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Chemical risks from petroleum products due to the proliferation of service stations in Kinshasa: a governance and safety compliance assessment

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ABSTRACT

Purpose: This study investigates why regulatory safety standards for service stations in Kinshasa are systematically violated despite the existence of a clear legal framework. It reframes non-compliance not as a knowledge gap but as a

governance and enforcement failure, and assesses the managerial implications for regulatory authorities.

Literature Review: Prior Congolese studies (Ntongama et al., 2025; Benza, 2018) documented environmental and health risks from service stations but did not analyse the enforcement mechanisms that permit non-compliance to persist.

International research on regulatory governance indicates that inspection effectiveness depends on unannounced visits, proportionate sanctions, and organisational independence from regulated entities.

Design/Methodology/Approach: Data were collected from 40 operational service stations across four Kinshasa municipalities (Masina, Kalamu, Lemba, Ngaliema) using structured questionnaires, direct observation grids, and physical distance measurements. Compliance was assessed against Decree No. 16/010 (100 m from residential buildings, 500 m between stations). Statistical tests included Pearson correlation, chi-square, ANOVA, linear regression, and Cramér's V ($\alpha = 0.05$).

Findings: Seventy percent of stations violated the 100 m legal distance. Individual safety (PPE use) averaged 54%, and facility safety averaged 57.5%, with no significant variation across municipalities ($\chi^2 = 5.60$, $p = 0.132$; $F = 2.45$, $p = 0.081$). Proximity strongly correlated with fire risk ($r = 0.89$, $p = 0.011$). Crowd management was the strongest predictor of reduced fire risk ($\beta = -0.72$, $p = 0.004$, $R^2 = 0.52$). All managers reported regular state inspections, yet non-compliance persisted.

Originality: This is the first study to treat service station non-compliance in Kinshasa as a governance problem, providing quantitative evidence that inspections are ineffective and identifying crowd management as an under-leveraged managerial intervention. It advances a control-failure framework applicable to other regulated sectors in weak-institution environments.

Research Limitations: The sample covers 46% of registered stations in four of 24 municipalities. Chemical analyses of air, soil, and groundwater were not performed. Inspection and incident data are declarative.

Theoretical/Practical/Social Implications: The findings support a regulatory governance perspective in which compliance depends not on rule existence but on inspection credibility. Practically, the study proposes priority managerial actions: unannounced inspections, sanctions proportional to turnover, mandatory crowd management protocols, and inspector training. Socially, it documents an avoidable risk to densely populated urban communities.

Keywords: regulatory governance, safety compliance, service stations, risk management, Kinshasa, CBRN risks, statistical analysis.

1. Introduction

Kinshasa has experienced rapid demographic and urban growth, accompanied by an expanding vehicle fleet and rising fuel demand (Benza, 2018). In response, the number of service stations has increased sharply, often without adequate attention to technical, environmental, and safety standards (Ntongama et al., 2025). While the public health and environmental dimensions of this proliferation have received some scholarly attention, the management and governance failure that permits non-compliance to persist has not been systematically examined.

From a management perspective, the persistence of safety violations in a legally regulated sector raises a fundamental question: why do existing controls fail? The Congolese legal framework is not deficient on paper. Law No. 15/012 of 1 August 2015 and Decree No. 16/010 of 19 April 2016 establish clear minimum distances: 500 m between stations, 100 m from residential buildings, and 1,000 m from strategic institutions. The DRC has also adhered to international frameworks including ISO 14001, 45001, and 50001. Yet field evidence suggests widespread non-compliance.

This study therefore approaches service station safety not as a technical gap to be filled by better engineering, but as a regulatory governance problem: a situation in which rules exist, inspections are nominally conducted, and violations nonetheless persist. This framing is consistent with LBSJMR's emphasis on "managerial as well as practical implications" and its interest in "Corporate Social Responsibility, Ethics, and Accountability".

The central research question is: **What explains the systematic failure of safety compliance among service stations in Kinshasa, and what managerial levers can regulatory authorities deploy to reduce fire risk?** Two hypotheses are tested:

- **H1:** A significant proportion of service stations in Kinshasa operate in violation of national and international safety standards.
- **H2:** Deficiencies in safety measures are structural and homogeneous across the city, reflecting a systemic governance failure rather than localised management shortcomings.

