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Geospatial Analysis of Fuel Station Distribution and Evaluation of Safety Standards Compliance in Kinshasa (DRC)

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Abstract

This study presents a geospatial analysis of fuel station distribution and a systematic evaluation of compliance with safety standards in the commune of Kasa-Vubu and the Funa district of Kinshasa (Democratic Republic of the Congo). Based on an approach combining geographic information systems (GIS), digital cartography and field observations, this research draws on data from the Ministry of Hydrocarbons (September 2024), OpenStreetMap data and a complementary study by Target SARL (2025). The objective is to assess the extent to which the current location of fuel stations complies with national and international safety standards (NFPA 30, IFC 2009, World Bank guidelines) and to analyse the implications of their spatial distribution for urban organisation, the environment and population safety. The results reveal a disproportionate concentration of fuel stations in densely populated areas, with 66.7% of establishments located less than 100 metres from sensitive infrastructure (schools, markets, health facilities). The regulatory compliance analysis shows that only **17.5%** of stations comply with the minimum safety distances prescribed by Congolese regulations. These findings confirm the hypothesis that the location of fuel stations is primarily driven by economic and urban-mobility logics, to the detriment of safety and land-use planning standards, thereby exposing populations to significant environmental and health risks.

Keywords

Fuel Stations, Geospatial Analysis, Safety Standards, GIS, Kinshasa, Urban Risks, Land-Use Planning, Sustainable Development

1. Introduction

1.1. Global Context

Rapid urbanisation is one of the most striking demographic phenomena of the 21st century. According to United Nations estimates, more than 68% of the world population will live in urban areas by 2050, compared with about 56% in 2021. This urban growth is accompanied by rising energy demand, particularly for petroleum products, which leads to a proliferation of fuel distribution infrastructure within urban agglomerations. Fuel stations, as industrial facilities for the storage and distribution of flammable products, constitute potential sources of major technological risk in urban environments. Their inappropriate siting can have devastating consequences in the event of fire, explosion or leakage of toxic products, as illustrated by numerous accidents worldwide.

1.2. African Context

The African continent is experiencing the fastest urbanisation in the world, with an average annual urban growth rate of 3.5%, nearly double the global average. This uncontrolled urbanisation, often described as "city-building without urban planning", is characterised by uncontrolled peripheral expansion, spontaneous densification of central neighbourhoods and a chronic shortfall in urban planning services. In this context, petroleum infrastructure, including fuel stations, is frequently sited without regard for safety standards, creating major risk situations for riverside communities.

Recent studies conducted in several African cities have highlighted similar issues. In Lagos (Nigeria), fuel stations are often located in immediate proximity to markets and dense residential areas, multiplying fire risks. In Nairobi (Kenya), the absence of effective regulatory zoning has led to chaotic siting of energy infrastructure. In Abidjan (Côte d'Ivoire) and Douala (Cameroon), comparable findings have been documented, revealing a generalised deficit in territorial planning for fuel station siting in sub-Saharan African cities.

1.3. Context of the Democratic Republic of the Congo

The Democratic Republic of the Congo (DRC), the largest country in sub-Saharan Africa with an area of 2,345,000 km^2 and approximately 100 million inhabitants, is experiencing accelerated urbanisation, particularly in its capital, Kinshasa. With an estimated population of more than 17 million inhabitants in 2024, Kinshasa ranks among the most dynamic megacities on the African continent. This exponential demographic growth exerts considerable pressure on urban infrastructure, public services and territorial planning, creating a growing gap between the needs of the population and the management capacity of local authorities.

The downstream petroleum distribution sub-sector in the DRC is governed by a regulatory framework whose main provisions are contained in Law No. 15/012 of 1 August 2015 on the hydrocarbons sector and its implementing measures. This legal framework establishes requirements regarding safety distances, siting conditions and technical standards for fuel stations. However, the effective application of these provisions remains problematic due to insufficient inspection capacity, weak institutions responsible for territorial planning, and economic pressures that favour illegal installations.

1.4. Importance of Fuel Stations in Urban Development

Fuel stations play a strategic role in the functioning of urban systems. They are essential links in the energy supply chain, supporting the mobility of people and goods and thereby contributing to the economic activity of cities. Their location influences traffic flows, land value and the urban morphology of the neighbourhoods in which they are embedded.

However, this functional importance must not obscure the inherent risks of these facilities: storage of highly flammable products, fuel handling, emissions of volatile organic compounds (VOCs) and risks of soil and groundwater contamination. The integration of fuel stations into the urban fabric therefore requires a delicate balance between energy accessibility and public safety, between economic profitability and environmental protection. This balance falls within the scope of territorial planning and urban governance, two domains in which African cities, and Kinshasa in particular, lag significantly behind international standards.

1.5. Scientific Justification of the Study

Despite the importance of this issue, scientific studies on the spatial distribution of fuel stations and compliance with safety standards in African cities remain rare and fragmentary. The existing literature focuses primarily on the environmental aspects of petroleum pollution, without systematically addressing the geospatial dimension of fuel station siting. The use of geomatic tools to analyse these questions remains underexploited in the Congolese context, despite the considerable potential of GIS for territorial planning and urban risk management.

The present study is justified by the need to fill this scientific gap by proposing an integrated analysis combining urban geography, geomatics and risk management. It aims to provide empirical data and methodological tools capable of informing political decision-makers and urban planners in their efforts to reduce technological risks in urban areas. The originality of this research lies in its multiscale approach, combining fine local analysis (Kasa-Vubu commune) and a broader regional perspective (Funa district), as well as in the integration of a comparative methodology with international safety standards.

1.6. Problem Statement

The present research is structured around the following central question: to what extent does the spatial distribution of fuel stations in Kinshasa comply with national and international safety standards, and what are the implications of their location for urban organisation, the environment and population safety? This problem raises multidimensional issues relating to territorial planning, urban risk management, industrial safety and sustainable development. It interrogates the determinants of fuel station location and their adequacy with regard to public safety and environmental protection imperatives.

1.7. Research Questions

To operationalise this problem, three specific research questions are formulated. First, what is the spatial distribution of fuel stations in the commune of Kasa-Vubu and the Funa district, and what factors determine their location? Second, to what extent do these stations comply with national and international safety standards, particularly with respect to minimum distances from sensitive infrastructure and residential areas? Third, what environmental and health risks are associated with the current location of fuel stations, and how do these risks fit into the urbanisation dynamics of Kinshasa?

1.8. Objectives

The general objective of this study is to analyse the spatial distribution of fuel stations and to assess their compliance with safety standards in the commune of Kasa-Vubu and the Funa district of Kinshasa. Specifically, this research aims to: 1) map the spatial distribution of fuel stations using GIS tools; 2) analyse the density of stations per spatial unit and identify areas of concentration; 3) assess the compliance of their siting relative to national and international safety standards; 4) identify sensitive infrastructure located in the vicinity of fuel stations; 5) determine the explanatory factors of their location; and 6) formulate recommendations for better integration of fuel stations into urban planning.

1.9. Hypotheses

The main hypothesis of this research postulates that the current location of fuel stations in Kinshasa is primarily determined by economic and urban-mobility considerations rather than by compliance with safety and territorial planning standards, thereby increasing the exposure of populations to environmental and technological risks. Three operational hypotheses follow: (H1) fuel stations are concentrated along major traffic corridors and in areas of high commercial activity, independently of safety constraints; (H2) the majority of fuel stations do not comply with the minimum safety distances prescribed by national regulations and international standards; (H3) the proximity of fuel stations to sensitive infrastructure creates high-risk zones for riverside communities.

2. Literature Review

2.1. Urbanisation and Energy Infrastructure

The relationship between urbanisation and the development of energy infrastructure constitutes a dynamic research field in urban geography and development studies. The work of UN-Habitat [1] and the World Bank [2] emphasise that urban growth in sub-Saharan Africa is accompanied by an exponential increase in energy demand, creating considerable pressure on fuel distribution networks. This dynamic is particularly visible in cities where individual motorised transport remains predominant, as is the case in Kinshasa where nearly 80% of daily trips are made by informal motorised means.

The literature highlights a positive correlation between urban density and the concentration of energy infrastructure. According to Magaji and Umar [3], fuel stations tend to be preferentially located in areas of high accessibility and high traffic density, creating an unequal spatial distribution that reflects market economic logics rather than public safety imperatives. This trend is reinforced by the progressive liberalisation of the petroleum sector in many African countries, which has led to a multiplication of operators and increased competition for strategic locations. Research by Eunice Abiola and Ajide Oyinloye [4] on the spatial distribution of fuel stations in Douala shows that economic factors, notably proximity to main roads and transport nodes, explain more than 75% of the variance in the location of these establishments.

