DOI: 10.24850/j-tyca-2026-04-08

Articles

Quality of rainwater harvesting from rural and urban areas, for home garden irrigation

Calidad del agua de lluvia captada en zonas rural y urbana, para riego en huertos familiares

Claudio Lobato-de la Cruz[1], ORCID: https://orcid.org/0009-0007-6451-6398

Irma Díaz-Aguilar[2], ORCID: https://orcid.org/0000-0001-9803-8231

Arturo Galvis-Spinola[3], ORCID: https://orcid.org/0009-0001-3112-3674

Jesús Pérez-Moreno[4], ORCID: https://orcid.org/0000-0001-5216-8313

Mercedes Aurelia Jiménez-Velázquez[5], ORCID: https://orcid.org/0000-0002-3440-8720

Sergio Miguel López-Ramírez[6], ORCID: https://orcid.org/0000-0002-5067-4746

[1]Colegio de Postgraduados, Posgrado en Edafología, Montecillo, Texcoco, State of Mexico, Mexico, lobato71@hotmail.com

[2]Colegio de Postgraduados, Posgrado en Edafología, Montecillo, Texcoco, State of Mexico, Mexico, idiaz@colpos.mx

[3]Colegio de Postgraduados, Posgrado en Edafología, Montecillo, Texcoco, State of Mexico, Mexico, galvispinola@gmail.com

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[4]Colegio de Postgraduados, Posgrado en Edafología, Montecillo, Texcoco, Estado de México, Mexico, jperezm@colpos.mx

[5]Colegio de Postgraduados, Posgrado Estudios del Desarrollo Rural, Montecillo, Texcoco, State of Mexico, México, mercedesaureliajv@gmail.com

[6]Fondo Mexicano para la Conservación de la Naturaleza, Mexico City, Mexico, sergiomiguel009@gmail.com

Corresponding author: Irma Díaz-Aguilar, idiaz@colpos.mx

Abstract

Rainwater harvesting systems (RWHS) are an alternative for supplying water to rural and urban areas. However, studies evaluating rainwater quality for irrigation in home gardens remain limited. This study assessed the quality of rainwater collected from RWHS in a rural area (Almoloya, Hidalgo) and an urban area (Iztapalapa, Mexico City) for home garden irrigation. Parameters evaluated included electrical conductivity (EC), sodium adsorption ratio (SAR), pH, and the concentration of specific ions. Nine samples were collected for each site using random sampling. Rainwater quality by area (rural and urban), and roof type (corrugated galvanized metal sheet and concrete) were compared using a t-test. The rural area presented EC (0.19 dS m^{-1}) and SAR without restrictions, a slightly alkaline pH (8.0) and its corrugated galvanized metal roofs captured rainwater of better quality. The urban area showed EC (1.29 dS m^{-1}), SAR (6.13), pH (7.95), and concentrations of Na^+, Cl^-, and HCO_3^-, with mild to moderate restrictions for irrigation use. Overall, rainwater

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collected from rural and urban RWHS is suitable for irrigation in home gardens. However, concrete roofs and chlorination for disinfection reduced the quality of harvested rainwater for irrigation in the urban area. Management practices should be implemented to prevent damage to soil and plants, and the inclusion of SAR in irrigation water quality analysis is recommended due to elevated Na^+ concentration.

Keywords: rain, water supply, water quality, irrigation, horticulture, rural areas, urban areas, Mexico.

Resumen

Los sistemas de captación de agua de lluvia (SCALL) son una alternativa para abastecer de agua a zonas rurales y urbanas. Sin embargo, son limitados los estudios que evalúan su calidad para riego en huertos familiares. Este estudio analizó la calidad del agua de lluvia recolectada de SCALL de una zona rural (Almoloya, Hidalgo) y una urbana (Iztapalapa, CDMX), para riego de huertos familiares. Se evaluó la conductividad eléctrica (CE), la relación de adsorción de sodio (RAS), el pH y la concentración de iones específicos. Se colectaron nueve muestras por cada zona con un muestreo al azar. Se comparó la calidad del agua de lluvia por zona (rural y urbana) y tipo de techo (lámina y concreto) con la prueba *t* de *Student*. La zona rural presentó CE (0.19 dS m^{-1}) y RAS sin restricción, pH de 8.0 ligeramente-alcalino y sus techos de lámina captaron agua de lluvia de mejor calidad. En contraste, la zona urbana presentó CE (1.29 dS m^{-1}), RAS (6.13), pH (7.95) y concentraciones de Na^+, Cl^- y HCO_3^-, con grados de restricción leve-moderado. En general, el agua de lluvia de los SCALL de la zona rural y urbana es viable para riego en huertos familiares. Sin embargo, los techos de concreto y la

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cloración para la desinfección del agua disminuyen la calidad para riego, por lo que se recomienda implementar prácticas de manejo para evitar daños al suelo y plantas, e incluir la RAS en los análisis de calidad de agua por la alta concentración de Na^+.

Palabras clave: lluvia, abastecimiento de agua, calidad del agua, riego, horticultura, zona rural, zona urbana, México.

Received: 30/06/2025

Accepted: 27/10/2025

Available ahead of print: 06/11/2025

Version of record: 01/07/2026

Introduction

Rainwater harvesting is an ancient practice for water supply in areas where water resources are limited, referring to the process of intercepting and storing rainfall for subsequent use. This practice is extensively employed as the primary accessible water source for millions of people in developing countries, principally in rural areas and more recently in urban zones where access to clean and safe water sources is limited (Torres-Hugues, 2019; Lepcha *et al*., 2024; Ssekyanzi *et al*., 2024). Interest in this practice has proliferated worldwide, even in developed countries, where regulations and legislation increasingly promote rainwater harvesting and utilization; countries such as China, Brazil, Australia, and India have mandated rainwater harvesting in the planning of new housing and future cities (García-Ávila *et al*., 2023; Ssekyanzi *et al*., 2024).

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Rainwater Harvesting Systems (RWHS) refer to modern rainwater collection installations specifically designed to intercept, collect, and store rainwater for subsequent use (Raimondi *et al*., 2023). These systems encompass the catchment area (such as roofs), collection and conveyance system (gutters and pipes), impurity filter, first-flush removal system, and storage tank or cistern (Téllez-Quintanar *et al*., 2022).

The escalating demand for water resources, coupled with factors including drought, contamination and depletion of rivers, wells, and dams, as well as aquifer overexploitation, has propelled global interest in RWHS research. Since 2004, a substantial increase in studies has been documented in both rural and urban areas, principally in countries such as the United States, China, and India (Raimondi *et al*., 2023). Nevertheless, limitations and disadvantages impede their implementation, including the requirement for high initial investment, space availability, seasonal distribution of rainfall, and ensuring water quality for its intended use (Téllez-Quintanar *et al*., 2022).

The utilization of roof-harvested rainwater for irrigation in local food production within home gardens is gaining increasing relevance in both rural and urban areas, as this activity aligns perfectly with approaches to sustainable water resource management, food security, environmental stewardship, and community resilience (Sanyé-Mengual *et al*., 2016).

In Africa, rainwater harvesting is employed to enhance rural community resilience against drought and to reduce dependence on unsafe water sources, positively impacting agricultural development and population health (Boelee *et al*., 2013; Dile *et al*., 2013). Furthermore, Lupia *et al*. (2017) have indicated that RWHS can fully or partially supply irrigation water to home gardens; for instance, in Rome, Italy, 33 % of

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the city's mixed-crop gardens would be self-sufficient with RWHS-harvested rainwater, demonstrating high irrigation efficiency, while the remainder could satisfy up to 44 % of garden water requirements, significantly reducing potable water consumption. In the context of food security, Huang and Chang (2021) indicated that if 30 % of the roof surface area (56 602 m²) of concrete buildings in Taipei, China, could be utilized as agricultural gardens, for example, annual yields of sweet potato leaves (*Ipomoea batatas* L.) would increase by 436 %, utilizing only 5.9 $m^3\ m^{-2}$ of tap water—3.8 $m^3\ m^{-2}$ of harvested rainwater and 2.1 $m^3\ m^{-2}$ of tap water—to produce 9.3 kg m^{-2} of the leafy vegetable. This demonstrates that urban agriculture can reduce water consumption through rainwater utilization.

In Mexico, the National Water Commission (Conagua) implemented the National Program for Rainwater Harvesting and Ecotechnologies in Rural Areas (PROCAPTAR) in 2016, installing RWHS in households across various rural regions of Mexico for water supply (Conagua, 2016). In Mexico City (CDMX), water demand and overexploitation of the Metropolitan Zone CDMX aquifer have increased due to urban sprawl and water loss through distribution system leaks (UNAM, 2017).

Consequently, 62 700 RWHS were installed in urban households through the "Rainwater Harvesting" Program from 2019 to 2023 (Sedema, 2024); 68 % of RWHS beneficiaries utilize the water for plant irrigation, and 26.2 % of these employ it for home gardens (Sedema, 2023). Fernández *et al*. (2023) noted that in the few urban gardens in CDMX, irrigation is conducted empirically, primarily using potable water. Furthermore, these authors calculated that an urban garden could harvest between 0.26 and 0.52 $m^3\ m^{-2}\ yr^{-1}$ of rainwater; this quantity could

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satisfy irrigation requirements for lettuce (*Lactuca sativa*) ranging from 0.13 to 0.39 $m^3\ m^{-2}$ or cherry tomato (*Solanum lycopersicum*) from 0.15 to 0.57 $m^3\ m^{-2}$ for a complete growing cycle.

