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The Effect of Treatment on Harvested Rainwater Quality

Primary PI: Sarah Keithley
Other PIs: Dr. Mary Jo Kirisits and Dr. Kerry Kinney

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Executive Summary

Introduction

Rainwater is an alternative water resource that is receiving increasing attention as the demand for fresh water increases globally. Many studies have found the physical and chemical qualities of harvested rainwater to be satisfactory, but the microbial quality is often lacking (Jordan *et al.*, 2008; Despins *et al.*, 2009; Mendez *et al.*, 2011). If properly treated, harvested rainwater can be used as a local potable water supply. Our study investigated the effect of two treatment systems on the quality of harvested rainwater: (1) chlorination followed by filtration, and (2) filtration followed by ultraviolet (UV) irradiation.

Chlorine is a common disinfectant, but it reacts with natural organic matter to produce disinfection byproducts (DBPs) that can be carcinogenic or genotoxic (as reviewed by Richardson *et al.*, 2007). Rook (1974) identified trihalomethanes (THMs) as the first group of chlorine DBPs. The United States Environmental Protection Agency (USEPA) regulates total THMs (TTHM), which is the sum of four THMs; the maximum contaminant level (MCL) is 80 μg/L (USEPA, 2012). One study found that THM formation in chlorinated harvested rainwater was below the USEPA MCL (Lantagne *et al.*, 2008).

UV irradiation is becoming increasingly popular in the United States among rainwater harvesters (Macomber, 2010). Filtration is an important part of UV treatment systems since particles disrupt UV by absorbing UV light and shielding microorganisms (Qualls *et al.*, 1983). Previous studies have found UV irradiation to be a suitable method for disinfection of harvested rainwater (Jordan *et al.*, 2008; Despins *et al.*, 2009; Ahmed *et al.*, 2012).

While the discussion of the results references drinking water standards set by the United States Environmental Protection Agency (USEPA), those standards only apply to public water systems, i.e., systems with more than 15 connections or regularly serving more than 25 individuals. Rainwater harvested for individual potable use at a residence does not have to comply with USEPA regulations, but these standards provide a quality benchmark.

Chlorination Studies

For the chlorination studies, rainwater was harvested from four pilot-scale roofs in Austin, Texas. Each has a different roofing material, which are concrete tile, green, Galvalume® metal, and asphalt-fiberglass shingle. Mendez *et al.* (2011) previously characterized the quality of raw rainwater harvested from these same roofs. The harvested rainwater was allowed to settle at 4 °C for at least 12 h, and then the siphoned supernatant was used in experiments. Bleach was added to the harvested rainwater to achieve a target chlorine residual of 2 or 0.2 mg/L at 10 min after chlorination. The chlorinated rainwater was kept in a headspace-free polypropylene tank for 24 h. The residual chlorine concentration and THM concentrations were measured 10 min, 2, 4, 8, 12, 18, and 24 h after chlorination. At 24 h, chlorinated rainwater was pumped through a carbon block filter with a nominal pore size of 0.5 μm, and the THM concentrations in the filtered water were measured. Total coliforms (TCs) and heterotrophic plate counts (HPCs) were measured in the raw water and measured after chlorination and chlorination/filtration at 24 h.

The physical and chemical qualities of the rainwater harvested from the pilot-scale roofs were similar to those measured previously by Mendez *et al.* (2011), and TCs were detected in the raw harvested rainwater in most rain events. Disinfection efficacy and THM formation were compared among roofing materials after a 24-h contact time; the type of roofing material, dissolved organic carbon (DOC) concentration, and pH of the rainwater affected disinfection efficacy and THM formation. Adequate disinfection of rainwater was defined as the TC concentration being less than 1 colony forming unit per 100 mL (CFU/100 mL) and the TTHM concentration less than 80 μg/L (USEPA, 2012).

