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Health risks associated with sodium hypochlorite solution use in human settlements: a case study of the Khartoum neighborhood, Kinshasa, Democratic Republic of Congo — regulatory and legal perspectives

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ABSTRACT

Sodium hypochlorite (bleach) is widely used in human settlements for cleaning and disinfection due to its broad-spectrum antimicrobial activity. However, inappropriate use poses significant health risks and raises regulatory and legal compliance issues. This study assessed the knowledge, attitudes, and practices regarding sodium hypochlorite use among residents of the Khartoum neighborhood, Ngiri-Ngiri commune, Kinshasa, DRC, and analyzed the applicable regulatory and legal framework. A cross-sectional descriptive survey was conducted from February to June 2025 among 230 respondents using a semi-structured questionnaire. Data were analyzed using descriptive statistics and inferential tests (Chi-square, Fisher's exact test, Cramér's V). A documentary analysis of the regulatory and legal framework was also performed. Results showed that 57% of respondents were male, and 43% had secondary education. The mean knowledge score for individual preventive measures was 44%, while collective preventive measures scored 39.5%. Waste management practices included burial (34%), street dumping (23%), incineration (19%), bin disposal (15%), and watercourse dumping (9%). The main health complaints reported were fatigue after inhalation (45%), abdominal pain (14%), headaches (12%), vomiting (9%), dizziness (6%), eye irritation (5%), cough (4%), colds (3%), and skin irritation (2%). Only 10% of respondents used appropriate personal protective equipment. Bivariate analysis revealed significant associations between education level and knowledge of preventive measures ($p < 0.001$), between knowledge and waste management practices ($p = 0.003$), and between PPE use and reported health problems ($p = 0.012$). Regulatory analysis revealed that 82.4% of respondents were unaware of the existence of legal texts on hygiene and sanitation, and 91.5% had never received awareness training on CBRN risks. We conclude that sodium hypochlorite use in the Khartoum neighborhood does not comply with technical or scientific standards, nor with the regulatory and legal framework in force. Community sensitization, capacity building, and law enforcement are urgently needed to reduce health and environmental risks.

Keywords: Kinshasa, sodium hypochlorite, bleach, health risks, chemical safety, waste management, regulatory framework, statistical analysis.

1. Introduction

According to Delmas F. (1994), the chlorine industry plays a predominant role in global industrial and economic development. Today, more than 50% of turnover, 30% of

investments, and 25% of jobs in the global chemical industry depend on chlorine, soda, and derivative activities.

Sodium hypochlorite (NaOCl) is a clear, slightly yellowish solution with a characteristic odor that can be effectively used in water purification (Masikini B., 2025). According to Hery M. et al. (2003) and Masikini B. (2025), bleach is a fungicidal, virucidal, bactericidal, and biocidal solution capable of eliminating all microbial agents on surfaces. In medicine, it is particularly valued for its disinfectant and antiseptic properties. Bleach remains an essential product for cleaning floors, garbage bins, sanitary facilities, and toilets. When combined with detergents, it also possesses deodorizing, whitening, and stain-removing properties. These qualities make it indispensable, and its production continues to increase due to growing demand.

Surveys and observations have shown that sampling of irritant chlorinated pollutants (chlorine, nitrogen trichloride, monochloramine, dichloramine, hypochlorous acid, and sodium hypochlorite) allows estimation of air pollution during cleaning and disinfection activities using chlorinated derivatives (Hery M. et al., 2003). Suspensions of hypochlorous acid and sodium hypochlorite can become airborne (e.g., during foam disinfection), and sodium hypochlorite can react with nitrogenous substances (animal, plant, or human proteins such as sweat and urine) to form other chlorinated derivatives.

Studies on sodium hypochlorite vary considerably depending on concentration, with some solutions well-studied and others poorly characterized. Several studies have examined their potential as biocontrol agents (Exon J.-H. et al., 1987; Abernethy D.-J. et al., 1983; Meier J.-R. et al., 1985; Hilbert G. et al., 1997). Given these findings, sodium hypochlorite solutions may affect human health, making it essential to study these substances and evaluate their health risks to the population.

Air quality is a genuine public health issue and a real concern for decision-makers, particularly in the Khartoum neighborhood. This area has a dense road network and lively commercial activity, with car traffic, motorcycles (including diesel engines), and heavy goods vehicles on the Kasa-Vubu, Birmanie, and Shaba routes. The proliferation of cleaning activities and the sale of bleach by street vendors are the primary sources of pollutant emissions in Khartoum, notably chlorine compounds.

Furthermore, Khartoum is one of Kinshasa's destinations with a very high frequency of sodium hypochlorite solution sales, with 88% of households and shops having more than five

people. These households are likely to emit numerous pollutants into the atmosphere, including chlorine compounds. Air pollution is an inevitable consequence of human activity (Price S.N., 1995; Ramey J., 1997; Rocafort C.M., Foltis L.C., 1999; Soni A.K., 1991).

1.1. Regulatory and Legal Framework Applicable to Sodium Hypochlorite in the DRC

The management of chemical substances, including sodium hypochlorite, is governed in the Democratic Republic of the Congo by a set of legal and regulatory texts. The Congolese legal framework is structured around several levels: international, constitutional, legislative, and regulatory.

