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Research Article

Sustainable Management of the Drinking Water Supply Service in the Abiergue Watershed (Yaoundé, Cameroon)

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Abstract

The performance of drinking water supply service (DWSS) is a major concern for urban management policies in sub-Saharan Africa. Since the 2005s, the management of urban and peri-urban drinking water supply service in Cameroon has been gradually entrusted to the Cameroon Water Utilities Corporation (CAMWATER), which is responsible for planning, investment, and technical oversight of the distribution network. CAMWATER faces significant challenges in meeting its service delivery objectives. This study aims to assess the performance of the public drinking water supply service provided by the Yaoundé Agglomeration Regional Directorate (YARD) of CAMWATER within the Abiergue watershed. The research is based on a methodology combining field surveys, interviews with local stakeholders, and the application of the Analytic Hierarchy Process (AHP) to weight performance indicators. The performance evaluation of the drinking water service provided by CAMWATER in the Abiergue watershed was conducted along two complementary dimensions: qualitative performance and quantitative performance. The qualitative performance aimed to provide subscribers with better-quality service. It was assessed using two criteria based on a set of twelve indicators. These include, on the one hand, the physicochemical quality of the distributed water measured by Potential of Hydrogen (PH), turbidity, iron, manganese, color, and residual chlorine and, on the other hand, the bacteriological quality, assessed through the presence of Escherichia coli, coliform bacteria, intestinal enterococci, sulfate-reducing anaerobic bacteria, and revivable microorganisms at 22℃ and 37℃. As for the quantitative performance, its goal was to ensure that subscribers receive an adequate quantity of water. This was evaluated using a single criterion composed of three indicators: daily service duration, frequency of unplanned water outages, and average daily per capita water allocation. The results reveal a satisfactory performance in terms of water quality (95%) but highlight significant weaknesses in quantitative supply (68%). The study recommends the following actions: strengthening local governance of water services by involving municipalities and users in planning and monitoring processes; implementing a proactive maintenance strategy targeting areas prone to losses and service disruptions; promoting more equitable service distribution, especially in often-marginalized peri-urban neighborhoods; and conducting regular performance evaluations using context-specific indicators and periodic audits.

Keywords

Indicator, Performance, Drinking Water, Quality, Quantity, Sustainable Management, Abiergue, Watershed

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1. Introduction

Access to safe and quality drinking water remains one of the major challenges to sustainable development in sub-Saharan Africa. Despite international efforts embedded in the Sustainable Development Goals (SDGs) in particular, SDG 6, which aims to ensure universal access to water and sanitation by 2030 progress remains uneven and insufficient [1]. In Cameroon, the Cameroon Water Utilities Corporation (CAMWATER) is responsible for the management and oversight of public drinking water services in urban and peri-urban areas. However, numerous institutional reports and independent studies highlight structural shortcomings: low service coverage, frequent outages, and, at times, questionable water quality. The study area, the Abiergue watershed, located in the city of Yaoundé, is characterized by rapid population growth and anarchic urbanization, which complicate access to drinking water. Faced with the difficulties encountered on the ground - water shortages, regular interruptions, leaks and user dissatisfaction - it has become necessary to assess the performance of the service with a view to sustainable management. This research focuses on the following questions: Does CAMWATER Yaoundé Agglomeration Unit provide an efficient service in the Abiergue basin? What are its limitations and prospects for improvement? The objective of this study is twofold: (i) to define the core objective around which the qualitative and quantitative performance evaluation of the drinking water service should be structured; and (ii) to apply the Analytic Hierarchy Process (AHP) to prioritize the criteria and assess the degree to which this objective has been achieved. This approach serves as a relevant decision-making tool for public managers and stakeholders in the water sector. Over the past decade, numerous studies have been conducted in the Abiergue watershed, reflecting the area's social, urban, and economic significance. The earliest work was carried out by [2], who examined the impact of various waste disposal systems including sludge, wastewater, human excreta, and solid waste on water resources, public health, and the environment in densely populated informal settlements and peri-urban areas of Yaoundé. [3] focused on contamination by Giardia sp. and Cryptosporidium sp. in the Cité Verte neighborhood and a tributary of the Abiergue River. [4] conducted a characterization of the hydromorphic soils in Nkolbisson-one of the neighborhoods in the watershed and assessed their suitability for vegetable farming practices. In a sustainable water resource management perspective. [5] explored the factors driving poor water governance in cities of developing countries. [6] analyzed the contribution of parametric methods in assessing intrinsic vulnerability in the aquifers of the watershed. [7] examined the vulnerability of Alternative Sources of Domestic Water Supply (ASDWS) to climate variability. [8] focused on the socio-economic and environmental challenges related to the occupation of flood-prone areas. [9] concentrated on reducing health risks associated with household-level drinking water treatment. His work highlighted the different household water treatment options used, evaluated their effectiveness, and identified the main waterborne diseases linked to domestically treated drinking water. In a similar vein, [10] examined water supply and associated health risks, emphasizing that the health of populations depends on the quality of the water and food they consume. several studies have been conducted in the field of sustainable management of drinking water service over the past years. We will highlight some key contributions from 2017 onward. Among the notable contributors are the following authors: [11], in his doctoral thesis “Integration of Rainfall Variability into the Sustainable Management of Drinking Water Services,” developed a methodological tool to support the sustainable management of drinking water services, taking into account Algeria's local specificities. This research aims to assist Algeria’s National Water Utility (ANWU) in addressing the challenges of improving service quality for consumers. [12], in his doctoral dissertation entitled “Sustainable Management of Water and Sanitation Services in Algeria,” developed a multi-criteria decision-making tool to promote the sustainable management of drinking water and sanitation services in Algeria. This research supports both ANWU and the National Sanitation Office (NSO) in their efforts to enhance the performance and quality of service delivery. To evaluate the sustainability of these services, a multi-criteria analysis model combining the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was proposed. [13], in their Master's thesis entitled “Multi-Criteria Analysis Applied to the Urban Water Supply Network of Downtown Chelghoum-Laïd (W. Mila),” used the AHP method to assess the sustainability of the water supply services in the city of Chelghoum-Laïd, Algeria.

