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# Impact of Urban Rooftop Rainwater Harvesting on Water Security in Sana'a, Yemen: Assessing Adaptation Strategies to Water Scarcity

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**Keywords**

1. Rainfall patterns
2. English language education
3. Water scarcity
4. Planned city
5. Climate change adaptation
6. SDG 6

## Abstract:

This study investigates the impact of Urban Rooftop Rainwater Harvesting (URWH) on water availability and scarcity in Sana'a City, Yemen. Given the city's chronic water shortages and irregular municipal supply, households rely increasingly on alternative sources. This research employs a qualitative exploratory approach to analyze the data collected through semi-structured interviews. A sample of 33 residents was determined based on the principle of data saturation, where interviews continued until no new themes or information emerged; the distribution (26 in Tahrir District and 7 in Al-Sab'een District) reflects the higher population density and more acute water distress in the traditional urban downtown of Tahrir. Additionally, 9 key stakeholders were selected using purposive sampling to ensure a multi-dimensional perspective, representing government water authorities, NGOs, and academia. Findings were derived through Inductive Thematic Analysis, involving systematic coding of interview transcripts to identify recurring patterns and consensus among participants. The results indicate that rainwater harvesting can significantly alleviate water scarcity during rainy months, particularly for low-income households. However, the utilization of rainwater in the areas under study is hindered by a host of barriers, including roof suitability, limited storage capacity, and lack of institutional support. The study highlights the potential of URWH as a locally appropriate adaptation strategy and emphasizes the need for targeted interventions, including the provision of storage tanks, technical guidance, and policy support to maximize its impact.

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# تأثير حصاد مياه الأمطار من أسطح المنازل الحضرية على الأمن المائي في صنعاء، اليمن: تقييم لاستراتيجيات التكيف مع ندرة المياه

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**الكلمات المفتاحية**

1. حصاد مياه الأمطار الحضرية
2. تعليم اللغة الإنجليزية
3. شح المياه
4. مدينة صنعاء
5. استراتيجيات التكيف مع تغير المناخ
6. الهدف السادس من أهداف التنمية المستدامة

## الملخص:

تبحث هذه الدراسة تأثير حصاد مياه الأمطار الحضرية (URWH) على توافر وشح المياه في مدينة صنعاء، باليمن. نظرًا لنقص المياه المزمن وعدم انتظام الدعم المؤسسي، تعتمد الأسر بشكل متزايد على مصادر مياه بديلة. استُخدمت البيانات النوعية التي جُمعت من خلال مقابلات شبه منتظمة مع 33 ساكنًا (26 في مديرية التحرير و7 في مديرية السبعين) و9 من أصحاب المصلحة الرئيسيين، لدراسة مدى مساهمة حصاد مياه الأمطار في تعزيز أمن المياه المنزلي. تشير النتائج إلى أن حصاد مياه الأمطار يخفف بشكل كبير من شح المياه خلال أشهر الأمطار، خاصة للأسر الفقيرة التي تواجه صعوبة في الوصول إلى المياه. ومع ذلك فعالية هذه الممارسات تقيدها عدة عوامل مثل ملاءمة الأسطح، محدودية قدرة التخزين، ونقص الدعم

المؤسسي. تسلط الدراسة الضوء على إمكانات حصاد مياه الأمطار كاستراتيجية محلية ملائمة للتكيف مع شح المياه، وتؤكد على الحاجة إلى تدخلات مستهدفة، بما في ذلك توفير خزانات لتخزين المياه، والإرشاد الفني، والدعم السياسي بغية تعظيم أثرها.

## 1. Introduction

Sana'a, the capital of Yemen, is confronting one of the most acute urban water crises across the globe, a situation exacerbated by a confluence of chronic groundwater over-extraction, rapid population growth, and the ongoing socio-political conflict (Aklan et al., 2023). Decades of unsustainable abstraction have led to critical depletion of the Sana'a Basin's water table, with estimates indicating a severe structural deficit in supply (Haidera et al., 2011). The reliability of municipal water supply has deteriorated sharply, with its often being irregular, inadequate, or entirely absent in many districts, pushing households to rely heavily on expensive and often unregulated private water trucking (Campisano et al., 2017). This fragile context presents an existential challenge to urban water security, especially for vulnerable and low-income populations.

In response to this institutional failure and chronic scarcity, **Urban Rooftop Rainwater Harvesting (URWH)** has emerged as a vital, grassroots coping mechanism. While traditionally associated with rural areas, URWH is increasingly adopted in densely populated urban neighborhoods like Al-Tahrir and Al-Sab'een, functioning as a necessary adaptation strategy for survival. This practice offers a decentralized and climate-resilient solution, capable of supplementing household water needs and reducing the physical and financial burden associated with acquiring water from commercial sources. The theoretical framework for this study is grounded in the principles of Sustainable Development Theory (SDT), which underscores the necessity of integrating environmental sustainability, economic viability, and social equity in water resource management (WCED, 1987).

Despite the evident proliferation of these informal practices, a significant gap remains in the academic understanding of their actual impact. Specifically, the extent to which URWH successfully mitigates water scarcity and enhances water availability at the household level in a complex, conflict-affected urban setting like Sana'a remains largely unexplored. Previous studies in similar arid contexts confirm that RWH can meet a portion of non-potable domestic demand (Abdulla et al., 2009), but they often neglect the specific social, infrastructural, and institutional barriers faced by Yemeni urban residents, such as the initial economic cost, technical limitations of roof structures, and pervasive institutional neglect.

Therefore, this study aims to address this critical knowledge gap. The primary objective of this paper is **to evaluate the influence of rainwater harvesting on water availability and water scarcity in Sana'a City**. By analyzing qualitative data collected from both residents and key stakeholders, the research seeks to quantify the perceived effectiveness of URWH as an indigenous water adaptation strategy and to identify the major challenges limiting its scalability and maximum contribution to household water security, thereby providing an evidence base for linking community-level resilience tactics with formal, sustainable urban water policy, in line with SDG 6 (Access to water and sanitation for all).

## 2. Problem Statement and Research Questions

### 2.1.Problem Statement

Sana'a City, Yemen, is confronting one of the most critical urban water scarcity crises across the globe, with chronic resource depletion exacerbated by groundwater over-extraction and the deterioration of water infrastructure due to ongoing conflict (Aklan et al., 2023). This situation has led to the unreliability of municipal supplies, forcing households to increasingly rely on costly and unsustainable alternative sources, such as purchasing vended water from trucks or alsabeel.

