Original Research Article

Comparative Analysis of the Fire and Explosion Risk Assessment in Petroleum Product Handling Facilities in Niger Delta, Nigeria

.

Abstract: This study investigates the risk levels associated with fire and explosion in petroleum handling facilities, considering variations based on facility type, operators, and geographical location. A qualitative risk analysis was used to determine the likelihood of fires and explosions for 118 petroleum products handling facilities in the Niger Delta region of Nigeria. Comparative analyses employed Browne-Forsythe and Welch tests to assess significant differences in risk across geographical locations, facility types, and operators. The study revealed significant variations in fire and explosion risks across geographical locations (Browne-Forsythe F-ratio = 4.888, p-value = 0.0099). Tukey multiple comparison tests revealed that the significant difference laid between facilities in Warri and Port Harcourt. The Petroleum Product handling facilities in Warri exhibited a higher mean fire and explosion risk levels ($\bar{X}$=9.43) than those in Port Harcourt ($\bar{X}$= 8.03) and Eket ($\bar{X}$=8.43). The result also showed that Facilities with Combined Petrol and LPG gas in the same premises had higher Mean Risk Score ($\bar{X}$=8.64) than the facilities that retail either Petrol only or LPG. However, the Browne-Forsythe and Welch comparative tests showed no significant statistical differences between their risk levels (P>0.05). Moreover, no significant differences were observed based on facility operators (independent, major, or mega retail outlets), suggesting that the ownership of the structure or size of the facility may not be a dominant risk determinant when standards are uniformly adhered to. The study recommends strict compliance to safety standards stipulated in the regulations including international best practices and improvement in compliance monitoring and enforcement by relevant regulatory authorities.
Keywords: Fire, explosion, risk analysis, petroleum products, facilities

1. INTRODUCTION

According to United Nation Fund for Population Action UNFPA report, the world is witnessing an unprecedented increase in urban population. It is estimated that up to half of the world's population currently live in urban areas and this number may rise up to five Billion by 2030 [1]. These rapid increases in urban population and rate of industrialization have been identified as major contributors to the increase in energy demand and consequently proliferation of filling stations in close proximity to residential and commercial areas [2], [3].

Despite the importance of Petroleum Products, they are highly prone to fire and explosion risks due to their high flammability and volatility nature. The facilities where they are refined, stored and dispensed are regarded as high risk environments. Fire and explosion risks are associated with normal operations such as Loading/Offloading, cleaning, dispensing into cars. Improper handling of these products has resulted in huge loss lives, adverse effects on the environment and damages to buildings worth Billions of dollars. Recent study of catastrophic explosions at gas stations across Europe revealed a large number of fatalities and loss of properties especially in Armenia where 220 people died and 300 were injured [4]. Catastrophic fire and explosion accidents occurred in Accra, Ghana in 2015 resulting in152 fatalities [5]. On March 17th 2016, a filling station fire and explosion accident killed seven people and

badly injured thirty people with varying degree of burns [6]. In Cape Town, South Africa 268 Petrol station fire incidences were reported between 2009 and 2017, [7]. In Kogi State, Nigeria a gas tanker explosion killed at least 28 persons in 2020 [8].
Risk assessment remains the most proactive and responsible means of managing the fire and explosion risks. While all petroleum handling facilities contain intrinsic hazards, the risk profile and potential impacts vary enormously based on factors like geographic location, facility type, and operating company. Most petrol and gas stations failed on the locational compliance criteria within the Niger Delta region of Nigeria. Most petroleum handling facilities were not situated 30m away from residential buildings [9]. Petroleum handling facilities in densely populated areas potentially endanger more human lives than comparable rural facilities. According to research conducted in Indonesia from September 2021 to August 2022, most of the worst causalities involved in the fire accidents that occurred in fuel station affected more community people in close proximity to the station than those outside the community [10]. Other researchers noted different levels of compliances to Setback requirements [3], [11], [12]. Also, refineries and storage terminals handle larger hydrocarbon inventories and feed stocks, elevate the scale of possible incidents above retail fuelling stations. In some places, parts of the industrial parks have been converted to residential areas, thereby bringing the large petroleum product storage facilities closer to residential/commercial buildings [13]

