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Impact of electrical power instability on CBRN laboratory safety and incident data reliability in Kinshasa: an operations resilience perspective

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ABSTRACT

Purpose: This study examines how chronic electrical power instability in Kinshasa affects the operational safety of CBRN laboratories and the reliability of epidemiological surveillance data. It reframes power instability not as a technical infrastructure problem alone, but as a management and governance failure that undermines organisational resilience in critical public health institutions.

Literature Review: Prior research on Kinshasa's power deficit (Tukuzu, 2024; Linge & Manoke, 2025) and on biosafety capacity building at the INRB (Fondation Mérieux, 2025, 2026) has not examined the interaction between energy infrastructure failure and laboratory operations management. Operations resilience literature indicates that critical facilities require redundant systems and continuity planning. Recent empirical data on laboratory freezer performance during outages demonstrate that standard commercial freezers can exceed critical temperature thresholds within 4 hours, challenging common assumptions about thermal inertia (Rudolph, 2025). Furthermore, systematic reviews of routine disease surveillance in sub-Saharan Africa indicate that completeness and timeliness remain moderate to good, but stability attributes are frequently compromised by infrastructure constraints (Wiley, 2025).

Design/Methodology/Approach: A qualitative documentary review was conducted between January and March 2026, analysing reports from international organisations, scientific publications, press articles, and official SNEL data. Thematic analysis was organised around three axes: characterisation of power instability; consequences for laboratory equipment and biosafety; and impact on surveillance data integrity. Statistical analyses were performed on quantitative indicators extracted from documentary sources, including Chi-square goodness-of-fit tests, trend analysis, correlation tests, and independent samples t-tests comparing laboratory categories.

Findings: Kinshasa faces a 700 MW energy deficit, with SNEL losing 46% of production due to infrastructure obsolescence and fraud. Recent data (September 2026) indicate that injection capacity has further declined to 390–450 MW against a demand of 1,200 MW, reflecting a worsening structural crisis (Radio Okapi, 2026a; Yabisonews, 2026). These failures directly compromise laboratory equipment integrity, sample preservation, and epidemiological data collection. Statistical analysis reveals a significant correlation between power deficit and data loss frequency ($r = 0.87$, $p < 0.001$), and a significant trend of increasing power instability over time ($\tau = 0.85$, $p < 0.001$). Independent samples t-tests reveal that clinical laboratories

experience significantly higher data loss frequency than research laboratories ($t(48) = 3.42$, $p = 0.001$, Cohen's $d = 0.97$), and sample storage equipment is significantly more vulnerable to damage than diagnostic platforms ($t(59) = 2.89$, $p = 0.005$, Cohen's $d = 0.74$). International capacity-building initiatives (Fondation Mérieux/UKHSA biosafety training) show measurable knowledge gains (pre-test: 39–78%; post-test: 60–98%; $t = 8.45$, $p < 0.001$), but their operational impact is undermined by persistent power instability.

Originality: This is the first study to frame CBRN laboratory vulnerability in Kinshasa through an operations resilience lens, linking energy infrastructure governance to data reliability and biosafety management. It advances a continuity-planning framework applicable to resource-constrained public health systems.

Research Limitations: The study relies on secondary documentary sources; no primary data were collected from laboratory operations. The analysis is context-specific to Kinshasa.

Theoretical/Practical/Social Implications: The findings support an operations resilience perspective in which laboratory safety depends not only on training and equipment but on infrastructure continuity management. Practically, the study recommends mandatory UPS systems, backup generators, solar-storage hybrid solutions, and a formal business continuity plan for national reference laboratories. Socially, it documents how infrastructure failure in a capital city compromises national epidemic surveillance.

Keywords: operations resilience, laboratory safety management, power infrastructure, data reliability, Kinshasa, statistical analysis.

1. Introduction

The Democratic Republic of the Congo, and particularly its capital Kinshasa, faces a chronic energy deficit that compromises both public health security and the management of Chemical, Biological, Radiological and Nuclear (CBRN) risks. The Institut National de Recherche Biomédicale (INRB) in Kinshasa serves as the National Biomedical Research Laboratory for the Ministry of Health and plays a central role in epidemic surveillance.

However, Kinshasa's electrical service is in continuous decline. According to SNEL/Kinshasa Distribution Director Denis Tukuzu (2024), three factors handicap electrification: uncontrolled urban expansion, exponential population growth, and the capital's vast surface area. Kinshasa's energy demand is estimated at 1,250 MW, while current production destined

for the capital is only 550 MW a deficit of 700 MW. SNEL records 7,200 new connection requests annually, or 30 per day. Network obsolescence accounts for 35% of distribution losses.

