Analysis of Water Point Management and Maintenance Systems in Tropical Environments: Case Study of Okola Municipality (Cameroon, Central Africa)

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Abstract

Rural water infrastructure sustainability in Sub-Saharan Africa is significantly hindered by weak management and maintenance systems. This study assessed water point governance in Okola Municipality, Cameroon, to identify factors affecting infrastructure sustainability and evaluate maintenance practices. Using a mixed-methods approach—field observations, household surveys (n = 80), and interviews across 12 villages—data were collected on 38 facilities (28 boreholes, 10 wells) and analyzed through descriptive statistics, Chi-square tests, and SWOT analysis. Findings show that 50% of facilities were non-functional ($\chi^2 = 12.4$, $p < 0.01$), resulting in only 26% water coverage. Management structures were largely inadequate: 57% of water points lacked committees, and 58% of existing committees were untrained ($p < 0.05$). Conflicts were common, with 75% involving users and committees, and 35% related to operational issues. India Mark II pumps dominated (64%), while pump aging explained 62% of failures. Financial management was also weak, as only 43% of committees kept operational accounts and none established renewal funds. Overall, results indicate that current maintenance practices are insufficient to ensure sustainable service delivery. Strengthening preventive maintenance, improving financial transparency, and building stakeholder capacity are essential. Cost-benefit analysis suggests that raising annual household contributions from 6,000 to 12,045 FCFA would significantly improve long-term sustainability.

Keywords: Borehole maintenance, rural water supply, community management, hand pumps, Sub-Saharan Africa, water governance

Highlights

- 50% of rural water points non-functional, with only 26% coverage rate, forcing communities to rely on unsafe surface water sources.
- 57% of water points lack management committees; 58% of existing committees untrained, revealing critical governance gaps.
- Financial sustainability severely compromised—no committees maintain equipment renewal funds, 72% of spending allocated to reactive repairs.
- Doubling household contributions from 6,000 to 12,045 FCFA annually required for sustainable operations and preventive maintenance.
- User-committee conflicts (75% prevalence) primarily driven by financial opacity, with 85% of committees never publishing financial statements

1. Introduction

Access to safe drinking water is widely recognized as a fundamental human right and remains central to Sustainable Development Goal 6.1, which targets universal and equitable access by 2030 (WHO & UNICEF, 2023). Despite notable global progress, Sub-Saharan Africa continues to face persistent disparities in water access, with rural populations being disproportionately affected (WHO & UNICEF, 2025). Cameroon exemplifies these regional inequalities, as nearly 35% of rural inhabitants still lack access to improved drinking water sources (WHO & UNICEF, 2023). In most rural areas, hand-pumped boreholes and modern wells constitute the dominant water supply technologies; however, their sustainability remains highly uncertain due to recurrent breakdowns, governance weaknesses, and insufficient post-construction support (Foster et al., 2018; Mvongo& Defo, 2024).

Across Sub-Saharan Africa, an estimated 30–40% of rural water points become non-functional within five years of installation (Foster et al., 2019), contributing to persistent service gaps and heightened vulnerability to waterborne diseases. In Cameroon, recent studies have demonstrated that system failures commonly stem from inadequate maintenance structures, aging infrastructure, limited community participation, weak tariff systems, and insufficient technical support (Mvongo et al. 2022a; Mvongo et al., 2019). Recent assessments in the Mvila Division demonstrate that one out of three handpumps is inoperable (32.61% non-functionality rate), resulting in approximately 1.3 billion FCFA (approximately 2 million USD) in immobilized investments that generate no benefits for affected rural communities (Mvongo et al., 2023). Studies in Mvangan show functionality rates of 69% for wells and 73% for boreholes, though isolated studies across various Cameroonian councils reveal that 10-60% of rural drinking water supply systems are non-functional or do not function optimally (Mvongo et al., 2022b; Mvongo & Defo, 2021; Mvongo et al., 2019). This work further highlights the importance of integrating socio-institutional diagnostics with technical assessments to better understand the sustainability challenges affecting rural drinking water services.

Within this context, Community-Based Management (CBM) has long been promoted as the dominant governance model for rural water supply. It emphasizes local ownership, participatory decision-making, cost recovery, and the establishment of Water User Associations or Water Point Management Committees (Harvey & Reed, 2007; Lockwood & Smits, 2011). Nevertheless, evidence shows that CBM remains difficult to operationalize: governance capacity, preventive maintenance, financial sustainability, and access to external technical support continue to determine success or failure (Hutchings et al., 2015; Moriarty et al., 2013). The broader "functionality crisis" observed across the sector highlights structural weaknesses, notably insufficient preventive maintenance, poor financial management, and fragmented institutional responsibilities (Foster, 2013). These dynamics are also reflected in findings from the Mvila Division that emphasize chronic underfinancing, inadequate training of rural water committees, and the weak functionality of Water Point Committees as primary barriers to sustainability (Mvongo et al., 2022a).

Although several studies have investigated water point performance in Cameroon (Mvongo et al., 2022a, 2022b, 2022c, 2023; Ndongo et al., 2012a), few have provided an integrated analysis combining technical, institutional, and financial dimensions. Comprehensive assessments remain particularly limited in the Central Region, where rural communities experience rapid demographic changes and increasing pressure on water infrastructure. Moreover, evidence-based maintenance strategies incorporating cost and financial sustainability analysis are largely absent from existing research.

The present study contributes to addressing these gaps by analyzing the management systems underpinning rural water points in Okola Municipality. Specifically, it examines the distribution of drinking water supply facilities, infrastructure functionality, governance performance, financial resource mobilization, and conflict dynamics within local management structures. In addition, it develops an evidence-based maintenance strategy supported by cost-benefit analysis to strengthen long-term service sustainability.

Overall, the study provides practical insights for national policymakers, development organizations, and local authorities seeking to improve rural water service reliability. By integrating technical diagnostics, institutional governance analysis, and financial modeling, it offers a holistic perspective on the constraints affecting water point sustainability and outlines context-appropriate solutions applicable to similar settings across Central Africa.

2. Materials and Methods

2.1 Study Area

Okola Municipality (4°04' N, 11°25' E) covers an estimated surface area of 605 km² in the Centre Region of Cameroon, approximately 30 km north of Yaoundé. Administratively, the municipality consists of 74 villages grouped under four second-degree chieftaincies, with a population estimated at about 65,000 inhabitants according to the most recent census projections (INS, 2017). Settlement patterns are predominantly rural, characterized by dispersed households and small village clusters typical of the forested southern plateau.

