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Microbiological Water Quality and Structural Determinants in Preschools of Matehuala, Mexico: Implications for Sustainability and Equity in Safe Water Access

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Abstract

Access to microbiologically safe water in preschool educational settings constitutes a pressing public health challenge, particularly in rural areas with deficient infrastructure. Repeated exposure to enteropathogens present in contaminated water has been associated with acute gastrointestinal infections, environmental enteropathy, and disruptions in the intestinal microbiota of young children. Motivated by this concern, the present study evaluates the microbiological quality of water in 32 public preschool facilities in the municipality of Matehuala, San Luis Potosí—18 urban and 14 rural—by analyzing the presence of aerobic mesophilic bacteria (AMB), total coliforms (TC), fecal coliforms (FC), and helminth eggs. The assessment was conducted in accordance with Mexican standards NOM-092-SSA1-1994 and NOM-230-SSA1-2002 and supplemented with the World Health Organization's guidelines for drinking-water quality. The findings revealed a marked territorial disparity: 100% of rural schools that relied on rooftop water tanks exceeded permissible limits for TC, and 35.7% tested positive for FC. In contrast, all urban schools—supplied through piped water systems—complied with current regulations. Statistical analysis (Mann–Whitney U test, $p < 0.05$) confirmed significant differences in microbiological contamination based on geographic location and type of water supply. In all FC-positive cases, a lack of sewage infrastructure and inadequate sanitation practices in storage containers were documented. These results demonstrate that formal access to water does not ensure its microbiological safety, particularly in settings with poor structural conditions. The study underscores the urgent need to implement point-of-use water treatment technologies, establish regular microbiological monitoring protocols, and provide training for educational staff in water hygiene practices.

Keywords: water quality; preschools; microbiological contamination; water inequality; sustainability; SDG 6: Clean Water and Sanitation

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Academic Editor: Fernando António Leal Pacheco

Received: 20 August 2025
Revised: 13 September 2025
Accepted: 15 September 2025
Published: 22 September 2025

Citation: Terrones-Gurrola, M.C.d.R.; Alvarez-Macias, H.A.; Compeán-Martinez, I.; Hernandez-Rangel, F.J.; Cruz-Alcantar, P. Microbiological Water Quality and Structural Determinants in Preschools of Matehuala, Mexico: Implications for Sustainability and Equity in Safe Water Access. *Sustainability* **2025**, *17*, 8488. https://doi.org/10.3390/su17188488

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1. Introduction

Globally, more than 2 billion people consume water contaminated with fecal matter, making it one of the primary routes for the transmission of infectious diseases during childhood [1]. This issue is particularly acute in low- and middle-income countries, where 41% of the rural population and 12% of the urban population rely on unsafe water sources [2].

Even among sources classified as "improved," 38% show detectable fecal contamination, with significantly higher risk in rural areas (odds ratio ≈ 2.37) [2].

The World Health Organization estimates that at least 485,000 deaths from diarrhea each year are directly related to unsafe drinking water, poor sanitation, and lack of hygiene [3]. In childhood, these illnesses are not only among the leading causes of mortality in children under five, but they also contribute to malnutrition, anemia, and a weakened immune system [4,5]. Repeated exposure to enteropathogens present in contaminated water has been linked to acute gastrointestinal infections, environmental enteropathy and alterations in the intestinal microbiota of children [6,7]. Furthermore, recent studies suggest that such exposure adversely affects cognitive development, particularly executive functions such as working memory and attention [8].

In Latin America, both access to and the quality of water in school environments are particularly concerning. In Brazil, a study reported total coliforms (TC) in 65% of water samples collected from elementary schools [9]. Similarly, in Argentina, 73% of school water samples failed to meet potability standards [10]. In Mexico, research conducted in Tepatitlan, Jalisco, revealed that 59% of water samples from schools exceeded the permissible limits for residual chlorine. Additionally, FC, such as *Escherichia coli*, and *Pseudomonas* spp. were detected in poorly maintained containers [11].

Although official reports state that 97.5% of households in Mexico have access to potable water, only 45% receive water continuously, with this figure dropping to 31.8% in rural areas [12]. Furthermore, 19% of public schools lack access to drinking water on their premises [13]. This structural inequality hinders the realization of the human right to water in school settings, particularly in rural and peri-urban communities, where inadequate sanitation and the absence of microbiological monitoring exacerbate health risks [14].

Assessing the microbiological quality of water in school settings is essential for identifying hidden risks that disproportionately impact children [9,15]. The presence of aerobic mesophilic bacteria (AMB), total coliforms (TC), and fecal coliforms (FC) is recognized by the World Health Organization as a key indicator for evaluating drinking water safety [1]. Notably, the detection of FC signals recent contamination from human or animal feces and constitutes an immediate public health alert.

Despite its relevance, few systematic studies in Mexico integrate microbiological water analysis in schools with contextual variables such as water source, geographic location, storage conditions, and the perceptions of school personnel. Available evidence tends to be fragmented and localized, lacking comparative approaches or territorial perspectives.

Comparable challenges have been reported internationally. For example, studies in Nepal found widespread coliform contamination in school water supplies [16], while research in Palestine highlighted deficiencies in disinfection and contamination in wells and tanker-based systems [17]. In Mozambique and Uganda, school WaSH deficiencies were significantly associated with the presence of *Escherichia coli* [18], and in Brazil, *enterococci* were detected in samples from public schools [19]. In Pakistan, primary schools were reported to have elevated turbidity, total dissolved solids, and microbial contamination [20]. In contrast, in Mexico systematic studies remain scarce and are mostly limited to localized case reports, underscoring the need for broader analyses. The present study contributes to filling this gap by analyzing urban–rural disparities in preschool facilities, providing novel evidence for children's health in educational environments.

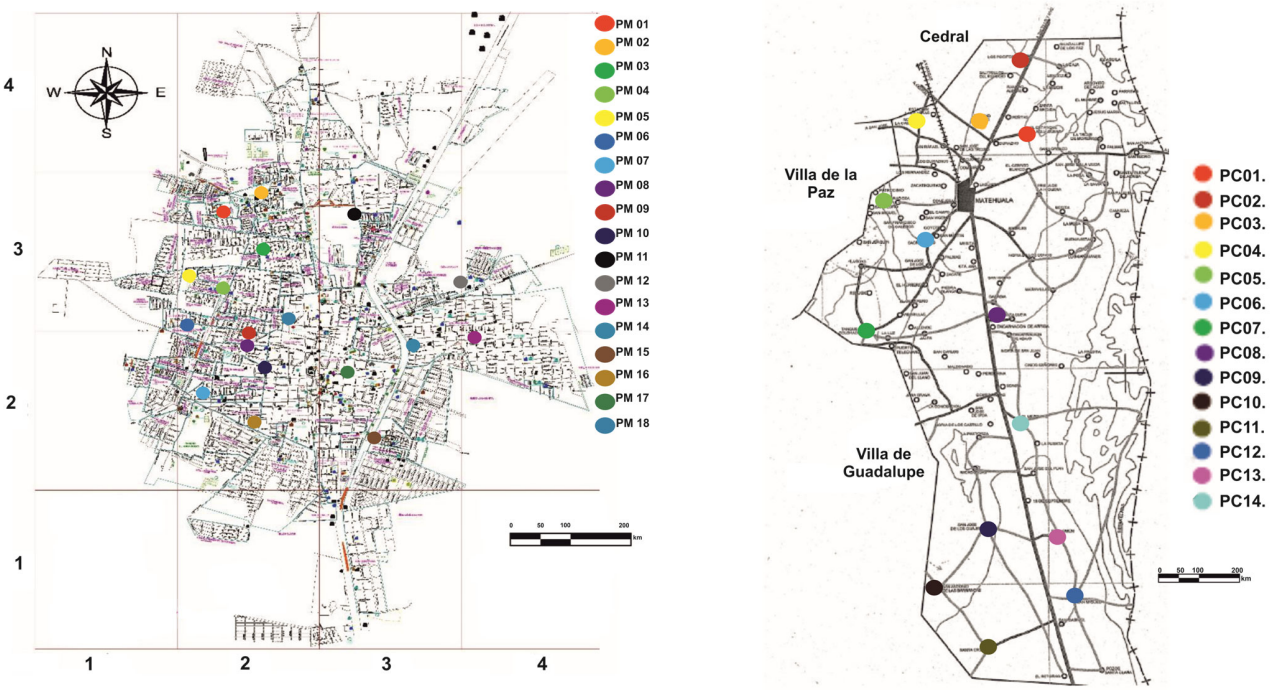
In this context, the present study analyzes the microbiological quality of water available in 32 urban and rural preschools in the municipality of Matehuala, San Luis Potosí. The evaluation included the presence of AMB, TC, FC, and helminth eggs, as well as the isolation and identification of bacterial genera indicative of fecal contamination. In parallel, structural variables were documented, including water source (piped vs. rooftop tank),

presence of drainage systems, condition of infrastructure, and perceptions regarding water quality, within a framework of territorial water justice.