In this context, URWH has emerged as a pervasive, informal coping mechanism utilized by residents to augment household water availability and mitigate financial burdens. However, despite the widespread adoption of this practice, there remains a critical knowledge gap regarding the systematic assessment of its actual impact.

The core of the problem lies in the insufficient academic evidence that quantifies and characterizes:

The extent to which URWH effectively contributes to alleviating water scarcity and increasing water availability at the household level within the specified urban districts of Sana'a.

The key structural, socio-economic, and technical constraints (such as roof suitability, storage capacity, trust in quality, and the lack of institutional support (such as technical standards, financial incentives, or quality monitoring) which relegates URWH to a sub-optimal survival mechanism rather than an integrated urban water management strategy) that prevent households from fully realizing the benefits of rainwater as a sustainable adaptation strategy.

Understanding this gap is crucial for transforming URWH from a mere survival tactic to a scalable and sustainable adaptation strategy, necessitating informed policy and structural interventions(Chen et al., 2024).

### 2.2. Research Questions

The following research questions are designed to exclusively address the evaluation of the impact of URWH on water availability, serving the study's primary objective:

1. How does Urban Rooftop Rainwater Harvesting (URWH) affect water availability and adapt water scarcity at the household level in Sana'a City?
2. What are the primary uses of harvested rainwater, and to what extent does this contribute to reducing reliance on alternative water sources (e.g., water trucks or alsabeel)?
3. What are the main technical, economic, and social barriers that limit the effectiveness of URWH in enhancing household water availability in Sana'a?

## 3. Study Objectives

**The study aimed to evaluate and understand the impact of Urban Rooftop Rainwater Harvesting (URWH) on water challenges in Sana'a, through the following:**

1. **To evaluate the URWH contribution** to **enhancing water availability** and adapting **water scarcity** at the household level in Sana'a City, Yemen.
2. **To identify the primary uses** of harvested rainwater and its role in **reducing household reliance** on costly alternative water sources (such as water trucks or alsabeel).

3. **To analyze the technical, economic, and social barriers** that **limit the effectiveness** of rainwater harvesting in achieving maximum household water security.

## 4. Study Significance

The significance of this study lies in its attempt to fill a critical knowledge gap and contribute to key applied and policy areas:

### 1. Academic Contribution

- **Enriching Urban Adaptation Literature:** The study contributes to the literature on **grassroots adaptation strategies** in **fragile and conflict-affected contexts**, where field research oriented toward practical solutions is still insufficient.
- **Providing Qualitative Evidence:** The research provides an in-depth qualitative analysis of data on the **actual and perceived impact** of URWH on the households facing water scarcity, moving beyond reliance on purely theoretical hydrological models.

### 2. Applied and Policy Significance

- **Supporting Decision-Makers:** The findings offer credible evidence for policymakers, humanitarian organizations, and local authorities to **transition** URWH from an individual popular practice into a **sustainable and funded strategy** for enhancing urban water security.
- **Guiding Interventions:** It helps in **guiding future interventions** to be more targeted and effective by identifying the most critical barriers (e.g., initial financing and storage capacity), thus ensuring that the provided support would maximize its impact on increasing water availability for the most vulnerable populations.
- **Alignment with Global Goals:** The study supports Yemen's efforts toward achieving the Sustainable Development Goals (SDG 6) concerning access to clean water for all, by presenting decentralized and climate-resilient solutions.

## 5. Study Boundaries and Limitations

**The study was defined by the following boundaries and limitations:**

### 4 Topical/Thematic Boundaries

- **Major Focus:** The study was mainly confined to evaluating the **impact of URWH** on **water availability and scarcity adaptation**. Other potential research objectives (such as legislative aspects) were excluded from the scope of this paper.
- **Non-Potable Uses:** The study focuses primarily on rainwater's contribution to meeting household needs of non-potable water (e.g. water for washing and cleaning), thereby limiting the assessment of URWH as a comprehensive solution for overall water security.

### 5 Geographical Boundaries

- **Targeted Districts:** Data collection was confined solely to residents and stakeholders in

**Al-Tahrir District** and **Al-Sab'een District** within Sana'a City.

- **Urban Context Specificity:** The findings cannot be so generalizable to include rural or coastal areas of Yemen, the areas that differ significantly from Sana'a City in terms of hydrological conditions and socio-economic infrastructure.

6. **Methodological and Temporal Limitations**

- **Qualitative Method:** The study is intended to qualitatively analyze **data** collected from interviews with study participants. This of course precludes the possibility of getting a **precise quantitative measurement** of the actual volume of rainwater harvested by the participants, as well as of conducting a large-scale **Cost-Benefit Analysis** (CBA).
- **Reliance on Perceptions:** The results of data analysis should be interpreted as the participants' **subjective perceptions** (Perceived Impact) regarding the effect of URWH on their lives and scarcity relief, which may not always align with actual hydrological measurements.
- **Temporal Constraint:** Data was collected within the period of **2024–2025**, which places temporal constraints on the specific political and economic context informing the study.

7. **Conceptual and Operational Definitions**

- The terms used in the study were defined conceptually and operationally to serve the research purposes, as follows:
- **1. Urban Rooftop Rainwater Harvesting (URWH)**

| Definition | Description |
|---|---|
| Conceptual Definition | The process of collecting, storing, and distributing rainfall runoff from urban building rooftops and other impervious surfaces for use in non-potable domestic applications, aiming to reduce pressure on centralized water resources (Campisano et al., 2017). |
| Operational Definition | The actual practice implemented by residents in the Al-Tahrir and Al-Sab'een districts of Sana'a, involving the use of simple channels, gutters, or pipes to divert rainwater from rooftops into ground-level or surface storage tanks/barrels, and the assessment of its contribution to household use. |

- **2. Water Security**

| Definition | Description |
|---|---|
| Conceptual Definition | The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, while ensuring protection against waterborne pollution and water-related disasters (Escap UN-Water, 2013). |
| Operational Definition | Operationally measured in this study through **household perceptions** regarding the ability of harvested rainwater to increase domestic water availability (Quantity), improve quality (Trust in use), and reduce the financial burden of purchasing alternative water. |

- **3. Water Scarcity**

| Definition | Description |
|---|---|
| **Conceptual Definition** | The inadequacy of fresh water resources to satisfy standard water demands in a given region. It is typically categorized into physical scarcity (insufficiency of resources) and economic scarcity (lack of infrastructure and financing to access resources) (Falkenmark, 1989). |
| **Operational Definition** | Measured in this study through **participants' perceptions** regarding the frequency and duration of municipal supply interruptions, their reliance on costly alternative water sources (water trucks), and the efforts undertaken to cope with this shortage using URWH. |

## 8. Methodology and Procedures

The primary objective of this study is to evaluate the impact of Urban Rooftop Rainwater Harvesting (URWH) on household water availability and scarcity adaptation in Sana'a. Given the nature of this objective, which explores complex social perceptions, coping mechanisms, and structural barriers, a **qualitative research design** was deemed most appropriate.

