IJCRM
International Journal of Contemporary Research In Multidisciplinary

Research Article

Assessing Water, Sanitation, and Hygiene (WASH) Service Functionality and Health Outcomes in Rural Chama District, Zambia: A Mixed-Methods Analysis

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DOI: https://doi.org/10.5281/zenodo.18197901

Abstract

Background: Despite substantial investments in rural water infrastructure across sub-Saharan Africa, functionality deficits and water quality problems continue to undermine public health gains. This study assessed water, sanitation, and hygiene (WASH) service status in rural Chama District, Zambia, examining how service reliability, water quality, and governance arrangements influenced health outcomes.

Methods: A convergent mixed-methods design integrated a household survey (n=400), microbiological water quality testing (n=200 samples), key-informant interviews (n=34), and focus-group discussions (n=6 groups, 54 participants) across 12 rural wards during dry and rainy seasons (2025). Quantitative data were analysed using descriptive statistics and logistic regression in SPSS v.27; qualitative data underwent thematic analysis in NVivo v.12. Data triangulation synthesised numerical patterns with institutional and behavioural explanations.

Results: While 65% of households reported using improved water sources, only 54% of tested sources were microbiologically safe (E. coli=0 CFU/100mL), and 40% of households experienced primary source non-functionality in the preceding month. Improved latrine coverage was 30%; handwashing stations with soap were observed in 35% of households. Logistic regression revealed that households using unsafe water sources had 2.70 times higher odds of reporting under-five diarrheal episodes (95% CI: 1.55–4.71, p=0.001), while recent source non-functionality increased odds by 1.85 (95% CI: 1.05–3.27, p=0.033). Women spent a mean of 18.2 hours weekly collecting water, correlating with elevated school absenteeism among girls. Qualitative analysis identified spare-parts shortages (median repair time 18 days), weak maintenance financing (only 20% of households paid water fees), and limited female representation in Water Point Management Committees as principal institutional barriers.

Conclusions: Nominal infrastructure coverage substantially overstated reliable, safe WASH access. Microbial contamination and service interruptions were significant predictors of diarrheal disease. Sustainable improvements require integrated interventions addressing spare-parts supply chains, transparent maintenance financing, gender-inclusive governance, and targeted water quality monitoring rather than infrastructure expansion alone.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 15-11-2025
- **Accepted:** 29-12-2025
- **Published:** 09-01-2026
- **IJCRM:**5(1); 2026: 18-27

- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Tembo E, Phiri j. Assessing Water, Sanitation, and Hygiene (WASH) Service Functionality and Health Outcomes in Rural Chama District, Zambia: A Mixed-Methods Analysis. Int J Contemp Res Multidiscip. 2026;5(1):18-27.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: WASH services; rural water supply; service functionality; water quality; health outcomes; mixed-methods research; Zambia

1. INTRODUCTION

Universal access to safe water, adequate sanitation, and hygiene (WASH) services constitutes a fundamental pillar of Sustainable Development Goal 6 (SDG 6), yet progress in rural sub-Saharan Africa remains markedly uneven (United Nations, 2015; WHO & UNICEF, 2022). While global monitoring reports indicate improvements in nominal infrastructure coverage, substantial gaps persist between the presence of improved water sources and the delivery of reliable, safe services (Bain et al., 2014). Infrastructure counts frequently overstate effective access where functionality, water quality, and maintenance systems are inadequately monitored, exposing rural populations to intermittent service and microbial contamination risks.

In Zambia, rural WASH coverage lags significantly behind urban areas, with approximately 52% of rural households accessing basic drinking water and only 34% using improved sanitation facilities (Central Statistical Office, 2023). Eastern Province exhibits lower coverage than national rural averages, with district audits documenting widespread dependence on boreholes and protected springs that experience frequent non-functionality, particularly during dry seasons (Ministry of Water Development, 2022). Chama District exemplifies these challenges: administrative records indicate that approximately 40% of installed boreholes are non-functional at critical periods, forcing households to revert to unprotected sources and increasing exposure to waterborne pathogens (Chama District Council, 2023; Jones & Mwila, 2022).

The public health consequences of inadequate WASH services are substantial. Health surveillance data indicate that diarrheal disease incidence among children under five in Eastern Province exceeds national rural averages, with investigations linking outbreaks to contaminated water sources and open defecation practices (Zambia Ministry of Health, 2023; Phiri et al., 2021). Beyond direct health impacts, WASH deficiencies produce cascading socioeconomic harms: women and girls bear disproportionate time burdens for water collection, constraining educational attendance and income-generating opportunities (Mulenga et al., 2020). Previous interventions have often emphasised drilling new boreholes without commensurate investments in maintenance financing, spare-parts logistics, or inclusive governance mechanisms, resulting in rapid post-installation deterioration (WaterAid, 2021; Hutton & Varughese, 2016).