This research aims to generate robust empirical evidence to inform the development of public policies focused on school water safety and equitable access to safe water, understanding that the quality of available water is a key determinant of child well-being, development, and learning.

2. Materials and Methods

This study adopted a methodological approach that acknowledges territorial inequalities in access to safe water in school environments. The sampling strategy was key to capturing the structural diversity of schools located in semi-arid zones. To ensure a robust comparative analysis between urban and rural settings, the sample was selected using purposive criteria designed to maximize variability in geographical location, water supply type, student population density, and sanitary conditions. As illustrated in Figure 1, which presents the main water supply schemes identified in preschool facilities of Matehuala, San Luis Potosí, this approach enabled the identification of microbiological contamination and its contextual causes, in line with a social epidemiological surveillance framework and the human right to water.



(**a**) (**b**)

Figure 1. Location of the 32 public preschool facilities: (**a**) urban (n = 18; 56.2%) and (**b**) rural (n = 14; 43.8%), with their corresponding nomenclature.

A non-probabilistic convenience sampling method was employed, which is a technique commonly used in exploratory research with logistical or structural constraints, as it allows the selection of units that represent empirically relevant conditions of the phenomenon under study [21].

Schools with higher population density were prioritized based on the assumption that larger student concentrations place greater pressure on water supply systems and consequently increase the risk of exposure to contaminants. In urban areas, schools with more than 100 enrolled students were included, whereas in rural areas, schools with at least 20 enrolled students were selected, acknowledging the demographic dispersion character-

istic of these territories. Only schools operating under one of the two predominant water supply schemes in the region were considered: piped water connected to the municipal network or water stored in plastic tanks. This distinction facilitated comparative analyses across settings with varying exposure levels and vulnerabilities, recognizing that prolonged water storage without adequate treatment represents a significant public health risk.

Although this strategy may not capture the smallest or most remote schools, the deliberate inclusion of both urban and rural facilities, with different sizes and supply types, ensured sufficient variability to identify the structural factors most relevant to microbiological risks in the region.

Explicit consent from school authorities was an essential requirement, along with the logistical feasibility of conducting sampling, particularly in rural communities with infrastructure constraints. In this study, explicit consent was equivalent to informed consent and was obtained through an official presentation letter issued by the Universidad Autónoma de San Luis Potosí and delivered to the principals of the participating preschools. Safeguards included strict adherence to NOM-230-SSA1-2002 for sterile sampling, transport, and preservation to ensure microbiological integrity [22]. All researchers had formal academic training and prior experience in microbiological methods, complemented by the technical procedures established in national standards. The final sample consisted of 32 public preschool facilities, of which 18 (56.2%) were located in urban areas (Figure 1a), and 14 (43.8%) in rural localities (Figure 1a). This distribution was deliberately designed to capture territorial asymmetries in water access and differences in sanitation infrastructure between central and peripheral zones. Figure 1 provides a complete overview of the geographic location and corresponding codes of all collected samples.

2.1. Contextual Variables

In addition to microbiological analysis, contextual structural, geographic, and social variables were documented to frame the findings territorially and identify environmental determinants of water quality. Special attention was given to the type of supply—piped systems or plastic tanks—and to storage conditions: tank type, physical state, cleanliness, and handling practices. In this study, the term "rooftop tank" refers to commercially manufactured plastic storage units (commonly known as tinacos in Mexico) that are supplied either by the municipal network or by local wells. These tanks are not rainwater harvesting systems and are not open reservoirs; they are closed containers typically installed on rooftops to enable gravity distribution of water. In some rural schools, however, tanks were placed at ground level to facilitate manual filling when piped water was not available. In rural preschools, information on rooftop tank cleaning was obtained through staff reports and visual inspection during fieldwork, focusing on whether tanks were periodically emptied and washed to remove sediment or biofilm from the inner walls. These factory-produced units include a screw-cap lid that keeps the water isolated from the external environment; therefore, deficiencies such as open vents, leaks, or intrusion by animals were not identified. In all facilities, water was mainly used for hygiene purposes (bathrooms, handwashing, and cleaning) and general school use, but not for direct drinking. To provide additional clarity, Figure 2 illustrates the typical water distribution system in these schools, highlighting the main supply schemes observed. Urban schools were consistently supplied through the municipal piped water network, whereas rural schools relied on multiple alternatives, most commonly stored rooftop tanks, and in some cases, local wells or water transported in jugs. According to staff reports, there was no certainty that chlorination was performed before storage, and possible contamination pathways included prolonged storage without residual disinfectant, lack of regular cleaning, and exposure during manual filling.

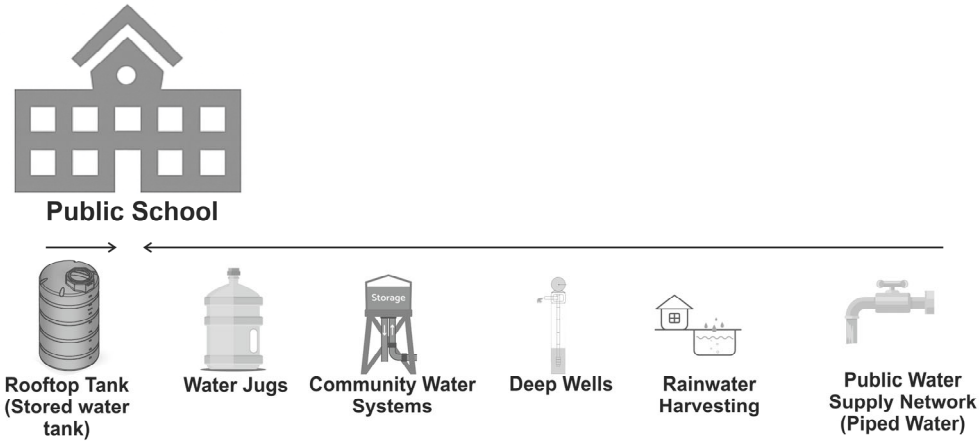


Figure 2. Main water supply schemes identified in preschool facilities (Matehuala, San Luis Potosí).

2.2. Sample Selection

In rural preschools, there was usually no dedicated staff for tank operation or maintenance. When custodial personnel were absent, teachers and sometimes parents assumed these tasks, reflecting the limited resources and staffing typical of rural schools.

These variables are key, since improper use can reverse the effects of prior treatment and enable microbiological contamination, especially in rural communities with low sanitation coverage [23].

Geographic location was also considered as a proxy for access to basic services, considering the distance (km) from the municipal seat. Remote areas tend to have lower water infrastructure, intermittent coverage, and maintenance issues, all of which affect water quality [24].

School sanitation infrastructure was another relevant variable, especially the connection to sewer systems and the general state of plumbing.

These have been linked to the presence of *Escherichia coli*, particularly where facilities are poor or lacking [18,25].

2.3. Water Sample Collection and Microbiological Analysis

Water samples were collected according to NOM-230-SSA1-2002, which sets technical procedures for sampling water for epidemiological surveillance, ensuring microbiological integrity [22]. This protocol defines criteria for sample point selection, sterility conditions, preservation, and transport, ensuring valid and representative results.

At each school, a one-liter sample was collected from the most representative child-use point (drinking fountains, sinks, or storage tanks), prioritizing those with direct and frequent contact. All samples were collected at the point of use, ensuring that the results reflected the actual exposure risk for children and staff, although this approach did not allow differentiation between contamination from the original source and that from the internal distribution system.

Samples were collected in sterile, hermetically sealed polypropylene containers without prior rinsing, following current regulations, and stored in coolers with chemical refrigerant at a controlled temperature of 2–8 °C. All samples were transported to the laboratory within six hours. As specified by NOM-230-SSA1-2002, the sterile containers used for sampling contained sodium thiosulfate to neutralize any potential chlorine residuals and preserve microbiological integrity [22]. Sampling took place during the dry season in the Altiplano region, a semi-arid area with very limited rainfall. Conducting the study under these conditions helped minimize seasonal variability, as heavy rains are known to increase microbial loads through runoff and infiltration.