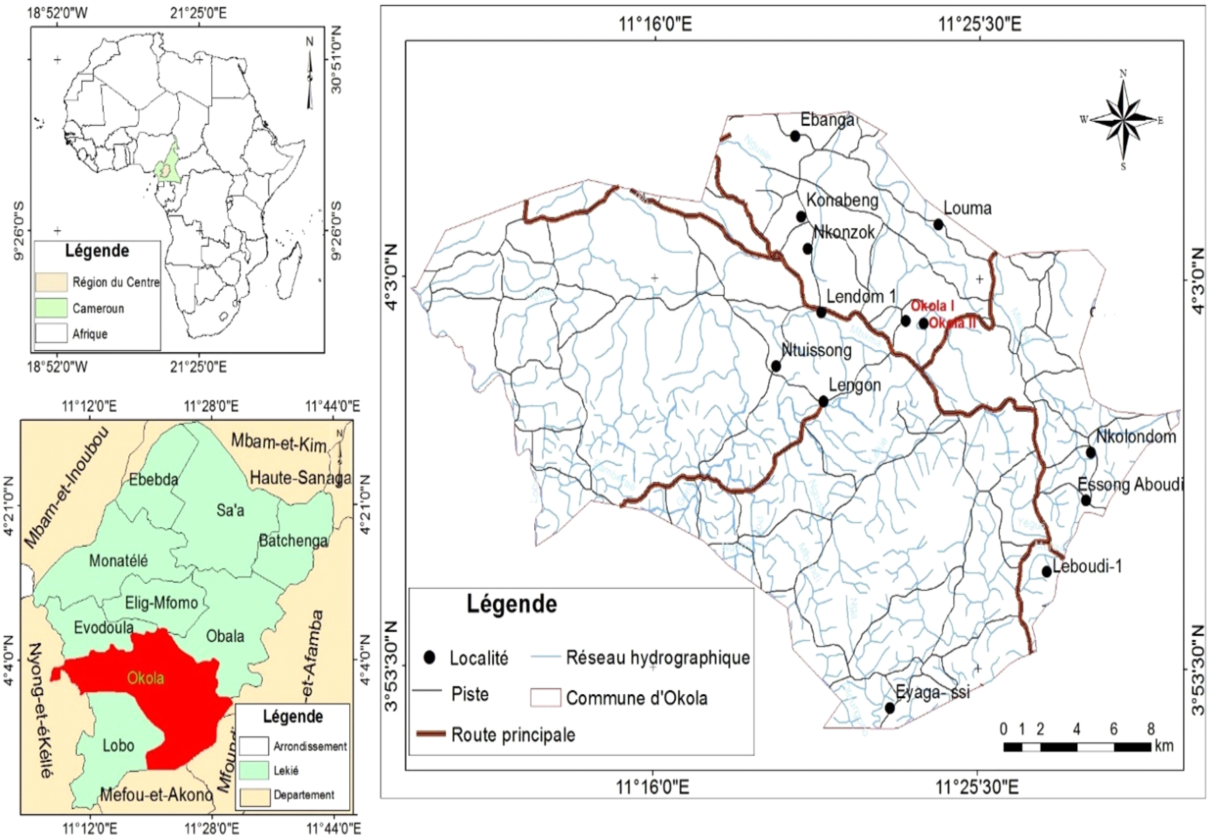

Figure 1. Location of Okala Council

The municipality lies within the Guinean-equatorial climatic zone, marked by a bimodal rainfall regime with two rainy seasons and two dry seasons. Annual precipitation averages 1,577 mm, while mean temperatures remain relatively stable around 25°C throughout the year. These climatic conditions, combined with dense hydrographic networks and deep weathered soils, favor the development of productive aquifers that serve as the main water source for rural populations.

Water supply systems in Okola exhibit a strong urban–rural divide. The urban centre is served by a mini-adduction system abstracting surface water from the Nyong River, providing piped water to a limited number of households and public facilities. In contrast, the vast majority of rural communities rely almost exclusively on groundwater accessed through hand-pumped boreholes and modern wells. A baseline assessment conducted in 2011 identified 17 existing drinking water points, of which 12 were functional and 5 non-functional, revealing both low coverage and pronounced spatial disparities across villages. This uneven distribution continues to influence water access patterns and underscores the need for updated diagnostic assessments and strategic planning.

2.2 Research Design

This cross-sectional study adopted a mixed-methods design integrating quantitative, qualitative, and technical assessment components to provide a comprehensive understanding of rural water service performance. Data collection was conducted between June and September 2024, a period that captures both peak rainy-season conditions and transitional phases relevant for evaluating water accessibility and infrastructure reliability. The quantitative component consisted of structured household surveys designed to assess user experiences, service continuity, water management practices, and system functionality. These were complemented by qualitative interviews with key stakeholders—including traditional authorities, water committee members, local council officials, pump mechanics, and school representatives—to explore governance dynamics, maintenance arrangements, and contextual drivers of service sustainability. In parallel, technical field assessments were performed on water points and associated infrastructure to document operational status, design characteristics, maintenance history, and potential environmental or structural risks. Together, these integrated methods provided robust triangulation and enhanced the validity of the study's findings.

2.3 Sampling Strategy

The sampling strategy combined purposive village selection with systematic household sampling to ensure both representativeness and analytical relevance. A total of twelve villages—corresponding to 16.2% of all settlements in the municipality—were purposely selected based on three objective criteria: (i) the presence of at least one functional or recently constructed modern water supply system (boreholes equipped with handpumps, standpipes, or small piped schemes); (ii) a balanced spatial distribution across the four second-degree chieftaincies, allowing the study to capture intra-municipal variability in service performance; and (iii) year-round physical accessibility, particularly during the rainy season, when several rural localities become partially isolated. This approach ensured inclusion of both centrally located and peripheral villages reflecting diverse hydrogeological, socio-economic, and governance contexts. The selected villages were: Legon, Ntuisson, Ebanga, Beleguié, Louma, Nkolodom, Eyaga-ssi, Leubouti, Konabeng, Nkong Zock, Lendom, and Essong Aboudi.

Within each village, households were selected using a systematic random sampling procedure to obtain a representative subset of water point users. A sampling interval was computed based on the estimated number of households per village, after which every k-th household was visited following a randomly determined starting point. In total, 80 households were surveyed—corresponding to an average of approximately seven households per village—which provided a sufficiently large and spatially distributed sample for capturing variability in user experiences, management practices, and functionality of water systems.

The sample size was determined using a conservative assumption of 50% prevalence of water management challenges, a 95% confidence level, and an 11% margin of error, parameters commonly recommended for exploratory rural water governance studies in data-scarce environments. This ensured adequate statistical power for estimating proportions related to functionality, cost recovery, and community participation while maintaining feasibility within logistical constraints.

2.4 Data Collection

Data collection relied on a multi-instrument approach designed to capture both user-level experiences and institutional dimensions of water service delivery. Structured household questionnaires were administered to document water access patterns, user satisfaction, breakdown frequency, financial contributions, and perceived management challenges. These were complemented by semi-structured interviews with Water Point Management Committees (WPMCs), which provided detailed insights into governance arrangements, tariff-setting practices, maintenance procedures, and committee functionality.

In addition, technical assessment forms were used to evaluate the physical condition, operational status, and design characteristics of water points, enabling systematic documentation of infrastructure performance and potential risk factors. Finally, interviews with municipal authorities captured information on institutional responsibilities, availability of technical documentation (e.g., borehole logs, inspection reports), budgetary constraints, and the mechanisms—formal or informal—through which maintenance support is provided to communities. This combination of tools ensured triangulated, multi-scalar evidence on the factors shaping water service sustainability.

2.5 Operational Definitions

Water Point Status:

The operational condition of each water point was categorized using a three-tier classification system to ensure consistent technical assessment across sites. A "Good" status indicated that all structural and mechanical components were fully functional and exhibited no signs of significant wear or deterioration. A "Poor" status referred to water points that remained operational but showed notable degradation—such as reduced discharge, worn pump components, or compromised structural elements—suggesting a heightened risk of imminent failure. Finally, a "Broken" status was assigned to non-operational water points unable to deliver water due to mechanical failure, structural collapse, or prolonged abandonment. This classification provided a robust basis for evaluating infrastructure performance and prioritizing maintenance needs.

Coverage Rate:

Coverage was evaluated by comparing the number of functional water points to the population they serve, using the national guideline of one functional water point per 300 inhabitants as a benchmark. This indicator allowed the study to assess adequacy of service provision, identify areas of undercoverage, and highlight communities where existing infrastructure does not meet population demand.