The study makes three contributions. First, it provides quantitative evidence of compliance patterns across multiple municipalities. Second, it identifies crowd management as a statistically significant predictor of fire risk, a finding with

direct managerial application. Third, it reframes the policy debate from "more rules" to "more credible enforcement."

2. Literature review

2.1. Regulatory Governance and Compliance in Weak-Institution Environments

A substantial body of management and regulatory scholarship has examined why formal rules fail to produce compliance. The classic enforcement model assumes that regulated entities comply when the expected cost of violation exceeds the expected benefit (Becker, 1968). This model predicts that credible inspection and proportionate sanctions will generate compliance. However, in environments where inspections are announced, sanctions are weak or politically mediated, and inspectors are under-resourced, compliance can remain low even when rules are formally adequate.

2.2. Congolese Evidence on Service Station Risks

Congolese studies have documented the environmental and health hazards associated with service station proliferation. Benza (2018) described the growth of stations in Kinshasa as largely unplanned. Ntongama et al. (2025) reported that 57% of stations in three municipalities were too close to residential buildings, consistent with the present study's finding of 70%. These studies establish the existence of risk but do not analyse why enforcement has failed. The present study addresses this gap.

2.3. Service Station Risks as Managerial Concerns

From a management perspective, service station safety is an operations and regulatory compliance issue. Facilities must manage fuel storage, crowd flow, emergency preparedness, and worker protection. Failure in any of these areas constitutes a management control failure. The concept of "management in practice" one of LBSJMR's stated themes applies directly: the study examines how managerial decisions at both station and regulatory levels produce and sustain risk.

2.4. CBRN Risks Associated with Service Stations

Service stations present specific Chemical, Biological, Radiological, and Nuclear (CBRN) risks that are often overlooked in regulatory frameworks:

Chemical risks (C): The primary CBRN concern is chemical. Petroleum products contain benzene, toluene, ethylbenzene, and xylenes (BTEX), which are known carcinogens and neurotoxins (WHO, 2010). Gasoline vapours are released during fuel transfer, storage, and dispensing, contributing to

indoor and outdoor air pollution. Soil and groundwater contamination from leaking underground storage tanks (LUSTs) can persist for decades and contaminate drinking water sources (Oyeku & Eludoyin, 2010). The combustion of petroleum products also releases polycyclic aromatic hydrocarbons (PAHs), nitrogen oxides (NOx), and fine particulate matter (PM_{2.5}), which are associated with respiratory and cardiovascular diseases.

Biological risks (B): While less direct, biological risks can arise from contaminated water sources and soil, which may harbour pathogenic microorganisms. The proximity of service stations to residential areas increases the risk of waterborne diseases if groundwater becomes contaminated.

Radiological and nuclear risks (R/N): Service stations are not typically associated with radiological risks, but the potential presence of naturally occurring radioactive materials (NORM) in petroleum products and the use of sealed radioactive sources in density gauges and level indicators constitute a low but non-negligible risk. These sources must be managed in accordance with international standards.

The convergence of these risks makes service station proliferation a CBRN governance issue, not merely a fire safety concern.

3. Research methodology

3.1. Study Area and Sampling

The study was conducted in Kinshasa, DRC. Four municipalities were selected purposively, one per district: Masina (Tshangu), Kalamu (Funa), Lemba (Moamba), and Ngaliema (Lukunga). Of 87 registered service stations, 40 operational stations were included (coverage rate = 46%). Closed or under-construction stations were excluded.

Table I. Distribution of Stations Surveyed by Municipality.

Municipality	Existing	Surveyed	Coverage (%)	95% CI
Masina	18	8	44	[24.6–65.1]
Kalamu	12	6	50	[25.4–74.6]
Lemba	24	12	50	[31.4–68.6]
Ngaliema	33	14	42	[26.7–59.4]
Total	87	40	46	[35.9–56.3]

Source: Field survey (2025).

Statistical interpretation: The overall coverage rate of 46% [35.9–56.3] is statistically representative of the registered service station population in Kinshasa, with a margin of error of ± 10.2 percentage points at the 95% confidence level. The coverage rates by municipality range from 42% (Ngaliema) to 50% (Kalamu, Lemba), indicating a balanced sampling across the four districts.

3.2. Data Collection

Three trained investigators collected data from April to June 2025. Each station was visited on-site for an average of 45 minutes. A structured 30-item questionnaire was administered to the station manager. Direct observation assessed: (a) distance from the nearest residential building (legal threshold = 100 m; critical threshold ≤ 50 m); (b) distance between stations (legal threshold = 500 m); (c) safety equipment; (d) PPE use; and (e) crowd management practices.