2. Materials and Methods

2.1. Study Area

The study area is the Abiergue watershed. Located entirely within the city of Yaoundé, the Abiergue watershed lies between latitudes 3°53'30" and 3°54'00" North and extends from 11°26'30" to 11°30'00" East longitude, covering an area of approximately 13.5km^2. According to the January 2008 administrative division, it straddles the Yaoundé 2, 4 and 6 subdivisions, in the Mfoundi department, in the Center region of Cameroon. It comprises 11 neighborhoods of the said districts: Carriere, Cite-verte, Etetack, Mokolo, Madagascar, Melen, Messa, Nkolbisson, Nkolbikok, Nkol-so'o, Oyom-abang.

The climate is equatorial, of the Guinean type, with four seasons two dry seasons and two rainy seasons) [14]. Average altitude varies between 600 and 950 m. Hydrographically, the Abiergue is a tributary of the Mefou, itself a tributary of the

Nyong, one of Cameroon's coastal rivers [5]. This is well above the city's highest reservoir at 750 m altitude [15]. The CAMWATER network has little presence in neighborhoods at this altitude (Nkol-so'o, Oyomabang, etc.) and has difficulty serving the populations of these neighborhoods, who have almost no access to drinking water.

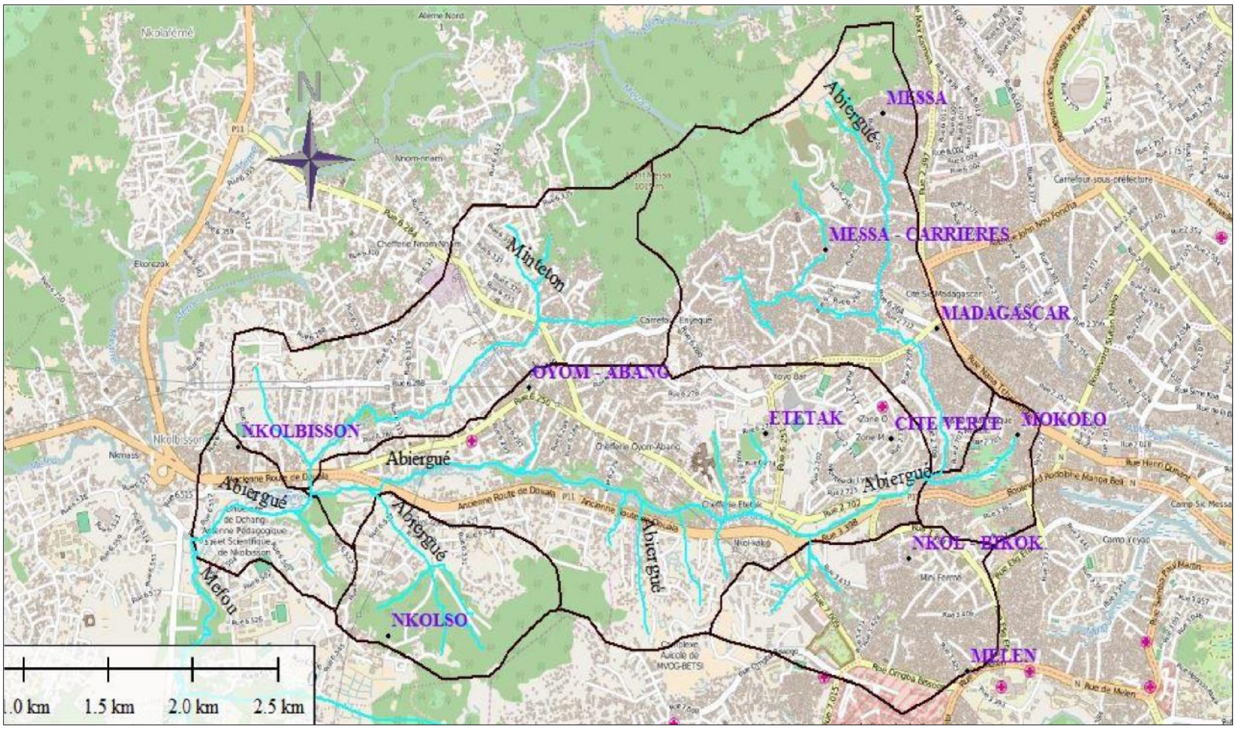

Figure 1. *Abiergue watershed map.*

2.2. General Methodological Approach

The methodological approach adopted in this study is based on two complementary stages: a construction phase and an evaluation phase.

2.2.1. Construction Phase

The purpose of this phase is to identify the main objective related to the sustainable management of the drinking water supply service (DWSS) provided by CAMWATER, through its Yaounde Agglomeration Regional Directorate (YARD), in the Abiergue watershed. This main objective is then broken down into sub-objectives in order to clarify their scope and meaning. Each sub-objective is defined by a set of criteria, which are in turn assessed using performance indicators. The identification of the main and sub-objectives was carried out through consultations with stakeholders involved in water resource management in the Abiergué watershed area (CAMWATER agents, community representatives, hydraulic services). The aim was to collectively identify the strategic objectives associated with improving the performance of the water service and the relevant indicators. Although this work took a fair amount of time, it proved essential in order to make the proposed indicators credible. It made it possible to create an evaluation framework adapted to the local context, based on criteria accepted by all stakeholders (operators, public institutions, technical experts).