Rainwater is generally of high quality until coming into contact with a surface or collection system (Rahman *et al*., 2014; Zdeb *et al*., 2020; García-Ávila *et al*., 2023). Previous studies have indicated that RWHS water quality does not always comply with established limits for potable use standards (Livhuwani *et al*., 2025), due to various factors significantly affecting water quality, including surrounding land use, catchment roof material type, air quality, dry season duration, rainfall intensity, filtration system type, and storage tank or cistern conditions, particularly when unprotected (Campisano *et al*., 2017; Ímaz-Gispert *et al*., 2018; Rangel-González & Domínguez-Sánchez, 2018; Zdeb *et al*., 2020; Beirne *et al*., 2021).

Furthermore, the type of water quality analysis performed on RWHS depends on the intended use of the harvested water. Generally, quality studies focus on suitability for potable use, both in rural areas (Igbinosa & Aighewi, 2017; Zdeb *et al*., 2018) and urban areas (Ímaz-Gispert *et al*., 2018; Rangel-González & Domínguez-Sánchez, 2018; Haque & Rinkey, 2019; Emmanuel *et al*., 2021), analyzing various physical, chemical, and biological parameters. However, the parameters evaluated are not yet standardized and vary according to each country's regulations and legislation. Based on reports from several studies, certain parameters are consistently evaluated when assessing rainwater quality, including pH, EC, and sulfate (SO_4^{2-}) and chloride (Cl^-) ion content (Zdeb *et al*., 2018; Haque & Rinkey, 2019; Emmanuel *et al*., 2021). Conversely, water quality for RWHS destined for non-potable or domestic uses, such as floor,

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clothing, vehicle washing, and toilet flushing, is not routinely analyzed (Rahman *et al*., 2014).

Despite growing interest in utilizing rainwater for home garden irrigation, there is a notable paucity of studies evaluating its quality for this purpose, particularly when collected from roofs in rural and urban areas (Amos *et al*., 2018). In this context, the literature reports the use of Ayers and Westcot's (1994) agricultural irrigation water analysis framework to assess RWHS rainwater quality for irrigation, employing key parameters including pH, electrical conductivity (EC), and sodium adsorption ratio (SAR) (Cuellar-Carrasco *et al*., 2015; Emmanuel *et al*., 2021), in addition to concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), iron (Fe^{2+}), boron (B^{3+}), copper (Cu^{2+}), zinc (Zn^{2+}), nitrate (NO_3^{-}), and sulfate (SO_4^{2-}) ions—essential plant nutrients—along with sodium (Na^{+}), chloride (Cl^{-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}), and certain trace elements, as these affect plant functions and soil or substrate properties (García, 2012; Ingram, 2014).

It is important to note that no established criteria or ranges exist for evaluating RWHS rainwater for irrigation, and these cannot be standardized to a single set due to rainwater composition depending on multiple factors, including climatic conditions (principally local microclimate), atmospheric pollution, catchment type, land use differences between rural and urban areas, and RWHS construction materials (Mendez *et al*., 2011; García, 2012; Zdeb *et al*., 2020).

The catchment roof material type significantly modifies collected water quality parameters (Livhuwani *et al*., 2025). It has been reported that rainwater, before running off roofs, exhibits a slightly acidic pH near 5.6 (Baird & Cann, 2014), and upon contact with roof materials, pH tends

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to increase (Emmanuel *et al*., 2021). Variation in various dissolved ions has also been reported when specific roof material types are employed, such as aluminum, asbestos, zinc sheets in Cameroon, corrugated materials, and Harvey tiles (Emmanuel *et al*., 2021; Nicholas & Ukoha, 2023). However, analysis of rainwater quality for irrigation from RWHS, changes in quality when rainwater contacts RWHS construction materials, and the suitability of RWHS rainwater for irrigation in rural and urban home gardens remain insufficiently documented. Therefore, this study aims to compare the quality of rainwater collected in rainwater harvesting systems (RWHS) in a rural area (Ejido Almoloya, State of Hidalgo) and an urban area (Iztapalapa, CDMX) and analyze the levels of pH, EC, SAR, and dissolved ion concentrations that might restrict its use for home garden irrigation.

Materials and methods

Sampling sites

The rural area sampling sites are located in Ejido Almoloya, belonging to the municipality of Almoloya, Hidalgo, situated at geographic coordinates 19° 43' 16.34" N latitude and 98° 22' 30.45" W longitude, at an elevation of 2 727 meters above sea level (masl) (Figure 1).

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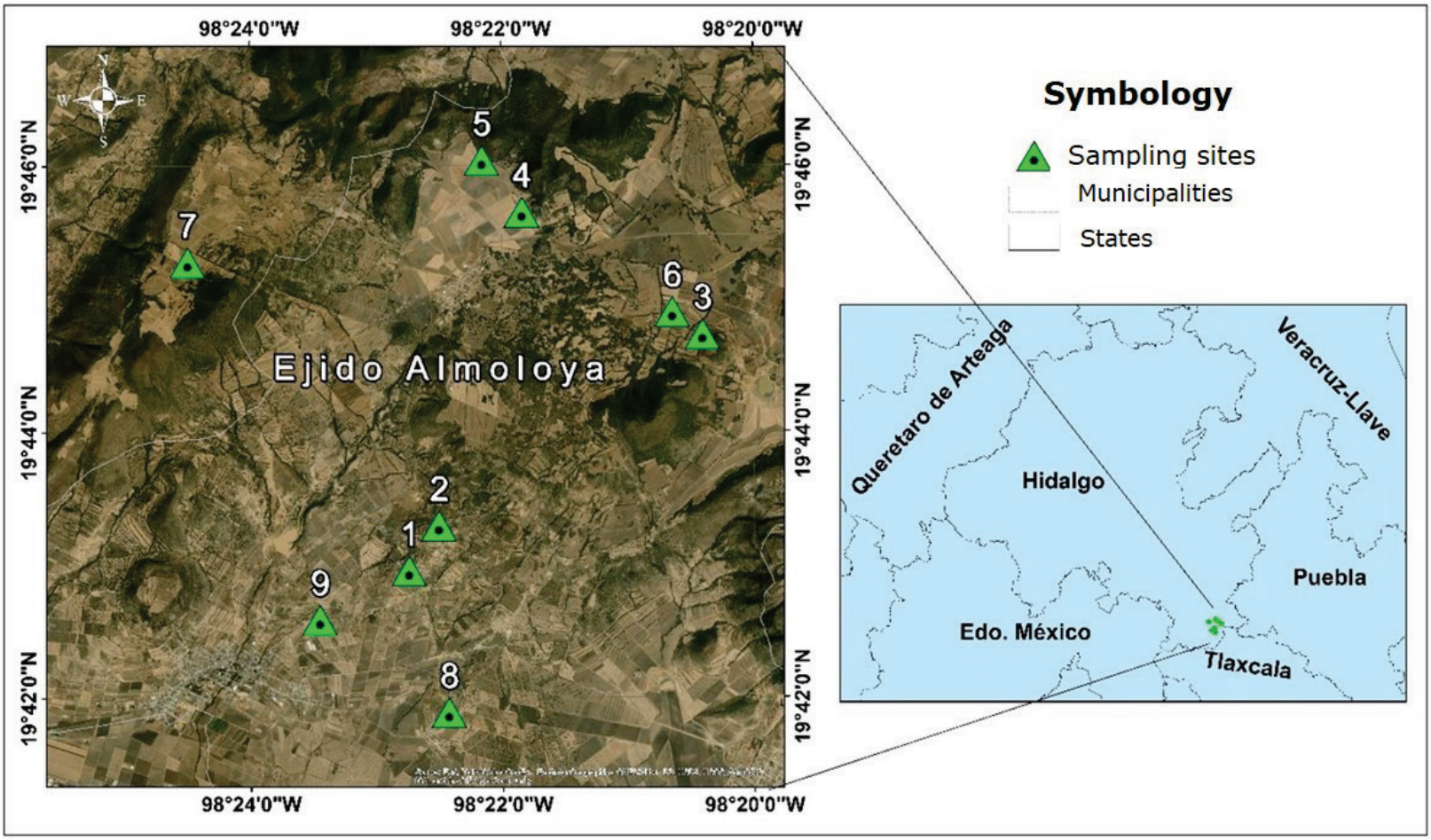

Figure 1. Location of rainwater sampling sites in the rural area, Ejido Almoloya, Almoloya, Hidalgo.

The climate is semi-dry temperate (BS1hw) due to scarce rainfall, with semi-desert vegetation (INEGI, 2010; Sánchez-Rojas & Bravo-Cadena, 2021). Mean annual temperatures range between 12 °C and 15 °C, with winter minimums of 0 °C and occasional severe frosts. In summer, temperatures reach 25 °C during the warmest daytime hours. Mean annual precipitation is 656 mm (GEH, 2011), with the rainy season concentrated in June and September.

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Ejido Almoloya has predominantly agricultural land use, with areas principally dedicated to barley, broad bean, and maize cultivation. Additionally, it presents semi-desert vegetation with forest areas containing pine, sacred fir, red cedar, certain broadleaf conifers, and predominantly grasslands used for sheep grazing (GEH, 2011).