In Nigeria the Petroleum Products are marketed by two main groups of dealers namely: the Major Marketers (comprising of stations owned by Multinationals such as Total Energies; Mobil and Nigeria National Petroleum Corporation, NNPC which belong to the government) and the Independent Marketers (Privately owned businesses). It was observed that Stations owned by Major Marketers have better safety practices than the Independent Marketers [14]. Thus considering the high rate of inflation in the global economy, a granular examination of how variables like location, facility type, and operator differentially influenced risk is crucial.

This paper presents a comparative risk analysis of over 100 petroleum handling facilities based on geographical location, types of Petroleum products marketed and the type of Operators in the Niger Delta region of Nigeria. A qualitative risk analysis was used to identify significant risk factors and quantify the relative influence of location, facility type, and operating company on overall site-specific risk profiles.

2. MATERIALS AND METHODS

2.1 Research Design

A walkthrough inspection was conducted at 118 petroleum handling facilities in total. The study adapted a well-structured and standardized checklist provided by the Nigerian Upstream Petroleum Regulatory Commission (NUPRC). The checklist contained specifications for evaluating compliance with location requirements, identifying hazardous areas (at the dispenser and storage tank locations), and assessing fire safety measures [15]. The likelihood of fires and explosions occurring at the studied facilities was determined by evaluating their adherence to location compliance standards, identifying potential fire and explosion risks present at the dispensing points and storage tank areas, and verifying the availability of safety measures as stipulated by the NUPRC's standards.

2.2 Study Area

The Niger Delta is an oil-rich region, located in the South-South Geopolitical Region of Nigeria. The study was conducted in three major cities namely: Warri in Delta State; Port Harcourt in Rivers State; and Eket in Akwa Ibom State. Eket is regarded as the second-largest city in Akwa Ibom State, Nigeria. It is located within Latitudes 4000’N to 4030’N and Longitudes 7045’E to 8000’E [16]. Port Harcourt is a metropolis situated between latitudes 4°51' 30''N and 4°57' 30''N and longitudes 6°50' 00''E and 7°00' 00''E. It covers an approximate area of 370 km2 and has an estimated population of over 3 million people [17]. Warri is located within latitude 5.544230 and longitude 5.760269, has a land area of approximately 1,520 square kilometers.

