 doi:10.20944/preprints201812.0053.v1

Article

Bacterial Contamination of Drinking Water in Guadalajara, Mexico

Francesca Rubino [1], Yahaira Corona [2], José Guadalupe Jiménez Pérez [2], and Charlotte Smith [1,*]

[1] University of California, Berkeley, Berkeley, California 94720 rubinofrancesca@berkeley.edu charlottesmith@berkeley.edu

[2] Instituto de Investigaciones Tecnológicas del Agua, Guadalajara, Jalisco, MX yahaira.corona@iitaac.org.mx jose.jimenez@iitaac.org.mx

* Author to whom correspondence should be addressed: charlottesmith@berkeley.edu Tel.: +1-415-250-0133

Abstract In many regions where drinking water supply is intermittent and unreliable, households adapt by storing water in cisterns or rooftop tanks. Both intermittent supply and stored water can be vulnerable to contamination by microorganisms with deleterious health effects. The Guadalajara Metropolitan Area is a rapidly growing urban center with over five million residents where household storage is nearly ubiquitous. This pilot study was conducted in July 2018 to examine the microbiological quality of drinking water in Guadalajara. Samples were tested for free available chlorine residual, total coliform bacteria, and *E. coli.* A survey on access to water and public perspectives was also conducted. Water exiting rooftop tanks exceeded regulatory limits for total coliform levels in half of the homes studied. Piped water arriving at two homes had total coliform levels that far exceeded regulatory limits. No *E. coli* were detected in any of the samples. Only 35% of homes had a chlorine residual between the recommended 0.2 and 1.5 mg/L. Many homes reported unpleasant odors and colors. Only 7% of residents drank the piped water. Future studies are needed, especially during April and May when many homes reported a higher disruption to water service.

Keywords: Guadalajara; coliform; intermittent water supply; Colilert, tanks

---

1. Introduction

A key target of the Millennium Development Goals was to halve the proportion of the population without access to safe drinking water by 2015. In an effort to increase access, piped water supply systems have quickly expanded in developing countries such as Mexico. Between 1990 and 2015 the percentage of Mexico's population with access to "improved" drinking water increased from 82% to 96% [1]. "Improved" denotes the construction of the water system (e.g., piped water, protected well). However, studies suggest that these "improved" drinking water systems are not analogous to clean, safe drinking water systems when assessed instead by water quality criteria [2,3].

A major issue with "improved" drinking water systems in developing nations is the lack of consistent water supply. Previous studies have shown that the changes in hydraulic pressure due to intermittent water supply (IWS) lead to microbial contamination that can cause dangerous gastrointestinal illnesses [4–8]. In addition, household practices to cope with intermittent water supply can introduce microbial contamination at the point of use. Many homes in Mexico store water either in rooftop tanks or in underground cisterns in order to maintain access to water when there is a lapse in the supply. This practice may affect the risk of diarrheal disease [9,10].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 December 2018 doi:10.20944/preprints201812.0053.v1

Figure 1. Typical rooftop tanks in Guadalajara

This study focused on Mexico's second largest city, where the practice of using cisterns and rooftop tanks is nearly ubiquitous (Figure 1). The Metropolitan Zone of Guadalajara (ZMG) encompasses the municipalities of San Pedro, Tlaquepaque, Tonalá, Zapopan, Tlajomulco de Zúñiga, El Salto, and Guadalajara. The region is the second most heavily populated in Mexico, with a population that surpassed five million in 2017 [11], and is expected to reach seven million by 2025 [12]. Rapid population growth and over-exploitation of the water supply have resulted in a severe water crisis [13]. The primary water source, Lake Chapala, provides around 60% of the region's water [14]. Wells and the Río Calderón serve as secondary sources. Water in the ZMG is provided by the Sistema Intermunicipal de los Servicios de Agua Potable y Alcantarillado (SIAPA). Despite high public concern about the quality of drinking water from these sources, access to independent studies on water quality and data from SIAPA have been limited. The objective of this study was to describe possible issues connected with IWS in the ZMG through a two- fold approach. The first part of the study analyzed biological, chemical and physical parameters linked to microbial contamination. The second part collected information on the public's perception of water quality.