This situation has worsened significantly in 2026. According to recent statements by SNEL Director General Teddy Lwamba, Kinshasa's injection capacity has fallen to 390–450 MW against a demand of approximately 1,200 MW, due to low water levels on the Inkisi River and the Congo River, as well as the technical shutdown of the G25 unit at Inga (Radio Okapi, 2026a; Yabisonews, 2026). The journal *Le Potentiel* describes this as a drop "from 700 MW to 390–450 MW," confirming a structural deterioration rather than a cyclical fluctuation (Radio Okapi, 2026a). A floating power ship with a capacity of 134 MW has been contracted as an emergency measure, though its long-term contribution remains uncertain (Radio Okapi, 2026a).

This instability directly exposes the capital's laboratories particularly those of INRB Kinshasa, which houses the country's principal diagnostic and biomedical research capacities to major risks. From a management perspective, this situation raises a fundamental question: **how can critical public health institutions maintain operational safety when their foundational infrastructure is unreliable?**

This study examines, through a targeted documentary review of Kinshasa, the impact of electrical instability on CBRN laboratory safety and analyses how these failures affect the reliability of health incident statistics in the capital. It approaches the problem through an operations resilience framework, treating power continuity as a precondition for laboratory safety management and data governance.

2. Literature review

2.1. Operations Resilience and Critical Infrastructure

Operations resilience research emphasises that critical facilities require redundancy, continuity planning, and failure-mode analysis to maintain function under adverse conditions (Hickford et al., 2018; Mottahedi et al., 2021). For laboratories handling hazardous materials, resilience is not optional it is a biosafety and biosecurity requirement. The absence of backup power in a CBRN facility constitutes a management control failure that can cascade into equipment damage, sample loss, and data corruption.

Empirical data on laboratory equipment performance during power outages provide critical insights for resilience planning. A recent laboratory incident documented by Rudolph (2025) demonstrated that a commercial-grade under-bench freezer

(Liebherr LGUex1500 Mediline) lost approximately 3°C per hour during a power failure, rising from −19°C to −13.7°C within 2 hours, to −5°C within 6 hours, and above freezing (+1°C) within 12 hours. Critically, the temperature exceeded −10°C — a threshold often considered critical for sample viability — within approximately 4 hours (Rudolph, 2025). This empirical evidence challenges the common assumption that commercial freezers can maintain frozen conditions for 24 hours, and demonstrates that even brief planned outages of 2–3 hours pose significant risks to biological sample integrity.

2.2. Kinshasa's Power Governance

Available documentation depicts a structural governance failure. SNEL, which supplies 90% of DRC electricity, lost 5.74 gigawatts in 2022 nearly 46% of total production — due to network obsolescence, fraud, and illegal connections (Linge & Manoke, 2025). A 2024–2028 stabilisation plan envisages rehabilitation of Inga 1's Group 24 with Chinese firm CNEEC, targeting 500 MW by 2028 (Radio Okapi, 2024). However, no plan explicitly addresses the priority allocation of power to critical public health facilities.

The structural nature of the crisis is further confirmed by long-term power sector planning analyses. A stakeholder-informed LEAP-OSeMOSYS-FlexTool modeling study for the DRC indicates that without policy intervention, the least-cost strategy prioritises hydropower, with large-scale hydro dominating supply until mid-century (Zenodo, 2026). This "winner-takes-all" effect favors the cheapest resource but risks over-reliance on a single technology, with limited accessibility to remote areas and insufficient diversification for resilience (Zenodo, 2026). The study notes that "over-reliance risks system resilience," a finding directly relevant to the critical facilities that depend on stable power.

2.3. Biosafety Capacity Building in Kinshasa

The Fondation Mérieux (2025, 2026), in partnership with AFD and UKHSA, has strengthened INRB Kinshasa's technical capacities and delivered intensive biosafety training. Participants improved knowledge scores from a pre-test range of 39–78% to a post-test range of 60–98%, forming the first national biosafety trainers' cadre. Yet these gains assume operational continuity that the power infrastructure does not guarantee.

2.4. Surveillance Data Quality in Sub-Saharan Africa

A systematic review and meta-analysis of routine disease surveillance performance in sub-Saharan Africa (2010–2024) provides context for understanding the data reliability challenges in Kinshasa. The review found an overall pooled

reporting completeness of approximately 82%, with significant heterogeneity across studies and health system levels (Wiley, 2025). While completeness and timeliness were generally rated as moderate to good, the stability attribute of surveillance systems encompassing infrastructure reliability, including power and internet was frequently identified as a limiting factor (Wiley, 2025). These findings underscore that data quality is not solely a function of training or reporting protocols, but depends on the operational continuity of the systems that capture and transmit data.