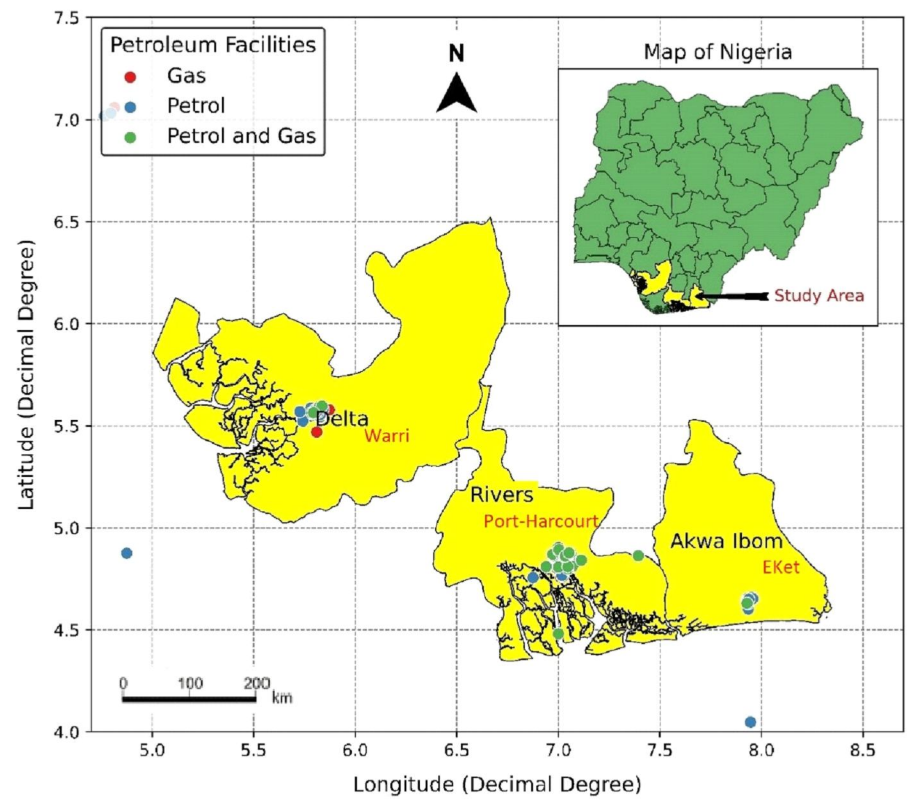

Figure 1: Map of the Niger Delta region in Nigeria

2.3 Data Analysis

Descriptive Statistic was performed by using XLSTAT Version 17 to determine the Mean, Percentage Compliance and Standard Deviation of the different constructs. For the detailed methodology and assumptions considered, refer to the paper by Jia, et. al. [18].

A qualitative risk analysis was used to evaluate the risk of fire and explosion in the petroleum handling facilities. For the comparative analysis, the Browne-Forsythe and Welch tests of significance were employed to check for significant differences in the risk of fire and explosion based on geographical location, facility types, and operators. These methods were used due to the violation of equal variance assumptions within the groups. The Browne-Forsythe test is a robust alternative to the traditional F-test for ANOVA when the assumption of homogeneity of variance is violated [19]. The Welch test is a t-test that adjusts for unequal variances between groups, making it suitable for comparing groups with different variances.

3. Results

3.1 Comparative analysis of fire and explosion risk in petroleum product handling Facilities in three selected cities in the Niger Delta Region.

The result of the comparative analysis of the risk of fire and explosion in petroleum product handling facilities in the three selected cities is presented in Table 1.

Table 1: Descriptive Statistics on the risk score in the three cities

Variable	State	Total Count	Mean	St. Dev	Coef Var	Minimum	Median	Maximum
Risk Score	Eket	17	8.46	1.50	17.76	5.66	8.33	11.41
	Port Harcourt	72	8.03	2.58	32.15	3.77	7.97	16.51
	Warri	29	9.43	2.24	23.78	4.95	9.41	14.49

The result showed that there were more fire and explosion risk factors in petroleum product handling facilities in Warri than those in Port Harcourt and Eket. The Mean risk score for fire and explosion in Warri facilities was 9.43, compared to 8.46 and 8.03 obtained for Eket and Port Harcourt respectively. The Coefficient of variation showed that Port Harcourt had more variation in the risk of fire and explosion than the other cities indicating that the risk of fire and explosion in Port Harcourt varies to a large extent. The variation of the risk is evidence in the minimum and maximum risk of fire and explosion recorded in the various facilities, as Port Harcourt had facilities with the lowest risk and with the highest risk among the three cities.

The Browne-Forsythe and Welch test was used to investigate if there was a significant difference in the fire and explosion risks between the facilities in the three cities. The result (as shown in Table 2) reveals that the fire and explosion risk between petroleum product handling facilities in the three cities was statistically significant (Browne-Forsythe F-ratio = 4.888, p-value = 0.0099).

Table 2: Browne-Forsythe and Welch test of Significance of the risk score in the three cities in the Niger Delta region.