Theoretical frameworks from institutional collective action theory, socio-technical systems thinking, and behavioural science provide complementary lenses for understanding WASH service sustainability. Ostrom's (1990) institutional analysis demonstrates that well-defined collective choice arrangements, transparent monitoring, and graduated cost-sharing predict successful resource stewardship. Socio-technical perspectives emphasise that technology performance depends on interactions between hardware, local skills, supply chains, and governance structures (Bijker et al., 1987). Behavioural models highlight how perceived risks, social norms, and self-efficacy mediate the adoption of hygiene practices and the willingness to contribute to maintenance costs (Ajzen, 1991; Rosenstock, 1974).

Despite growing recognition that WASH service delivery requires addressing technical, institutional, and behavioural dimensions concurrently, empirical evidence integrating these elements remains limited, particularly at village and ward levels where services are managed and used. This study addressed critical evidence gaps by employing a convergent mixed-methods design to: (1) quantify household access to safe water sources and improved sanitation facilities; (2) identify technical, financial, and socio-cultural barriers to sustained service delivery; (3) examine associations between WASH deficiencies and health and educational outcomes; and (4) generate actionable, context-appropriate recommendations for district planners, Water Point Management Committees (WPMCs), and development partners.

By pairing representative household surveys and microbiological water quality testing with in-depth qualitative inquiry into governance practices and community experiences across dry and rainy seasons, this research provides robust, triangulated evidence on the proximate determinants of WASH service performance and their health consequences in rural Chama District, Zambia.

2. METHODS

2.1 Study Design and Setting

This study employed a convergent mixed-methods design, integrating quantitative household surveys and water quality testing with qualitative key-informant interviews (KIIs) and focus-group discussions (FGDs) to achieve methodological triangulation (Creswell & Plano Clark, 2018). The research was conducted across 12 rural wards of Chama District, Eastern Province, Zambia, between February and November 2025, encompassing one complete dry season (May–October) and one rainy season (November–April) to capture seasonal variability in service functionality and health outcomes.

Chama District was selected due to documented WASH service challenges, presence of diverse water source types (boreholes with handpumps, protected springs, rainwater harvesting, unprotected streams), and active engagement by district technical offices and local non-governmental organisations (NGOs) that facilitated fieldwork access. The district's wards exhibit variation in settlement density, hydrogeology, and road access, providing an opportunity to examine how contextual factors influence functionality and maintenance dynamics.

2.2 Sampling Procedure and Sample Size

A multi-stage sampling strategy combined stratified random sampling for household surveys with purposive and quota sampling for qualitative components. The 12 rural wards served as strata to ensure geographic representation. Within each ward, villages were selected using probability proportional to size (PPS) sampling from ward registers to avoid over- or under-sampling of larger or smaller settlements (Kish, 1965). Within selected villages, household lists obtained from community leaders served as the sampling frame; households were selected using simple random sampling.

The sample size for the household survey was calculated using standard formulas for estimating proportions with 95% confidence and ±5% margin of error. Assuming maximum variance (p=0.5), the basic calculation yielded n_0≈384 households. After adjusting for design effects from clustering and anticipated non-response, the final target was set at 400 households to preserve statistical power for subgroup analyses across wards.

For water quality testing, samples were collected from the primary water source reported by each surveyed household. Logistical constraints and laboratory capacity necessitated testing a stratified subsample of approximately 200 primary sources (50% of surveyed households), ensuring representation across wards and source types (boreholes, protected springs, unprotected streams). Duplicate testing on 10% of samples supported quality control (WHO, 2017).

Qualitative sample sizes prioritised information richness and saturation over statistical representation. Purposive sampling selected 24 WPMC executives (two per ward), six district water and health officers, and four NGO field staff based on roles and experience with WASH management (total n=34 KIIs). Quota sampling structured six FGDs (8–10 participants each; total n≈54) to ensure balanced representation by gender and age, with separate male and female groups to facilitate open discussion of gendered experiences.

2.3 Data Collection Instruments and Procedures

2.3.1 Household Survey

Structured household questionnaires were administered face-to-face by trained enumerators using tablet computers running KoboToolbox, enabling offline data capture, automated skip logic, GPS coordinate recording, and rapid upload to secure servers. The questionnaire comprised modules on: (1) household demographics and socioeconomic characteristics; (2) water source typology, access, and functionality; (3) sanitation facilities and hygiene practices; (4) two-week recall of diarrheal episodes among children under five; (5) time-use estimates for water collection; (6) household WASH expenditures; and (7) awareness of and participation in WPMC activities.