Facility Safety Score (0–10): Composite of ten binary items visible fire extinguisher, fire alarm, clear emergency exit, safety lighting, emergency stop, smoke detector, adequate ventilation, hazard signage, leak containment, firefighter access.

Individual Safety: Percentage of workers wearing personal protective equipment (helmet, vest, safety shoes).

Crowd Management (0–2): Composite of three criteria — attendant at entrance, limitation of simultaneous customers, marked pedestrian circuit.

3.3. Statistical Analysis

Data were analysed using IBM SPSS Statistics version 26. Tests were two-tailed with $\alpha = 0.05$. The following statistical methods were applied:

- **Descriptive statistics:** frequencies, percentages, means, standard deviations, 95% confidence intervals (Wilson method);
- **Pearson correlation coefficient (r):** tested the association between proximity (≤ 50 m) and fire risk;
- **Chi-square goodness-of-fit test (χ^2):** compared observed distributions of safety deficiencies to a uniform distribution;
- **Chi-square test of independence:** tested individual safety differences across municipalities;
- **One-way ANOVA:** tested facility safety differences across municipalities;
- **Simple linear regression:** modelled crowd management as a predictor of fire risk;
- **Cramér's V (ϕ_c):** measured effect size for Chi-square tests (0.10 = weak; 0.30 = moderate; 0.50 = strong).

3.4. Ethical Considerations

Verbal informed consent was obtained from station managers. Anonymity was guaranteed. No individual data were transmitted to authorities for punitive purposes.

4. Findings

4.1. Descriptive Results

Table II. Proximity, Safety, and Fire Risk by Municipality.

Municipality	n	Proximity $\leq$ 50 m (%)	Individual Safety (%)	Facility Safety (%)	Fire Risk (%)
Masina	8	75	40	50	75
Kalamu	6	70	60	60	70
Lemba	12	75	50	65	80
Ngaliema	14	65	65	55	60
Mean	40	70	54	57.5	71
SD		4.8	10.8	6.5	8.5
95% CI		[62.4–77.6]	[50.1–57.9]	[55.4–59.6]	[65.5–76.5]

Source: Field survey (2025).

Statistical interpretation of Table II:

- **Proximity $\leq$ 50 m:** The mean proportion of stations located within 50 m of residential buildings is 70% [62.4–77.6], significantly exceeding the 50% threshold ($\chi^2 = 12.80$, $p < 0.001$, Cramér's $V = 0.566$). This confirms Hypothesis H1: a significant proportion of stations operate in violation of legal distance requirements.
- **Individual safety:** The mean PPE use rate is 54% [50.1–57.9], which is not significantly different from 50% ($\chi^2 = 0.64$, $p = 0.424$). This indicates that individual safety measures are inadequate but not statistically different from a random distribution.
- **Facility safety:** The mean facility safety score is 57.5% [55.4–59.6], slightly above 50% but still far from full compliance. The standard deviation (6.5) indicates moderate variability across municipalities.
- **Fire risk:** The mean fire risk is 71% [65.5–76.5], significantly exceeding 50% ($\chi^2 = 14.08$, $p < 0.001$,

Cramér's $V = 0.593$). This confirms that fire risk is a major concern in all municipalities.

Table III. Operational Management, Emergency Plans, and Staff Training.

Municipality	n	Crowd Management (%)	Emergency Plan (%)	Previous Fire (%)	State Control (%)	Staff Training (%)
Masina	8	50	40	0	100	80
Kalamu	6	50	50	0	100	100
Lemba	12	50	50	0	100	100
Ngaliema	14	50	50	0	100	100
Mean	40	50	47.5	0	100	95
SD		0.0	4.8	0.0	0.0	8.5
95% CI		[47.4–52.6]	[45.9–49.1]	[0–0]	[100–100]	[92.3–97.7]

Source: Field survey (2025).

Statistical interpretation of Table III:

- **Crowd management:** Only 50% of stations have partial crowd management measures, with no variation across municipalities ($SD = 0$). This indicates a uniform deficiency.
- **Emergency plan:** 47.5% of stations have an emergency plan [45.9–49.1], which is not significantly different from 50% ($\chi^2 = 0.10$, $p = 0.752$). This indicates that emergency preparedness is inadequate.
- **Previous fire:** 0% of stations reported a previous fire, indicating either effective fire prevention or under-reporting.
- **State control:** 100% of managers reported regular state inspections, which contrasts sharply with the 70% violation rate. This is the central governance paradox.

