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Impact Evaluation of Water Access Rwanda's INUMA™ Safe Water Mini-Grids

FINAL REPORT

Report commissioned by

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EXECUTIVE SUMMARY

RWANDA faces a critical water access challenge: while the nation has made remarkable progress, 44% of households still lack basic water access, with stark disparities between rural and urban areas. There is also a wide divergence by wealth, with 85% of the richest quintile and 38% of the poorest having access to basic water supply. This disparity poses a challenge to Rwanda's National Strategy for Transformation (NST2) goals of universal village-level water access by 2029.

To address this, Water Access Rwanda (WAR) launched the INUMA™ Safe Water Mini-Grids, aimed at providing safe water throughout rural and peri-urban areas. These Mini-Grids currently serve 45,748 public users across nine districts, connecting 3,009 private homes and 16 businesses through 50 solar-powered mini-grids and deliver around 200 million liters of safe water annually.

While WAR has demonstrated success through internal assessments of its services' impact, the organization recognizes the need for independent verification. Current evaluations primarily rely on self-reported surveys and qualitative reports conducted by WAR personnel or affiliated individuals. This internal focus naturally raises questions about the objectivity of claims regarding service delivery speed, reliability, affordability, sustainability, and overall impact. To address these methodological limitations and ensure transparency, WAR commissioned this independent evaluation of its INUMA Safe Water Mini-Grids initiative.

METHODOLOGY— The evaluation was conducted in three phases between August 2023 and August 2024. The first phase was a baseline assessment using a mixed-methods quasi-experimental design, comparing communities served by INUMA Mini-Grids with matched non-served communities pre-selected for future INUMA installations. The sample included 640 households (400 in treatment areas, 240 in control areas), selected through stratified random sampling. The second phase involved a comparative analysis of long-term (>1 year, N=185) and short-term (<1 year, N=170) INUMA customers. The third phase used targeted qualitative research to explore critical issues identified during the quantitative analysis. Statistical analysis employed both descriptive and inferential methods, carefully measuring the size and significance of differences, and using advanced techniques to ensure these differences were not due to chance.

KEY FINDINGS— INUMA™ Safe Water Mini-Grids have a positive impact on water access, safety, affordability, and broader societal outcomes acrossvarious dimensions:

1. **Improvement in water accessibility and time efficiency**: In areas served by INUMA Mini-Grids, 42.2% of households access water within 200 meters, compared to only 17% in non-served areas. The disparity becomes even more pronounced over greater distances: while 36.7% of households in non-INUMA areas must travel over a kilometer to fetch water, this challenge affects a mere 1.7% of households benefiting from INUMA's service. Furthermore, a mere 1.1% of INUMA households spend over 30 minutes collecting water, in stark contrast to 66.3% in non-INUMA served areas.
2. **Improved water safety and potability**: The introduction of INUMA water has led to a statistically significant and practically meaningful reduction in waterborne diseases, with a Number Needed to Treat (NNT) of 3.0.To

put this in practical terms: if INUMA serves 300 households in a community, it prevents approximately 100 cases of waterborne illness every three months. During the study period, 92.8% of INUMA households reported no water-related illnesses, compared to 58.9% in non-INUMA areas. INUMA has also dramatically reduced reliance on unsafe water sources, with 86% of users adopting it as their primary source, a significant improvement from the 44.4% who previously relied on contaminated wells and other unsafe alternatives.

3. **Enhancement in water services delivery and reliability**: INUMA Mini-Grids deliver superior reliability compared to alternatives, with only 18.6% of users experiencing frequent water shortages, significantly lower than the 39% reported in non-INUMA communities. Service restoration is notably efficient, with 55.4% of interruptions resolved within 24 hours, compared to 37.1% of non-INUMA communities facing outages lasting over six days. Reliability remains high regardless of operational duration, with 92.7% of long-term and 88.0% of short-term users reporting rare or no shortages, and over 90% observing no leaks.
4. **Offering cost-effective water solutions**: The Mini-Grids have lowered household water costs, with 57.5% of served households spending less than 100 RWF daily, compared to only 23.5% in non-served areas, while high-cost expenditures above 200 RWF daily affect just 4.1% of INUMA users versus 23.9% in non-INUMA communities. The grids also have price stability amid inflation, with 78.2% of users reporting stable water prices over three months, far surpassing the 21.7% in non-served areas. Affordability has reduced reliance on unsafe water sources, with 78.9% of INUMA households never resorting to such alternatives due to cost, compared to only 20.9% in non-INUMA areas. Both new and long-term users rate INUMA water as moderately to very affordable (65.6% and 55.7%, respectively), and the program minimizes cost-driven restrictions, with only 10.4% of INUMA households limiting water use due to cost, compared to 48.5% in non-served areas, ensuring consistent and equitable access.
5. **Catalyzing broader positive societal impacts**: Beyond safe water provision, INUMA Mini-Grids have led to other positive social impacts by improving hygiene, health, education, and gender dynamics in served communities. Cost-related compromises in hygiene practices have nearly disappeared, with only 0.9% of households reducing bathing frequency due to cost, compared to 8.9% in non-INUMA areas. Educational outcomes have also benefited, with 69.2% of INUMA communities reporting improved academic performance and a drop in academic decline rates to 3.3%, compared to 14.9% in non-INUMA regions. Finally, women's time availability has increased, with 76.7% reporting more free time, leading to higher participation in income-generating activities. Gender dynamics around water collection have shifted, reducing the burden on women and increasing male participation.

IMPLICATION— WAR's successful market-based approach to providing clean and affordable water to rural communities while maintaining strong social impact positions it as a potentially scalable model for addressing Rwanda's water access challenges. The program's demonstrated ability to maintain high operational standards while achieving significant social outcomes suggests strong potential for expansion. This evaluation provides compelling evidence that INUMA represents a viable pathway toward achieving Rwanda's NST2 and Vision 2050 water access objectives. Its combination of operational excellence, social impact, and sustainability offers valuable lessons for scaling water access solutions across Rwanda and potentially other developing nations in Africa and beyond.

1

INTRODUCTION

1.1 Background

THE global landscape of access to essential drinking water and sanitation services has undergone remarkable transformation since the turn of the millennium. A 2019 collaborative report by UNICEF and WHO revealed extraordinary progress, with 1.8 billion individuals gaining access to drinking water and 2.1 billion to sanitation[1]. Despite these achievements, persistent disparities in accessibility, availability, and quality of safe drinking water continue to affect approximately one-third of the world's population, with particularly acute challenges in rural areas and least-developed countries.

Access to essential drinking water and sanitation services has transformed dramatically since the millennium's turn. A seminal 2019 UNICEF-WHO collaborative report documented unprecedented progress, with 1.8 billion people gaining access to drinking water and 2.1 billion to sanitation services. However, this progress remains uneven – approximately one-third of the global population continues to face persistent challenges in accessing safe drinking water, with particularly acute disparities affecting rural areas and least-developed countries.

Rwanda's journey in water access exemplifies both notable progress and persistent challenges. The Global Water Partnership's 2020 snapshot[2] revealed significant improvements, with 83% of the population gaining access to improved drinking water by 2020, up from 79% in 2015. Access to safely managed drinking water services also saw substantial growth, rising from 7% in 2015 to 12% by 2020. However—as emphasized by the WHO[3]—considerable challenges persist.

1.2 Country context

Rwanda's water, sanitation, and hygiene (WASH) landscape presents a complex picture of progress and challenges. The most recent UNICEF report[4] highlights significant advances in water access while revealing persistent challenges in equitable access, service reliability, and sustainable financing, particularly in rural areas. The urban-rural divide remains stark, with 87% access to basic water supply in urban areas contrasting sharply with just 49% in rural regions. The 2022 Census data shows that while 72% of households have access to basic sanitation services, considerable disparities persist across geographical regions.

Infrastructure challenges further impede service delivery across Rwanda, with a troubling 41% of water lost through non-revenue water losses as of 2022. Furthermore, as illustrated in Figure 1.1, there is a significant regional disparities in coverage and access. While the central regions around

[1] World Health World Organization (WHO) and the United Nations Children's Fund (UNICEF) (2019) Progress on household drinking water, sanitation and hygiene 2000-2017: Special focus on inequalities. New York. Available at:https://www.who.int/publications/i/item/9789241516235 (Accessed: October 12, 2024)

[2] Global Water Partnership (2022) Rwanda snapshot on water and climate. Available at:https://www.gwp.org/en/country-snapshots/ (Accessed: October 12, 2024).

[3] World Heath Organization (2023) "Unsafe water, sanitation and hygiene are key drivers of epidemics in the African Region," Analytical Fact Sheet, June. Available at:https://files.aho.afro.who.int/afahobckpcontainer/production/files/iAHO_WASH_Regional_Factsheet.pdf (Accessed: October 12, 2024).

[4] UNICEF Rwanda (2024) Water, Sanitation and Hygiene (WASH) in Rwanda: A situation analysis. Available at: https://www.unicef.org/rwanda/media/5381/file/UNICEF%20Rwanda.pdf (Accessed: December 6, 2024).

Kigali showcase dense, well-developed water networks, the eastern regions has scattered, isolated facilities. The northern areas maintain uniform distribution, but the western and southwestern regions display uneven coverage patterns.

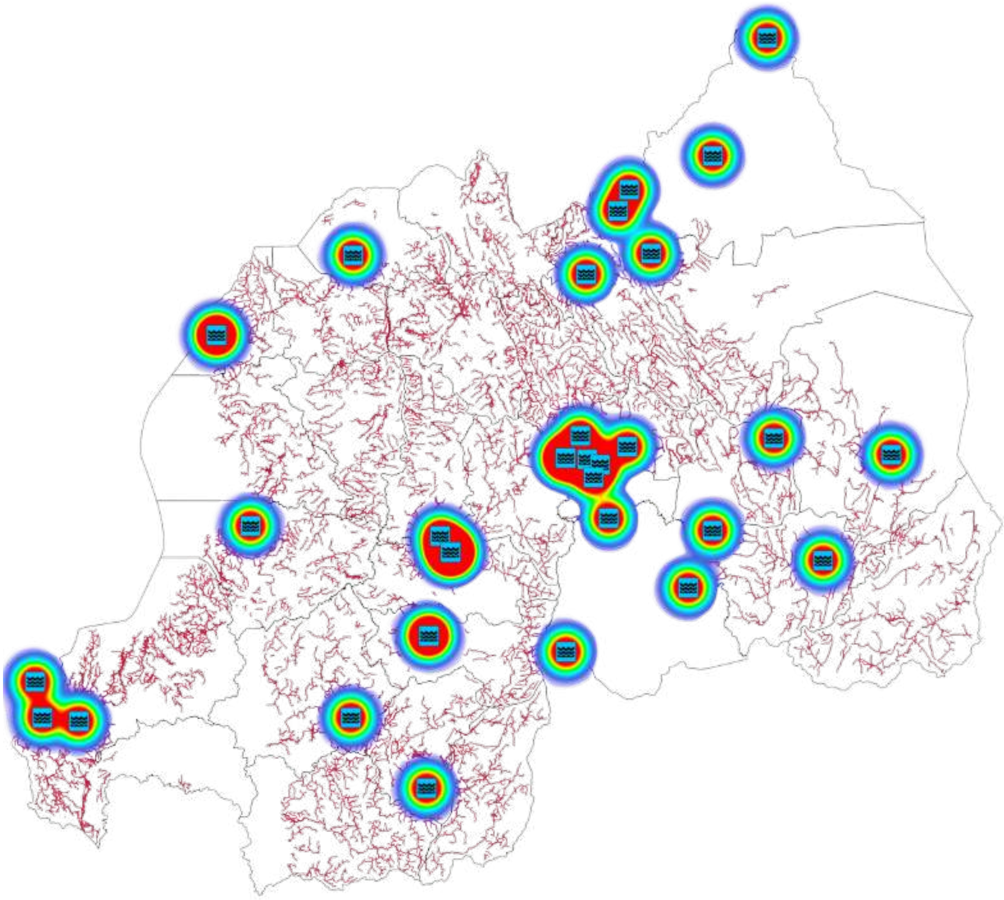

Fig. 1.1. Spatial distribution of WASAC's Water supply infrastructure in Rwanda
Red lines represent water bodies and waterways, while black lines delineate district boundaries. Blue circular overlays indicate service points, with their size and color intensity representing capacity and distribution density. Clustered, high-intensity areas indicate well-developed water networks, while scattered, smaller circles represent areas with less developed distribution infrastructure. Source: WASAC.

The situation is particularly dire in rural areas, where approximately 45% of piped water systems are either fully or partially non-functional. Climate change further compounds these technical difficulties, as increasing frequencies of droughts, floods, and landslides continue to disrupt services and damage infrastructure.

The hygiene landscape has additional challenges, with only 25% of Rwanda's population having access to basic hygiene facilities with soap and water. The urban-rural divide is notable, with 37% of urban residents having access compared to only 23% in rural areas. The impact extends beyond immediate health concerns, affecting education and economic opportunities, particularly for women and girls. Studies show that 18% of women and girls miss school or work due to inadequate menstrual hygiene facilities [5].

[5] UNFPA Rwanda(2022) "Menstrual Health and Hygiene: Why there is still more to be done"

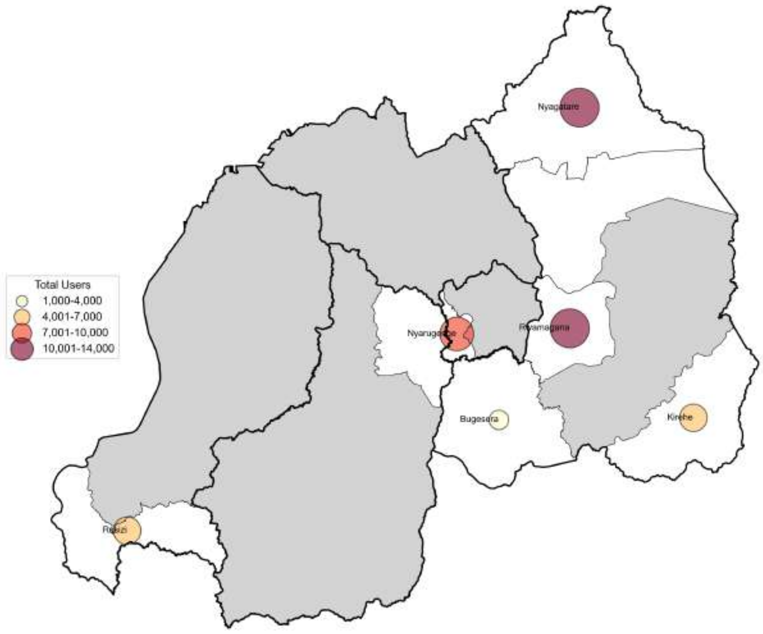

Fig. 1.2. Spatial Distribution of INUMA Mini-grid customers at District Level
Bubble size and color intensity reflect user populations ranging from 1,000-4,000 (smallest, lightest bubbles) to 10,001-14,000 (largest, darkest bubbles). Districts shown in light grey indicate areas without INUMA service

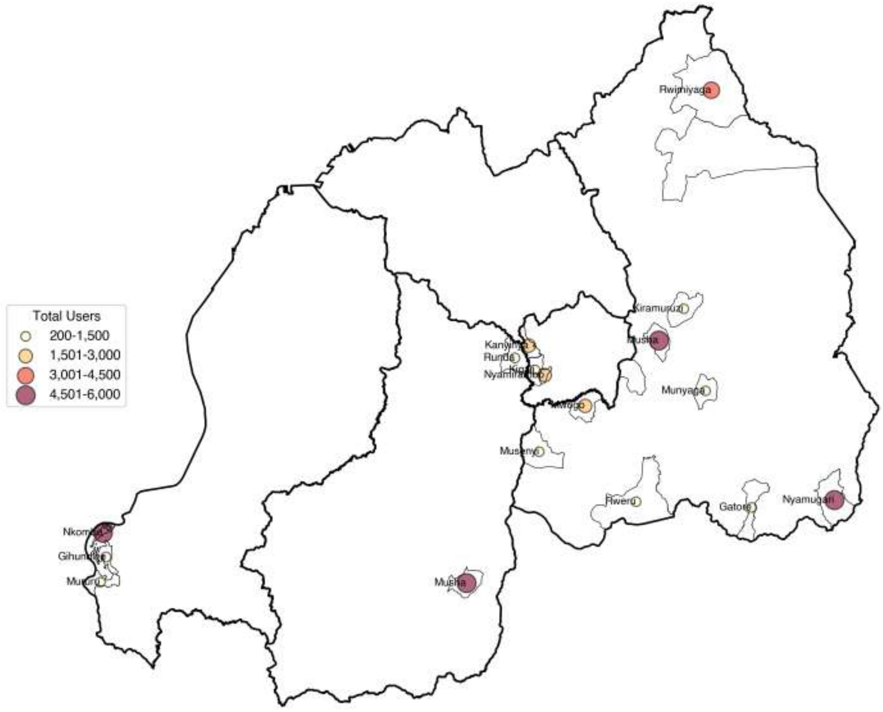

Fig. 1.3. Spatial Distribution of INUMA Mini-grid Customers at Sector Level
Bubble dimensions and color intensity indicate user density: smaller, lighter bubbles represent 200-1,500 users, while larger, darker bubbles indicate 4,501-6,000 users. Sectors without INUMA coverage are left blank.

In response to these challenges, the government has set ambitious targets through Vision 2050, aiming to increase renewable water resources to 1,000m^2 per capita by 2035 and 1,700 m^3 by 2050. The recently published Rwanda's National Strategy for Transformation (NST2) 2024-2029[6] outlines comprehensive plans for water and sanitation development, emphasizing infrastructure expansion and efficiency improvements. A key focus lies in doubling daily water production capacity and ensuring nationwide village-level access, with particular attention to rehabilitating non-functional water supply systems to address current water losses.

It is against this backdrop of complex challenges and governmental initiatives that Water Access Rwanda (WAR) has emerged as a key implementing partner in the country's water sector. As a youth-led social enterprise, WAR has pioneered innovative solutions that directly support Rwanda's national water access objectives.

WAR's flagship initiative, the INUMA™ safe water mini-grids, represents an innovative approach to providing reliable, affordable, and safe water across rural and peri-rural communities. This intervention directly addresses many of the fundamental challenges outlined in Rwanda's national context, from infrastructure inefficiencies to urban-rural disparities, while aligning with the government's ambitious Vision 2050 goals for universal water access.

1.3 Purpose and significance

As of 2024, WAR's data indicates that these mini-grids have provided water supply to 3,009 private homes and 16 businesses, including schools, churches, a health facility, and hospitality businesses. Additionally, its impact extends further to 45,748 public users, with a cumulative delivery of nearly 200 million liters of safe water across nine districts, as illustrated in Figure 1.3 and Figure 1.2 on the facing page.

The WAR annual report 2023 reveals impressive operational metrics. Their efficiency in establishing new water kiosks in just 9.1 days has enabled them to build a network of 35 mini-grids, powered by 64KW of solar capacity, which have delivered 196 million liters of safe water. Each installation serves up to 1,500 people at WHO Standards, delivering an average of 3,900 liters per person daily. Their financing model, offering RWF 150,867 with 0% interest over 12 months, has made clean water accessible to rural communities, though the 9% utilization rate compared to full capacity indicates potential for further growth. This approach has not only enhanced water affordability but has also attracted substantial investment, including a notable $7.5 million commitment from the Steele Foundation for Hope for establishing 230 new mini-grids.

While WAR's impact monitoring surveys consistently demonstrate high effectiveness and positive outcomes for customers, earning numerous national and international accolades, the current evaluation methodology relies heavily on internal self-reported surveys and qualitative assessments conducted by WAR personnel or affiliated individuals. This internal focus raises legitimate concerns about the objectivity and independence of service quality and impact claims. To address these considerations and foster transparent communication with stakeholders and potential partners, WAR has commissioned this impact evaluation to serve as an independent, unbiased assessment tool.

[6] Government of Rwanda (2024) National Strategy for Transformation (NST2).

1.4 Objectives of the impact evaluation

This impact evaluation aims to provide a credible evidence of the Mini-Grid's effectiveness. It focuses on quantifying the Mini-Grids' impact on water accessibility in the communities they serve, assessing their ability to provide reliable, affordable, and safe drinking water.

In addition to water-related outcomes, this evaluation takes a broader view by investigating the socioeconomic effects of the Mini-Grids on the target populations. It investigates their influence on health, economic activities, and social dynamics, aiming to offer a comprehensive understanding of the initiative's transformative potential.

Finally, the findings presented in this report provide actionable insights and evidence-based recommendations. These insights are designed to inform strategic decision-making, guide operational improvements, and enhance service delivery. Furthermore, they offer a foundation for future policy and investment decisions in the water access sector, with the goal of maximizing the social impact and operational effectiveness of the Mini-Grid initiative.

1.5 Scope

This evaluation report focuses on WAR INUMA™ Safe Water Mini-Grids initiative across Rwanda. The study's temporal scope extends from their initiative's inception to the present day, with a strategic emphasis on comparative analysis. It juxtaposes outcomes between communities with and without access to INUMA mini-grids, while also differentiating between long-term customers and recent adopters within the serviced areas. The evaluation framework encompasses five key dimensions that are critical to understanding the initiative's impact and effectiveness:

- Water accessibility and time efficiency metrics examines changes in distance to water points, time spent collecting water, and frequency of collection.
- Water quality and safety benchmarks against national and international standards while considering user perceptions.
- Reliability and sustainability metrics scrutinizes service continuity, maintenance practices, and the long-term operational viability of the mini-grids.
- Economic impact explores household expenditure on water, perceptions of affordability, and the broader economic ripple effects on local communities.
- Social and cross-cutting impacts examines effects on education, gender equality, health outcomes, and environmental sustainability to ensure a comprehensive understanding of the initiative's influence on community well-being and development.

2

METHODOLOGY

Our evaluation employed a mixed-methods quasi-experimental design to assess the effectiveness of INUMA™ Safe Water Mini-Grids in improving water access and related socioeconomic outcomes in Rwanda. The study compared communities served by INUMA™ Safe Water Mini-Grids (treatment group) with matched non-served communities (control group) pre-selected for future INUMA installations.

2.1 Theory of change

IF

WAR introduces INUMA Mini-Grids in underserved rural and peri-urban communities through:

- Centralized water infrastructure development and management
- Professional operation and maintenance systems
- Market-based service delivery model
- Quality control and water safety protocols
- Community engagement and feedback mechanisms

THEN

The intervention will generate:

- **Short-term impact:** Improved water accessibility, reduced water collection time and effort, enhanced water quality and safety, increased water supply reliability, and lower per-unit water costs for households.
- **Medium-term impact:** Decreased incidence of waterborne diseases, improved household hygiene practices, reduced household expenditure on water treatment, increased household water consumption, and greater time availability for productive activities.
- **Long-term impact:** Strengthened community health, improved educational attainment, enhanced economic opportunities, advanced gender equity, and increased community resilience.

BECAUSE

WAR's private enterprise model addresses critical barriers through multiple reinforcing mechanisms:

- **Financial sustainability:** Market-based pricing ensuring cost recovery, ability to attract private investment capital, and revenue-driven incentives for service expansion.
- **Technical innovation:** Flexibility to adopt new technologies, continuous improvement of service delivery, data-driven optimization of operations, and adaptive management practices.
- **Customer focus:** Direct accountability to service users, market incentives for customer satisfaction, responsive feedback mechanisms, and competitive pressure for service quality.
- **Infrastructure Management:** Preventive maintenance protocols, regular quality control monitoring, efficient resource allocation, and long-term asset management.

2.2 Evaluation design

To minimize selection bias and ensure meaningful comparisons, communities were matched based on key characteristics, including population size (±10%), socioeconomic indicators, pre-existing water infrastructure, and geographic features. This approach ensured that comparison groups were as similar as possible in all aspects except for INUMA water access.