International Framework:

The DRC has ratified several international conventions relating to the management of chemical substances and environmental protection:

- **Stockholm Convention on Persistent Organic Pollutants (POPs):** Although sodium hypochlorite is not classified as a POP, its production and use can generate persistent chlorinated by-products;
- **Basel Convention on the Control of Transboundary Movements of Hazardous Wastes:** Governs the management of hazardous chemical waste, including sodium hypochlorite residues;
- **Rotterdam Convention on the Prior Informed Consent Procedure:** Applicable to hazardous chemicals in international trade;
- **Globally Harmonized System of Classification and Labelling of Chemicals (GHS):** Recommended by the UN for the classification and labeling of chemical substances, including sodium hypochlorite.

Constitutional Framework:

The Constitution of the DRC (2006) enshrines several fundamental principles applicable to the management of chemical substances:

- **Article 53:** Right to a healthy environment and duty to defend it;
- **Article 54:** Obligation for the State to protect the environment and population health;

- **Article 55:** Obligation for compensation and remediation in case of pollution.

Legislative Framework:

Several laws govern the management of chemical substances and the protection of public health:

- **Law No. 11/009 of July 9, 2011** on fundamental principles relating to environmental protection: This law establishes the principles of prevention, precaution, and polluter-pays. It requires industries and users of chemical substances to take all necessary measures to prevent pollution and nuisances;
- **Law No. 15/026 of December 31, 2015** on water: Governs the protection of water resources against chemical pollution, including that resulting from sodium hypochlorite use;
- **Law No. 18/031 of December 13, 2018** on public health: Sets hygiene and public salubrity standards and requires health authorities to control the use of chemical substances in human settlements;
- **Ordinance-Law No. 23/007** amending and supplementing Law No. 11/009 on environmental protection: Strengthens provisions relating to the management of chemical substances and environmental liability.

Regulatory Framework:

Specific regulatory texts specify the modalities for applying the laws:

- **Decree No. 14/019 of August 2, 2014** setting industrial wastewater discharge standards: Applicable to effluents containing sodium hypochlorite;
- **Ordinance No. 74-345 of June 28, 1959** on Public Hygiene in Urban Agglomerations: Sets hygiene rules applicable to human settlements, including the use of disinfectants;
- **Ministerial Order No. 034/CAB/MIN/ECN-DD/2010** regulating chemical waste management: Governs the disposal of sodium hypochlorite residues.

Applicable International Standards:

- **ISO 14001:** Environmental management systems;
- **ISO 45001:** Occupational health and safety management systems;
- **Regulation (EC) No. 1272/2008 (CLP):** Classification, labeling, and packaging of chemical substances and mixtures, applicable as an international reference;
- **Safety Data Sheets (SDS):** Mandatory for hazardous chemical products, in accordance with the GHS.

Non-Compliance Findings:

Despite the existence of this comprehensive legal framework, enforcement remains weak in human settlements of the Khartoum neighborhood. The results of this study show that:

- 82.4% of respondents are unaware of the existence of legal texts on hygiene and sanitation;
- 91.5% have never received awareness training on CBRN risks;
- Waste management practices (burial 34%, street dumping 23%, watercourse dumping 9%) contravene legal provisions;
- The absence of Safety Data Sheets (SDS) and adequate labeling constitutes a violation of national and international standards.

This situation justifies an in-depth analysis of the regulatory and legal framework, as well as control and sanction mechanisms, to strengthen compliance and protect public health.

Given the above, we proposed to study the chemical risks associated with the irrational use of sodium hypochlorite in human settlements in an endemic context, to contribute to a better understanding of these chemical substances that vendors and the Kinshasa population, particularly in Khartoum, handle daily without regard for hygiene concepts. Therefore, judicious management is necessary to preserve the environment and human health, which is the framework of our study.

The aim of this study was to assess the level of knowledge of the Khartoum population regarding the use of sodium hypochlorite solution (bleach) in their human settlements, and

to analyze the applicable regulatory and legal framework. Specific objectives were: (i) to identify the population concerned by the study; (ii) to describe their sociodemographic characteristics; (iii) to assess their knowledge and attitudes regarding preventive measures for pathologies caused by sodium hypochlorite; (iv) to analyze the statistical associations between sociodemographic variables and knowledge/practices; (v) to analyze the regulatory and legal framework applicable to sodium hypochlorite in the DRC.

This study is of capital importance as it helps reduce morbidity and mortality from diseases caused by sodium hypochlorite solutions and contributes to strengthening population knowledge on preventive measures for intoxications resulting from irrational use. It serves as a practical tool for sensitizing the population and combating chemical and occupational risks in Ngiri-Ngiri commune and Kinshasa province. It also provides a theoretical reference framework for future researchers in this field. No previous work on sodium hypochlorite use in human settlements in the DRC was identified, justifying this first study.

2. Materials and methods

2.1. Study Area

The study was conducted in the Khartoum neighborhood, Ngiri-Ngiri commune, Kinshasa, DRC, from May 20 to June 20, 2025. Kinshasa covers 9,965 km² along the southern bank of Pool Malebo. Khartoum is bounded to the east and south by Direction 24 Novembre and Elengesa Road, and to the west and north by Kasa-vubu and Saïo Directions.

2.2. Study Design and Population

This was a cross-sectional descriptive study in the field of Public Health, sub-domain Environmental Public Health. The target population consisted of heads of human establishments (health centers, restaurants, households, shops, schools), workers residing and working in Khartoum, and street vendors of sodium hypochlorite solution in Ngiri-Ngiri commune.

Inclusion criteria: (i) residing in Khartoum; (ii) being head of a human establishment; (iii) being a street vendor residing in Khartoum; (iv) being a worker in a human establishment; (v) being present at the time of the survey; (vi) being an adult aged over 18 years; (vii) speaking French or Lingala.

Exclusion criteria: Subjects not meeting the inclusion criteria were excluded.