The urban area rainwater sampling sites are located in the San Miguel Teotongo neighborhood, Iztapalapa Borough, Mexico City, at geographic coordinates 19° 20' 25.18" N latitude and 98° 59' 05.85" W longitude, at an elevation of 2 356 masl (Figure 2). The climate is semi-dry temperate (BS1k), predominantly dry (INEGI, 1992; Delegación Iztapalapa, 2011). Mean temperature ranges between 15 °C and 17 °C. In winter, temperatures descend to 5 °C, and in summer, they reach maximums of 27 °C, with mean annual precipitation of 679 mm (SMN, 2024); most rainfall is concentrated between June and September (Figure 3). The terrain is predominantly mountainous, affected by excessive erosion (Delegación Iztapalapa, 2011).

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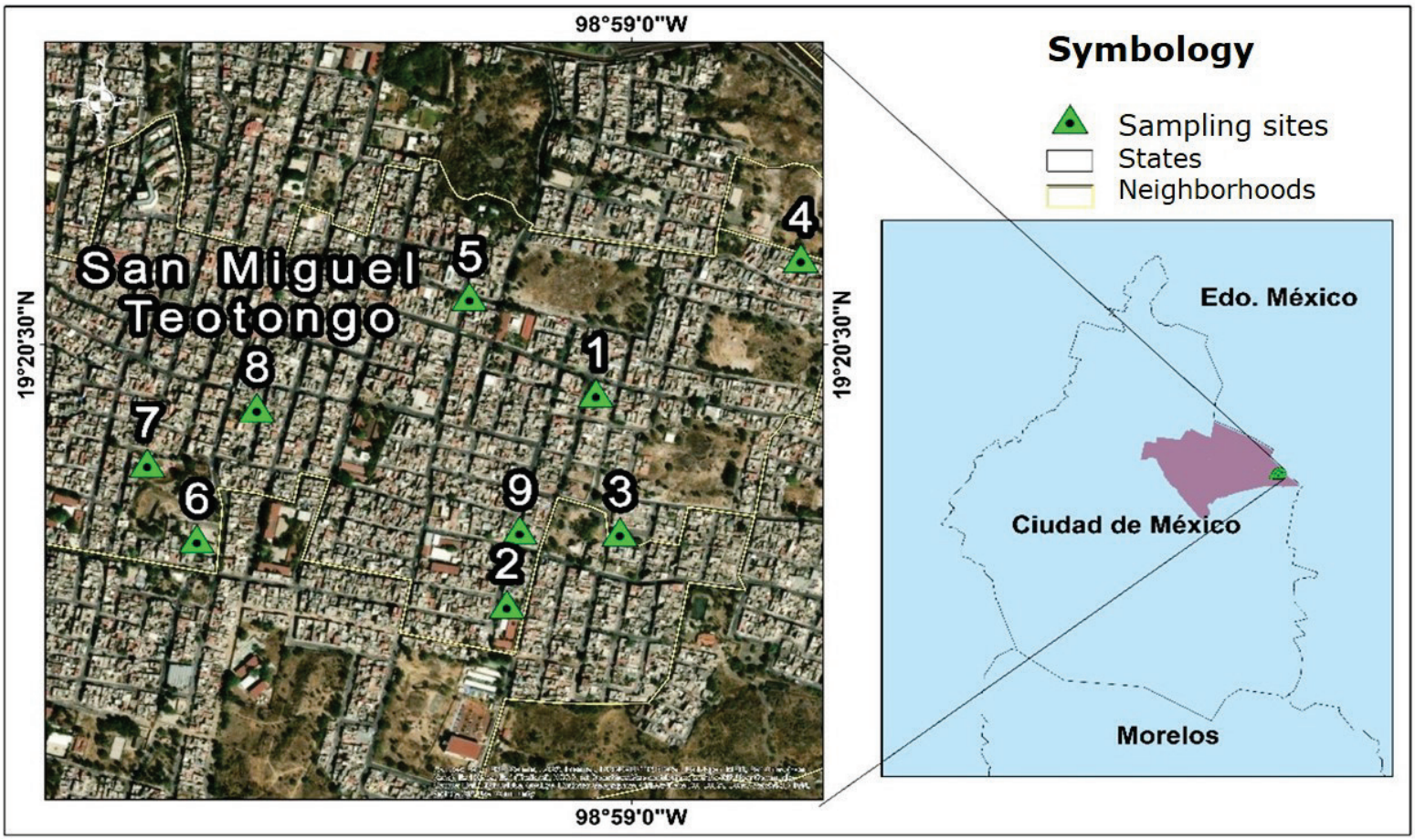

Figure 2. Location of rainwater sampling sites in the urban area, San Miguel Teotongo, Iztapalapa, CDMX.

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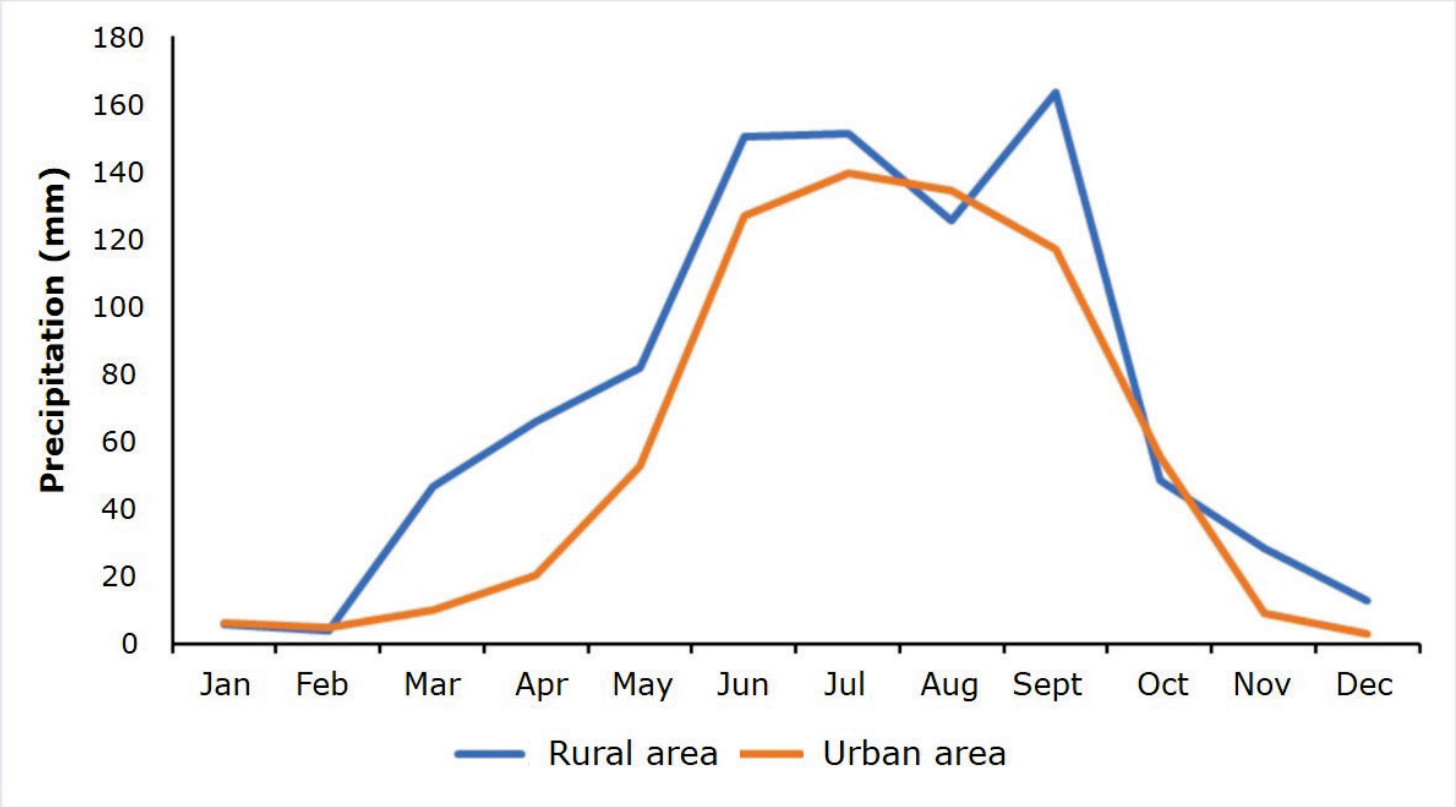

Figure 3. Monthly precipitation distribution in the rural area (Ejido Almoloya, Hgo.) and urban area (Iztapalapa, CDMX); data from climatological stations 13168 and 9036 (SMN, 2024).

The San Miguel Teotongo neighborhood is an urban area with predominantly residential land use. This area is densely populated, with continuous human settlement, small commercial zones, schools, and basic services. Urban expansion has transformed land use over the years, impacting vegetation reduction and increasing ground impermeabilization due to paved streets and concrete constructions (DOF, 1992).

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Description of rainwater harvesting systems (RWHS)

In the studied rural and urban areas, households possess Rainwater Harvesting Systems (RWHS) installed by Conagua in 2014 and the Government of CDMX in 2021, respectively. In both systems, the rainwater collection area consists of roofs, additionally featuring conveyance, filtration, storage, and distribution systems for harvested rainwater, primarily used for domestic purposes.