2.4. MPN 5-Tube, 1:1:1 Technique for Estimating the Most Probable Number of Total Coliforms

The microbiological analysis of the water samples followed the Mexican Official Standard NOM-127-SSA1-1994, which regulates the permissible quality limits for water intended for human use and consumption [26]. This standard includes key microbiological parameters for public health protection, such as the complete absence of fecal coliforms in 100 mL of sample, as well as acceptable levels of total coliforms and other indicator bacteria.

The national regulatory framework was complemented by international guidelines, particularly the Guidelines for Drinking-Water Quality issued by the World Health Organization [1], which provide a risk-based approach and promote the progressive realization of the human right to safe water. These guidelines broaden the analytical scope by including not only mandatory indicators but also recommendations on emerging parameters, epidemiological context, and structural access conditions. The integration of national and international frameworks strengthened the reliability and relevance of the microbiological assessment. Three groups of microbiological indicators with sanitary relevance were selected: aerobic mesophilic bacteria (AMB), coliforms (total and fecal), and helminth eggs.

The selection of microbiological indicators was based on their public health relevance and on their explicit inclusion in the Mexican Official Standards NOM-230-SSA1-2002 [22], NOM-127-SSA1-1994 [26], and NOM-092-SSA1-1994 [27]., as well as in the WHO Guidelines for Drinking-Water Quality. Aerobic mesophilic bacteria were included as indicators of general hygienic conditions and handling efficiency; total and fecal coliforms were analyzed as internationally recognized markers of fecal contamination; and helminth eggs were considered due to their epidemiological importance in rural and low-sanitation settings.

The analysis of aerobic mesophilic bacteria (AMB) was carried out per NOM-092-SSA1-1994, which describes the plate count method of AMB using the pour plate technique with standard agar (BIOXON) [27]. Aliquots of 1 mL and 0.1 mL were seeded in duplicate on sterile plates with agar, and incubated at 35 $\pm$ 1 °C for 48 h in a manual-temperature-controlled incubator (Felisa-FE 398). Colony-forming units (CFU) were then quantified using a dark-field colony counter (Scorpion Scientific CVP-CM3), with results expressed as CFU/mL. Although these bacteria are not pathogenic, their presence is an indirect indicator of hygiene levels and the efficiency of water handling, storage, and distribution processes.

To estimate the most probable number (MPN) of total coliforms, the multiple-tube technique was used, following the 5:1:1 scheme as per NOM-230-SSA1-2002 [22]. This method includes a presumptive test in lactose broth with Durham tubes, followed by a confirmatory test in 2% brilliant green bile broth. Tubes were incubated at 35 °C for the specified times, and results were interpreted using MPN tables, as shown in Figure 3.

2.5. Technique for Quantification and Identification of Helminth Eggs

Finally, for the detection of helminth eggs, a modified version of the Faust technique adapted for aqueous matrices was used. This procedure involved a double centrifugation step with a 33% zinc sulfate solution. Microscopic examination was then carried out using Neubauer chambers, in search of structures compatible with viable helminth eggs such as *Ascaris lumbricoides* or *Trichuris trichiura*. Although this analysis is not included in NOM-127-SSA1-1994, its inclusion was justified due to its epidemiological relevance in contexts of water poverty and inadequate sanitation, especially in rural school settings (see Figure 4) [26].

The modified Faust method was selected due to its greater sensitivity in detecting helminth eggs in aqueous samples, a relevant advantage in rural sanitation contexts where parasitic contamination may occur. Its main strength lies in the capacity to identify eggs even at low concentrations, while its limitation is the longer processing time compared to

simpler techniques. These considerations justified its use in the present study despite not being explicitly required by national regulations.

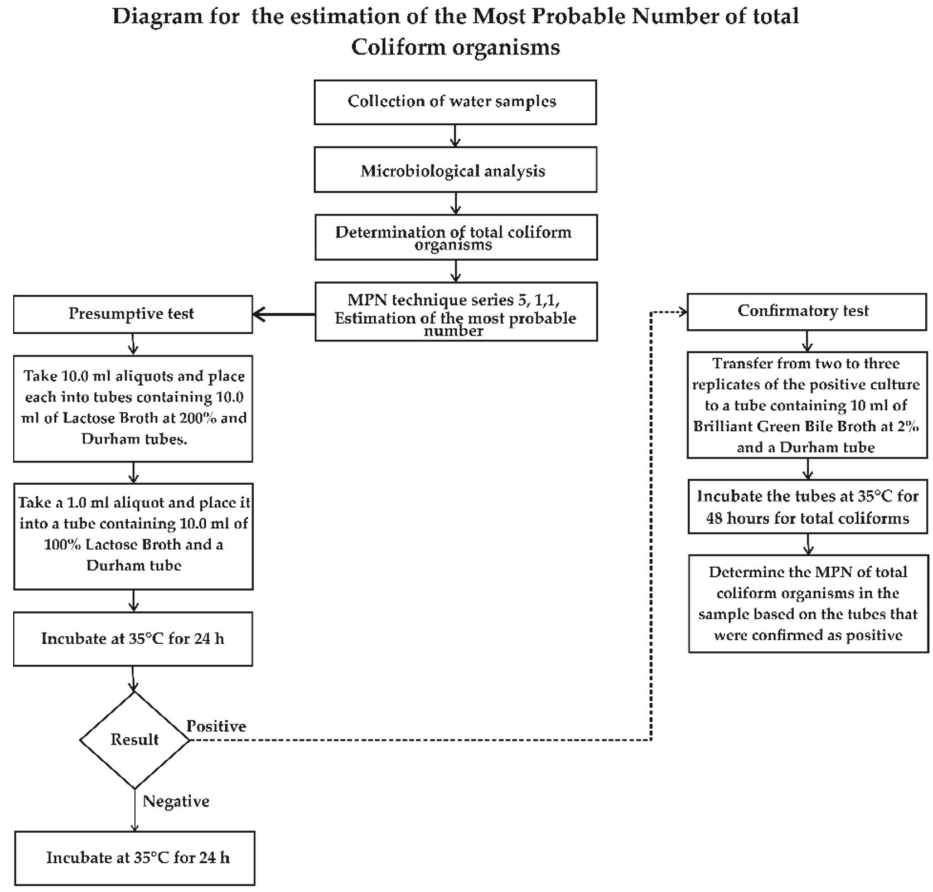


Figure 3. Flow diagram of the multiple-tube fermentation method (5:1:1 scheme) for estimating the most probable number (MPN) of total coliforms, following NOM-230-SSA1-2002.

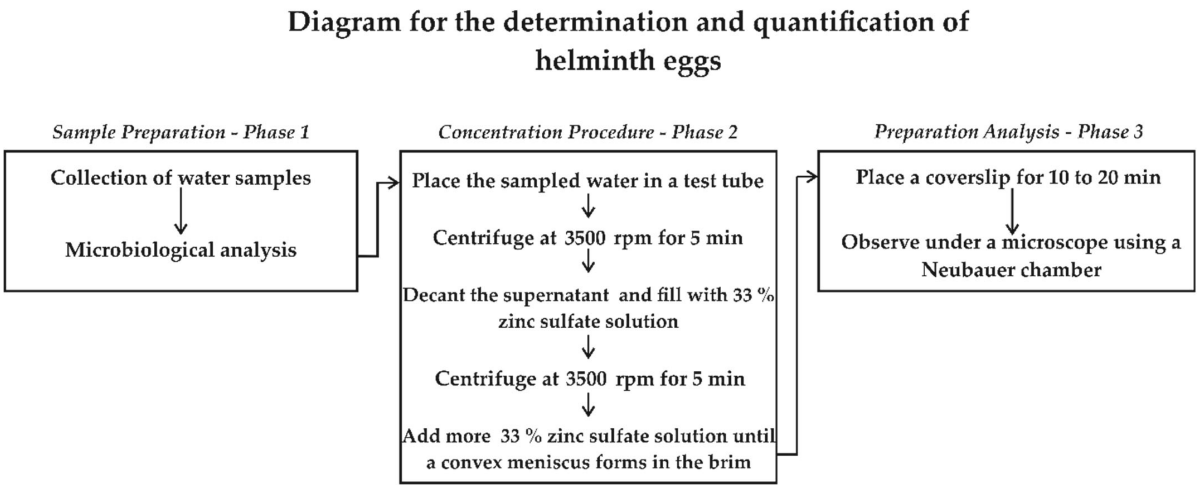


Figure 4. Flow diagram for the determination and quantification of helminth eggs, including sample preparation, concentration by zinc sulfate flotation, and microscopic observation using a Neubauer chamber.

2.6. Isolation and Identification of Bacteria

In addition to the quantitative analysis, preliminary isolation and identification of fecal contamination indicator bacteria were carried out by plating aliquots onto selective and differential media, following a classical microbiological protocol.