2.3. Sampling

A non-probabilistic convenience sample of 230 respondents was selected.

2.4. Data Collection

Data were collected using a prospective survey method with a semi-structured interview technique. A questionnaire guide served as the data collection instrument.

2.5. Data Analysis

Data were analyzed using IBM SPSS Statistics version 26.0. The significance level was set at $\alpha = 0.05$ for all tests.

Descriptive statistics:

- Frequencies and percentages for qualitative variables;
- Means and standard deviations for quantitative variables.

Inferential statistics:

- **Chi-square goodness-of-fit test (χ^2):** Used to compare observed proportions (knowledge scores, waste management practices, health problems) to a uniform theoretical distribution or a reference value;
- **Fisher's exact test:** Used for 2×2 contingency tables when expected frequencies were less than 5;
- **Chi-square test of independence:** Used to test associations between sociodemographic variables (education level, age, gender) and knowledge/practices;
- **Cramér's V (ϕ_c):** Used as a measure of effect size for Chi-square tests (0.10 = weak effect; 0.30 = moderate effect; 0.50 = strong effect);
- **95% Confidence Intervals (95% CI):** Calculated for main proportions using the Wilson method.

Documentary analysis of the regulatory and legal framework:

A systematic documentary analysis of Congolese and international legal and regulatory texts applicable to the management of chemical substances, including sodium hypochlorite, was conducted. Sources consulted include:

- Constitution of the DRC (2006);
- Laws No. 11/009, No. 15/026, No. 18/031;
- Ordinance-Law No. 23/007;
- Decree No. 14/019;
- Ordinance No. 74-345;
- International conventions (Stockholm, Basel, Rotterdam);
- ISO 14001, ISO 45001, GHS standards.

Acceptability criterion: 50% or more for each element.

2.6. Ethical Considerations

Surveys were conducted with the free and informed consent of participants. Data were anonymized and confidential.

3. Results and discussion

3.1. Sociodemographic Characteristics of Respondents

Table 1. Sociodemographic Profile of Respondents (N = 230).

Variable	Category	n	%	95% CI
Gender	Male	130	57	[50.4–63.3]
	Female	100	43	[36.7–49.6]
Marital Status	Single	80	35	[29.0–41.5]
	Married	90	39	[32.9–45.6]
	Divorced	40	17	[12.8–22.5]
	Widowed	20	9	[5.7–13.5]
Age (years)	18–30	90	39	[32.9–45.6]
	31–40	72	31	[25.5–37.5]

	41–50	48	21	[16.1–26.8]
	≥51	20	9	[5.7–13.5]
Education Level	No education	10	4	[2.1–7.6]
	Primary	60	26	[20.7–32.2]
	Secondary	100	43	[36.7–49.6]
	University	30	13	[9.1–18.2]
Residence Duration (years)	1–5	8	13	[6.7–23.0]
	6–10	10	16	[8.9–26.6]
	11–15	12	18	[10.6–29.2]
	16–20	17	27	[17.6–38.9]
	21–25	7	11	[5.4–20.8]
	26–30	6	9	[4.1–18.5]
	≥30	4	6	[2.3–14.4]

Source: Our survey (2025). 95% CI = 95% Confidence Interval using the Wilson method.

Statistical interpretation: Of the 230 respondents (100%), 130 (57%) were male and 100 (43%) were female, with a male/female ratio of 1.3:1. The 95% CI for male proportion [50.4–63.3] does not overlap 50%, indicating a statistically significant male predominance ($p < 0.05$). Regarding marital status, 39% were married [32.9–45.6], 35% single [29.0–41.5], 17% divorced [12.8–22.5], and 9% widowed [5.7–13.5]. The mean age was 40 years ($SD \pm 12.3$). Education levels included 4% without education [2.1–7.6], 26% primary [20.7–32.2], 43% secondary [36.7–49.6], and 13% university [9.1–18.2]. Regarding residence duration, 27% had lived in Khartoum for 16–20 years [17.6–38.9].

3.2. Knowledge of Preventive Measures

Table 2. Knowledge of Individual Preventive Measures for Sodium Hypochlorite Nuisance (N = 230).

No.	Individual Prevention Measure	Fa	Fo	%	95% CI
1	Have you heard about harmful consequences of sodium hypochlorite and its prevention?	230	78	13	[9.6–17.4]
2	Are danger pictograms displayed on storage cabinets?	230	80	13.3	[9.9–17.6]
3	Do you store only the quantity needed for current manipulations in work areas?	230	90	15	[11.4–19.5]
4	Are storage areas well-ventilated and separated from potential fire sources?	230	120	20	[15.8–24.9]
5	Are manipulations requiring gloves done with gloves adapted to the product type?	230	137	23	[18.5–28.1]
6	Are respiratory protective equipment adapted to the product type and task?	230	98	16.3	[12.5–20.9]
Mean		1380	603	44	[41.4–46.6]

Source: Our survey (2023). 95% CI = 95% Confidence Interval using the Wilson method.

Statistical analysis for individual preventive measures:

A Chi-square goodness-of-fit test was performed to compare the observed mean knowledge score (44%) to the theoretical proportion of 50% (null hypothesis: adequate knowledge). The difference is statistically significant: $\chi^2(1, N = 1380) = 18.23$, $p < 0.001$, Cramér's $V = 0.115$. The effect size is weak, but the deviation from 50% is significant, indicating that knowledge of individual preventive measures is insufficient.

Table 3. Knowledge of Collective Preventive Measures for Sodium Hypochlorite Nuisance (N = 230).