Statistical calculations, assuming a 5% significance level and 80% power, determined a minimum sample size of (±400)households. To account for potential non-response and support robust subgroup analyses, the sample size was increased to 640 households (400 in treatment areas and 240 in control areas). This larger sample size improved the ability to detect meaningful differences and facilitated stratified analyses across rural and urban settings.

The evaluation was conducted in three phases between August 2023 and August 2024:

1. **Baseline assessment phase (August-October 2023)**: Data were collected through household surveys involving 640 participants. The evaluation focused on the impact of INUMA™ water on accessibility, affordability, and broader societal outcomes. Standardized quantitative surveys measured water access, health outcomes, and socioeconomic indicators, complemented by focus group discussions conducted in each assessed community.
2. **Comparative analysis phase (February-April 2024)**: This phase involved assessing long-term (>1 year, N=185) and short-term (<1 year, N=170) INUMA™ customers. Detailed household surveys were conducted to evaluate water quality, reliability, affordability, and socioeconomic metrics. The aim was to assess the sustainability of positive effects and identify opportunities for optimizing services.
3. **Deep dive phase (June-August 2024)**: Critical issues identified during the quantitative analysis were further explored through targeted qualitative research. Key informant interviews were conducted, and findings were cross-validated using qualitative surveys to ensure robustness and depth in the insights gathered.

The intervening periods between phases were dedicated to data analysis, preliminary reporting, and methodological refinement based on emerging findings. While interim reports were produced following the baseline and monitoring surveys, this report presents a comprehensive new analysis integrating all collected evidence across the evaluation period.

2.3 Sampling framework and data collection

The study employed a multi-phase sampling approach tailored to each evaluation phase. Stratified random sampling was used in the baseline phase to select 640 households across intervention and control areas. Stratification factors included geographic distribution, water service delivery models, socioeconomic indicators, and distance from existing water infrastructure.

In the comparative analysis phase, systematic non-probability sampling was used to select 355 INUMA™ Safe Water Mini-Grid customers. The sample was stratified based on service duration:

long-term customers (>1 year of service) and recent customers (<1 year of service). Systematic selection ensured geographic and socioeconomic diversity within each segment.

The final evaluation phase used purposive sampling to select 132 households in areas with previously identified performance issues. Theoretical saturation principles guided selection, focusing on communities with water availability, technical failures, service interruptions, and quality concerns.

The study received ethical approval from the Rwanda National Council for Science and Technology (Research Permit No: NCST/482/433/2023).

2.4 Statistical data analysis

The statistical data analysis employed descriptive and inferential methods as detailed in Section 5 on page 56. Descriptive statistics, including measures of central tendency and dispersion, were calculated for quantitative data related to water usage. For qualitative responses concerning water safety and service reliability, the analysis focused on evaluating the distribution of perceptions.

The selection of statistical tests was guided by the nature of each variable and its distribution. Numerical variables underwent a Shapiro-Wilk test[7] to assess normality within each group. When both groups demonstrated normal distributions, an independent t-test [8] was applied; otherwise, the non-parametric Mann-Whitney U test [9] was utilized. To quantify the magnitude of differences between groups, Cohen's d was calculated [10]. For categorical variables, a chi-square test of independence was employed to determine significant associations between variables and group membership[11], with Cramer's V[12] computed to measure the strength of these associations.

Interpretation of effect sizes followed established guidelines, with Cohen's d thresholds ranging from negligible to large ($|d| < 0.2 to |d| \geq 0.8$). The interpretation of Cramer's V was adjusted based on the degrees of freedom of the contingency table. To mitigate the risk of Type I errors resulting from multiple comparisons, the Bonferroni correction was applied. Results were deemed statistically significant if the adjusted p-value fell below 0.05. All statistical analyses were conducted using custom Python software developed by the authors of this report.

[7] S. S. Shapiro and M. B. Wilk. (1965) "An analysis of variance test for normality (complete samples)," Biometrika, 52(3–4), pp. 591–611. Available at: https://doi.org/10.1093/biomet/52.3-4.591

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[12] Cramér, H. (1946) Mathematical Methods of Statistics (PMS-9). Princeton University Press. Available at: https://doi.org/10.1515/9781400883868

3
KEY FINDINGS

3.1 Accessibility and time efficiency

SINCE their introduction, the Mini-Grids have transformed water access in the communities they serve, delivering measurable improvements across multiple dimensions. These include reduced walking distances to water sources, shorter collection times, and an overall better user experience. Statistical evidence confirms these improvements are both significant and durable. Despite occasional variations in user perceptions over time, sustained positive outcomes have been observed consistently across both new and established users.

KEY INSIGHTS

- The INUMA Mini-Grids have made water much more accessible in local communities. In areas served by INUMA, 42.2% of households can find water within 200 meters of their homes, while only 17.0% of households in non-served areas have this convenience. The contrast is even more striking at longer distances—while 36.7% of non-INUMA households must travel more than 1000m to collect water, this affects only 1.7% of INUMA-served households.

- The time savings in water collection are remarkable—while 66.3% of households without INUMA spend more than 30 minutes collecting water (against WHO recommendations), only 1.1% of INUMA-served households face such long collection times.

- Communities have enthusiastically embraced the improved water access, shown by both numbers and their direct feedback. While 65.2% of INUMA households report "very easy" access to water, only 14.8% of non-INUMA households share this experience. Conversely, the proportion reporting "very difficult" access drops dramatically from 42.6% in non-INUMA communities to just 1.4% in INUMA-served communities.

- The Mini-Grids allow people to collect more water in fewer trips. This is shown by the fact that 28.8% of INUMA households collect water 2-3 times daily, compared to 45.3% of non-INUMA households. Rather than making multiple small water collection trips throughout the day, families can now get their needed water more efficiently, reducing the physical strain of water collection.

- Most importantly, these improvements have lasted over time. Both new and long-term customers of INUMA Mini-Grids show high adoption rates, with 89.2% of short-term and 94.3% of long-term customers using INUMA as their primary water source. Short-term users report slightly higher satisfaction (76.5% indicating significant time savings) compared to long-term users (61.7%), but both groups show overwhelmingly positive results.

3.1.1 Physical access to water

Physical access to water has improved in INUMA-served communities compared to non-served areas (adjusted $p < 0.01$, Figure 3.1 on the facing page). The impact is most evident in shorter-distance access: 42.2% of INUMA-served households can access water within 200 meters of their homes, compared to only 17.0% in non-served areas. This advantage extends across all distance categories, with the most difference seen in long-distance water collection. While 36.7% of non-INUMA households must travel more than a kilometer to collect water, this burden affects only

1.7% of INUMA-served households.

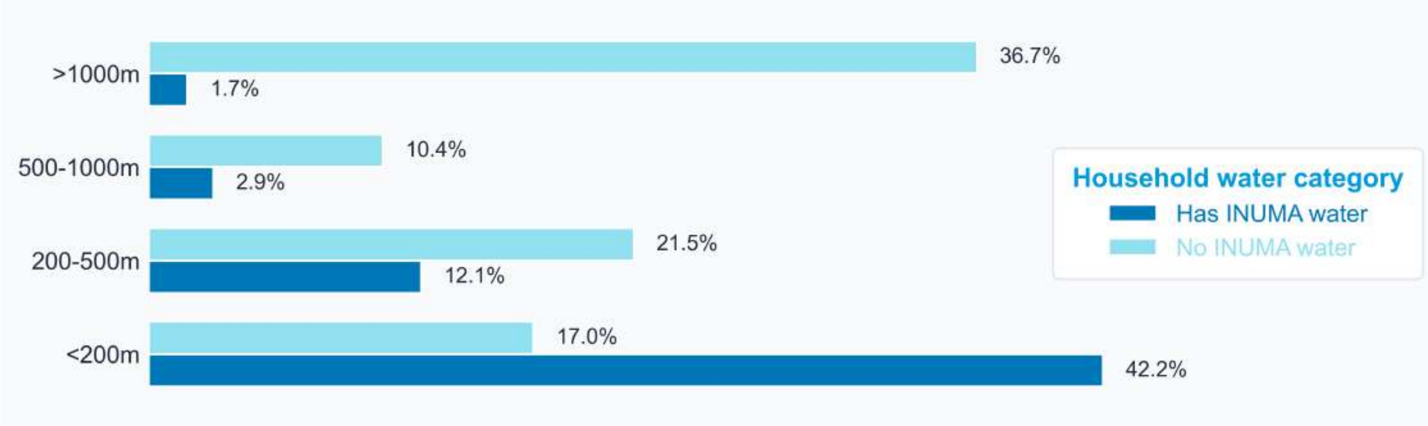

Fig. 3.1. **Distance to water collection points in communities with and without INUMA water access**

Moreover, the evidence is supported by large statistical effect size, which suggests that the observed differences between INUMA-served and non-served communities are not due to chance, providing further strong evidence of the program's transformative impact.

3.1.2 Time efficiency

Access to INUMA water has improved time efficiency in water collection (Figure 3.2). The most notable improvement is seen in extended walk time to collect water: while 66.3% of families in non-INUMA communities spend more than 30 minutes on water collection, only 1.1% of INUMA-served households face such time burdens. This improvement aligns with WHO guidelines for maximum recommended walk time for water collection[13]. The data shows additional efficiency gains across other time categories: 33.9% of INUMA households complete their water collection in less than 10 minutes, compared to just 5.2% in non-served areas.

The substantial time savings likely translate into a significant reduction in the physical burden associated with water collection. Moreover, the substantial time savings allows community members to engage in productive activities, pursue educational opportunities, or simply enjoy more leisure time with their families.

3.1.3 Community perceptions and water usage patterns

The perceived accessibility of water sources (Figure 3.3) further reinforces the positive impact of INUMA Mini-Grids. The analysis reveals a strong and statistically significant relationship between INUMA access and improved accessibility perception (adjusted $p < 0.01$). The large effect size (Cramer's $V = 0.67$) indicates that INUMA implementation has substantially transformed how communities perceive water accessibility. This transformation is evident across all accessibility categories: 65.2% of INUMA households report "very easy" access to water, compared to only 14.8%

[13] WHO and UNICEF (2017) Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva: World Health Organization and the United Nations Children's Fund. Available at: https://www.who.int/publications/i/item/9789241512893 (Accessed: November 4, 2024)

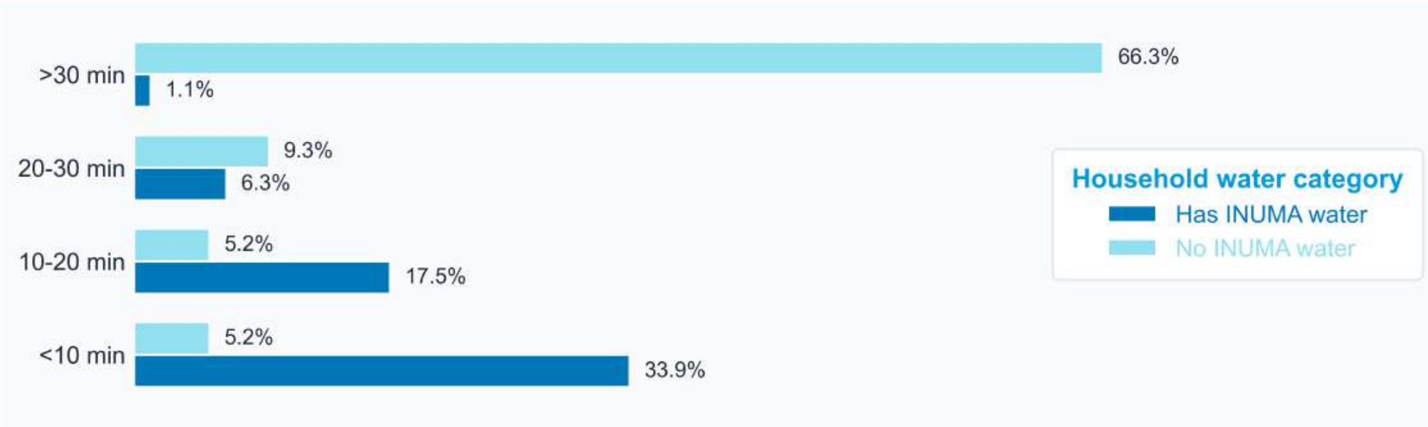

Fig. 3.2. **Time required for water collection in communities with and without INUMA water access**

of non-INUMA households. Additionally, 19.3% of INUMA users report "somewhat easy" access, while only 7.8% of non-INUMA users share this experience. Most notably, the proportion reporting "very difficult" access drops dramatically from 42.6% in non-INUMA communities to just 1.4% in INUMA-served communities.

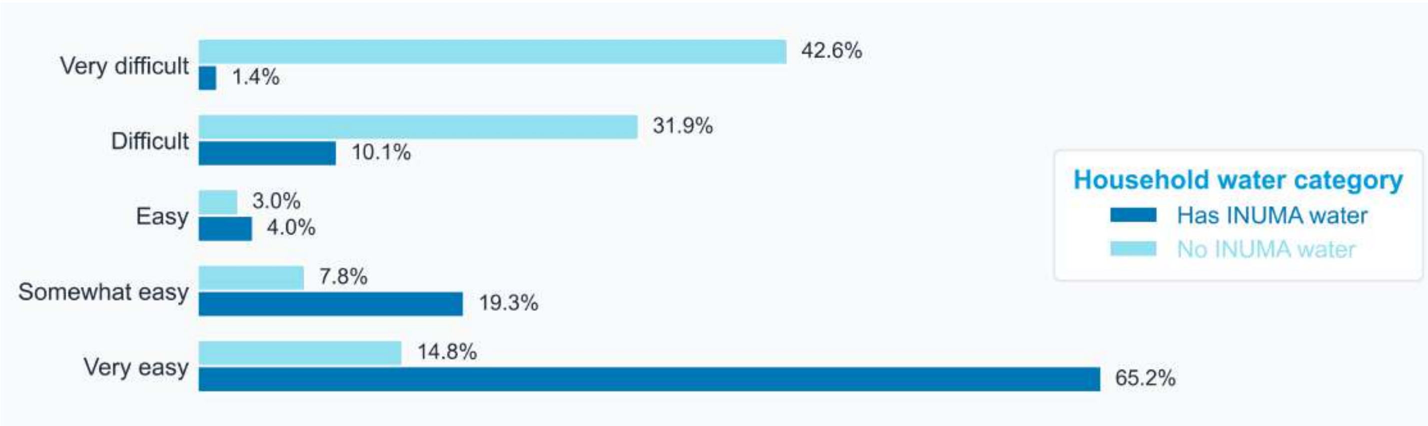

Fig. 3.3. **Community perception of water accessibility in communities with and without INUMA water access**

Analysis of water collection frequency patterns (Figure 3.4) also indicates improvements in collection efficiency, both in terms of collection frequency and, indirectly, changes in water usage patterns. The statistical analysis confirms a significant relationship between INUMA implementation and changes in collection patterns (adjusted $p < 0.01$), indicating these improvements are not random. While the effect size (Cramer's $V = 0.30$) suggests a moderate rather than dramatic change, the practical implications are significant: 28.8% of INUMA households collect water 2-3 times daily, compared to 45.3% of non-INUMA households. This indicates that INUMA users can collect larger volumes in fewer trips—an efficiency gain that is particularly valuable given the challenging terrain often faced by non-INUMA users.

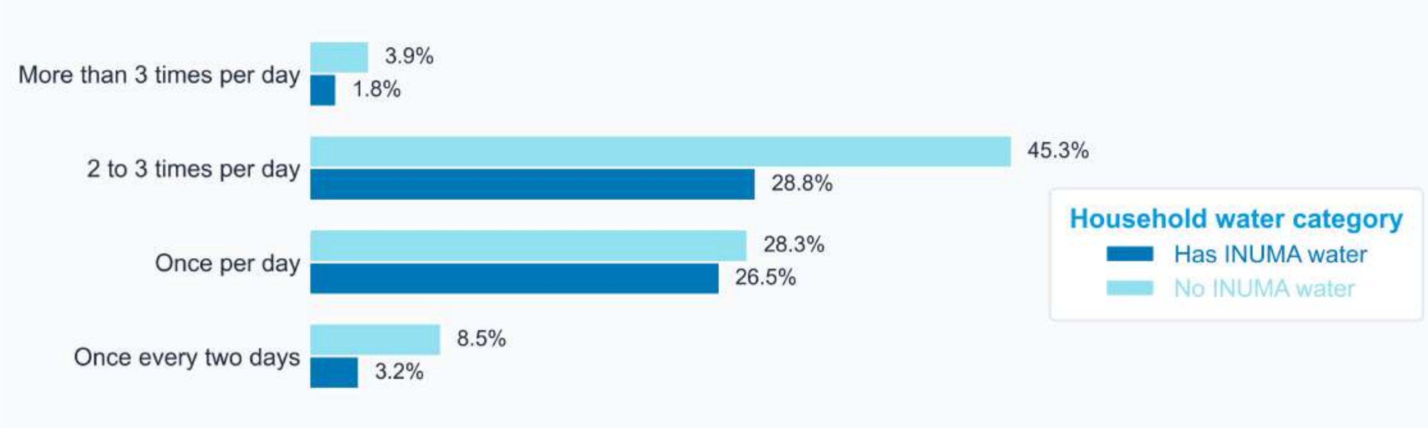

Fig. 3.4. **Frequency of daily water collection in communities with and without INUMA water access**

3.1.4 Long-term impact on water accessibility and time efficiency

Long-term analysis demonstrates that INUMA's positive impacts persist over time, with both accessibility and efficiency gains maintained. When comparing households with different durations of INUMA access reveals sustained positive impacts.

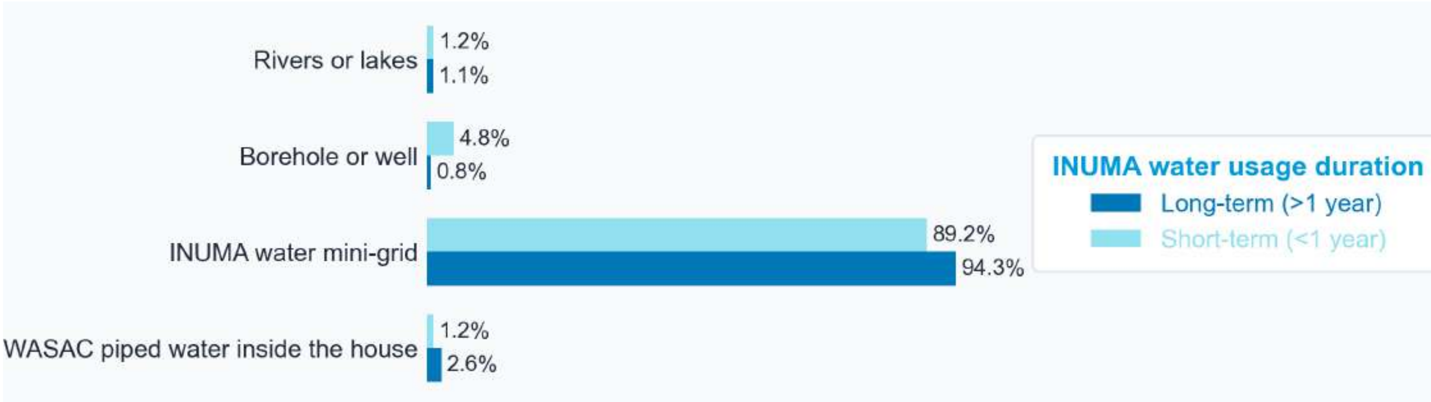

Fig. 3.5. **Primary water sources for daily household needs among long and short-term INUMA customers**

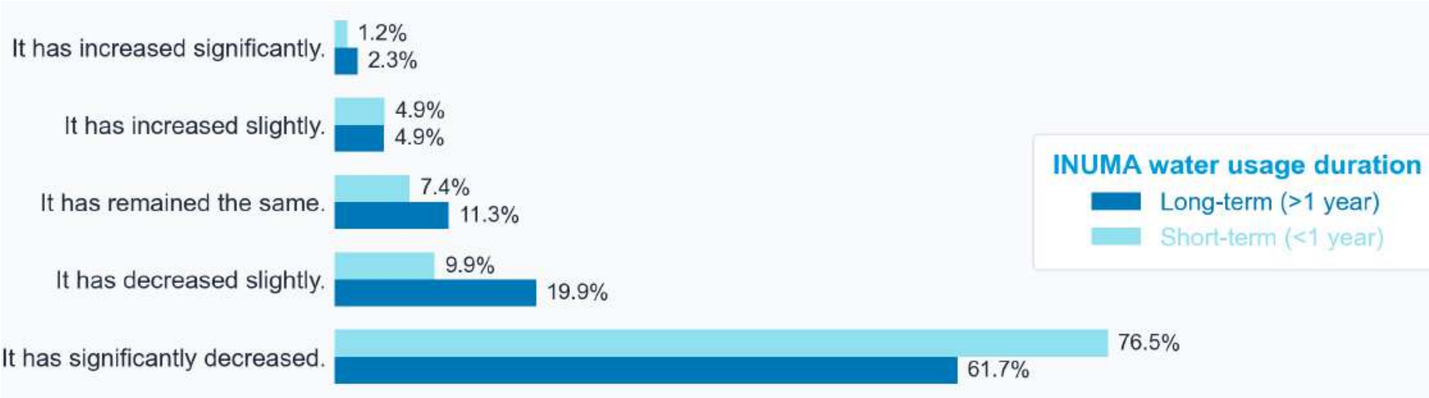

Fig. 3.6. **Changes in household water collection time after introduction of INUMA water**

As shown in Figure 3.5, the Mini-Grids have become the primary water source for both long-term and short-term users, with adoption rates of 94.3% and 89.2% respectively. Traditional (and likely unsafe) water sources such as lake, rivers and rain water, have been largely abandoned: only about 5% of users still rely on boreholes (4.8% short-term, 0.8% long-term) or rivers (1.2% short-term, 1.1% long-term). The low usage of WASAC[14] piped water (2.6% long-term, 1.2% short-term) further confirms INUMA's role as the preferred water source.

Finally, time efficiency's improvement (Figure 3.6) is also nuanced. Short-term users report the most noteable improvements, with 76.5% indicating significant decreases in collection time. Long-term users maintain positive perceptions but show more varied responses: while 61.7% report significant time savings, others report slight decreases (19.9%), no change (11.3%), or some increase (7.2%). The small effect size (Cramer's $V = 0.140$) between long-term and short-term users' experiences, combined with non-significant differences after controlling for multiple comparisons (adjust p >0.05), suggests that the program's impact remains robust over time. Rather than indicating diminishing returns, this pattern suggests that while there may be some variation in how users perceive benefits over time, these differences are not strong enough to conclude that the program's impact diminishes. Rather, the trend suggests successful normalization of improved water access, with initial dramatic improvements evolving into sustained positive impacts.

3.2 Water safety and potability

INUMA Mini-Grids have improved water safety and community well-being across multiple quantifiable dimensions. Key findings show improvements in water quality, health outcomes, and hygiene behaviors, with statistically significant differences between INUMA-served and non-served communities. The positive impacts are both immediate and sustainable, with evidence of continued benefits among long-term users.

KEY INSIGHTS

- The introduction of INUMA water has led to a statistically significant and practically meaningful reduction in waterborne diseases, with a Number Needed to Treat (NNT) of 3.0 —a metric indicating the number of households that need to receive INUMA water access to prevent one case of waterborne illness. To put this in practical terms: if INUMA serves 300 households in a community, it prevents approximately 100 cases of waterborne illness every three months. The evidence is compelling—while 92.8% of households with INUMA water reported no water-related illnesses during our study period, only 58.9% of households without INUMA water stayed illness-free. While these findings strongly suggest INUMA's effectiveness, further research would help establish definitive cause-and-effect relationships. While these findings strongly suggest INUMA's effectiveness, further research would help establish definitive cause-and-effect relationships.

- INUMA Mini-grids have significantly reduced reliance on unsafe water sources. Before INUMA water was introduced, communities relied heavily on unsafe water sources —44.4% used potentially

[14] Water and Sanitation Corporation, which is Rwanda's national water and sanitation utility

contaminated wells, 27.2% drew water from rivers or lakes, and 10.8% collected rainwater. The transformation with INUMA has been remarkable: 86.0% of households with INUMA access now use it as their primary water source, with only 12.3% still using unsafe alternatives.

