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RESEARCH ARTICLE

DIAGNOSIS AND PROPOSAL OF A STORMWATER DRAINAGE NETWORK FOR THE N'DAKRO EXTENSION DISTRICT (BOUAKÉ, CÔTE D'IVOIRE): AN INTEGRATED SOCIO-HYDROLOGICAL AND HYDRAULIC APPROACH

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ABSTRACT

Rapid urbanisation in West African cities exacerbates stormwater management problems. This study aimed to diagnose the state of stormwater drainage in the N'Dakro Extension district of Bouaké, Côte d'Ivoire, and to propose a suitable drainage network. A field survey of 271 residents, combined with watershed delineation using QGIS and Global Mapper and flow estimation using the Caquot method, was conducted. The results show that the district lacks adequate infrastructure: 85% of residents rely on natural infiltration, while runoff has damaged 30% of roads and 22% of property. Peak flows calculated at the two main outlets are 118.94 m³/s and 40.45 m³/s, respectively, for a 10-year return period. Hydraulic design using the Manning–Strickler formula (Ks = 60) resulted in primary collector sections of 4 × 2 m and 3 × 1 m. Implementing this network, alongside community involvement, could significantly reduce flooding and erosion in this peripheral district.

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INTRODUCTION

Accelerated urbanisation in West Africa poses a major challenge for stormwater management. Cities in the Gulf of Guinea are experiencing rapid population and spatial growth, often exceeding the capacity of existing sanitation infrastructure (UNDP, 2016; ASTEE, 2017). In Côte d'Ivoire, only twelve urban centres have a sanitation master plan, and the programmes included in these plans remain largely unimplemented (ONAD, 2019). This situation results in recurrent flooding, road deterioration and increased health risks in peripheral neighbourhoods. In Bouaké, the country's second-largest city, the stormwater drainage network remains very limited. Streams and low-lying areas act as primary collectors, while only paved roads are equipped with drains, which are often blocked by solid waste (TED/ERGEC, 2013; CREPA-CI, 2002). N'Dakro Extension, located in the south-western part of the city, illustrates these shortcomings: drainage structures are almost entirely absent, construction is unplanned, and wastewater is discharged directly into the natural environment.

Several studies conducted in West Africa have demonstrated the effectiveness of the Caquot method for designing urban stormwater drainage networks in tropical settings (Andrianisa, 2014; Ouedraogo, 2014; Savadogo, 2019). This approach, suitable for catchments smaller than 200 ha, incorporates the runoff coefficient, slope and catchment shape. It has been successfully applied in similar settings in Burkina Faso, Benin and Niger (Vitegni, 2015; Diallo, 2019; Rachidatou, 2019). The present study had two objectives: (i) to diagnose the current state of stormwater evacuation in N'Dakro Extension through a field survey; and (ii) to propose a drainage network designed using conventional hydrological and hydraulic methods (Caquot and Manning–Strickler). The findings are intended to provide local authorities with a decision-support tool for improving residents' living conditions.

MATERIALS AND METHODS

Study area: Bouaké is located 372 kilometres from Abidjan. It is the departmental capital of the Gbèkè Region and covers an area of 312 km². This study focuses on N'Dakro Extension, a

district of Bouaké. The district is located between latitudes 841500 and 852500 m North and longitudes 264000 and 275000 m West, in the south-west of the city of Bouaké (Figure 1).

