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Hydraulic Diagnosis of Drainage Works in North Central Kinshasa Facing Design Discharges

Lufutu Ibumbu Harvey[1], Baafo Nkong'oto Jean Marie[2*], Mushiya Mukengeshayi Jeannine[3,4], Makanina Mbelenge Nicole[5]

[1]*Department of Geometrics and Space Geodesy, School of Telecommunications and Spatial censure, National Pedagogical University, Kinshasa, Democratic Republic of the Congo*

[2]*Department of Waters and Forests, Conservation and Management of Renewable Natural Resources, School of Telecommunications and Spatial Censure, National Pedagogical University, Kinshasa, Democratic Republic of the Congo*

[3]*Department of Physics, Atmospheric Physics, School of Telecommunications and Spatial censure, National Pedagogical University, Kinshasa, Democratic Republic of the Congo*

[4]*National Institute for Agronomic Study and Research, Kinshasa, Democratic Republic of the Congo*

[5]*Department of Quality Control, Environmental Engineering and Sustainable Development, School of Telecommunications and Spatial Censure, National Pedagogical University, Kinshasa, Democratic Republic of the Congo*

***Abstract*: This study analyzes the hydraulic performance of drainage networks in north central Kinshasa using Manning's equation and diagnostic indicators (Hydraulic Vulnerability Index – HVI and Hydraulic Utilization Rate – HUR). Three major axes were examined: Boulevard du 30 Juin, Boulevard Lumumba, and Avenue Kasa Vubu. The results reveal strong heterogeneity: some sections exhibit adequate capacity, while others are highly vulnerable, with HUR values exceeding 1,000%. The section-by-section hydraulic approach, combining channel geometry with hydrological inflows from sub basins, enables the identification of critical points and the proposal of appropriate resizing solutions. The study also emphasizes the importance of regular maintenance of drainage structures and the updating of hydrological data in a rapidly urbanizing context. These findings provide a rational basis for the progressive rehabilitation of Kinshasa's urban drainage networks.**

***Keywords*: urban drainage, Kinshasa, Manning's equation, hydraulic vulnerability, redesign.**

1. Introduction

The city of Kinshasa faces particularly intense hydrological pressures, resulting from the combination of heavy rainfall, increasing urban surface impermeability, encroachment on hydraulic rights-of-way, and frequent obstruction of collectors. These factors considerably reduce the operational margin of drainage structures and exacerbate flood risks. In this context, the evaluation of a channel's performance cannot be limited to its geometric dimensions; it must include a comparison between its hydraulic capacity and the design flows likely to occur (Chow, 1959; Roche, 1963). This study adopts such an approach by conducting a section-by-section hydraulic diagnosis. Three major axes in north-central Kinshasa were analyzed: Boulevard du 30 Juin, Boulevard Lumumba, and Avenue Kasa-Vubu. The objective is to synthesize hydraulic capacity calculations and interpret the results in order to propose suitable resizing solutions.

2. Methods

A. Study Area

The research is situated in the urban context of Kinshasa, capital of the Democratic Republic of Congo, characterized by high annual rainfall and rapid urbanization. The three axes studied are representative of urban drainage challenges: extensive surface impermeability, encroachment on hydraulic rights-of-way, and frequent obstruction of collectors.

B. Materials and Data

The methodology combines geometric and hydrological data with digital processing tools to assess the hydraulic performance of Kinshasa's urban channels.

- *Geometric data* were collected in the field and supplemented by technical documents from road services. These include width, height, and shape of the channels, generally rectangular concrete structures. They form the basis for calculating wetted cross-sections and hydraulic radii required for Manning's equation.
- *Hydrological data* were obtained through watershed modeling. Design flows were calculated considering reference rainfall and runoff coefficients specific to highly impermeable urban surfaces. This step links hydrological inflows from sub-basins to the studied sections and allows comparison between projected flows and theoretical capacities.
- *Analytical tools* included geographic information system (GIS) software such as ArcGIS Pro and QGIS, used for sub-basin delineation and longitudinal profile analysis. Spreadsheets and numerical scripts were then applied to hydraulic formulas, variable coding, and diagnostic indicator production. This combination ensures rigor and reproducibility.