2. Materials and Methods

Sampling took place in July 2018 during the rainy season. No publicly available maps delineate the source of water (Lake Chapala or groundwater). Therefore, specific conductivity was measured at 51 houses to determine the water source for each location. Chlorine residual was measured at each house. Samples were taken for coliform bacteria and *E. coli* at 10 of the 51 houses (before and after the storage tank or cistern). A map was created to illustrate the chlorine residual values using QGIS.

To limit ancillary variables, samples taken for bacteriological testing were from areas within the ZMG serviced by the main water provider, SIAPA, and supplied from the main water source, Lake Chapala. The ten homes were chosen based upon willingness to participate, dependency on a rooftop tank, and proximity to the other homes such that all ten homes were accessible by vehicle within a six hour round trip. This six hour maximum holding time between collection and incubation is recommended by the World Health Organization [15]. Within each neighborhood, houses were approached until a person agreed to participate, or a local contact was able to facilitate access. Each home was tested twice at the same time of day. The Hach DR900™ (method 8021) was used to test for residual chlorine, the IDEXX Colilert-18™ MPN test was used to test for total coliform bacteria, and the IDEXX Colilert-18™ test for fluorescence was used to test for *E. coli*. Analysis of results were compared to the standards stated in the revised Official Mexican Standard NOM-127-SSA1-1994 [16].

In low-resourced settings it can be difficult to obtain access to an incubator. Due to this limitations, an incubator was constructed from a reptile heating lamp, a Styrofoam container, and aluminum foil. A cloth sheet was placed between the lamp and the container to prevent bright light from reaching the samples. The temperature was monitored constantly over the 28 hour incubation period. Sample results were analyzed at 24 hours and again at 28 hours.

In addition to the water quality tests, a brief survey on water access and perception was conducted in Spanish. Permission for sampling was obtained by the local not-for-profit organization Instituto de Investigaciones Tecnológicas del Agua (IITAAC) in Spanish. They conducted all surveying during sample collection. Homeowners' verbal consent was obtained to collect samples after explaining the purpose of the study and that no one was obliged to answer any questions. No personal identifiers were obtained. Participants were asked about their water storage devices, how often they cleaned them, how they used the piped water, the intermittency of the supply, and the perceived aesthetic quality of the water. A total of 61 surveys were completed.

3. Results

3.1.Chlorine Residuals

Chlorine residuals of the water supplied directly from the SIAPA infrastructure varied greatly throughout the ZMG. The results are shown in Figure 2. For houses that participated in the microbial testing, only the chlorine residual value from the first day is shown. In five locations, chlorine residuals exceeded the local standard of 1.5 mg/L. In 26 locations, chlorine residuals were below the minimum local standard of 0.2 mg/L. Of the 51 homes visited, only 18 homes had a chlorine residual that met the local permissible range of 0.2 to 1.5 mg/L. Figure 3 displays houses with chlorine residual results that met the standard in blue, houses that were below the standard (0.2 mg/L) in yellow, and above the standard (1.5 mg/L) in red. Figure 4 shows the results of the chlorine residual testing from the 10 sites chosen for microbial analysis. Chlorine residual measurements were highly variable between sample sites and between days. Given the small sample size, a statistical analysis was not conducted.