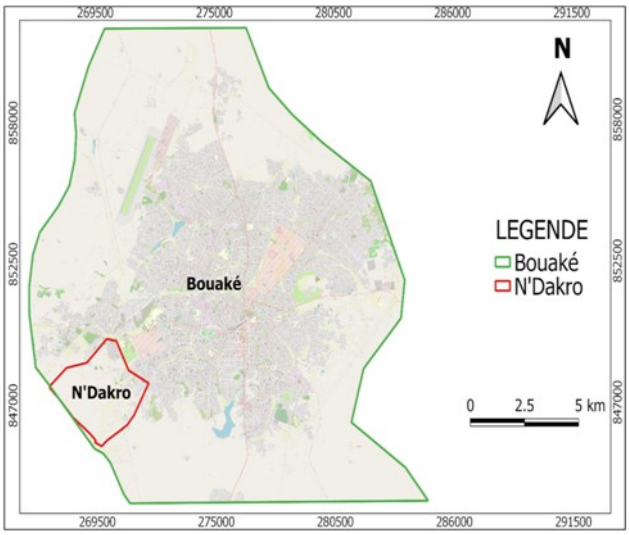


Figure 1. Location of the study area

Field survey

Hydrological analysis: The catchments were delineated from a digital elevation model using Global Mapper and QGIS. Sixty-one elementary sub-catchments were digitised. Their morphometric characteristics (area, longest hydraulic flow path and mean slope) were calculated. Runoff coefficients were assigned according to land use (Satin and Selmi, 1999). Peak flows were estimated using the Caquot formula:

$$Q = m \times K \times I^{u} \times C^{v} \times A^{w}$$

where Q is the flow rate (m^3/s), I is the slope (m/m), C is the runoff coefficient, A is the area (km^2), m is the shape coefficient, and K, u, v and w are regional coefficients for a 10-year return period (K = 2.03; u = 0.22; v = 1.15; w = 0.83), adapted to the Bouaké region (Akossi, 2011). The elementary catchments were combined in series or in parallel to obtain equivalent flows at the outlets.

Hydraulic analysis: The collectors were sized using the Manning–Strickler formula:

$$Q = K_s \times S \times R_h^{2/3} \times I^{1/2}$$

where Ks = 60 (concrete), S is the wetted cross-sectional area and Rh is the hydraulic radius. A rectangular cross-section was selected because it is easy to construct and maintain. Flow velocities were checked ($0.5 \text{ m/s} \leq V \leq 4 \text{ m/s}$), and the flow regime was assessed using the Froude and Reynolds numbers. Reinforced concrete lining was selected for its durability (Mounirou, 2017).

RESULTS

Current situation and residents' perceptions

Stormwater management: The survey of residents in N'Dakro Extension revealed major shortcomings in stormwater management. According to the results, 85% of respondents stated that water is evacuated through natural infiltration, without specific infrastructure, while 12% reported that no intervention was undertaken and fewer than 1% mentioned infiltration wells (Figure 2). These findings indicate that purpose-built structures to control runoff are largely absent. However, the effectiveness of natural infiltration depends on soil permeability and rainfall intensity (Figure 2).

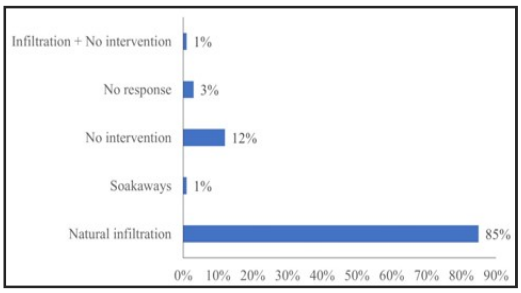


Figure 2. Stormwater evacuation methods in N'Dakro Extension

Stormwater evacuation conditions: Residents' perceptions confirm these difficulties: 59% consider stormwater evacuation conditions unsatisfactory, 21% regard them as acceptable, and 20% expressed no opinion (Figure 3). This majority dissatisfaction highlights the need to improve the evacuation system. However, these perceptions must be considered alongside the site's physical characteristics to identify the causes of operational problems (Figure 3).