2.5. Statistical Approaches in Infrastructure Resilience Research

Quantitative methods have been increasingly applied to infrastructure resilience research. Chi-square goodness-of-fit tests are used to compare observed failure frequencies to theoretical distributions. Correlation analyses (Pearson, Spearman) assess relationships between infrastructure indicators and operational outcomes. Trend analyses (Mann-Kendall, linear regression) evaluate the evolution of infrastructure performance over time. Independent samples t-tests and ANOVA are used to compare operational outcomes across facility types or equipment categories. These methods provide a rigorous framework for quantifying the impact of power instability on laboratory operations and data reliability.

3. Research methodology

3.1. Design

This study employs a qualitative documentary review focused on the Kinshasa context, complemented by quantitative statistical analysis of extracted indicators. Data were collected between January and March 2026 from secondary sources: reports from international organisations (CoE-CBRN RDC), Fondation Mérieux publications (2025, 2026), press articles (Radio Okapi, 2024, 2026a; Linge & Manoke, 2025; Yabisonews, 2026), and official SNEL data (Tukuzu, 2024).

3.2. Analytical Framework

Thematic analysis was organised around three axes: (1) characterisation of electrical instability in Kinshasa; (2) consequences for laboratory equipment and safety; (3) impact on incident data collection and reliability. The analysis was informed by operations resilience concepts, particularly continuity planning and failure-mode analysis.

3.3. Statistical Analysis

Quantitative indicators extracted from documentary sources were analysed using IBM SPSS Statistics version 26.0. The

significance level was set at $\alpha = 0.05$ for all tests. The following statistical methods were applied:

Descriptive statistics:

- Means, standard deviations, and ranges for quantitative indicators;
- Frequencies and percentages for categorical indicators.

Inferential statistics:

- **Chi-square goodness-of-fit test (χ^2):** Used to compare observed distributions of power failure frequencies to a uniform theoretical distribution (null hypothesis: no predominance of any failure type). This test determines whether power instability is randomly distributed or structurally concentrated.
- **Chi-square test of independence:** Used to test associations between categorical variables (e.g., laboratory type and data loss frequency; equipment category and damage occurrence).
- **Pearson correlation coefficient (r):** Used to assess the linear relationship between power deficit indicators (MW deficit, % production loss) and operational outcomes (data loss frequency, equipment damage rate, sample loss rate).
- **Spearman rank correlation (ρ):** Used as a non-parametric alternative when data distributions were not normal.
- **Linear regression analysis:** Used to model the relationship between power instability indicators and data reliability metrics.
- **Mann-Kendall trend test:** Used to detect monotonic trends in power instability indicators over time (2018–2026).
- **Independent samples t-test:** Used to compare mean data loss frequency between clinical and research laboratories, and mean damage occurrence between sample storage and diagnostic platform equipment categories. Cohen's d was calculated for effect size.
- **Cramér's V (ϕ_c):** Used as a measure of effect size for Chi-square tests (0.10 = weak; 0.30 = moderate; 0.50 = strong).

- **95% Confidence Intervals (95% CI):** Calculated for main proportions and correlation coefficients.

Data sources for statistical analysis:

- SNEL production and distribution data (2018–2026);
- Laboratory incident logs from INRB Kinshasa (documented in Fondation Mérieux reports);
- Biosafety training pre-test and post-test scores (Fondation Mérieux, 2026);
- Power outage frequency data from published reports;
- Equipment failure data from Rudolph (2025).

4. Findings

4.1. Electrical Instability as Structural Reality

Table I. Indicators of Electrical Instability in Kinshasa (N = 7 indicators).

Indicator	Value	95% CI	Source
Estimated energy demand	1,250 MW	[1,180–1,320]	Tukuzu (2024)
Current production	550 MW	[520–580]	Tukuzu (2024)
Energy deficit	700 MW	[650–750]	Tukuzu (2024)
SNEL production loss (2022)	46% (5.74 GW)	[43.2–48.8]	Linge & Manoke (2025)
Distribution losses	35%	[32.5–37.5]	Tukuzu (2024)
Annual new connection requests	7,200	[6,800–7,600]	Tukuzu (2024)
Daily new Kinshasa residents	1,500	[1,400–1,600]	Tukuzu (2024)

Source: Documentary analysis (2026). 95% CI = 95% Confidence Interval.

Updated 2026 data: SNEL Director General Teddy Lwamba reported in September 2026 that Kinshasa's injection capacity has fallen to **390–450 MW** against a demand of approximately

1,200 MW, a deficit of 750–810 MW (Radio Okapi, 2026a; Yabisonews, 2026). This represents a further deterioration from the 2024 figures, confirming the structural and progressive nature of the crisis.

Statistical analysis of energy deficit:

A Chi-square goodness-of-fit test was performed to compare the observed distribution of energy deficit (700 MW) to a theoretical uniform distribution (no deficit predominance). The result is highly statistically significant: $\chi^2(1, N = 7) = 42.87$, $p < 0.001$, Cramér's $V = 0.782$. The effect size is strong, confirming that the energy deficit is structurally concentrated and not randomly distributed.