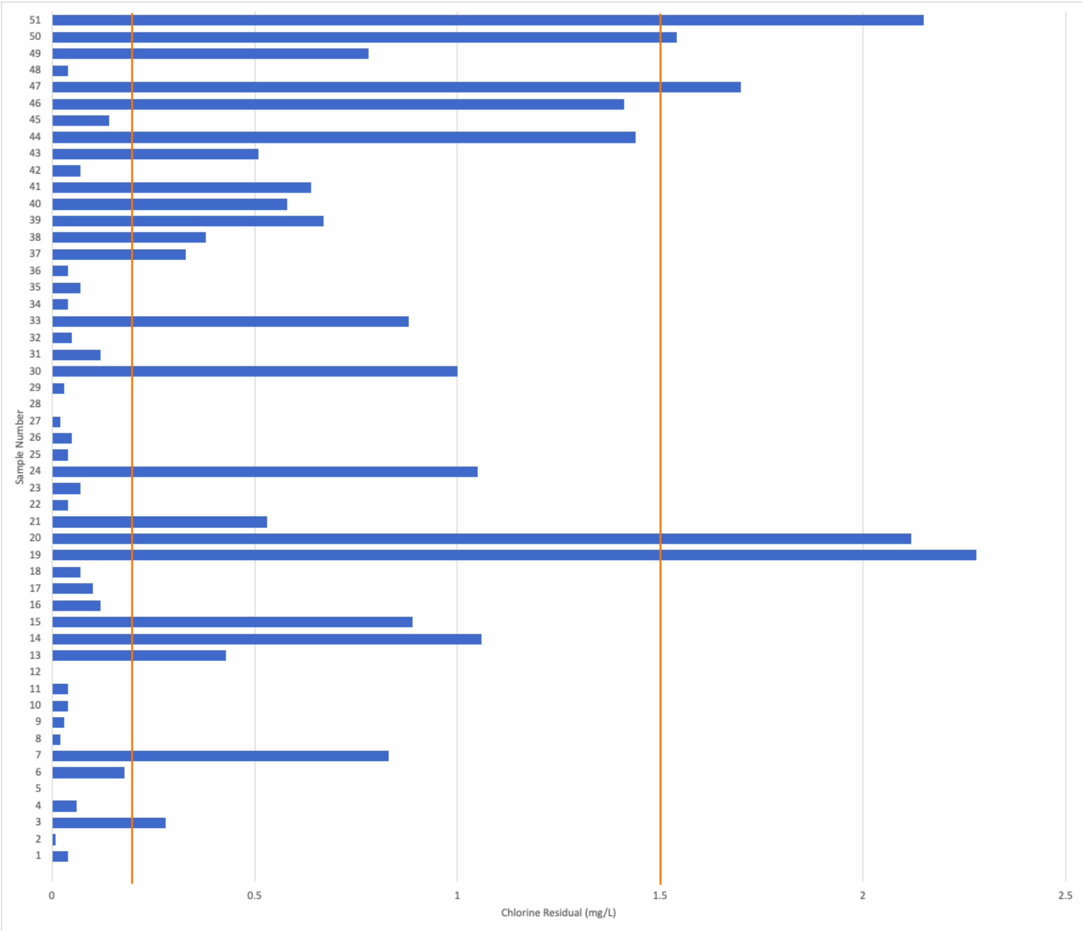

Figure 2. Chlorine residual in the ZMG, July 2018. Mexican drinking water standards require chlorine residual to be between 0.2 and 1.5 mg/L; this range is demarcated by the red lines.

