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Environmental Assessment of Urban Drainage, Surface-Water Quality, Soil Contamination, and Household Impacts in Mont-Ngafula, Kinshasa

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ABSTRACT

Introduction

Urban flooding and soil erosion constitute major environmental challenges in rapidly growing cities, particularly where rainfall intensity exceeds the capacity of natural and artificial drainage systems. In Kinshasa, these challenges are exacerbated by rapid urban expansion, inadequate drainage infrastructure, poor waste management, and uncontrolled land occupation.

Purpose

This study assessed the environmental performance of the urban drainage system along a critical section of Mobutu Avenue linking the Masanga-Mbila, Mazamba, and Maman Yemo neighborhoods in Mont-Ngafula Municipality.

Methods

The methodological framework combined household surveys across 202 households selected through non-probability convenience sampling using KoboCollect, direct field observations, and physicochemical characterizations of water and soil samples collected across three locations (upstream, discharge point, and downstream) during sixteen field campaigns. Analytical determinations were performed using an Energy-Dispersive X-Ray Fluorescence (ED-XRF Xepos III) spectrometer. Environmental impacts were evaluated via a structured interaction matrix.

Results

Results indicated that 55.4% of households lacked drainage channels in front of their plots, while 53.5% experienced frequent structure blockages primarily driven by solid waste (48.0%) and sediments (24.3%). Consequently, 63.4% of households reported property damage and 72.3% noted daily activity disruptions. Surface-water analyses revealed extreme phosphate concentrations (maximum up to 22.42 ± 20.92 mg/L at the discharge point), significantly exceeding environmental reference criteria. Soil concentrations of copper (82.73–96.47 mg/kg) and cadmium (2.06–4.20 mg/kg) also surpassed threshold criteria. One-way ANOVA tests confirmed statistically significant spatial variations for nickel, copper, and cadmium in water ($p < 0.05$).

Conclusion

Priority measures must include weekly solid waste collection, routine pre-rainy-season channel inspections, and infrastructure rehabilitation.

INTRODUCTION

Urban flooding and soil erosion currently represent major challenges for environmental management in rapidly growing cities, particularly in tropical and developing urban areas where rapid land-use change and inadequate drainage infrastructure increase stormwater runoff and environmental degradation (Diémé et al., 2025; Intergovernmental Panel on Climate Change [IPCC], 2021). Recent studies in African urban environments have shown that inadequate drainage capacity, concentrated runoff, and insufficient maintenance contribute significantly to recurrent flooding, erosion, and the degradation of urban infrastructure (Diémé et al., 2025; Muke et al., 2026). In Kinshasa and other cities across the Democratic Republic of the Congo (DRC), recent research highlights the critical role of land cover, road density, slope gradients, and sandy soil properties in controlling the initiation and expansion of urban gullies (Mawe et. al., 2024, 2025). Furthermore, investigations of urban rivers in Kinshasa emphasize the profound influence of surface runoff, uncontrolled waste disposal, and untreated wastewater on aquatic contamination (Tshibanda et al., 2021).

In Kinshasa, these problems are particularly acute in rapidly expanding peri-urban municipalities such as Mont-Ngafula. The municipality features rugged topography and extensive areas highly vulnerable to erosion and flooding. Heavy tropical rainfall, expanding impervious built surfaces, inadequate drainage networks, and infrequent maintenance concentrate stormwater flows and drastically accelerate erosion risks. Recent work on urban stormwater management in Kinshasa underscores the urgent need to enhance hydraulic capacity and adapt municipal infrastructure to escalating meteorological extremes (Diémé et al., 2025; Mawe et al., 2024; Muke et al., 2026). Along the Mobutu Avenue section connecting the Masanga-Mbila, Mazamba, and Maman Yemo neighborhoods, these pressures manifest as chronic drainage blockages, water stagnation, localized flooding, structural soil erosion, and severe infrastructure degradation, directly threatening environmental quality and community safety.