2.6 Data Analysis

Quantitative data were entered, cleaned, and analyzed using SPSS version 25, following standard statistical procedures to ensure accuracy and reliability. Descriptive statistics were computed to summarize key variables, while Chi-square tests were applied to examine associations between infrastructure performance, management factors, and user-reported challenges, using a significance threshold of $p < 0.05$.

The analysis incorporated three core indicators derived from established rural water supply assessment methodologies:

- Water Point Need: Bp = (N/300) × 100, where N represents the population of the locality and 300 the recommended population per functional water point.
- Coverage Rate: Tc = (Npf/Bp) × 100, where Npf is the number of functional water points.
- Functionality Rate: Tf = (Npf/Npt) × 100, where Npt is the total number of existing water points.

Qualitative data from stakeholder interviews were transcribed and subjected to thematic coding, allowing the identification of recurrent patterns related to governance, maintenance systems, and institutional support. Spatial analysis was conducted using ArcGIS 10.8, which enabled the mapping of water point locations, their functionality status, and coverage disparities across the municipality. This integrative analytical approach ensured robust triangulation between quantitative, qualitative, and spatial evidence.

3. Results

3.1 Water Supply Infrastructure and Distribution

3.1.1 Water Source Typology

The field inventory documented a total of 38 modern water supply facilities across the twelve surveyed villages, comprising 28 boreholes equipped with handpumps (73.7%) and 10 modern wells (26.3%). Despite this relatively high concentration of improved water infrastructure, data from the household survey revealed substantial variability in water sourcing behaviors. Notably, 50% of respondents (40 out of 80) reported relying on surface water sources—including streams and natural springs—either as their primary source or as a supplementary option when improved facilities were inaccessible or non-functional (Table 1).

Table 1. Water Source Distribution and User Patterns

Water Source Type	Number of Facilities	Percentage	Users Surveyed (n=80)	Percentage
Boreholes	28	73.7%	28	35.0%
Modern wells	10	26.3%	12	15.0%
Surface water/springs	-	-	40	50.0%
Total	**38**	**100%**	**80**	**100%**

The continued heavy dependence on unimproved surface water sources—despite the presence of modern water infrastructure—highlights persistent challenges related to functionality, reliability, accessibility, and user trust. This disconnect suggests that existing facilities may experience frequent breakdowns, seasonal shortages, long queuing times, or governance constraints limiting effective use. Such reliance on untreated water exposes communities to heightened risks of waterborne diseases, underscoring the need for improved maintenance systems, strengthened local governance, and targeted investments to enhance the sustainability and performance of rural water services.

3.1.2 Water Point Functionality Assessment

Classification of water points by operational status revealed major infrastructure performance constraints across the study area. Of the 38 water points assessed during the field inventory (figure 2).

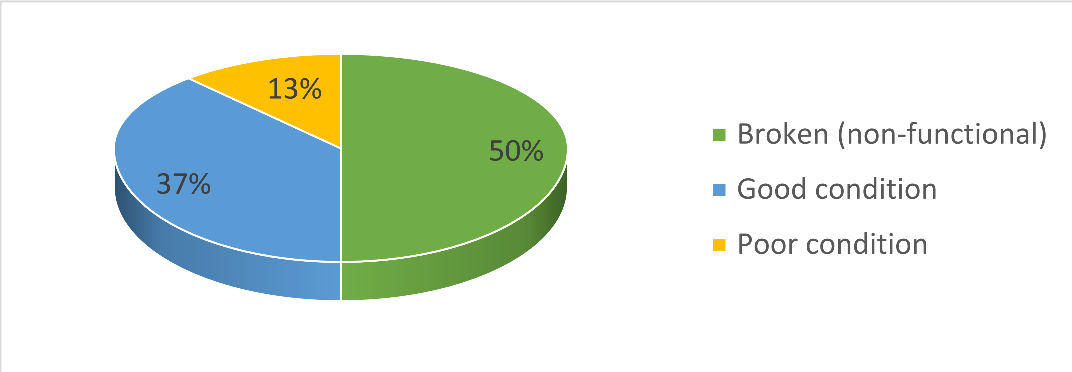

Figure 2. Classification of water points by operational status

This distribution indicates that half of all facilities were completely non-operational, demonstrating a severe decline in service reliability. A Chi-square test confirmed a statistically significant deviation from an expected equal distribution ($\chi^2 = 12.4$, df = 2, $p < 0.01$), with the number of broken facilities significantly higher than those in good or poor condition.

Table 2. Water Point Functionality by Infrastructure Type

Status	**Boreholes (n=28)**	**Wells (n=10)**	**Total (n=38)**	**Percentage**
Good	11	3	14	36.8%
Poor	3	2	5	13.2%
Broken	14	5	19	50.0%
Functionality Rate	**50.0%**	**50.0%**	**50.0%**	-

When disaggregated by infrastructure type, results reveal that both boreholes and modern wells exhibited identical functionality rates of 50%, suggesting that performance issues transcend technology choice. Chi-square analysis ($\chi^2 = 0.18$, $p = 0.91$) confirmed no statistically significant difference between the two technologies. This pattern points to system-wide constraints, likely rooted in maintenance gaps, weak governance structures, limited spare-part availability, and inadequate financial mechanisms rather than deficiencies inherent to specific water supply technologies. These findings align with evidence from the Mvila Division, where 46% of handpumps are in good condition, 12% require repairs, and 31% need reconstruction, with similar patterns observed across both boreholes and wells (Mvongo et al., 2022a).

These findings underscore the urgent need for institutional strengthening, preventive maintenance, and improved support systems to enhance the long-term sustainability of rural water infrastructure.

3.1.3 Water Coverage Analysis

Based on the recommended service standard of one water point per 300 inhabitants, the coverage assessment reveals substantial and widespread deficits across the municipality (Table 3). Out of an estimated population of 65,000 inhabitants, a total of 215 functional water points would be required to meet basic service thresholds. However, only 54 functional point-equivalents are currently available, translating to a municipality-wide coverage of just 26%. This gap illustrates a profound mismatch between infrastructure needs and existing service provision.

At the village level, disparities are equally striking. Coverage rates range from 11.8% in Legon, where only 2 functional points serve over 5,000 residents, to approximately 33% in Beleguié and Essong Aboudi, which nonetheless remain far below acceptable standards. Most villages operate at less than one-third of the minimum required capacity, reflecting chronic underinvestment, recurrent breakdowns, and limited expansion of water infrastructure.

Such persistent deficits force communities to rely heavily on unimproved or unsafe alternative sources—primarily shallow wells, springs, and surface water bodies—thereby increasing exposure to waterborne diseases and undermining progress toward universal access. The findings highlight an urgent need for strategic investments targeting both infrastructure expansion and the rehabilitation of non-functional water points to close the existing service gap.

Table 3. Water Coverage Assessment by Village

Village	Population	Required Points	Functional Points	Coverage Rate (%)
Legon	5,200	17	2	11.8%
Ntuisson	4,800	16	5	31.3%
Ebanga	6,100	20	4	20.0%
Beleguié	5,500	18	6	33.3%
Louma	4,200	14	3	21.4%
Nkolodom	5,800	19	5	26.3%
Eyaga-ssi	4,900	16	4	25.0%
Leubouti	5,300	18	5	27.8%
Konabeng	6,500	22	7	31.8%
Nkong Zock	7,200	24	5	20.8%
Lendom	4,600	15	3	20.0%
Essong Aboudi	4,900	16	5	31.3%
Total	**65,000**	**215**	**54**	**26.0%**

3.2 Institutional and Governance Analysis

3.2.1 Water Point Management Committee Status

Governance assessment revealed substantial institutional weaknesses affecting the sustainability of rural water services. As shown in Table 4, only 43% of the assessed water points had an established Water Point Management Committee (WPMC), a proportion significantly lower than the expected baseline of 50% ($\chi^2 = 7.89$, $p < 0.01$). Conversely, 57% of water points operated without any formal management structure, reflecting a major governance gap with direct implications for functionality and maintenance. This governance deficit mirrors patterns documented across Cameroon's rural water sector, where weak functionality of Water Point Committees and poor post-construction monitoring constitute primary barriers to sustainability (Mvongo et al., 2022a, 2022b, 2022c).