- The data shows a significant increase in water safety confidence among INUMA users. In communities with INUMA access, 71.4% of households consider their water safe enough to drink directly, compared to just 49.2% in communities without INUMA. This increased confidence has practical benefits —only 19.4% of INUMA users feel the need to boil their water, compared to 32.7% in non-INUMA communities. This reduction in boiling not only reflects improved trust in water safety but also suggests potential environmental benefits through reduced energy consumption for water treatment.

- INUMA's performance demonstrates sustained positive outcomes over the evaluation period. Among long-term users (those using INUMA for more than one year), 94.2% reported no waterborne diseases over a 12-month period, with only 0.4% reporting regular occurrences. This demonstrates that INUMA's benefits aren't just immediate but persist over time.

- Beyond direct water quality improvements, INUMA has catalyzed wider public health benefits through enhanced hygiene practices. A striking 82.3% of new users report significant improvements in their hygiene practices. Statistical analysis shows a meaningful connection between how long people use INUMA water and improvements in hygiene, suggesting that access to clean water encourages better overall health practices.

3.2.1 Transition from unsafe to safe and clean Water

The introduction of INUMA Mini-Grids has catalyzed a dramatic shift in primary water sources (Figure 3.7). In INUMA-served communities, 86.0% of households have transitioned to using INUMA water as their primary source, abandoning less reliable alternatives such as rainwater collection, surface water, and wells.This shift is particularly notable when compared to control communities, where:

- 44.4% of non-INUMA served households continue to rely on potentially contaminated groundwater from wells as their primary water source
- 27.2% of non-INUMA served households obtain their water from untreated surface water sources, including rivers and lakes
- 10.8% of non-INUMA served households depend on potentially contaminated harvested rainwater for their water needs

This persistent reliance on unimproved water sources in non-INUMA communities presents significant public health risks, as both surface water and shallow wells are highly susceptible to contamination. Both surface water and shallow wells face high contamination risks from agricultural runoff, human waste, and natural contaminants. The notable shift in INUMA-served communities—reducing unsafe water source usage from baseline levels comparable to control communities down

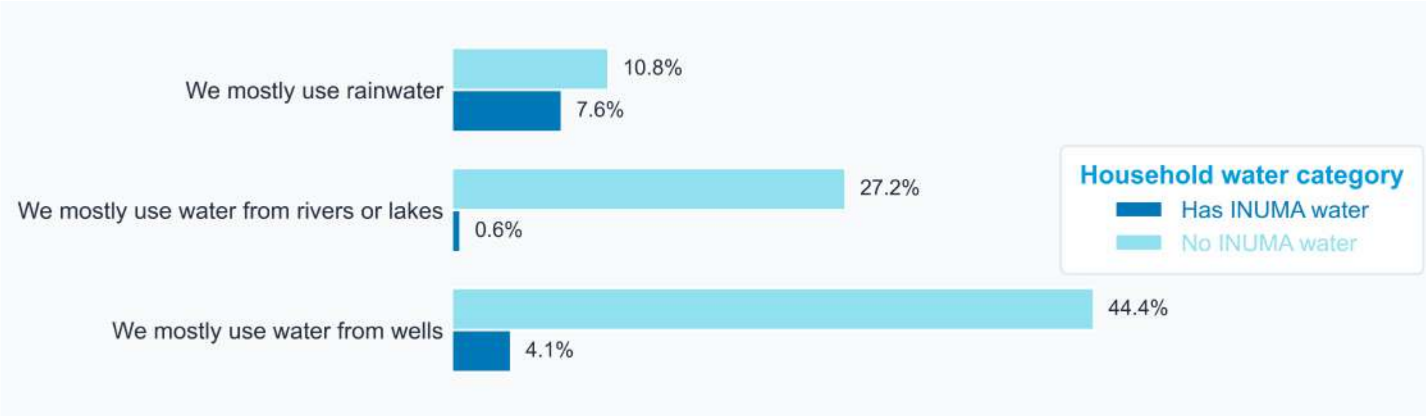

Fig. 3.7. Primary household water sources in communities with and without INUMA water access

to just 14.0% —demonstrates the program's success in promoting safe water adoption.

3.2.2 Impact on public health

This transition to improved water sources has led to a positive epidemiological impact. Statistical analysis shows a significant reduction in waterborne diseases among INUMA users (adjusted $p < 0.001$). The strength of this improvement, measured by Cramer's $V = 0.394$, indicates a moderate to strong relationship between INUMA access and disease reduction.

To strengthen our understanding of INUMA's public health impact, we employed the Number Needed to Treat (NNT) analysis[15], which is a standard epidemiological measure used in public health evaluations. While typically used in medical trials, NNT provides valuable insights for water access interventions by quantifying how many households must receive treatment (in this case, INUMA access) to prevent one negative outcome (a case of waterborne illness).

Our analysis resulted in an NNT of 3.0 over a three-month observation period. For context—while it's crucial to remember that NNT values are specific to the context of the study from which they are derived—a lower NNT indicates higher treatment efficacy[16], suggesting that, in this context, INUMA water provides stronger justification for introducing similar programs. For reference, NNT values below 5 are considered exceptional in clinical interventions, and such low values are even rarer in public health interventions where effects are typically measured at the population level. This strong NNT suggests that for every three individuals given access to INUMA water, one case of water-borne illness is prevented.

In practical terms, this implies that having INUMA water substantially decreases a household's risk of waterborne illness. Figure 3.8 illustrates this impact clearly:

- 92.8% of INUMA-served households reported no water-related illnesses during the three-

[15] Laupacis, A., Sackett, D.L. and Roberts, R.S. (1988) "An Assessment of Clinically Useful Measures of the Consequences of Treatment," New England Journal of Medicine, 318(26), pp. 1728–1733. Available at: https://doi.org/10.1056/NEJM198806303182605

[16] Cook, R.J. and Sackett, D.L. (1995) "The number needed to treat: a clinically useful measure of treatment effect," BMJ, 310(6977), pp. 452–454. Available at: https://doi.org/10.1136/bmj.310.6977.452.

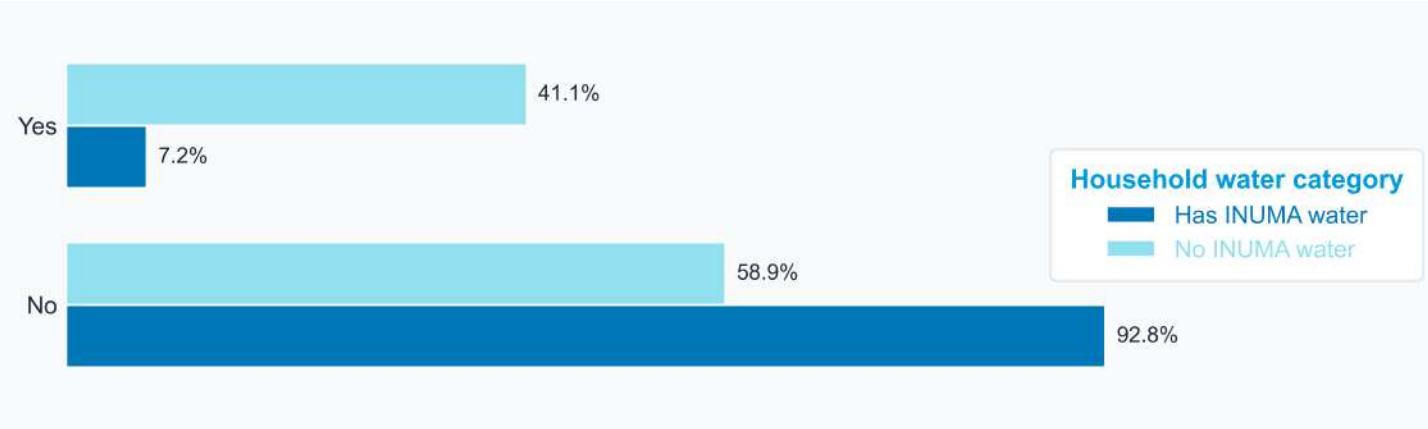

Fig. 3.8. Prevalence of water-related illnesses in INUMA-served versus non-INUMA communities

month study period, compared to 58.9% of non-INUMA households

- The NNT is 3.0, meaning that for every three households given INUMA water access, one case of waterborne illness is prevented. This metric helps translate our statistical findings into practical terms for planning and implementation. For example, when a community of 300 households receives INUMA access, we can expect to prevent approximately 100 cases of waterborne illness over a three-month period.

These findings suggest that INUMA implementation delivers meaningful public health benefits at both individual and community levels. However, it is important to contextualize these findings appropriately:

- The NNT of 3.0 reflects outcomes during a three-month period and may not capture seasonal variations in water quality and disease patterns, long-term changes in community health practices, or potential differences in effectiveness across seasons.
- While the study compared INUMA and non-INUMA communities, other factors may influence health outcomes, such as environmental conditions, socioeconomic differences, local health infrastructure, and pre-existing community health practices.

3.2.3 Water safety perception and treatment practices

INUMA has also improved how communities perceive their water safety ($p < 0.001$, Cramer's $V = 0.518$). As illustrated in Figure 3.9, trust in water safety shows marked differences between INUMA and non-INUMA communities:

- Among INUMA-served households, 71.4% consider their water safe for direct consumption, compared to only 49.2% in non-INUMA households. This 22.2 percentage point difference reflects a substantial shift in community trust, which, in turn, likely translates to improved hydration practices and overall health outcomes.
- INUMA users have increased confidence in their water, which has led to a decrease in water treatment through changed behavior, with only 19.4% boiling their water compared

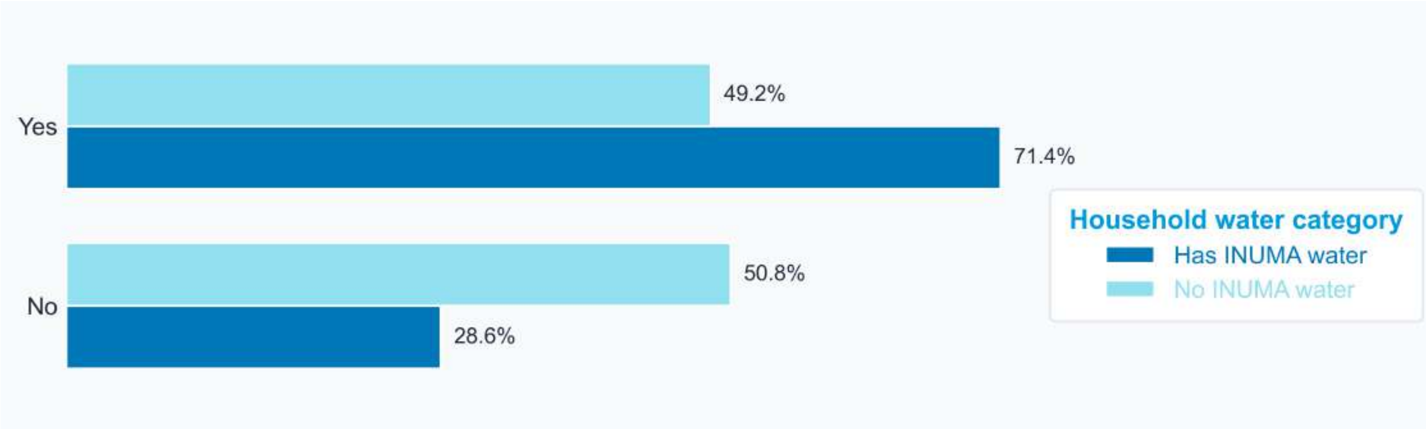

Fig. 3.9. Household perception of water safety for direct consumption in INUMA-served and non-INUMA communities

to 32.7% of non-INUMA households. This reduction in water treatment suggests both improved trust in water safety and potential energy savings.

Analysis reveals significant differences in water safety perceptions between INUMA-served and non-served communities ($p < 0.001$). Key findings include:

1. Water Safety Confidence
   - 71.4% of INUMA-served households consider their water safe for direct consumption
   - Only 49.2% of non-INUMA households express similar confidence
   - The difference of 22.2 percentage points represents a substantial improvement in perceived water safety

2. Treatment Behaviors
   - 66.4% of INUMA users drink water without treatment
   - Only 19.4% of INUMA users boil their water, compared to 32.7% in non-INUMA communities
   - This reduction in boiling practices suggests both improved trust and potential environmental benefits through reduced fuel consumption

Importantly, this increased confidence is not merely a perception but is supported by observable changes in behavior. For instance, as shown in Figure 3.10, although both groups drink their water without treatment (66.4% for INUMA vs 64.3% for non-INUMA), there is a notable difference in the practice of boiling water. Only 19.4% of INUMA users feel the need to boil their water, compared to 32.7% of those without INUMA access. This reduction in boiling has implications beyond convenience, potentially impacting household energy consumption and environmental outcomes, although these secondary benefits were not directly assessed in this study.

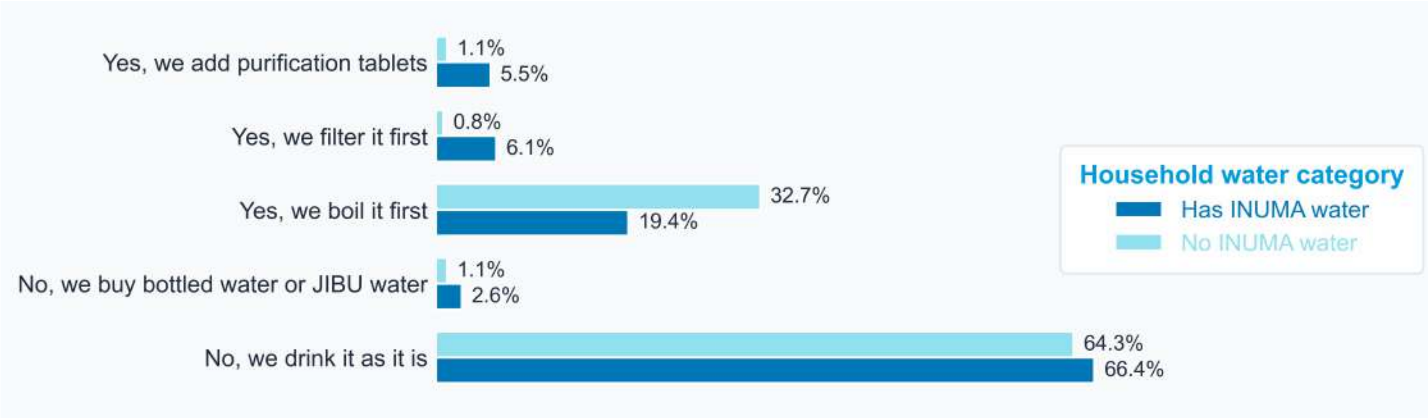

Fig. 3.10. **Household water treatment practices before consumption in INUMA-served and non-INUMA communities**

User satisfaction with water quality provides additional evidence of INUMA's impact. When rating their water's taste and smell (Figure 3.11), INUMA users reported significantly higher satisfaction levels (Cramer's $V = 0.518$, $p < 0.001$):

- 56.2% of INUMA-served households rated their water as "very good," compared to only 27.4% of non-INUMA users
- 22.6% of INUMA users rated their water as "good but not very," versus 12.2% of non-INUMA users
- 13.4% of INUMA users found their water "neither good nor bad," compared to 8.7% of non-INUMA users 6.5% of INUMA users rated their water as "bad but not very," while 17.5% of non-INUMA users gave this rating
- Only 0.6% of INUMA users rated their water as "very bad," in stark contrast to 34.2% of non-INUMA users

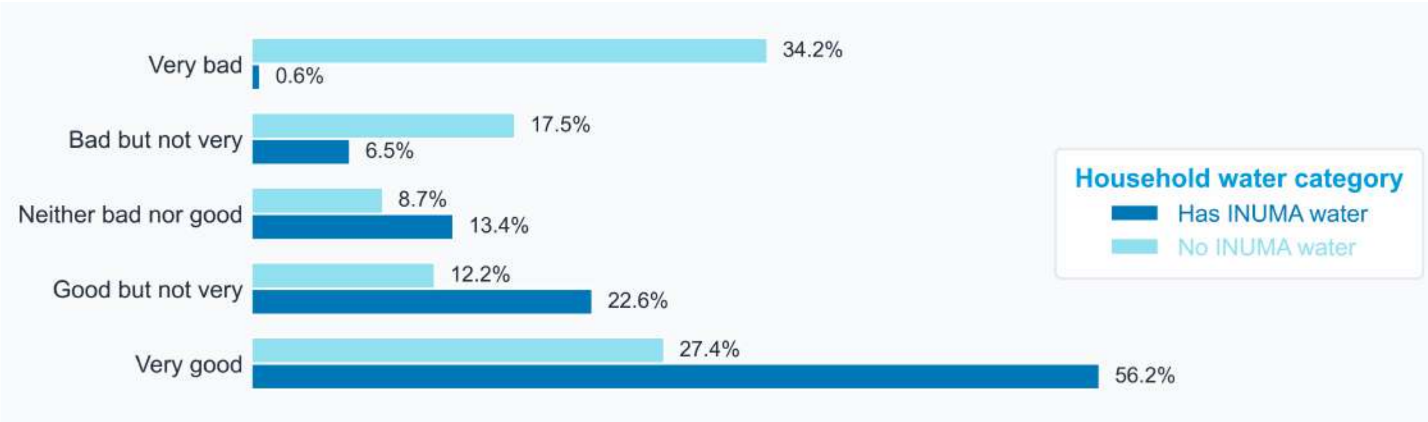

Fig. 3.11. **Consumer assessment of water taste and odor characteristics in INUMA-served and non-INUMA communities**

Despite the overwhelmingly positive findings, some questions arise. The persistence of water boiling practices among 19.4% of INUMA users, despite the demonstrated safety of the water, and the higher adoption rates of chemical purification and home filtration methods in INUMA-served communities (11.6% combined vs 1.9%) are perplexing. These seemingly paradoxical findings may stem from localized challenges such as occasional issues with salinity or sediment contamination, or natural geological conditions in Rwanda[17] and other issues identified in **??** on page ??

This behavior may also be attributed to deeply ingrained habits, varying levels of trust, or differences in health risk perception. Additionally, while the statistical analysis is robust, the self-reported nature of the data, particularly concerning illnesses, may be subject to recall bias.

3.2.4 Long-term impact on water trust and safety perception

Longitudinal analysis comparing long-term (>1 year) and short-term (<1 year) INUMA users reveals nuanced patterns in water trust and health outcomes. The data shows (Figure 3.12):

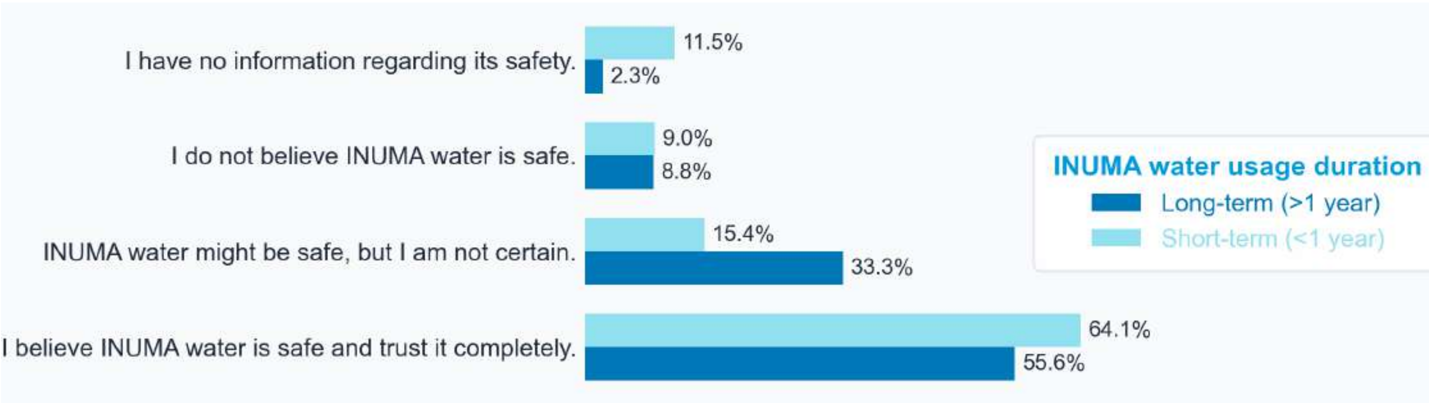

Fig. 3.12. Water safety perception comparison between long-term and short-term INUMA customers

- Quantitative trust analysis shows that 64.1% of short-term users express complete trust in water safety, compared to 55.6% of long-term users, with the 8.5 percentage point difference indicating an evolution in user perspectives.
- Statistical correlation between usage duration and safety perception demonstrates a modest relationship (Cramer's $V = 0.233$), between usage duration and safety perception, though this association is not statistically significant after adjusting for multiple comparisons.
- Trust development progresses from initial high confidence based on immediate water quality improvements, through to a more nuanced understanding in long-term users, ultimately resulting in sustained but more realistic expectations about system performance.

One of the most compelling findings in our analysis is the remarkable level of user confidence in INUMA water quality, regardless of usage duration (Figure 3.13). In what might seem counterintuitive at first glance, short-term users actually reported slightly higher levels of complete satisfaction, with an impressive 89.0% indicating they had never avoided using INUMA water due to concerns about its appearance, taste, or smell. Long-term users followed closely behind at 83.4%,

[17] Rwanda Water and Forestry Authority (2016) "Annual Water Status Report 2016-2017." Available at: https://waterportal.rwfa.rw/.

still demonstrating overwhelming confidence in the water's sensory qualities. Interestingly, long-term customers demonstrate a more nuanced appreciation of the INUMA Mini-Grids. Indeed, long-term users, despite their overall satisfaction, show a slightly higher rate of occasional concerns (13.2%) compared to short-term users (6.1%). However, these concerns remain infrequent, with only 3.4% of long-term users and 4.9% of short-term users reporting frequent quality issues.

Fig. 3.13. Frequency of water quality concerns affecting consumption among long and short-term customers

This pattern suggests that while overall confidence remains high, long-term users develop a more nuanced understanding of their water supply. They maintain strong trust in the system while being more attuned to occasional variations in water characteristics.

Moreover, a particularly revealing finding emerges in the dramatic reduction of uncertainty about water safety. Among recent adopters, 11.5% express doubts about their water's safety, but this uncertainty plummets to just 2.3% among long-term users—a five-fold reduction. This sharp decline in uncertainty suggests that extended engagement with INUMA water systems cultivates a deep-rooted trust, as if the daily experience of using the water gradually validates its safety in users' minds. Such findings highlights the positive evolution of community confidence in INUMA water safety, which is a crucial factor in public health interventions that often goes unmeasured in similar programs.