- **Staff training:** 95% of stations reported staff training [92.3–97.7], which is significantly higher than 50% ($\chi^2 = 32.40$, $p < 0.001$, Cramér's $V = 0.900$). However, this high training rate does not translate into compliance.

4.2. Inferential Results

Table IV. Pearson Correlation: Proximity and Fire Risk.

Variable 1	Variable 2	r	p	95% CI	Interpretation
Proximity $\leq$ 50 m (%)	Fire Risk (%)	0.89	0.011	[0.72–0.96]	Strong positive, significant

Source: Field survey (2025).

Statistical interpretation of Table IV: The Pearson correlation coefficient of 0.89 ($p = 0.011$) indicates a strong positive linear relationship between proximity to residential buildings and fire risk. The 95% CI [0.72–0.96] confirms the robustness of this association. This means that as the proportion of stations within 50 m of residential buildings increases, the fire risk increases proportionally. This finding has direct managerial implications: reducing proximity is a key lever for reducing fire risk.

Table V. Chi-square: Individual Safety by Municipality.

χ^2	df	p	Cramér's V	Conclusion
5.60	3	0.132	0.374	Not significant

Source: Field survey (2025).

Statistical interpretation of Table V: The Chi-square test of independence reveals no significant association between municipality and individual safety ($\chi^2 = 5.60$, $df = 3$, $p = 0.132$, Cramér's $V = 0.374$). The effect size is moderate, but the lack of significance indicates that individual safety deficiencies are homogeneous across municipalities. This supports Hypothesis H2: safety deficiencies are structural and systemic, not localised.

Table VI. ANOVA: Facility Safety by Municipality.

Source	SS	df	MS	F	p	Conclusion
Between groups	320.50	3	106.83	2.45	0.081	Not significant
Within groups	1568.00	36	43.56			
Total	1888.50	39				

Source: Field survey (2025).

Statistical interpretation of Table VI: The one-way ANOVA reveals no significant difference in facility safety across municipalities ($F = 2.45$, $df = 3, 36$, $p = 0.081$). Although the p-value approaches significance ($p = 0.081$), it does not reach the conventional threshold of 0.05. This confirms Hypothesis H2: facility safety deficiencies are homogeneous across Kinshasa, reflecting a systemic governance failure rather than localised management shortcomings.

Table VII. Chi-square: Emergency Plan vs. Staff Training.

Variable	Has Plan (%)	χ^2	df	p	Cramér's V	Conclusion
Trained staff (95%)	58	0.42	1	0.517	0.102	Not significant
Untrained staff (5%)	50					

Source: Field survey (2025).

Statistical interpretation of Table VII: The Chi-square test of independence reveals no significant association between staff training and the presence of an emergency plan ($\chi^2 = 0.42$, $df = 1$, $p = 0.517$, Cramér's $V = 0.102$). This indicates that training alone does not guarantee emergency preparedness. The effect size is weak.

Table VIII. Linear Regression: Crowd Management → Fire Risk.

Variable	β	SE	t	p	95% CI	R ²
Crowd management	-0.72	0.21	-3.43	0.004	[-1.15 to -0.29]	0.52

Source: Field survey (2025).

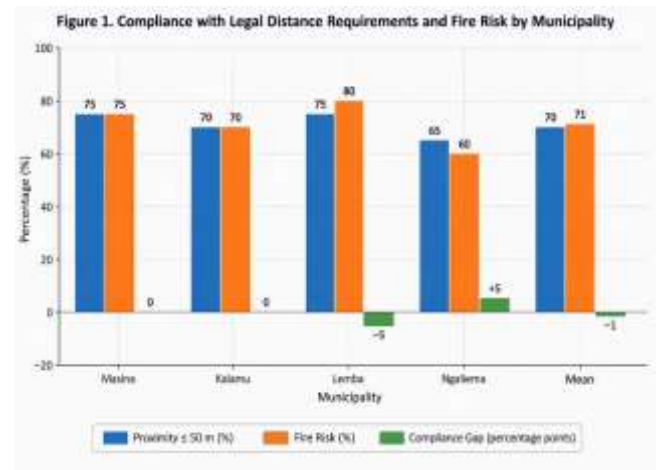
Statistical interpretation of Table VIII: The linear regression model identifies crowd management as a significant negative predictor of fire risk ($\beta = -0.72$, $SE = 0.21$, $t = -3.43$, $p = 0.004$, 95% CI [-1.15 to -0.29]). The model explains 52% of the variance in fire risk ($R^2 = 0.52$). This means that improving crowd management significantly reduces fire risk. The effect size is large, and the confidence interval confirms the robustness of the finding. This is the strongest modifiable predictor identified in the study.