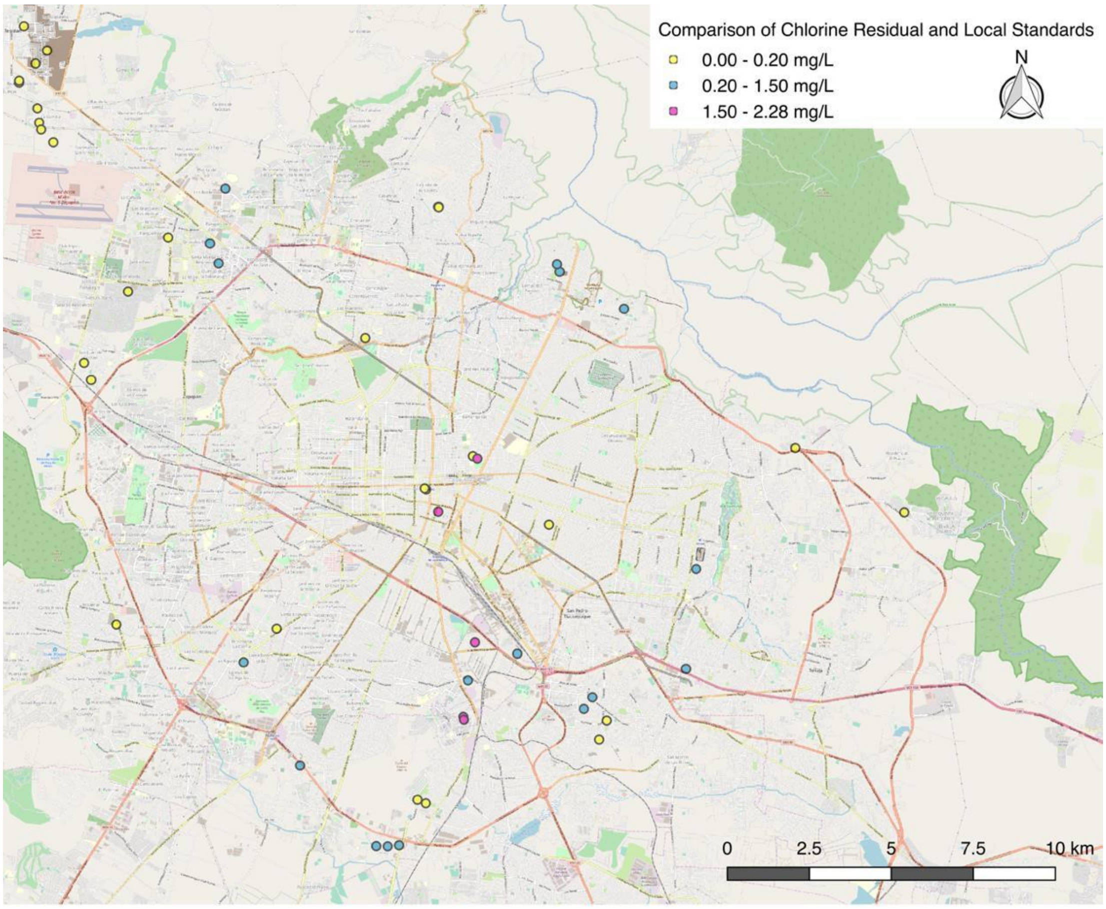

Figure 3. Map of chlorine residuals in the ZMG, July 2018.