Samples that tested positive for fecal coliforms were streaked on MacConkey agar plates (BIOXON) and incubated at 37 °C for 24 h. Colonies with typical morphology (pink/lactose-positive or colorless/lactose-negative) were selected for subculturing on nutrient agar to obtain pure cultures. Additional media included Eosin Methylene Blue (EMB) agar, Xylose Lysine Deoxycholate (XLD) agar, and *Salmonella-Shigella* (SS) agar. Basic biochemical tests were then applied for presumptive identification, including Gram staining, oxidase, catalase, lactose fermentation, motility, and citrate utilization.

These analyses enabled classification of bacteria at the genus level, based on the criteria of the Manual of Clinical Microbiological Diagnosis [28]. Isolations were performed on samples with high fecal coliform loads and greater sanitary risk.

2.7. Statistical Analysis

Data were analyzed using IBM SPSS Statistics (v.22) through descriptive and inferential statistics to characterize the microbiological quality of water and its relationship with structural factors in preschool facilities that affect safe water availability.

In the descriptive phase, measures of central tendency and dispersion (mean, standard deviation, absolute and relative frequencies) were calculated to characterize both the microbiological conditions of the water (aerobic mesophilic bacteria, total coliforms, fecal coliforms, and helminth eggs), and the associated contextual variables (type of water supply, geographic location, sanitation infrastructure, and storage conditions).

In the inferential phase, non-parametric tests were applied, as the data did not follow a normal distribution (Shapiro–Wilk, $p < 0.050$). First, the Mann–Whitney U test was used to identify significant differences in microbiological contamination between territorial contexts. Specifically, comparisons were made between schools located in urban versus rural areas, as well as those with piped water versus those relying on rooftop water tanks. This test revealed variations in bacteriological indicators depending on the setting and type of supply, reflecting structural inequalities in access to safe water.

Additionally, Spearman's correlation coefficient was used to explore the relationship between the distance to the municipal seat (as an indicator of territorial marginalization) and levels of microbiological contamination in rural schools. This helped identify potential territorial gradients that affect water quality available to children. The threshold for statistical significance was set at $p < 0.05$.

3. Results

The interpretation of results was framed within the human rights approach to water, realizing that the systematic presence of microbiological contamination serves as an indirect indicator of inequity in access to basic services in school settings characterized by structural vulnerability. The findings are organized into three sections: characterization of water access, microbiological analysis of samples, and relationships between structural variables and contamination levels.

3.1. Characterization of Water Access in Preschool Facilities

A total of 32 preschool facilities from the municipality of Matehuala were included, of which 18 were located in urban areas and 14 in rural areas. Territorial differences in enrollment, access to piped water, form of supply, and presence of sanitary drainage are presented in Table 1. Notably, only 35.7% of rural schools had piped water, while the remainder depended on storage in rooftop tanks. The mean distance of these schools to the municipal seat was 23.3 ± 14.8 km, reflecting a pattern of geographic dispersion associated with lower coverage of water and sanitation infrastructure.

Table 1. General characterization of preschool schools according to geographical location, enrollment, distance from the municipal capital, and water supply.

Variable	Total (n = 32)	Urban (n = 18)	Rural (n = 14)
Average number of students (mean ± SD) *	87.9 ± 53.1	133.9 ± 26.8	27.0 ± 8.6
Average distance to municipal center (km)	-	-	23.3 ± 14.8
Access to piped water (%)	71.9% (23/32)	100% (18/18)	35.7% (5/14)
Water supply via rooftop tank (%)	28.1% (9/32)	0%	64.3% (9/14)
Presence of sanitary sewer system (%)	71.9% (23/32)	94.4% (17/18)	35.7% (5/14)

* SD = Standard deviation. Geographic distance was considered only for rural schools due to its contextual relevance. Percentages were rounded to one decimal place. Source: Own elaboration.

3.2. Microbiological Analysis of Available Water

The microbiological analysis revealed significant differences in water quality according to geographic context (urban vs. rural) and type of supply (piped vs. stored), as shown in Table 2.

Table 2. General characterization of preschool-level schools by geographic location, enrollment, distance to the municipal center, and water supply type.

School	Area	Water Supply Type	AMC (CFU/100 mL)	TC (MPN/100 mL)	FC (MPN/100 mL)	Helminth Eggs
PE19	Rural	Rooftop tank	5,000,000	>16,000	311	Absent
PE20	Rural	Rooftop tank	2,509,000	>16,000	210	Absent
PE21	Rural	Piped	–	12	–	Absent
PE22	Rural	Rooftop tank	5,000,000	>16,000	56	Absent
PE23	Rural	Piped	–	>16,000	–	Absent
PE24	Rural	Piped	–	>16,000	–	Absent
PE25	Rural	Rooftop tank	–	>16,000	–	Absent
PE26	Rural	Rooftop tank	18,000	>16,000	–	Absent
PE27	Rural	Rooftop tank	18,000	16,000	14	Absent
PE28	Rural	Rooftop tank	18,000	38	–	Absent
PE29	Rural	Rooftop tank	18,000	12	–	Absent
PE30	Rural	Rooftop tank	18,000	>16,000	220	Absent
PE31	Rural	Piped	–	4.4	–	Absent
PE32	Rural	Piped	–	38	–	Absent
PE01–PE18	Urban	Piped	Not detectable	Not detectable	Not detectable	Absent

"–" indicates that the measurement was not performed or the result was below the quantification limit. All urban samples (PE01 to PE18) were free from microbiological contamination. AMC = aerobic mesophilic bacteria; TC = total coliforms; FC = fecal coliforms. Source: Authors' own elaboration.

Regarding aerobic mesophilic bacteria (AMB), all urban samples remained within the limit established by NOM-092-SSA1-1994 (<100 CFU/100 mL), suggesting acceptable hygienic conditions in the distribution systems [27]. In contrast, 57.1% of rural samples (n = 8) showed elevated concentrations ranging from 18,000 to 5,000,000 CFU/100 mL, indicating widespread contamination.

For total coliforms (TC), 100% of rural samples exceeded the regulatory limit of 2 MPN/100 mL (NOM-127-SSA1-1994), reaching up to 16,000 MPN/100 mL. No urban samples showed presence of this indicator [26]. Fecal coliforms (FC) were detected in five rural samples (35.7%) with concentrations between 14 and 311 MPN/100 mL, representing a high or very high health risk according to WHO criteria. Again, urban samples were free of this contamination.

Finally, the parasitological analysis detected no helminth eggs in any of the 32 samples analyzed, indicating the absence of viable intestinal parasite contamination at the time of the study.

3.3. Identification of Isolated Bacteria

The qualitative analysis identified bacteria indicative of recent fecal contamination and inadequate storage. A total of 26 strains were isolated from samples positive for fecal coliforms, corresponding to 11 rural schools supplied by rooftop tanks. No isolates were identified in urban schools or schools with a piped supply and negative fecal coliform results (Table 3).

Table 3. Bacterial genera isolated from samples contaminated with fecal coliforms.

Bacterial Genus	No. of Strains Isolated	Sample Type (Rooftop Tank/Piped)	Geographic Area (Urban/Rural)	Relevant Observations
Escherichia spp.	8	Rooftop tank	Rural	Lactose +, indole +, motile
Enterobacter spp.	5	Rooftop tank	Rural	Lactose +, citrate +
Klebsiella spp.	4	Rooftop tank	Rural	Encapsulated, indole –
Citrobacter spp.	3	Rooftop tank	Rural	Variable lactose, citrate +
Proteus spp.	3	Rooftop tank	Rural	Lactose –, motility +
Pseudomonas spp.	3	Rooftop tank	Rural	Lactose –, oxidase +

The isolated bacterial genera included *Escherichia*, *Enterobacter*, *Klebsiella*, *Citrobacter*, *Proteus*, and *Pseudomonas*, all recognized as indicators of fecal or environmental contamination. *Escherichia* spp. was the most frequent genus, with eight isolates, followed by *Enterobacter* spp. and *Klebsiella* spp., corroborating previous findings of fecal coliform presence in the analyzed samples.

This bacterial profile evidences exposure to contaminated water and structural conditions favoring microbial proliferation, especially in untreated storage containers. The presence of *Pseudomonas* spp. and *Proteus* spp. further suggests additional environmental contamination and risk of opportunistic infections in vulnerable populations such as children.

3.4. Relationship Between Contextual Variables and Microbiological Contamination

To understand structural factors affecting water quality in school contexts, variables related to water infrastructure, storage, handling, and school staff perception were analyzed. These aspects were evaluated according to geographic location (rural/urban) and microbiological results.