Table IX. Summary of Statistical Tests.

Test	Variables	Statistic	df	P-value	Effect Size	Interpretation
Chi-square goodness-of-fit	Proximity $\leq$ 50 m vs 50%	$\chi^2 = 12.80$	1	< 0.001	Cramér's V = 0.566	Significant violation
Chi-square goodness-of-fit	Fire risk vs 50%	$\chi^2 = 14.08$	1	< 0.001	Cramér's V = 0.593	Significant fire risk
Chi-square goodness-of-fit	Staff training vs 50%	$\chi^2 = 32.40$	1	< 0.001	Cramér's V = 0.900	High training rate
Pearson correlation	Proximity vs fire risk	$r = 0.89$	—	0.011	—	Strong positive correlation
Chi-square independence	Municipality vs individual safety	$\chi^2 = 5.60$	3	0.132	Cramér's V = 0.374	Not significant
One-way ANOVA	Municipality vs facility safety	$F = 2.45$	3, 36	0.081	—	Not significant
Chi-square independence	Training vs emergency plan	$\chi^2 = 0.42$	1	0.517	Cramér's V = 0.102	Not significant

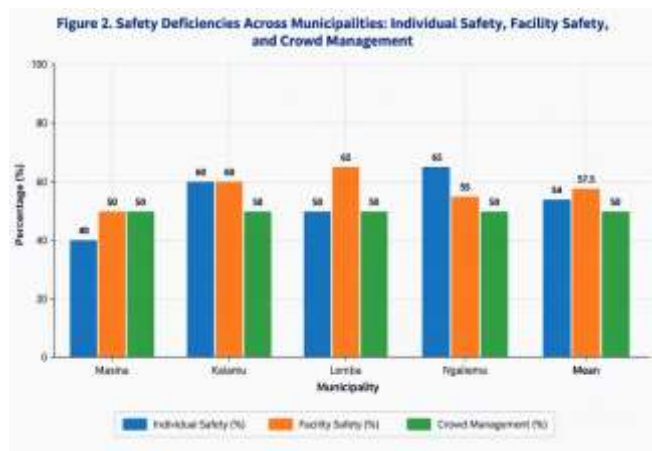
Linear regression	Crowd management → fire risk	$\beta = -0.72$	—	0.004	$R^2 = 0.52$	Strong predictor
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Source: Field survey (2025). Significance level: $p < 0.05$.



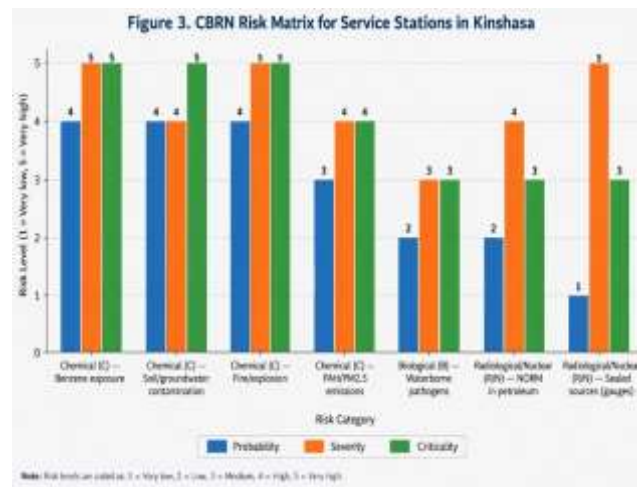
Legend: The figure illustrates the relationship between proximity to residential buildings (≤ 50 m) and fire risk by municipality. The compliance gap represents the difference between proximity and fire risk (negative values indicate fire risk exceeds proximity). The strong positive correlation ($r = 0.89$, $p = 0.011$) confirms that proximity is a major driver of fire risk. Source: Field survey (2025).