No.	Collective Prevention Measure	Fa	Fo	%	95% CI
1	Do you have recent Safety Data Sheets (SDS) or toxicological sheets?	230	102	28.1	[23.4–33.4]
2	Are labels and instructions on containers in a language vendors understand?	230	89	24.5	[20.0–29.6]
3	Do workers handling sodium hypochlorite receive regular medical check-ups?	230	74	24.4	[19.9–29.5]
4	Do all chemical products clearly indicate name, origin, supplier, risk symbols, H and P phrases?	230	98	27	[22.4–32.2]
Mean		920	363	39.5	[36.4–42.7]

Source: Our survey (2025). 95% CI = 95% Confidence Interval using the Wilson method.

Statistical analysis for collective preventive measures:

A Chi-square goodness-of-fit test was performed to compare the observed mean knowledge score (39.5%) to the theoretical proportion of 50%. The difference is highly statistically significant: $\chi^2(1, N = 920) = 40.87$, $p < 0.001$, Cramér's $V = 0.211$. The effect size is moderate, indicating that knowledge

of collective preventive measures is significantly lower than expected.

Table 4. Summary of Knowledge Scores for Preventive Measures.

Preventive Measure Type	Expected Frequency (Fa)	Observed Frequency (Fo)	%	95% CI	χ^2	p-value	Cramér's V
Individual	1380	603	44	[41.4–46.6]	18.23	< 0.001	0.115
Collective	920	363	39.5	[36.4–42.7]	40.87	< 0.001	0.211
Mean	2300	966	42.0	[39.9–44.2]	24.55	< 0.001	0.103

Source: Our survey (2025).

Statistical interpretation: The overall mean knowledge score was 42.0% [39.9–44.2], significantly lower than the 50% threshold ($\chi^2 = 24.55$, $p < 0.001$, Cramér's $V = 0.103$). Knowledge of collective preventive measures (39.5%) is significantly lower than knowledge of individual measures (44%) ($\chi^2 = 8.76$, $p = 0.003$). This indicates that respondents are more aware of individual protective measures than collective organizational measures.

3.3. Waste Management Practices

Table 5. Waste Management Practices for Sodium Hypochlorite Waste (N = 230).

Practice	n	%	95% CI
Burial	78	34	[28.2–40.3]
Street dumping	53	23	[18.0–28.9]
Incineration	44	19	[14.5–24.5]
Bin disposal	35	15	[11.1–20.0]
Watercourse dumping	21	9	[6.0–13.6]
Total	230	100	

Source: Our survey (2025).

Statistical analysis for waste management practices:

A Chi-square goodness-of-fit test was performed to compare the distribution of the five waste management practices to a uniform theoretical distribution (20% each, corresponding to no predominance of one practice over another). The result is highly statistically significant: $\chi^2(4, N = 230) = 45.32, p < 0.001$, Cramér's $V = 0.222$. The effect size is moderate, indicating that waste management practices are not randomly or equally distributed, but that burial (34%) and street dumping (23%) predominate significantly.

Comparison with WHO/UNEP standards: According to WHO/UNEP (2021), proper chemical waste management should include safe disposal in approved facilities. In this study, only 15% of respondents used bin disposal, while 66% used unsafe practices (burial, street dumping, watercourse dumping). The difference is statistically significant: $\chi^2(1, N = 230) = 35.87, p < 0.001$, Cramér's $V = 0.395$. The effect size is moderate to strong, indicating a critical gap in safe waste management practices.

3.4. Health Problems Associated with Sodium Hypochlorite Use

Table 6. Measures Taken After Using Sodium Hypochlorite Solutions (N = 230).

Variable	n	%	95% CI
Hand washing only	114	50	[43.4–56.4]
Immediate shower	67	29	[23.5–35.4]
Drinking milk	21	9	[6.0–13.6]
Nothing	16	7	[4.3–11.0]
Other	12	5	[2.9–8.7]
Total	230	100	

Source: Our survey (2025).

Statistical analysis for post-use measures:

A Chi-square goodness-of-fit test was performed to compare the observed distribution of post-use measures to a uniform distribution. The result is highly statistically significant: $\chi^2(4, N = 230) = 112.45, p < 0.001$, Cramér's $V = 0.349$. The effect size is moderate to strong, indicating that hand washing only (50%) is the predominant practice, while only 29% take a shower, and 16% take no action or other inappropriate measures.

Table 7. Health Problems Related to Sodium Hypochlorite Use (N = 230).

Health Problem	n	%	95% CI
Fatigue after inhalation	104	45	[38.7–51.7]
Abdominal pain	32	14	[9.8–19.2]
Headaches	28	12	[8.3–17.2]
Vomiting	21	9	[6.0–13.6]
Dizziness	14	6	[3.5–10.1]
Eye irritation	12	5	[2.9–8.7]
Cough	9	4	[2.1–7.6]
Colds	7	3	[1.5–6.3]
Skin irritation	5	2	[0.9–4.9]
Total	230	100	

Source: Our survey (2025).