Table 4 presents the general distribution of contextual variables by urban or rural setting.

Table 4. Distribution of contextual variables in urban and rural schools in the municipality of Matehuala, SLP.

Variable	Total (n = 32)	Urbana (n = 18)	Rural (n = 14)	*p*-Value
Water supply via rooftop tank (%)	28.1%	0%	64.3%	<0.001 *
Presence of sanitary sewer system (%)	71.9%	94.4%	35.7%	0.008 *
Hydraulic installations in good condition (%)	59.4%	83.3%	28.6%	0.005 *
Proper rooftop tank cleaning (%)	31.3%	N/A	45.5%	-
Perception of water quality as “good” (%)	65.6%	88.8%	28.6%	0.004 *

* Chi-square test. Statistical significance for $p < 0.05$.

Significant differences were identified in the type of water supply: while 100% of urban schools had piped water, 64.3% of rural schools depended on storage in rooftop tanks ($p < 0.001$). Additionally, sanitary sewer connection was reported in 94.4% of urban schools but only in 35.7% of rural schools ($p = 0.008$). The overall condition of plumbing installations was rated as "good" in 83.3% of urban schools compared to only 28.6% in rural schools ($p = 0.005$). Regarding water quality perception, 71.4% of staff in rural schools rated it as "poor" or "fair," whereas 88.8% of urban school staff considered it "good."

Subsequently, the relationship between contextual variables and the presence of fecal coliforms (FC)—a key marker of sanitary risk— was explored. Results (Table 5) showed statistically significant associations: 100% of FC-positive cases corresponded to schools storing water in tanks; 80% lacked sewer connections and had poor storage container conditions; and in 4 of 5 FC-positive cases, school personnel expressed negative perceptions of water quality.

Table 5. Associations between contextual variables and microbiological results, including teachers' perception of water quality.

Variable	Positive FC (n = 5)	Negative FC (n = 27)	*p*-Value
Use of rooftop tank (%)	100%	18.5%	0.001 *
Absence of sanitary sewer system (%)	80%	22.2%	0.009 *
Rooftop tank without proper cleaning (%)	60%	25.9%	0.047 *
Perception of water as "poor" (%)	80%	18.5%	0.011 *

* Fisher's exact test. Statistical significance for $p < 0.05$.

To identify associations between microbiological contamination and key structural factors, the Mann–Whitney U test was applied to compare levels of aerobic mesophilic bacteria (AMB), total coliforms (TC), and fecal coliforms (FC) based on location (urban vs. rural) and supply type (piped vs. stored). The inferential analysis results are presented in Table 5.

Results showed statistically significant differences between geographic zones for total coliforms ($p = 0.000$) and fecal coliforms ($p = 0.000$), confirming higher microbial loads in rural schools. For aerobic mesophilic bacteria, a marginally significant difference was observed ($p = 0.051$), indicating a notable trend that merits attention. When comparing supply types, highly significant differences were found between schools with piped water and those storing water in tanks. The latter exhibited higher levels of AMB, total coliforms, and fecal coliforms ($p = 0.000$ in all cases), reinforcing the critical role of storage conditions in microbiological risk within school settings.

To analyze whether geographic distance influences water quality in rural schools, Spearman's correlation test was applied between kilometers to the municipal head and microbiological contamination levels. Results, shown in Table 6, revealed no statistically significant correlations for aerobic mesophilic bacteria ($\rho = 0.064$; $p = 0.826$), total coliforms ($\rho = 0.297$; $p = 0.221$), or fecal coliforms ($\rho = 0.357$; $p = 0.179$).

Table 6. Inferential analysis using the Mann–Whitney U test to compare the presence of microbiological contamination by location and type of water supply.

Microorganism	Geographic Area (Urban vs. Rural)	Water Supply Type (Piped vs. Rooftop Tank)
Aerobic mesophilic bacteria (AMB)	$p = 0.051$	$p = 0.000$ *
Total coliforms (TC)	$p = 0.000$ *	$p = 0.000$ *
Fecal coliforms (FC)	$p = 0.000$ *	$p = 0.000$ *

* Mann–Whitney U test.

These findings suggest that water contamination in rural areas is not solely associated with geographic distance from urban centers, but rather with more complex structural factors such as water supply type, storage conditions, and the availability of sanitation infrastructure [2,29,30].

Multivariate analysis confirmed that the strongest predictors of fecal coliform presence were the use of rooftop tanks (OR = 9.8, 95% CI: 2.1–45.1, $p = 0.003$) and the absence of sanitary sewer systems (OR = 4.6, 95% CI: 1.2–18.2, $p = 0.028$). For aerobic mesophilic bacteria, higher counts were significantly associated with poor plumbing installations ($\beta = 0.42$, $p = 0.021$) and lack of proper tank cleaning ($\beta = 0.38$, $p = 0.034$). These findings reinforce the relevance of infrastructure and maintenance conditions as key drivers of microbiological risk in preschool water systems.

4. Discussion

The results of this study confirm that the microbiological quality of water in preschools in Matehuala municipality is strongly influenced by structural factors, including water supply type, storage conditions, and sanitation infrastructure availability. While urban schools met regulatory standards, rural schools—particularly those relying on poorly maintained rooftop tanks—exhibited significantly higher levels of total and fecal coliform contamination. The consistent absence of microbiological contamination in urban schools can be explained by the continuous supply of piped water from the municipal network, which is routinely chlorinated and subject to sanitary monitoring. This reflects the greater reliability of urban infrastructure compared with rural settings, rather than a deviation in sampling points or laboratory methods. It is important to note that the preschools included in this study are not routinely used by the municipal water utility as official monitoring sites for bacteriological or lead sampling. The present research therefore provides an independent assessment of water quality at the school level, complementing the surveillance activities normally carried out by the municipal system.

Residual chlorine was not directly measured in this study; however, field reports from school staff indicated that rooftop storage tanks in rural communities were rarely disinfected or cleaned, which is consistent with the higher levels of microbiological contamination observed in these schools. This finding highlights that deficiencies in routine disinfection practices represent an additional sanitary risk in remote locations.

According to staff, the main limitation for routine chlorination in rural preschools was not the cost of chlorine, which is relatively low, but the lack of infrastructure, equipment, and trained personnel to apply it properly. Consequently, stored water often remained without adequate disinfection, increasing vulnerability to microbial contamination.

Although no statistically significant correlation was found between distance to the municipal center and contamination levels, the convergence of inadequate infrastructure, negative perceptions of water quality, and the absence of regular sanitary monitoring programs reflect a persistent form of inequity in effective access to essential basic services.

This interpretation is supported by multivariate models, which demonstrated that structural and maintenance-related factors—particularly the use of rooftop tanks, poor plumbing, and lack of proper tank cleaning—were more influential on microbiological contamination than geographic distance. These results underscore that deficiencies in water infrastructure and management practices are the main determinants of sanitary risk in rural schools.

Notably, elevated concentrations of aerobic mesophilic bacteria (AMB), total coliforms (TC), and fecal coliforms (FC) were exclusively observed in rural schools with water stored in tanks. This finding is consistent with international studies that highlight heightened

health risks in rural schools due to deficiencies in water supply, sanitation, and hygiene systems [18,31,32].

Qualitative analysis complemented this evidence: contaminated schools reported poor cleaning practices, lack of sanitary drainage, and a widespread perception of water quality as "poor". This local perception, far from anecdotal, was consistent with microbiological results, validating school staff's empirical knowledge as a reliable risk indicator.

In addition, in several schools staff noted a strong odor in the water, typically associated with chlorine, reflecting the reliance on municipal disinfection practices in urban areas. This sensory experience further illustrates how user perceptions align with the sanitary conditions documented in the study.

The seriousness of the issue is further underscored by the isolation of bacteria such as *Escherichia* spp., *Klebsiella* spp., *Pseudomonas* spp., *Proteus* spp., *Enterobacter* spp., and *Citrobacter* spp., all recognized as indicators of recent fecal contamination and inadequate hygienic-sanitary conditions [33–36]. Their presence suggests deficiencies in water handling and storage, especially where containers are infrequently cleaned or exposed to environmental contaminants [37]. The identification of these bacteria in water intended for school use constitutes an epidemiological alert, given their potential to cause gastrointestinal, urinary, or systemic infections in vulnerable pediatric populations [20,38].

