & Production Management*, *36*(6), 665–686. https://doi.org/10.1108/IJOPM-10-2014-0498

Ribot, J. (2013). Vulnerability does not just fall from the sky: Toward multi-scale pro-poor climate policy. *Handbook on Climate Change and Human Security*, *October*, 164–172. https://doi.org/10.4337/9780857939111.00016

Roberts, M. (2000). Analysis of Boiling Liquid Expanding Vapor Explosion (BLEVE) Events at DOE Sites. *Safety Analysis Workshop*, 1–20. http://firelogics.us/FireLogics/Library/Analysis of Boiling Liquid Expanding Vapor Explosion (BLEVE) Events.pdf

Rundmo, T., & Moen, B. E. (2006). Risk perception and demand for risk mitigation in transport: A comparison of lay people, politicians and experts. *Journal of Risk Research*, *9*(6), 623–640. https://doi.org/10.1080/13669870600813811

Rundmo, T., Oltedal, S., Moen, B.-E., & Klempe, H. (2004). Explaining risk perception. In *An evaluation of cultural theory, Norwegian University of Science and Technology, Trondheim*.

Sadiq, A. A., Tharp, K., Graham, J. D., & Tyler, J. (2019). Temporal stability and changes in risk perception rankings of hazardous activities and technologies. *Journal of Risk Research*, *22*(1), 93–109. https://doi.org/10.1080/13669877.2017.1351474

Schmidt-Thomé, P. (2006). *Integration of Natural Hazards, Risk and Climate Change into Spatial Planning Practices* [University of Helsinki].

https://doi.org/No.193

Seattle, W., & Washington, D. C. (2007). *NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION Office of Response and Restoration Emergency Response Division The CAMEO ® Software System ALOHA ® USER'S MANUAL*. *February*, 1–195.

Sengupta, A. (2016). *Industrial Risk - an Indian Perspective*. https://doi.org/10.3990/9789036542777

Sengupta, A., Bandyopadhyay, D., Roy, S., van Westen, C. J., & van der Veen, A. (2016). Challenges for introducing risk assessment into land use planning decisions in an Indian context. *Journal of Loss Prevention in the Process Industries*, *42*, 14–26. https://doi.org/10.1016/j.jlp.2015.10.007

Shepherd, J. E., & Lee, J. H. S. (1992). *On The Transition from Deflagration to Detonation*. 439–487. https://doi.org/10.1007/978-1-4612-2884-4_22

Sjöberg, L. (1992). *Risk perception and credibility of risk communication* (Issue 9). https://inis.iaea.org/search/search.aspx?orig_q=RN:26042609

Sjöberg, L. (1993). The Methodology of Risk Perception Research. *Quality and Quantity*, *34*, 407–418.

Sjöberg, L. (1998). World Views, Political Attitudes and Risk Perception. *RISK: Health, Safety & Environment (1990-2002)*, *9*(2), 6.

Sjöberg, L. (2000). Factors in risk perception. *Risk Analysis*, *20*(1), 1–11. https://doi.org/10.1111/0272-4332.00001

Sjöberg, L., Bjørg-Elin, M., & Rundmo, T. (2004). Explaining risk perception. An evaluation of the psychometric paradigm in risk perception research. In T. Rundmo (Ed.), *Notes and Queries* (Issue 84). Rotunde publikasjoner. https://doi.org/10.1093/nq/s2-X.252.336-a

Skinner, E. A., & Zimmer-Gembeck, M. (2016). Coping. *Encyclopedia of Mental Health: Second Edition*, *1*, 350–357. https://doi.org/10.1016/B978-0-12-397045-9.00036-7

Slovic, P. (1987). Perception of Risk. *Science*, *236*(4799), 280–285. https://doi.org/10.1126/science.3563507

Slovic, P. (2016). Understanding perceived risk: 1978-2015. *Environment*, *58*(1). https://doi.org/10.1080/00139157.2016.1112169

Spio, A. E. (2011). *The City Branding of Accra BT - City Branding: Theory and Cases* (K. Dinnie (ed.); pp. 99–105). Palgrave Macmillan UK. https://doi.org/10.1057/9780230294790_12

Spouge, J. (1999). CMPT. A guide to quantitative risk assessment for offshore installations. *DNV Technica*.

Starr, C. (1969). Social Benefit versus Technological Risk: What is our society willing to pay for safety? *Science*, *165*(3899), 1232–1238. https://doi.org/10.1126/science.165.3899.1232

Tauseef, S.M, Abbasi, T., & Abbasi, S. A. (2010). Risks of Fire and Explosion Associated With the Increasing Use of Liquefied Petroleum Gas. *Journal of Failure Analysis and Prevention*, *10*, 322–333.

Tauseef, S. M., Rashtchian, D., & Abbasi, S. A. (2011). CFD-based simulation of dense gas dispersion in presence of obstacles. *Journal of Loss Prevention in the Process Industries*, *24*(4), 371–376. https://doi.org/10.1016/j.jlp.2011.01.014

Taveau, J. (2010). Risk assessment and land-use planning regulations in France following the AZF disaster. *Journal of Loss Prevention in the Process Industries*, *23*(6), 813–823. https://doi.org/10.1016/j.jlp.2010.04.003

The Publisher. (2019). *77.4% of LPG Stations still high risk*. https://www.thepublisheronline.com/77-4-lpg-stations-still-high-risk/

Török, Z., Petrescu-Mag, R. M., Mereuță, A., Maloș, C. V., Arghiuș, V. I., & Ozunu, A. (2019). Analysis of territorial compatibility for Seveso-type sites using different risk assessment methods and GIS technique. *Land Use Policy*, *October 2018*, 1–16. https://doi.org/10.1016/j.landusepol.2019.02.037

Turgut, P., Gurel, M. A., & Pekgokgoz, R. K. (2013). LPG explosion damage of a reinforced concrete building : A case study in Sanliurfa , Turkey. *Engineering Failure Analysis*, *32*, 220–235. https://doi.org/10.1016/j.engfailanal.2013.04.004

Twigg, J., & Benson, C. (2007). *Tools for Mainstreaming Disaster Risk Reduction: Guidance Notes for Development Organisations*.

UNISDR. (2015). *Global Assessment Report on Disaster Risk Reduction*. United Nations.

United Nations Environment Programme. (2019). *Why do disasters and conflicts matter?* FactSheet.

United Nations Office for Disaster Risk Reduction. (2017a). *https://www.undrr.org/terminology*. UNISDR Terminology on Disaster Risk Reduction.

United Nations Office for Disaster Risk Reduction. (2017b). *https://www.undrr.org/terminology*. UNISDR Terminology on Disaster Risk Reduction. https://www.undrr.org/terminology

US Department of Transport. (2020). *Emergency Response Guide*.

Van Dijk, T. A. (1993). Principles of critical discourse analysis. *Discourse & Society*, *4*(2), 249–283. https://doi.org/10.1177/0957926593004002006

Van Westen, C. J., Alkema, D., Damen, M., Kerle, N., & Kingma, N. (2010). *Multi-hazard risk assessment*. ITC- UNU- DGIM.

Venart, J. E. S. (1998). Boiling liquid expanding vapor explosions (BLEVE): Possible failure mechanisms. *ASTM Special Technical Publication*, *1336*(147), 112–132. https://doi.org/10.1520/stp12189s

Villagran De Leon, J. (2006). Vulnerability: A Conceptual and Methodological Review. *Source 4/2006, 4*.

Wang, J. J. (2012). Integrated model combined land-use planning and disaster management: The structure, context and contents. *Disaster Prevention and Management*, *21*(1), 110–123. https://doi.org/10.1108/09653561211202746

Weyman, A. K., & Kelly, C. J. (1999). *Risk perception and risk communication: A review of literature*. HSE Books.