3.2.5 Long-term impact on household water treatment practices

Analysis of household water treatment practices reveals consistent patterns across user groups, providing insights into long-term behavioral adaptation to INUMA water systems (Figure 3.14):

1. Direct water consumption patterns:
   - 60.6% of long-term users drink water without treatment
   - 64.2% of short-term users follow the same practice
   - The similarity in rates suggests early establishment of trust in water quality
2. Water treatment behaviors:

- Approximately 20% of both user groups continue to boil water
- No significant statistical difference exists between duration groups (statistically significant with $p > 0.05$, small effect size)
- Additional treatment methods (filtration, chemical purification) remain minimal across both groups

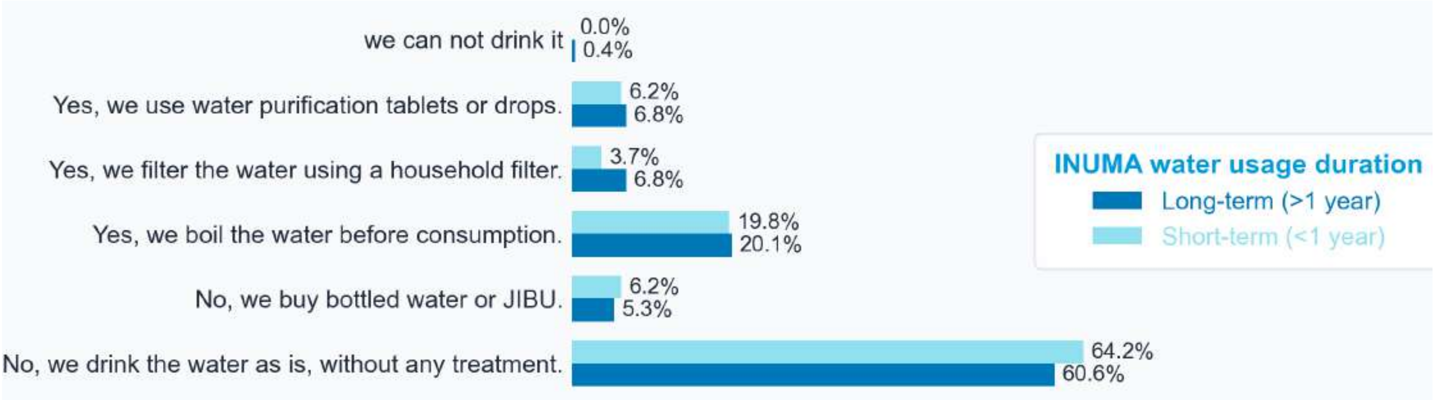

Fig. 3.14. Distribution of household water treatment practices among long-term and short-term INUMA customers

This consistency in treatment practices, particularly the persistent minority continuing to boil water, warrants further investigation into cultural factors and risk perception.

To understand the implications of these treatment patterns, we conducted a more detailed analysis of changes in water boiling practices since gaining INUMA access (Figure 3.15). The data shows similar patterns between user groups (Fisher's Exact Test, effect size = 0.1463, not statistically significant). The key findings indicate:

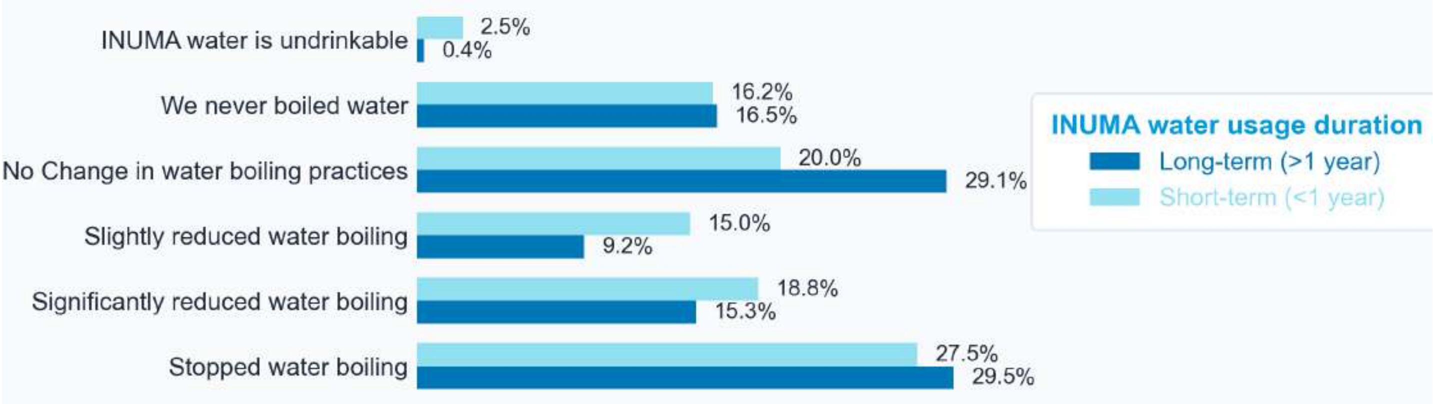

Fig. 3.15. Changes in water boiling after the introduction of INUMA water among long and short-term customers

- A significant proportion of households have discontinued water boiling entirely (29.5% of long-term users and 27.5% of short-term users)
- Another segment reports substantial decreases in boiling frequency (15.3% of long-term users and 18.8% of short-term users)

- Approximately one-quarter of households maintain their pre-INUMA practices, with similar distributions between those who continue boiling (25.1% long-term, 20.0% short-term) and those who never adopted boiling practices (16.5% long-term, 16.2% short-term)

This seemingly paradoxical behavior, where high trust coexists with precautionary treatment practices, raises intriguing questions about the complex interplay between perceived and actual water safety needs. Further investigation is warranted to understand the underlying reasons for this behavior, which may reveal insights into cultural habits, residual health concerns, knowledge gaps regarding water safety, or residual risk perception that persists regardless of exposure duration.

3.2.6 Long-term impact on water quality perception

Our analysis of sensory perceptions reveals how user experience with INUMA water evolves across different quality dimensions:

- **Water odor** (Figure 3.16)—Long-term users report notably different experiences with water odor, with 64.5% noting no detectable smell compared to 49.4% of short-term users. While this difference approaches but does not reach statistical significance, it suggests potential adaptation patterns or improvements in water treatment processes over time. Importantly, reports of unpleasant odors remain minimal across both groups (0.8% long-term, 1.3% short-term), indicating consistent quality maintenance.

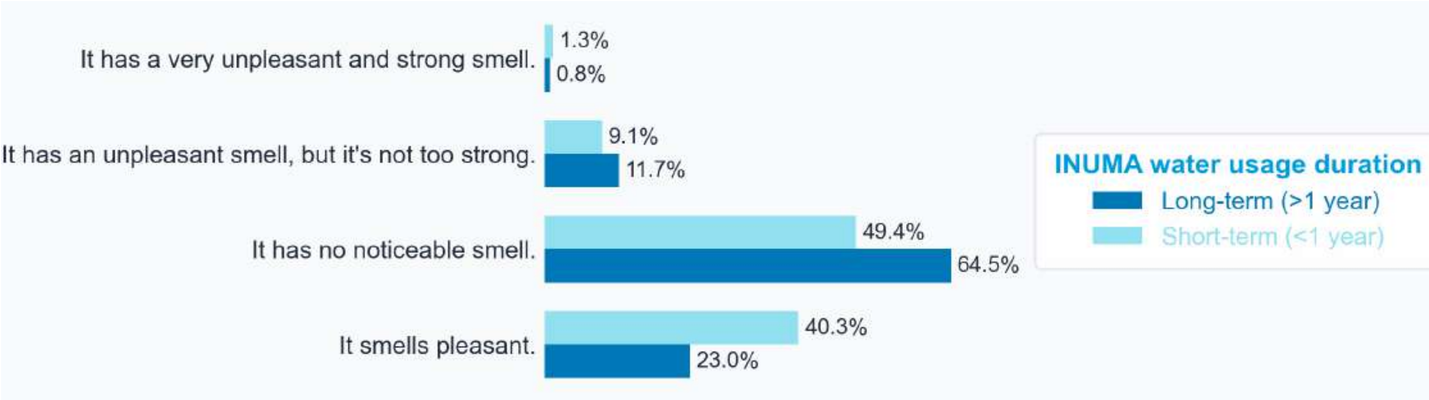

Fig. 3.16. Comparative analysis of water odor perception between long-term and short-term INUMA customers

- **Water taste** (Figure 3.17)—Taste perceptions show consistency, with approximately 59% of both user groups reporting pleasant and refreshing taste. An interesting pattern emerges in the proportion of neutral taste responses: long-term users show a higher rate of neutral taste experiences (34.0% versus 27.5% for short-term users). Although this result is not statistically significant after Bonferroni correction, it hints at a gradual increase in trust over time, particularly when considered alongside perceived changes in water quality.
- **Water clarifity (Figure 3.18)**—Assessment of water clarity demonstrates exceptionally high satisfaction levels across both user groups. The vast majority—80.6% of long-term

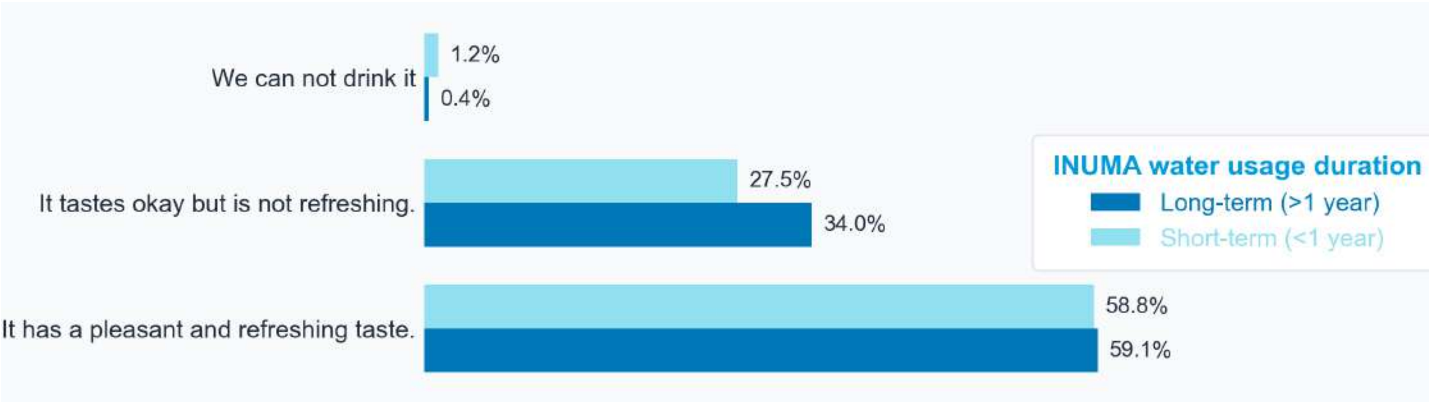

Fig. 3.17. **Water taste satisfaction ratings comparing long-term and short-term INUMA customers**

users and 77.2% of short-term users—report completely clear water with no visible particles. The small effect size in group differences (Cramer's V = 0.1000, $p > 0.05$) indicates that water clarity remains consistently high regardless of usage duration. Notably, only a small fraction of users report issues with water clarity - 4.0% of long-term users and 3.8% of short-term users noting visible particles. The minimal difference between these groups and the overall low percentage of clarity issues further reinforces the consistency of INUMA's water quality. The intermediate category of "mostly clear, with very few visible particles" shows a slight variation between long-term (15.4%) and short-term users (17.7%), though this difference is not statistically significant (p>0.05).

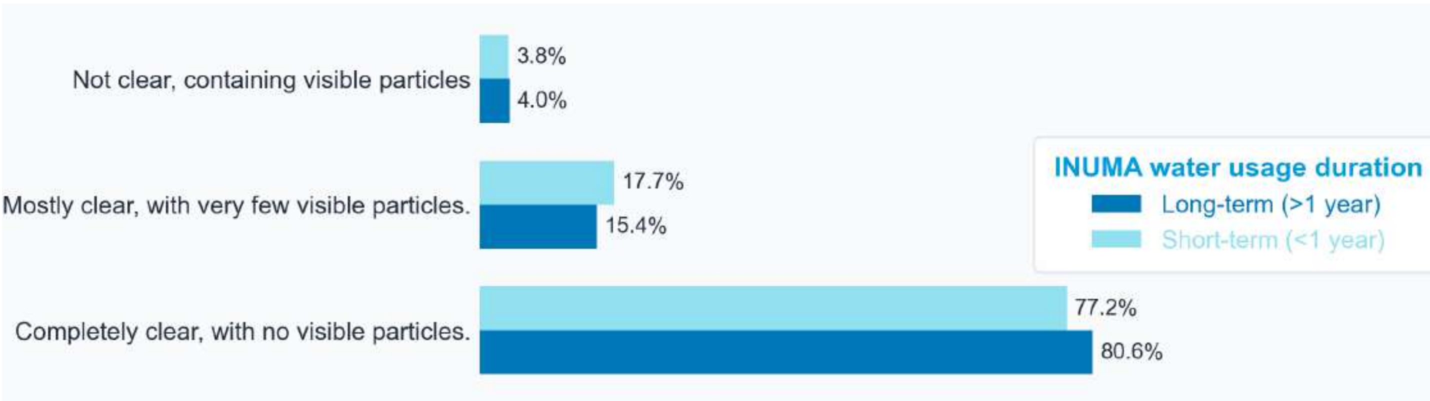

Fig. 3.18. **Water clarity assessment comparing long-term and short-term INUMA customers**

- **Water potability** (Figure 3.19)—In regard to user confidence in water drinkability, while the Fisher's Exact Test (p = 0.0744) approached but did not reach conventional significance levels, the pattern of responses tells a complex story. Short-term users tend to have a slightly higher rates of being "very confident" at 63.0%, compared to 55.1% of long-term users. Conversely, long-term users showed greater representation in the "confident" category, with 35.5% compared to 29.6% of short-term users. This subtle shift in confidence distributions, coupled with a small effect size, might reflect a maturation of user perspectives over time, evolving from initial enthusiasm to measured confidence based on sustained experience.

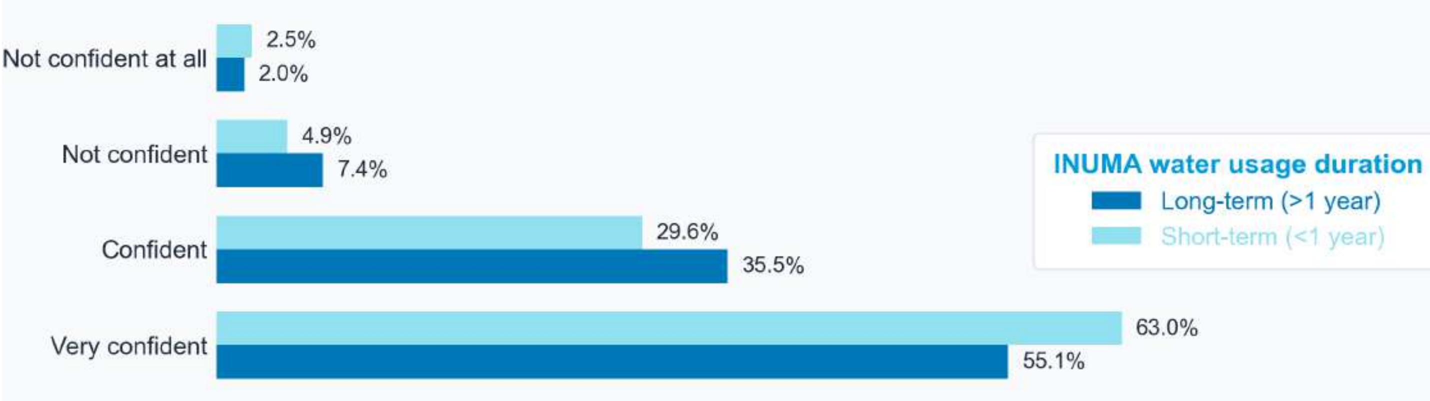

Fig. 3.19. **Confidence in water potability based on its appearance and smell among long and short-term customers**

3.2.7 Long-term Impact on Hygiene Practices and Health Outcomes

The introduction of INUMA water has also catalyzed long-term improvements in household hygiene practices (Figure 3.20). Statistical analysis reveals a moderate association between usage duration and perceived hygiene improvement (Cramer's $V = 0.205$, p = 0.002). Although this effect becomes marginally significant after applying the Bonferroni correction (adjusted p-value = 0.098), the observed patterns suggest meaningful changes in hygiene behaviors.

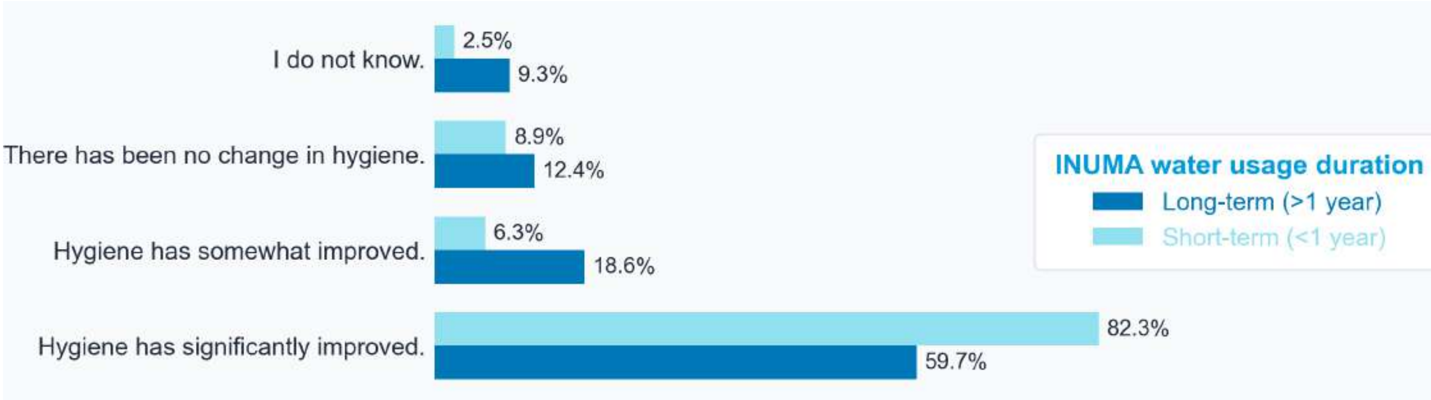

Fig. 3.20. **Changes in hygiene practices after INUMA-water access among long and short-term customers**

Short-term customers show particularly notable improvements, with 82.3% reporting significant enhancements in their hygiene practices, compared to 59.7% among long-term customers. While this difference maintains only marginal significance after Bonferroni correction (adjusted p = 0.098), it reveals an interesting temporal pattern in how INUMA water influences household practices. Long-term customers tend to report more moderate improvements, suggesting a gradual normalization of enhanced hygiene behaviors over time. This pattern indicates that while INUMA water access initially catalyzes dramatic improvements in household hygiene, these benefits naturally evolve into sustained, albeit more moderate, positive changes. Despite some variation in the rates of unchanged or uncertain responses between customer groups, the data clearly demonstrate that INUMA water access has a profound and enduring impact on household hygiene practices.

The pattern of hygiene improvement shows distinct phases:

- An initial phase of dramatic improvement, reported by 82.3% of short-term users
- A transition to moderate improvement, observed in 18.6% of long-term users
- A stabilization phase, where 12.4% of long-term users maintain enhanced practices

This pattern suggests an initial surge in hygiene improvement followed by a normalization of enhanced practices, ultimately leading to sustained behavioral change.

Supporting this interpretation, data shows significantly fewer incidents of water-related illnesses among long-term users ($p < 0.05$, small effect size), attributable to their established hygiene routines (Figure 3.21). Neverthless, long-term users show particularly encouraging results, with 94.2% reporting no waterborne diseases in the past 12 months, slightly surpassing the already impressive 91.0% reported by short-term users. When examining the occasional occurrence of waterborne diseases, the data shows minimal incidence across both user groups. Short-term users reported slightly higher rates of occasional illness, with 6.4% experiencing one or two episodes and 2.6% reporting several occurrences. In comparison, long-term users showed even lower rates, with 5.0% experiencing one or two episodes and just 0.4% reporting several occurrences. Regular occurrences of waterborne diseases were virtually non-existent, reported by 0.0% of short-term users and only 0.4% of long-term users.

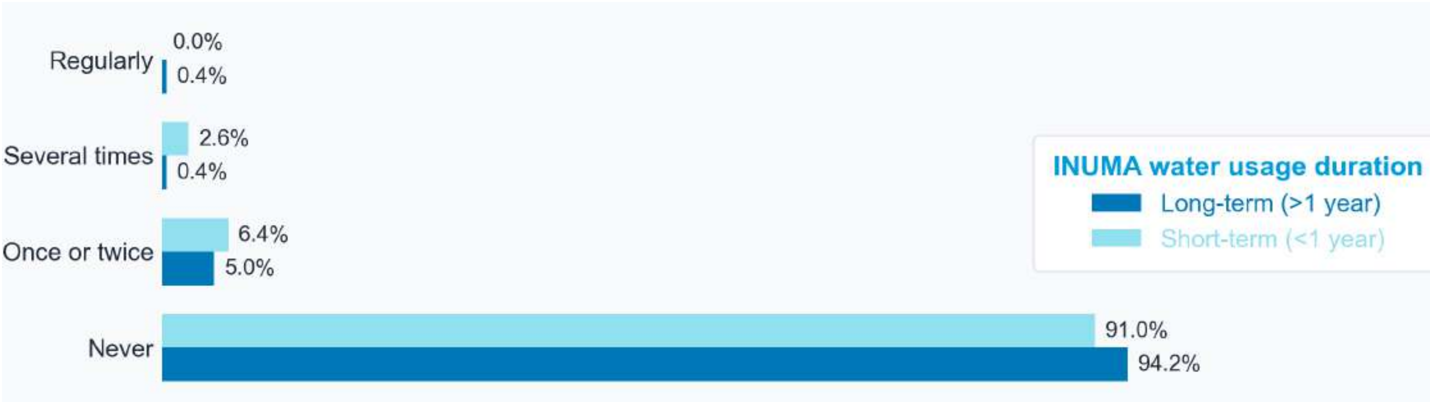

Fig. 3.21. Incidence of waterborne diseases comparing long-term and short-term INUMA customers

Statistical analysis using Fisher's Exact test ($V = 0.104$, medium effect size) indicates that while differences exist between user groups, they do not reach statistical significance. The consistently low disease rates across both groups provide compelling evidence of INUMA's effectiveness in delivering safe, potable water. The marginally better outcomes among long-term users suggest potential benefits of sustained clean water access, though further research would be necessary to establish a definitive causal relationship.

Finally, it is important to note, however, that while users' perceptions and habits show shifts with extended access, the baseline confidence in water safety as a health metric remains consistent across user groups, independent of usage duration ($p > 0.05$). This suggests that while perceived quality and hygiene practices may improve over time, the initial confidence in health safety remains stable, underscoring an enduring trust in INUMA water safety regardless of access length.

3.3 Water service performance and reliability

Accessiblity and reliability metrics were also enhnaced by the introduction of INUMA Mini-Grids in served communities, though some operational challenges persist. The evidence consistently show INUMA's superior performance in water service delivery while highlighting areas for targeted improvement. The data reveals a pattern of sustained reliability across user groups, coupled with evolving community engagement and adaptation over time.