Field teams comprised six trained enumerators and two supervisors who completed a three-day training covering research ethics, questionnaire administration, water sample handling, GPS use, and FGD facilitation. Before main fieldwork, instruments were piloted in a non-study ward (n=20 households) to test clarity, timing, and logistics; pilot results informed minor revisions to survey wording and sample labelling conventions.

2.3.2 Water Quality Testing

Microbiological water quality assessment followed WHO surveillance protocols for community supplies (WHO, 2017). Field teams collected 300mL samples from households' reported primary sources using sterile bottles, rinsing bottles three times before collection. Samples were placed in ice-packed coolers and delivered to the district laboratory within six hours. Laboratory analyses used membrane filtration and m-ColiBlue24® agar to enumerate *Escherichia coli* colonies (CFU/100mL). Duplicate samples were run for 10% of sources as quality control; daily blanks monitored contamination. Results were classified into safety categories: safe (0 CFU/100mL), intermediate risk (1–10 CFU/100mL), and unsafe (>10 CFU/100mL) per WHO thresholds.

2.3.3 Qualitative Data Collection

Semi-structured KII guides explored governance arrangements, fee collection practices, spare-parts procurement experiences, maintenance financing, and past rehabilitation efforts. Interviews were audio-recorded with informed consent; participants included WPMC chairs and treasurers, district water and health officers, and NGO program staff. Interviews lasted 45–75 minutes and were conducted in private settings.

FGD guides employed thematic prompts and participatory exercises (ranking maintenance priorities, mapping failure causes) to stimulate discussion around water collection routines, coping strategies during pump failures, perceptions of WPMC effectiveness, barriers to latrine use, and community priorities for service improvement. Separate male and female groups facilitated discussion of gendered time burdens and decision-making exclusion. FGDs were audio-recorded and supported by detailed facilitator notes capturing non-verbal cues and group dynamics; sessions lasted 60–90 minutes.

Direct observations used structured checklists to document pump type and condition, latrine superstructure integrity, presence of handwashing facilities with soap, and accessibility features for persons with disabilities. WPMC financial audits collected fee schedules, recent repair receipts, and current fund balances using standardised templates.

2.4 Data Analysis

2.4.1 Quantitative Analysis

Survey data were exported from KoboToolbox, cleaned, and analysed using SPSS v.27. Descriptive statistics (frequencies, means, medians, standard deviations) summarised WASH coverage, functionality, latrine ownership, water quality, time burdens, and health outcomes. Bivariate analyses (chi-square tests, t-tests) examined associations between categorical and continuous variables.

Multivariable logistic regression modelled associations between WASH service variables (independent variables: access to improved source, recent pump non-functionality, E. coli contamination category) and under-five diarrheal episodes in the preceding two weeks (dependent binary variable), controlling for socioeconomic covariates (household size, maternal education, wealth proxy based on asset index). Robust standard errors clustered at the village level addressed design effects. Model diagnostics included variance inflation factor checks for multicollinearity and Hosmer-Lemeshow goodness-of-fit tests.

Water quality results were analysed both as categorical safety classes and as continuous counts (log-transformed where appropriate). Spatial analysis used GPS coordinates in ArcGIS to visualise clusters of unsafe sources and compute household-to-source distances; spatial autocorrelation tests (Moran's I) identified non-random clustering patterns.

2.4.2 Qualitative Analysis
Interview and FGD audio recordings were transcribed verbatim and, where necessary, translated into English. Transcripts were imported into NVivo v.12 for systematic thematic analysis using a hybrid inductive–deductive approach (Guest, MacQueen & Namey, 2012). A preliminary coding framework was developed from the conceptual model (institutional governance, spare-parts supply chain, gendered decision-making, behavioural drivers) and refined iteratively as emergent themes surfaced. Matrices linked themes to respondent characteristics (role, ward) to examine cross-case patterns. Intercoder reliability checks on 20% of transcripts ensured consistency (kappa >0.75 for key nodes).

2.4.3 Data Integration and Triangulation
Integration employed joint displays and mixed-methods matrices juxtaposing numerical indicators (e.g., per cent non-functional pumps, E. coli prevalence, diarrheal incidence) with qualitative explanations (e.g., reported spare-parts delays, governance weaknesses, social norms) to produce meta-inferences. Triangulation evaluated convergence, complementarity, and divergence between data streams, strengthening the validity of causal interpretations and policy implications (Creswell & Plano Clark, 2018).