2.2. Environmental Risks Associated with Fuel Stations

Fuel stations represent potential sources of multiple environmental risks. Fuel leaks from underground tanks constitute one of the main threats to soil and groundwater quality. Volatile organic compounds (VOCs), particularly benzene, toluene, ethylbenzene and xylenes (BTEX), are recognised as priority pollutants by the World Health Organization due to their toxicity and persistence in the environment. Recent studies conducted by Alumona [5] in several Nigerian cities have demonstrated that BTEX concentrations in soil and groundwater near fuel stations frequently exceed the thresholds recommended by the WHO [6] and in updated global assessments [7].

Fire and explosion risks constitute another major dimension of the threat posed by fuel stations in urban areas. The history of accidents involving fuel stations in Africa reveals an alarming recurrence of fires, often caused by technical failures, human errors or inadequate siting conditions. The work of Ogunwemimo and Adeleke (2023) documents more than fifty major incidents involving fuel stations in West Africa between 2015 and 2023, with a cumulative toll of more than 300 victims and considerable material damage. These data underline the urgency of a systematic approach to risk assessment related to fuel station siting in urban African environments.

Furthermore, atmospheric emissions related to refuelling operations and fuel storage contribute to the degradation of air quality in dense urban areas. Research by Rattanajongjitrakorn and Prueksasit [8] shows that concentrations of nitrogen dioxide and fine particles are significantly higher within a 200-metre radius around fuel stations, with direct health implications for exposed populations, particularly regarding chronic respiratory diseases.

2.3. Geomatics and Spatial Analysis of Urban Risks

The application of geographic information systems (GIS) to the analysis of urban risks is a rapidly expanding field. GIS offers powerful tools for the collection, integration, analysis and visualisation of geospatial data, enabling a deep understanding of the spatial dynamics underlying the distribution of risks in urban environments. According to Kresse and Fadaie [9], spatial analysis methods, such as Kernel Density Estimation (KDE), proximity analyses (buffers) and multi-criteria overlays, are particularly well suited to assessing urban vulnerability to technological risks.

The integration of remote sensing data, OpenStreetMap data and field surveys into GIS enables the construction of robust spatial models for risk assessment. The work of Fernández and Lutz [10] has demonstrated the effectiveness of the geospatial approach for mapping risk zones related to industrial facilities in developing cities, offering decision-support tools for urban planners. In the African context, however, the use of GIS for analysing the distribution of petroleum infrastructure in urban areas remains underdeveloped, despite the considerable potential of these tools for risk management.

2.4. International Standards for Fuel Station Siting

Several international normative frameworks define the safety requirements applicable to fuel station siting. NFPA 30 (Flammable and Combustible Liquids Code), published by the National Fire Protection Association, is one of the most widely adopted references. This code establishes minimum safety distances between fuel storage tanks and adjacent properties, buildings and public ways. According to NFPA 30 [11], the minimum distance between an underground storage tank and an occupied building must be at least 1.5 metres (5 feet) for protected tanks, and 3 metres (10 feet) for unprotected tanks.

The International Fire Code (IFC) [12], promoted by the International Code Council, provides specific safety distances according to storage capacity and the nature of neighbouring establishments. The World Bank guidelines on industrial safety and environmental risk management [13] (Environmental, Health, and Safety Guidelines, 2007) recommend safety distances adapted to the context of developing countries, taking into account local emergency response capacities. The World Health Organization, in its guidelines on air quality and environmental health, recommends buffer zones of at least 100 metres around fuel distribution facilities to protect populations from exposure to toxic emissions.

2.5. Regulatory Framework in the DRC

The Congolese regulatory framework relating to fuel station siting is structured around several fundamental texts. Law No. 15/012 of 1 August 2015 on the hydrocarbons sector [14] constitutes the legislative pillar of the sub-sector by defining the general conditions for downstream petroleum activities. This law is complemented by ministerial orders specifying the technical standards for the siting and operation of fuel stations, particularly regarding safety distances from residential areas, public-receiving establishments and sensitive infrastructure.

The Master Plan for Urban Planning and Development (PDAU) of Kinshasa, although dating back several decades, establishes zoning principles that should govern the siting of industrial and commercial activities, including fuel stations. However, the considerable gap between regulatory provisions and their effective application constitutes one of the structural weaknesses of the urban governance system in Kinshasa. Insufficient inspection staff, lack of coordination between the various competent administrations and weak sanction mechanisms contribute to a chronic deficit in regulatory compliance.

2.6. African Case Studies

Several recent studies have documented the problems of fuel station siting in various African cities, offering a relevant comparative framework for the present research. In Nairobi, Makiti and Minga'ate [15] used GIS to analyse the spatial distribution of 287 fuel stations and revealed that 62% of them were located less than 50 metres from public-receiving establishments, despite regulations requiring a minimum distance of 100 metres. This study also showed that fuel station density was positively correlated with population density and the presence of major road axes.

In Abidjan, Neghab *et al.* [16] conducted a similar analysis in the commune of Cocody, revealing siting practices contrary to Ivorian regulations, with fuel stations installed near schools and hospitals. In Lagos, Daramola and Ibrahim [17] documented fire risks related to the proximity of fuel stations and open markets, proposing a GIS-based risk assessment methodology. In Douala, Iman *et al.* [18] analysed the distribution of fuel stations in five arrondissements and found that economic factors (accessibility, visibility, proximity to activity centres) systematically prevailed over safety considerations in location decisions.

2.7. Scientific Gaps

The analysis of the literature reveals several scientific gaps that the present study aims to fill. First, the quasi-total absence of systematic geospatial studies on the distribution of fuel stations in the DRC constitutes a major gap, even as Kinshasa experiences rapid expansion of these facilities. Second, existing studies in Africa are generally limited to descriptive analyses without integrating systematic comparative evaluation against international safety standards. Third, the multi-scale approach, combining fine local analysis and a regional perspective, has not been applied to this issue. Finally, existing studies do not fully exploit the potential of GIS for risk mapping and decision support in urban planning.

3. Study Area

3.1. Presentation of Kinshasa

Kinshasa, capital of the Democratic Republic of the Congo, is located in the western part of the country, on the left bank of the Congo River, facing Brazzaville

(Republic of the Congo) (**Figure 1**). With an estimated population of about 17 million inhabitants in 2024 and an area of approximately 9965 km^2.

Kinshasa is the third largest city in Africa, after Lagos and Cairo. The city-province of Kinshasa is administratively divided into four districts: Tshangu, Mont-Amba, Lukunga and Funa, comprising a total of 24 communes. The urban fabric is characterised by a strong duality between relatively planned central neighbourhoods and peripheral neighbourhoods marked by spontaneous urbanisation and a deficit of collective facilities.

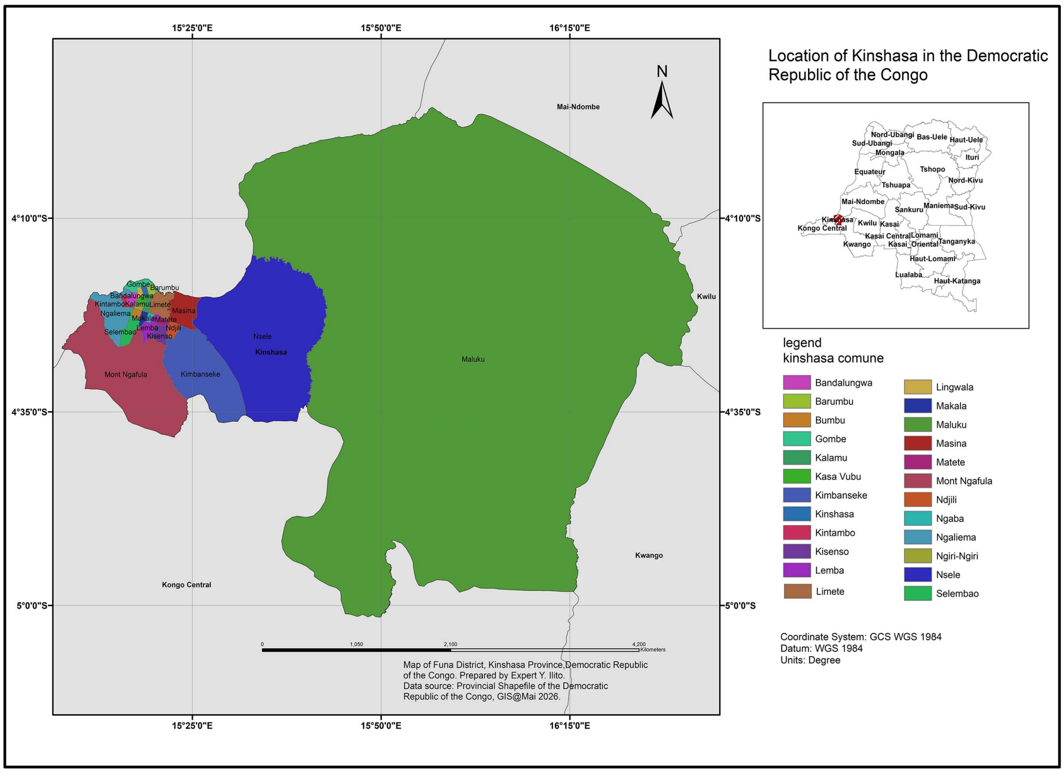

Figure 1. Location of Kinshasa in the Democratic Republic of the Congo.