The RWHS in rural and urban areas exhibit variations in construction materials employed and system components (Figure 4).

Figure 4. RWHS in the rural (A) and urban (B) areas: 1) catchment roof, 2) conveyance system, 3) filter (and chlorination system in the urban area), 4) cistern or storage tank, and 5) distribution system.

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In the rural area, eight catchment roofs are corrugated galvanized metal sheet and one is concrete, whereas in the urban area, seven roofs are concrete and two are corrugated galvanized metal sheet. In both areas, the conveyance material corresponds to PVC plastic pipes (Figure 4A2 and B2). However, differences exist in filtration and storage systems. In the rural area, the filtration system comprises a gravel filter, and rainwater is stored in a 12 000 l ferrocement cistern (Figure 4A3 and A4). In the urban area, a mesh filter with first-flush diverter and an inline chlorination system employing sodium hypochlorite tablets (Figure 4B3) are used, with 2 500 l plastic tanks for rainwater storage (Figure 4B4). Distribution systems in both contexts (rural and urban) are designed to facilitate access to stored rainwater from domestic consumption points. In the rural area, the distribution system consists of a manual rope pump connected to the ferrocement cistern, allowing water extraction to the sink (Figure 4A5); in the urban area, distribution systems are connected via electric pump from the plastic tanks to washing areas, toilets, or specific points within the dwelling (Figure 4B5).

Rainwater sample collection

Nine rainwater samples were collected from the rural area and nine from the urban area, employing random sampling; sites where RWHS are located are indicated in Figures 1 and 2. Samples were taken during the well-established rainy season to ensure RWHS contained rainwater from the current season and to avoid water from first rains, which typically carry materials and contaminants from the catchment area. Point samples were collected in this study as they represent specific rainwater quality

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conditions at the time of collection, enabling comparison of different laboratory analysis parameters of RWHS rainwater quality for irrigation in two contrasting areas. In the urban area (Iztapalapa, CDMX), sampling was conducted on July 18, 2023, and in the rural area (Ejido Almoloya, Hidalgo) on July 19, 2023.

New, clean one-liter capacity plastic bottles were used to collect rainwater from each cistern or storage tank. One stored rainwater sample was taken per RWHS, following guidelines of Mexican Standard NMX-AA-003-1980 for wastewater discharge sampling (Secofi, 1980). Before each sample collection, the bottle was rinsed twice with the same stored water to avoid cross-contamination from particles potentially contained in the bottles and to ensure sample representativeness. In the rural area, rainwater samples were collected using a bucket and a rope, as cisterns are two meters deep; in the urban area, samples were taken directly from the tanks. Collected samples were immediately placed in a cooler with gel refrigerants to preserve samples and minimize potential alterations in rainwater properties due to high ambient temperatures. This methodology ensured obtaining representative samples that preserved the characteristics of the rainwater stored in the RWHS.

Laboratory analysis and rainwater quality evaluation criteria

To evaluate RWHS rainwater quality and the degree of use restriction for home garden irrigation in urban and rural areas, rainwater quality was analyzed according to parameters recommended by Ayers and Westcot (1994), García (2012), and Castellanos (2000) (Table 1) at the Soil

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Fertility Laboratory, S.A. de R.L. (FERTILAB), in Celaya, Guanajuato. Additionally, maximum permissible limits for agricultural use established in the Federal Rights Law concerning National Waters and their Inherent Public Assets (LFD, 2024), the official Mexican regulation governing water quality for different uses, were considered.

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Table 1. Criteria used to evaluate rainwater quality from rainwater harvesting systems (RWHS) for home garden irrigation use.

Parameter	Unit	Degree of use restriction			Source	Maximum permissible for agricultural use (LFD, 2024)
		None	Slight to Moderate	Severe		
Electrical conductivity (EC)	dS m^{-1}	< 0.7	0.7 - 3	> 3	Ayers and Westcot (1994)	
pH*		< 7	7 - 8	> 8	García (2012)	6.0 - 9.0
Sodium absorption ratio (SAR)		<3	3 - 6	> 6	Castellanos (2000)**	
Sodium (Na^+)†	mg l^{-1}	< 460			Ayers and Westcot (1994)	
Chlorides (Cl^-)†	mg l^{-1}	< 142	142 - 355	> 355	Ayers and Westcot (1994)	150
Boron(B^{3+})	mg l^{-1}	< 0.7	0.7 - 3	> 3	Ayers and Westcot (1994)	0.7-3.0
Bicarbonates (HCO_3^-) †	mg l^{-1}	< 92	92 - 519	> 519	Ayers and Westcot (1994)	
Carbonates (CO_3^{2-})	mg l^{-1}	No restrictions			Ayers and Westcot (1994)	No restrictions
Nitrates (NO_3^-)	mg l^{-1}	< 5	5 – 30	> 30	Ayers and Westcot (1994)	No restrictions
Calcium (Ca^{2+})	mg l^{-1}	< 400			Ayers and Westcot (1994)	No restrictions
Magnesium (Mg^{2+})†	mg l^{-1}	< 61			Ayers and Westcot (1994)	No restrictions
Sulfates (SO_4^{2-})†	mg l^{-1}	< 961			Ayers and Westcot (1994)	250
Iron (Fe^{2+})	mg l^{-1}	< 5			Ayers and Westcot (1994)	5
Manganese (Mn^{2+})	mg l^{-1}	<1	0.1 -1.5	> 1.5	García (2012)	0.2
Copper (Cu^{2+})	mg l^{-1}	< 0.2			Ayers and Westcot (1994)	0.2
Zinc (Zn^{2+})	mg l^{-1}	< 2			Ayers and Westcot (1994)	2
Potassium (K^+)	mg l^{-1}	< 2			Ayers and Westcot (1994)	No restrictions

*Ayers and Westcot (1994) report a normal range of 6.5 – 8.4

**3 - 6 is considered sodic water, and SAR > 9 indicates water with severe sodium problems

†These values were converted from meq L^{-1} to mg l^{-1}

The parameters analyzed in RWHS rainwater were EC, pH, and SAR. EC was measured to detect potential problems of reduced soil water

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availability for plants. Irrigation water pH can influence soil pH changes, and irrigation with water having high SAR values deteriorates soil physical and chemical quality. Concentrations of different ions were analyzed to evaluate whether they fall within permissible levels and whether these contents might influence other water quality parameter values. High carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) contents would indicate potential alkalization risk and pH increases.

Toxicity risk from high sodium, chlorine, and boron concentrations was also evaluated; Na^+ affects soil structure by displacing calcium and magnesium, reduces water infiltration, and hinders plant water absorption; Cl^- produces leaf necrosis, flower and fruit drop, and reduces plant yield; and B^{3+}, although essential for plants in small quantities, is toxic in larger amounts, causing plant tissue damage and affecting plant growth. Additionally, concentrations of nitrate (NO_3^-), potassium (K^+), sulfate (SO_4^{2-}), iron (Fe^{2+}), manganese (Mn^{2+}), copper (Cu^{2+}), and zinc (Zn^{2+}) ions were evaluated as essential plant nutrients.

Treatments and experimental design

The experimental design employed in this study was completely randomized, with the objective of comparing stored rainwater quality in RWHS from an urban area and a rural area. Each treatment had nine replicates, yielding a total of 18 experimental units. Additionally, data were grouped by roof type (concrete or corrugated galvanized metal sheet) of the rainwater catchment area to analyze potential effects of material type on rainwater quality. Statistical analysis employed Student's t-test (Amat, 2016), comparing means of a response variable between two treatments: by area (rural and urban) and by roof type (corrugated

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galvanized metal sheet and concrete). When data did not meet criteria for normal distribution and homogeneity of variances, they were transformed using natural logarithm (ln). If transformed data met normal distribution but presented unequal variances between groups, Welch's t-test was employed (Lu & Yuan, 2010); in cases where transformed data still did not follow normal distribution, the non-parametric Mann-Whitney U test was applied (Amat, 2017). t-tests and Mann-Whitney U tests were performed using R statistical software, version 2023.12.1 (R Core Team, 2025).

Results

Laboratory results of rainwater quality from samples collected in RWHS in the rural area (Almoloya, Hgo.) and urban area (Iztapalapa, CDMX) showed statistically significant differences between areas in nine parameters, while seven parameters were statistically similar between the two areas (Table 2).

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Table 2. Rainwater quality results from rainwater harvesting systems (RWHS) in the rural area (Almoloya, Hidalgo) and urban area (Iztapalapa, CDMX).