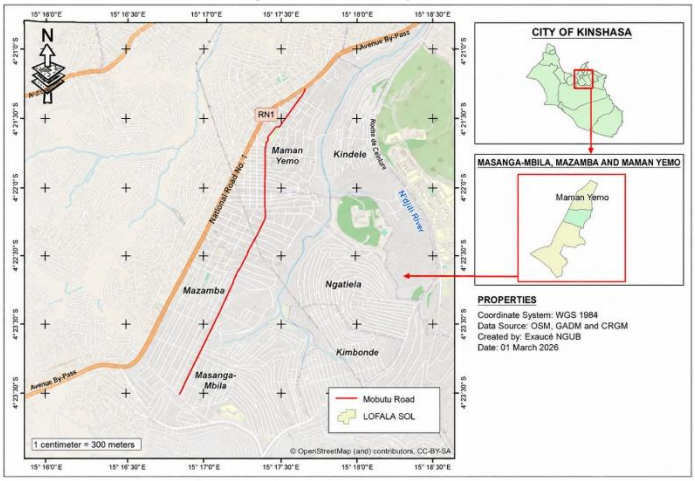
Although previous studies have examined flooding, soil erosion, urban runoff, and heavy-metal contamination in Kinshasa, most have focused on macro-scale river basins, major urban gully systems, or isolated environmental compartments. Micro-scale assessments that integrate drainage-system performance with surface-water and soil physicochemical quality, household vulnerability, and socio-health impacts along specific urban transportation corridors remain sparse. Therefore, this study evaluated the urban drainage system along the Masanga-Mbila–Mazamba–Maman Yemo section of Mobutu Avenue in Mont-Ngafula Municipality, aiming to appraise its structural condition, quantify its environmental and socio-health impacts, and propose targeted remediation strategies.

METHODS

Study Area

The study was conducted along the segment of Mobutu Avenue spanning the neighborhoods of Masanga-Mbila, Mazamba, and Maman Yemo within the Mont-Ngafula Municipality in western Kinshasa, Democratic Republic of the Congo **(Map 1)**. The municipality is characterized by rapid, largely unregulated urbanization, steep and rugged topography, and high susceptibility to rain-induced erosion and severe flooding.

Map 1:
The three neighborhoods crossed by Mobutu Avenue (Masanga-Mbila, Mazamba and Maman Yemo) in Mont-Ngafula Municipality, Kinshasa.



Map 1 illustrates the spatial configuration of the three study neighborhoods crossed by Mobutu Avenue, detailing geographic coordinates in WGS 1984, data sources from OpenStreetMap, GADM, and CRGM, and operational boundaries for sampling locations. The regional climate is humid tropical, featuring a distinct rainy

season from October through May and a dry season from June through September. Heavy precipitation combined with deficient sanitary infrastructure drives high-velocity stormwater runoff and structural degradation along this vital transport corridor.

Data Collection and Analytical Methods

This research utilized a mixed-methods design integrating socio-environmental surveys, direct field observations, physicochemical laboratory analyses of water and soil samples, and an environmental impact assessment matrix. Socio-environmental data were gathered from 202 households using a structured questionnaire administered via the KoboCollect mobile application. A convenience sampling technique was employed to select participating households present in Masanga-Mbila, Mazamba, and Maman Yemo during the survey window. Because a non-probability convenience sampling framework was applied, sample size calculations based on formal confidence intervals or error margins were omitted; findings reflect the specific empirical baseline of the surveyed households rather than a statistically representative demographic census for Mont-Ngafula Municipality. Collected parameters encompassed socio-demographic profiles, infrastructure conditions, domestic sanitation practices, and perceived flooding or erosion impacts.