Among the 16 existing WPMCs, performance indicators further highlight systemic limitations. Fewer than half of the committees (42%) had received any form of training, a statistically significant deviation from an expected even distribution ($\chi^2 = 4.0$, $p < 0.05$). Only 31% reported holding regular meetings, and a mere 25% possessed written bylaws—elements considered fundamental for transparency, accountability, and long-term planning. These findings align with evidence from the Mvila Division showing that approximately 60% of functional WPCs have only an approximate knowledge of their prerogatives and partially fulfill them, while none are capable of repairing small breakdowns or maintaining handpumps due to lack of toolboxes or locally trained technicians (Mvongo et al., 2022a).

Critically, the absence of WPMCs was strongly associated with non-functionality of water points ($\chi^2 = 9.3$, $p < 0.01$), underscoring the centrality of local governance structures in ensuring system reliability. Furthermore, inadequate committee training exhibited a strong positive correlation with poor financial management practices ($r = 0.67$, $p < 0.01$), suggesting that capacity building remains a key determinant of effective operation and maintenance. These findings collectively point to the urgent need for strengthened governance frameworks, professionalization of community management structures, and targeted training programs to enhance the sustainability of water services.

Table 4. Management Committee Characteristics

Indicator	**Number**	**Percentage**	**Statistical Test**
Water points with WPMCs	16	43%	χ^2=7.89, p<0.01*
Water points without WPMCs	22	57%	
Among existing WPMCs (n=16)			
Trained committees	7	42%	χ^2=4.0, p<0.05*
Untrained committees	9	58%	
Committees with regular meetings	5	31%	-
Committees with written bylaws	4	25%	-

*Significant deviation from expected 50% distribution

3.2.2 Stakeholder Roles and Responsibilities

The stakeholder analysis identified six primary actor groups, each with clearly defined but insufficiently coordinated roles within the rural water supply governance system. These include:

- **State actors** (MINEE Departmental Delegation, Sub-Prefecture), responsible for policy oversight, enforcement of technical standards, and issuance of construction permits;
- **Municipal authorities**, tasked with infrastructure planning, partial financing, and overall coordination of service delivery;
- **Water Point Management Committees (WPMCs)**, in charge of day-to-day operations, fee collection, and minor maintenance activities;
- **Local maintenance technicians**, who provide curative repairs and technical diagnostics;
- **Water users**, whose responsibilities revolve around tariff payment, safeguarding facilities, and adhering to usage rules;

- **Development partners** (PNDP, FEICOM, UNICEF), contributing through capital investments, technical assistance, and capacity-building interventions.

Despite this structured distribution of responsibilities, interview data highlight pervasive fragmentation in stakeholder coordination. A substantial 68% of WPMCs reported insufficient technical support from the municipality, particularly during recurrent breakdowns. Additionally, 82% cited significant delays in response to fault reports, reflecting systemic communication gaps and limited institutional accountability. These coordination challenges reflect systemic institutional weaknesses affecting Cameroon's water sector, including weak coordination among government institutions, functional overlaps between MINEE and other ministries, and a centralized top-down policy approach that concentrates decision-making at central and regional levels rather than empowering local authorities (Mvongo et al., 2022c). The inadequate technical support is further exacerbated by insufficient qualified technical personnel and weak financial resources at both the council and state levels. These findings underscore the need for strengthened multi-actor coordination mechanisms, clearer role delineation, and improved technical backstopping to enhance the reliability and sustainability of water service delivery.

3.3 Financial Management Analysis

3.3.1 Revenue Generation and Fund Management

Water pricing across the municipality remains standardized at 500 FCFA per household per month (equivalent to 6,000 FCFA annually), applied uniformly at all functional water points. Despite this apparent consistency in tariff policy, substantial variation exists in the financial management practices of Water Point Management Committees (WPMCs), as detailed in Table 5.

More than half of the committees (57%) reported having operational bank accounts and formally designated treasurers, yet only 19% produced regular financial reports—a critical component of transparency and accountability. Alarmingly, none of the committees-maintained savings accounts or dedicated funds for equipment renewal, exposing water points to significant financial vulnerability in the event of major breakdowns requiring capital-intensive repairs. Only 13% had set aside emergency funds for urgent repair needs, indicating limited capacity for rapid response.

For the 43% of committees without formal financial accounts, revenue handling was conducted informally by treasurers without any mechanisms for verification or traceability. Such arrangements heighten the risk of mismanagement, leakage of funds, and reduced community trust.

Estimated annual revenue per functional water point—approximately 180,000 FCFA (calculated based on 30 households paying 500 FCFA monthly)—may be adequate to cover minor curative repairs. However, this amount remains insufficient to support routine preventive maintenance or periodic equipment replacement.

The low tariff structure observed in Okola mirrors patterns documented across the Mvila Division, where financial flows generated by water sales are very low and do not permit adequate maintenance of water points (Mvongo et al., 2023). This situation is exacerbated by the absence of a water-selling culture, as the principle of payment for water appears in opposition to the shared values of equatorial forest peoples. Free water is associated with the representation that water is a gift from nature; therefore, it is considered an inalienable resource that must be accessible to all (Mvongo et al., 2022b). Additionally, the presence of other water points where access to water is free (traditional wells and undeveloped springs) tends to have a negative impact on water demand from modern water points where access is chargeable.

In rural areas of the Mvila Division, social ties are strong and linked to kinship and neighborhood relationships, making it difficult to refuse to provide water to a relative or neighbor who cannot afford it (Mvongo et al., 2023). Furthermore, for a long time, the State gave free water to the populations and it is now becoming very difficult to make users pay for the water service. This absence of the culture of selling water coupled with limited user capacity to pay determines the overall willingness of users to pay for water services.

These findings underscore the need for strengthened financial governance, structured savings mechanisms, capacity-building interventions to enhance long-term financial sustainability of rural water systems, and culturally sensitive approaches to tariff-setting that acknowledge local socio-economic contexts while ensuring adequate cost recovery.

Table 5. Financial Management Capacity of WPMCs

Financial Management Indicator	Number (n=16)	Percentage
Committees with operational accounts	9	57%
Committees with documented treasurer	9	57%
Committees providing regular financial reports	3	19%
Committees with savings accounts	0	0%
Committees with equipment renewal funds	0	0%
Committees with repair emergency funds	2	13%

3.3.2 Expenditure Patterns

Among the nine committees that maintained documented financial accounts, expenditure patterns reveal a strong bias toward short-term, crisis-driven spending. The distribution of expenses shows that:

- 72% of total expenditure was devoted to curative repairs,
- 15% to administrative and operational costs,
- 8% to preventive maintenance activities, and
- 5% to committee training and routine meetings.

The predominance of curative repair spending reflects a highly reactive maintenance model, where financial resources are mobilized only after system failure has occurred. In contrast, the very limited investment in preventive maintenance (8%) underscores insufficient efforts to protect and prolong asset lifespan. This imbalance accelerates mechanical wear, increases the frequency of breakdowns, and ultimately raises long-term operational costs. Moreover, the minimal allocation to training and governance activities (5%) further limits the capacity of committees to implement effective asset management practices.