3.3.1 Service reliability

The INUMA Mini-Grids have improved reliability metrics compared to traditional water access methods, though opportunities for enhancement exist. Quantitative analysis reveals (Figure 3.22):

- 46.4% of INUMA-served households experience water unavailability "very rarely"
- 18.6% report frequent shortages
- Comparative analysis shows significantly better performance than non-INUMA communities, where 39.0% of households face regular availability issues ($p < 0.05$)

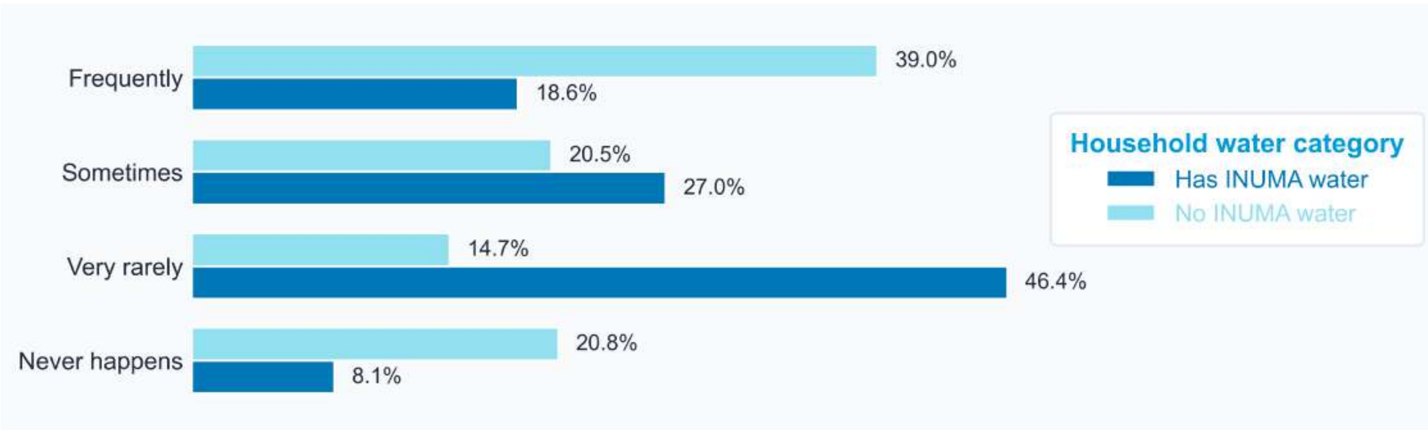

Fig. 3.22. **Frequency of water service interruption frequency comparing INUMA-served and non-INUMA**

Nevertheless, while the data highlights INUMA's substantial improvements over traditional systems, the frequent shortages experienced by 18.8% of users reveal specific areas requiring targeted infrastructure enhancements. A regional analysis indicates that these challenges are concentrated in particular geographic areas, notably the districts of Rwamagana, Nyarugenge, and Bugesera, as outlined in Table 5.1 on page 55. These issues primarily stem from high salinity, contamination, and other factors compromising the water's suitability for domestic use. Additional obstacles, including limited mini-grid functionality, inadequate infrastructure, supply-demand imbalances, and frequent pipe disruptions, further hinder water access in certain INUMA mini-grids.

KEY INSIGHTS

- INUMA Mini-Grids deliver more reliable water service than alternatives, demonstrated by only 18.6% of INUMA users facing frequent shortages compared to 39.0% in non-INUMA communities
- Service restoration in INUMA systems is markedly more efficient, with 55.4% of interruptions resolved within 24 hours versus 37.1% of non-INUMA communities experiencing outages exceeding six days, which in turn, minimizes community exposure to unsafe alternative water sources during outages.
- INUMA Mini-Grids maintain exceptional reliability regardless of operational duration, with 92.7% of long-term users and 88.0% of short-term users reporting rare or no water shortages , and over 90% reporting no observable leaks, indicating robust maintenance practices and strong potential for long-term sustainability.
- While INUMA Mini-Grids are relatively reliable, there are still water interruption with technical issues accounting for 48.0% of service interruptions, followed by maintenance requirements (30.2%) and insufficient supply (5.9%).

3.3.2 Service interruption and availability

The contrast in service restoration times between INUMA and non-INUMA systems reveals significant operational advantages of the INUMA approach (Figure 3.23). INUMA-serviced communities demonstrate superior recovery times, with:

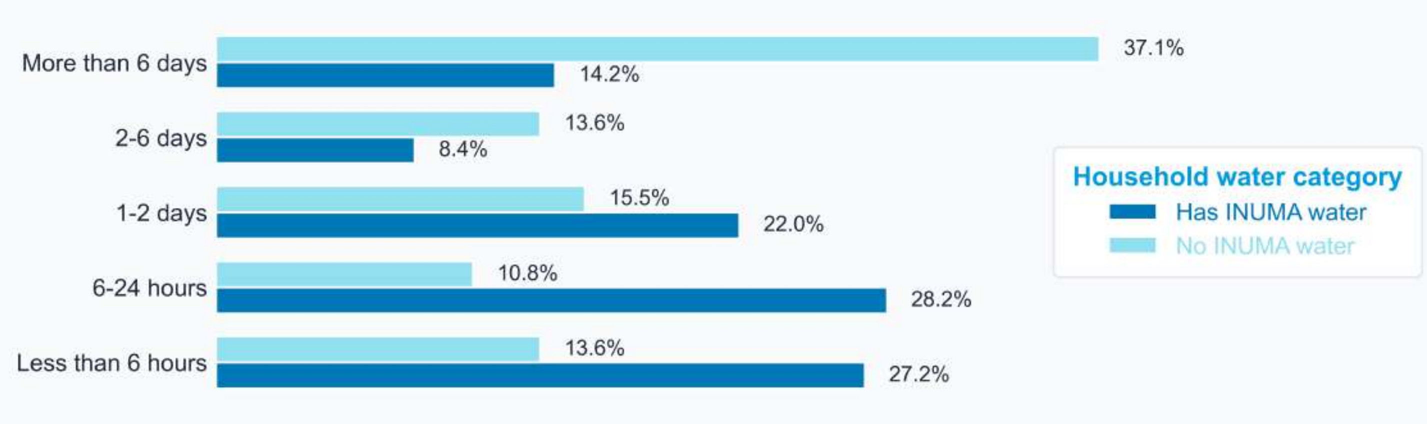

Fig. 3.23. Average service restoration times following interruptions in communities with and without INUMA water

- 27.2% of interruptions resolved within 6 hours
- 28.2% resolved within 24 hours
- Total of 55.4% resolved within one day

In contrast, communities without INUMA face substantially longer disruptions, with 37.1% experiencing outages exceeding six days. This disparity ($p < 0.05$, Cramer's $V = 0.391$) has significant public health implications, as prolonged water outages often force households to resort to alternative, potentially unsafe water sources, elevating their risk of waterborne diseases.

In INUMA-served communities—while service interuption is relatively rare—our investigation has identified three primary causes of service interruptions:

- Technical issues at water sources (48.0% of incidents)
- Infrastructure maintenance requirements (30.2%)
- Insufficient water supply at distribution points (5.9%)

Regional (Table 5.1) analysis reveals variation in these challenges, with technical issues more prevalent in eastern province.

3.3.3 Long-term impact on water availability and reliability

Comparative analysis between long-term (>1 year) and short-term (<1 year) INUMA users reveals nuanced patterns in system performance and user experience. The evidence show remarkable consistency in water availability between these groups ($p < 0.05$, Figure 3.24), with 92.7% of long-term users and 88.0% of short-term users reporting rare or no water shortages. This statistically significant consensus strongly indicates that the system maintains its reliability regardless of operational duration.

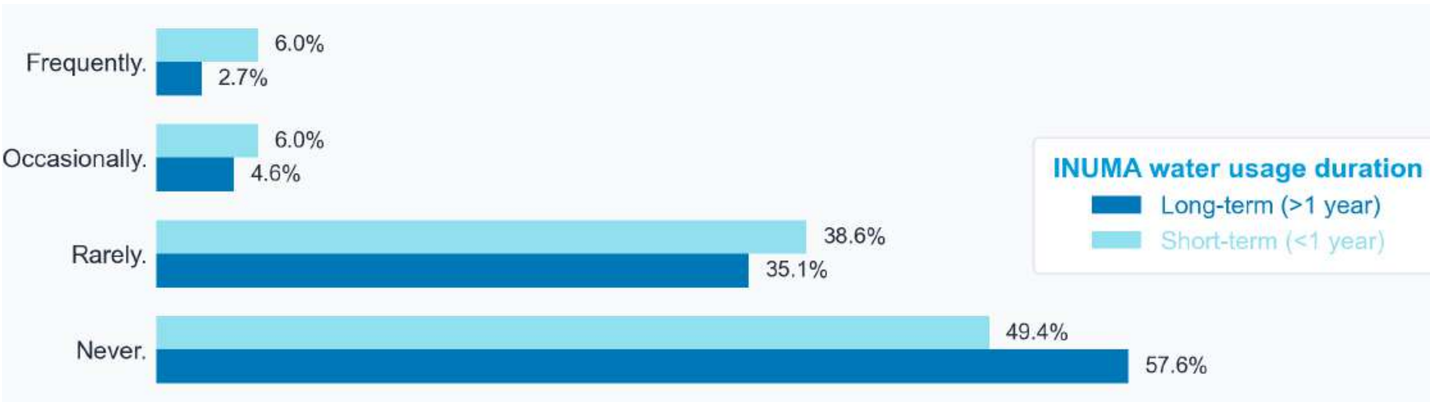

Fig. 3.24. Frequency of water service interruptions for long-term and recent INUMA customers

The investigation into service disruptions reveals nuanced patterns in system maintenance and user experience. While both groups primarily attribute interruptions to infrastructure maintenance (39.5% long-term, 28.5% short-term), long-term users have greater awareness of specific maintenance issues and technical factors ($p < 0.01$, Figure 3.25). This suggests an evolution in community knowledge and system engagement over time.

In a similar manner, there is a nuanced pattern in service restoration times across the two user groups. While both long-term and short-term INUMA users generally report a swift service restorations within six hours (60.0% and 45.1% respectively, Figure 3.26), our statistical analysis reveals

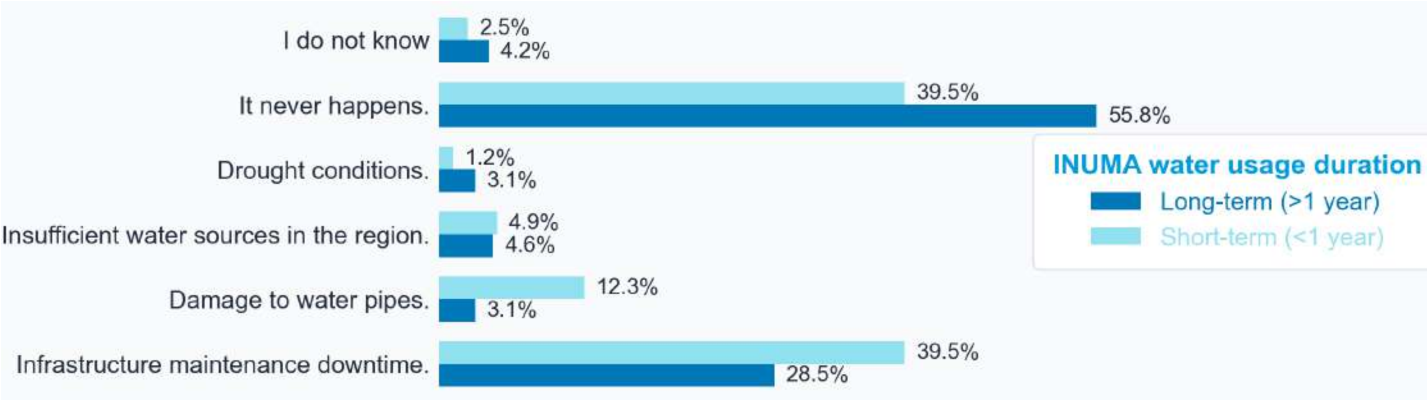

Fig. 3.25. **Primary drivers of water service disruptions among INUMA mini-grid customers**

an intriguing trend. Long-term users tend to face marginally longer disruptions compared to their short-term counterparts, though this difference approaches but does not reach statistical significance ($p = 0.09$). While this pattern warrants attention, it's crucial to note that it does not represent a systemic or persistent challenge (Figure 3.24). Rather, these findings serve as a valuable reminder that infrastructure systems face evolving challenges over time. This underscores the critical importance of implementing robust monitoring protocols, embracing proactive maintenance strategies, and maintaining responsive intervention mechanisms to ensure the INUMA water supply system's continued reliability and long-term sustainability.

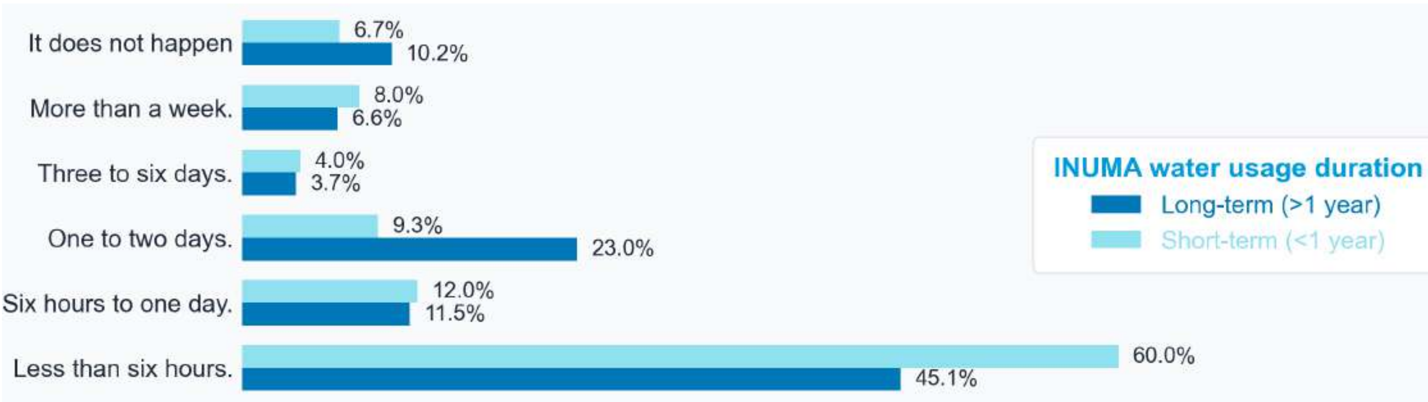

Fig. 3.26. **Water service restoration time after service interruptions among long and short-term INUMA customers**

Moreover, infrastructure integrity, which is measured through reported water wastage, demonstrates exceptional consistency across user groups (Figure 3.27). A majority of users—92.6% of long-term users and 91.6% of recent users—report no observable leaks in the INUMA network. This consistency suggests effective maintenance practices irrespective of system age and indicates strong potential for long-term sustainability.

Building on these reliability findings, the investigation of water storage tank ownership between long-term and short-term INUMA users reveals a somehow paradoxical behavior between the two groups. Despite the system's demonstrated reliability—with over 90% of users reporting rare or no shortages—there is a notable difference in storage tank adoption. Long-term users show a higher

Fig. 3.27. Frequency of observed water wastage due to leaks in the INUMA water distribution network

propensity for maintaining water storage tanks (48.5%) compared to short-term users (33.3%).

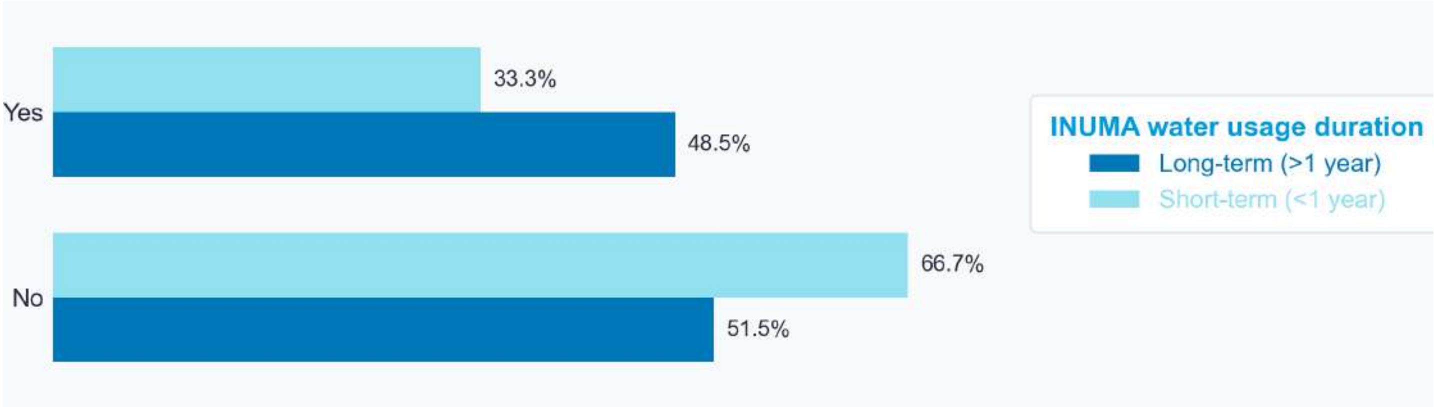

Fig. 3.28. Household water storage tank ownership among long-term and short-term INUMA customers

This pattern, while not statistically significant after Bonferroni correction, has a medium-strength relationship between usage duration and storage practices (Cramer's $V = 0.122$). The finding becomes partially explainable when contextualized against the backdrop of previous findings. Indeed, while both user groups generally experience swift service restoration within six hours, long-term users tend to face marginally longer disruptions. This subtle difference, though not statistically significant, may partly explain their higher propensity for maintaining storage tanks. However, given that these interruptions don't represent a systemic challenge—as evidenced by the consistently high reliability statistics—the higher rate of tank ownership among long-term users more likely represents proactive water management rather than a response to service inadequacy. Moreover, it is worthy to note that the analysis cannot account for various confounding factors, such as socioeconomic differences between early and late adopters of INUMA systems, variations in local water infrastructure, or seasonal effects that might influence storage decisions.

3.4 Cost and affordability

The implementation of INUMA Mini-Grids has fundamentally transformed household water economics across served communities in Rwanda. The evidence consistently shows

INUMA's success in transforming water access through multiple interconnected improvements: reduced costs, enhanced stability, and eliminated unsafe alternatives. The system shows remarkable sustainability, with both short and long-term users maintaining positive outcomes despite different usage patterns. Most importantly, INUMA's impacts extend beyond direct cost savings to create lasting behavioral changes that promote public health and financial stability in served communities.

KEY INSIGHTS

- INUMA Mini-Grids dramatically reduce household water costs, with 57.5% of served households spending less than 100 RWF daily versus 23.5% in non-served areas.
- INUMA significantly reduces high-cost water expenditure, with only 4.1% of served households spending more than 200 RWF daily compared to 23.9% in non-INUMA areas
- INUMA Mini-Grids provide crucial price stability during inflation, with 78.2% of users experiencing stable water prices over three months compared to 21.7% in non-served areas.
- Do to its affordability, INUMA Mini-Grids significantly reduce use of unsafe water sources, with 78.9% of served households never resorting to unsafe water due to cost constraints, versus 20.9% in non-served communities.
- The INUMA Mini-Grids demonstrate long-term sustainability, with both new and long-term users finding water affordable (65.6% of long-term users and 55.7% of short-term users rate it moderately to very affordable).
- The program effectively prevents cost-driven water restrictions, with only 10.4% of INUMA households limiting water use due to cost compared to 48.5% in non-INUMA areas, ensuring consistent access to adequate water supplies.

3.4.1 Household water expenditures

Analysis show a statistical correlation between INUMA Mini-Grid implementation and reduced household water expenditure (Figure 3.29). Key findings include:

- The majority (57.5%) of INUMA-served households maintain daily water expenses below 100 RWF, representing a significant improvement compared to non-INUMA areas (23.5%)
- High-cost water expenditure (>200 RWF daily) is substantially reduced in INUMA communities, affecting only 4.1% of households compared to 23.9% in non-INUMA areas
- Statistical analysis confirms the significance of these differences ($p < 0.01$, Cramer's $V = 0.489$), with results remaining robust after controlling for multiple comparisons (adjusted $p < 0.01$)

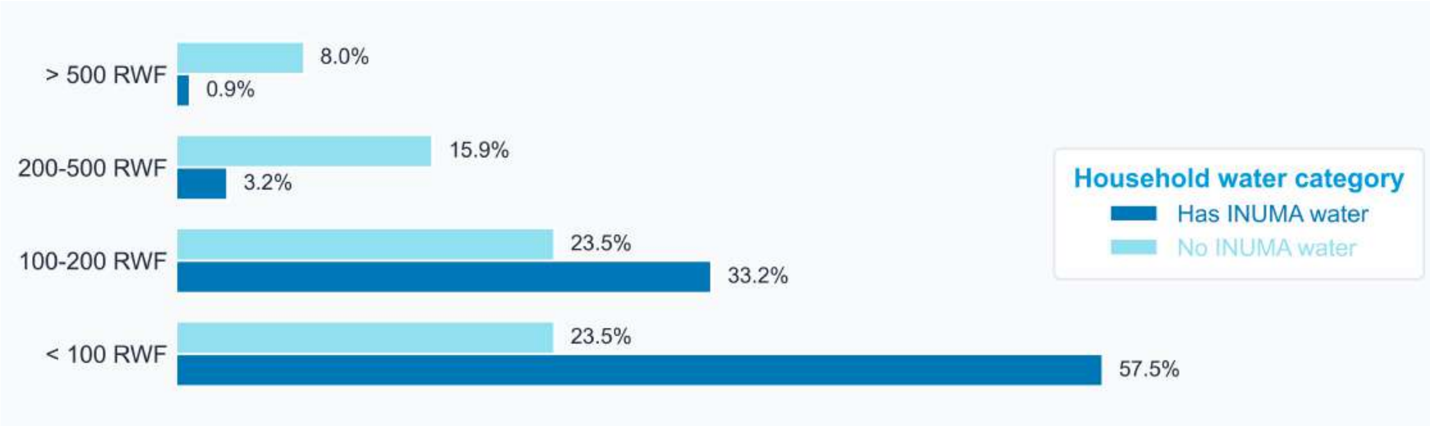

Fig. 3.29. **Daily household water expenditure in INUMA-served and non-INUMA communities**

3.4.2 Perceived affordability and water consumption

Beyond pure economics, the impact of INUMA Mini-Grids extends beyond direct economic benefits, fundamentally transforming community water consumption behaviors and perceptions. This transformation is evident across three key dimensions: affordability perceptions, consumption patterns, and water source choices.

1. **Affordability perceptions**—Analysis of household surveys reveals a significant improvement in perceived water affordability among INUMA-served communities (Figure 3.30). The data indicates:

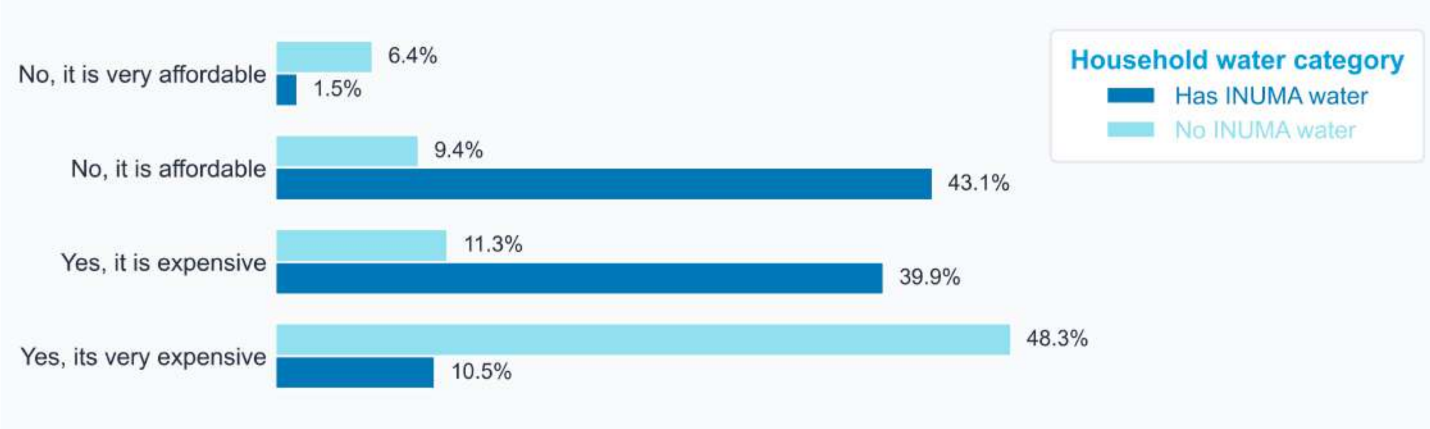

Fig. 3.30. **Perceived water cost affordability in INUMA and non-INUMA households**

- A disparity exists between INUMA and non-INUMA areas in terms of perceived water costs. While 59.6% of households in non-INUMA areas consider water costs burdensome ("expensive" or "very expensive"), only 10.5% of INUMA households share this perception.
- Analysis reveals a significant six-fold difference between the two groups ($p < 0.001$, Cramer's $V = 0.618$), demonstrating INUMA's substantial impact on water affordability and financial accessibility.