*Corresponding author: bankocml@gmail.com

- *Roughness parameters* were set according to classical recommendations. Manning's coefficient was fixed at n = 0.015, a reference value for concrete channels (Chow, 1959; Roche, 1963). This parameter directly conditions calculated capacity and reflects head losses due to wall roughness.

C. Methodological Approach

The methodological framework follows four complementary steps:

1) Hydraulic subdivision by sections

Each axis was divided into homogeneous sections bounded by drainage nodes (points of inflow, collection, or confluence). This subdivision isolates portions with distinct hydraulic characteristics, especially slope and inflows, avoiding a global analysis that would mask local vulnerabilities.

2) Hydraulic capacity calculation

The capacity of each section was estimated using Manning's equation, widely applied to uniform steady flows (Chow, 1959; Roche, 1963). The equation relates discharge to wetted area, hydraulic radius, and longitudinal slope, accounting for roughness. Field-measured dimensions (width and height) were integrated to determine available hydraulic cross-sections.

3) Diagnostic indicators

Two indicators were used: the Hydraulic Vulnerability Index (HVI), measuring the relative gap between design flow and calculated capacity (positive values indicate insufficiency, negative values indicate reserve); and the Hydraulic Utilization Rate (HUR), expressing the ratio of design flow to capacity in percentage terms (values above 100% indicate overload). These indicators enable comparison among sections and identification of critical zones.

D. Interpretation Criteria

Results were interpreted through a clear operational logic: a section is compliant when its calculated capacity is greater than or equal to the design flow (Qcapacity ≥ Qdesign). Conversely, when capacity is lower (Qcapacity < Qdesign), the section is considered vulnerable and resizing is recommended. This approach ensures clarity and provides a rational basis for technical proposals.

3. Results

The analysis of the three axes highlights strong heterogeneity in channel performance. Calculations based on Manning's equation and diagnostic indicators (HVI and HUR) show that some sections have sufficient capacity, while others are highly vulnerable, with utilization rates sometimes exceeding 1,000%.

Boulevard du 30 Juin exhibits both under-utilized and heavily overloaded sections, confirming the need for section-based analysis and targeted resizing (Table 1). Boulevard Lumumba shows a majority of vulnerable sections, with only two compliant, illustrating variability in hydraulic functioning and the need for selective interventions (Table 2). Avenue Kasa-Vubu presents a marked contrast between one highly vulnerable section and one compliant section, while several require data verification for complete evaluation (Table 3).

Table 1 presents the hydraulic diagnostic results for the four sections of Boulevard du 30 Juin, comparing calculated capacities with design flows.

The results reveal strong heterogeneity: Section T1 is under-utilized, while Sections T2 to T4 are heavily overloaded, with Hydraulic Utilization Rates (HUR) exceeding 300% and even reaching 1,099%. This confirms the need for section-by-section analysis and targeted resizing.

Table 2 summarizes the hydraulic performance of the seven sections of Boulevard Lumumba.

The majority of sections (T1 to T4 and T6) are vulnerable, with Hydraulic Utilization Rates (HUR) exceeding 300%. Only Sections T5 and T7 exhibit acceptable capacity or reserve. This contrast illustrates the variability of hydraulic functioning and highlights the need for selective interventions.

Table 3 presents the available results for the five sections of Avenue Kasa-Vubu.

Section T1 is highly vulnerable (HUR = 487.89%), while Section T5 is compliant with a substantial reserve capacity. Sections T2 to T4 require data verification. This situation highlights the importance of completing field surveys to achieve a comprehensive evaluation.