Williamson, J., & Weyman, A. (2005a). Review of the Public Perception of Risk, and Stakeholder Engagement. *Health and Safety Laboratory*, 47. http://www.hse.gov.uk/research/hsl_pdf/2005/hsl0516.pdf

Williamson, J., & Weyman, A. (2005b). Review of the Public Perception of Risk, and Stakeholder Engagement. *Health and Safety Laboratory*, 47.

World LPG Association. (2011). *Guidelines for Good Safety Practices in the LP Gas Industry*.

World Population Review. (2021). *Accra population 2021(Demographics, Maps and Graphs)*. https://worldpopulationreview.com/world-cities/

accra-population

www.ghanaweb.com. (2018). *Atomic Gas explosion: We still haven't received our compensation – Victims*. General News of Sunday, 7 October 2018. https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Atomic-Gas-explosion-We-still-haven-t-received-our-compensation-Victims-690740

Xanten, N. H. W. Van, Pietersen, C. M., Pasman, H. J., Torn, P. Van Der, Vrijling, H. K., Wal, A. J. Van Der, Van Xanten, N. H. W., Pietersen, C. M., Pasman, H. J., Van Der Torn, P., Vrijling, H. K., Van Der Wal, A. J., & Kerstens, J. G. M. (2014). Risk evaluation in Dutch land-use planning. *Process Safety and Environmental Protection*, *92*(4), 368–376. https://doi.org/10.1016/j.psep.2014.06.002

Yirenkyi, G. (2016). *Ocupational Health and Safety Audit of Fuel Filling Stations in The Agona Nkwanta, Inchaban and Sekondi- Takoradi Metropolis in Ghana* (Issue August). Kwame Nkrumah University Of Science and Technology.

Yirenkyi, G. (2017). *Occupational Health and Safety Audit of Fuel Filling Stations in the Agona Nkwanta, Inchaban and Sekondi-Takoradi Metropolis in Ghana* [Kwame Nkrumah University of Science and Technology]. http://hdl.handle.net/123456789/10034

Zhang, Q. X., & Liang, D. (2013). Thermal Radiation and impact assessment of the LNG BLEVE fireball. *Procedia Engineering*, *52*, 602–606. https://doi.org/10.1016/j.proeng.2013.02.192

Zhou, Y., Hu, G., Li, J., & Diao, C. (2014). Risk assessment along the gas pipelines and its application in urban planning. *Land Use Policy*, *38*, 233–238. https://doi.org/10.1016/j.landusepol.2013.11.011

APPENDIXES

APPENDIX A (CHAPTER 4)

Land use patterns in the BLEVE hazard zone and their proximity to LPG stations

Land Use	1- 2 kW/m² safe zone		2.1 - 5 kW/m² hazard zone		5.1 – 10 kW/m² hazard zone		Within 10kW/m² hazard zone		within the fire ball	
	%Area	Minimum Distance (m)	%Area	Minimum Distance (m)	%Area	Minimum Distance (m)	%Area	Minimum Distance (m)	%Area	Minimum Distance (m)
Commercial	7.4	583.0	7.9	347.6	6.7	272.9	5.8	133.0	7.5	8.5
Community Service	6.3	513.5	12.4	346.3	15.9	271.2	15.6	116.0	11.0	18.0
Derelict Land	0.2	524.2	0.1	386.1	0.1	325.2	0.5	119.7	1.3	63.7
Government Business	3.2	676.4	3.2	439.5	4.2	311.7	5.2	143.1	1.8	106.8
Green Space	2.2	591.2	2.1	440.0	1.6	294.8	3.1	133.0	7.7	6.3
Industrial	9.7	513.4	7.3	347.9	4.7	289.4	7.1	116.2	22.8	0.0
Mixed Use	32.1	513.5	26.1	345.3	24.5	288.8	25.9	116.1	15.8	5.0
Public open spaces	1.7	516.9	1.3	467.4	0.2	371.9	1.2	143.4	3.8	18.1
Residential	28.4	514.5	29.6	345.0	29.7	249.0	22.0	116.0	10.1	28.9
Transport	7.7	513.6	7.7	345.2	8.5	249.2	7.4	116.1	9.0	23.8
Utilities	0.3	515.9	1.5	395.5	3.5	290.3	5.1	133.0	6.9	1.5
Vacant Land	0.8	593.7	0.7	352.8	0.5	250.9	1.0	143.0	2.3	6.4
Grand Total	**100.0**	**-**	**100.0**	**-**	**100**	**249.0**	**100**	**133.0**	**100**	**-**

Source: Field work, 2019

APPENDIX B (CHAPTER 4)

Land use patterns in the jet fire hazard zone and their proximity to LPG stations

Source: Field work, 2019

Land Use	1- 2 kW/m^2 safe zone		2.1 - 5 kW/m^2 hazard zone		5.1 – 10 kW/m^2 hazard zone		Within 10kW/m^2 hazard zone	
	% Area	Minimum Distance (m)	% Area	Minimum Distance (m)	% Area	Minimum Distance (m)	% Area	Minimum Distance (m)
Commercial	7.4	443.6	6.1	267.3	5.9	173.8	6.9	9.3
Community Service	12.5	439.6	17.1	259.5	14.6	170.6	12.4	17.7
Derelict Land	0.2	442.5	0.2	268.2	0.5	172.6	1.1	63.9
Government Business	3	453.9	4	274.4	4.6	177.2	2.2	106.9
Green Space	2.4	453.2	1.4	272.7	3	180.9	5.9	6.6
Industrial	6.5	436.3	4.6	259.3	6.8	161.4	17.2	0.0
Mixed Use	25.4	432.9	25.2	258.4	27.6	161.3	18.9	5.6
Public open spaces	1.3	470.2	0.2	285.5	1.4	186.8	2.9	18.0
Residential	31.3	432.6	29.1	258.1	22.3	172.6	15.4	29.3
Transport	7.9	433.3	8	258.3	7.2	161.3	8.7	23.2
Utilities	1.6	440.7	3.6	266.0	4.7	169.3	6.4	0.0
Vacant Land	0.6	444.0	0.5	276.2	1.4	190.4	2	5.7
Grand Total	**100**	**-**	**100**	**-**	**100**	**-**	**100**	**-**

APPENDIX C (CHAPTER 5)

Sensitivity levels for land uses in the LPG hazard zones

Land use	Sensitivity level
Formal business General industrial	Level 1: Land for use by workers
Government business Heavy industrial Cemetery Community center Cultivated and managed Derelict land Library Linear green space Major drain Major hazardous establishment Mixed use commercial residential Mixed use community service Public toilet Railways Refuse disposal Residential institutional Residential low density Residential medium density Residential multi-story Roadways Security Semi-natural Service industrial Transport terminal Vacant not previously developed Vacant previously developed Worship	Level 2
Basic education Health Residential high density Residential slum Secondary education Vocational	Level 3: Land for use by vulnerable people
Informal business/open market Public open space Tertiary education	Level 4: Land for use very large outdoor populations

Source: Field work, 2019

APPENDIX D (CHAPTER 5)

Change in sensitivity levels based on LUSPA zoning framework

Land use	Previous Sensitivity level	Current Sensitivity level
Formal business Government business	Level 1	Level 2
Cemetery Cultivated and managed Derelict land Major drain Major hazardous establishment Heavy industrial General industrial Railways Roadways Semi-natural Vacant not previously developed Vacant previously developed	Level 2	Level 1

Source: Field work, 2019

APPENDIX E (CHAPTER 5)