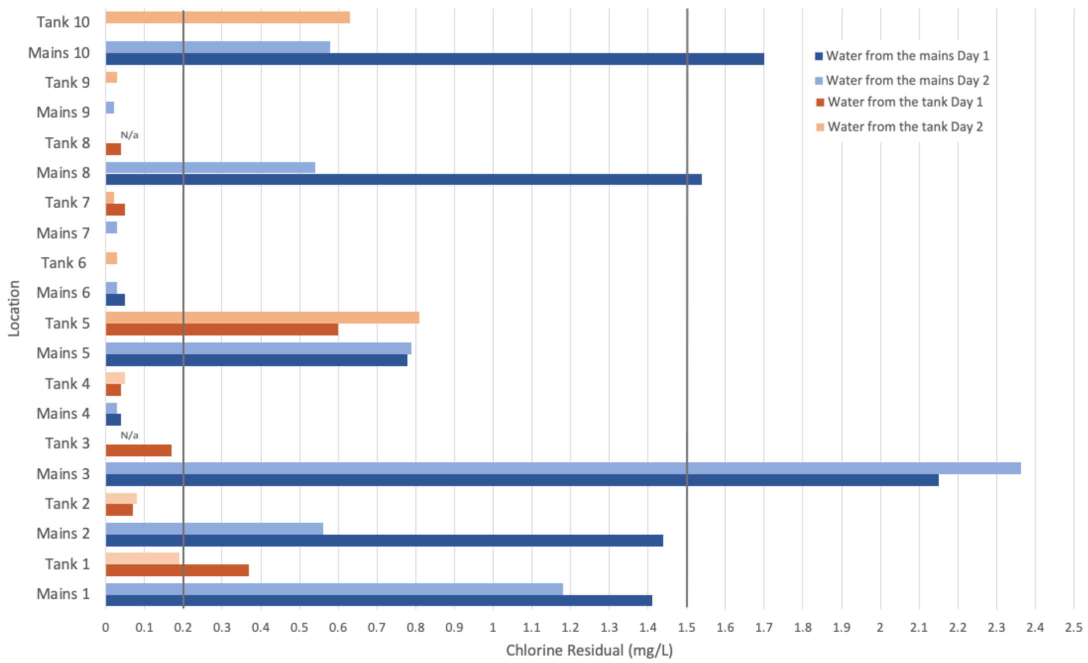

Figure 4. Changes in chlorine residual in the region of the ZMG supplied by Lake Chapala/SIAPA in July 2018. Measurements were taken at the same time in each location. Mexican drinking water standards require chlorine residual to be between 0.2 and 1.5 mg/L; this range is demarcated by the vertical lines in bold.

3.2. Microbial Analysis

The results of the microbial analysis are presented in Table 1. No changes in results occurred between the 24 and 28 hour analysis times. No *E. coli* was detected. However, at the exterior taps of two homes (representing water from the SIAPA infrastructure), total coliform counts exceeded the local standards of no detectable organisms in 100 ml. Samples taken from taps supplied by the water tanks at five of the 10 homes showed contamination. Three of the five homes which exhibited higher than acceptable total coliform counts had old water tanks models. Two of the homes which exhibited higher than acceptable total coliform counts in the water drawn from the tanks, but no more than 1.1 MPN in the water drawn from the mains, reported a low frequency of cleaning the water tanks. In one home the single cleaning that occurred within the past 12 months was insufficient to prevent contamination.

Table 1. Colilert-18™ Results. MPN is calculated using 10, 10mL test tube analysis except where noted.

Type of Tank	Tank Chlorine (mg/L)	Mains Chlorine (mg/L)	Presence/Absence of total coliforms	Tank MPN	Mains MPN
Older model	0.37	1.41	Presence	9.2[a]	<1.1
Rotoplast	0.07	1.44	Absence	<1.1	1.1
Older model	0.17	2.15	Absence	<1.1	<1.1
Older model (Rotoplast)	0.04	0.04	Presence	>23	>23
Older model	0.6	0.78	Absence	<1.1	<1.1[b]
Rotoplast	0	0.05	Presence	<1.1	1.1[c]
Rotoplast	0.05	0	Presence	5.1	1.1
Rotoplast	0.04	1.54	Absence	<1.1	<1.1
Rotoplast	0	0	Presence	>23	>23
Older model	0	1.7	Presence	3.6	<1.1

[a]MPN is calculated from 8 samples; [b]One test tube only contained 5m; [c]MPN is calculated from 9 samples. Chlorine results presented are those collected on the first day.

3.3. Survey

The survey showed that most households depended on a rooftop tanks and that rooftop tanks were more common than cisterns. Additionally, at least one household was not actively using their cistern. Asbestos rooftop tanks were more common in older regions of the city; only six houses that we visited had rooftop tanks made with asbestos. The other 45 rooftop tanks were plastic Rotoplast™ models. Of the 34 homes with cisterns, 11 were asbestos. The other 22 were plastic or concrete. Of the 51 households with tanks, eight had never cleaned their tanks. The longest anyone remembered cleaning their tanks was 10 years. One person rented their home and did not know when the tank was cleaned.