3.2. Presentation of the Funa District

The Funa district, located in the southern part of Kinshasa, covers an area of approximately 59 km^2 and comprises seven communes: **Selembao, Bandalungwa, Bumbu, Makala, Ngiri-Ngiri, Kasa-Vubu and Kalamu.** With an estimated population of about 3.2 million inhabitants, the Funa district is among the most densely populated areas of the capital. This district is characterised by a high concentration of commercial activities, high population density (approximately 11,000 inh./km^2) and a relatively developed road network that makes it an attractive space for fuel station siting. The major road axes of the district, notably Kasa-Vubu Boulevard, Kalamu Avenue and the Matadi Road, constitute intense traffic corridors that partly explain the numerous presence of fuel stations in this area (**Figure 2**).

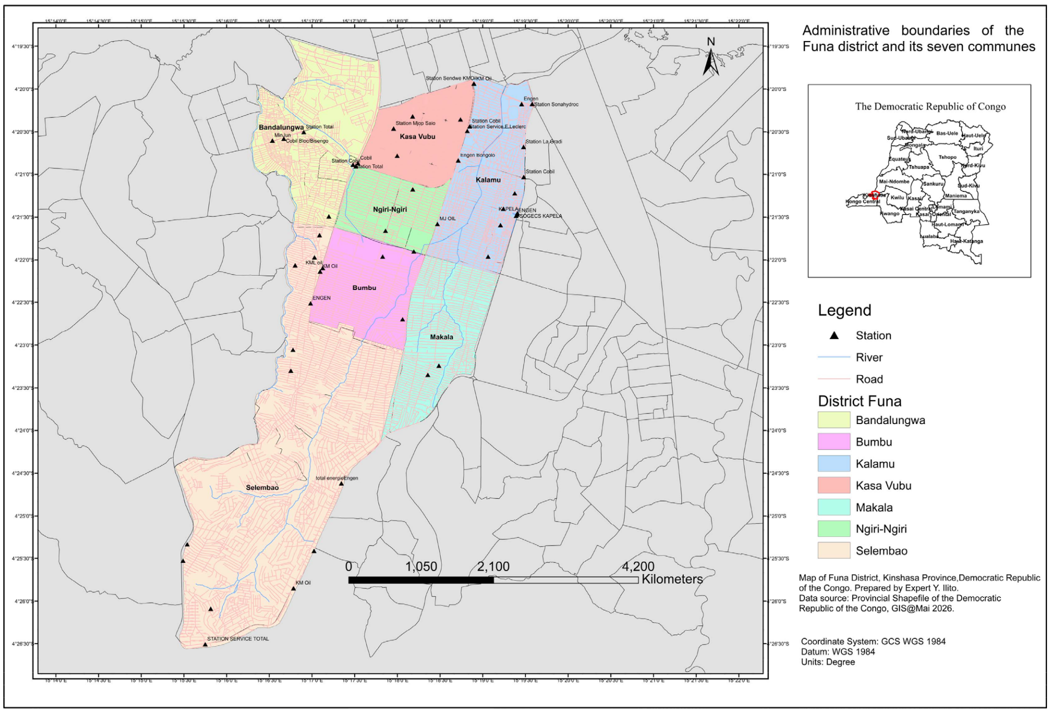

Figure 2. General view of the Funa district in Kinshasa.

3.3. Presentation of the Kasa-Vubu Commune

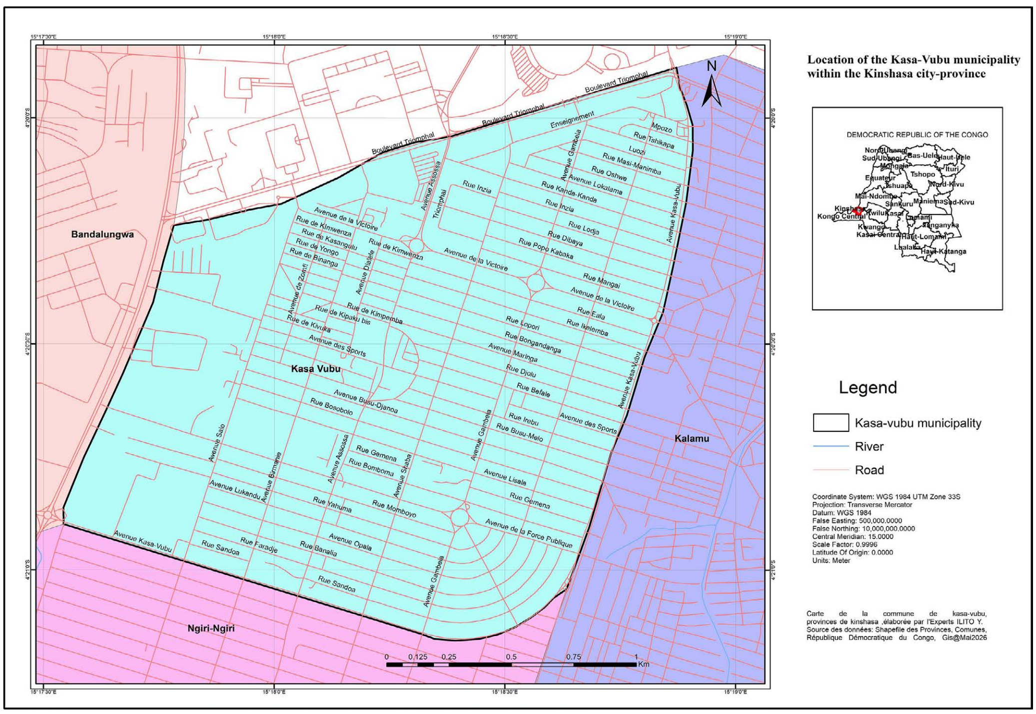

Figure 3. Location of the Kasa-Vubu commune in the city-province of Kinshasa.

3.4. Justification of the Choice of Study Area

The choice of the Kasa-Vubu commune and the Funa district as the study area is justified by several methodological and scientific considerations. On the one hand, the Kasa-Vubu commune (**Figure 3**) has a high density of fuel stations, allowing for a rich and significant spatial analysis at the local scale. On the other hand, the Funa district, as an administrative entity encompassing seven communes, offers a regional perspective enabling the comparison of spatial dynamics at different scales. This multi-scale approach constitutes one of the original methodological contributions of this research. Finally, the availability of recent data from the Ministry of Hydrocarbures [19] and the Target SARL (2025) study [20] and the possibility of field access constitute practical assets that guided this choice.

4. Methodology

4.1. Data Sources

The present research is based on a mixed methodological approach combining primary data and secondary data. Primary data come from systematic field observations conducted between March and June 2025 in the Kasa-Vubu commune and all communes of the Funa district. These observations covered the precise location of fuel stations, the identification of sensitive infrastructure in their vicinity, the visual assessment of safety conditions and the verification of distances from dwellings and public-receiving establishments. A precision GPS was used to georeference each fuel station with sub-3-metre accuracy.

Data quality assurance protocol. To guarantee the reliability of the geospatial database, a three-step quality assurance protocol was implemented. 1) GPS precision: each fuel station was georeferenced using a Garmin GPSMAP 66s handheld receiver operating in multi-band GNSS mode (GPS + GLONASS + Galileo), with an average positional accuracy of ≤3 metres (95% confidence ellipse); each point was recorded as the mean of at least 60 epochs collected over a 60-second static occupation. 2) Duplicate handling: a topological deduplication procedure was applied in QGIS 3.34 using the "Delete duplicate geometries" algorithm (tolerance = 1 metre), followed by an attribute-based check on operator name and address; any pair of points belonging to the same operator and located within 15 metres of each other was considered a single station. 3) Field verification: all stations identified from the Ministry register and the Target SARL (2025) report were systematically cross-checked on the ground; 9% of records required position correction, and 4 records initially considered operational were reclassified as "decommissioned" after field verification and excluded from the analysis.