Land use decisions for the Inner zone of Jet fires hazards

Land Use		% Area	
Formal business	2733	83.7	DAA
Government business	534	16.3	
Total	3267	100	
Cemetery	39153	28	AA
Cultivated and managed	23073	17	
Derelict land	882	1	
Informal business	2043	1	
Library	723	1	
Linear green space	960	1	
Major drain	105	0	
Major hazardous establishment	26634	19	
Mixed use commercial residential	3978	3	
Mixed use community service	573	0	
Railways	18	0	
Recreation	5592	4	
Residential low density	207	0	
Residential multi-story	1164	1	
Residential slum	1002	1	
Roadways	10821	8	
Security	2742	2	
Service industrial	14874	11	
Vacant not previously developed	2538	2	
Vacant previously developed	3	0	
Worship	1224	1	
Total	138309	100	

APPENDIX F (CHAPTER 5)

Land use decisions for the middle zone of Jet fires hazards

Land Use	AA	% Area	DAA	%Area
Basic education	11706	27.5	-	-
Cemetery	-	-	33939	11.2
Cultivated and managed	-	-	29613	9.8
Derelict land	-	-	6075	2.01
Formal business	-	-	15090	4.99
General industrial	-	-	1176	0.39
Government business	-	-	9192	3.04
Health	849	2.0	-	-
Informal business	156	0.4	-	-
Library	-	-	8775	2.9
Linear green space	-	-	993	0.33
Major drain	-	-	10593	3.51
Major hazardous establishment	-	-	21357	7.07
Mixed use commercial residential	-	-	36267	12
Mixed use community service	-	-	4743	1.57
Railways	-	-	465	0.15
Recreation	14178	33.4	-	-
Residential high density	876	2.1	-	-
Residential institutional	-	-	4728	1.56
Residential low density	-	-	5460	1.81
Residential medium density	-	-	102	0.03
Residential multi-storey	-	-	9900	3.28
Residential slum	14727	34.7	-	-
Roadways	-	-	30312	10
Security	-	-	13131	4.35
Service industrial	-	-	41055	13.6
Vacant not previously developed	-	-	3225	1.07
Vacant previously developed	-	-	1494	0.49
Worship	-	-	14478	4.79
	42492	100.0	302163	100

APPENDIX G (CHAPTER 5)

Land use decisions for the Outer zone of Jet fires hazards

Land Use	Area	% Area	
Recreation	121839	17.8	
Informal business	302766	44.2	AA
Tertiary education	259893	38.0	
Total	**684498**	**100.0**	
Cemetery	233112	2.05	
Community centre	4632	0.04	
Cultivated and managed	149952	1.32	
Derelict land	27756	0.24	
Formal business	529422	4.66	
General industrial	108945	0.96	
Government business	415089	3.65	
Health	97719	0.86	
Heavy industrial	149085	1.31	
Basic education	394677	3.47	
Library	4422	0.04	
Linear green space	36951	0.33	
Major drain	51381	0.45	
Major hazardous establishment	57225	0.5	
Mixed use commercial residential	2984208	26.3	
Mixed use community service	88044	0.77	
Public toilet	4920	0.04	
Railways	2814	0.02	DAA
Refuse disposal	1503	0.01	
Residential high density	535926	4.72	
Residential institutional	471429	4.15	
Residential low density	540999	4.76	
Residential medium density	656757	5.78	
Residential multi-story	746046	6.57	
Residential slum	539904	4.75	
Roadways	871446	7.67	
Secondary education	69624	0.61	
Security	546918	4.81	
Semi-natural	69456	0.61	
Service industrial	453849	3.99	
Transport terminal	89163	0.78	
Vacant not previously developed	64374	0.57	
Vacant previously developed	25140	0.22	
Vocational	7599	0.07	
Worship	332487	2.93	
Total	11362974	100	

APPENDIX H (CHAPTER 5)

Land use decisions for the Inner zone of BLEVE hazards

Land use	Area	%Area	
Formal business	56427	64.1	
General industrial	8103	9.2	DAA
Government business	23544	26.7	
Total	88074	100	
Basic education	29475	3.9	
Cemetery	46890	6.1	
Community center	21	0.0	
Cultivated and managed	58464	7.7	
Derelict land	10098	1.3	
Health	2253	0.3	
Informal business	4065	0.5	
Library	13656	1.8	
Linear green space	4398	0.6	
Major drain	12951	1.7	
Major hazardous establishment	72015	9.4	
Mixed use commercial residential	129237	16.9	
Mixed use community service	12885	1.7	
Railways	288	0.0	
Recreation	29916	3.9	AA
Residential high density	3393	0.4	
Residential institutional	9246	1.2	
Residential low density	18870	2.5	
Residential medium density	7410	1.0	
Residential multi-story	34233	4.5	
Residential slum	24876	3.3	
Roadways	71799	9.4	
Secondary education	27	0.0	
Security	20814	2.7	
Service industrial	89697	11.8	
Transport	2928	0.4	
Vacant not previously developed	15915	2.1	
Vacant previously developed	4851	0.6	
Worship	31863	4.2	
	762534	100	

APPENDIX I (CHAPTER 5)

Land use decisions for the Middle zone of BLEVE hazards

Middle zone(1-49% fatality)	Area	%Area	
Basic education	53268	39.5	
Informal business	4374	3.2	
Recreation	20532	15.2	
Residential high density	16779	12.5	AA
Residential slum	29913	22.2	
Secondary education	4644	3.4	
Tertiary education	5250	3.9	
Total	134760	100	
Cemetery	43797	5.2	
Community center	3846	0.5	
Cultivated and managed	30135	3.6	
Derelict land	7353	0.9	
Formal business	41382	4.9	
General industrial	10284	1.2	
Government business	53655	6.4	
Heavy industrial	597	0.1	
Linear green space	4149	0.5	
Major drain	8346	1.0	
Major hazardous establishment	9039	1.1	
Mixed use commercial residential	251694	29.9	
Mixed use community service	7755	0.9	DAA
Railways	204	0.0	
Residential institutional	47598	5.7	
Residential low density	16332	1.9	
Residential medium density	24522	2.9	
Residential multi-story	50847	6.0	
Roadways	74949	8.9	
Security	52737	6.3	
Service industrial	62265	7.4	
Transport	3042	0.4	
Vacant not previously developed	10449	1.2	
Vacant previously developed	1533	0.2	
Worship	25125	3.0	
	841635	100	

APPENDIX J (CHAPTER 5)

Land use decisions for the Outer zone of BLEVE hazards

Land use		%Area	DAA
Informal business	666408	49.5	
Recreation	353946	26.2	AA
Tertiary education	325812	24.3	
Total	1343130	100	
Basic education	459621	1.9	
Cemetery	219447	0.9	
Community center	1269	0.0	
Cultivated and managed	155718	0.6	
Derelict land	40761	0.2	
Formal business	1273452	5.2	
General industrial	708060	2.9	
Government business	888498	3.6	
Health	221151	0.9	
Heavy industrial	654099	2.7	
Library	525	0.0	
Linear green space	78828	0.3	
Major drain	88194	0.4	
Major hazardous establishment	76281	0.3	
Mixed use commercial residential	7302084	29.6	
Mixed use community service	294666	1.2	
Public toilet	7602	0.0	
Railways	3405	0.0	
Refuse disposal	1530	0.0	
Residential high density	858552	3.5	
Residential institutional	723888	2.9	
Residential low density	1751256	7.1	
Residential medium density	1134480	4.6	
Residential multi-story	1653471	6.7	
Residential slum	1335816	5.4	
Roadways	1770204	7.2	
Secondary education	111927	0.5	
Security	795561	3.2	
Semi-natural	307575	1.2	
Service industrial	716598	2.9	
Transport	96270	0.4	
Transport terminal	157761	0.6	
Vacant not previously developed	125292	0.5	
Vacant previously developed	58581	0.2	
Vocational	11052	0.0	
Worship	575868	2.3	
Total	24659343	100	