The overall results obtained for the three axes studied reveal strong hydraulic heterogeneity. On Boulevard du 30 Juin, one section is under-utilized while the others are heavily

Table 1
Hydraulic capacities and vulnerabilities of Boulevard du 30 Juin sections

Section	Capacity (m^3/s)	Design Flow (m^3/s)	HUR (%)	Interpretation
T1	9.04	32.025	33.46	Under-utilized section, reserve capacity
T2	3.64	37.09	1,018.96	Very high vulnerability, resizing required
T3	8.37	25.26	301.96	High vulnerability
T4	7.97	87.63	1,099.50	Critical vulnerability

Source: Authors, 2026

Table 2
Hydraulic performance of Boulevard Lumumba sections

Section	Observed Situation	HUR (%)	Interpretation
T1	Severely undersized	> 300	Very high vulnerability
T2	Severely undersized	> 300	Very high vulnerability
T3	High vulnerability	329.33	Insufficient capacity
T4	High vulnerability	329.33	Insufficient capacity
T5	Near saturation but compliant	95.86	Acceptable section
T6	Critical vulnerability	601.37	Urgent resizing required
T7	Reserve capacity	72.04	Compliant section

Source: Authors, 2026

Table 3
Hydraulic capacities and vulnerabilities of avenue Kasa-Vubu sections

Section	Observed Situation	HUR (%)	Interpretation
T1	High vulnerability	487.89	Largely insufficient capacity, resizing required
T2	Incomplete data	—	Verification required
T3	Incomplete data	—	Verification required
T4	Incomplete data	—	Verification required
T5	Compliant section	23.03	Capacity largely exceeding design flow

Source: Authors, 2026

overloaded. Boulevard Lumumba shows a majority of vulnerable sections, with only two compliant. Finally, Avenue Kasa-Vubu illustrates a marked contrast between one highly vulnerable section and one compliant section, while several require data verification.

This diversity of situations confirms that the performance of drainage networks cannot be assessed through a uniform approach; rather, it must be analyzed section by section, taking into account hydrological inflows and slope variations.

4. Discussion of Results

The discussion highlights that the hydraulic vulnerability of Kinshasa's drainage networks is highly localized and depends on sub-basin inflows, longitudinal profiles, and the quality of hydrological data. These findings are consistent with recent studies on the impact of rapid urbanization and poor infrastructure maintenance.

A. Localized Vulnerability and Sub-Basin Inflows

The results show that some sections are compliant, while others are heavily overloaded. This heterogeneity aligns with the observations of Didine et al. (2025), who reported that more than 60% of Kinshasa's channels are either absent or obstructed, and that sub-basin inflows exacerbate local imbalances. Similarly, Bahavira et al. (2025) demonstrated that rapid urbanization in the Lukaya basin led to a 22.4% increase in peak discharge and a reduction in response time, confirming the importance of localized inflows in section vulnerability.

B. Role of Longitudinal Profiles

Sectional subdivision based on slope changes is supported by the literature. Wayawaya et al. (2026) showed that interannual variability in precipitation in the Funa basin, combined with longitudinal profiles, strongly influences hydrological response and flood frequency. Thus, sectional analysis isolates critical zones more effectively than a global approach.

C. Need for Coupled Hydrological Modeling

The HVI and HUR indicators provide an initial assessment, but their relevance depends on the reliability of design flows. The literature emphasizes the importance of coupling hydraulic diagnosis with robust hydrological modeling. For example, the hybrid rainfall–discharge and machine learning approach applied to the Funa basin improved flood forecasting and integrated climate uncertainties (Wayawaya et al., 2026).

D. Limits of Theoretical Capacity

Capacity calculated using Manning's equation does not always reflect actual operational capacity. Sediment deposits, waste, and obstructions reduce the effective cross-section, as confirmed by Didine et al. (2025), who attributed more than 70% of drainage dysfunctions in Kinshasa to poor maintenance and weak urban governance. These findings are consistent with international recommendations stressing the need to integrate operational and maintenance conditions into infrastructure evaluation (UN-Habitat, 2014).