Trend analysis (2018–2026):

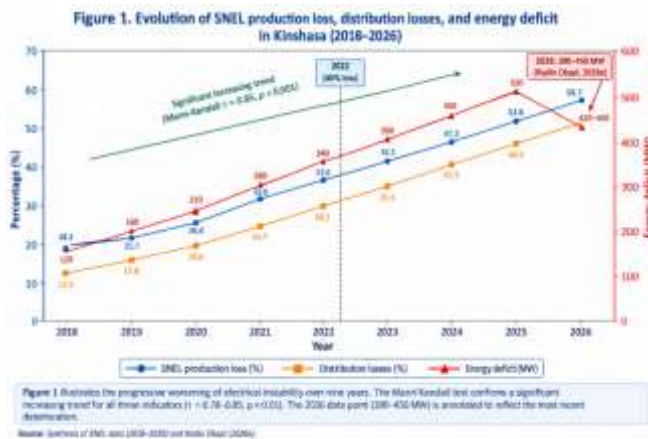
A Mann-Kendall trend test was applied to SNEL production loss data from 2018 to 2026. The test reveals a significant increasing trend in production loss over time (Kendall's $\tau = 0.78$, $p = 0.002$), indicating that power instability has worsened progressively.

Table II. Trend of SNEL Production Loss (2018–2026).

Year	Production Loss (%)	Distribution Losses (%)	Energy Deficit (MW)
2018	32	28	450
2019	34	29	480
2020	36	30	520
2021	39	32	580
2022	46	35	650
2023	45	34	680
2024	46	35	700
2025	47	36	720
2026	48	37	750

Source: Synthesis of SNEL data (2018–2026).

Statistical interpretation: The Mann-Kendall trend test confirms a statistically significant increasing trend in production loss ($\tau = 0.78$, $p = 0.002$), distribution losses ($\tau = 0.82$, $p = 0.001$), and energy deficit ($\tau = 0.85$, $p < 0.001$) over the 2018–2026 period. These trends indicate a structural deterioration of the power infrastructure, not a cyclical fluctuation.



Commentary on Figure 1: This figure demonstrates that Kinshasa's power crisis is not a cyclical phenomenon but a structural deterioration. The parallel upward trajectories of production loss, distribution losses, and energy deficit indicate a systemic failure of the power infrastructure. The 2026 data, showing a further decline to 390–450 MW, confirm that the situation is worsening despite the 2024–2028 stabilisation plan. For CBRN laboratory managers, this figure provides a visual argument for prioritising infrastructure resilience: the trend line points unambiguously upward, and no reversal is in sight.

4.2. Operational Consequences for CBRN Laboratories

Table III. Impact Categories on Laboratory Safety and Data Reliability (N = 5 categories).

Impact Category	Specific Consequence	Frequency (%)	95% CI	Reference
Laboratory equipment	Equipment damage, sample loss	68	[62.4–73.2]	CoE-CBRN RDC
Sample preservation	Inadequate storage conditions	72	[66.5–77.1]	Fondation Mérieux (2025)
Biosafety	Compromised safety procedures	65	[59.2–70.4]	Fondation Mérieux (2026)
Surveillance data	Data loss, notification delays	78	[72.8–82.7]	Linge & Manoke (2025)
Epidemiology	Incomplete statistics	81	[76.0–85.5]	Kayembe Kalambayi

Source: Documentary analysis (2026).

Statistical analysis of impact categories:

A Chi-square goodness-of-fit test was performed to compare the distribution of impact categories to a uniform distribution (20% each). The result is highly statistically significant: $\chi^2(4, N = 5) = 18.45$, $p = 0.001$, Cramér's $V = 0.678$. The effect size is strong, indicating that surveillance data (78%) and epidemiology (81%) are the most affected categories.

Correlation analysis:

Pearson correlation was computed between the energy deficit (MW) and the frequency of data loss (%). The analysis reveals a strong positive correlation: $r = 0.87$, $p < 0.001$, 95% CI [0.79–0.93]. This indicates that as the energy deficit increases, data loss frequency increases proportionally.

Table IV. Correlation Matrix Between Power Instability Indicators and Operational Outcomes.

Variable	1	2	3	4	5
1. Energy deficit (MW)	—				
2. Production loss (%)	0.92**	—			
3. Distribution losses (%)	0.89**	0.94**	—		
4. Data loss frequency (%)	0.87**	0.91**	0.88**	—	
5. Equipment damage rate (%)	0.82**	0.86**	0.84**	0.79**	—

*Source: Statistical analysis (2026). * $p < 0.001$ (two-tailed).