This reactive approach contrasts sharply with international best practices, which demonstrate that preventive maintenance programs can reduce long-term expenditure by 30-40% while extending equipment lifespan (Foster, 2013). Collectively, these trends highlight the urgent need to shift from a corrective to a preventive maintenance culture to ensure the sustainability and resilience of water infrastructure.

3.4 Conflict Dynamics in Water Management

Analysis of user surveys and WPMC interview data revealed two major categories of conflicts, each with distinct patterns and underlying drivers (Table 6). User–WPMC conflicts accounted for the majority of reported cases (75%), while operational conflicts occurring directly at water points represented 35% of the total. The difference in prevalence between these two conflict types was statistically significant ($\chi^2 = 25.6$, $p < 0.001$), indicating that governance-related tensions far outweigh operational disputes.

User–WPMC conflicts were primarily driven by issues of financial opacity (48%), followed by disputes related to abusive water use (35%) and fee enforcement (17%). Qualitative interview findings further revealed that 85% of committees did not publish financial statements, a practice that deeply undermines trust and diminishes user willingness to pay monthly fees. These results highlight the central role of transparent financial management in maintaining community confidence and service continuity.

Operational conflicts, though less frequent, emerged mainly from queue management problems (64%) and disputes over water allocation (36%), reflecting pressure on limited water infrastructure and inadequate user organization mechanisms.

Cross-tabulation analysis demonstrated a strong association between committee training and conflict levels: trained committees experienced 40% fewer user-related conflicts compared to untrained committees ($\chi^2 = 7.2$, $p < 0.01$). This finding underscores the importance of capacity building as a key strategy to reduce social tensions, enhance accountability, and improve overall governance of rural water points.

Table 6. Conflict Types and Distribution

Conflict Type	**Frequency Reported**	**Percentage**	**Primary Causes Identified**
User-WPMC conflicts	60	75%	Financial opacity (48%), Abusive water use (35%), Fee enforcement (17%)
Operational conflicts (at water point)	28	35%	Queue management (64%), Water allocation disputes (36%)
Total conflicts reported	**80***	-	-

*Multiple conflicts reported by same respondents

3.5 Technical Infrastructure Assessment

3.5.1 Hand Pump Technology Analysis

Technical diagnostics revealed the presence of four hand pump brands across the 28 surveyed boreholes, each exhibiting varying but generally low levels of functionality (Table 7). India Mark II pumps were the most widely installed (64%), largely due to their relatively low procurement cost and greater local availability of spare parts. Despite this predominance, overall functionality across all brands remained limited: India Mark II (55.6%), Vergnet (50.0%), SWN80 (50.0%), and Volanta (0%).

Statistical analysis showed no significant difference in functionality rates across pump types ($\chi^2 = 2.1$, $p = 0.55$), indicating that the choice of technology was not the primary factor influencing system performance. Instead, the findings suggest that maintenance quality, supply chain consistency, and local operational practices play a more decisive role in determining pump reliability. This observation aligns with findings from the Mvila Division, which showed that India Mark II pumps constitute 97.22% of installed handpumps, with no significant difference in functionality rates between different pump types (Mvongo et al., 2023).

Further analysis of pump selection criteria revealed that technicians placed strong emphasis on technical specifications (72%) and VLOM certification (21%), reflecting a supply-driven approach to technology choice. However, factors such as community preference, local repairability, and long-term sustainability received minimal attention during procurement and installation. This misalignment between technical decision-making and community needs may contribute to reduced user ownership, lower fee compliance, and ultimately shorter system lifespans.

Overall, the results underscore the necessity of integrating technical performance considerations with community participation, context-specific maintenance capacity, and adaptive technology selection to improve long-term functionality outcomes.

Table 7. Hand Pump Distribution and Functionality

Pump Brand	Number Installed	Percentage	Functional	Non-Functional	Functionality Rate
India Mark II	18	64%	10	8	55.6%
Vergnet	4	14%	2	2	50.0%
SWN80	4	14%	2	2	50.0%
Volanta	2	8%	0	2	0%
Total	**28**	**100%**	**14**	**14**	**50.0%**

3.5.2 Failure Analysis

The comprehensive technical evaluation of the 14 non-functional hand pumps revealed several recurrent failure modes (Table 8), providing valuable insights into the underlying drivers of system breakdowns. Pump aging and generalized mechanical wear constituted the most frequent cause, accounting for 62% of failures, with an average operational lifespan of 8.2 ± 2.1 years prior to major breakdown. This lifespan is significantly below the expected 15–20 years design life typically associated with these models, highlighting the cumulative effects of inadequate preventive maintenance and irregular servicing.

Other failure modes included broken pipes or connecting rods (21%), often linked to excessive mechanical stress and delayed corrective repairs, and cylinder wear (14%), reflecting long-term abrasion from suspended particles and poor seal maintenance. Pump depriming was reported in 7% of cases, usually resulting from improper installation or prolonged disuse. Additionally, missing components (14%) were identified in some units, pointing to theft, vandalism, or incomplete repairs.

Several pumps exhibited multiple simultaneous causes of failure, underscoring the complex and interconnected nature of mechanical deterioration when routine maintenance is absent. These findings align with evidence from the Mvila Division, where technical diagnostics showed that the main causes of handpump non-functionality are mechanical defects such as broken pipes, corroded pumps, worn cylinders, and pump aging, alongside pump theft and technician bricolage causing cylinder drops (Mvongo et al., 2023).

Furthermore, technical challenges are compounded by the weak structuring of the handpump maintenance chain. The lack of repair artisans and the absence of spare parts sales outlets in rural areas lead to increased repair duration and costs. The main points of sale for handpump spare parts are typically in major urban centers (Yaoundé and Douala), and the sale of spare parts in rural areas is not commercially viable (Harvey & Reed, 2004). The correlation between the spare parts supply chain, the cost of repairs, and the duration of breakdowns has been demonstrated previously by several authors (University of Colorado Boulder, 2020) in different countries in Sub-Saharan Africa.

Overall, the dominance of aging-related failures and premature wear indicates that strengthening preventive maintenance regimes, ensuring timely part replacement, improving technical supervision, and restructuring the spare parts supply chain are essential to extend pump longevity and reduce system downtime.

Table 8. Causes of Pump Failure

Failure Cause	Frequency	Percentage	Mean Age at Failure (years)
Pump aging/wear	9	62%	8.2 ± 2.1
Broken pipes/rods	3	21%	5.7 ± 1.8
Cylinder wear	2	14%	6.3 ± 1.5
Pump depriming	1	7%	3.2
Missing components	2	14%	-

*Multiple causes identified for some pumps

3.5.3 Water Quality and Productivity

The evaluation of water quality was severely constrained by the absence of historical testing records, which prevented any comprehensive assessment of potability. In the absence of microbiological or physicochemical data, user perceptions served as the primary basis for judging water quality, relying mainly on organoleptic criteria such as visual clarity (absence of ferric iron staining), taste, and odor. This reliance on subjective indicators underscores a critical monitoring gap, given that many contaminants of public health concern—particularly fecal bacteria, nitrates, and heavy metals—are not detectable through sensory evaluation alone.

The absence of systematic water quality monitoring in Okola represents a critical vulnerability documented across Cameroonian river basins, where studies demonstrate progressive quality degradation from upstream to downstream due to increased wastewater discharge, agricultural expansion, and inadequate sanitation infrastructure (Defo et al., 2022). In the Kienké watershed (Southern Cameroon), analysis revealed that water quality deteriorates from upstream to downstream, with DCO and nitrate concentrations exceeding maximum admissible concentrations according to national standards. While concentrations of most parameters remained below regulatory thresholds, the discharge of untreated wastewater rich in nitrogen and phosphorus could lead to eutrophication and reduced biodiversity, as observed in several Cameroonian coastal river basins where water hyacinth (Eichhornia crassipes) has become a national challenge (Ndongo et al., 2012b).