2.5 Ethical Considerations
Ethical approval was obtained from DMI-St. Eugene University Research Ethics Committee. Written informed consent was obtained from all participants before data collection; verbal consent was audio-recorded for interviews and FGDs. Participation was voluntary; respondents could withdraw at any time without consequence. All data were anonymised; identifiable information was removed during transcription and coding. Digital files were stored on password-protected institutional servers. Findings were shared with community leaders and district officials through validation workshops.

3. Results
3.1 Sample Characteristics
The study completed surveys with 400 households across 12 rural wards (response rate: 94.3%). Mean household size was 6.2 members (SD=2.4); 38% of households had at least one child under five years. Among respondents, 62% were female; 54% had completed primary education, 18% secondary education, and 28% had no formal schooling. Primary livelihood activities were subsistence farming (72%), casual labour (16%), and petty trade (12%). Water quality testing analysed 200 primary source samples. Thirty-four KIIs were conducted (24 WPMC executives, 6 district officers, 4 NGO staff); six FGDs engaged 54 community members (32 female, 22 male).

3.2 WASH Coverage, Functionality, and Infrastructure
3.2.1 Water Access and Source Types
Two hundred sixty households (65.0%) reported using improved water sources (boreholes with handpumps or protected springs) as their primary drinking water source; 140 households (35.0%) relied on unprotected streams, shallow wells, or intermittent rainwater harvesting (Table 1). Among improved sources, boreholes with handpumps predominated (n=220, 84.6% of improved sources).

Table 1: Household WASH Coverage and Functionality Indicators (n=400)

Indicator	Count	Percentage
Water Access		
Households using an improved water source (borehole/protected spring)	260	65.0%
Households using an unimproved source (unprotected stream/shallow well)	140	35.0%
Functionality		
Households reporting a primary source as non-functional in the past month	160	40.0%
Median reported downtime when non-functional (days)	14	—
Sanitation		
Households with improved latrine (VIP/covered pit)	120	30.0%
Households with unimproved latrine	156	39.0%
Households practising open defecation	124	31.0%
Hygiene		
Handwashing station with soap observed at the household	140	35.0%
Financial Participation		
Households reporting paying the water fee to WPMC	80	20.0%
Mean annual contribution among fee-paying households (ZMW)	45	—
Governance		
Households are aware of the local WPMC	312	78.0%
WPMC receipts/repair records visible at water point (enumerator observation, n=60 points)	18	30.0%

Source: Household survey and water point observations, 2025

However, service reliability was substantially lower than coverage figures suggested: 160 households (40.0%) experienced primary source non-functionality in the preceding month, with a median reported downtime of 14 days (interquartile range: 7–21 days). Spatial analysis revealed marked ward-level heterogeneity in functionality, ranging from 45% to 78% of water points operational at the time of assessment (Figure 1 - not shown; ward-level variation documented in field records).

Distance to primary water source averaged 520 meters (SD=340m) round-trip, translating to a mean collection time of 32 minutes per trip (SD=18 min). Households reported a mean of 2.8 daily trips (SD=1.2), yielding an aggregate mean weekly water collection time of 18.2 hours (SD=6.5 hours), predominantly borne by women and girls.

3.2.2 Sanitation and Hygiene Infrastructure
Improved latrine coverage was 30.0% (n=120); 39.0% of households had unimproved latrines (simple uncovered pits), and 31.0% practiced open defecation (Table 1). Among households with latrines, only 68% (n=187 of 276) reported consistent use, with privacy concerns, structural disrepair, and cultural taboos cited as principal barriers in FGDs.

Direct observation identified handwashing stations with soap in 140 households (35.0%). Where present, stations typically consisted of simple tippy-taps or buckets; soap availability at the time of observation was inconsistent, suggesting intermittent.

Rather than sustained practice.

3.3 Water Quality Results

Microbiological testing of 200 primary sources revealed Substantial contamination (Table 2). Overall, 108 sources (54.0%) met the "safe" threshold (0 CFU/100mL E. coli), 34 (17.0%) were classified as intermediate risk (1–10 CFU/100mL), and 58 (29.0%) were unsafe (>10 CFU/100mL).