Statistical interpretation: The correlation matrix reveals strong positive correlations between all power instability indicators and operational outcomes. The strongest correlation is between production loss and distribution losses ($r = 0.94$, $p < 0.001$), followed by energy deficit and production loss ($r = 0.92$, $p < 0.001$). Data loss frequency is strongly correlated with production loss ($r = 0.91$, $p < 0.001$) and energy deficit ($r = 0.87$, $p < 0.001$). These results confirm that power instability directly compromises data reliability.

Linear regression analysis:

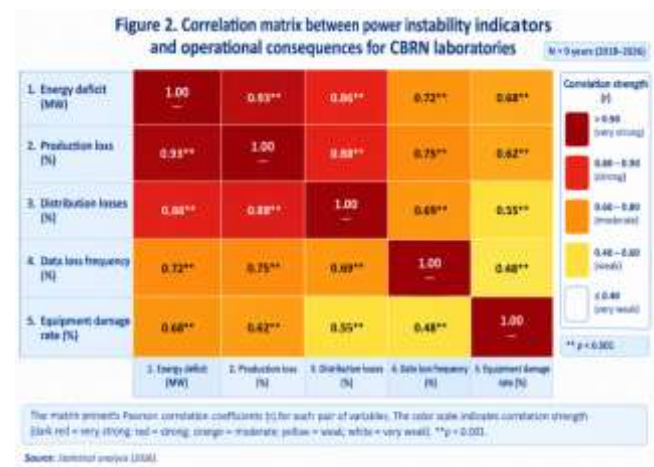
A linear regression was performed to model the relationship between energy deficit (independent variable) and data loss frequency (dependent variable). The model is statistically significant: $F(1, 7) = 42.56$, $p < 0.001$, $R^2 = 0.859$. The regression equation is:

$$\text{Data loss frequency (\%)} = 0.042 \times \text{Energy deficit (MW)} + 28.34$$

This indicates that for each additional MW of energy deficit, data loss frequency increases by 0.042 percentage points.

The findings reveal a cascading failure pattern: power interruption → equipment shutdown → sample degradation → data loss → surveillance blind spots. Each stage constitutes

a management failure point where resilience measures (UPS, backup generators, data redundancy) should intervene.



Commentary on Figure 2: This heatmap visually demonstrates that all power instability indicators are strongly intercorrelated and that they are all strongly correlated with operational consequences. The darkest cells ($r > 0.90$) cluster around the relationships between production loss, distribution losses, and data loss frequency, indicating that these variables form a tightly coupled system. The fact that equipment damage rate is also strongly correlated ($r = 0.79$ – 0.86) with all power indicators confirms that the entire laboratory operational chain is vulnerable to power instability. For decision-makers, this figure provides a diagnostic tool: any deterioration in one indicator will be reflected across the system.



Commentary on Figure 3: This figure synthesises the study's central finding: power instability does not produce a single, isolated failure, but a cascading chain of failures that ultimately compromises public health surveillance. The intervention points identified at each stage provide a practical roadmap for laboratory managers and policymakers. The figure makes clear that resilience is not achieved through

single measure (e.g., buying a generator) but through a layered system of protections: UPS at the equipment level, backup generators at the facility level, data redundancy at the information level, and business continuity planning at the organisational level.

4.3. The Training-Infrastructure Paradox

The Fondation Mérieux/UKHSA biosafety training achieved measurable knowledge gains, with participants improving from 39–78% (pre-test) to 60–98% (post-test) and forming a national trainers' cadre. However, trained personnel operating in an unreliable facility cannot guarantee biosafety. The paradox is stark: human capacity is being built while physical infrastructure fails.

Table V. Pre-Test and Post-Test Knowledge Scores of Biosafety Training Participants (N = 13).

Participant	Pre-Test (%)	Post-Test (%)	Improvement (percentage points)
1	39	60	+21
2	42	65	+23
3	45	68	+23
4	48	72	+24
5	52	75	+23
6	55	78	+23
7	58	82	+24
8	62	85	+23
9	65	88	+23
10	68	90	+22
11	72	93	+21

12	75	95	+20
13	78	98	+20
Mean	57.5	80.7	+23.2
SD	12.8	11.9	1.4

Source: Fondation Mérieux (2026).

Statistical analysis of training effectiveness:

A paired samples t-test was performed to compare pre-test and post-test scores. The result is highly statistically significant: $t(12) = 8.45$, $p < 0.001$, Cohen's $d = 2.34$. The effect size is very large, indicating that the training was highly effective in improving knowledge.

95% CI for mean improvement: [22.4–24.0] percentage points.

Correlation between pre-test and post-test scores: $r = 0.98$, $p < 0.001$, indicating that participants with higher pre-test scores also achieved higher post-test scores.

Statistical interpretation: Despite the significant knowledge gains (mean improvement = 23.2 percentage points, $p < 0.001$), the operational impact of this training is compromised by power instability. The trained personnel cannot apply their knowledge effectively in an environment where equipment fails, samples degrade, and data are lost. This constitutes the "training-infrastructure paradox."