Statistic	F	DF1	DF2	Pr > F
Welch statistic	3.6573	2.0000	48.9383	0.0331
Browne-Forsythe F-ratio	4.8880	2.0000	82.2578	0.0099

Tukey multiple comparison tests revealed that the significant difference laid between facilities in Warri and Port Harcourt (Table 3). Fire and explosion risk was significantly higher in Warri than in Port Harcourt. No significant difference in the fire and explosion risk was observed between facilities in Warri and Eket.

Table 3: Tukey Multiple comparison test of significance

Category	LS means	Groups
Warri	9.4343	A

Eket	8.4601	A	B
Port Harcourt	8.0314		B

3.2 Comparative Analysis Of The Risk Score Of Type Of Petroleum Product Handled In The Facilities In The Niger Delta Region.

The comparative analysis of the risk of fire and explosion in the three petroleum products handling facilities type reveals interesting findings. The result showed that the Mean risk score in Combined Petrol and Gas stations was slightly higher than in Petrol only or Gas only stations (Table 4).

Table 4: Descriptive Statistic on the risk score in petroleum product handling facilities in the Niger Delta Region

Variable	Type	Total Count	Mean	St. Dev	Coef. Var	Minimum	Median	Maximum
Risk Score	Gas	16	7.67	1.804	23.52	4.635	7.888	9.635
	Petrol	75	8.53	2.54	29.77	3.765	8.265	16.505
	Petrol and Gas	27	8.637	2.432	28.16	4.906	8.284	14.128

In addition, the coefficient of variation highlights that Petrol only stations exhibit more variation in the fire and explosion risk compared to the other petroleum products handling facility types. They also vary in their compliance to the NUPRC Site Location Specifications as shown in Figure 2 below. The result revealed that the Gas facilities complied with 8(46%) out of the 17 Specifications while the Petrol only and Combined Petrol and LPG facilities had 6(35.29%) each. The Combined Petrol and LPG facilities had the least compliance (22.22%) to the minimum setback distance from Public Utilities like schools, hospitals and recreational areas than Petrol only and Gas only facilities which had 28.00% and 25.00% compliance respectively.

See Legend in Appendix

Figure 2: Compliance to NUPRC Site Location Specification by the different Petroleum Product facilities.

However, the Browne-Forsythe and Welch tests for significant difference in the risk of fire and explosion between the three types of Petroleum Product handling facilities surveyed showed no significant difference between them, (see the result in Table 5)

Table 5: Browne-Forsythe and Welch test of Significance of the risk score in petroleum product handling facilities in the Niger Delta region

Statistic	F	DF1	DF2	Pr > F
Welch statistic	1.4869	2.0000	40.6652	0.2381
Browne-Forsythe F-ratio	1.1442	2.0000	67.4409	0.3246

3.3 Comparative analysis of the risk of fire and explosion in petroleum product Handling Facilities based on the Marketers

The result of the analysis of risk scores in petroleum product handling facilities by marketers is presented in Table 6. The result showed that independent Marketers had a mean risk score of 8.46 compared to Major Retail Outlets' risk score of 8.19. Z-tests were conducted to assess the significance of these differences between the risk scores of Independent and the Major Marketers.

Table 6: Descriptive Statistic on the risk score in petroleum product handling facilities based on the marketers.

Variable	Marketers	Total Count	Mean	Std Dev	Coef Var	Minimum	Median	Maximum
Risk Score	Independent	81	8.460	2.241	26.49	4.635	8.330	16.505
	Major Retail Outlet	26	8.185	2.921	35.68	3.765	8.069	14.493

The results as presented in Table 7, indicate no statistically significant differences in risk scores based on the Marketers (Z-value = 0.44, Z-critical = 1.96, p-value=0.660). This suggests that based on the available data, the risk of fire and explosion in petroleum product handling facilities does not significantly vary among Marketers.

Table 7: Z-test of the risk score in petroleum product handling facilities based on the marketers.