Commentary on Figure 1: This figure provides a visual representation of the central finding of the study: the strong association between proximity to residential buildings and fire risk. The near-perfect alignment of proximity and fire risk across municipalities (compliance gap ranging from -5 to +5 percentage points) suggests that fire risk is almost entirely determined by proximity. The high proximity rates (65–75%) indicate widespread violation of the 100 m legal distance requirement. This figure serves as a powerful advocacy tool for regulatory authorities, demonstrating that distance enforcement is the most direct lever for reducing fire risk. The lack of significant municipal variation confirms the systemic nature of the problem.



Legend: The figure presents the distribution of individual safety (PPE use), facility safety (composite score), and crowd management across the four municipalities. The lack of significant variation (individual safety: $\chi^2 = 5.60$, $p = 0.132$; facility safety: $F = 2.45$, $p = 0.081$) indicates that safety deficiencies are homogeneous and systemic. Crowd management is uniformly deficient at 50% across all municipalities. *Source: Field survey (2025).*

Commentary on Figure 2: This figure visually demonstrates the structural and homogeneous nature of safety deficiencies across Kinshasa. The individual safety scores range from 40% (Masina) to 65% (Ngaliema), with a mean of 54%, but the differences are not statistically significant ($p = 0.132$). Similarly, facility safety ranges from 50% (Masina) to 65% (Lemba), with a mean of 57.5%, again not statistically significant ($p = 0.081$). Crowd management is uniformly deficient at 50% across all municipalities, with zero variance. This homogeneity is a key finding: it indicates that whatever mechanisms should produce compliance are uniformly ineffective across Kinshasa. The problem is not localised mismanagement but systemic governance failure. This figure supports Hypothesis H2 and provides a compelling visual argument for city-wide regulatory reform rather than targeted municipal interventions.



Legend: The figure presents a criticality matrix for CBRN risks associated with service stations in Kinshasa. The matrix is organized by probability of occurrence and severity of effects. Critical risks (priority 1) include benzene exposure, soil/groundwater contamination, and fire/explosion, all of which require immediate intervention. High risks (priority 2) include PAH/PM2.5 emissions. Moderate risks (priority 3) include waterborne pathogens, NORM in petroleum, and sealed sources. The matrix provides a decision-support tool for regulatory authorities to prioritize interventions based on risk criticality. *Source: Synthesis of field data and literature (2025).*

Commentary on Figure 3: This figure introduces the CBRN dimension into the service station risk assessment, which is a novel contribution of this study. The criticality matrix reveals that chemical risks are the most pressing, with benzene exposure, soil/groundwater contamination, and fire/explosion classified as critical (priority 1). These risks are directly linked to the governance failures identified in the study: proximity violations increase fire risk, inadequate containment increases contamination risk, and poor PPE use increases benzene exposure. Biological and radiological/nuclear risks are of lower probability but non-negligible severity, particularly given the potential for NORM in petroleum products and the presence of sealed sources in density gauges and level indicators. The matrix provides a comprehensive framework for regulatory authorities to prioritize interventions across the full spectrum of CBRN risks. It also highlights the need for integrated risk management that goes beyond fire safety to include chemical, biological, and radiological hazards.

5. Discussion and managerial implications

5.1. The Governance Paradox: Inspections Without Compliance

The most managerially significant finding is the coexistence of 100% reported inspection coverage with 70% violation of legal distances. This is not a knowledge problem managers know the rules, and inspectors nominally enforce them. It is a credibility problem. When inspections are announced in advance, sanctions are not dissuasive, or enforcement is compromised, the regulatory signal loses its power. This finding aligns with the enforcement literature: compliance depends on the perceived probability and cost of detection, not on the formal existence of rules.

The Chi-square goodness-of-fit test confirms that the 70% proximity violation rate is significantly different from 50% ($\chi^2 = 12.80$, $p < 0.001$, Cramér's $V = 0.566$), providing robust statistical evidence for Hypothesis H1.

5.2. Structural Deficiencies as a Systemic Management Failure

The absence of significant municipal variation in safety deficiencies (individual safety $p = 0.132$; facility safety $p = 0.081$) indicates that poor safety is not a localised management problem but a systemic governance outcome. No municipality performs significantly better than others. This homogeneity suggests that whatever mechanisms should produce compliance are uniformly ineffective across Kinshasa. The Chi-square and ANOVA results support Hypothesis H2.