Our findings align with previous studies documenting microbial contamination of school water systems. In Guadalajara, Mexico, total coliforms were widespread in households with rooftop tanks and intermittent supply [39], which is consistent with the high levels observed in rural preschools. International evidence also supports these patterns: in Cruz das Almas, Brazil, 25 schools showed frequent exceedance of *E. coli* and total coliform limits [9], while a systematic review highlighted the scarcity of robust WaSH data in Brazilian schools [40]. In rural Mexico, fecal coliform contamination in spring water sources has been reported, indicating that risks extend beyond municipal supply failures to natural systems used in marginalized communities [41]. Together, these studies emphasize that storage practices, sanitation infrastructure, and inequities in service provision are central determinants of water safety in schools, and they contextualize the novel contribution of our study in documenting rural–urban disparities at the preschool level

Beyond immediate clinical effects, multiple studies have documented that re-peated exposure to enteric pathogens during childhood, even in the absence of symptoms, can trigger environmental enteropathy. This condition is characterized by chronic intestinal inflammation, dysbiosis, nutrient malabsorption, and immune dysfunction [42,43], leading to consequences such as stunted growth, malnutrition [44,45], and increased susceptibility to opportunistic infections [46–48]. Khabo-Mmekoa and Momba (2022) emphasize that contaminated water is a major transmission route for enteropathogens in developing countries, with particularly severe effects in children under five years of age [49]. Complementarily, Naylor et al. (2015) warn that environmental enteropathy may reduce the efficacy of oral vaccines, such as rotavirus and poliovirus vaccines, by compromising the immune response of children exposed to degraded sanitary environments [50].

The impact of this issue goes beyond physical or immunological effects. Cognitive development consequences have also been documented. Lorntz et al. (2006) demonstrated that children with a history of frequent diarrhea in early childhood tend to exhibit lower academic performance and deficits in functions such as working memory and verbal comprehension [51]. These effects have been attributed to the interplay between chronic inflammation, alterations in the gut–brain axis, and intestinal dysbiosis. Similarly, He et al. (2024) note that pathogen exposure can interfere with neurotransmitter production, synaptic plasticity [52], and the maturation of neuronal circuits during critical developmental periods, potentially resulting in attention deficits, learning difficulties, and

emotional regulation problems [53]. These frequently overlooked consequences directly affect educational inclusion and academic achievement.

This scenario is exacerbated when considering the technical-operational context of the municipal water system. Water supply in Matehuala depends on 12 deep wells located outside the urban area. In 2024, total production was recorded at 7.4 million m^3, but with severe failures in strategic wells such as Tanque Colorado (5.75% efficiency) and Caleros (28.5%) [54]. As a response to water quality problems, over 111 tons of sodium hypochlorite were applied, revealing a strategy focused on corrective actions without addressing critical points such as storage in uncovered or infrequently cleaned containers. In rural areas, the lack of sanitary drainage and deterioration of hydraulic infrastructure increase the risk of recontamination. Within this context, the school staff's perception of water as "poor" reflects not only a negative sensory experience but also an empirical validation of the observed health risks.

At the national level, there remains a notable scarcity of systematic studies documenting the microbiological quality of water in school environments. Most available research has been conducted in a fragmented and localized manner. For instance, Iñiguez-Muñoz et al. (2022) in Jalisco, Ávila-Díaz et al. (2024) in Sinaloa, and Rubino et al. (2019) in Guadalajara reported the presence of coliforms in school or household tanks, attributed to deficiencies in chlorination or container maintenance [11,39,55]. While valuable, these studies underscore the urgency of generating broader, systematic, and contextually grounded research at the national level, as presented herein.

This study focused exclusively on microbiological indicators. The absence of non-biological parameters such as water temperature or residual chlorine is acknowledged as a limitation, and future studies should integrate these aspects for a more comprehensive assessment. Another limitation is that the distance between the schools and the municipal water distribution system could not be uniformly reported. While for urban schools an approximate distance could be estimated given their location within or near the city of Matehuala, most rural preschools did not receive piped water directly but relied on local wells or rooftop tanks. Under these conditions, the "water age" varied considerably, introducing uncertainty regarding potential degradation of disinfectant residuals in rural settings.

Collectively, the results not only reveal regulatory non-compliance in terms of potability but also highlight a persistent structural risk compromising the physical, cognitive, and immunological development of rural children. This situation deepens existing inequalities between urban and rural contexts and calls into question the effective guarantee of the human rights to safe water, health, and education under dignified conditions.

Beyond microbiological contamination, studies in San Luis Potosí have documented the presence of inorganic hazards that also compromise water safety. High fluoride concentrations in groundwater have been reported in the San Luis Potosí Valley [56], and elevated levels of arsenic, fluoride, and total dissolved solids (TDS) have been found in different sources across the region [57]. In Matehuala, arsenic persistence in groundwater has also been confirmed, with concentrations that, while decreasing, still exceed safe thresholds [58]. While our study focused exclusively on microbiological parameters, these findings highlight that water quality challenges in the Altiplano are multidimensional, combining microbial and chemical risks that disproportionately affect vulnerable school populations.

As a low-cost approach, terminal or site-specific treatment technologies could be considered as feasible disinfection strategies for schools, such as automated chlorination units or low-cost ceramic filters. Although ultraviolet (UV) disinfection is effective, its implementation in rural preschools is hindered by energy and maintenance requirements, making automated chlorination units or ceramic filters more sustainable options under local conditions. These alternatives are more consistent with the infrastructural and economic

conditions of the studied communities and could provide an effective means of reducing microbiological risks in the absence of reliable centralized treatment.

This research contributes to sustainability by highlighting the inequities in access to safe water between urban and rural preschools, thereby supporting actions aligned with Sustainable Development Goal 6 (Clean Water and Sanitation). By documenting microbiological risks and their structural determinants—such as type of supply, storage practices, and sanitation infrastructure—our study provides evidence for interventions that promote both environmental sustainability (through safe management of local water resources) and social sustainability (by reducing health risks and supporting children's well-being in vulnerable communities). Addressing these challenges in early education settings is essential not only for protecting child health but also for fostering long-term community resilience and reducing intergenerational inequities in access to basic services.

5. Conclusions

This study evaluated the microbiological quality of water in 32 preschools within the municipality of Matehuala, San Luis Potosí. The results highlight a significant disparity between urban and rural areas, with over 60% of rural schools—especially those relying on poorly maintained water tanks—showing coliform contamination, including fecal coliforms in about one-third of cases. Based on these findings, the following conclusions are drawn:

- The mode of water supply is a key predictor of microbiological risk in the school environment. 64.3% of rural schools relied on storage in tanks, and in 100% of these cases, total coliforms exceeded regulatory limits (up to >16,000 MPN/100 mL), while 35.7% showed fecal coliforms at levels up to 311 MPN/100 mL, classifiable as high or very high risk according to WHO guidelines. In contrast, none of the urban schools (all with piped water supply) exhibited microbiological indicators beyond the permissible limits, underscoring a critical structural disparity in child health protection.
- Qualitative analysis results confirm an association between water storage type and the presence of pathogenic bacteria. The exclusive detection of *Escherichia* spp., *Klebsiella* spp., *Pseudomonas* spp., and *Proteus* spp. in rural schools with tank water supply suggests that this storage system represents a significant exposure risk to microbiological agents, reinforcing the need to improve sanitary infrastructure conditions in rural areas.
- From a contextual perspective, schools testing positive for fecal coliforms also shared other structural characteristics: 100% stored water in tanks, 80% lacked sanitary drainage, 60% exhibited poor cleaning conditions of storage containers, and 80% of school staff perceived the water quality as "poor" ($p < 0.05$ for all associations). These conditions, beyond being statistically significant, reflect a sustained and systematically overlooked pattern of structural risk.
- Inferential analysis using non-parametric tests (Mann–Whitney U) demonstrated significant differences ($p = 0.000$) in total and fecal coliform levels across geographic zones and types of water supply, confirming that microbiological risk is not randomly distributed but determined by structural environmental conditions.

Although viral and parasitic contaminants were not analyzed, and helminth eggs were not detected, the findings demonstrate that formal access to water does not guarantee its safety, particularly in contexts with limited infrastructure. It is recommended to implement point-of-use treatment technologies that are sustainable and adapted to rural conditions, such as dosed chlorination systems or ceramic filters, accompanied by regular microbiological monitoring and training of school personnel in water hygiene and resource management. This comprehensive approach is key to advancing true water security in educational environments. The study provides robust evidence to guide public policies

focused on water justice and educational equity, affirming that access to safe water in schools is essential for the well-being and development of children.