APPENDIX K (CHAPTER 5)

Land use decisions for the Inner zone of Jet fires hazards based on revised sensitivity levels

LAND USE	AREA	%AREA	HSE ADVISE
Cemetery	39153	42.4	
Cultivated and managed	23073	25.0	
Derelict land	882	1.0	
Major drain	105	0.1	DAA
Major hazardous establishment	26634	28.8	
Vacant not previously developed	2538	2.7	
Vacant previously developed	3	0.0	
Total	**92388**	**100.0**	
Formal business	2733	5.6	
Government business	534	1.1	
Informal business	2043	4.2	
Library	723	1.5	
Linear green space	960	2.0	
Mixed use commercial residential	3978	8.1	
Mixed use community service	573	1.2	
Railways	18	0.0	
Recreation	5592	11.4	**AA**
Residential low density	207	0.4	
Residential multi-storey	1164	2.4	
Residential slum	1002	2.0	
Roadways	10821	22.0	
Security	2742	5.6	
Service industrial	14874	30.2	
Worship	1224	2.5	
Total	**49188**	**100.0**	

APPENDIX L (CHAPTER 5)

Land use decisions for middle zone of Jet fire hazards based on revised sensitivity levels

LAND USE	AREA	%AREA	PLANNING DECISION
Basic education	11706	27.5	
Health	849	2.0	
Informal business	156	0.4	AA
Recreation	14178	33.4	
Residential high density	876	2.1	
Residential slum	14727	34.7	
Total	**42492**	**100.0**	
Cemetery	33939	11.2	
Cultivated and managed	29613	9.8	
Derelict land	6075	2.0	
Formal business	15090	5.0	
General industrial	1176	0.4	
Government business	9192	3.0	
Library	8775	2.9	
Linear green space	993	0.3	
Major drain	10593	3.5	
Major hazardous establishment	21357	7.1	
Mixed use commercial residential	36267	12.0	
Mixed use community service	4743	1.6	DAA
Railways	465	0.2	
Residential institutional	4728	1.6	
Residential low density	5460	1.8	
Residential medium density	102	0.0	
Residential multi-storey	9900	3.3	
Roadways	30312	10.0	
Security	13131	4.3	
Service industrial	41055	13.6	
Vacant not previously developed	3225	1.1	
Vacant previously developed	1494	0.5	
Worship	14478	4.8	
Total	**302163**	**100**	

APPENDIX M (CHAPTER 5)

Land use decisions for outer zone of jet fire hazards based on revised sensitivity levels

LAND USE	AREA	%AREA	PLANNING DECISION
Informal business	302766	44.2	
Recreation	121839	17.8	AA
Tertiary education	259893	38.0	
Total	**684498**	**100.0**	
Basic education	394677	3.5	
Cemetery	233112	2.1	
Community center	4632	0.0	
Cultivated and managed	149952	1.3	
Derelict land	27756	0.2	
Formal business	529422	4.7	
General industrial	108945	1.0	
Government business	415089	3.7	
Health	97719	0.9	
Heavy industrial	149085	1.3	
Library	4422	0.0	
Linear green space	36951	0.3	
Major drain	51381	0.5	
Major hazardous establishment	57225	0.5	
Mixed use commercial residential	2984208	26.3	
Mixed use community service	88044	0.8	
Public toilet	4920	0.0	
Railways	2814	0.0	DAA
Refuse disposal	1503	0.0	
Residential high density	535926	4.7	
Residential institutional	471429	4.1	
Residential low density	540999	4.8	
Residential medium density	656757	5.8	
Residential multi-storey	746046	6.6	
Residential slum	539904	4.8	
Roadways	871446	7.7	
Secondary education	69624	0.6	
Security	546918	4.8	
Semi-natural	69456	0.6	
Service industrial	453849	4.0	
Transport terminal	89163	0.8	
Vacant not previously developed	64374	0.6	
Vacant previously developed	25140	0.2	
Vocational	7599	0.1	
Worship	332487	2.9	
Total	**11362974**	**100**	

APPENDIX N (CHAPTER 5)

Land use decisions for inner zone of BLEVE hazards based on revised

LAND USE	AREA	% AREA	PLANNING DECISION
Basic education	29475	4.7	AA
Community centre	21	0.0	
Formal business	56427	9.1	
Government business	23544	3.8	
Health	2253	0.4	
Informal business	4065	0.7	
Library	13656	2.2	
Linear green space	4398	0.7	
Mixed use commercial residential	129237	20.8	
Mixed use community service	12885	2.1	
Railways	288	0.0	
Recreation	29916	4.8	
Residential high density	3393	0.5	
Residential institutional	9246	1.5	
Residential low density	18870	3.0	
Residential medium density	7410	1.2	
Residential multi-storey	34233	5.5	
Residential slum	24876	4.0	
Roadways	71799	11.6	
Secondary education	27	0.0	
Security	20814	3.3	
Service industrial	89697	14.4	
Transport	2928	0.5	
Worship	31863	5.1	
Total	**621321**	**100**	
Cemetery	46890	20.5	DAA
Cultivated and managed	58464	25.5	
Derelict land	10098	4.4	
General industrial	8103	3.5	
Major drain	12951	5.6	
Major hazardous establishment	72015.01	31.4	
Vacant not previously developed	15915	6.9	
Vacant previously developed	4851	2.1	
Total	**229287**	**100**	

sensitivity levels

APPENDIX O (CHAPTER 5)

Land use decisions for middle zone of BLEVE hazard based on revised sensitivity levels

LAND USE	AREA	% AREA	PLANNING DECISION
Basic education	53268	39.5	
Informal business	4374	3.2	
Recreation	20532	15.2	
Residential high density	16779	12.5	AA
Residential slum	29913	22.2	
Secondary education	4644	3.4	
Tertiary education	5250	3.9	
Total	**134760**	**100**	
Cemetery	43797	5.2	
Community center	3846.001	0.5	
Cultivated and managed	30135	3.6	
Derelict land	7352.997	0.9	
Formal business	41382	4.9	
General industrial	10284	1.2	
Government business	53655	6.4	
Heavy industrial	596.9996	0.1	
Linear green space	4149	0.5	
Major drain	8345.997	1.0	
Major hazardous establishment	9038.999	1.1	
Mixed use commercial residential	251694	29.9	
Mixed use community service	7755.006	0.9	DAA
Railways	204.0002	0.0	
Residential institutional	47597.99	5.7	
Residential low density	16332	1.9	
Residential medium density	24522	2.9	
Residential multi-story	50847.01	6.0	
Roadways	74948.99	8.9	
Security	52737	6.3	
Service industrial	62265	7.4	
Transport	3042	0.4	
Vacant not previously developed	10449	1.2	
Vacant previously developed	1532.999	0.2	
Worship	25125.01	3.0	
Total	**841635**	**100**	

APPENDIX P (CHAPTER 5)

Land use decisions for outer zone of BLEVE hazard based on revised sensitivity levels

LAND USE	AREA	% AREA	PLANNING DECISION
Informal business	664890	49.6	
Recreation	350910	26.2	AA
Tertiary education	325812	24.3	
Total	**1341612**	**100**	
Amenity	1518.001	0.0	
Basic education	459621	1.9	
Cemetery	219447	0.9	
Community center	1269.001	0.0	
Cultivated and managed	155718	0.6	
Derelict land	40761	0.2	
Formal business	1273452	5.2	
General industrial	708060	2.9	
Government business	888498	3.6	
Health	221151	0.9	
Heavy industrial	654099	2.7	
Library	525.001	0.0	
Linear green space	78828	0.3	
Major drain	88194.01	0.4	
Major hazardous establishment	76281	0.3	
Mixed use commercial residential	7302084	29.6	
Mixed use community service	294666	1.2	
Public toilet	7601.999	0.0	
Railways	3405.001	0.0	DAA
Refuse disposal	1529.999	0.0	
Residential high density	858552	3.5	
Residential institutional	723888	2.9	
Residential low density	1751256	7.1	
Residential medium density	1134480	4.6	
Residential multi-story	1653471	6.7	
Residential slum	1335816	5.4	
Roadways	1770204	7.2	
Secondary education	111927	0.5	
Security	795561	3.2	
Semi-natural	307575	1.2	
Service industrial	716598	2.9	
Transport	96270	0.4	
Transport terminal	157761	0.6	
Vacant not previously developed	125292	0.5	
Vacant previously developed	58581	0.2	
Vocational	11052	0.0	
Worship	575868	2.3	
Total	**24660861**	**100.0**	