4.2. Data from the Ministry of Hydrocarbons

Secondary data were obtained from the Ministry of Hydrocarbons of the DRC [19], which maintains an official register of operational fuel stations across the national territory. This register, updated in September 2024, provides information on the administrative location, storage capacity, products marketed and operator managers of each station. A complementary study carried out by Target SARL in 2025 was also mobilised to enrich the database and validate the information from the official register. Cross-referencing these sources enabled the constitution of an exhaustive and reliable spatial database.

4.3. GIS and OpenStreetMap Data

Complementary geospatial data were extracted from OpenStreetMap (OSM), which constitutes a particularly useful open data source for cities where official data are limited. The OSM data layers mobilised include the road network, administrative boundaries of communes, the location of schools, health centres, markets and places of worship. The quality of OSM data for Kinshasa was assessed by comparison with field observations and Google Earth Pro satellite imagery, revealing satisfactory coverage for major infrastructure. All data were integrated into a geographic information system under QGIS 3.34 and ArcGIS Pro 3.2.

4.4. Tools Used

The geospatial analysis was carried out using several complementary tools. QGIS 3.34 was used as the main platform for data integration, spatial analysis and cartography. ArcGIS Pro 3.2 was mobilised for Kernel Density Estimation (KDE) analyses and multi-criteria overlays. Google Earth Pro enabled visual verification of the location of fuel stations and the identification of sensitive infrastructure. Microsoft Excel was used for statistical data processing and the preparation of summary tables. Thematic maps were produced according to international cartographic standards, with an appropriate scale, a clear legend and coherent graphic semiology conventions.

4.5. Density Analysis

Kernel Density Estimation (KDE) was applied to identify areas of fuel station concentration and to visualise spatial density gradients. This non-parametric method estimates point density from a kernel function applied around each fuel station. A search radius (bandwidth) of 500 metres was used, corresponding to the average walking distance in the urban context of Kinshasa. The analysis was conducted at two scales: the Funa district scale (regional perspective) and the Kasa-Vubu commune scale (local perspective). Results were classified into five density classes (very low, low, medium, high, very high) using the natural breaks (Jenks) discretisation method.

Methodological clarification on density metrics. Two distinct density metrics are used in this study and must not be conflated. 1) Commune density (reported in Table 1) is a discrete, zonal-based indicator computed as the ratio of the number of fuel stations within an administrative boundary to the polygon area of that commune (n/km^2); it characterises the average load of each administrative unit but masks intra-communal heterogeneity. 2) Kernel Density Estimation (KDE; reported in Figure 4 and Figure 5) is a continuous-surface, model-based indicator that produces a smooth raster of intensity values (stations per km^2) independently of administrative boundaries; it reveals local hotspots and gradients that the zonal average cannot capture. The two metrics are therefore complementary and are kept separate throughout the analysis: commune density is used for inter-commune comparison and ranking, while KDE is used for hotspot identification and risk-zone mapping. Numerical values from the two approaches should not be directly compared at the same point, as the KDE value at a given pixel integrates neighbouring stations within the 500-metre bandwidth and is not bounded by the commune polygon.

4.6. Proximity Analysis (100 m and 200 m Buffers)

Proximity analysis constitutes the methodological core of the regulatory compliance assessment. Two concentric buffer zones were created around each fuel station: a 100-metre buffer and a 200-metre buffer. These distances correspond to the regulatory thresholds most commonly cited in international and national standards. The intersection of these buffers with the sensitive infrastructure layer (schools, health centres, markets, places of worship, public transport stops) enabled quantification of the number of infrastructure items located in risk zones and assessment of the compliance level of each station. This spatial proximity analysis method is widely proven in the scientific literature on urban risk assessment.

Specification of measurement units and reference points. To ensure reproducibility and eliminate ambiguity in the distance calculations, the reference point used for each fuel station and each sensitive infrastructure is specified as follows. 1) For fuel stations, the reference point is the geometric centroid of the pump island cluster (*i.e.*, the canopied forecourt where refuelling pumps are located), not the underground storage tank farm and not the parcel centroid; this choice reflects the most plausible ignition source in the event of an incident and is consistent with NFPA 30 [11] and IFC 2009 [12] definitions of the “dispenser area”. 2) For sensitive infrastructure, the reference point is the centroid of the main built footprint of the establishment (school building, health facility, market hall, place of worship), digitised from Google Earth Pro imagery (≤1 m resolution) and verified on the ground. 3) All distances are measured as planar Euclidean distances in the WGS 84/UTM zone 34S projected coordinate reference system (EPSG:32734), expressed in metres with one decimal precision. 4) When several sensitive infrastructures of the same type coexist within the buffer, only the nearest one is retained for the compliance test against the minimum regulatory distance; the others are nevertheless counted in the exposure inventory reported in **Table 2**. This rule is applied uniformly across all 57 stations and all three normative benchmarks (DRC, NFPA 30, WHO).

4.7. Regulatory Compliance Analysis

The regulatory compliance analysis consisted of systematically comparing the distances measured between each fuel station and the nearest sensitive infrastructure with the thresholds prescribed by three normative frameworks: 1) Congolese regulations, which require variable minimum distances according to the type of infrastructure; 2) NFPA 30 [11], which establishes safety distances according to storage capacity and tank protection type; and 3) World Bank guidelines and WHO guidelines, which recommend minimum buffer zones of 100 metres. Each fuel station was classified as compliant or non-compliant with respect to each of these frameworks, and a global compliance index was calculated for each commune.

4.8. Comparative Method with International Standards

The comparative method enabled situating Kinshasa relative to international standards for fuel station siting. This comparison covered three dimensions: prescribed safety distances, compliance control mechanisms and territorial planning practices integrating industrial safety constraints. The reference cities selected for this comparison are Nairobi, Abidjan, Douala and Lagos, for which recent studies document the situation of fuel stations. This comparative approach allows contextualising the results obtained for Kinshasa and identifying potentially transposable good practices.

4.9. Limitations of the Study

Several methodological limitations must be acknowledged. First, the quality of OpenStreetMap data, although satisfactory for major infrastructure, may present gaps for small establishments or recent infrastructure. Second, field observations, although systematic, were limited by access constraints in certain areas. Third, the absence of detailed data on the volumes of fuel stored in each station prevented a fine-grained risk assessment based on storage capacity. Finally, the study does not take into account the geological and hydrogeological conditions of the subsoil, which nevertheless influence the environmental vulnerability of the sites.

5. Results

5.1. Spatial Distribution of Fuel Stations

The inventory carried out identified a total of 57 fuel stations in the Funa district, including 15 in the Kasa-Vubu commune alone. These stations are operated by around twenty different operators, with a predominance of major oil companies (TotalEnergies, Engen, Shell, OiLibya) and a significant presence of local operators. The spatial distribution of these stations reveals a clearly centro-peripheral pattern, with a high concentration along major road axes, particularly Kasa-Vubu Boulevard, Kalamu Avenue and the Matadi Road. This distribution reflects commercial logics of maximum accessibility and customer capture, with stations being preferentially located on high traffic arteries.

5.2. Density Analysis by Commune

The analysis of station density by commune, complemented by Kernel Density Estimation (KDE), reveals significant disparities between the communes of the Funa district. The Kasa-Vubu commune has the highest density with 3.00 stations per km², followed by Kalamu with 1.12 stations per km² and Bandalungwa with 0.76 stations per km². At the opposite end, the peripheral communes of the district, such as Bumbu and Selembao, display significantly lower densities of 0.50 and 0.48 stations per km², respectively. The density map highlights a very high density core at the intersection of Kasa-Vubu Boulevard and de la Démocratie Avenue, where three fuel stations are located within a 300-metre radius, creating a zone of overconcentration that is concerning from a safety perspective. The results confirm hypothesis H1 that fuel stations concentrate along major traffic corridors and in areas of high commercial activity.

The results presented in **Table 1** and **Figure 4** reveal an unequal distribution of fuel station density within the Funa district, with a pronounced centro-peripheral gradient. The Kasa-Vubu commune displays a density of 3.00 stations per km², a level six times higher than that of the least dense commune. This extreme concentration is explained by the convergence of several factors: the presence of major road axes (Kasa-Vubu Boulevard, de la Démocratie Avenue), high population density and intense commercial activity. From an urban planning perspective, this overconcentration constitutes a critical issue: it reflects an absence of integrated planning of fuel distribution infrastructure in the Master Plan for Urban Planning and Development, where commercial logics systematically prevail over safety and risk management considerations.