Difference	0.275
z (Observed value)	0.440
|z| (Critical value)	1.960
p-value (Two-tailed)	0.660
alpha	0.05

4. Discussion

The results of this study highlight the significant influence that geographical location can have on the risk profile of petroleum handling facilities. The comparative analysis revealed a statistically significant difference in fire and explosion risk levels across the three cities studied - Warri, Port Harcourt, and Eket. Facilities located in Warri displayed notably higher mean risk scores compared to those in Port Harcourt and Eket. A major contributing factor to the higher risks observed in Warri may be the poor overall compliance with locational standards compared to facilities in Port Harcourt. Facilities in Warri had significantly worse adherence to setback distances from residential buildings, other structures, and electrical power lines [9]. Various studies have affirmed that non-compliance with proper siting guidelines and inadequate buffer distances increases both the likelihood and potential severity of fire and explosion incidents at these facilities [13], [20], [21]. Encroachment into the recommended setback zones heightens the vulnerability of surrounding communities and assets. Geographical location increases the risk of fire and explosion due to limited land space or the cost associated with acquiring adequate land space for the facilities, especially in urban locations. In addition, facilities in Warri exhibited higher noncompliance with the provision of Fire Safety equipment and Emergency preparedness than the facilities in the Port Harcourt and Eket [9]. The provision of fire extinguishers, fire alarms/sensors, Emergency switch buttons among others are necessary for reducing potential severity of fire and explosion incidents. Similar poor provision of fire extinguisher was reported in Dutse, Jigawa State [3].

The analysis of Site Location compliance showed that the Gas facilities compiled better than the

Petrol only and Combined Petrol and LPG in nine out of the seventeen specifications. This may be attributed to the fear of the consequences of gas explosion. However, they fell short in the specifications concerning the setback distance from residential and public utilities. This may have a severe consequence in terms of the thermal effects of exposure of the persons within 45m of flame. Consequence modeling has shown that the maximum diameter of a fireball could reach 193m within 12s of burning time [4]. Interestingly, the type of petroleum products handled (petrol only, gas only, or combined petrol and gas) did not demonstrate a statistically significant difference between fire and explosion risks in the facilities studied although the Combined petrol and gas operations had an elevated mean risk score compared to dedicated petrol only or gas only facilities. This shows that facilities with Combined Petrol and Gas retailing outlet require more stringent Fire and Explosion Safety strategies to keep their facilities and environments safe. It is important to note that having Combined Petrol and LPG Refueling in the same premises is a new trend in the retailing of petroleum product, therefore limited literature exists concerning the risk assessment in these stations. Further research is required to determine the level of intolerable fire risk available within 1.5m radius of the Dispensers and the refueling area.

5. Conclusions

This study provides valuable insights into the risk factors influencing fire and explosion hazards at petroleum handling facilities. By conducting a comparative analysis, the research highlights the significant role that geographical location plays in shaping the risk profile of fire and explosion at petroleum handling facilities. Facilities situated in Warri exhibited considerably higher mean risk scores compared to those in Port Harcourt and Eket. A major underlying driver appears to be the poorer overall compliance with locational standards observed in Warri compared to Port Harcourt. Interestingly, the specific type of petroleum products handled (petrol, gas, or combined petrol and gas operations) did not emerge as a statistically significant determinant of risk levels. Similarly, no significant discrepancies in risk were found between facilities operated by independent marketers versus major or mega retail outlets. Notwithstanding, potential fire and explosion risks exist in both types of Petroleum product marketers and should not be overlooked.

This research recommends that the Government Regulators should:

- Carryout effective monitoring of the Petroleum handling facilities in line with the NUPRC Statutory requirements.
- Apply appropriate penalties in line with the law as may be required.
- Insist on compliance with the Law before Permits for siting and operation of petroleum handling facilities are issued.