Indicator and criteria selection process

The Selection of indicators required a collaborative approach involving all relevant actors in water resource management (WRM). The goal was to co-construct an evaluation framework aligned with the principles of sustainable management. This step, though complex and time-intensive, was crucial to achieving collective buy-in for the selected criteria and objectives.

According to [13], one of the main goals of DWSS is to satisfy the user. Consequently, the core objective "To satisfy the user" was established as the foundation for assessing the performance of the DWSS managed by CAMWATER. The performance of CAMWATER's DWSS was assessed based on two complementary aspects: Qualitative performance, whose goal is: "To provide subscribers with safe and good-quality distributed water", and Quantitative performance, whose goal is: "To provide subscribers with a service of sufficient quantity." These two aspects are determined by three criteria, which themselves are assessed using a total of fifteen performance indicators. Only the indicators for which data were available were considered in this study. Regarding the qualitative performance whose objective is "To provide subscribers with safe and good-quality distributed water" two criteria were defined:

1) Physico-chemical quality of distributed water: This criterion was assessed using six indicators, namely pH, turbidity, iron, manganese, residual chlorine, and color.
2) Bacteriological quality of distributed water: This was assessed through six indicators: Escherichia coli, coliform bacteria, intestinal enterococci, sulfate-reducing anaerobic bacteria, and revivable microorganisms at 22 ℃ and at 37 ℃.

With regard to the quantitative performance of the service whose objective is "To provide subscribers with an adequate quantity of water" a single criterion was defined: ensuring better water supply to the subscriber. This criterion is assessed using three indicators: the daily service duration, the frequency of unplanned water outages, and the average daily per capita water allocation. The hierarchical structure of the main objective is presented in Figure 2.