Table 1. Spatial density analysis of fuel stations by commune of the Funa district.

Commune	Number of stations	Area (km²)	Station density (st/km²)	Risk level
Kasa-Vubu	15	5.00	3.00	Very high
Kalamu	12	10.70	1.12	High
Bandalungwa	9	11.80	0.76	Moderate
Bumbu	3	6.00	0.50	Low
Makala	8	8.00	1.00	Moderate
Selembao	5	10.50	0.48	Low to moderate
Ngiri-Ngiri	5	7.00	0.71	Low to moderate
District total	**57**	**59.00**	**0.97 (mean)**	**—**

The analysis of these disparities highlights a land-use conflict characteristic of African cities undergoing rapid demographic expansion. In high-density communes (Kasa-Vubu, Kalamu), land pressure pushes operators to site fuel stations on already highly urbanised parcels, generating a problematic coexistence between risky industrial activities and sensitive uses (housing, education, health). Conversely, the peripheral communes of Bumbu and Selembao exhibit negligible densities, suggesting either insufficient fuel supply for local populations or a shift in demand towards central communes, which further increases congestion and risks in the latter. This spatial imbalance constitutes a major challenge for territorial planning in Kinshasa, calling for a more balanced redistribution of petroleum infrastructure across the entire district.

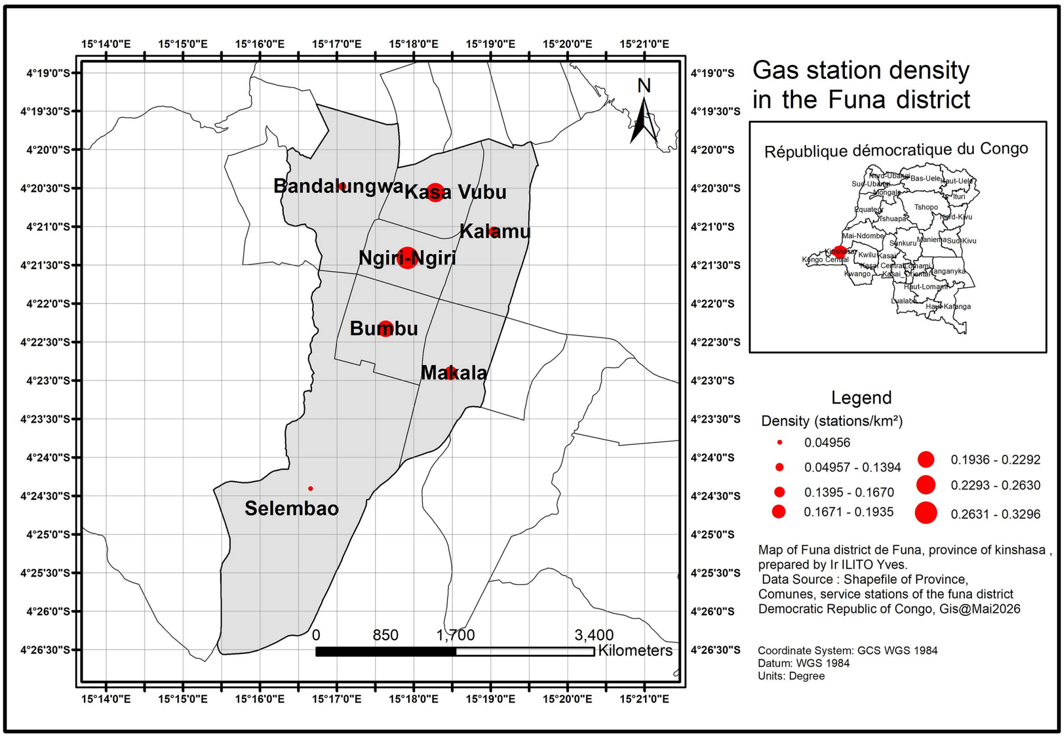

Figure 4. Density map of fuel stations in the Funa district.

5.3. Analysis of Sensitive Infrastructure

The proximity analysis identified a total of 342 sensitive infrastructure items in the vicinity of the 57 fuel stations of the Funa district. These infrastructure items are distributed as follows: 128 schools (37.4%), 87 markets and commercial centres (25.4%), 64 health centres and hospitals (18.1%), 38 places of worship (11.1%) and 25 major transport stations or stops (7.3%). Within the 100-metre buffer, 38 fuel stations (66.7%) have at least one sensitive infrastructure item in their immediate vicinity. Within the 200-metre buffer, this figure rises to 51 stations (89.5%). These results reveal a concerning imbrication between fuel stations and vulnerable establishments, confirming hypothesis H3 on the creation of high-risk zones for riverside communities.

Table 2 and Figure 5 quantify the extent of exposure of vulnerable populations to technological risks associated with fuel stations. Of the 342 sensitive infrastructure items identified, schools represent the most exposed category with 128 schools (37.4%), followed by markets (87, *i.e.* 25.4%) and hospitals (64, *i.e.* 18.1%). The predominance of schools is particularly alarming insofar as children constitute a high-risk population due to their physiological vulnerability and their inability to react quickly in emergency situations. The presence of 38 fuel stations (66.7%) with at least one sensitive infrastructure within a 100-metre radius testifies to a structural imbrication between petroleum installations and essential collective facilities, resulting from uncontrolled spontaneous urbanisation.

Table 2. Distribution of sensitive infrastructure exposed to risks in the vicinity of fuel stations (Funa district).

Infrastructure type	Count (n)	Proportion (%)	Buffer 100 m (n)	Buffer 200 m (n)
Schools	128	37.4	43	112
Markets and commercial centres	87	25.4	31	76
Health centres/Hospitals	64	18.1	19	58
Places of worship	38	11.1	12	33
Stations/Transport stops	25	7.3	7	21
Total	**342**	**100.0**	**112**	**300**

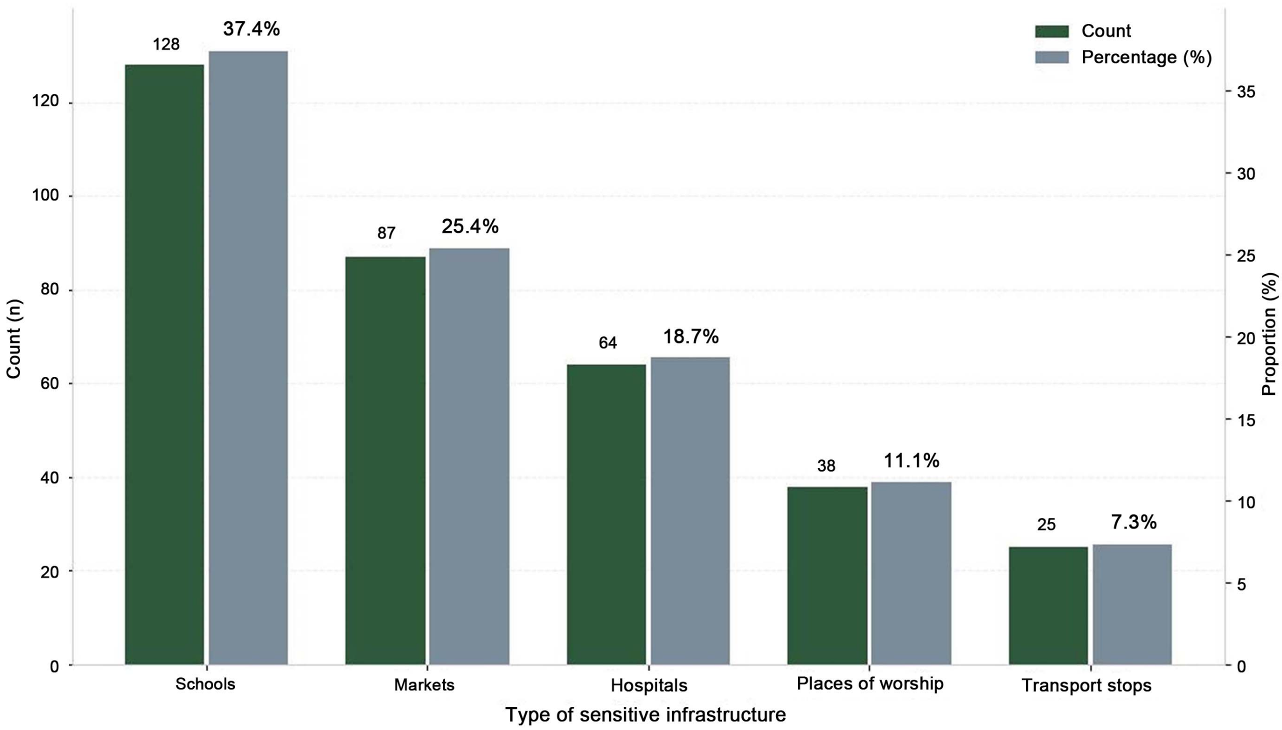

Figure 5. Distribution of sensitive infrastructure exposed to risks in the vicinity of fuel stations.