Only four families out of 61 consumed water from the public supply. One of these families filtered the water before consumption. It was more common to use the water for cleaning produce and for cooking. However, it was common practice to filter or boil the water or add disinfectant when washing fruits and vegetables or using it for cooking. A summary of the survey results is shown in

Tables 2 and 3. Nearly half of the homes reported unpleasant odors and 59% reported unpleasant colors. During sampling, brown or yellow water was observed at multiple homes. Odors of high chlorine levels or stale water were observed at several locations. Interviewees reported a higher disruption to water service and increased odors and colors during the dry season, particularly in the months of April and May, which is consistent with the decreased water quality reported in May by COFEPRIS, Mexico's Federal Commission for the Protection against Sanitary Risk (Figure 5) [17].

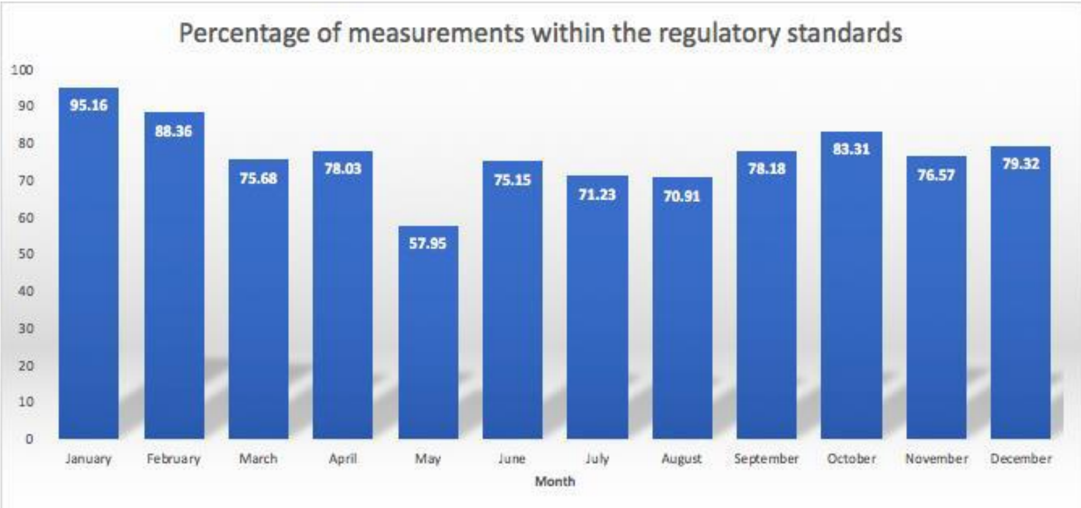

Figure 5. Monthly variation in water quality in 2015 assessed by Mexican regulatory standards according to NOM- 127-SSA1-1994.[9]

Table 2. Survey Results on Public Perception of Drinking Water

Description	Yes	No	% (Yes) Usage of Tap Water
Drinking	4[a]	57	7
Washing fruits & vegetables	58[b]	3	95
Cooking	12[c]	49	20
Observed Water Aesthetic			
Unpleasant Odors	28	33	46
Unpleasant Colors	36	25	59

[a]One home drank the water after additional filtration; [b]Includes households which take extra precautionary steps such as additional filtration or adding disinfectant; [c]Includes households which take extra precautionary steps such as additional filtration or boiling.