The Petroleum Product Marketers should:

- Strictly adhere to the safety requirements as stipulated in the Guidelines.
- Prevent Water from building up on the tanks as part of the corrosion prevention strategy. Corrosion predisposes leaks, spills among others.
- Ensure the manholes are free from water, products and other debris.
- Adequately label tanks to ensure accuracy of products management and thus prevent unintended mixing of products which can lead to fire and explosion.
- Appropriately lock Filled pipes to prevent fuel vapor from escaping into the environment which could serve as ignition source or pose a health risk to the workers, customers and neighborhood residents.
- Adequately label the Ground offset fill point chambers and ensure that they are free from products, debris and shrubs
- Ensure that Manholes covers are correctly and firmly seated on the manholes and that they can easily be lifted using appropriate lifting device.

- Use only high quality Product storage tanks in line with standard engineering and best practices for product storage tanks.

In conclusion, all the facilities should provide adequate emergency preparedness such as the provision of Emergency switch buttons, Fire alarms, Fire extinguishers, Water Hydrants, Leak/Overfill monitoring devices and personal protective equipment among others in case of unintended incidents.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

References

- D.A.Anang; K. Anyomi, B. Afotey, M.A.Rockson, E. Kwao-Boateng, E.Antwi and A.T. Tagoe. Petrol Filling Station Safety Assessment and Fire Safety Knowledge of Fuel Pump Attendants. Journal of Ghana Science Association. 2021; 20(2): 47-54.
- S.T. Dogara. GIS-based locational analysis of petrol filling stations in Kaduna Metropolis. Science World Journal. 2017; 12(2):8–13.
- S. Yunus. Analysis of Locational Compliance and Fire Safety Preparedness among Petrol Filling Stations in Dutse Town, Jigawa State. Confluence Journal of Environmental Studies.2020;1(13):107–118.
- K. Mäkká; A. Šiser; L. Mariš and K. Kampová. Impact of Filling Stations: Assessing the Risks and Consequences of the Release of Hazardous Substances. Appl. Sci. 2024, (14), 22. https://doi.org/10.3390/app14010022.
- S. Asumadu-Sarkodie, P.A. Owusu and P. Rufangura. Impact analysis of flood in Accra, Ghana. Advances in Applied Science Research.2017;6(9):53-78.
- G. Ma and Y. Huang, "Safety Assessment of Explosions During Gas Station Refilling Process," Journal of Lo. Prevention in the Process Industries.2019;60 (9):133-144. DOI:10.1016/j.jlp.2019.04.012.
- K. Qonono. Analysis of the Fire Hazard Posed by Petrol Stations in Stellenbosch and the Degree of Risk Acknowledgment in Land Use Planning. International Journal of Architectural and Environmental Engineering.2024;18 (2): Available: https://www.researchgate.net/publication/378182594_Analsis_of_the_Fire_Hazard_Posed_by_Petrol_Stations_in_Stellenbosch_and_the_Degree_of_Risk_Acknowledgement_in_Land-Use_Planning.
- Cable News Network, (CNN).Nigerian Gas Tanker Explosion Kills 28 Persons. Reuters, CNN. 2020. Available: https://edition.cnn.com/2020/09/24/africa/nigeria-explosion-oil-tanker-kogi-intl/index.html.
- N.I. Jia, I.L. Nwaogazie and P. Mmom. Assessment of Locational Compliance Status of Petroleum Products Handling Facilities in Niger Delta Region, Nigeria. Journal of Environment Protection.2022;13(10):750-765.
- A. Wibowo, F. Lestari and R. Modjo. Preventing Fuel Station Accidents: The Importance of Community Involvement. In IOP Conference Series: Earth and Environmental Science. 2020;1111(2022):1-8, 012077.
- J.O. Ulasi, B. O. Uwadiegwu and C. O. Okoye. Assessment of the Level of

Compliance of Petroleum Filling Stations to Development Control Standards on Land Space/Size and Setbacks in Anambra State. Civil and Environmental Research. 2020;12(2):77-87.