The analysis of these results reveals a land-use conflict deeply rooted in the urbanisation dynamics of Kinshasa. The unplanned expansion of neighbourhoods has led to a juxtaposition of activities incompatible from a safety perspective: stations distributing highly flammable products coexist with open-air markets, overcrowded schools and health centres whose evacuation in the event of a disaster would be extremely complex. This land-use conflict is exacerbated by the absence of effectively applied regulatory buffer zones, but also by the economic pressure that pushes operators to maximise their footprint in dense environments, and by the deficiencies of urban planning control mechanisms. The situation observed in the Funa district is not isolated and is part of a recurrent pattern in African cities where territorial planning struggles to integrate industrial safety constraints into urban planning documents, leaving the most vulnerable populations exposed to major risks.

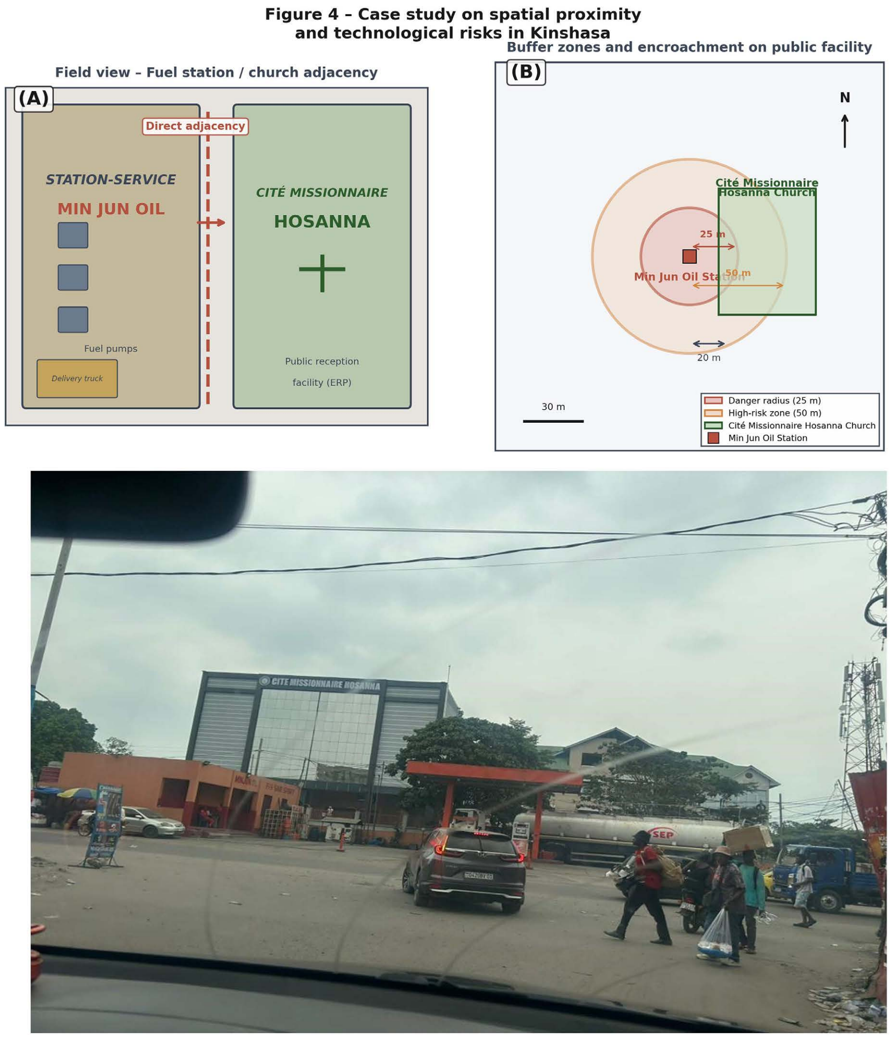

Figure 6. Case study on spatial promiscuity and technological risks in Kinshasa: (A) Field view showing the direct contiguity between the Min jun oil fuel station and the Citié Missionnaire Hosanna infrastructure; (B) Cartographic modelling of buffer zones highlighting the encroachment of the danger radius (25 m) and high-risk radius (50 m) on the church building. (Source: Field surveys and GIS analyses, 2026).

Figure 6(A) presents field photographic documentation that exemplifies the spatial promiscuity between petroleum installations and public-receiving establishments in Kinshasa. The SEP fuel station and the Citié Missionnaire Hosanna share an immediate parcel boundary, without any separation zone, which constitutes a flagrant violation of the minimum safety distances prescribed both by Congolese national regulations and by international standards such as NFPA 30 and WHO guidelines. This direct contiguity between a facility storing and distributing highly flammable products and a place of worship frequented by hundreds of faithful represents an acute land-use conflict whose potential consequences in the event of a technological accident—fire, explosion or toxic vapour leak—would be catastrophic for the users of the public-receiving establishment. This spatial configuration is not an isolated case in the Funa district: it reflects a systemic dynamic of spontaneous urbanisation where industrial safety constraints are systematically ignored in favour of maximising the built footprint and land profitability logics.

Figure 6(B) proposes a cartographic modelling of buffer zones that precisely quantifies the extent of this spatial vulnerability. The analysis reveals that more than 50% of the Citié Missionnaire Hosanna structure is trapped within the critical 25-metre danger radius (red zone), corresponding to the minimum evacuation distance in the event of a major fire with tank explosion. Even more concerningly, the entirety of the public-receiving establishment is confined within the 50-metre high-risk zone (orange zone), encompassing all circulation, assembly and evacuation areas of the establishment. This spatial vulnerability directly exposes users to major risks of fire, explosion and atmospheric pollution through inhalation of volatile organic compound (VOC) vapours, and testifies to a chronic failure of urban zoning control in Kinshasa, where the absence of effective implementation of rules on functional incompatibility between risky activities and sensitive uses leads to the creation of cumulative vulnerability zones for riverside communities.

5.4. Compliance with Safety Standards

The regulatory compliance analysis reveals a concerning compliance deficit. With respect to Congolese regulations, only 10 stations out of 57, *i.e.* a compliance rate of **17.5%**, comply with all prescribed minimum safety distances. With respect to NFPA 30 [11], 12 stations (21.1%) are compliant. Applying the thresholds recommended by WHO (100-metre buffer zone), the compliance rate falls to 15.8% (9 stations). In the Kasa-Vubu commune, the situation is particularly critical: none of the 15 identified stations fully complies with Congolese regulations, and only two stations (13.3%) meet the minimum requirements of NFPA 30 [11]. The distances measured between fuel stations and the nearest schools (Figure 7) range from 8 metres to 156 metres, with a mean of 42.3 metres, less than half the recommended minimum distance. These results fully validate hypothesis H2 on the generalised non-compliance with safety standards.

Table 3 synthesise the results of the compliance assessment of the 57 fuel stations in the Funa district against three complementary normative benchmarks. Whatever the standard applied, the compliance rate remains critically low: **17.5%** for Congolese national regulations, 21.1% for NFPA 30 standards and only 15.8% for WHO guidelines. These results mean that **over eighty per cent** of fuel stations present at least one non-compliance with respect to prescribed safety distances. The fact that international standards (NFPA 30, WHO) are not significantly more respected than national regulations suggests that the problem is not so much related to the stringency of thresholds as to the absence of effective control and compliance mechanisms.