2. **Water consumption behavior**—INUMA implementation demonstrates a positive correlation with sustained water usage patterns, primarily through the reduction of cost-related access barriers (Figure 3.31). Key findings demonstrate:

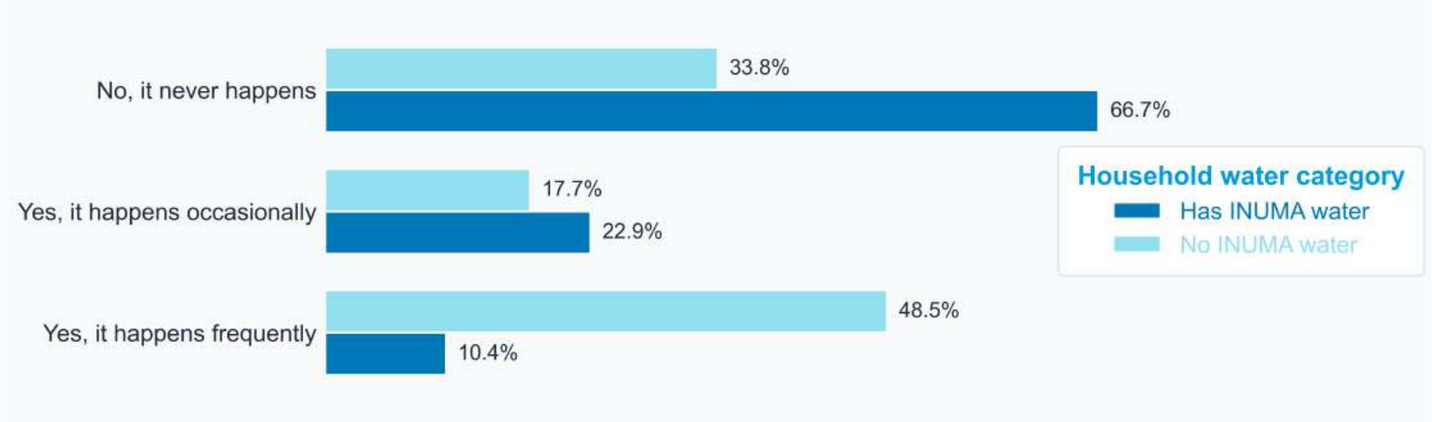

Fig. 3.31. Water consumption reduction due to cost concerns in INUMA and non-INUMA communities

- Analysis indicates that while 48.5% of households in non-INUMA communities report cost-driven water usage restrictions, only 10.4% of INUMA households face similar constraints ($p < 0.001$, Cramer's $V = 0.426$).
- The enhanced accessibility and consistent usage patterns in INUMA communities suggest positive implications for public health outcomes and overall quality of life, though further research is needed to quantify these benefits.

3. **Water source selection and safety**—The implementation of INUMA Mini-Grids has reduced community reliance on potentially unsafe water sources (Figure 3.32). Analysis reveals:

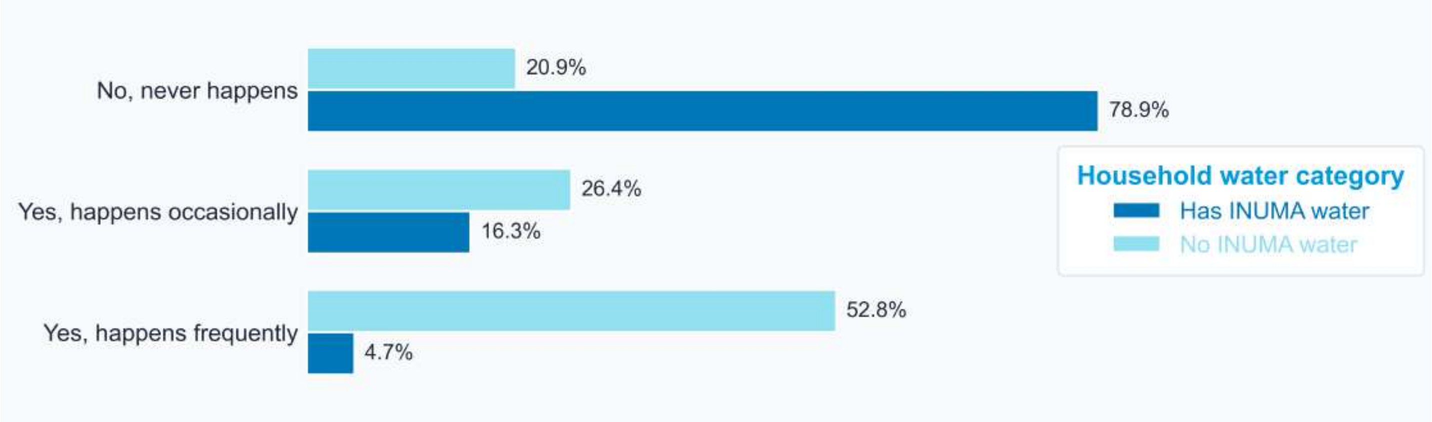

Fig. 3.32. Unsafe water source usage due to cost constraints in INUMA and non-INUMA communities

- A significant majority (78.9%) of INUMA households report never resorting to unsafe water sources due to cost constraints, compared to only 20.9% in non-INUMA communities. This difference is statistically significant ($p < 0.001$, Cramer's $V = 0.609$).

- While causal relationships between INUMA implementation and specific health outcomes require additional research, the substantial reduction in unsafe water source usage suggests potential positive implications for community health outcomes. Future longitudinal studies may help quantify these benefits.

These findings collectively demonstrate that INUMA Mini-Grids have effectively addressed multiple barriers to safe water access:

- Financial barriers by reducing household water expenditure and improved affordability
- Behavioral and community barriers by increasing water consumption, reducing reliance on unsafe sources, and promoting safer water usage practices

While these findings strongly support INUMA's effectiveness, additional longitudinal research would be valuable to quantify specific health outcomes and long-term community benefits.

3.4.3 Price stability in a volatile economy

INUMA Mini-Grids have price stability compared to alternative water sources, a particularly significant achievement within Rwanda's post-COVID-19 inflationary environment (Figure 3.33). Quantitative analysis reveals several key findings:

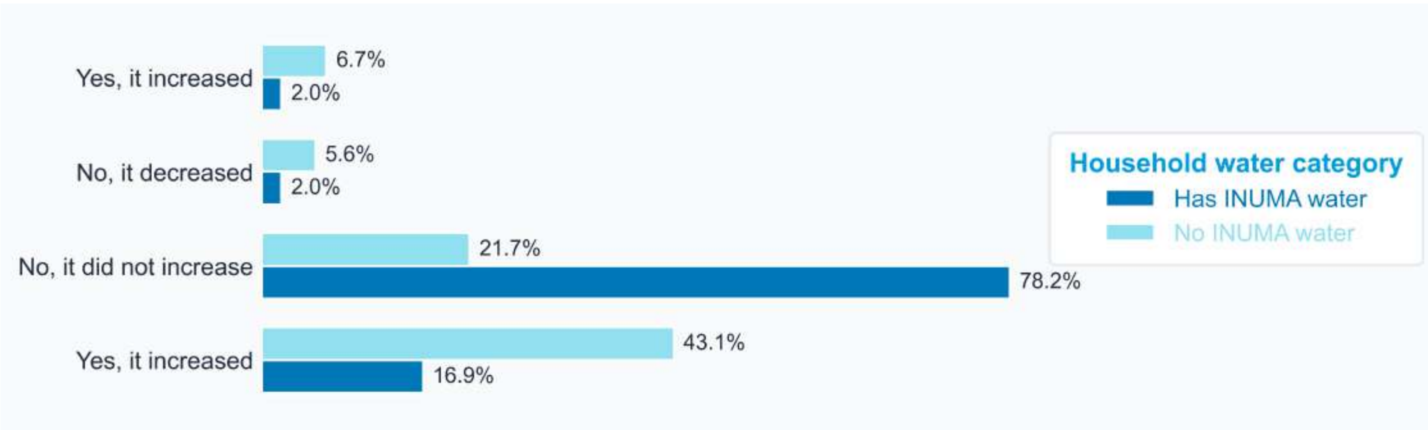

Fig. 3.33. Three-month water service cost trends in INUMA and non-INUMA communities

- A significant majority (78.2%) of INUMA households reported stable water prices over the three-month assessment period, contrasting sharply with non-INUMA areas where only 21.7% experienced price stability ($p < 0.001$, Cramer's $V = 0.581$). These results maintain statistical significance after controlling for multiple comparisons (adjusted $p < 0.01$).
- INUMA users demonstrated significantly lower exposure to price volatility, with only 16.9% experiencing substantial price increases compared to 43.1% of non-INUMA households. This represents a three-fold reduction in vulnerability to price spikes.

These findings suggest that INUMA's pricing model offers both immediate cost benefits and longer-term economic stability for served communities—a crucial factor for household budget management in low-resource settings.

It is important to note that, this pricing variation—while seemingly inconsistent with WAR's standard uniform pricing policy—aligns with WAR's extended operating hours initiative, where prices increase between 6 PM and 6AM to compensate kiosk attendants for their overtime. If this is the case, the higher prices paid bylong-term users suggest a greater likelihood of accessing water during these premium hours, thoughthe underlying factors driving this behavioral pattern warrant further investigation.

3.4.4 Long-terms sustainability of water affordability

When comparing long and short-term users in terms of long-term sustainablity of INUMA services, evidence paints a picture of a nuanced patterns in expenditure, pricing, and consumption behaviors that speak to the long-term sustainability of the INUMA model in terms of expenditure behaviour and water costs for a typical household:

- Analysis of household spending patterns reveals that long-term INUMA users typically maintain higher daily water expenditures than short-term users. Data indicates that 34.5% of long-term users spend over 200 RWF daily on water, compared to just 13.8% of short-term users (Figure 3.34). However, statistical analysis shows no significant increase in reported financial strain among long-term users attributable to these higher costs ($p > 0.05$ for affordability measures). This finding suggests that increased expenditure reflects higher water consumption rather than indicating financial burden, pointing to successful household adaptation to improved water access.

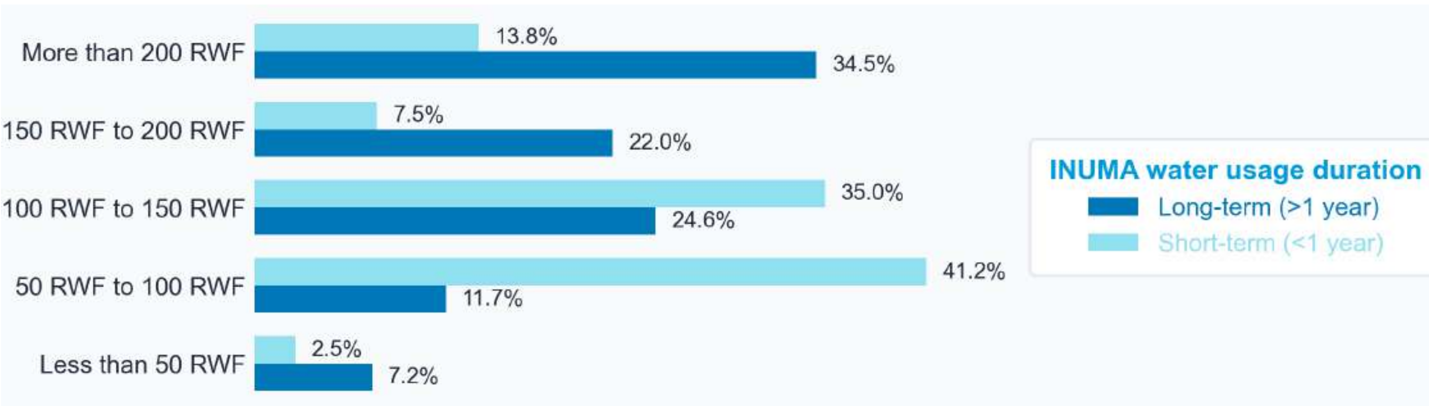

Fig. 3.34. Daily household water expenditure among long and short term customers

- Significant variations in pricing patterns emerge between long-term and short-term INUMA users (adjusted $p < 0.05$, Cramer's $V = 0.218$, Figure 3.35). The standard rate of 25 RWF per jerrycan, while most common across all users, shows notably higher adoption among long-term users at 65.1% compared to 49.3% for short-term users. This disparity in rate distribution suggests evolving usage patterns as households gain experience with the system.

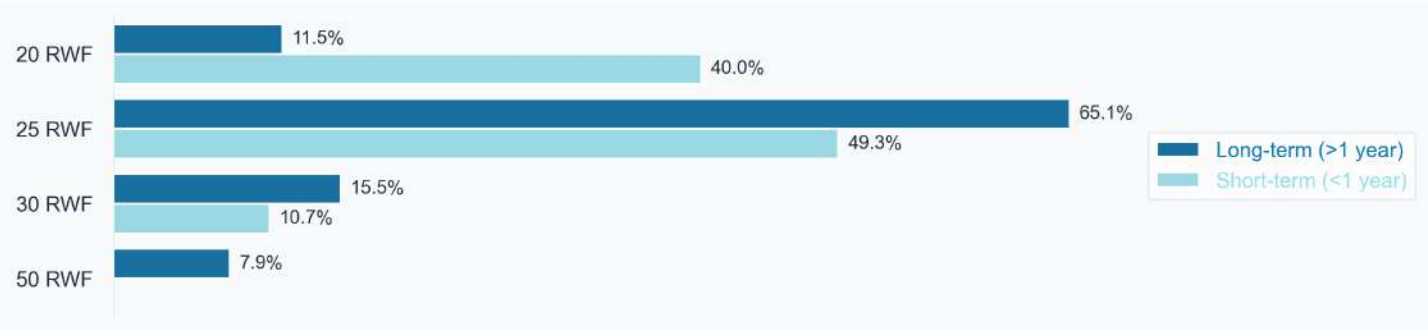

Fig. 3.35. **Price of 20-liter jerrycan water among long and short term INUMA customers**

- Further analysis reveals notable disparities across price tiers. Short-term users demonstrate a stronger preference for lower-cost access, with 40.0% paying 20 RWF compared to only 11.5% of long-term users. Conversely, long-term users show greater representation in premium price brackets. At the 30 RWF tier, long-term user participation reaches 15.5% versus 10.7% for short-term users, while at the highest tier of 50 RWF, only long-term users (7.9%) participate.

These pricing variations, while appearing to diverge from WAR's uniform pricing policy, reflect the organization's extended operating hours initiative. Under this program, prices increase between 6 PM and 6 AM to provide appropriate compensation for kiosk attendants working extended hours. The higher proportion of long-term users paying premium rates suggests evolving water collection patterns, with these users more likely to access services during extended hours. However, the underlying factors driving these behavioral adjustments require further investigation to inform future service optimization.

Regardless of the underlying causes, financial impact assessment shows that both user groups find INUMA water expenses manageable, with analysis revealing only modest differences between groups (medium effect size, Cramer's $V = 0.104$). Long-term users demonstrate a slight, though statistically non-significant, tendency to adjust other household expenditures to accommodate water costs (p = 0.07, medium effect size, Cramer's $V = 0.123$). These adjustments appear to reflect strategic budget management rather than financial hardship. While short-term users report more immediate cost relief upon transitioning to INUMA water, both groups maintain positive perceptions of affordability, suggesting successful long-term adaptation to service costs.

- Both long-term and short-term INUMA users generally find water costs manageable, as indicated by a medium effect size of 0.104. Long-term users display a slight but non-significant tendency toward adjusting their budgets to accommodate water expenses (p = 0.07, Cramer's $V = 0.123$). These adjustments suggest budget optimization rather than financial strain.
- Analysis of consumption patterns reveals minimal cost-related reductions in water usage across both user groups. Short-term users demonstrate marginally higher consumption stability, with 79.0% reporting no reductions compared to 69.4% of long-term users. When consumption adjustments occur, they remain relatively infrequent for both groups

(18.2% and 17.3% for long-term and short-term users, respectively). However, within the subset of users who report reductions, long-term users show a higher frequency of regular adjustments (12.4% compared to 3.7% for short-term users, Figure 3.36), suggesting more active management of water consumption patterns.

Fig. 3.36. Reduction in water consumption due to cost concerns among long and short term customers

- Financial analysis indicates that while long-term users more frequently report budget adjustments (22.2% versus 12.7% for short-term users), these changes do not correlate with increased financial hardship ($p > 0.05$ for affordability measures). The low rate of severe adjustments—fewer than 7% of households eliminating other purchases—suggests these changes represent prudent financial planning rather than economic stress. The higher proportion of short-term users reporting no adjustments (68.4% versus 54.5% for long-term users) indicates immediate cost benefits from INUMA adoption(Figure 3.37).

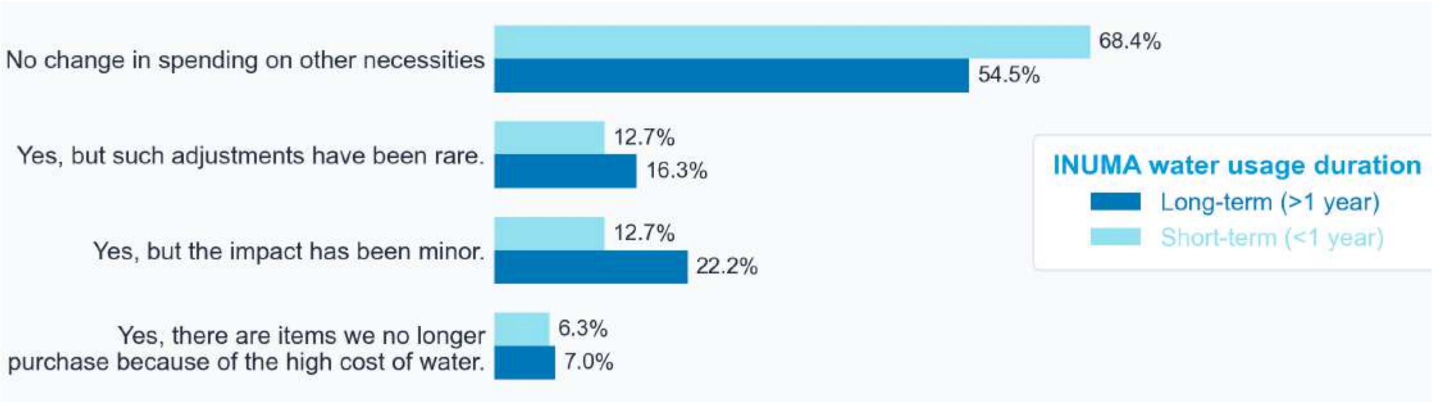

Fig. 3.37. Household spending adjustments due to water costs among long and short term customers

- The majority of both user groups perceive INUMA water as at least moderately affordable (65.6% for long-term users and 55.7% for short-term users). Short-term users exhibit a higher tendency to rate the water as "slightly affordable" (39.2% vs. 30.9% for long-term users), but perceptions of complete unaffordability remain low across both groups (3.5% for long-term users, 5.1% for short-term users). These findings suggest that INUMA's pricing structure supports accessibility regardless of usage duration. Over time, long-term users may perceive water as more affordable, reflecting adaptation to recurring expenses (Figure 3.38).

- Affordability perceptions remain positive across both user segments, with most households rating INUMA water as moderately affordable or better (65.6% of long-term users; 55.7% of short-term users). While short-term users more frequently categorize costs as "slightly affordable" (39.2% versus 30.9%), reports of unaffordability remain minimal for both groups (3.5% long-term; 5.1% short-term). Over time, long-term users may perceive water as more affordable, reflecting adaptation to recurring expenses (Figure 3.38).

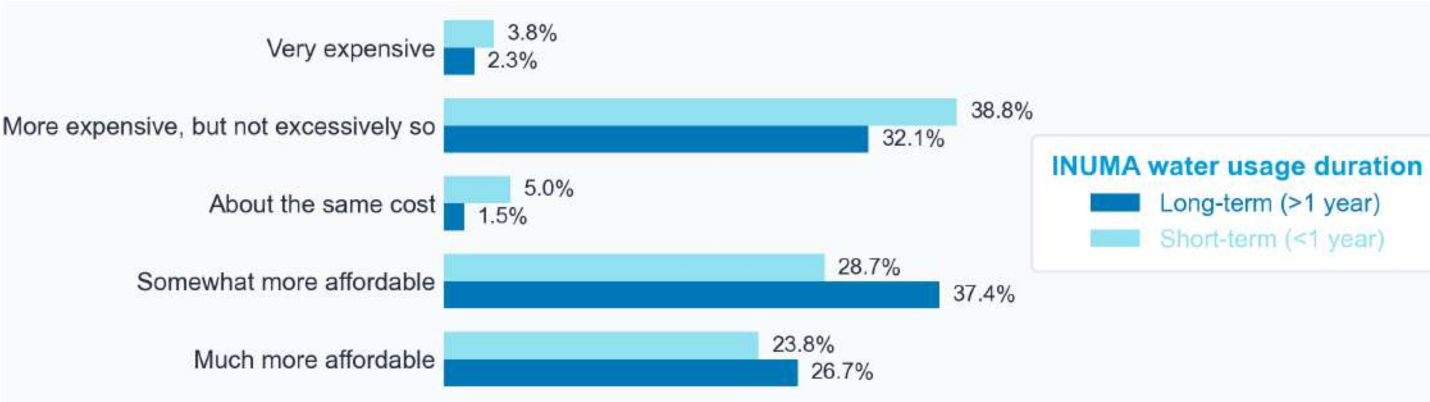

Fig. 3.38. Perceived water affordability among long and short term customers

3.5 Broader societal impacts

Beyond providing clean drinking water, the Mini-Grids have become catalysts for broader community development. Communities with the Mini-Grids access show improvements across health, education, and economic opportunities. The impact on gender equity is particularly notable, as women previously burdened with water collection can now pursue economic activities. INUMA has evolved from a water access solution into a comprehensive program that demonstrates how infrastructure improvements can transform entire communities.

KEY INSIGHTS

- INUMA Mini-Grids have nearly eliminated cost-related compromises in hygiene practices in served communities, with only 0.9% of households reporting reduced bathing frequency due to cost, compared to 8.9% in non-INUMA areas.
- The introduction of INUMA Minigrids has led to statistically strong evidence of reducing waterborne diseases, with 90.5% of short-term users and 88.3% of long-term users reporting no water-related illnesses, while statistical analysis highlights significant health improvements among new

users (73.2% reporting disease reduction compared to 55.0% among long-term users).

- INUMA access has substantially improved educational outcomes, with 69.2% of INUMA communities reporting improved academic performance (compared to 51.8% in non-INUMA areas), while also reducing academic decline rates to just 3.3% versus 14.9% in non-INUMA regions.
- The INUMA initiative has significantly impacted women's time availability, with 76.7% of women in INUMA households reporting increased free time compared to 51.3% in non-INUMA communities , leading to greater participation in income-generating activities (62.5% versus 58.4%).
- INUMA has catalyzed a shift in gender dynamics around water collection, reducing the burden on adult females (5.6% in INUMA households versus 11.2% in non-INUMA) while increasing male participation, though maintaining similar rates of shared responsibility (59.5% versus 56.9%).
- Short-term INUMA users report more pronounced immediate benefits—such as improved hygiene (82.3%) and study time (86.4%)—compared to long-term users, who experience sustained but less pronounced gains. This suggests an adaptation phase, where initial benefits stabilize into long-term behavioral and lifestyle changes.

3.5.1 Health and hygiene transformation

Our analysis reveals that INUMA Mini-Grids have fundamentally altered public health outcomes in served communities through three primary mechanisms.

First, the introduction of reliable water access has virtually eliminated hygiene-related compromises previously common in these communities (Figure 3.39). Statistical analysis strongly supports this transformation ($p < 0.001$, adjusted p-value = 0.002), with INUMA households showing near-complete elimination of suboptimal hygiene practices. While non-INUMA communities continue to report compromised bathing frequencies (5.2% twice weekly, 1.5% weekly, 2.2% rarely), INUMA households demonstrate consistent daily hygiene practices, with negligible reports of compromised schedules (0.9%, 0%, 0% respectively).