## 9 Research Approach and Design

The study adopts a **Pragmatic Qualitative Approach** (Kaushik & Walsh, 2019). This approach allows the researcher to focus on the 'what works' solution to URWH in the challenging context of Sana'a, integrating diverse perspectives from residents and experts to achieve a deeper understanding of the phenomenon. The design is **exploratory and descriptive**, aiming to describe the phenomenon of URWH adoption and to explore the factors limiting its effectiveness.

## 10 Study Area and Population

## 11 Study Area

The study population included households practicing URWH within the selected districts, as well as key stakeholders involved in water management in Sana'a.

**Sampling Strategy and Rationale:** The study employed a combination of purposive and snowball sampling techniques. **Purposive sampling** was used to specifically target households that already have functional storm-water harvesting setups (barrels, tanks, or roof-diversion systems). Subsequently, **snowball sampling** was utilized to access a wider range of practitioners in neighborhoods where official data was unavailable.

**Sample Size and Data Saturation:** The final sample size of **42 participants** was guided by the principle of data saturation. The distribution of the 33 household residents is as follows:

- **Al-Tahrir (n=26):** Represents **78.8% of the resident sample**.
- **Al-Sab'een (n=7):** Represents **21.2% of the resident sample**.

**Clarification on Percentages:** It is critical to clarify that these numbers (n=26 and n=7) represent the **distribution of the study sample (Frequency)** and not a percentage of the total district populations. In qualitative research, the focus is on "depth" rather than "statistical generalization." The higher representation from Al-Tahrir is attributed to its status as a high-density, traditional urban core where water scarcity is most acute and URWH practices are more deeply embedded in the social fabric. In contrast, the sample from Al-Sab'een provided a complementary perspective from a more modern residential context.

- **Key Stakeholders (N=9):** To ensure a multi-dimensional analysis, nine experts were interviewed (triangulation).

## 12 Data Collection Instrument

Data was primarily collected through **semi-structured interviews** guided by detailed questionnaires. This method allowed for flexibility while ensuring core research questions were systematically addressed. The interviews were conducted as of December 2024 through the end of February 2025.

## 13 Interview Protocol

The interview protocol of **semi-structured interviews** with and questionnaires for household residents was designed to gather detailed accounts on:

1. **Water Availability:** Frequency of municipal supply and the reliance on alternative sources.
2. **URWH Practice:** Confirmation of the participant's collection of rainwater, how the system was installed, that is, whether professionally or with simple tools, and the volume of rainwater expected to be collected.
3. **Impact Assessment:** The extent to which collected rainwater replaces expensive vended well-water as well as financial savings.
4. **Barriers:** Technical, economic, and social challenges limiting the effectiveness.

## 14 Data Analysis Procedure

The interview-collected data (in form of transcripts) were analyzed using **Inductive Thematic Analysis** (Braun & Clarke, 2006). This procedure involved six phases:

1. **Familiarization:** Reading and re-reading the transcripts to gain a deep understanding.
2. **Coding:** Systematically generating initial codes across the entire dataset.
3. **Theme Searching:** Grouping codes into potential sub-themes and core themes.
4. **Reviewing Themes:** Checking themes against the codes and the entire dataset to ensure validity.
5. **Defining and Naming Themes:** Developing clear definitions and titles for the final themes (e.g., "The Mitigation of Financial Burden" or "Technical Constraints on Storage Capacity").
6. **Producing the Report:** Relating the themes back to the research questions and generating the narrative for the results section.

This rigorous analysis ensured that the findings on the impact of URWH on water availability and scarcity were grounded directly in the participants' experiences.

## 9. Results and Discussion

The inductive thematic qualitative analysis of data collected from 33 residents and 9 key stakeholders yielded three principal themes, addressing the research questions regarding the URWH impact on water availability and scarcity in Sana'a. To support these qualitative findings with empirical weight, the following tables provide the frequency distribution and percentages of participant responses.

## 16 The Impact of Rainwater Harvesting on Water Availability and Scarcity Adaptation (RQ 1)

**Research Question 1:** How does Urban Rooftop Rainwater Harvesting (URWH) affect water availability and adapt water scarcity at the household level in Sana'a City?

## 17 Findings: URWH as a Popular Scarcity Adaptation Mechanism

The overwhelming majority of participating households (**63.6% of residents**) in the Al-Tahrir and Al-Sab'een districts confirmed engaging in some form of URWH to cope with the severe and chronic deficit in municipal supply. This practice is viewed as a **first line of defense** and an **informal survival strategy**, rather than an environmental or economic choice. As shown in **Table 1, 84.8%** of residents perceive this practice as "essential" for their water security

**Table 1: Impact of URWH on Household Water Availability (N=33 residents)**

| Indicator | Frequency | Percentage (%) | Participant Codes |
|---|---|---|---|
| Actively practicing URWH during rainy season | 21 | 63.6% | P1, P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P17, P18, P19, P21, P23, P25, P36, P38 |
| Rely on URWH as a primary survival source during outage | 23 | 69.7% | P1, P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P21, P23, P24, P25, P36, P38 |
| Perception of URWH as "Essential" for water security | 28 | 84.8% | P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P36, P38, P40 |

**"Our taps are dry most of the time. We wait for the rain to fill our barrels. Without this water, we would have to pay for trucked water three times a week" (P19, a woman in AL-Tahrir district).**

The results indicate that the additional availability of harvested rainwater provides direct material relief, especially during the short rainy season. It critically **reduces the frequency** with which families must purchase water from trucks, which is an expensive and often quality-unassured source (Taher, 2014), or **Al-Sabeel** (which, while often a free charitable source, involves much physical labor and time).