- M. A. Oyinloye and O. E. Abiola. Locational Impact of Petrol Filling Stations Close to Residential Buildings in Ife Central, Nigeria. International Journal of Humanities and Social Sciences. 2021; 8(2):29–36.
- A. Akpi, P.C. Mmom and L. Olanrewaju. Liquefied Petroleum Gas Stations Disaster Risk Preparedness Assessment of Port Harcourt City Nigeria. Journal of Risk Analysis and Crisis Response 2023, 13 (3) 209-219.
- S. Ahmed, A. S. Abdul Rahman, A. S. Kovo, S. Ibrahim, E. O. Okoro and A. A. Agbo. Health, risk and safety of petrol stations in Minna town: An overview. World Applied Sciences Journal.2014;32(4):655-660.
- Nigerian Upstream Regulatory Commission, (NUPRC). Guideline for Approval to construct and Operate Petroleum Products Filling Stations. 2021. https://www.nmdpra.gov.ng/wp-content/uploads/2021/12/FILLING-STATION-GUIDELINES.pdf
- J. G. Atat, N.J. George and A. G. Atat. Immediate Settlement of Footing Using Interpreted Seismic Refraction Geo-elastic Data: A Case Study of Eket County, Nigeria. NRIAG Journal of Astronomy and Geophysics. 2020;9(1):433-446.
- A. Obisesan and V. E, Weli. Assessment of Air Quality Characteristics across Various Land-Uses in Port-Harcourt Metropolis. Journal of Environmental Pollution and Management.2019; 2:106. Available: https://doi.org/10.46654/ij.24889849.s61121.
- N. I. Jia, I. L. Nwaogazie and P. Mmom. Fire Risk Evaluation For Petroleum Products Handling Facilities in Niger Delta Region, Nigeria. Current Journal Of Applied Science and Technology. 41(37):19-29, 2022.
- M. Vimal, V. Venugopal and N. Anandabaskar. Parametric Tests. In Introduction to Basics of Pharmacology and Toxicology, 3, Experimental Pharmacology: Research Methodology and Biostatistics.2022; 877-888. Singapore: Springer Nature Singapore. DOI:10.1007/978-981-19-5343-9 61.
- I. Wadembere and J. Apaco. Urban Spatial Risk Assessment of Fire from Fueling Stations on Buildings Case Study: Lubaga Division, Kampala City, Uganda. Journal of Building Construction and Planning Research.2020; 8,:57-72.
- S. B. Arokoyu, M. Ogoro and A. Jochebed. Petrol Filling Stations Location and Minimum Environmental Safety Requirements in Obio-Akpor LGA, Nigeira. International Journal of Innovative Science and Research Technology.2015; 2:21-39.

Appendix

Number	Locational Compliance Specifications
1	Min plot-size of fuel station shall be 35 m × 35 m
2	Max plot coverage is 60%
3	Mini vehicle maneuvering area is 1100 m2 with a minimum frontage of 9 m facing the primary street
4	Min of 12m from Station Building to the road.

5 Min of 30 m from Petrol pumps from residential buildings.
6 Min distance of 10 m from Underground Storage Tank (UST) to dispensing pumps
7 Min of 3 dispensing pumps (one for each of the petrol, diesel and kerosene)
8 32m Min set back of stations from 330 Kv line
9 8m Min set back from stations to a 66 Kv power line
10 Minimum set back of stations to a 132 Kv line is 16 m
11 Not more than 4 stations within 2 km stretch on both sides of the road.
12 Not less than 15 m from the edge of the road to the nearest pump
13 Not than 400 m between two stations
14 No direct drainage from the station into streams or rivers.
15 150 m minimum distance from Stations to from any public building
16 Minimum of 50m distance from station to residential structure.
17 Wall fence demarcating the station (minimum height of 1.5 m high).

m= meters;Km = Kilometer; Kv= Kilovolts Max = Maximum; Min = Minimum