Concurrently, systematic field inspections identified primary degradation drivers and structural bottlenecks. Water and soil samples were collected across three representative stations along the corridor: upstream, at the discharge confluence point, and downstream. Field sampling took place across sixteen monitoring campaigns conducted between July 10 and July 26, 2023. Water samples were collected approximately 20–30 cm below the surface, while surface soil samples were retrieved from a 0–20 cm depth. A total of nine water samples and nine soil samples were analyzed, each with four analytical replicates.

Samples were transported to the Central Analysis Laboratory of the CGEA/CREN-K. Water samples (3-mL test portions) were evaluated using internal FP-Water and Solo-Water protocols via an Energy-Dispersive X-Ray Fluorescence (ED-XRF Xepos III) spectrometer. Soil samples were air-dried, sieved to 63 µm, and tested using 3-g portions via the internal FP-Powder method. Instrument calibration relied on synthetic laboratory standards for liquids and certified reference materials (ISE870, ISE890, ISE919, and ISE961) for solids, utilizing four secondary targets (molybdenum, aluminum oxide, cobalt, and an HOPG Bragg crystal). Potassium was quantified using the $K\alpha_1$ line at 3.313 keV normalized against scattering peaks, with 95% confidence intervals derived from Student's t-distribution.

Due to the absence of comprehensive national regulatory standards for all tested parameters in the DRC, environmental concentrations were evaluated against the surface water and soil quality criteria established by the Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP, 2009). World Health Organization (WHO, 2020) guideline values were also utilized as comparative benchmarks to appraise potential public health pathways, recognizing that drainage networks frequently intersect human exposure routes through domestic contact or informal urban agriculture. An interaction matrix was constructed to map impact-generating activities against environmental receptors and define corresponding mitigation frameworks.

Statistical Analysis

Data were coded and processed using Microsoft Excel and SPSS (Version 25). Analyses included descriptive statistics (frequencies, percentages, means, and standard deviations) and one-way analysis of variance (ANOVA) to evaluate spatial variations across upstream, discharge, and downstream stations ($p < 0.05$).

RESULTS

Socio-demographic Characteristics of Surveyed Households

The demographic profile of the 202 surveyed households indicates a young and recently established resident population distributed relatively evenly across the three neighborhoods, with Maman Yemo representing the largest share **(Table 1)**.

Table 1:
Socio-demographic characteristics of the surveyed households (n = 202)

Category	Modalities	Frequency (n)	Percentage (%)
Gender	Male	119	58.9
	Female	83	41.1
Age group	18–30 years	118	58.4
	31–45 years	53	26.2
	46 years and above	31	15.3
Neighborhood	Masanga-Mbila	70	34.7
	Mazamba	56	27.7
	Maman Yemo	76	37.6
Length of residence	Less than 5 years	98	48.5
	5–10 years	72	35.6
	More than 10 years	32	15.8
Housing status	Tenant	110	54.5
	Homeowner	92	45.5

Condition of Drainage Infrastructure

The field assessment confirmed severe structural and maintenance deficiencies across the urban drainage network along Mobutu Avenue **(Table 2)**.

Table 2:
Condition of drainage infrastructure and factors contributing to its degradation (n = 202)

Category	Modalities	Percentage (%)
Presence of drainage channels	Yes	44.6
	No	55.4
Condition of drainage channels	Good condition	47.5
	Degraded	15.3
	Absent	37.2
Drainage channel blockage	Yes	53.5
	No	46.5
Causes of blockage	Household waste	48.0
	Sediments	24.3
	Wastewater	21.8
	Others	5.9
Causes of erosion	Poor waste management	41.6
	Inadequate drainage infrastructure	34.2
	Heavy rainfall	16.3
	Poor stormwater drainage	7.9

Waste Management and Sanitation Practices

Domestic sanitation and waste disposal habits show heavy reliance on informal or suboptimal practices that compound drainage failure **(Table 3)**.