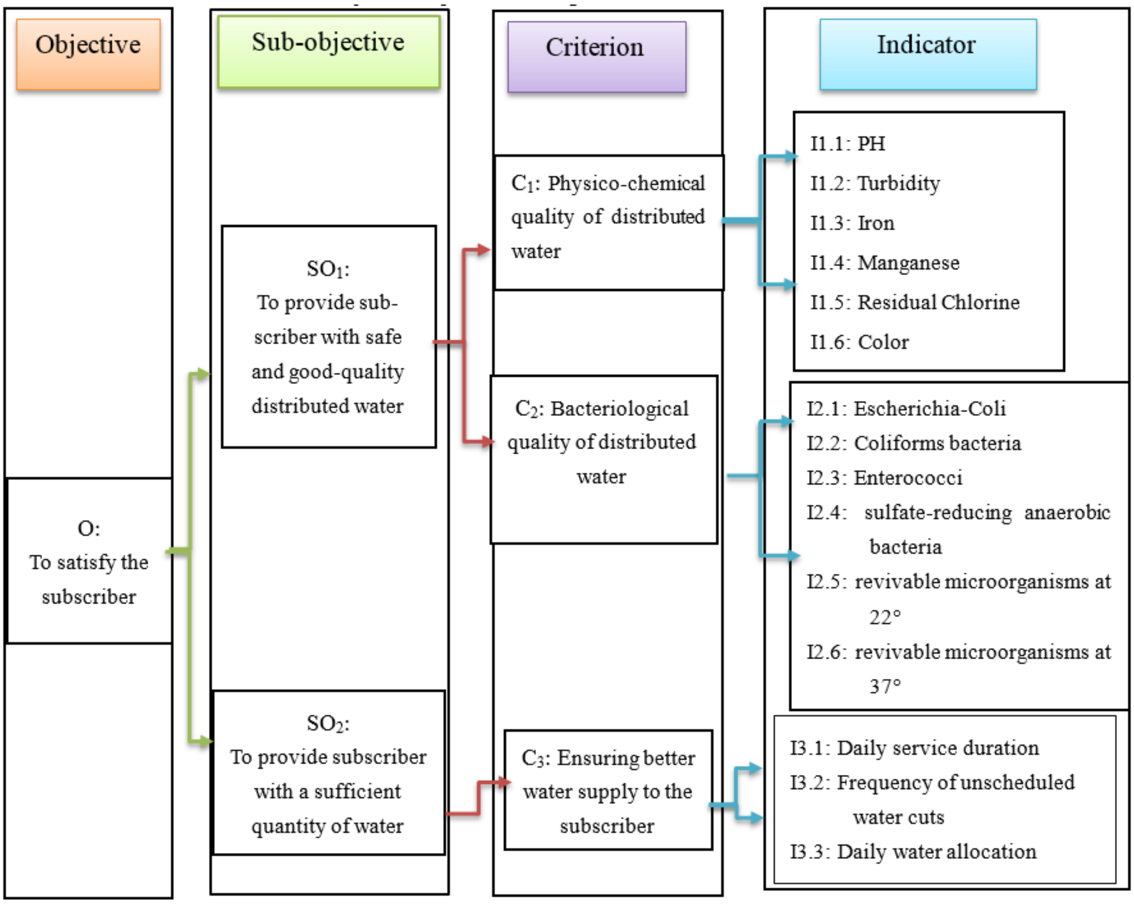

Figure 2. *Hierarchical Structure of the Main Objective.*

2.2.2. Assessment Phase

The assessment phase consists of developing aggregation methods that allow performance values to be traced from individual indicators up to an overall performance assessment of the system. This phase requires the collection of a database generated from field measurement campaigns necessary for calculating the previously defined indicators. The collected values are then converted into performance scales to assign performance scores to each indicator. The performance of each criterion is determined by weighting and aggregating the performance scores of its respective indicators. Aggregating the performance scores of the criteria yields the qualitative performance of the service (Sub-objective 1) and the quantitative performance of the service (Sub-objective 2). Finally, combining these two dimensions leads to an assessment of the overall performance of the drinking water service (performance of the main objective). The proposed methodology for assessing the performance of the drinking water supply service consists of several key steps:

1) Aggregation of indicators: to do this, we have adopted an aggregation that combines the indicators into criteria, then the aggregation of the criteria into an evaluation of the performance of the objectives. This will make it possible to calculate the performance of the various elements;
2) Weighting of indicators: The determination of weighting coefficients is based on the application of the Analytical

Hierarchy Process (AHP) method, a decision-making tool widely used to model complex problems by structuring them hierarchically [16]. It allows each element to be given a weighting;

3) Indicator performance: This generally refers to the level of achievement of the indicator, expressed as a percentage relative to a reference value.

A. Aggregation of indicators

The aggregation method selected is full aggregation based on the principle of a single synthetic criterion. The linear additive method (also known as the weighted sum method) was chosen for its clarity and ease of implementation [17]. The indicators were aggregated using equation (1):

$$PCi = \sum_{j}^{n} PIij \text{ x } Wij \quad (1)$$

Where:

n: number of indicators involved in criterion Ci

PCi: performance value of criterion Ci;

PIij: performance value of indicator Ij of criterion Ci;

Wij: value of the weighting coefficient of indicator Ij of criterion Ci.

This formula makes it possible to weight each indicator according to its relative importance, thus ensuring a balanced evaluation, taking into account the diversity of the qualitative and quantitative dimensions of the service.

B. Indicator weighting

The weighting coefficients for the indicators are calculated using the AHP method. This method reduces the complexity of a decision-making problem by making pairwise comparisons between elements at the same level. Its application follows the following basic steps:

1) Define the problem and determine its goal.
2) Decompose the complex problem into a hierarchical structure at different levels.
3) Construct pairwise comparison matrices for each level, with one matrix for each element.
4) Make (NXN) judgements of all the matrices constructed in step 3.
5) Calculate the weight of each element in the set of matrices and then calculate the eigenvector (**λ**max) of each matrix.
6) Calculate the coherence index:

$$CI = \frac{\lambda \max - N}{N-1} \quad (2)$$

Then check the consistency of the judgements

$$CR = \frac{CI}{RI} \quad (3)$$

If, CR ≥ 0.10, the judgements need to be reviewed and improved.