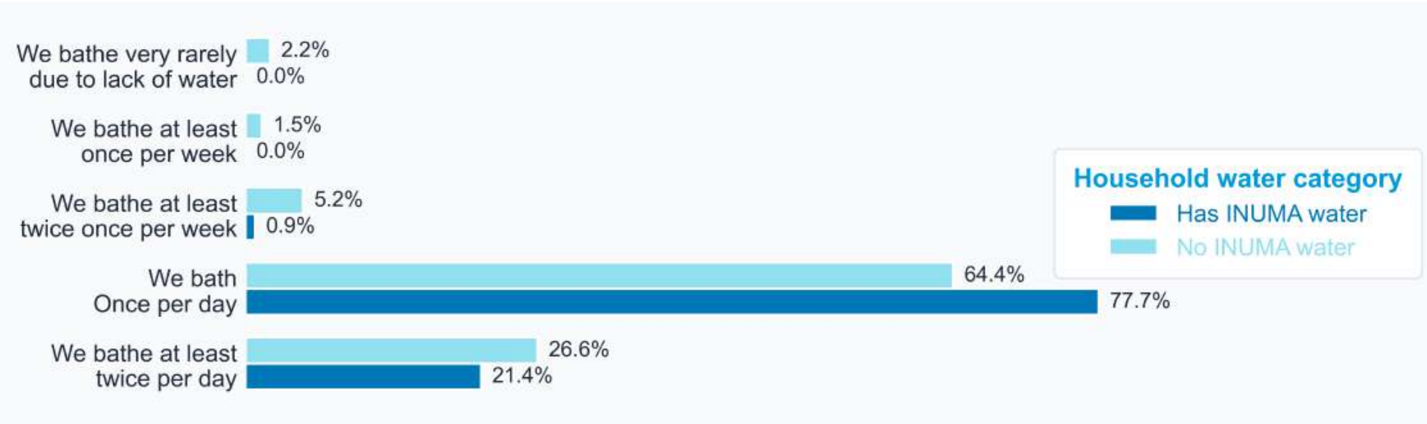

Fig. 3.39. Frequency of household bathing practices in INUMA and Non-INUMA communities

Second, the perceived health improvements are substantial across both recent and long-term users (Figure 3.40), though with notable variations in impact perception. Short-term users report more health benefits (73.8% citing significant improvements) compared to long-term users (62.8%), suggesting an initial strong positive impact that stabilizes over time. The consistency of positive health outcomes is further evidenced by the low percentage of users reporting no changes (11.6% long-term, 7.5% short-term) or uncertainty about impacts (3.1% long-term, 2.5% short-term).

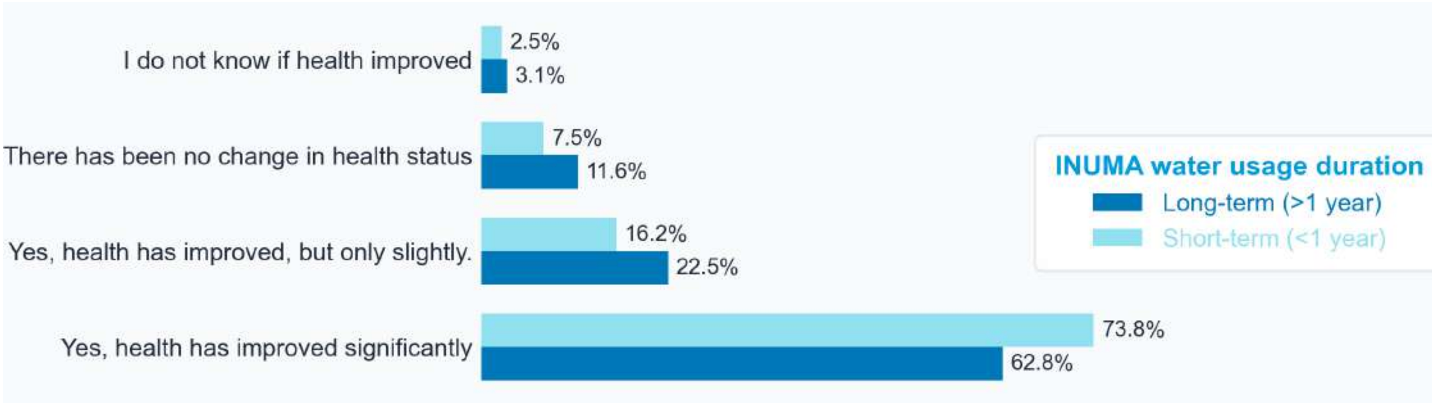

Fig. 3.40. Perceived health improvements after INUMA water access among long and short-term customers

Third, while correlation does not imply causation, the data suggests a strong association between INUMA minigrid access and reduced incidence of waterborne diseases (Figure 3.41). Statistical analysis reveals differences between those long and short term INUMA water users ($p < 0.01$, medium effect size = 0.199), with short-term users reporting notably higher rates of perceived disease reduction (73.2%) compared to long-term users (55.0%). When including those reporting somewhat reduced disease occurrence, the total proportion of users reporting health improvements reaches 66.6% for long-term and 83% for short-term users. This association is further supported by the minimal water-related illness concerns reported (Figure 3.42), with the vast majority of users (90.5% short-term, 88.3% long-term) reporting no suspected illness from INUMA water use. These findings, while correlative, suggest a potentially beneficial relationship between INUMA water access and community health outcomes.

3.5.2 Improvements in educational outcomes

The introduction of INUMA water Mini grids has led to improvements in educational outcomes, fundamentally transforming learning environments across served communities. As illustrated in Figure 3.43, the impact on academic performance has been particularly remarkable. Communities with INUMA access have higher rates of academic improvement, with an 69.2% of respondents reporting positive changes in examination performance of school going children. Within this group, 37.4% noted significant improvements, while 31.8% observed modest enhancements. These findings stand in sharp relief against non-INUMA communities, where merely 51.8% reported similar improvements and this difference is statistically significant ($p<0.01$, Cramer's $V = 0.295$).

Beyond academic improvement, INUMA's presence has also mitigated negative educational outcomes. The contrast between INUMA and non-INUMA communities is also encouraging when

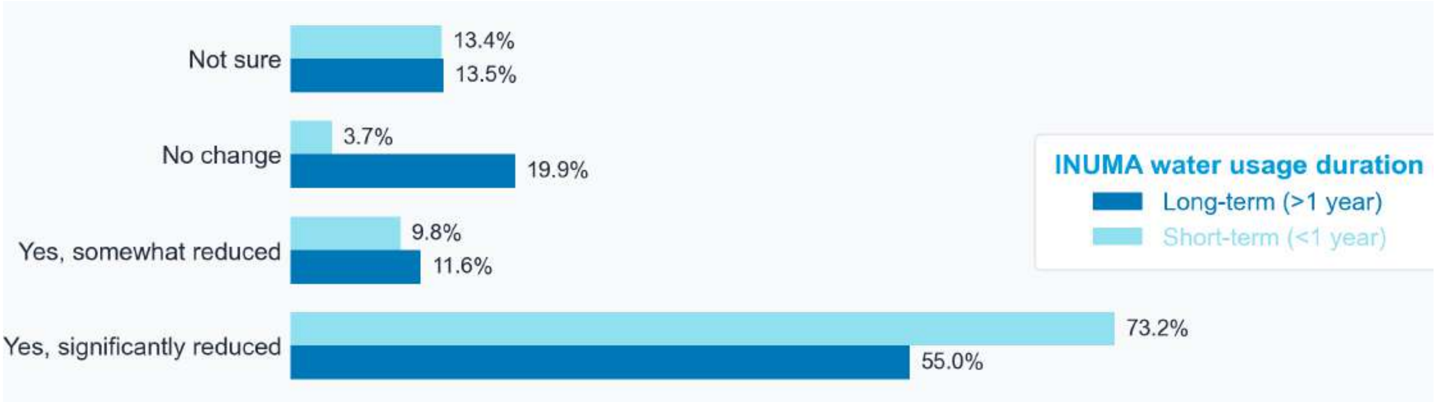

Fig. 3.41. Reduction in waterborne diseases after INUMA water access among tong and short-term customers

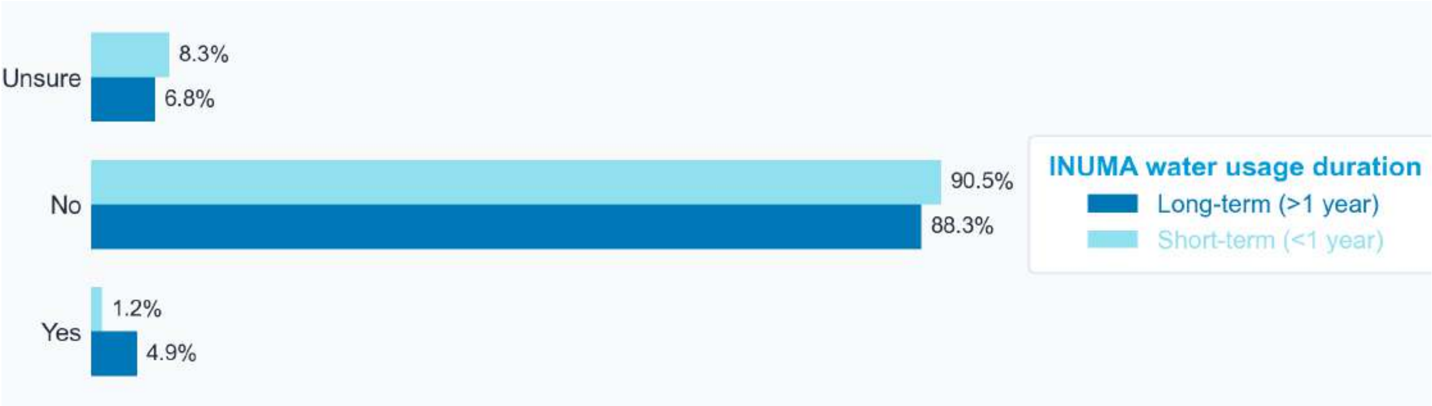

Fig. 3.42. Reported health concerns associated with INUMA water use among long and short-term customers

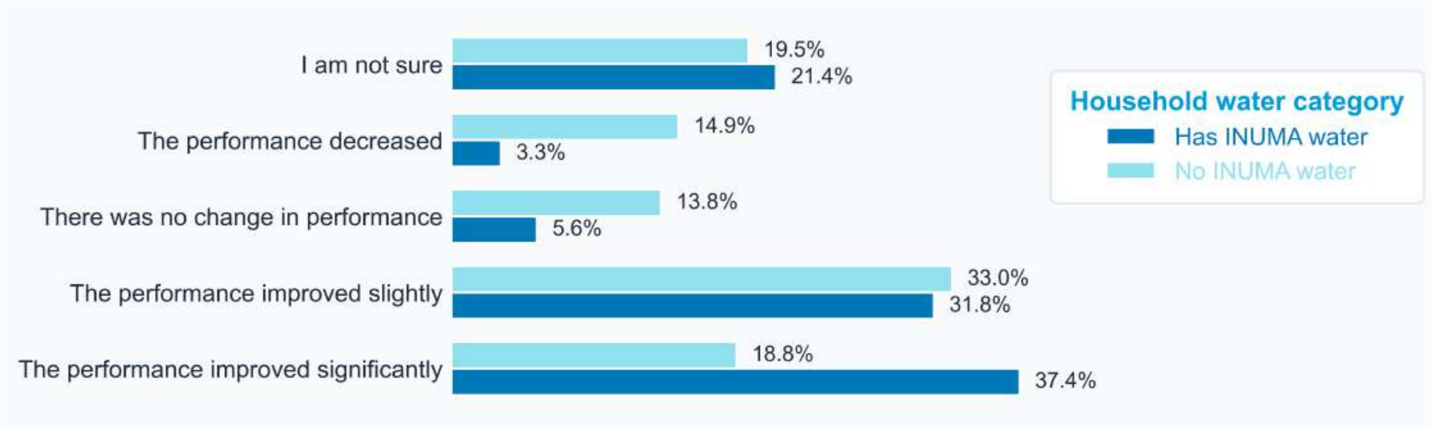

Fig. 3.43. Impact of Water Access on student academic performance in INUMA and Non-INUMA communities

examining academic decline rates. In INUMA-served areas, a mere 3.3% of communities reported deteriorating exam performance, compared to a concerning 14.9% in non-INUMA regions—a difference of 11.6 percentage points. The impact extends to performance stability as well, with INUMA communities showing notably lower rates of stagnant academic performance (5.6% versus 13.8% in non-INUMA areas). These disparities maintain their statistical significance even under the scrutiny of rigorous post-hoc analysis and multiple comparison controls (adjusted $p < 0.001$).

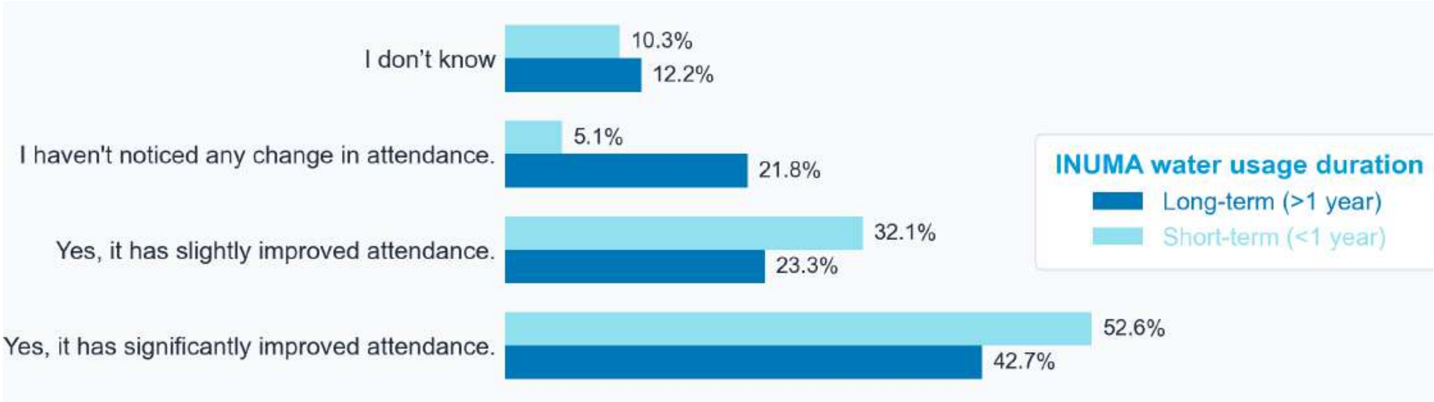

Fig. 3.44. **Impact of INUMA Water access on children's school attendance among long-term and short-term customers**

The temporal dimension of INUMA's impact reveals equally compelling patterns in educational empowerment, particularly regarding school attendance and study time allocation. As demonstrated in Figure 3.44, both short-term and long-term customers report that their children's school attendance has improved ($p < 0.05$). Short-term customers report greater improvements in this regard, with 84.7% noting positive changes in attendance—52.6% citing significant improvements and 32.1% reporting slight enhancements. While long-term users show somewhat moderated yet consistently positive trends, with 66.0% reporting improvements, the overall pattern suggests sustained educational benefits.

The impact on study time allocation, depicted in Figure 3.45, reveals similarly encouraging trends. An 86.4% of short-term customers report significant increases in study time, compared to 66.2% among long-term customers. This pattern aligns with broader monitoring findings, where short-term users consistently report more favorable experiences across multiple dimensions, including water quality perception and service satisfaction.

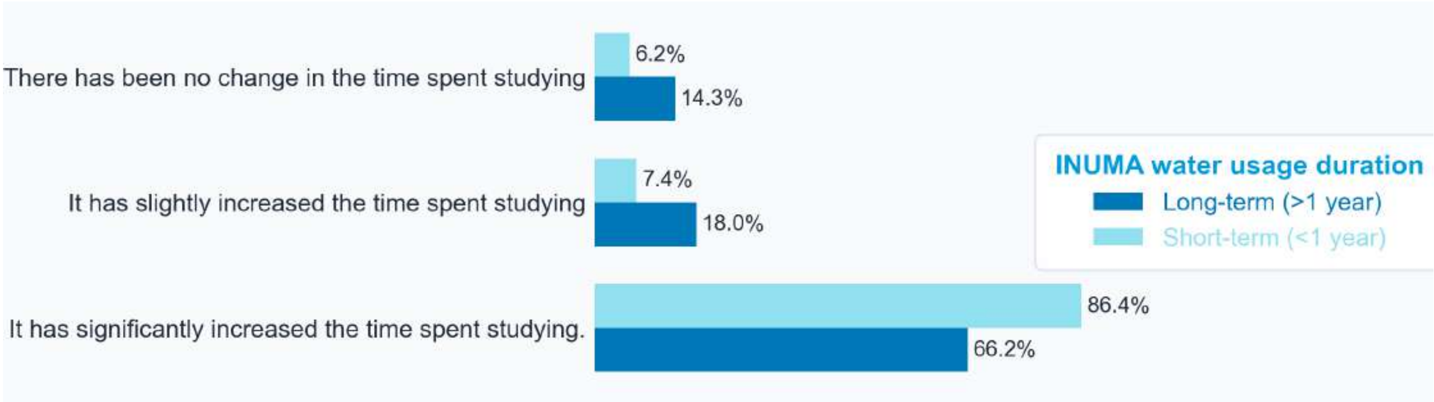

Fig. 3.45. **Impact of INUMA Water Access on Children's Study Time among Long-Term and Short-Term Communities**

While these findings present compelling evidence of INUMA's positive educational impact, several methodological considerations merit attention. The self-reported nature of our data introduces potential recall bias, and seasonal variations in water availability may influence response patterns. Additionally, concurrent educational initiatives in certain communities could act as confounding factors. Nevertheless, the consistency and magnitude of reported improvements, coupled with strong statistical significance, provide robust evidence of INUMA's substantial and meaningful impact on education.

3.5.3 Promoting gender equity

INUMA's impact on gender dynamics and women's empowerment is particularly significant. INUMA mini-grids have led to increased free time for women, enhanced opportunities to engage in income-generating activities, and a reduced burden of water collection as shown in Figure 3.46

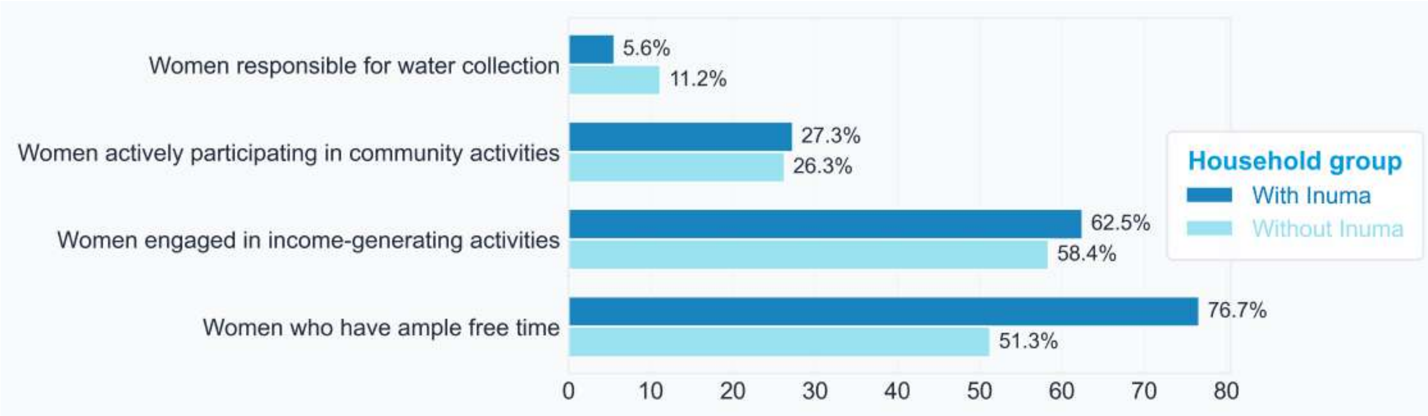

Fig. 3.46. Impact of INUMA Mini-Grids on women's time allocation, community and economic participation

The collected evidence show shift toward more equitable water collection responsibilities in INUMA communities, especially in how women spend their time and engage in various activities beyond traditional household duties, with an eye-opening contrast: a whopping 76.7% of women in INUMA-equipped households report having "much more time" available, compared to just 51.3% in communities without INUMA. This difference isn't merely anecdotal—it's substantiated by significant statistical test ($p < 0.001$) and an large effect size (Cramer's V = 0.310). This impact becomes even more apparent when we consider that barely 1.8% of INUMA households report decreased time availability for wome, while this figure soars to 15.1% in non-INUMA areas (Figure 3.47).

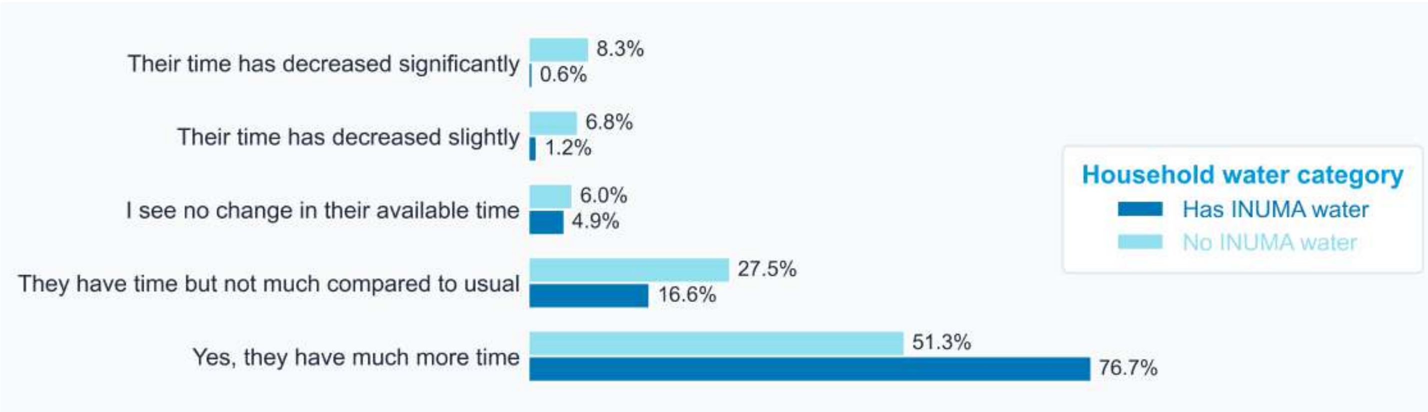

Fig. 3.47. Women's Time Availability for Non-Household Activities in INUMA and Non-INUMA Communities

When it comes to water collection responsibilities —traditionally a significant burden on women's time—the changes are subtle yet meaningful (Figure 3.48). Statistical analysis through Fisher's Exact test (Effect Size = 0.191) show a shift in household dynamics between hoseholds with INUMA water and those without it. While both groups show similar rates of shared responsibility (59.5% with INUMA vs 56.9% without), there's a notable reduction in the burden on adult females in INUMA households (5.6% versus 11.2%). Most importantly, this has alsoled to a slight increase in boys' participation (21.7% versus 16.5%), suggesting a gradual breakdown of traditional gender roles in water collection duties.