Variable	Unit	Mean		*p*-Value
		Rural area	Urban area	
Electrical conductivity (CE)	dS m^{-1}	0.19(±0.09) a	1.29(±0.18) b	$p < 0.001$
pH		8.00(±0.21) a	7.95(±0.19) a	$p = 0.62$
Sodium absorption ratio (SAR)		0.34(±0.31) a	6.13(±3.40) b	$p < 0.001$
Calcium (Ca^{2+})	mg l^{-1}	21.09(±7.79) a	15.47(±6.74) a	$p = 0.12$
Magnesium (Mg^{2+})	mg l^{-1}	3.37(±3.51) a	19.25(±13.73) b	$p = 0.01$
Sodium (Na^{+})	mg l^{-1}	7.07(±7.50) a	170.86(±125.26) b	$p < 0.001$
Potassium (K^{+})	mg l^{-1}	7.35(±3.54) a	21.22(±9.82) b	$p < 0.001$
Sulfates (SO_4^{2-})	mg l^{-1}	1.74(±0.82) a	4.2(±2.62) b	$p = 0.02$
Bicarbonates (HCO_3^{-})†	mg l^{-1}	89.27(±44.20) a	392.11(±274.90) b	$p = 0.02$
Chlorides (Cl^{-})‡	mg l^{-1}	6.12(±3.91) a	162.39(±106.32) b	$p = 0.02$
Carbonates (CO_3^{2-})‡	mg l^{-1}	3.37(±6.17) a	3.4(±6.91) a	§
Nitrates (NO_3^{-})	mg l^{-1}	1.87(±0.58) a	2.6(±1.46) a	$p = 0.31$
Boron (B^{3+})	mg l^{-1}	0(±0.00)	0.71(±0.56)	§
Iron (Fe^{2+})†	mg l^{-1}	0.01(±0.01) a	0.25(±0.30) a	$p = 0.55$
Manganese (Mn^{2+})‡	mg l^{-1}	0.001 (±0.00) a	0.002(±0.001) b	$p = 0.03$
Copper (Cu^{2+})‡	mg l^{-1}	0.001 (±0.00) a	0.001 (±0.00) a	$p = 0.37$
Zinc (Zn^{2+})	mg l^{-1}	0.18(±0.36) a	0.03(±0.03) a	$p = 0.12$

Student's t-test ($P \leq 0.05$)
†Welch's t-test ($p \leq 0.05$)
‡Mann-Whitney U test ($p \leq 0.05$). Values with the same letters within the same column are statistically equal. Values in parentheses correspond to standard deviation
§B^{3+} and CO_3^{2-} were not statistically analyzed because no boron values were obtained in the rural area (mean zero) and for CO_3^{2-}, only three values were obtained in the rural area and only two values in the urban area, out of nine replicates

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Mean EC in the urban area (1.29 ± 0.18 dS m^{-1}; $p < 0.001$) was significantly higher than in the rural area (0.19 ± 0.09 dS m^{-1}; $p < 0.001$), indicating greater dissolved salt concentration in urban rainwater (Figure 5A). Similarly, SAR of urban area rainwater (6.13 ± 3.40; $p < 0.001$) was statistically significant compared to that recorded in the rural area (0.34 ± 0.31; $p < 0.001$). Regarding pH, no statistically significant differences were found between rural and urban area rainwater (8.0 ± 0.21 and 7.95 ± 0.19, respectively, $p = 0.62$) (Figure 5B), both considered alkaline waters with pH exceeding 7.

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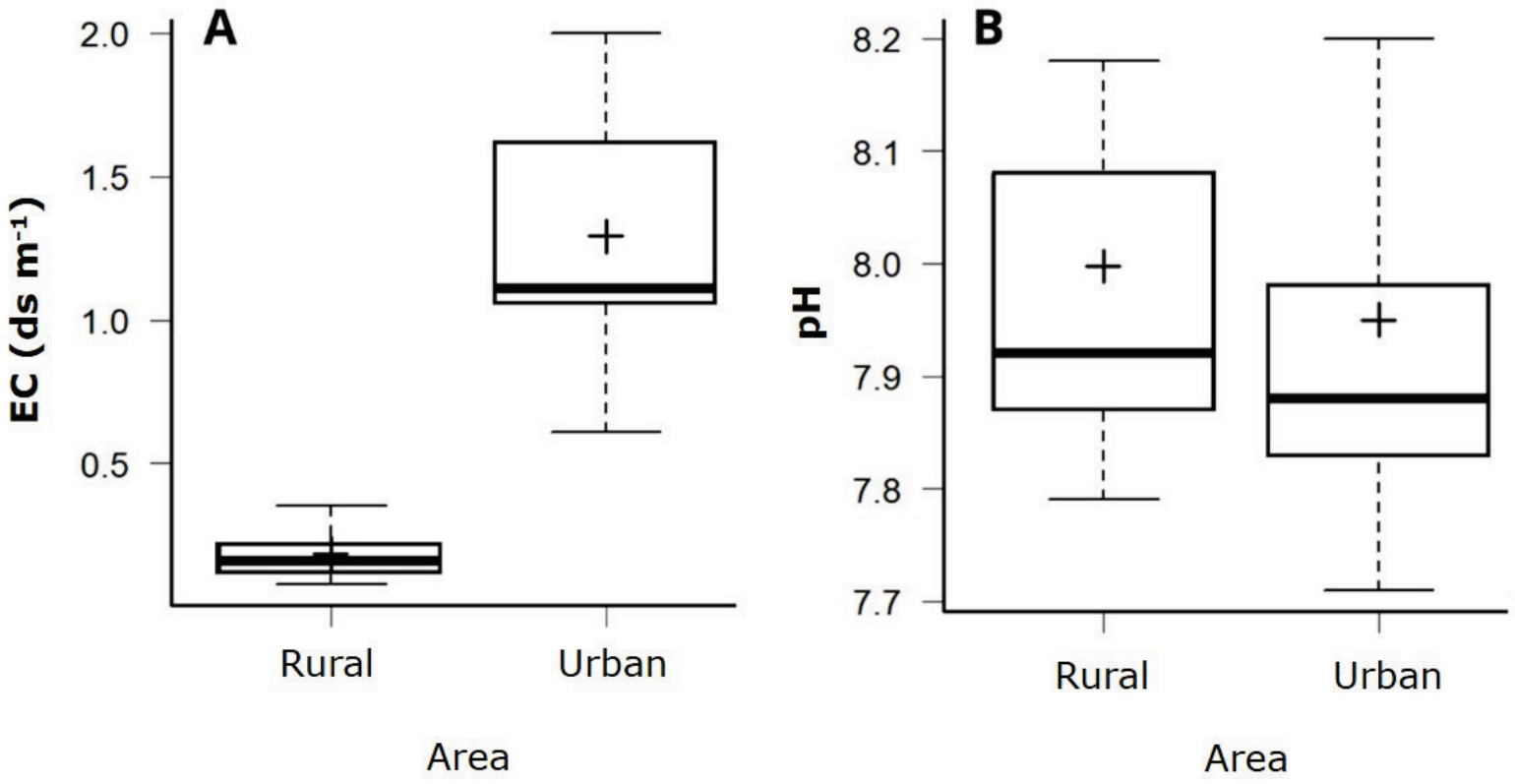

Figure 5. Values of A) electrical conductivity (EC) and B) pH of rainwater samples from RWHS in rural and urban areas. Note: The (+) sign indicates the mean of observations.

Results of cation and anion contents in rural and urban area rainwater showed that concentrations of Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, HCO_3^{-}, Cl^{-}, and Mn^{2+} were highly significant ($p \leq 0.05$), with the urban area presenting the highest concentrations of these ions; however, Na^{+}, HCO_3^{-}, and Cl^{-} ions reached the highest concentrations, with values of 170.86 ± 125.3 mg l^{-1}, 392.11 ± 274.9 mg l^{-1}, and 162.39 ± 106.3 mg l^{-1}, respectively. Conversely, no significant differences were found between Ca^{2+}, NO_3^{-}, Fe^{2+}, Cu^{2+}, and Zn^{2+} ion contents ($p > 0.05$), with very low concentrations present in both rainwater types; in the rural area,

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B^{3+} ion content was not quantified in samples, and for CO_3^{2-}, only three values were obtained from nine replicates.

The material type of the RWHS rainwater catchment area is a variable affecting rainwater quality. To evaluate the effect of rainwater catchment roof material type, results from analyses of rainwater samples collected in RWHS in rural and urban areas were grouped by roof material, corrugated galvanized metal sheet or concrete, revealing highly significant differences in several parameters (Table 3).

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Table 3. Rainwater quality results by material type of rainwater catchment roofs of RWHS, corrugated galvanized metal sheet or concrete.