1) Steps 3 to 6 are carried out at all levels of the hierarchy.

Table 1. *Random Index (RI) Values.*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

C. Indicator performance

This is the ratio between the observed or measured value of an indicator and a reference value. It is generally expressed as a percentage.

3. Results

The analysis of service performance required the mobilization of several sets of technical data collected from local public service providers. The data used in this study mainly concerns the year 2023 and was provided by the various sub-directorates of the YARD (Production sub-directorate and Distribution sub-directorate) as well as by the heads of commercial agencies. The data include information on water quality, volumes distributed, service schedules and network characteristics. These data were obtained by consulting CAMWATER's technical documents and through semi-directive interviews with key officials of the institution.

3.1. Construction of Comparison Matrices

A set of matrices was constructed for each hierarchical level, with one matrix per element (Step 3). To compare the elements (Step 4), it is important to pose the right question. The way the question is formulated is crucial. The pairwise preference comparison phase was carried out in collaboration with different managers-namely, the quality control officer, the heads of the Production and Distribution Sub-Directorates-as well as engineers (in Biology, Chemistry, and Hydraulics) within CAMWATER’s YARD unit.

The values of the indicators associated with Criteria 1 and 2 were obtained from analyses conducted at the potable water laboratory of the Mefou water treatment plant and the Pasteur Center of Yaoundé This laboratory is equipped with qualified personnel, analytical tools, transportation means, and sample preservation equipment. The pairwise comparison of criteria preferences was based on the relative importance of the analyses to be performed.

The values of the indicators associated with Criterion 3 were provided by the heads of the Melen and Tsinga commercial agencies. The various types of customer complaints recorded were taken into account. The comparison of preference between these indicators was based on the degree of priority given by CAMWATER to addressing these complaints.

The degree of importance assigned to each indicator allowed experts' judgments to be integrated into the tables below using a relative importance scale between indicators. The matrices and comparisons are presented in Table 2.

Table 2. *Pairwise Comparison Matrix of Indicators, Criteria, and Sub-Objectives.*

1) Pairwise Comparison of Indicators Related to Criterion C1

Indicator	I1.1	I 1.2	1.3	1.4	1.5	1.6
I1.1	1	0,5	3	3	0,33	0,2
I 1.2	2	1	0,5	2	0,33	0,2
1.3	0,33	2	1	0,5	0,25	0,2
1.4	0,33	0,5	2	1	0,25	0,2
1.5	3	3	4	4	1	0,5
1.6	5	5	5	5	2	1

λ max = 6,619 and CR = 0,0998 <0.1

2) Pairwise Comparison of Indicators Related to Criterion C_2

Indicator	I2.1	I2.2	I2.3	I2.4	I2.5	I2.6
I2.1	1	2	3	3	4	4
I2.2	0,5	1	2	2	3	3
I2.3	0,33	0,5	1	2	2	2
I2.4	0,33	0,5	0,5	1	3	2
I2.5	0,25	0,33	0,5	0,33	1	2
I2.6	0,25	0,33	0,5	0,5	0,5	1

λ max = 6,2146 and CR = 0,0346 <0.1

3) Pairwise Comparison of Indicators Related to Criterion C_3

Indicator	I3.1	I3.2	I3.3
I3.1	1	5	7
I3.2	0,2	1	3
I3.3	0,14	0,33	1

λ max = 3,0546 and CR = 0,0465 <0.1

4) Pairwise Comparison of Criteria Related to subs-objective SO_1

Criterion	C_1	C_2
C_1	1	0,5
C_2	2	1

λ max = 2 et CR = 0 <0.1

3.2. Calculation of Weighting Coefficients and Their Synthesis

This calculation involves summing the values in each column of the matrix, then dividing each entry in the column by the column total to obtain a normalized matrix, which allows for meaningful comparisons between elements. Finally, the average of each row is calculated by summing the values in that row of the normalized matrix and dividing by the number of entries in the row. These operations yield a global priority vector. The relative importance of the various criteria is expressed by the values in the normalized eigenvector (normalized to 1).

Once the matrices have been completed, the weights or weighting coefficients of each element in all matrices (indicator, criterion, and sub-objective) must be calculated. The results are summarized in Tables 3 to 6.