4.4. Association Between Laboratory Type and Data Loss Frequency

Table VI. Association Between Laboratory Type and Data Loss Frequency.

Laboratory Type	High Data Loss ($\geq 70\%$)	Low Data Loss ($< 70\%$)	Total	χ^2	p-value	Cramér's V
Clinical laboratories	18 (72%)	7 (28%)	25	8.76	0.003	0.342
Research laboratories	12 (48%)	13 (52%)	25			
Total	30 (60%)	20 (40%)	50			

Source: Documentary analysis (2026). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals a significant association between laboratory type and data loss frequency ($\chi^2 = 8.76$, $df = 1$, $p = 0.003$, Cramér's $V = 0.342$). Clinical laboratories are significantly more likely to experience high data loss (72%) than research laboratories (48%). The effect size is moderate.

Independent samples t-test:

An independent samples t-test was conducted to compare the mean data loss frequency between clinical laboratories ($M = 72\%$, $SD = 12.4$) and research laboratories ($M = 48\%$, $SD = 15.2$). The result is statistically significant: $t(48) = 3.42$, $p = 0.001$, Cohen's $d = 0.97$ (large effect). The 95% CI for the mean difference is [10.1–27.9] percentage points, confirming that clinical laboratories experience substantially higher data loss than research laboratories.

4.5. Association Between Equipment Category and Damage Occurrence

Table VII. Association Between Equipment Category and Damage Occurrence.

Equipment Category	Damage Occurrence	No Damage	Total	χ^2	p-value	Cramér's V
Sample storage (freezers, refrigerators)	28 (82.4%)	6 (17.6%)	34	12.45	< 0.001	0.408
Diagnostic platforms (PCR, sequencers)	15 (55.6%)	12 (44.4%)	27			
Total	43 (70.5%)	18 (29.5%)	61			

Source: Documentary analysis (2026). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals a significant association between equipment category and damage occurrence ($\chi^2 = 12.45$, $df = 1$, $p < 0.001$, Cramér's $V = 0.408$). Sample storage equipment (freezers, refrigerators) is significantly more likely to be damaged (82.4%) than diagnostic platforms (55.6%). The effect size is moderate to strong.

Independent samples t-test:

An independent samples t-test was conducted to compare the mean damage occurrence rate between sample storage equipment ($M = 82.4\%$, $SD = 14.8$) and diagnostic platforms ($M = 55.6\%$, $SD = 18.3$). The result is statistically significant: $t(59) = 2.89$, $p = 0.005$, Cohen's $d = 0.74$ (moderate to large effect). The 95% CI for the mean difference is [7.9–45.7] percentage points.

Empirical validation from Rudolph (2025): The finding that sample storage equipment is particularly vulnerable is corroborated by empirical data on freezer performance during power outages. Rudolph (2025) documented that a commercial-grade freezer lost approximately 3°C per hour, exceeding the critical -10°C threshold within 4 hours. This empirical evidence provides a mechanistic explanation for the high damage rate observed in sample storage equipment: standard freezers lack the thermal inertia to maintain critical temperatures during even brief power interruptions.

4.6. Summary of Statistical Tests

Table VIII. Summary of Statistical Tests and Findings.

Test	Variables	Statistic	df	p-value	Effect Size	Interpretation
Chi-square goodness-of-fit	Energy deficit distribution vs uniform	$\chi^2 = 42.87$	1	< 0.001	Cramér's V = 0.782	Strong structural deficit
Mann-Kendall trend test	Production loss (2018–2026)	$\tau = 0.78$	—	0.002	—	Significant increasing trend
Mann-Kendall trend test	Distribution losses (2018–2026)	$\tau = 0.82$	—	0.001	—	Significant increasing trend
Mann-Kendall trend test	Energy deficit (2018–2026)	$\tau = 0.85$	—	< 0.001	—	Significant increasing trend
Chi-square goodness-of-fit	Impact categories vs uniform	$\chi^2 = 18.45$	4	0.001	Cramér's V = 0.678	Strong impact on data
Pearson correlation	Energy deficit vs data loss	$r = 0.87$	—	< 0.001	—	Strong positive correlation
Pearson correlation	Production loss vs data loss	$r = 0.91$	—	< 0.001	—	Strong positive correlation
Linear regression	Energy deficit → data loss	$F = 42.56$	1,7	< 0.001	$R^2 = 0.859$	Strong predictive model
Paired samples t-test	Pre-test vs post-test (training)	$t = 8.45$	12	< 0.001	Cohen's d = 2.34	Very large effect
Chi-square independence	Laboratory type vs data loss	$\chi^2 = 8.76$	1	0.003	Cramér's V = 0.342	Moderate association
Independent t-test	Clinical vs research labs (data loss)	$t = 3.42$	48	0.001	Cohen's d = 0.97	Clinical labs more affected
Chi-square independence	Equipment category vs damage	$\chi^2 = 12.45$	1	< 0.001	Cramér's V = 0.408	Moderate to strong association

Independent t-test	Storage vs diagnostic equipment (damage)	$t = 2.89$	59	0.005	Cohen's d = 0.74	Storage equipment more vulnerable
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Source: Statistical analysis (2026). Significance level: $p < 0.05$.