Variable	Unit	Mean		*p*-Value
		Corrugated galvanized roof	Concrete roof	
Electrical conductivity (EC)	dS m^{-1}	0.35(±0.40) a	1.22(±0.61) b	$p < 0.001$
pH		7.92(±0.14) a	8.04(±0.25) a	$p = 0.23$
Sodium absorption ratio (SAR)		0.46(±0.54) a	6.70(±3.12) b	$p < 0.001$
Calcium (Ca^{2+})	mg l^{-1}	16.39(±7.27) a	20.64(±7.88) a	$p = 0.25$
Magnesium (Mg^{2+})	mg l^{-1}	2.90(±3.42) a	21.83(±12.21) b	$p < 0.001$
Sodium (Na^{+})	mg l^{-1}	9.63(±12.42) a	200.98(±99.50) b	$p < 0.001$
Potassium (K^{+})	mg l^{-1}	6.57(±2.09) a	23.93(±7.19) b	$p < 0.001$
Sulfates (SO_4^{2-})	mg l^{-1}	1.60(±0.7) a	4.68(±2.40) b	$p < 0.001$
Bicarbonates(HCO_3^{-})	mg l^{-1}	72.24(±39.37) a	451.25(±233.21) b	$p < 0.001$
Chlorides (Cl^{-})	mg l^{-1}	10.04(±9.62) a	187.41(±94.82) b	$p < 0.001$
Carbonates (CO_3^{2-})	mg l^{-1}	1.20(±2.53) a	6.11(±8.64) a	§
Nitrates (NO_3^{-})	mg l^{-1}	1.70(±0.64) a	2.89(±1.33) b	$p = 0.02$
Boron (B^{3+})	mg l^{-1}	0.00(±0.00)	0.79(±0.53)	§
Iron (Fe^{2+})†	mg l^{-1}	0.16(±0.46) a	0.10(±0.11) a	$p = 0.21$
Manganese (Mn^{2+})‡	mg l^{-1}	0.001(±0.00) a	0.002(±0.001) a	$p = 0.17$
Copper (Cu^{2+})‡	mg l^{-1}	0.001 (±0.00) a	0.001 (±0.00) a	$p = 0.31$
Zinc (Zn^{2+})	mg l^{-1}	0.18(±0.34) a	0.015(±0.018) a	$p = 0.25$

Student's t-test ($p \leq 0.05$)
†Welch's t-test ($p \leq 0.05$)
‡Mann-Whitney U test ($p \leq 0.05$). Values with the same letters within the same column are statistically equal. Values in parentheses correspond to standard deviation
§B^{3+} and CO_3^{2-} were not statistically analyzed because no boron values were obtained for corrugate galvanized roofs (mean zero) and for CO_3^{2-}, only two values were obtained for corrugate galvanized roofs and only three values for concrete roofs, out of nine replicates.

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EC presents higher values in concrete roofs (1.22 ± 0.61 dS m^{-1}; p< 0.001) compared to corrugated galvanized roofs (0.35 ± 0.4 dS m^{-1}; p < 0.001). Likewise, SAR is considerably higher in concrete roofs (6.70 ± 3.12; p < 0.001) than in corrugated galvanized roofs (0.46 ± 0.54; p < 0.001); an effect of roof material on these parameters was observed, while pH did not present statistically significant differences (p = 0.23). Regarding ions, highly significant mean concentrations (p < 0.001) were recorded for Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, HCO_3^{-}, and Cl^{-}, while NO_3^{-} was significant with p = 0.02; contents of these ions were higher in concrete roofs. Conversely, no significant differences (p > 0.05) were found in pH, Ca^{2+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} between both roof types.

To understand the dynamics of rainwater characteristics due to contact with roofs or rainwater catchment areas in RWHS, EC and pH of different water types were measured and compared (Figure 6). Samples were plotted of rainwater without roof contact in Almoloya, Hgo. (A); distilled water 1 from the Hydrosciences Laboratory of the Postgraduate College (B); distilled water 2 from the Soil Fertility and Environmental Chemistry Laboratory of the Postgraduate College (C); puddle water on pavement collected after rainfall (D); tap water from the Montecillo Campus, Postgraduate College (E); cistern water from rural area RWHS (Almoloya, Hgo.) (F); and tank water from urban area RWHS (Iztapalapa, CDMX) (G). Figure 6 shows that rainwater before roof contact exhibits EC and pH similar to distilled water (Figure 6A, B, C), beginning to increase slightly in puddle rainwater (Figure 6D), with parameter values increasing in urban area concrete roof RWHS (Figure 6G), and tap water presenting higher EC values than rural area rainwater (Figure 6E and F).

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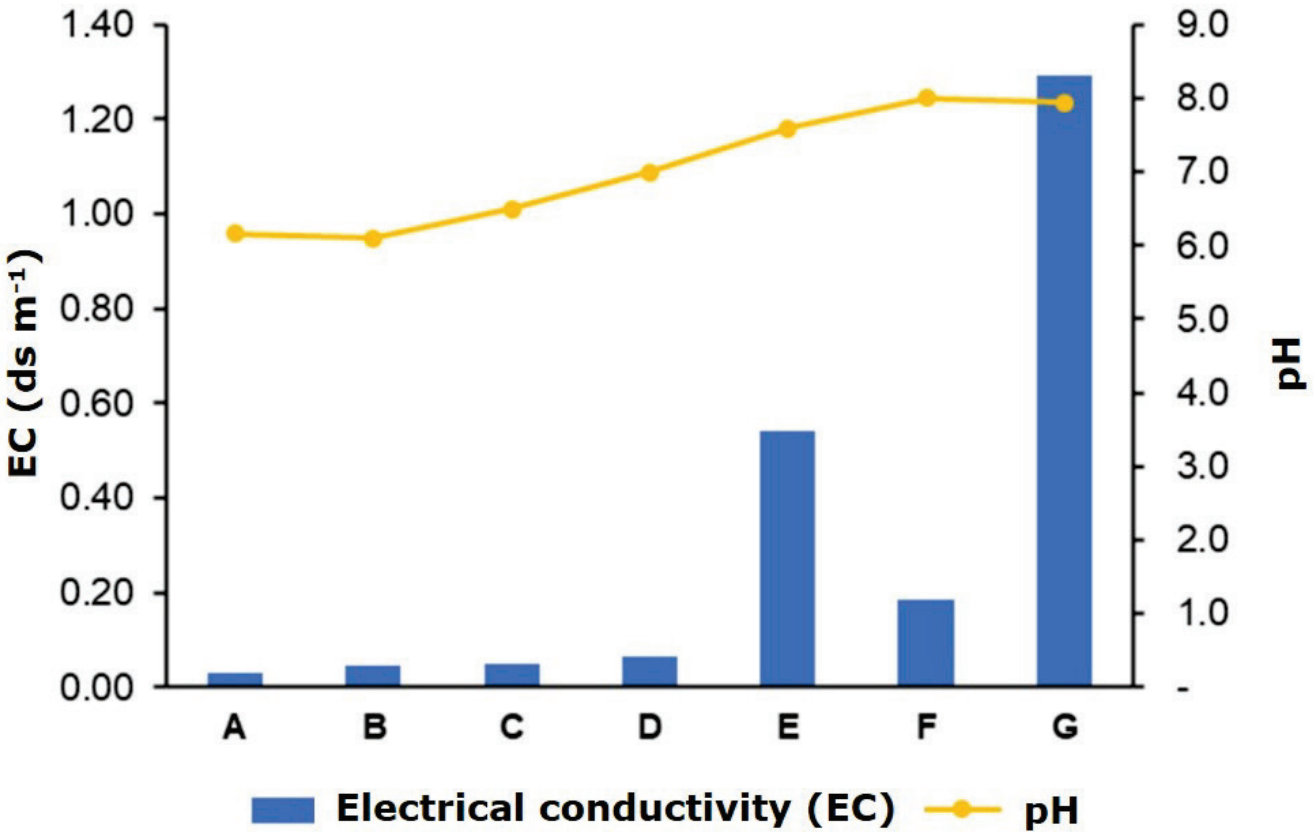

Figure 6. Comparison of electrical conductivity (EC) and pH values from different water sources; A) rainwater; B) distilled water 1; C) distilled water 2; D) puddle water; E) tap water; F) rural RWHS water and G) urban RWHS water.

Degree of restriction of RWHS rainwater for use in home garden irrigation

The degree of restriction for use of RWHS rainwater for irrigation according to Ayers and Westcot (1994), Castellanos (2000), and García (2012) shows that the rural area (Almoloya, Hgo.) presented no degree of restriction for most parameters, except for pH at the limit of slight to

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moderate restriction. In contrast, the urban area (Iztapalapa, CDMX) showed a slight to moderate degree of restriction for EC, pH, SAR, Cl^-, and HCO_3^-; pH and SAR are at the limit of this restriction degree (Table 4).

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Table 4. Degree of restriction of RWHS rainwater for garden irrigation in rural and urban areas.

Variable	Unit	Rural area		Urban area	
		Mean (Standard deviation)	Degree of restriction	Mean (Standard deviation)	Degree of restriction
Electrical conductivity (EC)	dS m^{-1}	0.19(±0.09)	none	1.29(±0.18)	slight-mod
pH		8(±0.21)*	slight-mod	7.95(±0.19)*	slight-mod
Sodium adsorption ratio (SAR)		0.34(±0.31)	none	6.13(±3.40)*	slight-mod
Calcium (Ca^{2+})	mg l^{-1}	21.09(±7.79)	none	15.47(±6.74)	none
Magnesium (Mg^{2+})	mg l^{-1}	3.37(±3.51)	none	19.25(±13.73)	none
Sodium (Na^{+})	mg l^{-1}	7.07(±7.50)	none	170.86(±125.26)	none
Potassium (K^{+})	mg l^{-1}	7.35(±3.54)	none	21.22(±9.82)	none
Sulfates (SO_4^{-})	mg l^{-1}	1.74(±0.82)	none	4.2(±2.62)	none
Bicarbonates (HCO_3^{-})	mg l^{-1}	89.27(±44.20)	none	392.11(±274.9)	slight-mod
Chlorides (Cl^{-})	mg l^{-1}	6.12(±3.91)	none	162.39(±106.32)	slight-mod†
Carbonates (CO_3^{2-})	mg l^{-1}	3.37(±6.17)	none	3.4(±6.91)	none
Nitrates (NO_3^{-})	mg l^{-1}	1.87(±0.58)	none	2.6(±1.46)	none
Boron (B^{3+})	mg l^{-1}	0(±0)	none	0.71(±0.24)	none
Iron (Fe^{2+})	mg l^{-1}	0.01(±0.01)	none	0.25(±0.30)	none
Manganese (Mn^{2+})	mg l^{-1}	0.001 (±0)	none	0.002(±0.001)	none
Copper (Cu^{2+})	mg l^{-1}	0.001 (±0)	none	0.001 (±0)	none
Zinc (Zn^{2+})	mg l^{-1}	0.18(±0.22)	none	0.03(±0.02)	none

Degree of restriction slight to moderate = slight-mod

*Values at the limit of slight to moderate (mod) restriction; pH is within the permissible range for agricultural use according to the Federal Rights Law (LFD, 2024)

† Chlorides (Cl^{-}) exceed the maximum permissible limit of LFD (2024)

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Discussion

Electrical conductivity

According to the degree of restriction ranges for irrigation use established by Ayers and Westcot (1994), EC of rainwater in the rural area (0.19 dS m^{-1}) presents no use restriction, being below 1 dS m^{-1}. This indicates suitability for home garden irrigation without risk of increasing soluble salt content in the soil; vegetables (stem and leaf), certain fruits, aromatic herbs, and medicinal plants that are cultivated continuously throughout the year and are adapted to local rural area conditions can be irrigated, thereby complementing family fresh produce requirements (Cano-Contreras, 2015).