Table 2: Water Quality (E. coli) by Source Type (n=200 samples)

Source Type	Samples (n)	Safe (0 CFU/100mL)	Intermediate (1–10 CFU/100mL)	Unsafe (>10 CFU/100mL)
Borehole with handpump	120	84 (70.0%)	18 (15.0%)	18 (15.0%)
Protected spring	40	20 (50.0%)	10 (25.0%)	10 (25.0%)
Unprotected stream/shallow well	40	4 (10.0%)	6 (15.0%)	30 (75.0%)
Total	**200**	**108 (54.0%)**	**34 (17.0%)**	**58 (29.0%)**

Source: Laboratory water quality testing, 2025

Contamination was concentrated but not exclusive to unprotected sources: 75.0% of unprotected streams and shallow wells tested unsafe, compared with 25.0% of protected springs and 15.0% of boreholes. Notably, the presence of nominally "improved" infrastructure did not guarantee microbial safety; seasonal factors (dry-season drawdown, rainy-season runoff) contributed to intermittent contamination even at protected points, as documented in qualitative narratives.

3.4 Health and Educational Outcomes

3.4.1 Diarrheal Disease Incidence

Sixty-four households (16.0% of the total sample) reported at least one diarrheal episode among children under five in the two weeks preceding the survey (Table 3). Among affected households, the mean number of episodes was 1.4 (SD=0.6). Health surveillance data from district clinics corroborated elevated diarrheal presentations during study periods, particularly following early rains when source contamination peaked.

Table 3: Time Burdens and Health Outcomes (n=400 households)

Indicator	Mean (SD) / Count (%)
Time Burdens	
The number of hours per week that women/girls spend collecting water	18.2 (6.5)
The number of hours per week the household spends on pump repairs/maintenance tasks	1.8 (2.4)
Health Outcomes	
Households reporting ≥1 under-five diarrheal episode in the past 2 weeks	64 (16.0%)
Mean diarrheal episodes per affected household	1.4 (0.6)
Educational Outcomes	
School-aged children (per household) who missed school due to water duties in the last term	0.8 (1.2)
Average days missed per child when absent for water duties	6.4 (3.2)

Source: Household survey, 2025

3.4.2 School Attendance

Among households with school-aged children, 42% (n=112 of 268 households) reported that at least one child had missed school in the preceding term due to water collection duties or WASH-related illness. Average absenteeism was 6.4 days per term (SD=3.2) among affected children. Gender disaggregation revealed disproportionate impact on girls: 68% of reported absences for water duties involved female children, particularly.

During peak dry-season months, when collection times increased.

3.5 Predictors of Diarrheal Disease: Logistic Regression Analysis

Multivariable logistic regression examined associations between WASH service variables and under-five diarrheal episodes, controlling for household socioeconomic characteristics (Table 4).

Table 4: Logistic Regression Analysis – Predictors of Under-Five Diarrheal Disease (n=400)

Predictor Variable	Adjusted Odds Ratio (OR)	95% Confidence Interval	p-value
WASH Variables			
Primary source non-functional in the past month (yes vs. no)	1.85	1.05 – 3.27	0.033
E. coli unsafe (>10 CFU/100mL) vs. safe (0 CFU/100mL)	2.70	1.55 – 4.71	0.001
E. coli intermediate (1–10 CFU/100mL) vs. safe	1.62	0.84 – 3.12	0.148
No improved latrine (vs. improved latrine present)	1.40	0.82 – 2.39	0.215
No handwashing station with soap observed (vs. present)	1.52	0.91 – 2.54	0.108
Socioeconomic Covariates			
Lowest wealth tertile (vs. highest tertile)	1.95	1.10 – 3.46	0.022
Middle wealth tertile (vs. highest tertile)	1.38	0.76 – 2.50	0.292
Maternal education, primary or higher (vs. no formal education)	0.68	0.38 – 1.23	0.202
Household size (per additional member)	1.08	0.96 – 1.21	0.185

Model fit: Hosmer-Lemeshow $\chi^2=6.42$, $p=0.598$; Nagelkerke $R^2=0.28$
Robust standard errors clustered at village level (n=48 villages)
Source: Household survey integrated with water quality data, 2025
After controlling for socioeconomic factors, households whose primary water source had been non-functional in the preceding month had 1.85 times the odds of reporting under-five diarrheal episodes compared to households with consistently functional sources (95% CI: 1.05–3.27, p=0.033). Microbial contamination exhibited a stronger association: households using water sources testing unsafe (>10 CFU/100mL E. coli) had 2.70 times the odds of diarrhoea compared to those using safe sources (95% CI: 1.55–4.71, p=0.001). Intermediate contamination levels (1–10 CFU/100mL) showed elevated but non-significant odds (OR=1.62, p=0.148).
Presence of improved latrine did not reach statistical significance (OR=1.40, p=0.215), suggesting that latrine presence alone was insufficient without sustained hygienic use and maintenance. The lowest wealth tertile predicted higher diarrheal odds (OR=1.95, p=0.022), reflecting broader socioeconomic vulnerability.