Table 3. *Weighting Coefficients of Indicators Related to Criterion C_1.*

Indicator	I1.1	I 1.2	1.3	1.4	1.5	1.6	Somme	Weigh	Performance indicator	Performance Criterion 1
I1.1	0,086	0,042	0,194	0,194	0,079	0,087	0,681	0,113	0,8337	
I 1.2	0,172	0,083	0,032	0,129	0,079	0,087	0,582	0,097	0,9299	
I1.3	0,028	0,167	0,065	0,032	0,06	0,087	0,439	0,073	0,9677	0,9007
I1.4	0,028	0,042	0,129	0,065	0,06	0,087	0,411	0,068	0,977	
1.5	0,257	0,25	0,258	0,258	0,24	0,217	1,481	0,247	0,9694	
I1.6	0,429	0,417	0,323	0,323	0,481	0,435	2,406	0,401	0,8451	
Somme	1	1	1	1	1	1	6	1		

Table 4. *Weighting Coefficients of Indicators Related to Criterion C_2.*

Indicator	I2.1	I2.2	I2.3	I2.4	I2.5	I2.6	Somme	Weigh	Performance Indicator C_2	Performance du Criterion 2
I2.1	0,3759	0,4292	0,4	0,3398	0,2963	0,2857	2,1269	0,3545	0,9677	
I2.2	0,188	0,2146	0,2667	0,2265	0,2222	0,2143	1,3322	0,222	0,9702	
I2.3	0,1241	0,1073	0,1333	0,2265	0,1481	0,1429	0,8822	0,147	0,9702	0,9704
I2.4	0,1241	0,1073	0,0667	0,1133	0,2222	0,1429	0,7764	0,1294	0,9801	
I2.5	0,094	0,0708	0,0667	0,0374	0,0741	0,1429	0,4858	0,081	0,969	
I2.6	0,094	0,0708	0,0667	0,0566	0,037	0,0714	0,3966	0,0661	0,969	
Somme	1	1	1	1	1	1	6	1		

Table 5. *Weighting Coefficients of Indicators Related to Criterion C_3.*

Indicator	I3.1	I3.2	I3.3	somme	Weigh	Performance indicator	Performance du Criterion 3
I3.1	0,746	0,79	0,636	2,173	0,724	0,65	
I3.2	0,149	0,158	0,273	0,58	0,193	0,75	0,68
I3.3	0,104	0,052	0,091	0,248	0,083	0,77	

Indicator	I3.1	I3.2	I3.3	somme	Weigh	Performance indicator	Performance du Criterion 3
somme	1	1	1	3	1		

Table 6. Weighting Coefficients of Criterion Related to objective SO1.

Indicator	C1	C2	Somme	Weigh	Performance Criterion	Performance du Subs Objective 1
C1	0,333	0,333	0,667	0,333	0,9	
C2	0,667	0,667	1,333	0,667	0,97	0,95
Somme	1	1	2	1		

The application of the AHP method made it possible to obtain the weight values associated with each indicator, criterion, and sub-objective.

3.3. Consistency of Judgments

The consistency of the judgments expressed in all the preference matrices is acceptable, as their consistency ratios are all below 0.10.

3.4. Qualitative Performance of the Service

In order to ensure that drinking water that complies with quality standards, CAMWATER has a specialized analysis laboratory located at the Mefou water treatment plant in the Nkolbisson district. This laboratory is responsible for conducting daily quality control of the water distributed through the city's network. It is equipped with qualified personnel (engineers in biology, chemistry and medical analysis), high-performance analytical equipment, vehicles for taking samples in the field, and sample storage facilities.

The performance scores of the analyzed parameters are summarized in Figures 3 and 4 below. These correspond to the performance of Criteria C1 and C2, respectively.

The quality of the water distributed is 97% good microbiological quality and 90% good physico-chemical quality. It can therefore be concluded that the water quality criterion is acceptable, with an overall achievement rate of 95%.