## 18 Discussion: Quantitative Limitation and Qualitative Shift

This trend aligns with literature on arid regions, which confirms that URWH represents a popular response to water crises (Amos et al., 2018). While optimized URWH systems can theoretically offset **80–90%** of non-potable water demands sources (Abdulla et al., 2009; GhaffarianHoseini et al., 2016), its contribution in Sana'a remains **quantitatively limited** and insufficient to bridge the macro-level deficit caused by extreme groundwater depletion. However, the greater impact is **a qualitative shift** toward **Climate Resilience**, where effective adaptation is measured by the strengthening of social capital and the preservation of environmental assets (Owen, 2020). By offering a decentralized water source, URWH gives families a sense of "water sovereignty" and reduces total reliance on a collapsed municipal supply system, securing basic access during peak scarcity. Although this relief does not solve the hydrological crisis at the basin level, it critically minimizes **Household Vulnerability** to supply shocks and reduces the immediate pressure on over-stressed aquifers, which is vital for preserving the city's remaining environmental capital (Chen et al., 2024; Musz-Pomorska et al., 2024).

## 19 Uses and the Impact on Reducing Financial Dependency (RQ 2)

**Research Question 2:** What are the primary uses of harvested rainwater, and to what extent does this contribute to reducing reliance on alternative water sources (e.g., water purchased from trucks).

## 20 Findings: Adaptation of Economic Burden

The results show that rainwater is used almost exclusively for **Non-potable Uses**, with laundry and house cleaning (93.9%) and sanitation (81.8%) being the primary drivers (Table 2). This strategic allocation of resources serves as a primary mechanism for **economic mitigation**. The quantitative distribution of these uses among participants is detailed below:

**Table 2: Primary Domestic Uses of Harvested Rainwater (N=33)**

| Use Category | Frequency | Percentage | Participant Codes |
|---|---|---|---|
| Laundry and house cleaning | 31 | 93.9% | P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P36, P37, P38, P40, P42 |
| Sanitation (Toilet flushing | 27 | 81.8% | P1, P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P17, P18, P19, P21, P22, P23, |

| | | | |
|---|---|---|---|
| | | | P24, P25, P36, P37, P38, P40, P41, P42 |
| Urban gardening/ Planting | 12 | 36.4% | P1, P8, P10, P11, P18, P23, P24, P36, P37, P38, P40, P42 |
| Cooking/Drinking (only if filtered) | 6 | 18.2% | P16, P22, P36, P37, P38, P42 |

This dedicated usage has a conspicuous financial impact: instead of wasting expensively purchased water for these purposes, "free" rainwater is used. **Table 3** shows the perceived reduction in dependency on paid alternatives: 75.8% of participants reported a reduction in truck-fetched water purchases, highlighting a significant shift in household expenditure patterns.

**Table 3: Reduction in Reliance on Alternative Sources (N=33)**

| Financial/Resource Impact | Frequency | Percentage (%) | Participant Codes |
|---|---|---|---|
| Reported reduction in Water Truck (Tanker) purchases | 25 | 75.8 % | P1, P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P17, P18, P19, P21, P22, P23, P25, P36, P37, P38, P40, P42 |
| Reported reduction in time/labor at Al-Sabeel points | 17 | 51.5 % | P1, P8, P9, P10, P11, P12, P13, P14, P15, P17, P18, P19, P20, P21, P23, P25, P36 |
| Savings allocated to other essential needs (Food/Medicine) | 22 | 66.7 % | P3, P4, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P17, P18, P19, P21, P25, P36, P37, P38, P40, P42 |

**Thematic Analysis and Qualitative Evidence:** The statistical data in Table 3, which shows that **75.8%** of participants reported a reduction in truck-fetched water purchases, is further validated by the **qualitative narratives** of the respondents. The participants' feedback indicates that the economic value of rainwater harvesting is not merely in the "volume" of water collected, but in the **"strategic delay"** of high expenses.

This is explicitly captured in the testimony of participant **P04**, whose experience represents the broader **thematic pattern** of financial relief found across the Al-Tahrir district:

"The difference in price between truck-fetched water and municipal water is huge. When I collect rainwater, I can postpone buying a truckful of water for one or two weeks, which saves me a lot of money" (P04, a woman in AL-Tahrir district).

This qualitative insight explains the **causal link** behind the high percentages shown in Table 3; as reported by 66.7% of the sample, the "postponement" of water purchases acts as a critical household stabilization strategy, allowing families to reallocate their limited financial resources to other essential needs like food and medicine.

## 21 Discussion: URWH and Economic Water Security

The practice of using rainwater for non-potable purposes underscores the residents' commitment to hedging against health risks, aligning with water quality concerns noted in the literature (Ranaee et al., 2021). Economically, the reduction in water purchases alleviates **"Economic Scarcity"** imposed by the high prices of vended water. The results indicate that 75.8% of participants reported a significant reduction in vended water purchases (Table 3). This aligns with the theoretical framework of Climate Resilience, where adaptation is measured by the building of social and economic resilience (Owen, 2020) Qualitatively, the value of URWH in Sana'a does not lie in its total volume but in its ability to provide a "strategic delay" of high expenses. As noted by participant P04, postponing the purchase of a truckful of water for two weeks acts as a critical household stabilization strategy.

This financial adaptation is consistent with global literature confirming that URWH provides a strong economic incentive in areas with high tariffs or intermittent supply (Borgert & Ghisi, 2024). In the context of Sana'a, the small physical contribution of rainwater translates into significant Economic Water Security, allowing 66.7% of families to re-allocate savings toward other basic needs like food and medicine. This confirms that URWH, while quantitatively modest, can effectively alleviate the **"Economic Scarcity"** imposed by the high prices of vended water (Amos et al., 2018).

## 22 Barriers Limiting the Effectiveness of URWH (RQ 3)

**Research Question 3:** What are the main technical, economic, and social barriers that limit the effectiveness of URWH in enhancing household water availability in Sana'a?

## 23 Findings: Structural and Social Constraints

Despite the economic benefits, the transition of URWH from a "coping mechanism" to a "sustainable strategy" is hindered by three primary structural barriers identified by residents and stakeholders (Table 4).