3.6 Qualitative Findings: Institutional, Financial, and Socio-Cultural Barriers

3.6.1 Spare-Parts Supply Chains and Repair Delays

Thematic analysis of KIIs and WPMC records identified spare-parts shortages as the principal driver of extended downtime. WPMC chairs consistently cited procurement delays:
"When the bearing fails, we may wait three weeks or longer. The parts are stocked in Chama town, but transport costs are high, and sometimes the supplier is out of stock. During that time, people use the stream." (WPMC Chair, Ward 4)
Median community repair time across wards was 18 days (IQR: 10–28 days); in wards where WPMCs maintained pre-positioned spare-parts kits and emergency cash reserves, median repair time fell to 7 days (IQR: 5–10 days), a 61% reduction. District officers corroborated supply-chain bottlenecks, noting that centralised procurement schedules and limited vendor networks created systematic delays.

3.6.2 Maintenance Financing and Governance Transparency

Only 20% of households reported paying water fees, reflecting weak financial sustainability. Qualitative data revealed that fee compliance was highly sensitive to governance transparency:
"People won't pay if they do not see receipts or know where money goes. When we started keeping a logbook and showing receipts publicly, more households began contributing." (WPMC Treasurer, Ward 2)
In wards where WPMCs maintained transparent ledgers, posted repair logs, and held quarterly public meetings, reported fee compliance averaged 68% of households; in wards with opaque financial practices, compliance fell below 25%. FGD participants emphasised that visible accountability—seeing repairs occur promptly after fee payment—built trust and motivated sustained contributions.
However, even where compliance was higher, collected funds typically covered only routine maintenance (seals, washers); major component replacements (pump rods, cylinders) required external donor support or district subsidies, which were intermittent. WPMC financial audits showed mean reserves of ZMW 380 (approximately USD $15), insufficient for emergency repairs.

3.6.3 Gendered Time Burdens and Decision-Making Exclusion

Women and girls bore 87% of water collection labour (per household time-use data), yet female representation on WPMCs averaged only 18% (range: 0–33% across wards). FGDs with women's groups revealed systematic exclusion from siting and maintenance priority decisions:
"We fetch water every day, walking far, but when they decide where to put the borehole or when to repair it, men make those choices. They do not know which path is safe or which source is closest to where we work." (Women's FGD, Village A)
Statistical analysis supported these narratives: in wards where female WPMC representation exceeded 30%, average household water collection time was 3.5 hours per week shorter (14.7 vs. 18.2 hours, t=4.83, p<0.001), suggesting that women's participation produced more equitable siting and maintenance scheduling.
Gender dynamics also mediated latrine adoption and hygiene behaviours. Male and youth FGDs acknowledged that:
"Some families say latrines are for the old or that pit smells bring shame. Women care more about privacy and cleanliness, but if the latrine has no roof or door, they will not use it." (Mixed youth FGD, Village B)
These perceptions, coupled with inadequate menstrual hygiene management facilities in schools, contributed to lower latrine usage rates and elevated school absenteeism among adolescent girls.

3.6.4 Water Quality Perceptions and Household Treatment Practices

A notable disconnect emerged between community perceptions of water safety and measured microbiological quality. Many households perceived boreholes as inherently safe based on clarity and taste, despite 15% of boreholes testing contaminated. Household water treatment adoption was correspondingly low: only 28% of households reported treating water "always" or "sometimes" (primarily boiling), and treatment was inconsistently practised even where awareness existed.

FGD participants explained reliance on sensory cues:
"We trust the borehole water because it looks clean and has no bad taste. The stream water looks dirty, so we know to boil it. But we did not know boreholes could also have germs we cannot see." (Women's FGD, Village C)

This perception-reality gap indicated that community education pairing microbiological findings with practical treatment demonstrations would be necessary to shift household behaviours.

4. DISCUSSION

4.1 Principal Findings in Context

This mixed-methods study provides robust empirical evidence that nominal WASH infrastructure coverage substantially overstates reliable, safe service access in rural Chama District. While 65% of households reported using improved water sources, functionality deficits (40% recent non-functionality) and microbial contamination (46% of sources unsafe or intermediate risk) exposed households to intermittent supply and waterborne pathogens. These patterns confirm global critiques that headline coverage metrics mask episodic service failures and water quality problems when functionality and quality monitoring are absent (Bain et al., 2014; WHO & UNICEF, 2022).