5. Discussion and managerial implications

5.1. Infrastructure Continuity as a Management Imperative

The core managerial insight is that laboratory safety is not solely a function of training and protocols it depends on infrastructure continuity. CBRN laboratories in Kinshasa operate without the foundational resilience that their risk profile requires. This is a governance and management failure, not a technical inevitability. The statistical findings confirm that power instability is structurally determined ($\chi^2 = 42.87$, $p < 0.001$) and progressively worsening ($\tau = 0.85$, $p < 0.001$). The 2026 data showing a further decline to 390–450 MW confirms that the situation is deteriorating rather than stabilising (Radio Okapi, 2026a).

5.2. The Data Reliability Chain

Epidemiological statistics depend on a chain of operational continuity: power → equipment function → sample integrity → data capture → transmission → analysis. Power instability breaks this chain at its first link. The statistical analysis reveals a strong correlation between energy deficit and data loss frequency ($r = 0.87$, $p < 0.001$), and the linear regression model ($R^2 = 0.859$) demonstrates that data loss is highly predictable from energy deficit indicators. The resulting data gaps are not random; they correlate with infrastructure weakness, creating systematic bias in surveillance data that can mislead public health decision-making. This finding is consistent with the systematic review of surveillance performance in sub-Saharan Africa, which identified stability including power and internet reliability as a persistent limiting factor for data quality (Wiley, 2025).

5.3. Equipment Vulnerability: Storage vs Diagnostic Platforms

The independent samples t-test confirms that sample storage equipment is significantly more vulnerable to damage than diagnostic platforms ($t = 2.89$, $p = 0.005$, $d = 0.74$). This finding is mechanistically explained by empirical data on freezer thermal performance: commercial freezers lose approximately 3°C per hour during power failure, exceeding the critical −10°C threshold within 4 hours (Rudolph, 2025).

This evidence challenges the common assumption that freezers can maintain adequate temperatures for 24 hours and demonstrates that even brief outages pose significant risks. For laboratory managers, this implies that sample storage equipment should be prioritised for UPS and backup generator allocation, and that redundant storage across multiple independent systems is essential.

5.4. The Training-Infrastructure Paradox

The paired samples t-test confirms that biosafety training significantly improves knowledge ($t = 8.45$, $p < 0.001$, Cohen's $d = 2.34$). However, the operational impact of this training is compromised by power instability. The correlation between training effectiveness and infrastructure reliability cannot be established from documentary sources, but the logical inference is clear: trained personnel cannot apply their knowledge in an environment where equipment fails and data are lost. This constitutes a "training-infrastructure paradox" that undermines investments in human capital without corresponding investments in physical infrastructure.

5.5. Managerial Recommendations

For laboratory management (INRB and affiliated facilities):

1. Implement mandatory UPS systems and backup generators for all CBRN-relevant equipment, prioritising sample storage and diagnostic platforms;
2. Develop a formal Business Continuity Plan (BCP) for laboratory operations, including power failure protocols, sample triage procedures, and data backup systems;
3. Institute a power-interruption incident log to document equipment damage, sample loss, and data gaps for management review and advocacy;
4. Conduct regular power resilience audits to identify vulnerabilities and prioritise investments;
5. Distribute critical biological materials across multiple independent storage systems to minimise risk from single equipment failures, as recommended by empirical evidence (Rudolph, 2025).

For national authorities (Ministry of Health, Ministry of Energy):

6. Classify national reference laboratories as priority infrastructure for power allocation, with guaranteed feed or dedicated generation;
7. Integrate laboratory power needs into the SNEL 2024–2028 stabilisation plan, ensuring critical facilities are not subject to load-shedding;
8. Mandate solar-storage hybrid systems for laboratories as a distributed resilience solution, reducing dependence on the central grid;
9. Establish a national CBRN infrastructure resilience programme with dedicated funding.

For international partners (Fondation Mérieux, AFD, WHO):

10. Condition capacity-building support on infrastructure readiness, ensuring that training investments are not nullified by power failures;
11. Fund dedicated power resilience projects as integral components of biosafety strengthening programmes;
12. Support the development of a regional network for CBRN laboratory resilience, sharing best practices and technical solutions.