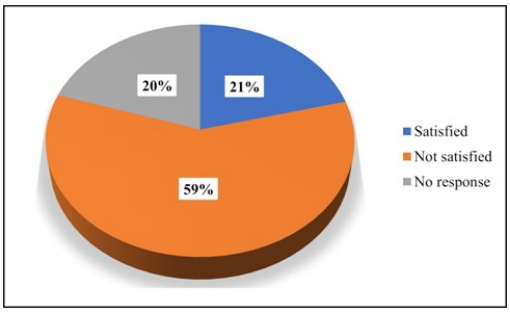


Figure 3. Stormwater evacuation conditions

Problems and causes of stormwater evacuation: The analysis of reported problems shows that the absence of drainage structures is a major difficulty, cited by 72% of respondents (Figure 4). In addition, 69% of respondents identify the lack of drainage infrastructure as the main cause of evacuation problems. The consistency between these findings highlights the central role of inadequate infrastructure in the difficulties reported by residents. It suggests that stormwater runoff is not managed by a sufficiently structured system to collect, convey and discharge water to suitable outlets. In the absence of a coherent system, runoff may flow along roads, accumulate in low-lying areas and cause ponding or erosion.

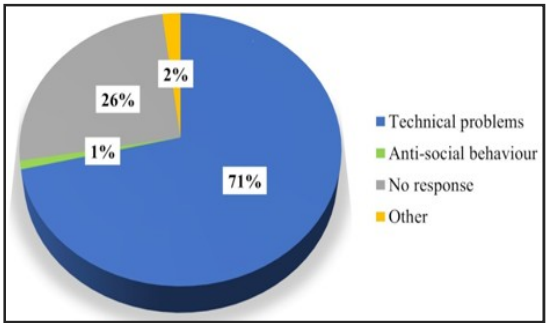


Figure 4. Problems experienced by residents

Damage associated with stormwater evacuation problems and proposed solutions: The main types of damage reported were road destruction (30%) and property damage (22%) (Figure 5). In addition, 71% of respondents believe that this damage can be prevented, while 72% identify the construction of drainage structures as the priority solution (Figure 5). These findings show that residents recognise the consequences of inadequate drainage and strongly support infrastructure improvements. To be effective, these structures must be designed on the basis of the neighbourhood's hydrological characteristics, particularly contributing areas and peak flows.
Field observations also confirmed poor sanitary conditions: wastewater from showers and latrines is discharged directly into the receiving environment, informal waste dumps are present, and structured drainage channels are absent.

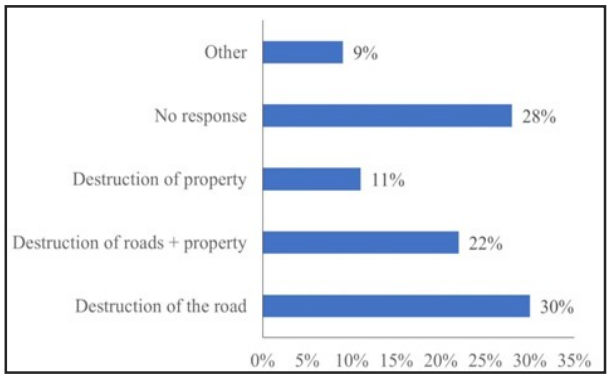


Figure 5. Damage associated with drainage problems

Catchment characteristics: Two main catchments drain the district: C1 (705 ha) and C2 (230 ha). Table 1 presents their morphometric characteristics. The district was divided into 61 elementary sub-catchments, with areas ranging from 2 to 73 ha, hydraulic flow-path lengths from 76 to 1,147 m, and slopes from 0.009 to 0.262. Runoff coefficients, determined according to land use, range from 0.2 for natural areas to 0.8 for densely built-up areas.

Table 1. Characteristics of the main catchments

Catchment	Area (ha)	Perimeter (m)	Lh (m)	Zmin (m)	Zmax (m)	Slope I
BV1	705	12 764	3 555.15	320	360	0.01
BV2	230	8 307	2 124.50	350	400	0.02

Peak flows: After calculating elementary flows using the Caquot method and combining the catchments in series or in parallel, equivalent flows at the outlets were estimated at 118.94 m³/s (outlet 1) and 40.45 m³/s (outlet 2) for a 10-year return period.