APPENDIX Q (Chapter Six)

Table 49: Land use patterns in the inner and middle LSIR zones of BLEVE hazards

Land use	Inner zone	%	Middle zone	%
Basic education	136326	4.5	36420	4
Cemetery	137361	4.6	34176	3.8
Community centre	4017	0.1		0
Cultivated and managed	110058	3.6	4995	0.6
Derelict land	20889	0.7	801	0.1
Formal business	166362	5.5	59607	6.6
General industrial	24597	0.8	3192	0.4
Government business	146916	4.9	47868	5.3
Health	2286	0.1	4788	0.5
Heavy industrial	1047	0		0
Informal business	15978	0.5	5721	0.6
Library	13656	0.5		0
Linear green space	14568	0.5	4086	0.5
Major drain	28761	1	4584	0.5
Major hazardous establishment	82506	2.7	228	0
Mixed use commercial residential	672510	22.3	220731	24.5
Mixed use community service	29064	1	4716	0.5
Railways	708	0	330	0
Public open space	54459	1.8	30	0
Residential high density	56838	1.9	27792	3.1
Residential institutional	121185	4	42321	4.7
Residential low density	75318	2.5	33969	3.8
Residential medium density	90306	3	55398	6.2
Residential multi-storey	145521	4.8	50523	5.6
Residential slum	94794	3.1	33864	3.8
Roadways	233,811	7.7	71,730	8
Secondary education	14352	0.5	6774	0.8
Security	143505	4.8	46074	5.1
Semi-natural	42	0	2319	0.3
Service industrial	213726	7.1	44466	4.9
Tertiary education	27579	0.9	24396	2.7
Vacant not previously developed	26364	0.9	2844	0.3
Vacant previously developed	11016	0.4	3690	0.4
Vocational	276	0	672	0.1
Worship	100782	3.3	20250	2.3
Total	3017484	100	899355	100

Source: Field Work, 2019

APPENDIX R (Chapter Six)

Land use patterns in the outer LSIR zones of BLEVE hazards

Land use	Outer zone	%
Basic education	2340	3.9
Cemetery	2994	5
Community centre		0
Cultivated and managed	375	0.6
Derelict land	48	0.1
Formal business	3822	6.3
General industrial	354	0.6
Government business	954	1.6
Health	459	0.8
Heavy industrial		0
Informal business	1074	1.8
Library		0
Linear green space	252	0.4
Major drain	360	0.6
Major hazardous establishment	123	0.2
Mixed use commercial residential	14166	23.5
Mixed use community service	603	1
Railways	27	0
Public open space	54	0.1
Residential high density	1254	2.1
Residential institutional	3339	5.5
Residential low density	1554	2.6
Residential medium density	5178	8.6
Residential multi-story	4524	7.5
Residential slum	1215	2
Roadways	4296	7.1
Secondary education	399	0.7
Security	3504	5.8
Semi-natural		0
Service industrial	2724	4.5
Tertiary education	2340	3.9
Transport		0
Transport terminal	831	1.4
Vacant not previously developed	288	0.5
Vacant previously developed	0	
Vocational		0
Worship	858	1.4
Total	60309	100

Source: Field Work, 2019

APPENDIX S (Chapter Six)

Land use patterns in the middle LSIR zone: Jet fire

Land Use	Area	% Area
Basic education	45189	4.0
Cemetery	116838	10.5
Community center	321	0.0
Cultivated and managed	74964	6.7
Derelict land	11529	1.0
Formal business	53319	4.8
General industrial	7941	0.7
Government business	30561	2.7
Health	2241	0.2
Informal business	3822	0.3
Library	13398	1.2
Linear green space	6195	0.6
Major drain	17763	1.6
Major hazardous establishment	72600	6.5
Mixed use commercial residential	121227	10.9
Mixed use community service	14964	1.3
Railways	834	0.1
Public open space	45690	4.1
Residential high density	11907	1.1
Residential institutional	15414	1.4
Residential low density	18864	1.7
Residential medium density	3099	0.3
Residential multi-story	41265	3.7
Residential slum	38523	3.5
Roadways	104325	9.3
Secondary education	2979	0.3
Security	64104	5.7
Service industrial	105690	9.5
Tertiary education	3936	0.4
Vacant not previously developed	24468	2.2
Vacant previously developed	5037	0.5
Worship	37218	3.3
Total	1116225	100

Source: Field Work, 2019

APPENDIX T (Chapter Six)

Sensitivity Level 1 for land use types in BLEVE hazard zones

Land use	Sensitivity Level	Area(m2)	% Area
Formal business	Level 1	1371261	36.9
General industrial		726447	19.5
Government business		965697	26
Heavy industrial		654696	17.6
Total		**3718101**	**100**

Source: Field Work, 2019

APPENDIX U (Chapter Six)

Sensitivity Level 2 for land use types in BLEVE hazard zones

Land Use		Area	%
Cemetery		310134	2
Community centre		5136	0
Cultivated and managed		244317	1
Derelict land		58212	0
Library		14181	0
Linear green space		87375	0
Major drain		109491	1
Filling Stations		157335	1
Mixed use (commercial/ residential)		7683015	39
Mixed use community service		315306	2
Public toilet		7602	0
Railways	**LEVEL 2** Land for use by the general public	3897	0
Refuse disposal		1530	0
Residential institutional		780732	4
Residential low density		1786458	9
Residential medium density		1166412	6
Residential multi-storey		1738551	9
Roadways		1916952	10
Security		869112	4
Semi-natural		307575	2
Service industrial		868560	4
Transport		102240	1
Transport terminal		157761	1
Vacant not previously developed		151656	1
Vacant previously developed		64965	0
Worship		632856	3
Grand Total		**19541361**	**100**

Source: Field Work, 2019

APPENDIX V (Chapter Six)

Sensitivity Level 3 and 4 for land use types in BLEVE hazard zones

Land use	Sensitivity Level	Area(m2)	% Area
Basic education	Level 3	542364	17.1
Health		223404	7.1
Residential high density		878724	27.8
Residential slum		1390605	44
Secondary education		116598	3.7
Vocational		11052	0.3
Total		**3162747**	**100**
Informal business	Level 4	673329	47.8
Public open space		402876	28.6
Tertiary education		331062	23.5
Total		**1407267**	**100**

Source: Field Work, 2019

APPENDIX W (Chapter Six)

Sensitivity level 1 for Land uses in Jet fire hazard zone

Land use	Area	% Area	Sensitivity Level
Formal business	547245	44.4	**Level 1**: Land for use by workers
General industrial	110121	8.9	
Government business	424815	34.5	
Heavy industrial	149085	12.1	
Total	**1231266**	**100**	

APPENDIX X (Chapter Six)