The regression analysis demonstrated that both microbial contamination and service interruptions were significant, independent predictors of under-five diarrheal disease, with adjusted odds ratios indicating materially elevated risk. These findings align with longitudinal intervention studies in Zambia and neighbouring countries showing that combined borehole rehabilitation and household water treatment reduce diarrheal incidence by 35–50% (Reynolds et al., 2014; Reynolds et al., 2017). The non-significant association between improved latrine presence and diarrheal risk underscores a critical nuance: sanitation infrastructure alone does not protect health without sustained hygienic use, proper maintenance, and safe faecal-sludge management (UN Water, 2020; Hutton & Varughese, 2016). Qualitative data revealing privacy concerns, structural disrepair, and cultural taboos help explain why latrine presence did not translate uniformly to reduced disease burden.

4.2 Institutional Determinants of Service Sustainability

The convergent evidence strongly implicates institutional and supply-chain weaknesses as primary drivers of functionality deficits. Spare-parts shortages and procurement delays produced median repair times of 18 days—more than two weeks during which households reverted to unsafe alternatives. Where WPMCs maintained pre-positioned kits and transparent financial reserves, repair times were reduced by 61%, demonstrating that local institutional arrangements can materially improve uptime. These findings validate Ostromian predictions that well-defined rules, monitoring, and predictable financing support collective resource management (Ostrom, 1990).

The observed sensitivity of fee compliance to governance transparency (68% vs. <25% compliance in transparent vs. opaque committees) further illustrates how accountability mechanisms mediate willingness to pay. Transparent practices—receipts, public repair logs, quarterly community forums—function as credible signals that household contributions will translate into services, reducing free-riding and building social trust. This pattern aligns with operational research across sub-Saharan Africa, showing that financial sustainability depends on visible, enforceable accountability alongside technical capacity (Whittington et al., 2016; WaterAid, 2021).

However, even well-governed WPMCs face structural financing constraints: modest user fees cover routine maintenance but not major component replacements, creating dependence on intermittent donor or district subsidies. This points to the need for blended financing models that combine local cost-recovery with external support for capital rehabilitation, an approach increasingly piloted through results-based financing mechanisms that link disbursements to verified uptime and quality metrics (Hassan & Schouten, 2017).

4.3 Gendered Dimensions of WASH Access and Governance

The gendered findings—women bearing 87% of collection labour yet comprising only 18% of WPMC membership—illustrate how exclusionary governance produces both inequitable burdens and suboptimal service outcomes. The empirical association between higher female representation and reduced household collection times suggests that women's participation reshapes infrastructure siting and maintenance priorities to reflect users' lived realities. This result supports growing evidence that gender-responsive WASH programming requires substantive inclusion—formal representation backed by capacity building and norms change—rather than token participation (Mulenga et al., 2020).

From a theoretical perspective, these dynamics are explicable through the Sustainable Livelihoods Framework (SLF), which positions WASH services within broader livelihood asset portfolios and shows how gendered control over resources mediates household vulnerability (Scoones, 1998). Water collection time directly reduces women's human capital accumulation (education, skills development) and constrains income-generating activities, perpetuating poverty. Behavioural theories complement this by showing that perceived control and social norms influence both individual practices and collective governance choices (Ajzen, 1991); where women lack decision-making power, their preferences and constraints remain invisible in infrastructure planning.

4.4 Socio-Technical Interactions and Technology Choices

The study's findings reinforce socio-technical perspectives, emphasising that technology performance depends on surrounding institutional, market, and social systems (Bijker et al., 1987). Stakeholder interest in solar pumps and mechanised systems—anticipated to reduce mechanical wear and manual labour—was tempered by recognition that higher capital costs, complex maintenance regimes, and equitable cost-recovery arrangements would be prerequisites for sustainability. Pilot evaluations elsewhere have shown that mechanised options reduce downtime but require mature spare-parts markets, trained technicians, and clear subsidy designs to protect poor households from exclusion (Carter & Ross, 2019; Njoroge et al., 2020).

The perception-reality gap regarding borehole safety further illustrates socio-technical disconnects: households relied on sensory cues (clarity, taste) to assess water quality, underestimating microbial risks and reducing adoption of household treatment. Bridging this gap requires integrating objective monitoring (routine E. coli testing) with participatory communication that translates laboratory findings into locally meaningful messages and practical actions, aligning with Health Belief Model predictions that increasing perceived susceptibility and providing cues to action drive preventive behaviours (Rosenstock, 1974).

4.5 Policy Implications and Pathways to Sustainable Services

The integrated evidence supports several high-priority policy interventions. First, district monitoring systems must transition from static infrastructure inventories to dynamic performance tracking. Instituting monthly uptime logs, quarterly E. coli sentinel testing, and simple dashboards aggregating repair turnaround times would enable planners to prioritise rehabilitations where health returns are highest, shifting investment logic from capital expansion to lifecycle asset management (Ministry of Water Development, 2022).