Table 3:
Waste management and sanitation practices among surveyed households (n = 202)

Category	Modalities	Percentage (%)
Waste disposal method	Waste collection service	45.5
	Open dumping	20.3
	Burning	17.8
	Burial	8.9
	Disposal into drainage channels	6.4
	Others	1.0
Access to waste collection service	Yes	63.4
	No	36.6
Contribution of waste to channel blockage	Yes	72.3
	No	27.7
Wastewater disposal method	Drainage network	48.5
	Septic tank	27.7
	Direct discharge into environment	16.8
	Discharge into drainage channels	6.9
Stormwater disposal method	Into drainage channels	51.0
	Onto the street	30.7
	Infiltration within plot	13.9
	Storage/harvesting	4.5
Type of toilet facility	Flush toilet with septic tank	51.5
	Improved latrine	35.1
	Simple latrine	10.4
	Open defecation	3.0
Toilet use	Shared	58.4
	Not shared	41.6
Recurrent diseases	Malaria	68.3
	Typhoid fever	14.4
	Diarrhea	10.4
	Skin infections	5.4
	Cholera	1.5

Impacts of Drainage System Dysfunction on Local Communities

Dysfunctions in the drainage network generate widespread socio-economic and public health repercussions for local residents **(Table 4)**.

Table 4:
Impacts of drainage system dysfunction on surveyed households (n = 202)

Category	Modalities	Percentage (%)
Material damage caused by erosion or flooding	Yes	63.4
	No	36.6
Disruption of daily activities	Yes	72.3
	No	27.7
Increase in diseases after flooding events	Yes	66.3
	No	33.7
Source of drinking water supply	Wells and boreholes	67.3
	REGIDESO water supply network	32.7
Knowledge of responsible institution	Yes	43.6
	No	56.4
Satisfaction with authorities' interventions	Satisfied	31.7
	Not Satisfied	68.3
Willingness to participate in maintenance	Yes	79.2
	No	20.8
Proposed solutions	Construction of drainage channels	29.7
	Improvement of drainage and water supply	25.7
	Awareness raising and maintenance	22.8
	Waste management and recycling	21.8

Physicochemical Quality of Surface Waters

Surface water analyses demonstrated widespread contamination exceeding MDDEP (2009) reference criteria, particularly for nutrients and heavy metals **(Table 5)**.

Table 5:
Mean concentrations of chemical parameters in surface waters and one-way ANOVA results

Parameter (mg/L)	Upstream	Discharge Point	Downstream	MDDEP (2009) Criterion	ANOVA (F, p)
Aluminum	0.879 ± 0.318	0.618 ± 0.517	1.740 ± 1.288	0.20	F(2, 6) = 1.532, p = 0.290
Phosphates	3.930 ± 0.257	22.420 ± 20.923	4.327 ± 0.764	0.03	F(2, 6) = 2.372, p = 0.174
Chromium	0.900 ± 0.000	0.310 ± 0.510	0.900 ± 0.000	0.008	F(2, 6) = 4.000, p = 0.079
Manganese	1.070 ± 0.290	0.540 ± 0.580	1.130 ± 0.250	0.12	F(2, 6) = 2.000, p = 0.216
Nickel	0.130 ± 0.230	0.180 ± 0.190	0.270 ± 0.230	0.025	F(2, 6) = 7.451, p = 0.024^*
Copper	1.870 ± 0.250	1.100 ± 0.260	1.870 ± 0.320	0.004	F(2, 6) = 7.451, p = 0.024^*
Zinc	ND	0.020 ± 0.020	0.630 ± 1.100	0.03	F(2, 6) = 0.976, p = 0.430
Cadmium	0.230 ± 0.020	0.240 ± 0.090	0.030 ± 0.010	0.0002	F(2, 6) = 14.551, p = 0.005^*
Lead	0.400 ± 0.690	0.830 ± 0.740	ND	0.001	F(2, 6) = 1.528, p = 0.291

Note. ND = Not Detected. Values presented as mean ± standard deviation. Asterisk (*) indicates statistical significance ($p < 0.05$).