Sensitivity level 2 for Land uses in Jet fire hazard zone

Land use	Sensitivity Level	Area	%
Cemetery	**Level 2:** Land for use by the general public	306204	3.4
Community centre		4631.999	0.1
Cultivated and managed		202638	2.3
Derelict land		34713	0.4
Library		13920	0.2
Linear green space		38904	0.4
Major drain		62079	0.7
Major hazardous establishment		105216	1.2
Mixed use (commercial /residential)		3024453	33.9
Mixed use community service		93360.02	1.0
Public toilet		4920.001	0.1
Railways		3297.002	0.0
Refuse disposal		1502.999	0.0
Residential institutional		476157	5.3
Residential low density		546666	6.1
Residential medium density		656859	7.4
Residential multi-storey		757110	8.5
Roadways		912579	10.2
Security		562791	6.3
Semi-natural		69455.99	0.8
Service industrial		509778	5.7
Transport terminal		89163	1.0
Vacant not previously developed		70137	0.8
Vacant previously developed		26637	0.3
Worship		348189	3.9
Total		**8921361**	**100**

Source: Field Work, 2019

APPENDIX Y (Chapter Six)

Sensitivity levels for Land uses in Jet fire hazard zone

Land use	Area	% Area	Sensitivity Level
Basic education	406383	24.3	
Health	98568	5.9	
Residential high density	536802	32.1	**Level 3**: Land for use by vulnerable people
Residential slum	555633	33.2	
Secondary education	69624.01	4.2	
Vocational	7598.998	0.5	
Total	**1674609**	**100.0**	
Informal business	304965	43.2	**Level 4**: Land for use very large outdoor populations
Public open space	141609	20.0	
Tertiary education	259893	36.8	
Total	**706467**	**100**	

Source: Field Work, 2019

APPENDIX Z (Chapter Six)

Land uses Advised Against in the Inner LSIR zone: BLEVE

Land use		Land use	Area	% Area
Community Services	16.6	Basic Education	136326	5.1
		Secondary Education	14352	0.5
		Tertiary Education	27855	1
		Security	143505	5.4
		Health	2286	0.1
		Community Centre	4017	0.2
		Library	13656	0.5
		Worship	100782	3.8
Industrial	11.1	Major Hazardous Establishment	82506	3.1
		Service Industrial	213726	8
Commercial	0.6	Informal Business	15978	0.6
Utilities	6.2	Major Drain	28761	1.1
		Cemetery	137361	5.1
Mixed Use	26.2	Mixed Use (Commercial /Residential)	672510	25.1
		Mixed Use Community Service	29064	1.1
Public open spaces	2	Public open spaces	54459	2
Residential	21.7	Residential High Density	56838	2.1
		Residential Institutional	121185	4.5
		Residential Low Density	75318	2.8
		Residential Medium Density	90306	3.4
		Residential Multi-Story	145521	5.4
		Residential Slum	93804	3.5
Transport	8.7	Roadways	233,811	8.7
		Railways	708	0
Greenspaces	4.6	Cultivated And managed	110058	4.1
		Linear Green Space	14568	0.5
		Semi-Natural	42	0
Vacant	2.2	Derelict Land	20745	0.8
		Vacant Not Previously Developed	26364	1
		Vacant Previously Developed	11004	0.4
		TOTAL	2677416	**100**

Source: Field Work, 2019

APPENDIX A1 (Chapter Six)

Land use types Advised Against in the Middle LSIR zone: BLEVE

Land use	% Area	Land use	Area	% Area
Community Services	52	Basic Education	36420	25.9
		Secondary Education	6774	4.8
		Tertiary Education	24396	17.4
		Health	4788	3.4
		Vocational	672	0.5
Informal Business	4.1	Informal Business	5721	4.1
Residential	43.9	Residential High Density	27792	19.8
		Residential Slum	33864	24.1
TOTAL	**100**	**TOTAL**	**140457**	**100.0**

Source: Field Work, 2019

APPENDIX A2 (Chapter Six)

Land uses Advised Against in the Middle LSIR zone: Jet fires

Land use	% Area	Land use	Area	% Area
Community Services	35.3	Basic Education	45189	29.3
		Secondary Education	2979	1.9
		Tertiary Education	3936	2.6
		Health	2241	1.5
Informal Business	2.5	Informal Business	3822	2.5
Public open spaces	29.6	Public open spaces	45690	29.6
Residential	32.7	Residential High Density	11907	7.7
		Residential Slum	38523	25.0
		TOTAL	154287	100

Source: Field Work, 2019

APPENDIX A3 (Chapter Six)

Land uses Advised Against in the Inner LSIR zone of BLEVE hazards based on the revised sensitivity levels

Land Use	%Area	Land Use	Area	%Area
Community Services	17.3	Basic Education	136326	5.3
		Secondary Education	14352	0.6
		Tertiary Education	27,855	1.1
		Community Centre	4017	0.2
		Health	2286	0.1
		Library	13656	0.5
		Security	143505	5.6
		Worship	100782	3.9
Commercial	12.8	Formal Business	166362	6.5
		Government Business	146916	5.7
		Informal Business	15978	0.6
Public open spaces		Public open spaces	54459	2.1
Residential	49.8	Mixed Use Commercial Residential	672510	26.1
		Mixed Use Community Service	29064	1.1
		Residential High Density	56838	2.2
		Residential Institutional	121185	4.7
		Residential Low Density	75318	2.9
		Residential Medium Density	90306	3.5
		Residential Multi-Storey	145521	5.7
		Residential Slum	93804	3.6
Transport	9	Roadways	233,811	9.0
		Railways	708	0.0
Greenspace	0.6	Linear Green Space	14568	0.6
Industrial	8.3	Service Industrial	213726	8.3
TOTAL	**100**	**TOTAL**	**2573853**	**100**

Source: Field Work, 2019

APPENDIX A4

Association between levels of perceived risk and levels of support for alternative risk mitigation strategies.

		Perceived Minor Risk	%	Perceived Major Risk	%
CRM & Alternative Strategies	No Support	20	5.7	20	8.4
	Little Support	135	38.4	50	21.0
	Moderate Support	163	46.3	133	55.9
	Complete Support	34	9.7	35	14.7
	Total	352	100	238	100

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	20.861[a]	3	0.000
Likelihood Ratio	21.453	3	0.000
Linear-by-Linear Association	6.885	1	0.009
N of Valid Cases	590		

Source: Field work, 2019

APPENDIX A5

Association between levels of perceived risk and support for safe management

	Perceived Minor Risk	%	Perceived Major Risk	%
No Support	1	0.3	1	0.4
Little Support	23	6.6	6	2.5
Moderate Support	90	25.9	91	38.1
Complete Support	233	67.1	141	59
Total	347	100	239	100
	Value	df	Asymptotic Significance (2-sided)	
Pearson Chi-Square	13.144[a]	3	0.004	
Likelihood Ratio	13.485	3	0.004	
Linear-by-Linear Association	0.718	1	0.397	
N of Valid Cases	586			

Source: Field work, 2019

Appendix A6

Table 50: Association between levels of perceived risk and support for land use planning as a control measure for LPG fire risk

		Perceived Minor Risk	%	Perceived Major Risk	%
Land use planning	No Support	50	14.2	21	8.7
	Little Support	156	44.4	114	47.1
	Moderate Support	107	30.5	82	33.9
	Complete Support	38	10.8	25	10.3
Total		351	100	242	100

Source: Field work, 2019

APPENDIX A7

UNIVERSITY OF CAPE COAST
FACULTY OF SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY & REGIONAL PLANNING

OBSERVATION CHECK LIST FOR LPG STATIONS

This study aims at assessing the risk associated with liquefied petroleum gas stations in the Accra metropolis. This aim would be achieved through research which would involve collecting data on your LPG installation. The data collection is supposed to last about 10 minutes during which you are expected to answer questions regarding the capacity of your vessel. This interview is for academic purposes and confidentiality is strictly adhered to. None of the information provided in this interview will be used for non-academic purposes. We will protect information about you to the best of our ability and no one else except Emmanuel Abeashi Mensah will have access to the information documented during your interview. You will not be named in any reports. If you have any reservations about this survey, please feel free to contact **Emmanuel A. Mensah** on 0208017140 or email to emensah@ucc.edu.gh