Chlorinating rainwater harvested from the metal roof achieved adequate disinfection, regardless of the targeted 10-min chlorine residual, and TTHM formation was well below the USEPA limit of 80 μg/L. The low DOC concentration and low pH of rainwater harvested from the metal roof likely contributed to the adequacy of chlorine as a disinfectant for this rainwater. Rainwater harvested from the concrete roof was of similar quality to rainwater harvested from the metal roof, and a target 10-min chlorine residual of 2 mg/L achieved adequate disinfection with TTHM formation below the USEPA limit. Chlorinating rainwater harvested from the shingle roof achieved adequate disinfection when the target chlorine residual was 2 mg/L, but the TTHM concentration exceeded the USEPA limit in one instance. The DOC concentration in rainwater harvested from the shingle roof differed by almost an order of magnitude among rain events, and this variability likely led to variable THM formation. This rainwater demonstrated that there is a balance between disinfection efficacy and DBP formation. Chlorination did not adequately disinfect rainwater harvested from the green roof, regardless of the targeted chlorine dose. The TTHM concentration was 4 times higher than the USEPA limit of 80 μg/L when the target 10-min residual was 2 mg/L, but was below the MCL when the targeted 10-min residual was 0.2 mg/L. Rainwater harvested from the green roof had the highest DOC concentration, which likely limited disinfection and led to high THM formation. Chlorine did not appear to be a good disinfectant for rainwater harvested from the green roof.

The activated carbon block filter used after chlorination reduced the TTHM concentration to well below the MCL, regardless of the influent TTHM concentration, but it often shed heterotrophic bacteria and TCs. Rainwater harvesters who chlorinate their rainwater often use a carbon filter after chlorination to remove taste and odor compounds; filtering through an activated carbon filter before chlorination would likely improve water quality by reducing DBP precursor concentrations, but the capacity of the activated carbon filter for DOC adsorption would need to be evaluated.

UV Studies

In addition to the bench-scale chlorination studies, a full-scale residential rainwater catchment system that used harvested rainwater as its primary potable water supply was sampled. The catchment surface is a Galvalume® metal roof, and the harvested rainwater is stored in two 5000-gal polypropylene cisterns. Rainwater is filtered through two sediment filters with nominal pore sizes of 25 and 5 μm and disinfected with a UV bulb that emits UV light at 254 nm for a minimum dose of 40 mJ/cm^2. Samples of the raw cistern-stored rainwater and the treated rainwater were collected on four occasions from October 2010 through September 2011. During that time, there was a severe drought in Central Texas, and the maximum air temperature exceeded 37.8 °C on 85 days.

TCs were detected in the raw rainwater in every sampling instance and were an order of magnitude higher during the summer than during the winter. The turbidity in the cistern-stored rainwater also was higher during the summer than during the winter. When the TC concentrations and turbidity were low ($<10^3$ CFU/100 mL and <3 NTU), the treatment system sufficiently disinfected the rainwater (TC <1 CFU/100 mL). When they were high ($>10^4$ CFU/100 mL and >10 NTU), however, the rainwater was not adequately disinfected; TCs on the order of 10^2-10^3 CFU/100 mL were detected in the treated water in July and September 2011. These results suggest that filtration followed by UV irradiation can be an effective treatment system for potable harvested rainwater, but its efficacy can be compromised by high turbidity in the cistern.

To examine individual impact of the filters and UV lamp on treated water quality, as well as the effect of their age on treated water quality, samples were collected at multiple points within the treatment system on one occasion when the system owner replaced each component as part of routine maintenance. As expected, the filters reduced the turbidity and TC concentration, and the UV bulb reduced the TC concentration. Changing the filters and UV bulb did not affect the water quality.

Conclusion

In summary, harvested rainwater can be used as a domestic potable water supply if it is treated properly. Chlorination followed by activated carbon filtration appeared adequate (TC <1 CFU/100 mL and TTHM <80 μg/L) for treating rainwater harvested from the metal and concrete roofs when a chlorine residual of 2 mg/L after 10 min was targeted. This target achieved adequate disinfection in rainwater harvested from the shingle roof but, depending on the DOC concentration, had the potential to form THMs that exceeded the USEPA MCL of 80 μg/L. Chlorine did not appear to be a suitable disinfectant for rainwater harvested from the green roof, likely because of its high DOC concentration. Filtration followed by UV irradiation adequately disinfected cistern-stored rainwater when the turbidity and TC concentration in the influent were low, but treatment was compromised as these two parameters increased as the temperature increased and the drought progressed.

References

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