Flow rate measurements from the functional water points ranged between 0.5 and 1.0 m^3/h, which falls within acceptable performance thresholds for hand pump systems designed to serve approximately 300 users with a daily demand of 25 liters per capita. Nevertheless, 23% of functional pumps exhibited declining yields, a trend that may signal emerging aquifer stress, progressive clogging of the borehole, or deficiencies in routine mechanical and hydrogeological maintenance.

These findings highlight the urgent need for establishing systematic water quality monitoring protocols and implementing regular borehole rehabilitation measures to ensure both safe and reliable water service delivery.

4. Discussion

4.1 Infrastructure Functionality Crisis and Public Health Implications

The 50% non-functionality rate documented in Okola Municipality significantly exceeds regional averages and is broadly consistent with alarming trends reported across Sub-Saharan Africa, where systematic reviews estimate that 30–40% of rural water points fail within five years of installation (Foster et al., 2019). However, Okola's performance appears more severe than continental averages and is comparable to the 83% failure rate reported in Sahelian Cameroon by Hassana (2010). Although slightly better than the 70% failure rate documented in South Cameroon by Dang (2016), the situation nonetheless reflects a deep and persistent infrastructure reliability crisis.

Recent assessments in the Mvila Division (Southern region of Cameroon) demonstrate that one out of three handpumps is inoperable (32.61% non-functionality rate), with approximately 1.3 billion FCFA (approximately 2 million USD) in investments immobilized, generating no benefits for affected rural communities (Mvongo et al., 2023). The average functionality rate across eight councils in the Mvila Division ranged from 21.43% in Mengong to 40.54% in Ebolowa I, with most councils experiencing non-functionality rates between 25% and 40%. At the national level, based on estimates of non-functionality, approximately 25 billion FCFA (approximately 38 million USD) invested in the construction of water points are immobilized and do not generate any benefit. This widespread non-functionality directly jeopardizes progress toward SDG 6.1, which aims for universal and equitable access to safe drinking water.

Particularly concerning is the finding that half of surveyed households still rely on surface water, despite the presence of improved systems. Numerous Cameroonian studies have established strong associations between surface water consumption and high prevalence of waterborne diseases—including diarrheal infections, typhoid fever, and cholera (Defo et al., 2015). Although epidemiological data were not collected in this study—a key limitation—the observed water access patterns with substantial surface water reliance suggest a likely elevated disease burden in the municipality.

The overall 26% water coverage rate falls far below both national policy benchmarks and international standards, demonstrating a pronounced service gap that demands urgent corrective measures. Spatial analysis revealed striking inequities, with coverage varying widely from 11.8% in Legon to 33.3% in Beleguié. Such disparities raise important environmental justice concerns, indicating that remote or socioeconomically marginalized communities remain disproportionately underserved. Addressing these inequalities will require targeted investment strategies, improved governance mechanisms, and context-specific interventions to expand safe water access across the municipality.

4.2 Governance Deficits and the Community-Based Management Paradox

The finding that 57% of water points operate without established management committees represents a fundamental challenge to Cameroon's community-based management (CBM) policy framework. This governance shortfall exceeds the 50% rate reported by Hassana (2010) in Maroua, yet remains lower than the 70% documented by Dang (2016) in Mvangan, indicating significant regional disparities in the effectiveness of CBM implementation across the country.

These results vividly illustrate what Lockwood and Smits (2011) describe as the "CBM implementation gap"—the persistent disconnect between policy formulation and on-the-ground practice. While CBM is theoretically designed to enhance local ownership, accountability, and service sustainability, its success hinges on sustained capacity-building, structured post-construction support, and realistic financial and technical expectations (Moriarty et al., 2013; Hutchings et al., 2015). In Okola, the finding that 58% of committees lack training strongly suggests that post-construction support mechanisms are either inadequate or inconsistently applied.

The governance challenges in Okola reflect systemic patterns across Cameroon's rural water sector, where economic, institutional, managerial, and technical factors interdependently influence service sustainability (Mvongo et al., 2022a). These include: (i) low economic viability of water point management due to insufficient revenue generation; (ii) weak functionality of Water Point Committees, with approximately 60% having only approximate knowledge of their prerogatives and partially fulfilling them; (iii) poorly structured handpump maintenance chains characterized by lack of repair artisans and absence of spare parts outlets; and (iv) poor post-construction monitoring of WPCs, resulting in low functionality, lack of real revenue collection, low willingness to pay, and absence of transparency in management.

The study's statistical evidence reinforces these governance concerns. The significant association between committee absence and water point non-functionality ($\chi^2 = 9.3$, $p < 0.01$), as well as between training status and conflict prevalence ($\chi^2 = 7.2$, $p < 0.01$), demonstrates that institutional capacity is a direct determinant of service reliability and social stability. These findings align with recent calls to transition from traditional CBM toward "professionalized community management" models, whereby community ownership is complemented by regular technical assistance from service authorities (Naughton, 2017).

At the institutional level, the political context of decentralization does not yet favor better management of water services (Mvongo et al., 2022c). Indeed, the State has transferred competences to councils without, however, providing them with the material, financial, and human resources necessary to provide water service. Their own financial resources are almost non-existent, and they depend on external financial resources, in particular the Communal Additional Centimes (CAC). However, the latter is insufficient and often arrives late in council accounts. In addition, the application of the principle of single funds practiced in Cameroon does not favor the rapid provision of financial resources to councils.

4.3 Financial Sustainability and the Real Cost of Water Services

The universal absence of equipment renewal funds among Okola WPMCs represents a critical financial sustainability failure, echoing broader challenges documented across West African rural water sectors (Naughton, 2017). The current 500 FCFA monthly household contribution generates approximately 180,000 FCFA annually per water point—manifestly insufficient for comprehensive lifecycle costs.

This study's financial modeling demonstrates that sustainable service provision requires household contributions of 12,045 FCFA annually (doubling current levels) when accounting for: preventive maintenance, equipment renewal amortization, committee remuneration, administrative costs, and contingency funds. This doubling aligns with IRC's (2015) findings in Burkina Faso's Sahel region, where similar cost-recovery analyses revealed 100-150% tariff increases necessary for financial sustainability.

However, significant affordability concerns emerge. At 12,045 FCFA annually, water expenditure would represent approximately 2-3% of average rural household income in Central Cameroon—within WHO affordability guidelines (≤3% of income) but potentially burdensome for poorest households. This raises equity questions requiring policy attention, potentially through: (1) pro-poor tariff structures with cross-subsidization, (2) partial government operational subsidies for remote communities, or (3) payment flexibility mechanisms.

The low tariff structure observed in Okola mirrors patterns documented across the Mvila Division, where financial flows generated by water sales are very low and do not permit adequate maintenance of water points (Mvongo et al., 2022a). This situation is exacerbated by a strong absence of the culture of selling water. Indeed, the principle of payment for water appears in opposition to the shared values of the peoples of the equatorial forest (Mvongo et al., 2022b). Free water is associated with the representation that water is a gift from nature. Therefore, it is considered an inalienable resource that must be accessible to all. In addition, the presence of other water points where access to water is free (traditional wells and undeveloped springs) tends to have a negative impact on water demand from modern water points where access is chargeable.

Furthermore, social ties in rural areas of the Mvila Division are strong and are linked to kinship and neighborhood relations. It is, therefore, difficult to refuse to provide water to a relative or neighbor who cannot afford it. This absence of the culture of selling water coupled with the capacity of users to pay for the water service determines the willingness of the user to pay for water.