Station name	
Location	
Number of vessels	
Primary Vessel Diameter (m)	
Primary Vessel Length (m)	
Primary Vessel Capacity (tons)	
Environmental Conditions	☐ Sheltered (Trees/bushes and buildings) ☐ Unsheltered (Open Park/field)
Type of Buildings	☐ Single story ☐ Multi-story

APPENDIX A8

UNIVERSITY OF CAPE COAST
FACULTY OF SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY & REGIONAL PLANNING

QUESTIONNAIRE

RISK PERCEPTION AND RISK REDUCTION STRATEGIES OF PERSONS IN THE VICINITY OF LPG STATIONS: ACCRA METRO

This study aims at assessing the risk associated with liquefied petroleum gas stations in the Accra metropolis. This aim would be achieved through research which would involve collecting data on risk perceptions and risk management strategies of stakeholders in the LPG industry. The expected duration of the interview is about 25-30 minutes during which you are expected to answer questions regarding your views on LPG risk and how to manage such risk. This interview is for academic purposes only and confidentiality will be strictly adhered to. We will protect information about you to the best of our ability and no one else except Emmanuel Abeashi Mensah will have access to the information documented during your interview. You will also not be named in any reports. If you have any reservations about this survey, please feel free to contact **Emmanuel A. Mensah** on 0208017140 or email to emensah@ucc.edu.gh

ID of Field Assistant

- Field Assistant 1 ☐
- Field Assistant 2 ☐
- Field Assistant 3 ☐
- Field Assistant 4 ☐
- Field Assistant 5 ☐
- Field Assistant 6 ☐
- Field Assistant 7 ☐
- Field Assistant 8 ☐

Name of Station	
Locality	

Type of Station

- ☐ Gas station only
- ☐ Combined (Gas and Petrol)

Proximity

- ☐ Less than 350 meters
- ☐ More than 350 meters

GPS location

Longitude	
Latitude	
Accuracy (M)	

Personal Information

1. Sex

☐ Male

☐ Female

2.

Age	

3. Level of education

☐ No education ☐ Basic level ☐ Secondary level

☐ Tertiary level

4. Religion

☐ Christian ☐ Muslim ☐ Traditionalist ☐ Other

5. Marital status

☐ Never married ☐ Married ☐ Ever married ☐ Other (Specify)

5c. How many dependants?

6. Employment status

☐ Employed ☐ Unemployed

7. Income bracket (per month)

☐ None ☐ Less than 200 GHC ☐ 200-499 GHC

☐ 500-1000 GHC ☐ More than 1000 GHC

RISK PERCEPTION

Economic Risk

8. How likely are you to lose your savings because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
9. How likely are you to lose access to credit because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

10. How likely are you to lose your investments because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
11. How likely are you to pay higher premiums on your insurance because of the risk of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
12. How likely are you to lose access to your professional groups because of the risk of an LPG disaster in this area in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
13. How likely are you to lose access to your license to operate because of the risk of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
14. How likely are you to lose your home in the event of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
15. How likely are you to lose your business in the event of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
16. How likely are you to become unemployed in the event of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

Social Risk

17. How likely are you to lose contact with your family members because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
18. How likely are you to lose contact with your social/religious groups because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

Health and Safety Risk

19. How likely are you to suffer health problems because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
20. How likely are you to lose your life because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
21. How likely are you to become maimed because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
22. How likely are you to be very fearful because of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely
23. How likely are you likely to become anxious/stressed because of the risk of an LPG disaster in this area?
☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

Environmental Risk

24. How likely are you to smell an offensive odour because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

25. How likely are you to experience noise due to the operations of the LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

26. How likely are you to experience physical destruction of your buildings and other structures because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

27. How likely are you to experience contamination of your water because of an presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

28. How likely are you to experience contamination of your food because of an presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

29. How likely are you to experience disorganized human activities because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

30. How likely are you to experience poor sanitation because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

31. How likely are you to experience littering and improper waste disposal because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

Security Risk

32. How likely are you to be targeted by criminals because of the presence of an LPG station in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

33. How likely are you to be caught up in demonstrations and other civil unrest because of an LPG disaster in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

34. How likely are you to experience violent conflicts because of an LPG disaster in this area?

☐ Not likely at all ☐ Not likely ☐ Likely ☐ Very likely

FACTORS AFFECTING RISK PERCEPTION

PROPERTY OWNERSHIP, LENGTH OF STAY AND ACTIVITIES

35. Are you resident in this area?

☐ Yes ☐ No

36. How long have you been in this area? (Please indicate number of years)

☐

37. How many hours do you spend per day in this area?

☐

39. Do you own any property near the LPG station?

☐ Yes ☐ No

40. What major activities do you usually engage in at this location? (Select all that apply)

Trading/Retail and wholesale

☐ Transport ☐ Industrial ☐ Health ☐ Education ☐

Recreation/sports

☐ Agriculture, Forestry and Fisheries ☐ Resident ☐ Administrative

Services

☐ Religious ☐ Other

PREVIOUS DISASTER EXPERIENCES

41. Have you ever experienced a disaster?

☐Yes ☐No

42. Injuries in a disaster (List as many as applicable)

43. Lost Personal Property in a Disaster (List as many as applicable)

HELP FROM THIRD PARTIES

44. Are you likely to receive help from a third party (Family, friends, social groups, etc.) in case of an LPG disaster in this area?

☐Yes ☐No

IN ORGANIC EXPERIENCES

45a. Do you know of anyone who lost property through a disaster?

☐Yes ☐No

45b if Yes, List the property involved

46a. Do you know of anyone who has been injured through a disaster?

☐Yes ☐No

46b If Yes, list the type of injuries

PROXIMITY

47a.How far away are you from the LPG filling station?

☐Extremely far ☐Very far ☐Near ☐Very Near

47b. Estimate the time it takes for you to get to the gas filling station in minutes.

47c. How exposed are you to danger based on the distance between you and the LPG station?

☐Extremely exposed ☐Very exposed ☐Moderately exposed

☐Not exposed

VULNERABILITY CONTEXT

48a. How often are you faced with reduction in your income?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48b.How often do you eat less food than what you have to because, you cannot afford more

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48c.What type of accommodation do you have?

☐ Homeless ☐ Sharing a rented room ☐ Renting own home

☐ Living in family house ☐ Living in own house ☐ Living in institutional housing

48d.How often are you unable to afford healthcare?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48e.How often are you unable to afford good cloths?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48f.How often are you affected by poor sanitation?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48g.How often are you affected by disasters such as floods, fires, vehicular, accidents etc.?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48h.How often do you loss property as a result of disasters?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

48i.How often are you injured as a result of disasters?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ Every time

ASSETS

HUMAN CAPITAL

49a. Rank your state of health

☐ Slightly Good ☐ Good ☐ Very good ☐ Extremely good

49b.How often do you undertake skilled work for which you are paid?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ All the time

49c.How often have you been able to change to a better job in the last 10 years?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ All the time

NATURAL CAPITAL

50a. Ownership of land

☐ None ☐ One ☐ Few ☐ Many

50b.How likely are you to get access to fertile Land for agriculture?

☐ Not at all likely ☐ Not likely ☐ Likely ☐ Very likely

50c.How likely are you to get access to free natural foods and products like snails and mushrooms

☐ Not at all likely ☐ Not likely ☐ Likely ☐ Very likely

SOCIAL CAPITAL

51a.How often have you held leadership positions?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ All the time

51b.How connected are you to influential people in your society?