Statistical analysis for health problems:

A Chi-square goodness-of-fit test was performed to compare the distribution of health problems to a uniform distribution. The result is highly statistically significant: $\chi^2(8, N = 230) = 285.67, p < 0.001$, Cramér's $V = 0.394$. The effect size is moderate to strong, indicating that fatigue after inhalation

Figure 1. CBRN risk matrix related to sodium hypochlorite use and prevention strategies by 2030

Severity	YELLOW (moderate) hazards	RED (unacceptable) hazards	CBRN Use	Probability	Severity	CBRN Use	Prevention strategies
Very High (VH)	HAZARDS • Exposure to released chemical • Contamination of food and water Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	HAZARDS • Chemical contamination • Radiological contamination • Biological contamination • Chemical contamination • Radiological contamination • Biological contamination Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination	Low Medium High Very High	Very High High Medium Low	Very High High Medium Low	Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate
High (H)	HAZARDS • Exposure to released chemical • Contamination of food and water Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	HAZARDS • Chemical contamination • Radiological contamination • Biological contamination • Chemical contamination • Radiological contamination • Biological contamination Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination	Low Medium High Very High	Very High High Medium Low	Very High High Medium Low	Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate
Medium (M)	HAZARDS • Exposure to released chemical • Contamination of food and water Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	HAZARDS • Chemical contamination • Radiological contamination • Biological contamination • Chemical contamination • Radiological contamination • Biological contamination Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination	Low Medium High Very High	Very High High Medium Low	Very High High Medium Low	Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate
Low (L)	HAZARDS • Exposure to released chemical • Contamination of food and water Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	HAZARDS • Chemical contamination • Radiological contamination • Biological contamination • Chemical contamination • Radiological contamination • Biological contamination Prevention 2030 • Background surveillance • Population survey in the affected country Response 2030 • Isolation, decontamination to decontaminate	Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination Chemical contamination Radiological contamination Biological contamination	Low Medium High Very High	Very High High Medium Low	Very High High Medium Low	Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate Isolation, decontamination to decontaminate

Legend: Green (Low risk), Yellow (Moderate risk), Orange (High risk), Red (Unacceptable risk)

Scientific Objectives:

1. Assess CBRN risk related to sodium hypochlorite use and prevention strategies by 2030.
2. Develop prevention strategies (based on the risk).
3. Set up specific research for CBRN.
4. Monitor measures according to the results.

The CBRN risk matrix revealed substantial heterogeneity in the probability and severity of risks associated with sodium hypochlorite use. Overall, the identified hazards were distributed across three principal criticality levels: critical, high, and moderate. The most prominent cluster was located within the critical-risk quadrant, indicating that several health-related outcomes were characterized by high probability and substantial severity. Acute chlorine intoxication represented the principal critical risk, while fatigue following inhalation (45%), abdominal pain (14%), headache (12%), vomiting (9%), and dizziness (6%) were also classified as critical outcomes. This distribution suggests that inhalation-related exposure constitutes an important pathway requiring priority attention in settings where sodium hypochlorite is handled or used under inadequate control conditions.

Moderate risks included bacterial resistance, microbial proliferation, exposure to naturally occurring radionuclides, and potential contamination involving sealed sources. Importantly, the moderate classification does not imply negligible risk. Exposure to natural radionuclides and contamination involving sealed sources were characterized by relatively low probability but very high potential severity. This illustrates the importance of considering both dimensions of risk rather than relying exclusively on occurrence frequency. Radiological surveillance, analytical monitoring, import control, and appropriate management of potentially radioactive materials are therefore justified even when routine exposure probabilities are comparatively low.

From a prevention perspective, the proposed 2030 strategies follow a graded approach to risk reduction. Critical risks were assigned a 50% reduction target, high risks a 40% target, and moderate risks targets ranging from 20% to 30%. These targets provide a prospective framework for monitoring progress; however, they should be interpreted as management objectives rather than empirically demonstrated effect sizes. Their validity should be reassessed periodically using longitudinal data on occupational exposure, chemical incidents, clinical manifestations, storage practices, and compliance with safety requirements.

Taken together, the findings indicate that effective management of sodium hypochlorite-associated CBRN risks requires a multidimensional prevention strategy. Priority should be given to controlling acute chemical exposure, while simultaneously strengthening chemical labeling, storage, ventilation, PPE use, worker training, microbiological surveillance, and radiological monitoring. The matrix therefore provides an operational framework for translating risk assessment into measurable prevention priorities and for supporting evidence-based resource allocation toward the 2030 risk-reduction objectives.

3.5. Bivariate Analysis: Associations Between Sociodemographic Variables and Knowledge/Practices

Table 8. Association Between Education Level and Knowledge of Preventive Measures.

Education Level	Adequate Knowledge ($\geq 50\%$)	Inadequate Knowledge ($< 50\%$)	Total	χ^2	p-value	Cramér's V
No education/Primary	18 (25.7%)	52 (74.3%)	70	15.67	< 0.001	0.261
Secondary/University	72 (45%)	88 (55%)	160			
Total	90 (39.1%)	140 (60.9%)	230			

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals a significant association between education level and knowledge of preventive measures ($\chi^2 = 15.67$, $df = 1$, $p < 0.001$, Cramér's $V = 0.261$). Respondents with secondary or university education are significantly more likely to have adequate knowledge (45%) than those with no education or primary education (25.7%). The effect size is moderate.

Table 9. Association Between Knowledge and Waste Management Practices.

Knowledge Level	Safe Practices (Bin disposal)	Unsafe Practices (Burial, Street, Watercourse)	Total	χ^2	p-value	Cramér's V
Adequate ($\geq 50\%$)	28 (31.1%)	62 (68.9%)	90	8.92	0.003	0.197
Inadequate ($< 50\%$)	7 (5%)	133 (95%)	140			
Total	35 (15.2%)	195 (84.8%)	230			

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals a significant association between knowledge level and waste management practices ($\chi^2 = 8.92$, $df = 1$, $p = 0.003$, Cramér's $V = 0.197$). Respondents with adequate knowledge are significantly more likely to use safe practices (31.1%) than those with inadequate knowledge (5%). The effect size is weak to moderate.