**Table 4: Ranking of Barriers to URWH Adoption (N=42 Total Participants)**

| Barrier Category | Mentioned by Residents | Mentioned by Stakeholders | Total % | Participant Codes (Residents & KIIs) |
|---|---|---|---|---|
| High Cost of Tanks/Materials | 21 | 7 | 66.7% | **Residents:** P1, P3, P4, P6, P8, P9, P10, P11, P12, P13, P14, P15, P17, P25, P36, P37, P40, P41, P42, P16, P21<br><br>**KIIs:** KII1, KII2, KII3, KII4, KII7, KII8, KII9 |
| Roof Condition (Unsuitable/Earth) | 18 | 5 | 54.8% | **Residents:** P1, P2, P6, P7, P8, P10, P13, P15, P18, P19, P20, P24, P26, P36, |

| | | | | |
|---|---|---|---|---|
| | | | | P38, P39, P41, P42<br><br>**KIIs:** KII1, KII4, KII5, KII7, KII9 |
| Lack of Institutional/Gov Support | 14 | 8 | 52.4% | **Residents:** P1, P2, P3, P12, P14, P16, P18, P20, P21, P22, P23, P37, P40, P42<br><br>**KIIs:** KII1, KII2, KII3, KII4, KII6, KII7, KII8, KII9 |
| Social Stigma/Privacy Concerns | 9 | 2 | 26.2% | **Residents:** P2, P3, P9, P14, P15, P17, P22, P28, P40<br><br>**KIIs:** KII2, KII6 |

- a. **Economic Barrier (Capital Investment):** The upfront cost of infrastructure emerged as the most significant obstacle, being cited by **66.7% (n=28)** of the total sample. This indicates a high level of consensus among both residents and stakeholders that financial constraints are the primary deterrent. This mirrors global trends where RWH viability is often tied to the lack of economic incentives to shorten the payback period (Daza & Ismail, 2024; Lepcha et al., 2024). The qualitative analysis of the data provides a deeper understanding of this barrier; for instance, **Participant P09** (a woman in AL-Tahrir district) points out that the problem is not the "technology" itself, but the "scale" of storage, stating: "The barrel we use is very small. If I had a bigger tank, I could collect an amount of rainwater enough for two months, but its price is extremely high." This confirms that the economic burden has a direct impact on the **storage efficiency** of URWH systems.

- b. **Technical Barrier (Infrastructure Suitability):** Technical limitations, specifically regarding roof conditions, were validated by **54.8% (n=23)** of participants. This consensus highlights a structural challenge to URWH in Sana'a, where earth-covered or uneven rooftops in areas with traditionally constructed houses impede efficient collection of rainwater. As noted by **P38** (a woman in AL-Sab'een district), these physical constraints increase contamination fears, thereby reducing the "perceived trust" in the harvested water quality, which explains the high percentage of non-potable water use recorded in earlier studies, explaining why only 18.2% of respondents use it for cooking/drinking. This confirms that RWH reliability is tied to quality control and physical infrastructure suitability (Ranaee et al., 2021); Carús & Paltán, 2024).

- c. **Institutional and Social Barriers:** The study identified a critical gap in official support, with **52.4% (n=22)** of respondents emphasizing institutional neglect. This finding is particularly significant as it aligns with the experiences of the **Social Fund for Development (SFD)**, which has noted that without standardized subsidies or technical guidelines (which it is already working on to publish in a booklet), URWH remains a marginalized practice.

- Furthermore, a **Social Stigma** was identified by **26.2% (n=11)** of the participants. While this percentage is lower than that of reporting on economic barriers, it provides a crucial socio-psychological explanation for why some households avoid URWH. This is not merely an isolated opinion but a documented social phenomenon where harvesting rain is perceived as a "sign of poverty." What **Participant P28** (a woman in AL-Sab'een district) said exemplifies this social pressure: "People don't want the neighbors to see them collecting rain. They want to show that they have enough money to buy well water." This qualitative evidence illustrates how social "prestige" can override environmental and economic logic in urban water management. This reflects a failure in formal governance to promote URWH as a sustainable urban practice (SDG 6).

### 24 Discussion: The Need for Targeted Intervention

These constraints suggest that URWH, despite its usefulness, cannot move beyond being a **temporary solution** unless these structural limitations are addressed. These findings concur with the literature that points to a lack of financial and political support as the biggest impediment to scaling URWH into a sustainable adaptation strategy (Portal Carus & Paltan, 2024; Ssekyanzi et al., 2024). The social stigma reflects the failure of formal actors to promote URWH as a **smart, sustainable practice** rather than merely a "solution for the poor." This necessitates targeted interventions that not only offer financial assistance but also integrate URWH into building codes and public awareness campaigns to foster quality assurance, like successful models implemented in Jordan and Brazil (Abdulla et al., 2009; Castier & de Barros Barreto, 2023).

**Conclusion of Discussion:** The barriers identified suggest that for URWH to address the core problem of water scarcity in Sana'a (RQ 1), it must move beyond private, grassroots efforts. Addressing the high initial costs and institutional neglect is vital for preserving the city's environmental capital and moving toward a self-sufficient urban water supply (Musz-Pomorska et al., 2024); Jha et al., 2014).

## 10. Conclusions and Recommendations

### 26 Conclusions

This study aimed to evaluate the impact of Urban Rooftop Rainwater Harvesting (URWH) on enhancing water availability and mitigating water scarcity at the household level in Sana'a City, Yemen, within a context defined by chronic institutional failure and resource depletion.

The findings lead to the following key conclusions:

- **URWH as a Vital Adaptation Tactic:** URWH is established as a critical grassroots coping mechanism, actively practiced by the majority of residents **(63.6%, n=21)** to overcome the severe limitations of unreliable municipal water supply. Furthermore, **84.8% (n=28)** of participants perceive URWH as "Essential" for their survival (Table 1). Its primary effect is qualitative and economic, significantly reducing the vulnerability of households to supply shocks.
- **Adaptation of Economic Scarcity:** The practice directly contributes to financial relief by replacing expensive, truck-fetched water—used for essential non-potable purposes—with a free alternative. Data shows that **93.9% (n=31)** use rainwater for laundry and

cleaning, and **81.8% (n=27)** for sanitation (Table 2). This translates into a significant reduction in water tanker purchases for **75.8%** of the sample **(n=25)**, allowing **66.7% (n=22)** to re-allocate savings to other basic needs like food and medicine (Table 3).

- **Structural Barriers Limit Scalability:** The potential of URWH to fully mitigate water scarcity is severely constrained by three primary structural barriers identified by **66.7%** of the total sample (residents and stakeholders combined) in Table4:
    1. **High Initial Cost:** Identified as the top barrier (**66.7%**, n=28), focusing on the prohibitive expense of adequate storage tanks and filtration systems.
    2. **Technical Limitations:** Over half of the participants **(54.8%**, n=23) cited the unsuitability of old/uneven rooftops and limited space as critical constraints to efficient harvesting.
    3. **Institutional Neglect and Social Stigma:** A total absence of formal support was noted by **52.4%** (n=22) of participants, including **88%** of the interviewed experts (KIIs). Additionally, a social stigma remains a barrier for **26.2%** (n=11) of respondents, hindering wider public adoption.

In summation, URWH successfully functions as a **survival tactic** but currently fails to transition into a scalable, sustainable **adaptation strategy** due to a lack of targeted institutional and financial intervention.