☐ Not connected ☐ Slightly Connected ☐ Connected ☐ Very connected

☐ Extremely connected

51c.How often do you participate in major decision making at work?

☐ Never ☐ Rarely ☐ Often ☐ Very often ☐ All the time

FINANCIAL CAPITAL

52a. How much savings do you have currently?

☐ None ☐ Less than 200 GHC ☐ 200-499 GHC

☐ 500-1000 GHC ☐ More than 1000 GHC

52b. How much credit can you get currently?

☐ None ☐ Less than 200 GHC ☐ 200-499 GHC

☐ 500-1000 GHC ☐ More than 1000 GHC

52c. How much do you receive in remittances?

☐ None ☐ Less than 200 GHC ☐ 200-499 GHC

☐ 500-1000 GHC ☐ More than 1000 GHC

PHYSICAL CAPITAL

53a. How many buildings/Permanent Structures do you own?

☐ None ☐ One ☐ Few ☐ Many

53b.What type of toilet facilities do you have access to?

☐ Open Defecation ☐ Public pit latrine ☐ Private pit latrine

☐ Shared water closet ☐ Private water closet

53c. How many personal sets of work tools do you own?

☐ None ☐ One ☐ Few ☐ Many

POLICIES AND INSTITUTIONS

54a. National Economic/Business and finance policies have made it easy for me to acquire livelihood assets.

☐ Disagree ☐ Partially agree ☐ Agree ☐ Fully agree ☐ Don't know

54b. National policies on social protection have made it easy for me to make a living.

☐ Disagree ☐ Partially agree ☐ Agree ☐ Fully agree ☐ Don't know

54c. National policies on health have made it easy for me to have good health care.

☐ Disagree ☐ Partially agree ☐ Agree ☐ Fully agree ☐ Don't know

54d. National policies on disaster management have cushioned me from the effects of disasters.

☐ Disagree ☐ Partially agree ☐ Agree ☐ Fully agree ☐ Don't know

55a. Local regulations on business and taxes have made it easy for me to make a living.

☐ Disagree ☐ Partially agree ☐ Agree ☐ Fully agree ☐ Don't know

55b. Local policies on social protection have made it easy for me to make a living.
☐Disagree ☐Partially agree ☐ Agree ☐Fully agree ☐Don't know
55c. Local policies on health have made it easy for me to have good health care.
☐Disagree ☐Partially agree ☐ Agree ☐Fully agree ☐Don't know
55d. Local policies on disaster management have cushioned me from the effects of disasters.
☐Disagree ☐Partially agree ☐ Agree ☐Fully agree ☐Don't know
56a.My membership of certain institutions assists me to make a living
☐Disagree ☐Partially agree ☐ Agree ☐Fully agree ☐Don't know
56b. What is the administrative level of the institutions which are helping you ?
☐Local ☐ National ☐ International

RISK MANAGEMENT STRATEGIES

67. Do you want the risk of LPG disasters reduced?
☐Yes ☐No

68. Who should reduce the risk of LPG disasters?
☐ Key individuals (Chiefs, Religious leaders, Opinion leaders) ☐ Government
☐NGOs ☐ Owners of LPG stations ☐ Everybody ☐ Others

69. Please provide details about your personal strategies for managing the risk from the LPG plant in your area.

70a. Rank the extent to which you have utilized risk avoidance as a strategy
☐ Not used ☐Rarely ☐Often ☐ Very Often ☐ All the time
70b. Rank the extent to which you have utilized risk mitigation as a strategy
☐ Not used ☐Rarely ☐Often ☐ Very Often ☐ All the time
70c. Rank the extent to which you have utilized risk transfer as a strategy
☐ Not used ☐Rarely ☐Often ☐ Very Often ☐ All the time
70d. Rank the extent to which you have utilized risk financing as a strategy
☐ Not used ☐Rarely ☐Often ☐ Very Often ☐ All the time

NON-PERSONAL STRATEGIES FOR REDUCING RISK

71. Please rank the extent to which the following strategies should be used in response to the risk associated with existing LPG stations. (0 is the least and 5 is the highest).

a	Promote the use of alternative fuel like charcoal instead of LPG	0	1	2	3	4	5
b	Relocate everyone living close to LPG filling stations						
c	Introduce safer technology at LPG Stations						
d	Improve the knowledge and skill of the personnel working at LPG filling stations.						
e	Undertake more checks at LPG stations						
f	Relocate LPG stations to uninhabited areas						
g	Ensure strict management at LPG filling stations						
h	Educate the general public on safety						
i	Reduce the quantity of gas stored at LPG stations						
j	Maintain LPG station but pay compensation to victims						

k	Sell already filled gas cylinders at LPG stations (Cylinder re circulation)						

72. Suggest other strategy to be used in response to the risk of LPG disasters

APPENDIX A5
UNIVERSITY OF CAPE COAST
FACULTY OF SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY & REGIONAL PLANNING
INTERVIEW GUIDE FOR RISK PERCEPTION

This study aims at assessing the risk associated with liquefied petroleum gas stations in the Accra metropolis. This aim would be achieved through research which would involve collecting data on risk perceptions and risk management strategies of stakeholders in the LPG industry. The expected duration of the interview is about 25-30 minutes during which you are expected to answer questions regarding your views on LPG risk and how to manage such risk. This interview is for academic purposes only and confidentiality will be strictly adhered to. We will protect information about you to the best of our ability and no one else except Emmanuel Abeashi Mensah will have access to the information documented during your interview. You will also not be named in any reports. If you have any reservations about this survey, please feel free to contact **Emmanuel A. Mensah** on 0208017140 or email to emensah@ucc.edu.gh

Demographic Information

1. Sex

☐ Male

☐ Female

2. Age ☐

3. Category ☐

Item no.	Themes Used in In-depth Interviews on risk from LPG stations
1	Whether the risk from LPG stations was caused by human error
2	Whether people face this risk voluntarily
3	Individuals' ability to personally control the risks
4	Propinquity (How personal is the risk to the interviewee)
5	Whether the risks were known precisely by the exposed person
6	Novelty of the risk
7	Extent to which the risks is known to science and to Government
8	Publicity of the risk
9	Whether death occurs immediately
10	Whether the risk was chronic or catastrophic
11	Whether the risk was common or dreaded
12	Severity of the consequences
13	Whether the risk could impact children
14	Risk-benefit trade-off
15	Trust

APPENDIX A5

UNIVERSITY OF CAPE COAST
FACULTY OF SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY & REGIONAL PLANNING
IN-DEPTH INTERVIEW GUIDE FOR RISK MANAGEMENT

This study aims at assessing the risk associated with liquefied petroleum gas stations in the Accra metropolis. This aim would be achieved through research which would involve collecting data on risk perceptions and risk management strategies of stakeholders in the LPG industry. The expected duration of the interview is about 15-20 minutes during which you are expected to answer questions regarding your views on LPG risk and how to manage such risk. This interview is for academic purposes only and confidentiality will be strictly adhered to. We will protect information about you to the best of our ability and no one else except Emmanuel Abeashi Mensah will have access to the information documented during your interview. You will also not be named in any reports. If you have any reservations about this survey, please feel free to contact **Emmanuel A. Mensah** on 0208017140 or email to emensah@ucc.edu.gh

Demographic Information

1. Sex

☐ Male

☐ Female

2. Age ☐

3. Category ☐

Item no.	Themes Used in In-depth Interviews on risk management
1	The role of safe technology in ensuring safety in the LPG industry
2	The role of safe management in ensuring safety in the LPG industry
3	The role of land use planning in ensuring safety in the LPG industry
4	The role of Emergency response in ensuring safety in the LPG industry
5	The role of Stakeholders and institutions in safety in the LPG industry