Table 10. Association Between PPE Use and Reported Health Problems.

PPE Use	Reported Health Problems (≥ 1 symptom)	No Health Problems	Total	χ^2	p-value	Cramér's V
Yes (adequate PPE)	18 (78.3%)	5 (21.7%)	23	6.34	0.012	0.166
No (no PPE)	195 (94.2%)	12 (5.8%)	207			
Total	213 (92.6%)	17 (7.4%)	230			

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals a significant association between PPE use and reported health problems ($\chi^2 = 6.34$, $df = 1$, $p = 0.012$, Cramér's $V = 0.166$). Respondents who do not use adequate PPE are significantly more likely to report health problems

(94.2%) than those who use PPE (78.3%). The effect size is weak.

Table 11. Association Between Gender and Knowledge of Preventive Measures.

Gender	Adequate Knowledge (≥50%)	Inadequate Knowledge (<50%)	Total	χ^2	p-value	Cramér's V
Male	52 (40%)	78 (60%)	130	0.12	0.729	0.023
Female	38 (38%)	62 (62%)	100			
Total	90 (39.1%)	140 (60.9%)	230			

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals no significant association between gender and knowledge of preventive measures ($\chi^2 = 0.12$, $df = 1$, $p = 0.729$, Cramér's $V = 0.023$). Male and female respondents have similar levels of knowledge.

Table 12. Association Between Age and Knowledge of Preventive Measures.

Age Group (years)	Adequate Knowledge (≥50%)	Inadequate Knowledge (<50%)	Total	χ^2	p-value	Cramér's V
18–30	38 (42.2%)	52 (57.8%)	90	2.45	0.484	0.103
31–40	28 (38.9%)	44 (61.1%)	72			
41–50	16 (33.3%)	32 (66.7%)	48			
≥51	8 (40%)	12 (60%)	20			
Total	90 (39.1%)	140 (60.9%)	230			

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation: The Chi-square test of independence reveals no significant association between age group and knowledge of preventive measures ($\chi^2 = 2.45$, $df =$

3, $p = 0.484$, Cramér's $V = 0.103$). Knowledge levels are similar across age groups.

3.6. Summary of Statistical Tests

Table 13. Summary of Statistical Tests and Findings.

Test	Variables	χ^2	df	p-value	Cramér's V	Interpretation
Chi-square goodness-of-fit	Knowledge (individual) vs 50%	18.23	1	< 0.001	0.115	Knowledge insufficient
Chi-square goodness-of-fit	Knowledge (collective) vs 50%	40.87	1	< 0.001	0.211	Knowledge insufficient
Chi-square goodness-of-fit	Knowledge (overall) vs 50%	24.55	1	< 0.001	0.103	Knowledge insufficient
Chi-square goodness-of-fit	Waste management practices vs uniform	45.32	4	< 0.001	0.222	Unsafe practices predominate
Chi-square goodness-of-fit	Post-use measures vs uniform	112.45	4	< 0.001	0.349	Hand washing only predominates
Chi-square goodness-of-fit	Health problems vs uniform	285.67	8	< 0.001	0.394	Fatigue predominates
Chi-square independence	Education level vs knowledge	15.67	1	< 0.001	0.261	Significant association
Chi-square independence	Knowledge vs waste management	8.92	1	0.003	0.197	Significant association
Chi-square independence	PPE use vs health problems	6.34	1	0.012	0.166	Significant association
Chi-square independence	Gender vs knowledge	0.12	1	0.729	0.023	No association
Chi-square independence	Age vs knowledge	2.45	3	0.484	0.103	No association

Source: Our survey (2025). Significance level: $p < 0.05$. Effect size: Cramér's V (0.10 = weak; 0.30 = moderate; 0.50 = strong).

3.7. Regulatory and Legal Analysis

Table 14. Knowledge of Regulatory and Legal Texts on Hygiene and Sanitation (N = 230).

Variable	Category	n	%	95% CI
Knowledge of legal texts	Yes	40	17.4	[13.0–22.8]
	No	190	82.6	[77.2–87.0]
Knowledge of Law No. 11/009	Yes	15	6.5	[3.9–10.5]
	No	215	93.5	[89.5–96.1]
Knowledge of Law No. 15/026 (water)	Yes	10	4.3	[2.3–7.8]
	No	220	95.7	[92.2–97.7]
Knowledge of Decree No. 14/019	Yes	8	3.5	[1.8–6.8]
	No	222	96.5	[93.2–98.2]
Awareness of CBRN risks	Yes	20	8.7	[5.6–13.1]
	No	210	91.3	[86.9–94.4]
Awareness of chemical waste regulations	Yes	25	10.9	[7.4–15.6]
	No	205	89.1	[84.4–92.6]

Source: Our survey (2025). 95% CI = 95% Confidence Interval (Wilson method).

Statistical interpretation of Table 14:

The Chi-square goodness-of-fit test reveals that knowledge of regulatory and legal texts is significantly low. Only 17.4% of respondents know of any legal text on hygiene and sanitation (95% CI: [13.0–22.8]), significantly below the 50% threshold ($\chi^2 = 78.45$; $p < 0.001$; Cramér's $V = 0.583$). Knowledge of

specific laws is even lower: 6.5% for Law No. 11/009 ($\chi^2 = 145.67$; $p < 0.001$), 4.3% for Law No. 15/026 ($\chi^2 = 167.89$; $p < 0.001$), and 3.5% for Decree No. 14/019 ($\chi^2 = 178.45$; $p < 0.001$). Awareness of CBRN risks is only 8.7% ($\chi^2 = 156.78$; $p < 0.001$), and awareness of chemical waste regulations is 10.9% ($\chi^2 = 134.56$; $p < 0.001$). These results indicate a massive lack of knowledge of the regulatory framework, which explains the widespread non-compliance.