Author Contributions: Conceptualization, M.C.d.R.T.-G.; methodology, M.C.d.R.T.-G. and P.C.-A.; software, F.J.H.-R. and H.A.A.-M.; validation, H.A.A.-M. and I.C.-M.; writing—original draft preparation, M.C.d.R.T.-G. and P.C.-A.; writing—review and editing, M.C.d.R.T.-G. and P.C.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request to the corresponding author. The data are not publicly available due to ethical and privacy considerations related to the information collected from educational institutions and respondents during the research.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. WHO (World Health Organization). *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum*; WHO Press: Geneva, Switzerland, 2017.
2. Bain, R.; Cronk, R.; Wright, J.; Yang, H.; Slaymaker, T.; Bartram, J. Fecal contamination of drinking-water in low- and middle-income countries: A systematic review and meta-analysis. *PLoS Med.* **2014**, *11*, e1001644. [CrossRef]
3. OMS Drinking-Water. World Health Organization. 2022. Available online: https://www.who.int/news-room/fact-sheets/detail/drinking-water (accessed on 15 May 2024).
4. Morales, F.; La Paz, M.; Leon, M.; Rivero-Pino, F. Effects of Malnutrition on the Immune System and Infection and the Role of Nutritional Strategies Regarding Improvements in Children's Health Status: A Literature Review. *Nutrients* **2023**, *16*, 1. [CrossRef]
5. Chiabi, A.; Obadeyi, B.; Nguefack, F.; Chiabi, R.; Berinyuy, E.; Chiabi, E.; Mbang, T.; Obama, M. The Vicious Cycle of Malnutrition and Childhood Infections—What are the policy implications? *Arch. Pediatr. Neonatol.* **2018**, *1*, 21–25. [CrossRef]
6. Ashour, F. Impact of Different Exposures, Including Environmental Enteropathies, on Gut Flora and Integrity. In *The Biology of the First 1000 Days*; CRC Press: Boca Raton, FL, USA, 2017; pp. 303–320. [CrossRef]
7. Syed, S.; Ali, A.; Duggan, C. Environmental Enteric Dysfunction in Children. *J. Pediatr. Gastroenterol. Nutr.* **2016**, *63*, 6–14. [CrossRef] [PubMed] [PubMed Central]
8. Acosta, A.M.; De Burga, R.R.; Chavez, C.B.; Flores, J.T.; Olotegui, M.P.; Pinedo, S.R.; Salas, M.S.; Trigoso, D.R.; Vasquez, A.O.; Ahmed, I.; et al. Early childhood cognitive development is affected by interactions among illness, diet, enteropathogens and the home environment: Findings from the MAL-ED birth cohort study. *BMJ Glob. Health* **2018**, *11*, e000752. [CrossRef]
9. Andrade, M.; Barros, L.; Rodrigues, T.; De Lima Santos, M.; Lima, D. Microbiological evaluation of drinking water available in schools in Cruz das Almas, Brazil. *Afr. J. Microbiol. Res.* **2016**, *10*, 1759–1766. [CrossRef]
10. Rodriguez-Alvarez, M.; Weir, M.; Pope, J.; Seghezzo, L.; Rajal, V.; Salusso, M.; Moraña, L. Development of a relative risk model for drinking water regulation and design recommendations for a peri urban region of Argentina. *Int. J. Hyg. Environ. Health* **2015**, *218*, 627–638. [CrossRef]
11. Iñiguez-Muñoz, L.E.; Anaya-Esparza, L.M.; Castañeda-Villanueva, A.A.; Martínez-Esquivias, F.; Carvajal-Hernández, M.; Méndez Robles, M.D. Calidad microbiológica del agua potable utilizada en escuelas públicas de la ciudad de Tepatitlán, Jalisco. *Boletín Cienc. Agropecu. ICAP* **2022**, *8*, 33–39. [CrossRef]
12. INEGI. Censo de Población y Vivienda 2020: Servicios Básicos. Instituto Nacional de Estadística y Geografía. 2022. Available online: https://www.inegi.org.mx (accessed on 8 May 2024).
13. UNICEF. Progress on Drinking Water, Sanitation and Hygiene in Schools: 2000–2023 Data Update. WHO/UNICEF Joint Monitoring Programme (JMP). 2023. Available online: https://washdata.org/ (accessed on 15 June 2025).
14. Coswosk, É.; Neves-Silva, P.; Modena, C.; Heller, L. Having a toilet is not enough: The limitations in fulfilling the human rights to water and sanitation in a municipal school in Bahia, Brazil. *BMC Public Health* **2019**, *19*, 137. [CrossRef] [PubMed]
15. Odiyo, J.; Mathoni, M.; Makungo, R. Health Risks and Potential Sources of Contamination of Groundwater Used by Public Schools in Vhuronga 1, Limpopo Province, South Africa. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6912. [CrossRef] [PubMed]
16. Shrestha, G.; Shrestha, M.; Byanju, R. Assessment of Bacterial Contamination in Drinking water of Schools of Tokha Municipality, Kathmandu. *J. Environ. Sci.* **2022**, *8*, 94–106. [CrossRef]

17. Khalil, R.; Mahmoud, N. Assessment of drinking water quality at public schools at Jenin Directorate of Education, Palestine. *Desalination Water Treat.* **2022**, *275*, 196–206. [CrossRef]
18. Morgan, C.; Bowling, J.; Bartram, J.; Kayser, G. Attributes of drinking water, sanitation, and hygiene associated with microbiological water quality of stored drinking water in rural schools in Mozambique and Uganda. *Int. J. Hyg. Environ. Health* **2021**, *236*, 113804. [CrossRef]
19. Waideman, M.; Teixeira, V.; Uemura, E.; Stamford, T.; Leal, D.; Stangarlin-Fiori, L.; Ferreira, S.; Taconeli, C.; Beux, M. Enterococci used as complementary indicator of fecal contamination to assess water quality from public schools in the city of Curitiba, Paraná, Brazil. *Braz. J. Food Technol.* **2020**, *23*, e2019155. [CrossRef]
20. Ahmed, J.; Wong, L.; Chua, Y.; Channa, N.; Mahar, R.; Yasmin, A.; Vanderslice, J.; Garn, J. Quantitative Microbial Risk Assessment of Drinking Water Quality to Predict the Risk of Waterborne Diseases in Primary-School Children. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2774. [CrossRef]
21. Speak, A.; Escobedo, F.; Russo, A.; Zerbe, S. Comparing convenience and probability sampling for urban ecology applications. *J. Appl. Ecol.* **2018**, *55*, 2332–2342. [CrossRef]
22. *NOM-230-SSA1-2002*; Environmental Health. Sanitary Requirements for Public and Private Water Supply Systems, as Well as Requirements for Water Purification. Secretaría de Salud: Mexico City, Mexico, 2002. Available online: https://www.dof.gob.mx (accessed on 25 April 2024).
23. Manga, M.; Balanji, E.; Nkhata, R. Storage tanks and water handling practices: A systematic review of their effects on household water quality. *Environ. Syst. Res.* **2021**, *10*, 18. [CrossRef]
24. Fall, M.; Kane, C.; Niang, A. Multilevel analysis of access to drinking water in rural communes in the south of the Kaffrine region, Senegal. *Discov. Water* **2024**, *4*, 41. [CrossRef]
25. Kouamé, P.K.; Galli, A.; Peter, M.; Loss, G.; Wassa, D.; Bonfoh, B.; Utzinger, J.; Winkler, M.S. Access to Water and Sanitation Infrastructures for Primary Schoolchildren in the South-Central Part of Côte d'Ivoire. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8863. [CrossRef]
26. *NOM-127-SSA1-1994*; Environmental Health. Water for Use and Human Consumption. Permissible Quality Limits and Treatments that Water Must Undergo for Its Purification. Secretaría de Salud: Mexico City, Mexico, 1994. Available online: https://www.dof.gob.mx (accessed on 1 October 2024).
27. *NOM-092-SSA1-1994*; Goods and Services. Method for the Plate Count of Aerobic Bacteria. Secretaría de Salud: Mexico City, Mexico, 1995.
28. MacFaddin, J.F. *Biochemical Tests for Identification of Medical Bacteria*, 3rd ed.; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2000.
29. World Health Organization (WHO) and the United Nations Children's Fund (UNICEF). Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. 2017. Available online: https://data.unicef.org/resources/progress-drinking-water-sanitation-hygiene-2017-update-sdg-baselines/ (accessed on 21 August 2024).
30. Fentie, M.; Abebe, T.; Alemayehu, E.; Mengesha, S.; Melaku, T. Determinant factors of microbial drinking water quality at the point of use in rural Ethiopia: A case study of the South Gondar Zone. *Water* **2024**, *16*, 1651. [CrossRef]
31. Diagbouga, S.; Nadembega, C.; Zabre, H.; Kabore, A.; Tarnagda, G.; Angulo, P.; Sinare, L.; Cisse, G. Microbiological quality of schoolchildren's drinking water in the rural communes of Coalla and Manni in the Eastern region of Burkina Faso. *SOJ Microbiol. Infect. Dis.* **2018**, *6*, 1–8. [CrossRef]
32. Srećković, M.; Čapo, N.; Dugandžija, T.; Vujkovic, B.; Dragičević, I.; Damnjanović, B.; Đekić-Malbaša, J. Assessment of microbiological quality of drinking water and sanitary-hygienic conditions in rural primary schools of the Mačva District, Serbia. *Glas. Javnog Zdr.* **2024**, *98*, 280–295. [CrossRef]
33. Nowicki, S.; O'Leary, C.; Mutua, A.; Kiiru, J.; Crump, J.A.; Egorov, A.I. The utility of Escherichia coli as a contamination indicator for rural drinking water: Evidence from whole-genome sequencing of isolates from Kitui County, Kenya. *PLoS ONE* **2021**, *16*, e0245910. [CrossRef]
34. Salamandane, A.; Vila-Boa, F.; Malfeito-Ferreira, M.; Brito, L. High Fecal Contamination and High Levels of Antibiotic-Resistant Enterobacteriaceae in Water Consumed in the City of Maputo, Mozambique. *Biology* **2021**, *10*, 558. [CrossRef] [PubMed]
35. Khanna, R.; Bhushan, K. Microbial safety and antibiotic resistance profiles of drinking water sources in Ludhiana, Punjab, India. *Int. J. Environ. Health Res.* **2025**, *35*, 1–15. [CrossRef]
36. Otorkpa, O.J. Overview of major bacterial contaminants of drinking water in Nigeria: A review. *Int. J. Pathog. Res.* **2019**, *2*, 1–9. [CrossRef]
37. Judah, L.A.; Beckerman, A.P.; Rakotoarisoa, A.; Randriamanantena, D.; Brown, J. Occurrence and mitigation of bacterial regrowth in stored household water in eastern coastal Madagascar. *Water* **2024**, *16*, 1592. [CrossRef]
38. Aw, T.; Scott, L.; Jordan, K.; Ra, K.; Ley, C.; Whelton, A. Prevalence of opportunistic pathogens in a school building plumbing during periods of low water use and a transition to normal use. *Int. J. Hyg. Environ. Health* **2022**, *241*, 113945. [CrossRef]