Table 3. Survey Results on Intermittent Water Supply Device

Description	n[a]	%	Description	n[a]	%
Storage Device			Last tank cleaning		
Rooftop tank	27	44	<1 month	7	17
Cistern	2	3	1-6 months	11	22
Both	32	52	6-12 months	12	24
Tank Type			12-24 months	8	16
Concrete/ Plastic	44	86	25-60 months	2	4
Asbestos	7	14	>5 years	12	24
Cistern Type			Last cistern cleaning		
Concrete/ Plastic	22	65	<1 month	5	15
Asbestos	11	32	1-6 months	8	26
Frequency of tank cleaning			6-12 months	10	29
>1 year	23	46	12-24 months	4	12
1-3 years	6	12	25-60 months	1	3
3-5 years	3	6	>5 years	8	24
>10 years	19	37			
Frequency of cistern cleaning					
>1 year	16	47			
1-3 years	3	9			
3-5 years	0	0			
>10 years	15	44			

[a] Number of answers

4. Discussion

The results of this pilot study suggest that there may be serious issues concerning the water quality in the ZMG that merit further investigation. Many households reported fluctuations in service from daily cuts to annual losses of service. Participants stated that these events were often associated with unpleasant colors and odors. Although such aesthetic problems are not always harmful, they can be related to contamination. The high chlorine residual in some areas was reported as alarming to residents who complained that their water smelled overwhelmingly of chlorine. Furthermore, these results suggest that disinfection practices in the system may need improvement to supply water that is both palatable and safe.

The effect of the region's intermittent water supply may also have a secondary impact on health through the storage systems. Over 42% of people surveyed had not cleaned their water storage devices within a year of the study, and half of the homes tested had contaminated water exiting their water tank. These results indicate that water storage systems, and thus the intermittent water supply that causes these devices to be necessary, may be a contributing factor to exposure of microbial contaminants. Furthermore, the survey showed that the public had low confidence in the quality of water supplied by SIAPA. The lack of perceived access to clean drinking water may have serious health implications if the lack of perceived access to clean water encourages the consumption of sugary drinks.

As a pilot study, there were clear limitations in our ability to assess the overall microbial quality and public perception of water in the ZMG. The difficulty randomizing participation in the study and the limited sample size mean that the heterogeneity in water quality and perception in the ZMG were not fully captured. During the survey, some respondents indicated that they did not use the water for cooking but were observed using the water to boil food. Furthermore, only adults were interviewed. In at least one home children drank the water without a parent's permission, suggesting that the number of people who are exposed to the water may be higher. It can be difficult to maintain proper conditions during the transportation of samples from the field in warm, rainy climates and improvements in field testing conditions could improve results. Finally, the incubator's design could be improved to limit samples' exposure to light. However, these results demonstrate the real need to further evaluate the water quality that is supplied to over five million people.

5. Conclusions

In this limited study, drinking water in homes in Guadalajara was found to be contaminated with coliform bacteria, and/or had a chlorine residual outside of regulatory norms. Future studies are needed to understand the complicated issues concerning water quality in the ZMG. A longer study would help evaluate the effects of the intermittent water supply and the risk of contamination. In addition to further studies needed to characterize the impact storing water in roof-top tanks or cisterns on water quality, environmental scientists will need to work together with city planners and community members to not only provide clean drinking water but to improve the infrastructure and build the public's appreciation of water.

Author Contributions Conceptualization, Charlotte Smith, and Francesca Rubino; methodology, Charlotte Smith and Francesca Rubino; validation, Charlotte Smith; formal analysis, Francesca Rubino and Charlotte Smith; investigation, Francesca Rubino and Yahaira Corona; resources, Francesca Rubino and José Guadalupe Jiménez Pérez; data curation, Francesca Rubino and Yahaira Corona; writing—original draft preparation, Francesca Rubino and Charlotte Smith; writing—review & editing, Charlotte Smith and Francesca Rubino; visualization, Francesca Rubino; supervision, Charlotte Smith and José Guadalupe Jiménez Pérez; project administration, Francesca Rubino, Charlotte Smith, and José Guadalupe Jiménez Pérez; funding acquisition, Francesca Rubino and Charlotte Smith.

Funding: This research was partially funded by the University of California Institute for Mexico and the United States (UC MEXUS) Small Grant, and by the Center for Latin American Studies at UC Berkeley Tinker Summer Research Grant.