Physicochemical Quality of Soils

Soil analyses identified persistent contamination by copper and cadmium across all sampled locations, exceeding environmental reference criteria **(Table 6)**.

Table 6:
Mean concentrations of chemical parameters exceeding MDDEP (2009) criteria in soils

Parameter (mg/kg)	Upstream	Discharge Point	Downstream	MDDEP (2009) Criterion	ANOVA (F, p)
Copper	96.47 ± 48.91	82.73 ± 7.57	82.97 ± 31.18	50.0	F(2, 6) = 0.163, p = 0.854
Cadmium	2.75 ± 3.23	4.20 ± 2.65	2.06 ± 0.77	1.5	F(2, 6) = 0.596, p = 0.581

Note. Values presented as mean ± standard deviation.

Environmental Impact Assessment Matrix

An interaction matrix was structured to systematically appraise negative impacts generated by corridor activities and define corresponding mitigation protocols **(Table 7)**.

Table 7:
Negative environmental impacts and proposed mitigation measures

Impact-Generating Activities	Environmental Receptors	Nature	Description of the Impact	Mitigation Measures
Encroachment on road right-of-way	Biophysical (Soil)	Negative	Unplanned land occupation and soil sealing by temporary or permanent structures.	Clear public right-of-way, demolish illegal structures, and restore land.
Encroachment on road right-of-way	Biophysical (Landscape)	Negative	Visual clutter and degradation of urban aesthetics along the avenue.	Plant roadside trees and improve building facades post-clearance.
Encroachment on road right-of-way	Human (Public Health)	Negative	Increased pedestrian and resident exposure to traffic accidents.	Establish adequate road setbacks and community awareness programs.
Encroachment on road right-of-way	Human (Traffic, Economy)	Negative	Reduced road width causing severe traffic congestion and conflicts.	Demarcate road boundaries and enforce urban planning laws.
Informal markets	Biophysical (Soil, Water, Air)	Negative	Pollution from solid waste, wastewater stagnation, and putrid odors.	Install public waste bins and ensure regular cleaning and collection.
Informal markets	Biophysical (Landscape)	Negative	Disorganization of public spaces and aesthetic deterioration.	Establish organized, uniform market facilities outside right-of-way.
Informal markets	Human (Local Population)	Negative	Early morning and nighttime noise disrupting residential privacy.	Strictly regulate operating and delivery hours.
Informal markets	Human (Public Health)	Negative	Proliferation of vectors (flies, mosquitoes, rats) from poor sanitation.	Conduct regular sanitary inspections and vector disinfection.
Informal markets	Human (Road Traffic)	Negative	Vendors and patrons overflowing onto pavement, blocking traffic.	Relocate market to dedicated municipal site off the roadway.
SNEL High-Voltage Tower	Biophysical (Landscape)	Negative	Industrial visual intrusion upon the urban landscape.	Establish vegetative buffers using tall trees maintaining safety clearances.
SNEL High-Voltage Tower	Human (Public Health)	Negative	Electrocution hazards during structural failure or storms.	Enforce electrical safety corridors and prohibit building underneath lines.
SNEL High-Voltage Tower	Human (Utility Network)	Negative	Infrastructure destabilization from nearby excavation or erosion.	Secure tower foundations and coordinate technical works with SNEL.
Soil erosion	Biophysical (Soil, Water, Flora)	Negative	Topsoil loss, channel sedimentation, and vegetation uprooting.	Implement reforestation and geotechnical soil stabilization measures.
Soil erosion	Biophysical (Landscape)	Negative	Formation of unsightly and hazardous roadside gullies.	Backfill, compact, and regrade eroded slopes.
Soil erosion	Human (Local Population)	Negative	Structural collapse risks threatening houses, walls, and plots.	Construct reinforced retaining walls to protect properties.
Soil erosion	Human (Transport, Utilities)	Negative	Road severance and exposure/rupture of buried utility pipelines.	Construct robust stormwater drainage collectors and channels.
Football fields	Biophysical (Soil, Landscape)	Negative	Soil compaction impeding infiltration and generating dust.	Periodically water field and install physical or vegetative barriers.
Football fields	Human (Local Population)	Negative	Noise disturbance and property damage from stray balls.	Install protective high-density ball-stop netting.
Football fields	Human (Road Traffic)	Negative	Spectator overflow obstructing traffic flow and pedestrian safety.	Provide secure spatial buffer zones between pitch and roadway.
Illegal dumpsites	Biophysical (All compartments)	Negative	Leachate soil/groundwater contamination and air pollution from burning.	Remove waste to controlled landfills and remediate contaminated sites.