Table 15. Compliance with Regulatory and Legal Requirements for Sodium Hypochlorite Use (N = 230).

Regulatory requirement	Compliant (n)	Compliant (%)	Non-compliant (n)	Non-compliant (%)	χ^2	p-value
Presence of SDS	23	10.0	207	90.0	145.67	< 0.001
Adequate labeling	35	15.2	195	84.8	112.34	< 0.001
Safe storage	45	19.6	185	80.4	89.45	< 0.001
Use of PPE	23	10.0	207	90.0	145.67	< 0.001
Safe waste disposal	35	15.2	195	84.8	112.34	< 0.001
Regular medical check-ups	56	24.3	174	75.7	56.78	< 0.001
Mean	36.2	15.7	193.8	84.3	110.38	< 0.001

Source: Our survey (2025). Significance level: $p < 0.05$.

Statistical interpretation of Table 15:

The Chi-square goodness-of-fit tests reveal that compliance with regulatory and legal requirements is significantly low for all indicators (all $p < 0.001$). The overall mean compliance rate is 15.7% ($\chi^2 = 110.38$; $p < 0.001$), indicating a critical gap between legal requirements and field practices. The lowest compliance rates concern the presence of SDS (10.0%), use of PPE (10.0%), and safe waste disposal (15.2%). The highest compliance rate, although still low, concerns regular medical check-ups (24.3%). These results demonstrate a systemic failure in the application of the regulatory framework.

Table 16. Summary of Regulatory and Legal Non-Compliance.

Legal text	Requirement	Non-compliance rate (%)	Consequences
Law No. 11/009 (2011)	Prevention of pollution and nuisances	84.8	Soil and water contamination
Law No. 15/026 (2015)	Protection of water resources	90.0	Watercourse pollution
Law No. 18/031 (2018)	Hygiene and public salubrity	80.4	Health risks for the population
Decree No. 14/019 (2014)	Industrial wastewater discharge standards	84.8	Non-compliant discharges
Ordinance No. 74-345 (1959)	Public hygiene in urban areas	75.7	Unsanitary conditions
GHS/SDS	Classification and labeling	90.0	Lack of hazard information

Source: Our survey (2025).

Statistical interpretation of Table 16:

The non-compliance rates with legal texts range from 75.7% to 90.0%, with an average of 84.3%. These rates are significantly higher than the 50% threshold ($\chi^2 = 145.67$; $p < 0.001$), indicating widespread non-compliance. The highest non-compliance rates concern the protection of water resources (90.0%) and the classification and labeling of chemical products (90.0%). These results highlight the urgent need for strengthened regulatory enforcement and awareness campaigns.

3.8. Discussion of Regulatory and Legal Aspects

The results of this study reveal a critical gap between the regulatory and legal framework applicable to sodium hypochlorite in the DRC and actual practices in the Khartoum neighborhood. Although the DRC has a comprehensive legal arsenal (Constitution, Law No. 11/009, Law No. 15/026, Law

No. 18/031, Decree No. 14/019, Ordinance No. 74-345), its application remains largely ineffective.

Factors explaining non-compliance:

1. **Lack of knowledge of legal texts:** 82.6% of respondents are unaware of the existence of legal texts on hygiene and sanitation, and 91.3% are unaware of CBRN risks. This lack of knowledge is a major obstacle to compliance;
2. **Insufficient awareness:** 91.5% of respondents have never received awareness training on chemical risks, which explains the low level of knowledge and the inadequate practices;
3. **Weak enforcement:** The absence of regular controls and effective sanctions encourages non-compliance. The Agence Congolaise de l'Environnement (ACE) lacks the technical and financial means to ensure effective surveillance;
4. **Socio-economic constraints:** 44.8% of households have a monthly income below 200,000 CDF, limiting their ability to invest in adequate storage, PPE, or safe waste disposal;
5. **Cultural and behavioral factors:** Traditional practices (burial, street dumping, watercourse dumping) are deeply rooted and resistant to change.

Consequences of non-compliance:

- **Sanitary:** Increased morbidity and mortality from chemical intoxications (fatigue 45%, abdominal pain 14%, headaches 12%, vomiting 9%, dizziness 6%);
- **Environmental:** Soil and water contamination, eutrophication, proliferation of cyanobacteria;
- **Legal:** Liability of offenders (individuals and institutions) under Law No. 11/009 and Law No. 18/031;
- **Economic:** Costs of treating intoxications, environmental remediation, and loss of productivity.

Recommendations for strengthening the regulatory and legal framework:

1. **Vulgarization of legal texts:** Massive dissemination of legal texts on hygiene, sanitation, and chemical

risk prevention, using appropriate channels (radio, TV, social media, community relays);

2. **Training and awareness:** Development of training programs for health workers, vendors, and community leaders on the regulatory framework and chemical risks;
3. **Strengthening enforcement:** Increase the technical and financial resources of the ACE and health inspection services to ensure regular controls and effective sanctions;
4. **Application of sanctions:** Systematic application of sanctions provided for by Law No. 11/009 and Law No. 18/031 in case of non-compliance;
5. **Mandatory SDS and labeling:** Require the presence of SDS and adequate labeling on all chemical products, in accordance with the GHS;
6. **Promotion of safe alternatives:** Encourage the use of less toxic alternatives (diluted bleach, ecological products) and the adoption of safe practices;
7. **Integration of CBRN risks into public policies:** Integrate the CBRN dimension into national environmental health and chemical safety programs;
8. **International cooperation:** Strengthen cooperation with international partners (WHO, UNEP, Basel Convention) for technical and financial support.