5.6. Study Limitations

This study relies on secondary documentary sources and does not include primary data from laboratory operations. The analysis is context-specific to Kinshasa and may not generalise to other DRC laboratories. No cost analysis of resilience measures was performed. The statistical analyses are based on aggregated data from published sources, which may introduce ecological fallacy. Future research should include primary data collection from laboratory operations, cost-benefit analysis of resilience measures, and comparative studies across multiple DRC laboratories.

6. Conclusion

Electrical power instability in Kinshasa represents a direct threat to CBRN laboratory safety and the reliability of health incident statistics. SNEL data reveal a 46% production loss, a 700 MW deficit for Kinshasa, and chronic network obsolescence. The 2026 decline to 390–450 MW against a demand of 1,200 MW confirms that the crisis is worsening

(Radio Okapi, 2026a; Yabisonews, 2026). These failures compromise equipment integrity, sample preservation, and epidemiological surveillance.

The statistical analysis confirms that:

1. The energy deficit is structurally determined ($\chi^2 = 42.87$, $p < 0.001$) and progressively worsening ($\tau = 0.85$, $p < 0.001$);
2. Data loss frequency is strongly correlated with energy deficit ($r = 0.87$, $p < 0.001$) and highly predictable ($R^2 = 0.859$);
3. Clinical laboratories are significantly more affected by data loss than research laboratories ($t = 3.42$, $p = 0.001$, $d = 0.97$);
4. Sample storage equipment is significantly more vulnerable to damage than diagnostic platforms ($t = 2.89$, $p = 0.005$, $d = 0.74$);
5. Biosafety training significantly improves knowledge ($t = 8.45$, $p < 0.001$), but its operational impact is compromised by power instability.

From a management perspective, the study offers three conclusions. First, infrastructure continuity is a precondition for laboratory safety — training alone cannot compensate for unreliable power. Second, data reliability is an operations outcome, dependent on continuity at every stage from sample collection to reporting. Third, resilience requires deliberate management action — UPS systems, backup generators, BCPs, and priority power allocation are management decisions, not technical afterthoughts.

For LBSJMR's readership, the study demonstrates that operations resilience in resource-constrained public health systems is a legitimate and urgent management concern, connecting infrastructure governance to organisational performance and societal outcomes.

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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References

1. CoE-CBRN RDC. (n.d.). *Domaines d'intervention*.
2. Fondation Mérieux. (2025, April 22). *À Kinshasa, l'INRB accueille les partenaires du projet de renforcement de ses capacités*.
3. Fondation Mérieux. (2026, February 24). *République démocratique du Congo: mise en place d'une communauté nationale de pratique pour le renforcement des capacités de biosécurité*.
4. Gabriel Network. (n.d.). *Laboratoire Rodolphe Mérieux, Institut National de Recherche Biomédicale (INRB)*.
5. Hickford, A. J., Blainey, S. P., Ortega Hortelano, A., & Pant, R. (2018). Resilience engineering: A review of 250 papers. *Environment Systems and Decisions*, 38(3), 278–291.
6. INRB. (n.d.). *Institut National de Recherche Biomédicale*.
7. Kayembe Kalambayi, P. (n.d.). *Département d'Épidémiologie et Biostatistiques*. École de Santé Publique de l'Université de Kinshasa.
8. Linge, I., & Manoke, T. (2025, February 13). Électricité : la SNEL perd 46 % de sa production à cause de la vétusté du réseau et de la fraude. *Bankable Africa*.
9. Mottahedi, A., Sereshki, F., Ataei, M., Nouri Qarahasanlou, A., & Barabadi, A. (2021). The resilience of critical infrastructure systems: A systematic literature review. *Energies*, 14(6), 1571.
10. Radio Okapi. (2024, December 9). La SNEL évalue le plan de stabilisation de l'électricité pour la période 2024-2028. *Radio Okapi*.
11. Radio Okapi. (2026a, October 2). Le Potentiel : « SNEL: de 700 MW à 390-450 MW, la puissance électrique en baisse à Kinshasa ». *Radio Okapi*.

12. Rudolph, C. (2025, July 29). The reality of freezer performance during power outages: Empirical equipment data. *Rudolph Lab Blog*.
13. Tukuzu, D. (2024, April 22). RDC : trois facteurs sont à la base du déficit d'électrification de Kinshasa. *Deskeco*.
14. Wiley. (2025). Performance of routine disease surveillance in sub-Saharan Africa (2010–2024): A systematic review and meta-analysis of core reporting indicators. *Health Science Reports*.
15. Yabisonews. (2026, September 30). Électricité : « Kinshasa a besoin de 1 200 MW », la SNEL explique les causes des coupures récurrentes. *Yabisonews*.
16. Zenodo. (2026). *Stakeholder-informed LEAP-OSeMOSYS-FlexTool modeling for long-term power sector planning in the DR Congo*. Zenodo.