Illegal dumpsites	Biophysical (Landscape)	Negative	Severe degradation fostering an image of municipal neglect.	Develop landscaped green spaces or paved public plazas post-cleanup.
Illegal dumpsites	Human (Public Health)	Negative	Elevated respiratory and vector-borne disease risks.	Implement weekly household solid waste collection services.
Illegal dumpsites	Human (Traffic, Economy)	Negative	Waste spilling onto roadway, impeding traffic and commerce.	Enforce strict legal penalties for illegal dumping.
SNEL Electrical Substation	Biophysical (Soil)	Negative	Permanent soil sealing, restricting ecological land functions.	Minimize ground footprint during facility modernization.
SNEL Electrical Substation	Human (Public Health)	Negative	Fire, transformer explosion, and electrocution hazards.	Install reinforced security fencing, danger signage, and maintenance.
SNEL Electrical Substation	Human (Traffic, Utilities)	Negative	Obstruction of potential road widening or drainage alignments.	Relocate substations outside core road alignment where necessary.
REGIDESO Water Pipeline	Biophysical (Soil, Water)	Negative	Leaks causing subgrade erosion, road foundation softening, and slips.	Promptly detect and repair leaks using high-density polyethylene pipes.
REGIDESO Water Pipeline	Human (Local Population)	Negative	Potable water supply interruptions during construction damage.	Plan temporary bypass supplies prior to excavation works.
REGIDESO Water Pipeline	Human (Traffic, Economy)	Negative	Pavement saturation, structural failure, and business disruption.	Position distribution pipelines beneath sidewalks rather than traffic lanes.
SNEL Utility Poles	Biophysical (Landscape)	Negative	Uncontrolled overhead cabling degrading visual aesthetics.	Bundle overhead lines and plan long-term underground conversion.
SNEL Utility Poles	Human (Public Health)	Negative	Collapse risks from decaying wooden poles during storms.	Systematically replace damaged poles with reinforced concrete units.
SNEL Utility Poles	Human (Traffic, Utilities)	Negative	Placement within pavement obstructing motorists and pedestrians.	Reposition poles along outer sidewalk boundaries per engineering standards.

DISCUSSION

Condition of the Drainage System and Environmental Degradation Processes

The findings indicate that the urban drainage network along Mobutu Avenue suffers from severe structural and operational deficiencies. Over half of surveyed households (55.4%) reported a total absence of drainage channels in front of their plots, while 53.5% highlighted chronic clogging of existing structures. These metrics reflect an acute shortfall in infrastructure investment compounded by nonexistent routine maintenance. Solid waste was identified as the primary driver of channel blockage (48.0%), followed by sediment deposition (24.3%), mirroring observations from other West and Central African urban settings where overloaded drainage pathways accelerate flooding and infrastructure decay (Diémé et al., 2025). The accumulation of domestic refuse severely constricts hydraulic cross-sections, forcing stormwater out of bounds during high-intensity tropical downpours.