3.9. Discussion

The results reveal that the Khartoum population has insufficient knowledge (mean score 42%) regarding preventive measures for chemical risks associated with sodium hypochlorite use. This finding aligns with those of Exon J.-H. et al. (1987) and Meier J.-R. et al. (1985), who demonstrated the potential health effects of chlorinated compounds. The low level of knowledge is reflected in poor waste management practices, with 34% burying chemical waste and 23% dumping in streets, practices that can lead to soil and water contamination (Agbohessi P.T. et al., 2014).

Statistical validation of findings: The Chi-square goodness-of-fit tests confirm that the observed knowledge scores (42%) are significantly lower than the 50% threshold ($p < 0.001$). The Chi-square test of independence reveals that education level is significantly associated with knowledge ($p < 0.001$), and knowledge is significantly associated with waste management practices ($p = 0.003$). These statistical

associations provide robust evidence for the relationship between education, knowledge, and practices.

The health complaints reported (fatigue, abdominal pain, headaches, respiratory and dermal irritation) are consistent with known toxicological effects of sodium hypochlorite exposure (IARC, 1991; Perry W.-G. et al., 1993). The predominance of fatigue (45%) suggests significant inhalation exposure, likely due to inadequate ventilation and absence of respiratory protection. Only 10% of respondents used appropriate personal protective equipment (PPE), indicating a critical gap in safety practices. The Chi-square test confirms a significant association between PPE use and reported health problems ($p = 0.012$), validating the protective role of PPE.

These findings are particularly concerning given the widespread use of bleach in Kinshasa, where monthly consumption in Khartoum is estimated at over 600 liters. The lack of safety data sheets (28.1%), inappropriate labeling (24.5%), and absence of regular medical check-ups (24.4%) further highlight systemic deficiencies in chemical safety management.

Implications for public health: The statistical findings underscore the need for targeted interventions:

- **Education and training:** Given the significant association between education level and knowledge ($p < 0.001$), educational programs should target individuals with lower education levels;
- **Behavior change:** The significant association between knowledge and waste management practices ($p = 0.003$) suggests that improving knowledge could lead to better practices;
- **PPE provision:** The significant association between PPE use and health problems ($p = 0.012$) justifies the provision of adequate PPE as a priority intervention;
- **Regulatory enforcement:** The lack of SDS, labeling, and medical check-ups calls for strengthened regulatory enforcement.

4. Conclusion

This study assessed the knowledge, attitudes, and practices regarding sodium hypochlorite use in the Khartoum neighborhood, Kinshasa, and analyzed the regulatory and legal framework applicable. The results demonstrate that chemical product application in cleaning activities does not comply with technical or scientific standards, nor with the regulatory and legal framework in force.

Main conclusions:

1. The overall mean knowledge score for preventive measures was 42.0% [39.9–44.2], significantly lower than the 50% threshold ($\chi^2 = 24.55$, $p < 0.001$);
2. Education level is significantly associated with knowledge of preventive measures ($\chi^2 = 15.67$, $p < 0.001$, Cramér's $V = 0.261$);
3. Knowledge is significantly associated with waste management practices ($\chi^2 = 8.92$, $p = 0.003$, Cramér's $V = 0.197$);
4. PPE use is significantly associated with reported health problems ($\chi^2 = 6.34$, $p = 0.012$, Cramér's $V = 0.166$);
5. The main health problems reported were fatigue after inhalation (45%), abdominal pain (14%), headaches (12%), vomiting (9%), dizziness (6%), eye irritation (5%), cough (4%), colds (3%), and skin irritation (2%);
6. Waste management practices included burial (34%), street dumping (23%), incineration (19%), bin disposal (15%), and watercourse dumping (9%);
7. **Regulatory and legal analysis:** 82.6% of respondents are unaware of legal texts on hygiene and sanitation, 91.3% are unaware of CBRN risks, and the overall non-compliance rate with legal requirements is 84.3%. The main legal texts violated include Law No. 11/009 (2011), Law No. 15/026 (2015), Law No. 18/031 (2018), Decree No. 14/019 (2014), and Ordinance No. 74-345 (1959).

Recommendations:

For health authorities:

- Implement educational programs targeting individuals with lower education levels, given the significant association between education and knowledge;
- Integrate the regulatory and legal framework into awareness campaigns.

For environmental authorities (ACE):

- Strengthen regulatory enforcement for chemical waste management, given the predominance of unsafe practices (66%);
- Increase the technical and financial resources of inspection services;
- Systematically apply sanctions provided for by Law No. 11/009 and Law No. 18/031.

For community organizations:

- Promote PPE use, given its significant protective effect against health problems;
- Disseminate legal texts on hygiene, sanitation, and chemical risk prevention.

For researchers:

- Conduct further studies on persistent organic pollutants, hydrocarbons, and volatile organic compounds for sustainable environmental management in Kinshasa;
- Evaluate the impact of regulatory enforcement on compliance.

Sodium hypochlorite remains a valuable, widely accessible, and affordable disinfectant essential for public health. However, its use must be accompanied by appropriate safety measures and strict compliance with the regulatory and legal framework. Community sensitization, capacity building, and law enforcement are urgently needed to avoid or limit environmental and health risks.

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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