Flows from individual sub-catchments range from 0.29 m³/s to 24.90 m³/s.

Collector sizing

A rectangular cross-section was selected. The proposed network comprises two primary collectors, six secondary collectors and 41 tertiary collectors. Their total lengths are 515 m (primary), 3,315 m (secondary) and 14,436 m (tertiary).
Table 2 presents the characteristics of the main collectors after sizing and velocity adjustment. Initially calculated velocities (up to 15.3 m/s) were reduced to a maximum of 4 m/s to prevent scour. Reynolds numbers (> 10^5) and Froude numbers (0.65–2.35) indicate flow regimes ranging from subcritical turbulent to supercritical turbulent. Subcritical turbulent flow was favoured to improve structural stability.

Table 2. Characteristics of the main collectors after adjustment

Reach	Q (m³/s)	Width B (m)	Flow depth Y (m)	Height H (m)	Velocity Va (m/s)	Flow regime
C51 (exut. 1)	118,94	7,81	3,90	4,20	4,00	Subcritical turbulent
C21 (exut. 2)	40,45	4,59	2,29	2,59	4,00	Subcritical turbulent
C13-18-55	35,13	4,28	2,14	2,44	4,00	Subcritical turbulent
C15-14-2-12	29,67	3,94	1,97	2,27	4,00	Subcritical turbulent
C22-7-11	21,56	3,37	1,69	1,99	4,00	Subcritical turbulent
C3	18,74	3,15	1,57	1,87	4,00	Subcritical turbulent

DISCUSSION

The results confirm the significant lag in stormwater drainage provision in the peripheral districts of Bouaké, consistent with national observations (ONAD, 2019; CREPA-CI, 2002). The lack of infrastructure and the disposal of waste into the few existing drains aggravate flooding, as documented in other Ivorian and West African cities (Ouattara *et al*., 2023a; Ouattara *et al*., 2023b).

The Caquot method, widely used in French-speaking Africa (Andrianisa, 2014; Savadogo, 2019), proved suitable for the morphometric conditions of N'Dakro Extension (sub-catchments smaller than 200 ha and slopes within the method's application range).

The resulting flows are consistent with those reported in comparable studies in Burkina Faso and Benin (Vitegni, 2015; Diallo, 2019). The rectangular cross-section and reinforced concrete were selected to address construction and maintenance constraints in a context of limited resources (Mounirou, 2017).

Nevertheless, the network's long-term performance will depend on community involvement. The surveys indicate strong demand for drainage structures, but also limited awareness of how public infrastructure should be used (Coulibaly and Bally, 2025). Awareness-raising activities and regular maintenance are essential to prevent collector blockage.

The study's limitations include the absence of in-situ flow measurements and the use of estimated runoff coefficients. Local rainfall and hydrometric monitoring campaigns would help refine the calculations. Despite these limitations, the technical proposal provides a sound basis for planning drainage investments.

CONCLUSION

The assessment of N'Dakro Extension highlights a critical lack of stormwater drainage infrastructure, contributing to road deterioration, erosion and health risks. Hydrological and

hydraulic calculations were used to design a network capable of conveying the 10-year peak flows (118.94 m³/s and 40.45 m³/s). Implementing this network, together with active community involvement and regular maintenance, would help improve living conditions in a sustainable manner. Similar studies in other districts of Bouaké are recommended to support an integrated approach to urban drainage.

DECLARATION OF CONFLICTS OF INTEREST: The authors declare that they have no conflicts of interest.

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LIST OF ABBREVIATIONS

PNUD: United Nations Development Programme (UNDP)
ASTEE: Scientific and Technical Association for Water and the Environment
ONAD: National Office for Sanitation and Drainage
TED/ERGEC: Technology, Economics and Development / Civil Engineering Studies and Projects
CREPA-CI: Regional Centre for Drinking Water Supply and Low-Cost Sanitation in Côte d'Ivoire
QGIS: QGIS (geographic information system software)
BV: Catchment

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