Second, establishing regional spare-parts hubs and ward-level emergency maintenance funds addresses the proximate cause of extended downtime. Pre-positioning commonly needed components (bearings, seals, pump rods) at sub-district centres and institutionalising small WPMC cash reserves (ZMW 500–1000) backed by transparent accounting templates would reduce median repair times to under one week, materially reducing exposure to unsafe alternatives.

Third, governance reforms mandating financial transparency (receipts, public repair logs) and minimum female representation (e.g., 30% threshold) would improve both fee compliance and service equity. Capacity-building programs providing women with bookkeeping, leadership, and technical training would ensure substantive rather than symbolic participation.

Fourth, behavioural interventions pairing water quality monitoring with participatory hygiene promotion and school-based menstrual hygiene management would address the perception-reality gap and reduce gendered educational disparities. Community forums presenting simplified microbial results, demonstrating household treatment methods, and co-developing maintenance priorities would strengthen risk awareness and collective efficacy.

Finally, donor funding models must rebalance toward lifecycle support, earmarking portions of capital grants for recurrent maintenance, spare-parts provisioning, and capacity building. Results-based financing pilots linking disbursements to verifiable uptime and quality indicators would create incentives for sustained performance while requiring robust monitoring to prevent gaming (Hassan & Schouten, 2017).

4.6 Study Limitations

Several limitations warrant acknowledgement. The two-season sampling captured dry-wet variability but not inter-annual fluctuations or acute shocks outside the observation window. Diarrheal incidence relied on a two-week household recall, which may be subject to recall bias despite efforts to minimise misclassification through standardised symptom definitions and enumerator training. Water quality testing focused on bacteriological indicators (E. coli) and did not encompass chemical contaminants (fluoride, arsenic, heavy metals) due to budgetary and laboratory constraints, limiting the ability to address non-microbial health risks.

Purposive sampling of WPMC executives and district officers maximised information richness but limited the statistical generalizability of institutional findings beyond Chama District's specific governance context. Some qualitative data may reflect social desirability bias, particularly in KIIs where officials described practices; triangulation with financial audits and direct observations mitigated but did not eliminate this risk.

Finally, while the convergent design strengthened internal validity through cross-verification, causal inference regarding long-term sustainability outcomes would benefit from longitudinal panel designs tracking service performance, governance evolution, and health impacts over multi-year cycles.

4.7 Directions for Future Research

Priority research needs include: (1) experimental or quasi-experimental evaluations of governance reforms (transparency protocols, gender quotas) and financing models (results-based mechanisms, blended funds) with embedded cost-effectiveness analyses; (2) longitudinal studies employing high-frequency monitoring (monthly uptime logs, repeated E. coli testing) to capture causal pathways and seasonal dynamics; (3) comparative assessments of spare-parts distribution models (regional hubs, franchised maintenance markets, private vendor networks) across districts with varying market maturity; and (4) mixed-methods investigations of socio-cultural determinants of latrine adoption and sustained use, informing culturally tailored behavior-change strategies.

5. CONCLUSIONS

This study provides robust, triangulated evidence that nominal WASH infrastructure coverage in rural Chama District substantially overstates reliable, safe service access. Functionality deficits and microbial contamination exposed households to intermittent supply and waterborne pathogens, producing measurable health harms: contaminated and non-functional sources significantly predicted under-five diarrheal disease, while women's water collection burdens correlated with elevated school absenteeism among girls. The convergent mixed-methods analysis identified spare-parts supply-chain weaknesses, inadequate maintenance financing, opaque governance, and gendered exclusion from decision-making as principal barriers to sustained service delivery.

Converting infrastructure investments into equitable, durable WASH services requires integrated interventions that address technical, institutional, and behavioural dimensions concurrently. Practical, high-impact priorities include: transitioning to performance-oriented monitoring (uptime, quality, repair turnaround); establishing spare-parts hubs and emergency maintenance funds; strengthening WPMC financial transparency and substantive female participation; pairing microbial monitoring with participatory hygiene promotion; and rebalancing donor funding toward lifecycle support. These evidence-based recommendations offer feasible pathways for district planners, Water Point Management Committees, and development partners to improve service functionality, water quality, and public health outcomes in rural Zambian settings and comparable contexts across sub-Saharan Africa.

Acknowledgments

The authors gratefully acknowledge the cooperation of Chama District Council, Water Point Management Committees, and community members who participated in this research. We thank field enumerators and laboratory staff for their dedication, and DMI-St. Eugene University for institutional support.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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