Acknowledgments: The authors thank Monserrat Aracili Ortega Linares and José Arturo Gleason Espindola for assistance with logistics. Equipment was graciously loaned to the project by the Universidad de Guadalajara, Centro Universitario de Arte Arquitectura y Diseño. Office and laboratory space were provided by the Instituto de Investigaciones Tecnológicas del Agua.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. United Nations International Children's Emergency Fund; Organisation mondiale de la santé *Progress on drinking-water and sanitation: 2015 update and MDG assessment*; World Health Organization ; Unicef: Geneva; New York, 2015; ISBN 978-92-4-150914-5.
2. Onda, K.; Lobuglio, J.; Bartram, J. Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *World Health Popul.* **2013**, *14*, 32–44.
3. 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, doi:10.1371/journal.pmed.1001644.
4. Kumpel, E.; Nelson, K.L. Comparing microbial water quality in an intermittent and continuous piped water supply. *Water Res.* **2013**, *47*, 5176–5188, doi:10.1016/j.watres.2013.05.058.
5. Ayoub, G.M.; Malaeb, L. Impact of intermittent water supply on water quality in Lebanon. *Int. J. Environ. Pollut.* **2006**, *26*, 379–397, doi:10.1504/IJEP.2006.009328.
6. Tokajian, S.; Hashwa, F. Water quality problems associated with intermittent water supply. *Water Sci. Technol.* **2003**, *47*, 229–234.
7. Ercumen, A.; Gruber, J.S.; Colford, J.M. Water Distribution System Deficiencies and Gastrointestinal Illness: A Systematic Review and Meta-Analysis. *Environ. Health Perspect.* **2014**, *122*, 651–660, doi:10.1289/ehp.1306912.
8. Erickson, J.J.; Smith, C.D.; Goodridge, A.; Nelson, K.L. Water quality effects of intermittent water supply in Arraijan, Panama. *Water Res.* **2017**, *114*, 338–350, doi:10.1016/j.watres.2017.02.009.
9. Abo-Shehada, M.N.; Hindyia, M.; Saiah, A. Prevalence of Cryptosporidium parvum in private drinking water cisterns in Bani-Kenanah district, northern Jordan. *Int. J. Environ. Health Res.* **2004**, *14*, 351–358, doi:10.1080/09603120400004030.
10. Cifuentes Enrique; Suárez Leticia; Solano Maritsa; Santos René Diarrheal diseases in children from a water reclamation site in Mexico City. *Environ. Health Perspect.* **2002**, *110*, A619–A624, doi:10.1289/ehp.021100619.
11. Ramírez, G. Área Metropolitana de Guadalajara | Gobierno del Estado de Jalisco Available online: https://www.jalisco.gob.mx/es/jalisco/guadalajara (accessed on Nov 16, 2018).
12. Insitituto Nacional de Estadística y Geografía Censo de Población y Vivienda 2010 Available online: http://www.beta.inegi.org.mx/proyectos/ccpv/2010/ (accessed on Nov 14, 2018).
13. von Bertrab, E. Guadalajara's water crisis and the fate of Lake Chapala: a reflection of poor water management in Mexico. *Environ. Urban.* **2003**, *15*, 127–140, doi:10.1177/095624780301500204.
14. Sistema Intermunicipal de los Servicios de Agua Potable y Alcantarillado Informe de Actividades y Resultados 2017.
15. Bartram, J.; Ballance, R. *Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programs*; World Health Organization: London, 1996;
16. Diario Oficial De La Federación Modificación a la norma oficial Mexicana NOM-127-SSA1-1994. 2000.
17. COFEPRIS Calidad del agua de uso y consumo humano Available online: https://datos.gob.mx/busca/dataset/calidad-del-agua-de-uso-y-consumo-humano (accessed on Nov 14, 2018).