The 72% expenditure allocation toward curative repairs versus only 8% for preventive maintenance illustrates classic "breakdown-and-fix" approaches that ultimately increase lifecycle costs. International evidence demonstrates that preventive maintenance programs reduce long-term expenditure by 30-40% while extending equipment lifespan (Foster, 2013). Transitioning to proactive maintenance requires initial investment in technician training, spare parts stocking, and regular inspection protocols—currently absent in Okola.

Funding for rural water services in Cameroon comes from three sources: tariffs, taxes, and transfers, known as the "three Ts" (Mvongo et al., 2022c). Tariffs come from revenue or contributions from the sale of water that WPCs collect from households using the water points. Taxes are typically the largest source of funding for rural water service. The taxes are collected, distributed, and transferred to councils by the Special Fund for Equipment and Inter-municipal Intervention (FEICOM) in the form of Communal Additional Centimes (CAC). Transfers involve funding from abroad in the form of Official Development Finance (ODF), NGO contributions, and remittances. However, in many areas, tariffs are very low and do not allow maintenance of water points, while transfers are often absent. Thus, the financing of handpump maintenance essentially depends on the CACs that municipalities receive each quarter. However, this funding simply does not arrive at the indicated frequency, which does not favor the efficient implementation of handpump maintenance strategies.

4.4 Conflict Dynamics and Governance Transparency

The 75% prevalence of user-WPMC conflicts, predominantly driven by financial opacity, underscores governance transparency as fundamental to community management success. This finding corroborates recent research emphasizing that citizen trust depends critically on transparent resource management and accountability mechanisms (Krah & Mertens, 2023). The 85% of committees never publishing financial statements represents a clear accountability failure.

Qualitative evidence suggests these conflicts erode social capital essential for collective action, creating vicious cycles: opacity reduces trust, reducing willingness to pay, reducing revenue, reducing service quality, further eroding trust. Breaking this cycle requires institutionalized transparency through: mandatory quarterly financial reporting, community validation meetings, and external auditing mechanisms.

Evidence from across Cameroon demonstrates that factors affecting the functionality of handpumps include the low economic viability of water point management, the weak functionality of WPCs, and the weak structuring of the pump maintenance chain. The main managerial factor identified is the weak functionality of WPCs. Indeed, among WPCs that work, about 60% have only an approximate knowledge of their prerogatives (missions) and only partially fulfill them. No WPC is capable of repairing small breakdowns or maintaining handpumps since they do not have a toolbox or locally trained technicians. In addition, councils and decentralized state services have numerous shortcomings (weak financial resources, insufficiently qualified technical personnel, etc.), which are the cause of poor post-construction monitoring of WPCs and result in their low functionality, the lack of real collection of revenue from the sale of water, the low willingness of populations to pay for water, and the lack of transparency in management.

The gender dimension of water governance, though not explicitly examined in this study, warrants consideration. International evidence demonstrates that women's inclusion in WPMCs improves financial transparency and user satisfaction (Gross et al., 2018). Future research should examine gender composition of Okola committees and its influence on governance outcomes.

4.5 Technical Considerations and Technology Choice

The 64% prevalence of India Mark II pumps reflects pragmatic decision-making prioritizing spare parts availability and procurement costs. However, the absence of functionality differences across pump brands (p=0.55) suggests maintenance practice, not technology choice, determines sustainability—consistent with global literature (Harvey and Reed, 2007). This finding is further reinforced by evidence from the Mvila Division showing that India Mark II pumps constitute 97.22% of handpumps, with no significant difference in functionality rates across different brands (Mvongo et al., 2023).

The 62% of failures attributable to pump aging, with mean operational life (8.2 years) far below design specifications (15-20 years), provides compelling evidence that inadequate preventive maintenance accelerates deterioration. This pattern mirrors findings from comprehensive pump audits across East Africa and West Africa (Baumann, 2006). In the Mvila Division, analysis of handpump functionality data showed that the functionality rate of pumps decreases with age: 93% for pumps less than 5 years old, 86% for pumps 5-10 years old, and 52% for pumps more than 10 years old. Diagnostic of non-functional pumps revealed that causes of dysfunction are principally due to mechanical failures such as broken pipes, pump corrosion, worn cylinders, and pump aging (Mvongo & Defo, 2025).

Furthermore, technical challenges are significantly compounded by corrosion of handpumps due to non-compliance with quality standards. Studies reveal that some stainless-steel parts are attacked by corrosion, causing malfunctions requiring major repairs only a few years after construction. Research conducted on six samples of handpump parts in Burkina Faso revealed that five of the six dewatering columns and two of the four rods do not comply with international standards for the composition of stainless steel of the grade indicated (Danert, 2019). The same challenges have been documented in Cameroon, where the extent of this phenomenon remains to be determined but represents a risk to achieving SDG 6 (Mvongo, 2025).

The weak structuring of the pump maintenance chain constitutes a major technical barrier to functionality. The lack of repair artisans and the absence of spare parts sales outlets in rural areas lead to increased repair duration and costs. The main points of sale for handpump spare parts are typically in major urban centers (Yaoundé and Douala). In addition, the sale of spare parts in rural areas in Sub-Saharan Africa and in most developing countries is not commercially viable (Harvey & Reed, 2004). The correlation between the spare parts supply chain, the cost of repairs, and the duration of breakdowns has been demonstrated previously by several authors (University of Colorado Boulder, 2020) in different countries in Sub-Saharan Africa. However, investing in professionalized maintenance of handpumps can reduce repair times to less than 2 days (Foster et al., 2022). Reduced repair times save households money on alternative water sources during breakdowns, which can add up to an amount equal to the initial capital outlay by governments and donors.

The complete absence of water quality testing documentation represents a serious limitation for public health protection. While organoleptic assessment provides crude indicators, systematic microbiological and chemical monitoring remains essential, particularly given Cameroon's documented groundwater contamination issues in some regions (Defo et al., 2016). The absence of systematic water quality monitoring represents a critical vulnerability documented across Cameroonian watersheds, where studies demonstrate progressive quality degradation from upstream to downstream due to increased wastewater discharge, agricultural expansion, and inadequate sanitation infrastructure (Defo et al., 2022). Establishing routine water quality surveillance should constitute a priority intervention.

4.6 Climate Risk and Environmental Sustainability

Climate risk represents an emerging threat to water service sustainability in Okola, particularly for wells and springs that are more vulnerable to climate variability. Although not explicitly measured in this study, regional assessments indicate that services risk being impacted by future climate change through modifications in monthly rainfall patterns and strong variations in water table levels (Ndongo et al., 2012b).

In the Mvila Division, climate risk assessment revealed that 70% of services (those relying on wells and springs) risk being impacted by climate change. Currently, they are not yet subject to the effects of climate change but are likely to be impacted by future effects such as modifications of monthly rains during dry seasons, which induce strong variations in the level of the water table (Mvongo et al., 2022a). One of the consequences of climate change in coastal river basins of Cameroon is the modification of monthly rainfall during dry seasons, inducing strong variations in water table levels (Ndongo et al., 2012b).

The impact of climate change on water services has been highlighted by Yopo et al. (2015), and Ndongo et al. (2012b). Studies in the Sahel region of Cameroon have demonstrated the vulnerability of water supply systems to climate risks, particularly drought and declining groundwater recharge (Yopo et al., 2015).

Adaptation strategies to enhance climate resilience should include: (i) diversification of water source types to reduce vulnerability; (ii) investment in deeper boreholes capable of accessing lower aquifer levels; (iii) rainwater harvesting systems as supplementary sources during dry seasons; (iv) watershed protection and reforestation to enhance groundwater recharge; and (v) development of contingency plans for drought periods.