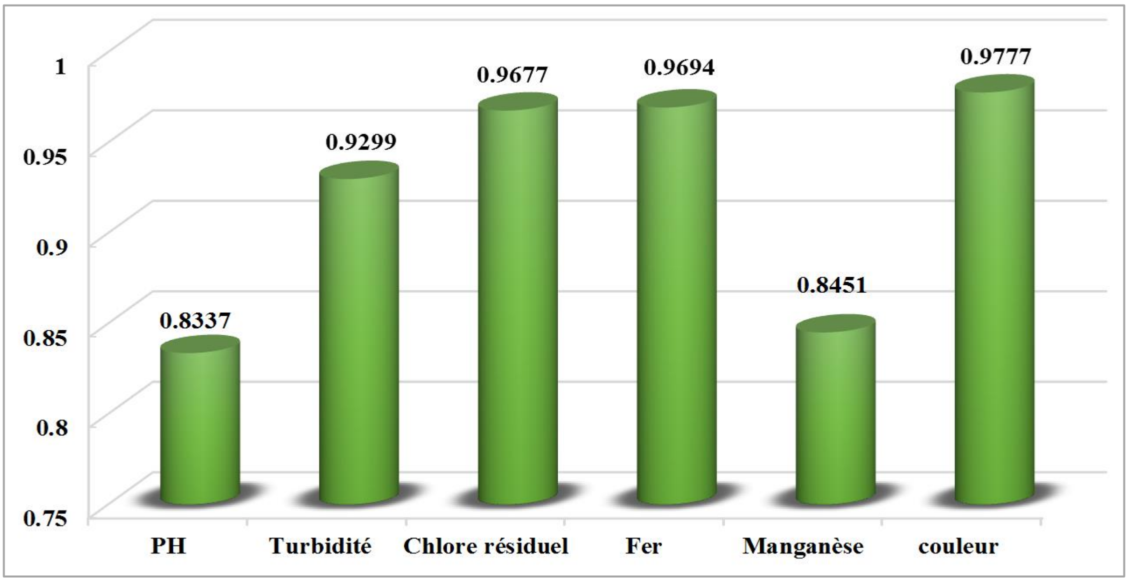

Figure 3. Performance of physico-chemical parameter (Indicators of Criterion C1).

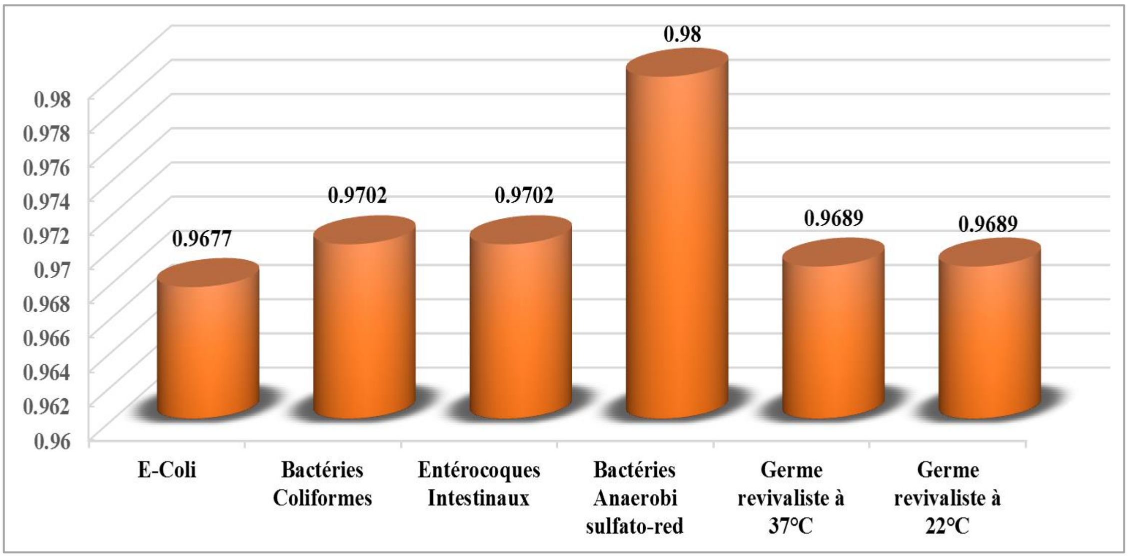

Figure 4. *Performance of Microbiological parameters (Indicators of Criterion C2).*

3.5. Quantitative Performance of the Service

The quantitative performance of the service corresponds to the performance of the indicators under Criterion C3. The observed performance levels for these indicators are presented in figure 5.