39. Rubino, F.; Corona, Y.; Jiménez Pérez, J.G.; Smith, C. Bacterial contamination of drinking water in Guadalajara, Mexico. *Int. J. Environ. Res. Public Health* **2019**, *16*, 67. [CrossRef]
40. Poague, K.; Blanford, J.; Martinez, J.; Anthonj, C. Water, sanitation and hygiene (WASH) in schools in Brazil pre-and peri-COVID-19 pandemic: Are schools making any progress? *Int. J. Hyg. Environ. Health* **2022**, *247*, 114069. [CrossRef]
41. Colín Carreño, R.; Hernández, G.; López, M. Human health risk and quality assessment of spring water associated with fecal coliforms in rural Mexico. *Water* **2023**, *15*, 1863. [CrossRef]
42. Prendergast, A.; Kelly, P. Enteropathies in the developing world: Neglected effects on global health. *Am. J. Trop. Med. Hyg.* **2012**, *86*, 756–763. [CrossRef] [PubMed]
43. Tickell, K.D.; Atlas, H.E.; Walson, J.L. Environmental enteric dysfunction: A review of potential mechanisms, consequences and management strategies. *BMC Med.* **2019**, *17*, 181. [CrossRef]
44. Petek, O.; Aydın, N. Evaluation of the Drinking Water Parameters in Primary and Secondary Schools Located in the Gaziantep Province Center. *J. Water Health* **2024**, *22*, 2423–2430. [CrossRef]
45. Budge, S.; Parker, A.H.; Hutchings, P.T.; Garbutt, C. Environmental enteric dysfunction and child stunting. *Nutr. Rev.* **2019**, *77*, 240–253. [CrossRef]
46. Gilmartin, A.A.; Petri, W.A. Exploring the role of environmental enteropathy in malnutrition, infant development, and oral vaccine response. *Philos. Trans. R. Soc. B Biol. Sci.* **2015**, *370*, 20140143. [CrossRef]
47. Kabir, F.; Iqbal, J.; Jamil, Z.; Iqbal, N.; Mallawaarachchi, I.; Aziz, F.; Kalam, A.; Muneer, S.; Hotwani, A.; Ahmed, S.; et al. Impact of enteropathogens on faltering growth in a resource-limited setting. *Front. Nutr.* **2023**, *9*, 1081833. [CrossRef]
48. Vonaesch, P.; Vonaesch, P.; Morien, E.; Andrianonimiadana, L.; Sanke, H.; Mbecko, J.; Huus, K.; Naharimanananirina, T.; Gondje, B.; Nigatoloum, S.; et al. Stunted childhood growth is associated with decompartmentalization of the gastrointestinal tract and overgrowth of oropharyngeal taxa. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, E8489–E8498. [CrossRef] [PubMed]
49. Khabo-Mmekoa, C.; Momba, M. The Impact of Social Disparities on Microbiological Quality of Drinking Water Supply in Ugu District Municipality of Kwazulu-Natal Province, South Africa. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2972. [CrossRef]
50. Naylor, C.; Lu, M.; Haque, R.; Mondal, D.; Buonomo, E.; Nayak, U.; Mychaleckyj, J.C.; Kirkpatrick, B.; Colgate, R.; Carmolli, M.; et al. Environmental enteropathy, oral vaccine failure and growth faltering in infants in Bangladesh. *eBioMedicine* **2015**, *2*, 1759–1766. [CrossRef]
51. Lorntz, B.; Soares, A.M.; Moore, S.R.; Pinkerton, R.; Gansneder, B.; Bovbjerg, V.E.; Guyatt, H.; Lima, A.A.; Guerrant, R.L. Early childhood diarrhea predicts impaired school performance: A long-term prospective cohort study. *Pediatr. Infect. Dis. J.* **2006**, *25*, 513–520. [CrossRef] [PubMed]
52. He, Y.; Wang, K.; Su, N.; Yuan, C.; Zhang, N.; Hu, X.; Fu, Y.; Zhao, F. Microbiota–gut–brain axis in health and neurological disease: Interactions between gut microbiota and the nervous system. *J. Cell. Mol. Med.* **2024**, *28*, e70099. [CrossRef]
53. Interino, N.; Vitagliano, R.; D'Amico, F.; Lodi, R.; Porru, E.; Turroni, S.; Fiori, J. Microbiota–Gut–Brain Axis: Mass-Spectrometry-Based Metabolomics in the Study of Microbiome Mediators—Stress Relationship. *Biomolecules* **2025**, *15*, 243. [CrossRef]
54. Sistema de Agua Potable, Alcantarillado y Saneamiento de Matehuala (SAPSAM). Informe Del Uso de Agua 2024. SAPSAM. Available online: http://sapsam-matehuala.com.mx/Informe%20Anual%202024.pdf (accessed on 21 January 2025).
55. Ávila-Díaz, J.A.; Arciniega-Galaviz, M.A.; Moreno-Rentería, K.J.; Llanes-Cárdenas, O. Contaminación microbiológica en agua potable de localidades rurales en el municipio de Ahome, Sinaloa, México. *Rev. Iberoam. Investig. Desarro. Educ. RIDE* **2024**, *15*, e781. [CrossRef]
56. Torres-Rivera, S.; Torres-Hernández, J.R.; Carranco-Lozada, S.E.; García-Arreola, M.E.; López-Doncel, R.A.; Montenegro-Ríos, J.A. Anthropogenic Contamination in the Free Aquifer of the San Luis Potosí Valley. *Int. J. Environ. Res. Public Health* **2023**, *20*, 6152. [CrossRef] [PubMed]
57. Martínez-Oviedo, A.; Monterrubio-Martínez, E.; Tuxpan-Vargas, J. Assessing the water contaminants in San Luis Potosi and its effects on its inhabitants: An interdisciplinary study on environmental contamination and public health. *J. Hazard. Mater.* **2024**, *464*, 132828. [CrossRef] [PubMed]
58. Gómez-Hernández, A.; Hernández-Martínez, J.L.; Meza-Figueroa, D.; Martínez-Villegas, N.; SenGupta, B. Arsenic transport from groundwater to soil solid phase in Matehuala (Mexico). In *Arsenic Research and Global Sustainability*; Sengupta, B., Ed.; CRC Press: Boca Raton, FL, USA, 2023; pp. 44–46. [CrossRef]

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