4.7 Limitations and Research Implications

Beyond limitations acknowledged in methodology, several additional caveats warrant discussion:

Temporal dynamics: This cross-sectional assessment cannot capture seasonal functionality variations or long-term institutional evolution. Longitudinal research tracking committee performance and infrastructure status over multiple years would provide richer insights.

Causality: While statistical associations emerged between governance factors and functionality, establishing causal mechanisms requires experimental or quasi-experimental designs, potentially comparing communities receiving intensive capacity building interventions against controls.

Generalizability: Okola's proximity to Yaoundé may influence results through better market access, higher literacy, or greater exposure to governance norms. Replication in more remote municipalities would test finding transferability.

Governance quality measurement: This study employed basic indicators (committee existence, training status). Future research should develop and validate comprehensive governance quality indices incorporating transparency, accountability, participation, and conflict resolution mechanisms, building on frameworks such as the Water Service Sustainability Index (WSSI) which consists of 21 indicators grouped into six dimensions: economic, environmental, social, technical, institutional, and governance (Mvongo et al., 2021).

Water quality assessment: The absence of systematic water quality testing represents a significant limitation. Future studies should incorporate comprehensive physicochemical and microbiological analyses to establish baseline water quality profiles and identify contamination risks.

Gender dimensions: The study did not systematically examine the role of gender in water governance. Future research should explore women's participation in WPMCs, gender-specific water collection burdens, and the influence of gender composition on committee performance and financial transparency.

5. Conclusions

This comprehensive assessment of water point management in Okola Municipality reveals a rural water sector in acute distress, marked by 50% infrastructure non-functionality, profound governance weaknesses, chronic financial unsustainability, and significant public health risks. With coverage at only 26%, the municipality falls far short of national policy targets and international standards, compelling nearly half of households to rely on unsafe surface water sources and exposing communities to preventable disease burdens.

Four key findings emerge with strong implications for policy and practice:

First, the widespread governance deficit—57% of water points lacking management committees and 58% of existing committees untrained—demonstrates that Cameroon's community-based management (CBM) framework remains largely aspirational. Achieving genuine community ownership will require mandatory pre-construction institutional development, standardized multi-phase training modules, and sustained post-construction technical and administrative support, moving away from the prevailing "construct-and-abandon" approach.

Second, the complete absence of equipment renewal funds and the heavy dependence on curative, crisis-triggered maintenance (72% of committee expenditure) reveal a structurally unsustainable financing model. Transitioning toward preventive maintenance will require incremental tariff adjustments (e.g., from 6,000 to 12,045 FCFA per household per year), strengthened financial transparency, and potential operational subsidies for the poorest communities—particularly where revenue potential is structurally low.

Third, the predominance of user-committee conflicts (75% of all conflicts, driven largely by financial opacity) highlights that governance transparency is not simply a normative principle but an operational necessity. Institutionalizing annual financial reporting, community validation forums, and periodic external audits would markedly enhance accountability and user trust.

Fourth, the finding that 62% of pump failures stem from aging and mechanical wear, with an average operational lifespan of only 8.2 years—far below the 15–20-year design expectation—demonstrates that inadequate maintenance practices, rather than technological shortcomings, are the primary drivers of the functionality crisis. Technology choice therefore matters less than ensuring robust preventive maintenance systems and reliable supply chains.

Taken together, these findings underscore that achieving sustainable rural water supply in Cameroon requires a systemic transformation that goes well beyond new infrastructure provision. Strengthening institutional capacity, ensuring financial viability, enhancing governance transparency, institutionalizing preventive maintenance, and providing continuous technical backstopping are essential components of durable service delivery. The proposed maintenance strategy—integrating lifecycle cost accounting and comprehensive operating charges—offers a practical foundation for long-term sustainability.

Future research should focus on: longitudinal assessment of WPMC capacity-building interventions using quasi-experimental designs; gender dynamics in water governance and their influence on transparency, conflict reduction, and user satisfaction; affordability, equity, and distributional effects of revised cost-recovery tariffs; comparative performance of alternative service delivery models (CBM, delegated private management, or public utility extension); and the scalability and contextual adaptability of the proposed maintenance framework across diverse rural settings in Cameroon.

Achieving SDG 6.1 by 2030 will demand not only accelerated construction efforts but also a fundamental rethinking of how rural water systems are governed, financed, and maintained. The challenges observed in Okola reflect broader patterns across Sub-Saharan Africa, making the lessons drawn from this study highly relevant for similar tropical environments confronting the rural water sustainability crisis.

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Ethics Statement

This study was conducted in accordance with the ethical principles for research involving human participants as outlined in the Declaration of Helsinki and national research ethics guidelines of Cameroon. Ethical clearance was obtained from the Ethics Committee of the Faculty of Agronomy and Agricultural Sciences, University of Dschang, Cameroon.

Informed Consent : Written informed consent was obtained from all adult participants (≥18 years of age) prior to their involvement in household surveys, interviews with Water Point Management Committees, stakeholder consultations, and field assessments. The consent process included detailed explanation of the study's objectives, procedures, expected duration of participation, potential risks and benefits, voluntary nature of participation, and the right to withdraw at any time without consequences or penalty.

Consent for Minors : For any household survey participants under 18 years of age, written informed consent was obtained from their parents or legal guardians prior to participation. Additionally, verbal assent was obtained from minors aged 12-17 years after explaining the study in age-appropriate language.

Confidentiality and Data Protection: All data were collected, stored, processed, and analyzed in strict accordance with confidentiality principles and data protection standards. Personal identifiers (names, addresses, contact information) were removed during data entry and replaced with unique numerical codes. All records linking identification codes to personal information were stored separately in password-protected digital files accessible only to the principal investigators. Hard-copy consent forms and field notes were stored in locked cabinets at the University of Dschang.

Minimal Risk: The study involved minimal risk to participants, consisting primarily of time commitment for interviews and surveys. No invasive procedures, biological samples, or sensitive personal information beyond basic demographics were collected. Participants were free to decline answering any questions they found uncomfortable.

Community Engagement: Prior to data collection in each village, formal authorization was obtained from traditional authorities and local administrative officials. Community sensitization meetings were conducted to explain the research objectives and address any concerns from community members.

Consent to participate

Participation in the study was entirely voluntary. Written informed consent was obtained from all adult participants (≥18 years of age) involved in household surveys, interviews with Water Point Management Committees, and stakeholder consultations prior to data collection. For participants under 18 years of age, written informed consent was obtained from their parents or legal guardians prior to participation, and verbal assent was obtained from minors aged 12-17 years. All participants were informed about the study objectives, procedures, voluntary nature of participation, potential risks and benefits, confidentiality measures, and their right to withdraw at any time without consequences.

Consent to publish

All participants were informed about the purpose of the research and consented to the publication of anonymized data and findings. No personal identifiers or sensitive information are disclosed in the manuscript. All data presented in this manuscript have been de-identified to protect participant privacy.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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Data availability statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Due to ethical restrictions related to participant confidentiality, raw data containing potentially identifying information cannot be made publicly available. However, anonymized aggregate data supporting the findings of this study can be provided upon request.

Author contributions

Douglas Tedah: Conceptualization, Methodology, Investigation, Data collection, Formal analysis, Writing - Original Draft. Célestin Defo: Conceptualization, Supervision, Writing - Review & Editing, Validation. Mabou Paul Blaise: Data analysis, Writing - Review & Editing. Victor Dang Mvongo: Methodology, Investigation, Data collection, Writing - Review & Editing, Visualization.

Clinical trial number

Clinical trial number: not applicable.