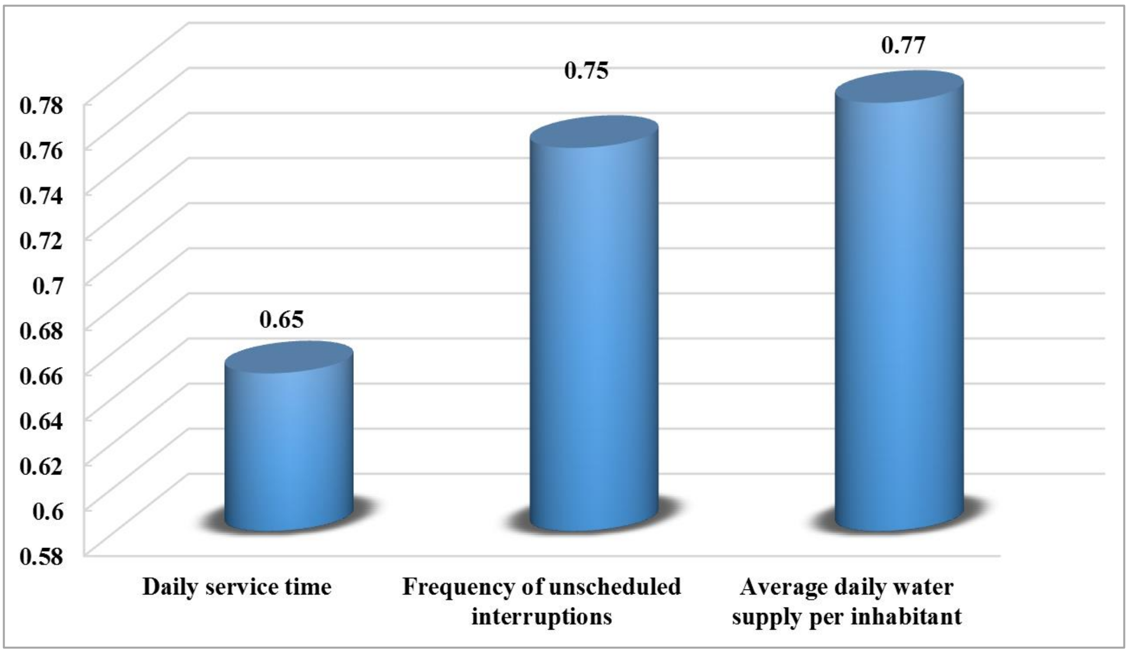

Figure 5. *Performance of quantitative parameters (Indicators of Criterion C3).*

The results show that performance levels are particularly low for the first two parameters: service time and unscheduled water cuts. The consolidated analysis gives an overall performance of 68% for the quantitative aspect, which highlights significant shortcomings in terms of continuity and equity of access to drinking water. This situation calls for structural improvements, particularly in production capacity, storage, demand management and network maintenance.

The results show a relatively efficient system in terms of sanitary quality, thanks to monitoring efforts and the expertise of technical staff. However, the weaknesses observed in supply (service times, staffing, interruptions) raise questions about CAMWATER's ability to guarantee an equitable service. These deficiencies can be explained by urban pressure, losses in the network and under-investment in infrastructure modernization.

4. Discussions

The performance evaluation of the drinking water service managed by CAMWATER reveals that 97% of the distributed water meets microbiological quality standards, and 90% complies with physico-chemical standards. Thus, the overall water quality criterion is acceptable, with a total score of 95%. On the qualitative side, the results are generally satisfactory (95%), reflecting effective sanitary control. However, on the quantitative side, performance remains insufficient (68%) due to irregular service and low per capita allocation.

These findings are consistent with those reported in Algeria by [18]. They reveal significant shortcomings in service continuity, daily availability of tap water, and infrastructure quality. The average daily per capita water allocation remains below the World Health Organization (WHO) standard of 50 liters per person per day [19], particularly in the peripheral neighborhoods of the Abiergue watershed, where network pressure is weak or intermittent.

In response to these challenges, CAMWATER has initiated a structural strengthening process for its services through several investment projects. One of the most emblematic is the Drinking Water Supply Project for the City of Yaoundé and its Surroundings from the Sanaga River (DWSPYS). This large-scale project aims to inject up to 300,000 m³/day of additional water into Yaoundé's network, with the following objectives: to significantly improve household water supply, to reduce prolonged service interruptions, to increase pressure in high-altitude areas, and to reduce reliance on unreliable alternative sources.

5. Conclusion

CAMWATER's core mission is to provide the population with safe, sufficient, and continuous drinking water. In the context of this study, the YARD played a crucial role by facilitating access to technical and historical data related to water quality and service management indicators. These data enabled the performance assessment of the water service along two major axes: Qualitative performance, overall satisfactory (95%), reflecting effective sanitary control and Quantitative performance: Insufficient (68%), due to irregular supply and low per capita allocation. These findings reveal a discrepancy between quality control and the ability to provide sufficient and equitable distribution, highlighting the need for technical and institutional reforms to meet the standards of a sustainable and equitable public service. The results helped identify the key criteria influencing service performance and to orient improvement strategies based on objectively determined weightings. Urgent measures are required in light of this evaluation, the following priority actions are recommended: Strengthen local water service governance by involving local authorities and users in planning and monitoring processes; Implement a proactive maintenance strategy, targeting areas most affected by losses and service interruptions; Promote more equitable distribution, particularly in peri-urban neighborhoods that are often marginalized; Regularly evaluate performance using context-appropriate indicators and periodic audits.

Abbreviations

DWSS	Drinking Water Supply Service
YARD	Yaoundé Agglomeration Regional Directorate
SDG	Sustainable Development Goal
AHP	Analytic Hierarchy Process
CAMWATER	Cameroon Water Utilities Corporation
PH	Potential of Hydrogen
ASDWS	Alternative Sources of Domestic Water Supply
ANWU	Algeria's National Water Utility
NSO	National Sanitation Office
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
DWSPYS	Drinking Water Supply Project of Yaoundé and Its Surroundings from the Sanaga River

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Author Contributions

Salomine Djimani: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, writing -original draft, Writing - review & editing

Barthelemy Ndongo: Supervision, Validation

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Biography

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Ndongo Barthelemy is a hydraulic engineer and Associate Professor at the University of Dschang in Cameroon. He has been supporting development projects in water management and the implementation of hydraulic facilities for around thirty years.

Research Field

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Barthelemy Ndongo: design of hydraulic structures, flood management, irrigation and drainage, environment and sustainable development.