Furthermore, deficient waste management (41.6%) and inadequate drainage capacity (34.2%) were recognized as principal catalysts of active soil erosion. In Mont-Ngafula's rugged topography, unmanaged concentrated runoff accelerates gully incision, a phenomenon widely documented across Kinshasa's fragile sandy substrates (Mawe et al., 2024, 2025).

Socio-Health Impacts of Drainage System Dysfunction

Drainage network failures exert profound adverse effects on community living conditions and public health. Two-thirds of respondents (66.3%) noted an upsurge in disease incidence following flood events, led by malaria (68.3%), typhoid fever (14.4%), and diarrheal illnesses (10.4%). Stagnant water bodies provide ideal vector-breeding habitats, while floodwaters facilitate pathogen transmission (WHO, 2020). Although these health outcomes rely on household reporting rather than clinical verification, they underscore significant exposure vulnerabilities.

Compounding these risks, 67.3% of households depend on local wells and boreholes for drinking water. Surface runoff infiltration during floods introduces microbiological and chemical contaminants into shallow groundwater tables, elevating public health hazards (WHO, 2020). Addressing these vulnerabilities requires coordinated investments in hydraulic infrastructure, environmental sanitation, and aquifer protection.

Water and Soil Quality

Physicochemical evaluations revealed pronounced aquatic contamination, with multiple parameters exceeding MDDEP (2009) criteria. Extreme phosphate concentrations at the discharge point (mean 22.420 ± 20.923 mg/L) reflect massive organic loading from domestic wastewater, urban runoff, and decomposing solid waste, aligning with urban assessments by the Japan International Cooperation Agency (JICA, 2010) and the World Bank (2024).

Elevated soil concentrations of copper (82.73–96.47 mg/kg) and cadmium (2.06–4.20 mg/kg) exceed environmental thresholds (50 mg/kg and 1.5 mg/kg, respectively), indicating cumulative anthropogenic pressures. Potential contributors include weathered municipal refuse, atmospheric deposition, road runoff, vehicular wear emissions (brake pads and tires), and degrading building materials (Mavakala et al., 2022; Tshibanda et al., 2021). Although source-apportionment modeling was beyond this study's scope, the data confirm pervasive heavy-metal loading across the urban corridor.

Implications for Sustainable Urban Drainage Management

Mitigating environmental risks along Mobutu Avenue requires an integrated management framework combining engineering rehabilitation, institutional coordination, and community engagement. Upgrading hydraulic conveyance capacity through new channel construction and the rehabilitation of degraded segments is paramount.

Given that household refuse is the leading cause of channel obstruction, establishing regular solid waste collection services—scheduled at least weekly—coupled with public awareness campaigns is essential to prevent indiscriminate dumping. Notably, 79.2% of households expressed willingness to participate in community maintenance initiatives, offering a strong foundation for participatory environmental governance. Sustained success will ultimately depend on multi-agency coordination among municipal authorities, sanitation providers, and public utility operators.

CONCLUSION

This study evaluated the environmental performance of the urban drainage system along the Masanga-Mbila–Mazamba–Maman Yemo section of Mobutu Avenue in Mont-Ngafula Municipality, Kinshasa. Results revealed widespread structural deterioration, channel absences, and chronic blockages driven by domestic waste disposal and sediment accumulation. These dysfunctions exacerbate flooding and erosion, inflicting material property damage and disrupting the daily activities of local residents.

Physicochemical analyses demonstrated significant deterioration in surface-water and soil quality, with phosphates, copper, and cadmium frequently exceeding environmental reference standards. While health impacts were primarily derived from household perceptions, the empirical water and soil data confirm substantial anthropogenic contamination across the corridor. The environmental impact assessment identified right-of-way encroachments, informal markets, unmanaged dumpsites, and utility failures as primary degradation drivers.

Municipal authorities should prioritize instituting weekly solid waste collection services, executing routine pre-rainy-season channel maintenance, rehabilitating damaged drainage infrastructure, and integrating local community participation into municipal sanitation programs to safeguard public health and environmental resilience.

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