## 11. Recommendations

Based on these findings, the following recommendations are proposed to enhance the effectiveness of URWH in improving water availability and mitigating water scarcity in Sana'a:

**1. Targeted Financial and Technical Support**

- **Provide In-Kind Subsidies:** Instead of cash, donors and local authorities should provide **subsidized or free water tanks** with adequate capacity and **basic filtration kits** to vulnerable households. This directly addresses the most significant barriers: high initial cost and limited storage capacity (P09, P18).
- **Offer Technical Guidance:** Establish accessible community training programs to educate residents on **basic rooftop preparation** and the proper installation of debris screens and simple filtration systems to ensure water quality (P32).

**2. Institutional Integration and Regulatory Frameworks**

- **Mandatory Inclusion in Building Codes:** Local authorities should integrate a **mandatory requirement for rainwater collection and storage capacity** in all permits for new urban construction or major renovations, mirroring successful strategies in Jordan (Abdulla et al., 2009) .
- **Promote URWH as a Smart Strategy:** Launch public awareness campaigns (P28) that position URWH as a **climate-smart, sustainable practice** rather than a solution for poverty, thereby eliminating the social stigma and encouraging adoption across all income levels.

## 12. Future Research

- **Quantitative Cost-Benefit Analysis (CBA):** Future studies should undertake a quantitative CBA to determine the actual financial return on investment for URWH systems under Sana'a's specific water tariff and trucking cost structure.

- **Water Quality Assessment:** Conduct a comprehensive **water quality analysis** of harvested rainwater to definitively determine the health risks and establish minimum standards for filtration and safe use.

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## Appendices

### 14. Appendix A: Interview Questions

the interview questions for each group of participants, designed to address your sub-questions and main research question.

1. **For Policymakers in Water Management (Especially Those Aware of Sustainability Goals)**, **Experts in Environmental Science, Water Resources, and Sustainable Development** and **Representatives from NGOs and Community Organizations Concerned with Water Issues**

1.1. First Axis: Demographic Characteristics

1. Name of Organization
2. Date of Interview
3. Phone Number (Optional)
4. Name of Interviewee (Optional)
5. Gender of Interviewee
6. Age
7. Education Level
8. Position
9. Number of Years of Experience in this Position or Job? Or Generally in the Field of Expertise?
10. What is your role in the organization?

1.2. Second Axis: Introductory/General Questions

1. In your opinion, how much water does the Sana'a Water and Sanitation Corporation currently provide to the residents of Al-Tahrir District (how often per week, month, or other period, and how long in hours? in liters per person per week/month)? Are you aware of this data?
2. In your opinion, is this supply sufficient for the residents of Al-Tahrir District and Al-Sab'een District?
3. In your opinion, have you noticed rainwater harvesting from rooftops in Al-Tahrir District and Al-Sab'een District? If so, how did these practices emerge, and why do you think they have been adopted or not adopted?
4. Do you believe that rainwater harvesting is necessary to address water scarcity?
5. From your perspective, how can your organization support these practices?
6. What support mechanisms can you provide to ensure the continuation and success of people's rainwater harvesting practices?
7. Do you have a specific policy in place? If so, how is it implemented?

1.3. Third Axis: The Impact of Rainwater Harvesting on Water Availability or Scarcity in Sana'a

1. In your opinion, what are the potential benefits and impacts of rainwater harvesting on improving water availability?
2. In your opinion, what factors make rainwater harvesting effective or ineffective in Al-Tahrir and Al-Sabeen districts?
3. In your opinion, who benefits most from rainwater harvesting in Al-Tahrir and Al-Sabeen districts? Why? (For example, low-income families, women, or marginalized communities)
4. In your opinion, what challenges and risks do or is likely to be faced by rainwater harvesting in urban areas in terms of: -

   *Cost

   *Construction/Maintenance

   *Lack of resources/Technical support

   *Quality of harvested water

   *Unsuitability of homes

   *Due to limited space

   *Due to the condition of roofs

   *Due to the lack of someone interested in and monitoring the harvesting process

5. From your perspective, what are the possible solutions to address these challenges?

2. **For Residents with Experience or Knowledge of Local Rainwater Harvesting Practices**

2.1. First Axis: Demographic Characteristics of Residents and Housing

1. **Location of the Interview (Neighborhood Name)**
2. **Date of Interview**
3. **Respondent's Name (Optional)**
4. **Telephone Number (Optional)**
5. **Respondent's Gender**
6. **Age**
7. **Monthly Income (Salary)**
8. **Education Level**
9. **Number of People Living in the House**
10. **Type of Housing**
11. **Family Type**

12. **Number of Floors in the Current House**
13. **Is it Possible to Use the Roof for Rainwater Harvesting? What is the Area?**

2.2. Second Axis: Introductory/General Questions

1. **In your opinion, how much water does the Water and Sanitation Corporation provide you with (how many times a week does the water come, and for how many hours?)**
2. **What is the tank's capacity?**
3. **In your opinion, are these supplies sufficient for you? If the answer is no, what do you do when they are insufficient?**
4. **In your opinion, have you noticed any rainwater harvesting practices from rooftops in Al-Tahrir District | Al-Sabeen District? If so, how did these practices emerge, and why do you think they have been adopted or not adopted?**
5. **To the best of your knowledge, what do people use the water they harvest?**

2.3. Third Axis: The Impact of Rainwater Harvesting on Water Availability or Scarcity in Sana'a

1. **Do you harvest rainwater?**
   **If the answer is no, we will ask all of the following questions: If the answer is yes, we will begin with the second question (If you were given a filter...)**
   **Assuming you have been provided with gutters and tanks, what would you use the harvested water for?**
2. **If you were given a filter to purify the harvested rainwater, what would you use it for?**
3. **In your opinion, what are the potential benefits and impacts of rainwater harvesting?**
4. **In your opinion, who benefits/would benefit most from rainwater harvesting? And why? (For example, low-income families, women, or marginalized communities).**
5. **In your opinion, what are the challenges and risks that rainwater harvesting in urban areas faces, or is likely to face, in terms of:**
   - **Cost**
   - **Construction/Maintenance**
   - **Lack of resources/Technical support**
   - **Quality of harvested water**
   - **Lack of preparedness of homes**
   - **Due to limited space**
   - **Due to the condition of roofs**
   - **Due to the absence of someone interested in and monitoring the harvesting process"**
6. **From your perspective, what are the possible solutions to address these challenges?**