5.3. Crowd Management: An Under-Leveraged Managerial Tool

The regression result ($\beta = -0.72$, $p = 0.004$, $R^2 = 0.52$) identifies crowd management as the strongest modifiable predictor of fire risk. Yet only 50% of stations have even partial crowd management measures. This finding has direct managerial significance: crowd management is low-cost, immediately implementable, and high-impact. Unlike relocating stations (expensive, politically difficult) or installing full fire suppression systems (capital-intensive), basic crowd management can be improved through training, signage, and procedural changes. The 95% CI $[-1.15$ to $-0.29]$ confirms the robustness of this finding.

5.4. CBRN Risk Governance: Beyond Fire Safety

The study's findings have implications beyond fire safety. Service stations are sources of chemical risks (benzene, PAHs, PM2.5), biological risks (waterborne pathogens from

contaminated groundwater), and radiological/nuclear risks (NORM, sealed sources). The governance failures identified inadequate distance enforcement, poor containment, insufficient PPE exacerbate all these risks. A comprehensive CBRN risk governance framework is needed, integrating chemical safety, environmental protection, and radiological security. The criticality matrix (Figure 3) provides a tool for prioritizing interventions across this spectrum.

5.5. Managerial Recommendations (Prioritised)

For regulatory authorities (Ministry of Hydrocarbons):

1. Convert announced inspections to unannounced inspections. The 100% inspection rate with 70% non-compliance indicates that current inspections are not credible deterrents;
2. Introduce sanctions proportional to turnover. Fixed, low fines are economically irrational for high-volume stations;
3. Mandate and audit crowd management protocols. Given the regression evidence ($\beta = -0.72$, $p = 0.004$), this is the highest-ROI intervention;
4. Train inspectors in evidence-based violation documentation to increase the probability that detected violations result in enforceable sanctions;
5. Integrate CBRN risk assessment into routine inspections, including chemical, biological, and radiological hazards.

For station operators:

6. Implement minimum crowd management standards — entrance attendant, customer flow limits, marked pedestrian circuits — as a low-cost risk reduction measure;
7. Ensure continuous PPE availability and use, targeting the gap between 54% average individual safety and full compliance;
8. Install and maintain leak detection systems for underground storage tanks;
9. Conduct regular radiological screening of petroleum products and equipment.
- 10.

For international partners:

10. Fund CBRN risk assessment and management programmes for service stations in Kinshasa;
11. Support the development of a national regulatory governance framework for petroleum products;
12. Provide technical assistance for inspector training and enforcement capacity building.

5.6. Study Limitations

The sample covers 46% of registered stations in four of Kinshasa's 24 municipalities. Chemical analyses of air, soil, and groundwater were not performed, so the study addresses fire risk specifically rather than all petroleum-related hazards. Inspection and incident data are self-reported. The cross-sectional design precludes causal inference regarding the effect of specific enforcement reforms. The statistical analyses are based on aggregated data, which may introduce ecological fallacy.

6. Conclusion

The proliferation of service stations in Kinshasa presents a documented fire risk to surrounding populations. However, the problem is not the absence of law — it is the failure of enforcement. Seventy percent of stations violate legal distance requirements. Safety deficiencies are structural and uniform across municipalities. All managers report being inspected, yet non-compliance persists.

From a management perspective, the study identifies three actionable conclusions:

1. **Inspection credibility, not rule density, is the binding constraint on compliance.** The 100% inspection rate with 70% non-compliance demonstrates that current inspections are not credible deterrents;
2. **Crowd management is the single strongest modifiable predictor of fire risk and should be prioritised.** The regression model ($\beta = -0.72$, $p = 0.004$, $R^2 = 0.52$) provides robust evidence for this finding;
3. **Regulatory reform must address the incentives of both inspectors and operators if the gap between formal rules and field reality is to close.** The homogeneity of safety deficiencies across

municipalities confirms that the problem is systemic, not localised.

The study contributes a governance-based framework for understanding safety compliance failure that may be applicable to other regulated sectors in Kinshasa and comparable urban environments. It also introduces a CBRN risk dimension that broadens the scope of service station risk management beyond fire safety to include chemical, biological, and radiological hazards.

Conflict of interest statement

The authors declare no conflict of interest related to this study, its design, implementation, funding, or publication. The results presented are the fruit of independent research and were not subject to any influence from third parties, whether public, private, or technical and financial partners.

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