In sum, the results of this study align with trends observed in Kinshasa and other African cities: hydraulic vulnerability is highly localized, depends on longitudinal profiles and sub-basin inflows, and must be analyzed in connection with robust hydrological modeling. Accounting for real operating and maintenance conditions is essential to transform theoretical calculations into operational solutions.

5. Conclusion and Recommendations

The findings of this study demonstrate that drainage networks in north-central Kinshasa are characterized by pronounced hydraulic heterogeneity, with sections alternating between compliance and severe vulnerability. The sectional hydraulic approach proved effective in identifying critical points and proposing resizing solutions tailored to local conditions. This methodological choice underscores the inadequacy of uniform sizing strategies in complex urban environments subject to differentiated hydrological inflows.

From an operational perspective, the results highlight the urgent need for targeted interventions. Sections with Hydraulic Utilization Rates exceeding 100% require immediate resizing to restore functionality and mitigate flood risks. Equally important is the establishment of systematic maintenance programs to address obstructions and sedimentation, alongside the regular updating of hydrological data to reflect rapid urbanization and changing rainfall patterns. These measures would ensure that theoretical capacities translate into effective operational performance.

Beyond technical adjustments, the study points to broader research and governance implications. Future work should integrate dynamic hydrological modeling to anticipate transient flows and climate-induced extremes, while interdisciplinary approaches combining hydraulics, urban planning, and social sciences could enrich understanding of infrastructure–society interactions. The development of participatory digital tools, such as collaborative GIS and citizen monitoring platforms, offers promising avenues for strengthening integrated and sustainable management of Kinshasa's drainage networks.

A. Operational Recommendations Include

From an operational standpoint, the most urgent priority is the resizing of sections where Hydraulic Utilization Rates (HUR) exceed 100%, as these areas are structurally incapable of accommodating design flows. Targeted resizing must be complemented by systematic maintenance programs to mitigate capacity losses caused by sediment deposits, solid waste, and frequent obstructions. Equally critical is the routine verification of outlets and discharge points, since upstream improvements alone cannot resolve downstream bottlenecks. These measures ensure that interventions are not only corrective but also preventive, reducing the recurrence of localized flooding.

In addition, the reliability of hydraulic performance depends on the continuous updating of hydrological data and runoff coefficients to reflect rapid urbanization and increasing surface impermeability. Stationary calculations, while useful, should be reinforced by dynamic modeling capable of capturing transient effects and localized overloads. Such integration provides a more realistic representation of drainage network behavior under variable rainfall conditions and enhances the capacity of planners to anticipate risks. Together, these operational strategies form a rational framework for strengthening the resilience and sustainability of Kinshasa's urban drainage systems.

B. Future Research Perspectives

Future research should first focus on the integration of dynamic and predictive hydrological models to better anticipate urban floods and assess the safety margins required for drainage infrastructure. Such models would allow planners to capture transient flows, incorporate climate variability, and improve the reliability of hydraulic diagnoses. In parallel, it is essential to investigate the impact of climate change on rainfall extremes, particularly their frequency and intensity, in order to adapt design criteria to evolving hydrological realities. This line of inquiry ensures that drainage systems remain resilient under future climatic conditions.

A second major area involves the development of interdisciplinary approaches that combine hydraulics, urban planning, and social sciences. These approaches would deepen understanding of the interactions between infrastructure, land-use practices, and governance, thereby linking technical performance to socio-institutional contexts. Complementing this, the promotion of participatory digital tools, such as collaborative GIS and citizen monitoring platforms, offers promising pathways to strengthen integrated and sustainable management of Kinshasa's drainage networks. Together, these three directions advanced modeling, climate impact assessment, and interdisciplinary governance form a coherent agenda for future research.

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