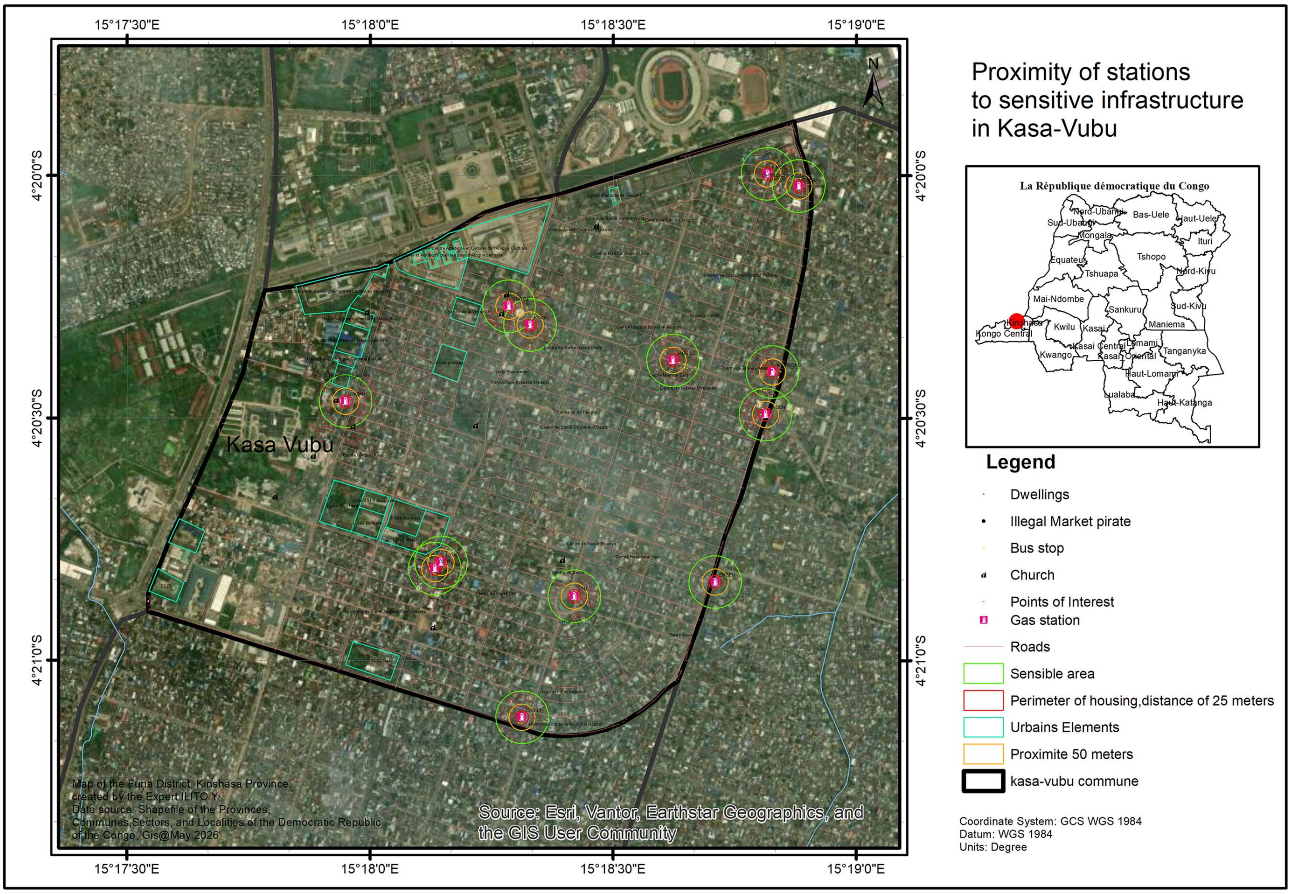

Figure 7. Proximity map of fuel stations with schools and hospitals.

Table 3. Regulatory compliance matrix of fuel stations in the Funa district according to three normative benchmarks.

Normative benchmark	Compliant stations (n)	Compliance rate (%)	Non-compliant stations (n)	Non-compliance rate (%)
National regulation (DRC)	**10**	**17.5**	**47**	**82.5**
NFPA 30 standards	12	21.1	45	78.9
Normative benchmark	**Compliant stations (n)**	**Compliance rate (%)**	**Non-compliant stations (n)**	**Non-compliance rate (%)**
WHO guidelines	9	15.8	48	84.2
Mean across all benchmarks	**—**	**18.1**	**—**	**81.9**

The analysis of these non-compliance rates reveals profound implications for urban governance and risk management in Kinshasa. The compliance deficit observed is not solely a technical or regulatory problem: it reflects a systemic failure of the governance chain, from norm elaboration to field application. The absence of periodic inspection systems, the lack of coordination between urban planning services and fire safety authorities, as well as the weakness of sanctions in case of non-compliance with safety distances, contribute to perpetuating this situation.

In terms of territorial planning, these results argue in favour of a revision of the Congolese regulatory framework, whose current minimum distances appear insufficient compared with international standards, and of an explicit integration of industrial safety constraints into local urban plans, particularly in high population density areas such as Kasa-Vubu and Kalamu.

5.5. Mapping of Risk Zones

The multi-criteria overlay of data layers enabled the production of a risk zone map integrating three vulnerability factors: fuel station density, proximity of sensitive infrastructure and population density. This map reveals the existence of five very high-risk sectors in the Funa district, all located in the Kasa-Vubu and Kalamu communes. These sectors correspond to the most frequented intersections, where the convergence of high fuel station density, massive presence of sensitive infrastructure and high population density creates conditions conducive to disasters in the event of a major incident.

5.6. Identification of Critical Sectors

Five critical sectors were identified on the basis of the multi-criteria analysis. Sector 1, located at the intersection of Kasa-Vubu Boulevard and de la Démocratie Avenue, concentrates three fuel stations, two schools, a market and a health centre within a 200-metre radius, with a population density exceeding 45,000 inh./km^2. Sector 2, along Kalamu Avenue, presents a similar configuration with a bus station and two schools near two fuel stations. Sectors 3, 4 and 5, located respectively in Bandalungwa, Makala and Ngiri-Ngiri, present high risk levels although slightly lower than the first two sectors. The identification of these critical sectors constitutes a valuable tool for the competent authorities in prioritising risk reduction actions.

6. Discussion

6.1. Correlation between Urbanisation and Fuel Station Density

The results of this study confirm the existence of a strong correlation between urban density and the concentration of fuel stations in the Funa district. The most densely populated communes, Kasa-Vubu and Kalamu, present the highest concentrations of fuel stations, while the less dense peripheral communes have significantly fewer. This observation is consistent with the results obtained by Makiti and Minga'ate [15] in Nairobi and by Iman *et al.* [18] in Douala, who also highlighted a positive relationship between population density and fuel station density. This correlation is explained by the commercial logics governing fuel station siting: the search for maximum clientele pushes operators towards high-attendance areas, creating overconcentration in central neighbourhoods to the detriment of coverage of peripheral areas.

However, this correlation raises a fundamental paradox: the areas that attract the most fuel stations due to their population density are precisely those where the consequences of an incident would be the most devastating. The coexistence between risky industrial installations and dense populations creates a systemic vulnerability that considerably amplifies urban risk. This paradox between economic attractiveness and public safety constitutes one of the major challenges of territorial planning in rapidly growing African cities.

6.2. Compliance with National and International Standards

The extremely low compliance rate observed in this study (**17.5% with respect to Congolese regulations**) is concerning and reveals a structural governance deficit in industrial safety. This result is consistent with observations made in other African cities: Makiti and Minga'ate [15] report a compliance rate of 38% in Nairobi, while Neghab *et al.* [16] observe a rate of 29% in Abidjan. The situation in Kinshasa therefore appears particularly critical, even in comparison with other African cities facing similar challenges. This finding can be attributed to several structural factors: insufficient inspection staff at the Ministry of Hydrocarbons, the absence of inter-institutional coordination between urban planning, fire safety and environmental services, and the weakness of sanction mechanisms.

The comparison with international standards also reveals a significant gap. While Congolese regulations set minimum safety distances, these are sometimes lower than the recommendations of NFPA 30 [11] or WHO. For example, the minimum distance prescribed by Congolese regulations between a fuel station and a school is 50 metres, whereas WHO recommends a minimum of 100 metres. This gap between national standards and international benchmarks constitutes an aggravating factor for population vulnerability, even in the rare cases where national regulations are respected.

6.3. Environmental and Health Risks

The close imbrication between fuel stations and dense residential areas, schools and health centres creates conditions conducive to chronic exposure of populations to environmental and health risks. Emissions of volatile organic compounds (BTEX) from refuelling operations and the ventilation of underground tanks constitute a permanent health threat for residents, particularly children attending schools located near fuel stations. Research by Rattanajongjitrakorn and Prueksasit [8] has demonstrated that chronic exposure to fuel station emissions is associated with an increase in respiratory pathologies, neurological disorders and leukaemia risks in children.

The potential contamination of groundwater by leaks from underground tanks constitutes a long-term environmental risk that is particularly concerning in a context where a significant proportion of the Kinshasa population depends on artesian wells for drinking water supply. The work of Alumona [5] has shown that soil contamination by hydrocarbons can persist for several decades and extend over several hundred metres around the pollution source. These environmental and health risks, reinforced by the promiscuity between fuel stations and populations, call for an urgent revision of territorial planning practices.