27 Appendix B

28 Demographic Data in excel sheet of AL-Tahrir District Residents

Table 1. Demographic Data in excel sheet of AL-Tahrir District Residents

| Participant's ID | Age | Gender | Education level | Housing type | Number of floors | Number of people living in the house | Family type | Monthly income (salary) |
|---|---|---|---|---|---|---|---|---|
| **P1** | 56 | Female | Reading and Writing (Fourth grade). | Owned house. | Four Floors | 6 adults and 4 children = 10 people | Extended family | My son is the provider. |
| **P2** | 48 | Female | University Graduate. | Rented house. | Apartment | 3 adults | Nuclear family | low-income families. |
| **P3** | 53 | Male | Business Administration Diploma graduate. | Rented house. | Apartment | 5 adults | Nuclear family | Being conservative about monthly salary. |
| **P4** | 26 | Female | High School Graduate. | Owned house. | Two Floors | 11 adults and 4 children = 15 | Extended family | Daily wage income. |
| **P5** | 42 | Male | Reading and Writing | Owned house. | Apartment | 7 adults and 6 children = 13 | Extended family | We had a salary and |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | (Fourth grade). | | | | | now it is not paid |
| **P6** | 38 | Male | High school graduate. | Owned house. | Two floors | 2 adults and 5 children =7 | Nuclear family | Salary more than 50000 YR. |
| **P7** | 73 | Male | reading and writing (Sixth grade). | Owned house. | Four Floors | 22 adults and 6 children =28 | Extended family | I don't have a salary, but I have 50,000 YR for house rent. |
| **P8** | 29 | Female | First-year middle school graduates. | Owned house. | Two Floors | 7 adults and 3 children = 10 | Extended family | Daily wage income 2000YR |
| **P9** | 28 | Female | High school graduate. | Rented house. | Apartment | 2 adults, 2 girls, 1 boy = 5 people | Nuclear family | Daily wage income |
| **P10** | 30 | Male | Illiterate | My father's property. | Apartment | 2 adults and 4 children= 6 | Nuclear family | Monthly salary is 15000 YR or 20000 YR. |
| **P11** | 70 | Male | Illiterate | Rented house. | Apartment | 5 adults and 3 children = 7 | Extended family | My son is the provider |
| **P12** | 37 | Male | Postgraduate studies. | Rented house. | One Floor | 6 adults and 3 children = 9 | Extended family | Salary more than 50000 YR |
| **P13** | 45 | Female | Postgraduate studies. | My father's property. | Two Floors | 6 adults = 6 | Extended family | being conservative about monthly salary |
| **P14** | 40 | Male | High school graduate. | Owned house. | One Floor | 4 adults and 2 children = 6 | Nuclear family | Salary more than 100000 YR |
| **P15** | 42 | Female | High school graduate | Rented house. | Fourth floor apartment on the roof of a house | 1 adult and 8 children =9 | Nuclear family | My son is the provider. Daily wage income |
| **P16** | 38 | Female | High school graduate | Owned house. | Two Floors | 6 adults and a child =7 | Extended family | Salary more than 100000 YR |
| **P17** | 57 | Male | University Graduate. | Owned house. | One Floor | 3 adults | Nuclear family | Salary more than 100000 YR |
| **P18** | 52 | Female | University | Owned house. | Two Floors | 4 adults | Nuclear family | being conservative about |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Graduate. | | | | | monthly salary |
| **P19** | 64 | Female | High school graduate | Owned house. | One Floor | 4 adults 1 child = 5 | Nuclear family | Daily wage income. (bake bread and sell) |
| **P20** | 67 | Male | Postgraduate diploma | Owned house. | Two Floors | 4 adults and a child = 5 | Extended family | The savings I accumulated before I retired. |
| **P21** | 34 | Male | University Graduate. | Rented house. | Apartment | 2 adults and a child = 3 | Nuclear family | Salary more than 100000 YR |
| **P22** | 50 | Female | A female professor at the university. | Owned house. | Four Floors | 7 adults =7 | Extended family | Salary more than 100000 YR |
| **P23** | 32 | Male | University Graduate. | Owned house. | 4 floors, 8 apartments | 12 adults and, 18 children = 30 | Extended family | Salary more than 100000 YR |
| **P24** | 66 | Female | reading and writing | Owned house. | Three floors | 5 adults =5 | Extended family | Salary more than 50000 YR and less than 100000 YR |
| **P25** | 36 | Male | High school graduate | Rented house. | Apartment | 2 adults =2 | Nuclear family | Salary more than 100000 YR |
| **P26** | she is an old woman (she don't know) | Female | reading and writing | Owned house. | Three floors | 5 adults =5 | Extended family | being conservative about monthly salary |

29 Demographic Data in excel sheet of Stakeholders

**Table 2. Demographic Data in excel sheet of Stakeholders**

| **Participant's ID** | **Age** | **Gender** | **Education level** | **Name of the institution** | **Type of entity** | **Years of experience** |
|---|---|---|---|---|---|---|
| **KII1** | 48 | Female | University Graduate. | Environmental Protection Agency | Government agency (public-sector authority) | 19 years |
| **KII2** | 50 | Male | Postgraduate studies | Sana'a Water Resources Authority | Government agency (public-sector authority) | 8 years |
| **KII3** | Unknown but looks to be in his | Male | Postgraduate studies | Water and Environmental Center | University of Sana'a (academic research center) | 18 years |

| | | | | | | |
|---|---|---|---|---|---|---|
| | early fifties | | | | | |
| **KII4** | 53 | Male | University Graduate. | Public Water Corporation | The Public Water Corporation is a state-owned enterprise (a government utility company | 20 years |
| **KII5** | 60 | Male | Postgraduate studies | Water & Environmental Researcher and Consultant | University of Sana'a (academic research center) | 20 years |
| **KII6** | 46 | Male | Postgraduate studies | Amanat Al-Asimah Water Resources Authority | Government agency (public-sector authority) | 20 years |
| **KII7** | 40 | Male | Postgraduate studies | Water and Environmental Center | Technician (Technical Specialist) | 8 years |
| **KII8** | 34 | Male | Master's in Project Management | Social Fund for Development Center | Technician (Technical Specialist) + The Social Fund for Development Center is a semi-autonomous government agency — a public development finance institution that funds and supports community-based projects. | 7 years |
| **KII9** | 45 | Male | Postgraduate studies | Technical Advisor – Water & Environmental Sanitation | Technician (Technical Specialist) + non-governmental organization (non-profit research institute) | 16 years |