Conversely, rainwater in the urban area presented an EC value of 1.29 dS m^{-1}, with a maximum value of 1.99 dS m^{-1}, exhibiting a slight to moderate degree of restriction as it falls between 0.7 and 3.0 dS m^{-1} (Ayers & Westcot, 1994). These results indicate that problems with increased soluble salt content in soil or substrate may occur in the short to medium term, depending on irrigation frequency and the very limited space characteristic of urban home gardens. The EC value of RWHS rainwater in urban areas should be considered when analyzing multifunctionality programs for urban home gardens in CDMX to ensure fulfillment of their objective as an external and complementary food source (Alcántara-Nieves & Larroa-Torres, 2022).

The mean EC value of 1.29 dS m^{-1} in the Iztapalapa urban area differs from those reported by Haque and Rinkey (2019) for urban areas of Dhaka city, Bangladesh, the world's second most polluted city, where EC values ranged from 0.026 to 0.436 dS m^{-1}, and Emmanuel *et al*.

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(2021) in Umuahia, Southeastern Nigeria, reported values between 0.012 and 0.044 dS m^{-1}, which, according to their countries' potable water quality standards and World Health Organization (WHO) guidelines, present no use restrictions.

This might indicate that rainwater from the Iztapalapa urban area exhibits higher dissolved salt concentration compared to other urban areas worldwide. However, it is important to note that climate, rainwater sample collection point within RWHS, sampling sites (rural or urban), and RWHS materials are highly variable, consequently yielding very different EC values among urban areas. In this regard, Haque and Rinkey (2019) analyzed rainwater samples collected from roof surface runoff at different city locations, while Emmanuel *et al*. (2021) analyzed rainwater from rooftop harvesting systems in an area with high-intensity tropical precipitation (1 900 mm to 2400 mm) producing large surface flow volumes; therefore, under these conditions, comparison with the Iztapalapa urban area, which has mean annual precipitation of 679 mm and where roof runoff rainwater was not analyzed, is not feasible.

Similarly, Rangel-González and Domínguez-Sánchez (2018) reported mean EC values of 0.68 dS m^{-1} (minimum 0.11 dS m^{-1} and maximum 6.69 dS m^{-1}) for stored rainwater from 91 RWHS in CDMX, from housing units, single-family homes, public and commercial buildings, evidencing the variability of this parameter across different RWHS. In this regard, Mendez *et al*. (2011) indicate that EC of RWHS rainwater can be affected by roof material, as over time, mean particle release increases, elevating concentrations compared to rainwater that has not contacted surfaces.

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The principal ions causing salinity (1.29 dS m^{-1}) in RWHS water from the Iztapalapa urban area are Na^+ (170.86 ± 125.2 mg l^{-1}), Cl^- (162.39 ± 106.32 mg l^{-1}), and HCO_3^- (392.11 ± 274.90 mg l^{-1}). In this regard, Mendez *et al*. (2011) indicate that a solution with high Na^+ and Cl^- concentrations will exhibit higher EC. Therefore, the higher EC values (6.69 dS m^{-1}) reported by Rangel-González and Domínguez-Sánchez (2018) could result from high sodium (946.50 mg l^{-1}), potassium (810 mg l^{-1}), and chloride (97.80 mg l^{-1}) concentrations originating from RWHS storage reservoirs.

When comparing rainwater sample results by catchment roof material type, concrete or corrugated galvanized metal sheet, EC presents higher values in concrete roofs (1.22 dS m^{-1}) compared to corrugated galvanized roofs (0.35 dS m^{-1}). These results indicate an effect of catchment roof material on RWHS water quality, as roof surfaces in urban settlements contribute excess ions to rainwater, increasing EC, turbidity, and total soluble solids values from concrete tile roofs, especially in aged roofs (Mendez *et al*., 2011). Furthermore, in urban areas such as CDMX, chloride and sodium ion concentrations increase due to chlorination treatment of harvested rainwater using sodium hypochlorite tablets to eliminate microorganisms harmful to health (Lozano-Quiroz, 2023); consequently, EC of urban RWHS rainwater increases.

pH

Regarding pH, according to the degree of restriction ranges published by Ayers and Westcot (1994), rainwater pH in the rural area is 8.00 and in the urban area 7.95, presenting a slight to moderate degree of restriction and considered alkaline waters in both cases. Previous studies have

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reported that rainwater is slightly acidic, pH = 5.6 (Baird & Cann, 2014), and becomes alkalinized by contact with RWHS materials, as reported for rainwater contact with concrete (Despins *et al*., 2009; Mendez *et al*., 2011; Emmanuel *et al*., 2021); this could explain the pH result in the Iztapalapa urban area where concrete roofs predominate.

The alkalinization of rainwater in rural and urban RWHS differs from that reported by Ímaz-Gispert *et al*. (2018), who recorded a mean pH of 6.22 for a RWHS at UNAM in CDMX. This difference is attributed to the roof material type used as the rainwater catchment area—tempered glass, considered an inert material that does not chemically react with rainwater; therefore, pH of water running over glass roofs remains in the slightly acidic range similar to rainwater. Likewise, Klein-Garavito (2015) reported that zinc tiles (range 5.75 - 6.79) and clay tiles (range 6.06 - 6.33) have near-neutral pH.

Furthermore, Rangel-González and Domínguez-Sánchez (2018) mention that in samples obtained from stored rainwater in cisterns and tanks in CDMX RWHS, pH values ranged mainly from neutral to slightly alkaline (mean = 7.60, max = 9.75, min = 5.37). However, a study in Ontario, Canada, of 360 RWHS samples showed pH variability in stored rainwater, with water in plastic tank reservoirs being slightly acidic and water in concrete reservoirs being slightly alkaline (Despins *et al*., 2009). This indicates that methodologies should be proposed to evaluate how materials used in constructing different RWHS components affect rainwater quality parameters in both rural and urban areas.

Rainwater quality is affected by various factors. In a study by Díaz-Ibarra *et al*. (2014) monitoring rainwater pH at four sites in the city of Culiacán, Sinaloa, mean pH values recorded were 6.09 for the southern

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zone, 6.97 for the northern zone, with maximum values of 7.7 and some minimum values of pH ≤ 5.5 in the southern and central city zones. Therefore, they suggest monitoring rainwater pH to understand this behavior. Additionally, they note that no studies consider whether the increase in vehicle fleet in recent years, the impact of brick kilns lacking regulation, clandestine logging, and soil erosion might affect rainwater pH values in Culiacán city.

According to Baird and Cann (2014), carbonate and bicarbonate content conditions pH, where carbonic acid is dominant at pH < 5, carbonate dominates at pH > 12, and bicarbonate is the predominant ion in the pH range of 7 to 10. In the case of bicarbonates, urban area rainwater (392.11 mg l^{-1}) presents a slight to moderate degree of restriction (Ayers & Westcot, 1994). Since alkaline pH is determined by the concentrations of HCO_3^- and CO_3^{2-} ions present in water, the HCO_3^- content in harvested rainwater from storage tanks in the urban area could have influenced the slightly alkaline pH of 7.95.

Conversely, in the rural area, mean bicarbonate content was 89.27 mg l^{-1}, four times lower than the urban area content, presenting no degree of restriction. Despite the lower HCO_3^- content in rural area rainwater, this may influence water pH of 8.0, as the low CO_3^{2-} content allows HCO_3^- to dominate, resulting in cistern rainwater exhibiting moderate alkalinity.

The slight to moderate restriction range of pH in rural and urban RWHS rainwater is at the limit of the desirable range for home garden irrigation, potentially affecting plant development due to reduced availability of phosphorus, iron, zinc, and manganese (García, 2012). However, simple practices maintaining pH near neutrality could be

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employed (Castellanos, 2000), such as compost application or soil/substrate replacement. Acid recommendations to lower pH are not advisable as rainwater will be used for home garden irrigation, and handling acids in a family setting poses risks, particularly with children present.