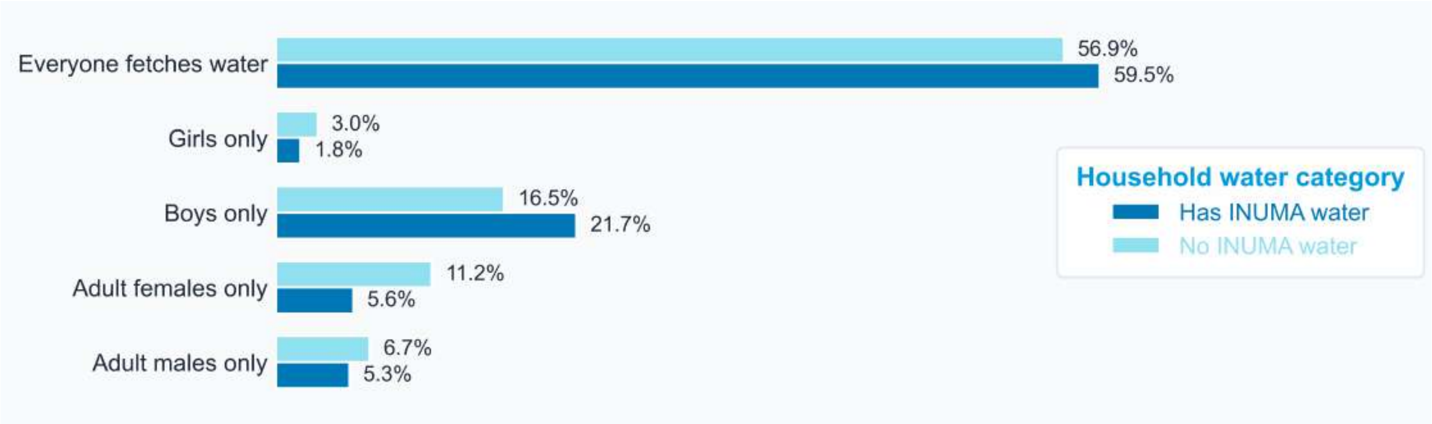

Fig. 3.48. Water collection responsibilities by household member in INUMA and Non-INUMA communities

The ripple effects of this time liberation are particularly evident in women's engagement with income-generating activities (Figure 3.49). Our data shows a modest but significant increase, with 62.5% of women in INUMA communities pursuing such opportunities compared to 58.4% in non-INUMA areas. This transformation, however, comes with interesting trade-offs. We observe a noticeable decline in participation in health-related activities (2.9% versus 11.1%) and continuous education (1.2% versus 4.2%). The reason for these changes are not clear. While these changes might initially raise concerns, they could reflect a strategic prioritization of economic opportunities over other activities. In contrast, community participation has remained remarkably stable (27.3% versus 26.3%), suggesting that the shift toward economic activities hasn't come at the cost of social engagement.

The introduction of INUMA water services has led to changes in household gender dynamics, particularly through its impact on women's time allocation and economic participation. Statistical analysis reveals compelling evidence of this transformation, with a significant correlation ($p < 0.05$) and substantial effect size (Cramer's V = 0.324) demonstrating INUMA's profound influence on women's daily lives. As illustrated in Figure 3.50, the majority of women have leveraged their reduced water-fetching responsibilities to pursue new opportunities, with 53.4% of long-term customers and 44.4% of short-term customers engaging in income-generating activities.

Moreover, with the newly acquired free time, women have changed their dialy routines (Figure 3.50). Short-term users initially show a higher preference for leisure activities (37.0%) compared to their long-term counterparts (12.9%). This contrast in time utilization suggests a evolution in

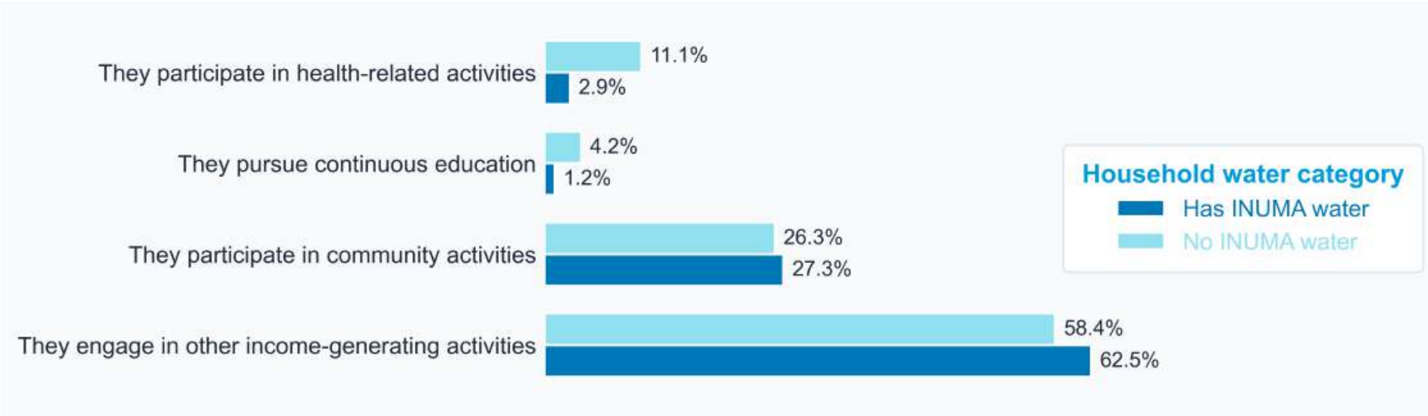

Fig. 3.49. **Activities undertaken by women outside of household duties in INUMA and Non-INUMA communities**

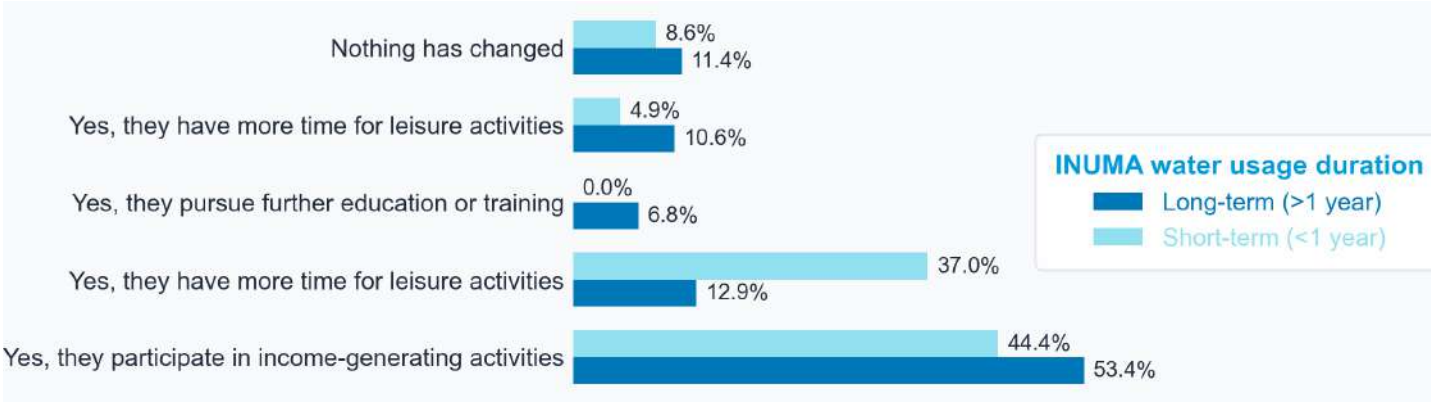

Fig. 3.50. **Perceived changes in women's time for non-household activities after INUMA water access**

time allocation patterns: as women adapt to improved water access over time, they increasingly channel their available hours toward economic opportunities rather than maintaining leisure time.

This shift is further emphasized by the educational pursuits among long-term users, with 6.8% engaging in further education or training —a opportunity notably absent (0%) among short-term users. Finally, women living in long-term customer households tend to pursuit furhter training compared to those in short-term communities, with 6.8% pursuing further education or training, compared to 0% among short-term users. While this percentage might seem modest, it represents a completely new opportunity that didn't exist before INUMA's implementation. The relatively low percentage of respondents reporting "Nothing has changed" (11.4% for long-term users and 8.6% for short-term users) further reinforces the impact INUMA has had on women's daily lives.

4
RECOMMENDATIONS

4.1 Overview

WAR's INUMA Mini-Grids program has led to a transformative impact in expanding reliable water access across Rwanda, achieving significant improvements in water accessibility, quality, and broader socioeconomic outcomes. Evidence shows that INUMA-served communities experience dramatically reduced waterborne disease incidence, with 92.8% of households reporting no water-related illnesses compared to 58.9% in non-served areas.

INUMA's operational model has proven particularly effective in promoting water accessibility and reliability. The evaluation found that 42.2% of INUMA-served households can access water within 200 meters of their homes, compared to only 17.0% in non-served areas. Service reliability shows marked improvement, with 55.4% of service interruptions resolved within 24 hours, contrasting sharply with non-INUMA communities where 37.1% of outages exceed six days. These improvements in accessibility and reliability have catalyzed significant public health benefits, evidenced by a Number Needed to Treat (NNT) of 3.0 —indicating that for every three households given INUMA access, one case of waterborne illness is prevented.

The program's impact extends beyond water access to create meaningful socioeconomic change, particularly in gender equity and education. In INUMA-served communities, 76.7% of women report increased free time availability compared to 51.3% in non-served areas, enabling greater participation in income-generating activities (62.5% versus 58.4%). Educational outcomes have similarly improved, with 69.2% of INUMA communities reporting enhanced academic performance compared to 51.8% in non-INUMA areas. The initiative has also promoted sustainable economic practices, with households demonstrating willingness to prioritize water expenditure despite economic constraints, indicating strong perceived value of reliable, clean water access.

WAR's INUMA Mini-Grids program has demonstrated remarkable success in transforming water access and community well-being. Building on its strong foundation, this evaluation has identified promising opportunities to strengthen its impact through enhanced water quality monitoring systems, expanded community education initiatives, and optimized infrastructure maintenance practices. The evaluation affirms that WAR's innovative model offers a practical template for addressing water access challenges in developing countries.

Based on INUMA's comprehensive evaluation, this report presents recommendations to enhance service delivery and maximize impact. Each recommendation has been evaluated for operational feasibility, scaling potential, and stakeholder alignment. These recommendations serve as a strategic roadmap for WAR to systematically enhance operations while allowing flexibility in implementation based on available resources and community needs.

4.2 Recommendations

I. Despite INUMA Mini grid's success in reducing unsafe water source usage to 14%, this remaining segment presents a critical public health challenge requiring immediate intervention. Based on household survey data and community feedback, the primary barriers to full adoption are cost constraints and limited health risk awareness. To address this, WAR should implement a dual-approach intervention:

1. WAR should establish a partnership with the Government of Rwanda (GoR) to provide subsidized water access in villages where affordability presents a significant barrier. This partnership is feasible and the GoR would be accommodating to this request, as it strategically aligns with national priorities: (1) Rwanda's National Strategy for Transformation (NST2) identifies universal water access as a key pillar; (2) the GoR already provides subsidies for similar interventions through its Local Administrative Entities Development Agency (LODA)[18], in line with its mission to support Rwanda's inclusive growth; and (3) improved access to clean water would contribute to NST2's core objective of ensuring that water is available 100% in all villages nationwide for both productive users and households

2. WAR should launch a targeted community awareness campaign by partnering with Rwanda's Community Health Worker (CHW) network to identify and engage households still using unsafe sources and progressively incentivize them to use WAR's clean water.

II. The evidence suggest that some kiosk attendants may be exploiting the variable pricing mechanisms that WAR introduced to compensate kiosks attendant's overtime. It was reported that, in some instances, when there are long queues or when available water is limited, some kiosk attendants arbitrarily increase prices by charging premium rates even during regular hours. This inconsistent and potentially exploitative pricing undermines INUMA's affordability objectives and erodes customer trust. To address this, INUMA should implement a comprehensive pricing transparency and accountability program. This should include:

- Prominently displaying standard prices at each kiosk
- Clearly delineating regular and off-peak hours, and the corresponding prices
- Installing signage emphasizing that customers should never be charged above posted rates
- Establishing an anonymous reporting hotline for customers to report overcharging incidents without fear of reprisal
- Implementing a rapid investigation protocol for reported violations and enforcing strict disciplinary measures against verified offenders

III. In response to findings that 18.6% of users experience frequent service disruptions, with 48% of interruptions stemming from technical issues, WAR needs to implement a preventive maintenance program. To optimize resource allocation, this should be structured as a three-tiered maintenance system:

- Tier 1: Train kiosk attendants in basic repairs and daily system checks
- Tier 2: Develop a network of community-based technicians for intermediate

[18] https://www.loda.gov.rw/what-we-do/departments-programs

maintenance

- Tier 3: Maintain a specialized rapid response team for complex issues

The program should include:

- Implementation of predictive maintenance technologies
- Establishment of bi-weekly preventive maintenance schedules
- Installation of backup systems at critical points

To ensure successful implementation:

- Pilot the program at sites with highest disruption rates
- Create detailed maintenance checklists and troubleshooting guides for kiosk attendants, requiring escalation to upper tiers only after failures are thoroughly documented through standardized reporting protocols.
- Establish a spare parts inventory system with local storage points
- Develop a tiered escalation protocol for technical issues

IV. While INUMA water is demonstrably safer than alternatives, with 71.4% user confidence compared to 49.2% in non-INUMA areas, the persistent 19.4% boiling rate indicates a trust gap. INUMA should implement a comprehensive water quality awareness program to build community confidence and trust in its water by:

- Transparently communicating its water quality testing processes
- Demonstrating compliance with national and international water quality standards
- Conducting regular public water quality demonstrations
- Displaying up-to-date water quality certificates at kiosks
- Engaging community leaders in quality assurance processes

V. In some cases, it was found that there is water shortage due to a limited capacity of the minigrid vs the demand. This is the case, for example, in Kavumu village in Mageragere. To address these supply shortages, WAR should expand water storage infrastructure by installing larger capacity tanks, enabling increased water collection during off-peak periods to meet peak demand. This infrastructure upgrade should be prioritized at sites where demand-supply gaps are most severe, with implementation phased based on:

- Current tank capacity utilization rates
- Peak demand periods and usage patterns
- Cost-benefit analysis of different storage capacity options

VI. To address water quality issues reported across multiple service areas (see Table 5.1 on page 55), including elevated salinity levels, technical failures leading to mini-grid inoperability, quality deterioration during rainy seasons, reduced water capacity, and damaged pipes, WAR should implement a comprehensive water quality management and monitoring program to ensure consistent water quality across all service areas and seasons while building trust with community members. This includes:

- Investigate the root causes of these issues through technical assessments of non-operational mini-grids, geological surveys for areas reporting high salinity, hydrological studies during rainy seasons, capacity assessment of underperforming systems, and infrastructure integrity evaluations.
- Establish a formal community feedback system to better understand and quickly respond to water quality complaints, particularly in areas reporting taste and quality issues
- Develop rapid response protocols for system failures to reduce downtime, particularly in areas with single operational systems serving large populations
- Establish an integrated quality monitoring system that combines regular testing, compliance tracking with national/WHO standards, trend analysis, and detailed documentation of all water quality parameters
- Create a data-driven management approach that consolidates quality metrics, seasonal variations, treatment effectiveness, and regular performance reporting into a single cohesive system

5
APPENDIX

INUMA Mini-Grids: challenges and areas for enhancement

The INUMA safe water mini-grid implementation across Rwanda has generally demonstrated significant success in improving water access for communities. However, our assessment has identified specific locations where targeted improvements could further enhance the system's effectiveness. As detailed in Table 5.1, while most mini-grids operate successfully, a few isolated areas warrant attention for optimization.

Table 5.1. Localized challenges and opportunities for INUMA Mini-Grid service optimization

District	Sector	Village	Reported Issues
Nyarugenge	Mageragere	Kavumu	• Mini-grid functionality critically impaired (3 out of 4 systems non-operational) • Community reverting to traditional water sources • Price inflation due to single operational mini-grid monopoly
	Nyamirambo	Gashuru and Karukoro	• Non-functional private mini-grid • Increased reliance on traditional water sources
	Mageragere	Kabeza	• Water quality issues affecting laundry (color changes, soap dissolution) • Excessive salinity affecting food preparation
	Mageragere	Nyarubande Nyarubuye Ntugamo Gikuyu	• Laundry discoloration from water use • Limited mini-grid functionality (1 of 2 operational) • Insufficient coverage leading to alternative source usage (Red Cross, Akagera wetland)
Nyagatare	Karangazi	Shimwaporo (Nkoma 2), Bwera	• High salinity concerns for cooking • Water primarily used for livestock • Seasonal water shortages during dry periods
Rwamagana	Munyaga	Nkungu	• Contamination concerns during rainy seasons
	Munyiginyu	Urugwiza	• Supply-demand imbalance • Extended collection times (up to 3 hours)
Gatsibo	Kiramuruzi	Businde	• Frequent pipe disruptions • Forced reliance on alternative water sources
Bugesera	Rwempashi	Mwogo	• High salinity levels • Altered food taste when prepared with INUMA water

In the Mageragere sector of Nyarugenge district, localized challenges have emerged, with some mini-grid systems requiring maintenance attention. While three out of four systems in one particular area need servicing, this situation appears to be an exception rather than the norm across the broader INUMA implementation. The temporary reduced functionality has reportedly led to an increase in prices and some customers resorting to other water sources. This merits investigation for potential service improvement.

Water quality monitoring has identified specific locations where additional treatment protocols might enhance user experience. For instance, in the Rwempashi sector of Bugesera district, some households reported that elevated salinity levels affected the taste of porridge (igikoma), a popular breakfast drink for children. Similarly, in isolated cases, residents noted that INUMA water was not ideal for washing clothes because its high mineral content reduced soap efficacy. These quality considerations, while limited to particular geographic areas, present opportunities for targeted water treatment adjustments.

The assessment also revealed opportunities for distribution network optimization in certain areas. In the Munyiginyu sector, peak usage times occasionally result in extended collection times, suggesting potential benefits from expanded capacity. Some communities near Nyarubande have indicated interest in expanded coverage, highlighting opportunities for future system growth. Seasonal variations in water availability, particularly noted in the Karangazi sector during dry periods, point to areas where additional storage capacity could enhance system resilience.

The findings from this assessment, while identifying specific areas for enhancement, should be viewed within the context of INUMA's broader success in providing safe water access across Rwanda. The isolated nature of these challenges suggests that targeted interventions in these specific locations could further strengthen what is already a largely successful program. Moving forward, these insights will be valuable for fine-tuning system operations and informing future expansion strategies, ensuring that INUMA continues to effectively serve Rwanda's communities.

Statistical analysis framework

Overview and data preparation

The statistical analysis was designed to rigorously evaluate differences between treatment and control groups across multiple variables. The analysis was implemented using Python statistical computing environment, leveraging specialized libraries for statistical computations and data manipulation. Figure 5.1 illustrates the systematic approach for selecting appropriate statistical tests based on variable type (numerical vs. categorical) and data distribution characteristics. The framework guides analysts through the process from initial data input to final results, incorporating proper effect size measurements and multiple comparison corrections to ensure robust statistical analysis.

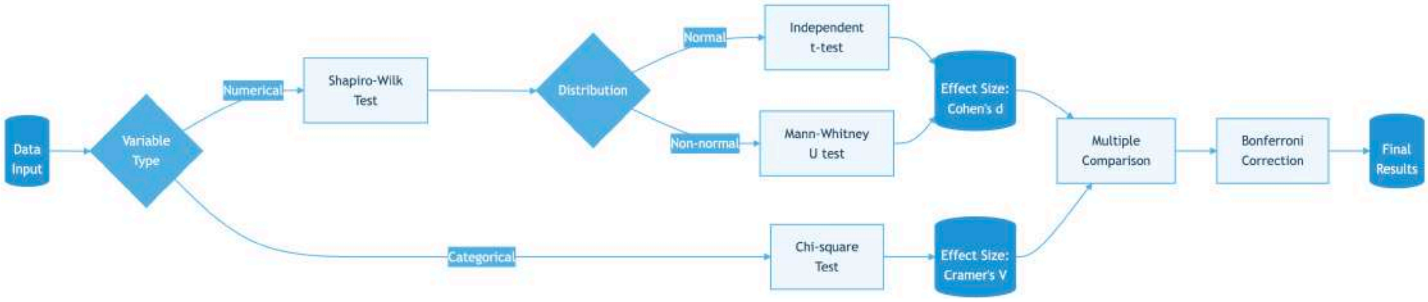

Fig. 5.1. **Statistical analysis decision for variable classification and effect size determination**

Power analysis and sample size determination

A Priori power analysis

Statistical power for primary outcome measures was calculated according to:

$$n = 2(Z_\alpha + Z_\beta)^2\sigma^2/\delta^2 \tag{5.1}$$

where n represents required sample size per group, Z_α denotes critical value for significance level α (two-tailed), Z_β represents critical value for power $1-\beta$, σ^2 indicates assumed population variance, and δ specifies minimum detectable effect size.

Minimum detectable effects

The minimum detectable effect size (MDES) calculation incorporates design parameters:

$$\text{MDES} = (M_N + M_{1-\beta})\sqrt{\frac{\rho(1-\rho)}{P(1-P)n}} \tag{5.2}$$

with M_N as statistical significance multiplier, $M_{1-\beta}$ as statistical power multiplier, ρ as intraclass correlation coefficient, and P as treatment group proportion.

Statistical testing framework

Continuous outcomes For normally distributed data, Welch's t-test was employed:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{5.3}$$

Degrees of freedom were calculated as:

$$df = \frac{(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2})^2}{\frac{(s_1^2/n_1)^2}{n_1-1} + \frac{(s_2^2/n_2)^2}{n_2-1}} \tag{5.4}$$

For non-normally distributed data, Mann-Whitney U test was used:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{5.5}$$

The standardized test statistic was computed as:

$$Z = \frac{U - \mu_U}{\sigma_U} \tag{5.6}$$

where $\mu_U = \frac{n_1 n_2}{2}$ and $\sigma_U = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}$

Categorical outcomes Chi-square test of independence was applied:

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{5.7}$$

For cases with small expected frequencies (< 5), Fisher's exact test was utilized:

$$p = \frac{\prod_{i=1}^{r}(a_{i\cdot}!) \prod_{j=1}^{c}(a_{\cdot j}!)}{n! \prod_{i=1}^{r} \prod_{j=1}^{c} a_{ij}!} \tag{5.8}$$

Effect size estimation

Standardized mean differences
Cohen's d with sample size correction:

$$d = \frac{\bar{X}_1 - \bar{X}_2}{s_{\text{pooled}}} \tag{5.9}$$

Where the pooled standard deviation (s_{pooled}) is calculated as:

$$s_{\text{pooled}} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}} \tag{5.10}$$

For small samples, Hedge's g correction was applied:

$$g = d \cdot \left(1 - \frac{3}{4(n_1 + n_2) - 9}\right) \tag{5.11}$$

Categorical association Cramer's V was calculated as:

$$V = \sqrt{\frac{\chi^2}{n \cdot \min(r - 1, c - 1)}} \tag{5.12}$$

Multiple comparison procedures

Family-wise error control Holm-Bonferroni sequential adjustment:

$$\alpha_k = \frac{\alpha}{m - k + 1} \tag{5.13}$$

where k represents the rank of the p-value under evaluation.

False discovery rate Benjamini-Hochberg procedure:

$$\alpha_{(i)} = \frac{i}{m} \cdot \alpha \tag{5.14}$$

where i denotes p-value rank and m total comparisons.

Missing Data Treatment

Multiple imputation Pooled estimates following Rubin's rules:

$$\bar{Q} = \frac{1}{m}\sum_{i=1}^{m} Q_i \tag{5.15}$$

Total variance estimation:

$$T = \bar{U} + (1 + \frac{1}{m})B \tag{5.16}$$

where $\bar{U}$ represents average within-imputation variance and B between-imputation variance.

Sensitivity Analysis

Treatment effect bounds Robustness assessment bounds:

$$[\beta_L, \beta_U] = \hat{\beta} \pm \sqrt{\frac{R^2_{max} - \tilde{R}^2}{1 - \tilde{R}^2}} \cdot SE(\hat{\beta}) \tag{5.17}$$

Effect size interpretation guidelines

Effect sizes were interpreted according to the following thresholds for cohen's d:

$$\begin{aligned} |d| < 0.2 &: \text{Negligible effect} \\ 0.2 \leq |d| < 0.5 &: \text{Small effect} \\ 0.5 \leq |d| < 0.8 &: \text{Medium effect} \\ |d| \geq 0.8 &: \text{Large effect} \end{aligned}$$

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