6.4. Comparison with Other African Cities

Putting the results of Kinshasa in perspective with those obtained in other African cities reveals significant similarities and differences. As in Lagos ([17]), the spatial distribution of fuel stations in Kinshasa is strongly correlated with traffic corridors and transport nodes. However, the non-compliance rate observed in Kinshasa (**82.5%**) is higher than that reported for Lagos (estimated at around 65%). Compared to Nairobi ([15]), Kinshasa has a slightly higher fuel station density per inhabitant, which is explained by the greater dependence on individual motorised transport and the absence of a structured public transport network. Compared to Abidjan [16], the similarities are striking in terms of explanatory factors of location, but Kinshasa stands out for the quasi-total absence of effective control mechanisms, which explains the particularly low compliance rates observed.

6.5. Implications for Urban Governance

The results of this study shed light on the structural failures of urban governance in Kinshasa in the area of technological risk management. The siting of fuel stations results from a confrontation between powerful economic logics and weak regulatory and institutional capacities. The fragmentation of competences between the Ministry of Hydrocarbons, the Urban Planning Division, the Civil Protection service and the communal authorities creates a governance vacuum that benefits unscrupulous operators. The effective integration of industrial safety constraints into urban planning processes requires an ambitious institutional reform, adequate training of control agents and a strong political commitment to risk prevention.

6.6. Implications for Public Safety

The implications for public safety are considerable. The presence of non-compliant fuel stations near schools, markets and health centres exposes vulnerable populations to potentially catastrophic fire and explosion risks. The analysis revealed that in certain critical sectors, the combination of high fuel station density, high population density and the presence of sensitive infrastructure creates conditions where a minor incident could degenerate into a major disaster. The weakness of firefighting resources in Kinshasa, where the response times of firefighters frequently exceed 30 minutes, reinforces this vulnerability. Improving public safety requires an integrated approach combining compliance with siting standards, strengthening emergency response capacities and raising population awareness of risks.

6.7. Risk Analysis and Land-Use Conflicts

The quantitative geospatial analysis revealed in the previous sections finds a striking confirmation in direct field observation. The presentation of in situ photographs enables documenting empirically the land-use conflicts and the documented risks that characterise the siting of fuel stations in densely populated areas of Kinshasa, and more particularly in the Kasa-Vubu commune.

Figure 8 illustrates a representative case of this conflictual coexistence observed near the "My Friend" fuel station, located on Prince Victor Boulevard (Kasa-Vubu). The overview (A) reveals an anarchic occupation of the immediate surroundings of the station: informal commercial activities (sale of food products, household items) deploy less than two metres from the fuel pumps, in manifest violation of the safety distances prescribed by Congolese regulations [14] and international standards [11] [12]. The detailed analysis (B) highlights the multiplicity of risks present on this single site: defective fencing of safety limits, accumulation of combustible waste near underground tanks, and partial blocking of access for emergency vehicles. This spatial configuration, frequently observed in high-density neighbourhoods of Kinshasa, transforms each fuel station into a critical point of urban vulnerability.

(A) (B) (C)

Figure 8. Conflictual coexistence between a fuel station ("My Friend" sign) and an informal market in the Kasa-Vubu commune. The composite figure presents three complementary views of the same site: (A) Frontal view showing the station building and the immediate proximity of informal commercial activities; (B) Detailed view of waste accumulation and stagnant water increasing health and fire risks; (C) Lateral perspective highlighting the encroachment of commercial activities on the station's safety perimeter.

Figure 9 proposes a synthetic schematisation of the main urban risks associated with fuel stations in dense environments, illustrated by a TotalEnergies station present in the Funa district. This schematisation integrates five risk dimensions identified both in the scientific literature [4] [17] [21] and in field observations: fire risk, explosion risk, air pollution by emissions of volatile organic compounds (VOCs), fuel leaks likely to contaminate groundwater, and the direct proximity of dwellings that amplifies the potential consequences of any accident. The imbrication of these five factors within a restricted perimeter creates a synergy effect in which the overall risk far exceeds the sum of the individual risks.

Figure 9. Schematisation of urban risks associated with fuel stations in dense environments (Fire, explosion, air pollution, fuel leak, proximity of dwellings).

These field observations corroborate the results of the geospatial analysis presented in Section 5, which revealed that 66.7% of fuel stations in the Funa district are located less than 100 metres from sensitive infrastructure. The photographs presented here testify to the concrete reality of these proximities: informal markets, health establishments and residential areas develop in contiguity with petroleum installations, without any isolation or risk reduction measures. This situation of flagrant non-compliance with safety and environmental standards [11] [12] [14] constitutes a permanent threat for riverside communities and calls for urgent corrective measures from the competent authorities.

7. Conclusions

This study proposed a systematic geospatial analysis of the distribution of fuel stations and an assessment of compliance with safety standards in the Kasa-Vubu commune and the Funa district of Kinshasa. The results obtained respond conclusively to the formulated problem and validate the main hypothesis of the research. The spatial distribution of fuel stations is primarily determined by economic and urban-mobility considerations, with a high concentration along major traffic corridors and in areas of high commercial activity, independently of safety constraints.

The regulatory compliance assessment revealed a concerning deficit, with only **17.5%** of fuel stations complying with Congolese regulations and even lower rates against international standards. The proximity analysis showed that 66.7% of stations present at least one sensitive infrastructure within a 100-metre radius, confirming the increased exposure of populations to environmental and technological risks. The mapping of risk zones enabled the identification of five critical sectors requiring urgent intervention by the competent authorities. The main hypothesis is thus validated: the location of fuel stations in Kinshasa is primarily dictated by economic logics to the detriment of safety and territorial planning standards, which significantly increases the exposure of populations to risks.

8. Recommendations

8.1. Strengthening the Regulatory Framework

It is imperative to revise and harmonise the regulatory framework relating to fuel station siting in the DRC, aligning it with the most stringent international standards, notably those of NFPA 30 [11] and WHO recommendations. Minimum safety distances should be revised upwards, with a minimum of 100 metres for schools and health centres. The regulatory framework should also integrate specific provisions relating to the environmental impact assessment prior to any new installation and to the continuous monitoring of soil and groundwater quality around existing fuel stations.

8.2. Strengthened Administrative Control

Strengthening administrative control capacities constitutes a prerequisite for improving regulatory compliance. The inspection staff of the Ministry of Hydrocarbons should be increased, formalised inter-institutional coordination mechanisms should be established between the various competent administrations, and sanctions in case of non-compliance should be reinforced. The introduction of a periodic certification system for fuel stations, with mandatory safety audits, would contribute significantly to improving the level of safety.

8.3. Integrated Urban Planning

The integration of industrial safety constraints into urban planning documents, notably the revision of the Master Plan for Urban Planning and Development of Kinshasa, is indispensable. This integration should translate into the definition of authorised, intermediate and prohibited siting zones for fuel stations within the framework of an enforceable regulatory zoning scheme. The establishment of a shared geospatial database between the various administrations, fed in real time and accessible to decision makers, would constitute a valuable decision-support tool for the daily management of urbanisation.

8.4. Environmental Monitoring

The establishment of a systematic environmental monitoring programme around existing fuel stations is recommended. This programme should include regular monitoring of soil and groundwater quality, measurement of atmospheric VOC emissions and assessment of the condition of underground tanks. Fuel stations identified as presenting a high environmental risk should be subject to an environmental remediation plan, including relocation to more appropriate sites where necessary. The participation of local communities in environmental monitoring, through neighbourhood committees, would strengthen the effectiveness of these arrangements.

8.5. Use of GIS in Decision-Making

The results of this study demonstrate the considerable potential of GIS for urban risk analysis and decision support in territorial planning. The systematisation of the use of geomatic tools by the competent administrations is strongly recommended. The creation of a geospatial observatory of urban risks, responsible for regularly producing updated risk maps and feeding decision-making processes, would constitute a significant advance in the urban governance of Kinshasa. The training of territorial executives in GIS tools and spatial analysis is also recommended to perpetuate these skills within the administrations.

9. Research Perspectives

Several research avenues deserve to be explored to deepen and extend the results of the present study. First, a quantitative assessment of environmental risks, including soil and water analyses, would enable measuring the actual impact of fuel stations on environmental quality and population health. Second, extending the analysis to the scale of the entire city-province of Kinshasa would offer a more comprehensive view of the issue and enable inter-district comparisons. Third, the development of spatial simulation models to evaluate relocation scenarios for non-compliant fuel stations would contribute to the elaboration of operational action plans. Fourth, a study of the perceptions and practices of fuel station operators would enable better understanding of the microeconomic determinants of location decisions. Finally, the integration of high-resolution remote sensing data for the temporal monitoring of the evolution of the spatial footprint of fuel stations would open new perspectives for the dynamic analysis of urban risks.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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