Sodium adsorption ratio

According to sodium adsorption ratio (SAR) ranges established by Castellanos (2000), rainwater in the rural area, with SAR of 0.34, presents no degree of restriction regarding sodium effects. Generally, RWHS rainwater quality studies do not include SAR as an analyzed parameter. In this regard, Ayers and Westcot (1994) only include SAR together with EC to evaluate water infiltration problems at the soil surface, and in irrigation water quality studies from groundwater sources, reporting SAR values is very common (Castellón-Gómez *et al*., 2015).

In contrast, for the urban area, SAR of 6.13 ± 3.40 was obtained, at the limit of slight to moderate restriction degree (Castellanos, 2000); therefore, there could be an effect on home garden soils from sodium accumulation, depending on irrigation frequency. Furthermore, some urban area RWHS presented maximum SAR values in the range of 7.35 to 10.3, falling within severe restriction degree. However, given the limited studies reporting high SAR in rainwater, evaluations are required to estimate what SAR value soil might attain (Aparicio *et al*., 2014) when irrigated with rainwater having slight to moderate or severe restriction degree SAR, to recommend such rainwater for home garden irrigation.

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Furthermore, although Na^+ does not represent risk as it falls below the irrigation use restriction threshold established by Ayers and Westcot (1994), sodium concentration in urban rainwater (170.86 ± 125.26 mg l^{-1}) is significantly higher than in the rural area (7.07 ± 7.50 mg l^{-1}). The high sodium concentration is attributed, similarly to chlorides, to the RWHS installed by Sedema in the urban area of CDMX including chlorination treatment using sodium hypochlorite tablets (Lozano-Quiroz, 2023). Additionally, Na^+ concentrations in some Iztapalapa, CDMX RWHS reached maximum measured quantities of 246 to 350 mg l^{-1}. From the results of this study, inclusion of SAR in rainwater quality analyses for home garden irrigation is recommended to evaluate irrigation suitability, as SAR is a parameter resulting from sodium, calcium, and magnesium concentrations contained in irrigation water.

Effect of specific ions

In addition to Na^+, ions presenting elevated concentrations in urban area rainwater causing some degree of restriction for home garden irrigation are HCO_3^- (392.11 mg l^{-1}) and Cl^- (162.39 mg l^{-1}), both with slight to moderate restriction degree (Ayers & Westcot, 1994); however, according to LFD (2024), Cl^- exceeds the maximum permissible limit (150 mg l^{-1}).

In the case of urban area rainwater, high HCO_3^- concentrations (392.11 mg l^{-1}) were measured, with even higher concentrations found due to concrete roof material (catchment areas) at 451.25 mg l^{-1}. Conversely, in the rural area, HCO_3^- concentration was 89.27 mg l^{-1}, and in corrugated galvanized roofs, which predominate in the area, a lower concentration was recorded (72.24 mg l^{-1}), both concentrations without restriction degree. Furthermore, Ímaz-Gispert *et al*. (2018) report

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very low HCO_3^- concentrations (mean 13.80 mg l^{-1}, maximum 68.2 mg l^{-1}) for a RWHS with glass roof; evidencing that materials used in RWHS construction can influence specific ion concentrations.

It is well known that HCO_3^- tends to form precipitates as calcium carbonate ($CaCO_3$) in waters with pH above 7.5, potentially causing obstruction in drip irrigation systems (García, 2012; Villavicencio & Villablanca, 2010); this potential issue should be considered as household drip irrigation is currently very common in home gardens, utilizing low-cost or recycled materials.

For Cl^-, according to Ayers and Westcot (1994), no restriction is considered when concentration is below 142 mg l^{-1}, while slight to moderate restriction applies for concentrations between 142 and 532 mg l^{-1}. Rainwater harvested in rural RWHS had a mean value of 6.1 mg l^{-1}, indicating water is safe for home garden irrigation without toxicity risk. In contrast, rainwater harvested in urban RWHS was 162.39 mg l^{-1}, a value within the slight to moderate restriction range, meaning that although urban rainwater can be used for irrigation, certain chloride toxicity risks may exist for some cultivated plants (Ayers & Westcot, 1994). To reduce Cl^- toxicity risk, sprinkling or spraying plants is not recommended, as Cl^- absorption through leaves could occur, causing toxicity (Bonet-Pérez & Ricardo-Calzadilla, 2011).

Chloride concentration in the urban area exceeds the maximum permissible limit for agricultural use (150 mg l^{-1}), according to the Federal Rights Law concerning national waters (LFD, 2024). High chloride concentration is attributed to RWHS installed by Sedema in the urban area of CDMX including disinfection treatment using sodium hypochlorite tablets (Lozano-Quiroz, 2023). In this regard, Ímaz-Gispert *et al*. (2018)

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mention that chloride concentrations were not discussed as they did not originate from rainwater but were added to the storage cistern for disinfection. However, in this study, Cl^- was considered in urban RWHS rainwater quality analysis because it is present in stored tank rainwater and could potentially be used for irrigation, affecting urban garden plants. Cl^- ion concentration in the Iztapalapa urban area differs from values reported by Haque and Rinkey (2019) and Emmanuel *et al*. (2021) of 4.98 and 0.76 mg l^{-1}, respectively, presenting no chloride restrictions; however, these studies do not report chlorination systems in RWHS storage systems.

Furthermore, recent studies by Lozano-Quiroz (2023) mention that chlorination in CDMX RWHS is performed incorrectly, as there is limited clarity regarding chlorination procedures—individuals do not adjust sodium hypochlorite tablet quantity to stored rainwater liters; only 10 to 14 % of people know the frequency of chlorination and thus proper chlorination management could reduce chloride and consequently sodium concentrations in RWHS water. This evidences disinfection problems in the Iztapalapa urban area, as collected samples yielded Na^+ values ranging from 6.21 to 350.0 mg l^{-1} and Cl^- ranging from 7.7 to 306.0 mg l^{-1}.

Ions K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and NO_3^- are present in low concentrations in rainwater, thus presenting no irrigation restrictions in either rural or urban areas; furthermore, these ions are essential nutrients that can be utilized by home garden plants (Andrade *et al*., 1995), if maintained in available form. However, ions Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}, and B^{3+} were present in very low concentrations. Rangel-González and Domínguez-Sánchez (2018) report concentrations of 0.14 and 0.12 mg

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l^{-1} for Fe^{2+} and Mn^{2+}, respectively, while in this study, values were 0.1 mg l^{-1} for Fe^{2+} in the rural area and 0.25 mg l^{-1} in the urban area, and for Mn^{2+}, 0.001 mg l^{-1} in the rural area and 0.002 mg l^{-1} in the urban area.

Analysis by roof type indicates that concrete roofs exhibit significant increases in concentrations of Mg^{2+}, K^{+}, SO_4^{2-}, and NO_3^{-} ions, contributing greater nutrient quantities for home garden plants in the urban area where concrete roofs predominate. Conversely, contributions of Ca^{2+}, B^{3+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} ions reflected no significant differences between areas or roof types.

In contrast, Emmanuel *et al*. (2021) report significant Zn^{2+} increase in corrugated iron sheet roofs compared to asbestos, aluminum, and Harvey tile roofs, coinciding with reports by Chizoruo and Onyekachi (2018); while Klein-Garavito (2015) found that zinc sheets, galvanized steel, or galvanized metals are most suitable for high-quality rainwater harvesting, due to their low roughness facilitating runoff and roof cleaning during first flush.

However, it must also be considered that transport of dry matter accumulated on roof surfaces from the previous dry period and particles accumulated due to catchment roof material wear, in addition to suspended dust and mist, bird droppings, and other residues, cause increases in rainwater quality parameter values from RWHS (Emmanuel *et al*., 2021).

Conclusions

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Rainwater from rainwater harvesting systems in the rural area (Ejido Almoloya, Hgo.) and urban area (Iztapalapa, CDMX) is viable for home garden irrigation. However, the comparative study showed that rainwater quality in the urban area presented significant increases in EC, SAR, and Mg^{2+}, K^{+}, and SO_4^{2-} ions, with very high concentrations of HCO_3^{-}, Na^{+}, and Cl^{-} found. These differences evidence that rainwater in the Iztapalapa urban area exhibited higher dissolved salt levels compared to the rural area in Ejido Almoloya. The catchment area roof type and disinfection treatment using sodium hypochlorite tablets are the probable cause of these increases. For urban RWHS rainwater in Iztapalapa, CDMX to be recommended for irrigation, simple practical adjustments are required, such as soil replacement, compost addition, and avoidance of sprinkler irrigation to prevent problems with slightly alkaline pH and bicarbonate concentration, in addition to better management of disinfection with sodium hypochlorite tablets, which are responsible for high sodium and chlorine ion values that can affect home garden soils and plants.

Therefore, when conducting water quality analyses with a focus on home garden irrigation, it is advisable to pay special attention to EC, pH, and SAR parameters and concentrations of Na^{+}, Cl^{-}, and HCO_3^{-} ions, particularly when RWHS have catchment areas with concrete roofs and stored water is disinfected. It is feasible to state that the rural area of Almoloya, Hgo., presents better water quality characteristics due to catchment roofs being primarily smooth corrugated galvanized metal sheet and filtration not including water chlorination; only pH monitoring of RWHS rainwater in the area will be required due to its slight alkalinity.

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