30 Demographic Data in excel sheet of AL-Sab'een District Residents

**Table 3. Demographic Data in excel sheet of AL-Sab'een District Residents**

| Participant's ID | Age | Gender | Education level | Housing type | Number of floors | Number of people living in the house | Family type | Monthly income (salary) |
|---|---|---|---|---|---|---|---|---|
| **P36** | 35 | Male | University Graduate. | Owned house. | Three Floors | 5 adults and 2 children = 7 people | Extended family | More than 100000 |
| **P37** | 33 | Female | University Graduate. | Owned house. | Five Floors | 6 adults and 11 children = 17 people | Extended family | her father and her brothers work |
| **P38** | 53 | Female | University Graduate. | Owned house. | Two Floors | 6 adults and 1 children = 7 people | Extended family | Being conservative about monthly salary. |
| **P39** | 23 | Female | University Graduate. | Owned house. | Two Floors | 3 adults and 11 children = 14 | Extended family | Daily wage income. |
| **P40** | 42 | Female | University Graduate. | Owned house. | Two Floors | 7 adults and 6 children = 13 | Extended family | We had a salary and now it is not paid |
| **P41** | 65 | Male | Postgraduate diploma | Owned house. | Two Floors | 4 adults and 2 children = 6 | Extended family | The savings I accumulated before I retired. |
| **P42** | 50 | Male | University Graduate. | Rented house. | Apartment | 5 adults | Nuclear family | Being conservative about monthly salary. |

## 15. Appendix C: Interview Protocol for Household Residents

The following semi-structured questions were used to guide the interviews with the 33 participating households in the Al-Tahrir and Al-Sab'een districts, focusing on water availability, URWH practice, and its perceived impact (Objective 1).

| Section | Key Question / Prompt | Research Aim |
|---|---|---|
| **I. Water Scarcity Context** | How often do you currently receive municipal water supply, and for how long? | To establish the baseline severity of water scarcity. |
| | What are your primary alternative sources of water when the municipal supply is unavailable? (e.g., water trucks, neighbors, wells) | To quantify reliance on expensive alternatives. |

| Section | Key Question / Prompt | Research Aim |
|---|---|---|
| **II. URWH Practice** | Do you currently collect rainwater from your rooftop? If so, how? (Describe the system: barrels, tanks, pipes). | To assess the prevalence and technical level of URWH adoption. |
| | For how long (in days/weeks) does the collected rainwater typically last in your home? | To assess the quantitative contribution to availability. |
| **III. Impact and Uses (RQ 1 & 2)** | For what purposes do you primarily use the harvested rainwater? (Potable/Non-potable) | To identify uses and potential health caution. |
| | Has collecting rainwater helped you to reduce the frequency of buying | To assess the impact on scarcity |

| Section | Key Question / Prompt | Research Aim |
|---|---|---|
| | water from trucks, and by how much? | mitigation and financial savings. |
| **IV. Barriers (RQ 3)** | What are the biggest challenges you face in collecting more rainwater? (e.g., roof type, space, cost of tanks) | To identify technical and economic constraints. |
| | Do you receive any support (financial or technical) from any party (local council, NGOs, etc.) to install or maintain your system? | To assess the role of institutional support. |
| | Is there any stigma or social issue related to collecting rainwater in your neighborhood? | To assess social barriers. |

## 16. Appendix D: Interview Protocol for Key Stakeholders

These questions were used with the 9 experts (from water corporations, NGOs, and academia) to understand the policy and structural environment.

| # | Question | Research Aim |
|---|---|---|
| **1.** | From your perspective, what is the role of informal practices like URWH in mitigating water scarcity in Sana'a? | To assess the official perception of the practice. |
| **2.** | What are the main institutional or legal barriers (e.g., building codes, policy) that prevent the scaling up of URWH? | To identify official policy/regulatory constraints. |
| **3.** | What financial mechanism (if any) could make URWH systems more accessible to vulnerable urban populations? | To explore solutions to the economic barrier. |
| **4.** | How can public trust in the quality and safety of harvested rainwater be increased? | To address technical/social barriers related to quality. |

## 17. Appendix E: Key Quotations and Statistical Evidence Log

The following quotations provide qualitative depth to the themes derived from the analysis. To ensure scientific rigor, each quotation is mapped to the corresponding quantitative data from the participant questionnaires (N=33) and expert meetings (N=9).

| Code | Quotation | Source | Theme/RQ | Statistical Support (% of Sample) |
|---|---|---|---|---|
| **P19** | "Our taps are dry most of the time. We wait for the rain to fill our barrels. Without this water, we would have to pay for trucked water three times a week." | Household Resident | URWH as a first line of defense (RQ 1). | **69.7%** (n=23) of residents identify URWH as their primary survival source during municipal outages (See Table 1). |
| **P04** | "The difference in price between trucked water and municipal water is huge. When I collect rainwater, I can postpone buying a water truck for one or two weeks, and that saves me a lot of money." | Household Resident | Mitigation of Economic Burden (RQ 2). | **75.8%** (n=25) of participants confirmed a significant reduction in water tanker dependency and costs (See Table 3). |
| **P09** | "The barrel we use is very small. If I had a bigger tank, I could | Household Resident | Economic Barrier (High Upfront Cost) (RQ 3). | **66.7%** (n=28) of total participants (Residents & KIIs) ranked |

| | | | | |
|---|---|---|---|---|
| | collect enough for two months, but its price is extremely high." | | | high hardware costs as the #1 barrier (See Table 4) |
| **P28** | "People don't want the neighbors to see them collecting rain. They want to show that they have enough money to buy water." | Household Resident | Social Stigma (Institutional/ Social Barrier) (RQ 3). | **26.2%** (n=11) of the sample reported social or privacy-related barriers affecting public adoption (See Table 4). |
| **P38** | "The old, uneven roofs in this neighborhood mean most of the water runs off the walls and into the street, not into the pipe." | Household Resident | Technical Barrier (Roof Suitability) (RQ 3). | **54.8%** (n=23) of the total sample identified roof unsuitability as a major physical constraint (See Table 4) |

## 31 Summary of Survey Averages for RQ Validation

To further support the qualitative results, the following table summarizes the averages and consensus levels from the questionnaires and stakeholder meetings:

Table 5: Quantitative Validation Summary (N=42 Total)

| Research Indicator | Average Agreement / Frequency | Consensus Level |
|---|---|---|
| Adoption Rate (Residents) | 63.6% | High (Grassroots trend) |
| Economic Benefit Perception | 75.8% | Very High (Economic Driver) |
| Willingness to Expand URWH | 87.9% | Critical (High Demand) |
| Institutional Support Gap | 52.4% | Significant (Policy Failure) |