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AN INVESTIGATION OF THE WATER QUALITY OF RAINWATER HARVESTING SYSTEMS

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ABSTRACT

Rain barrels can be a first step in promoting water conservation and reducing stormwater runoff in communities. Many homeowners and community gardens use harvested rain barrel water to irrigate vegetable gardens, yet limited information exists about the safety of roof runoff for this purpose. In this study, roof runoff collected in plastic rain barrels was analyzed for the presence of several water quality contaminants: lead, zinc, total coliform bacteria, *Escherichia coli*, and polycyclic aromatic hydrocarbons. Twelve plastic food grade rain barrels were installed on homes that have asphalt shingled roofs, the dominant catchment surface on New Jersey homes. In order to investigate the effects of land use, 6 barrels were located in a suburban community and 6 were in an urban community. Rain barrel water samples were collected in 2011, 3 to 5 days after a rain event. Results showed PAHs were non-detect for all samples. Based on federal guidelines for water reuse, results for lead and zinc were all below the recommended maximum concentrations for irrigation water. Based on the proposed 2013 U.S. Food and Drug Administration Food Safety Modernization Act, 4 *E. coli* samples exceeded recommended maximum concentrations for irrigation water. Results showed that rain barrel water may need treatment to prevent pathogen contamination if the water is to be used for irrigating a vegetable garden.

Introduction

In New Jersey, many communities are promoting residential rain water harvesting using rain barrels as a tool for encouraging water conservation and reducing stormwater runoff. However, most research in the United States on rooftop runoff has been conducted with a focus on determining contributions to stormwater pollution, not for purposes of rain water harvesting. Techniques for promoting outdoor water conservation have become increasingly important due to drinking water supply deficits in many regions of the state. Safe alternative water supplies for irrigation are being sought that can help reduce our dependence on the drinking water supply. Many homeowners and community gardens harvest rooftop runoff with the purpose of irrigating vegetable gardens. In surveys done at four residential “Build A Rain Barrel” workshops in Middlesex and Union Counties, NJ, in the spring of 2010, 57% of the survey participants (n=58) indicated that they would be using water from their rain barrel to irrigate a vegetable garden (Bakacs, unpublished data).

Studies have shown that roof runoff can have high levels of pathogens, zinc (Zn), lead (Pb), and polycyclic aromatic hydrocarbons (PAHs) (Bannerman, 1993; Clark, 2008; DeBusk, 2009; Van Metre, 2003). Many homeowners and community gardens harvest rooftop runoff with little to no protection from the first flush of runoff that has been shown to have the highest levels of contaminants. P.C. Van Metre (2003) investigated major and minor trace elements and PAHs in roof runoff from galvanized metal and asphalt shingle roofs at different distances from major roadways in Austin, TX. The researchers found that distance to the expressway was a major determinant of contaminants, including PAHs, lead and zinc. Metal roofing was found to be a source of cadmium and zinc, and asphalt shingles a source of lead. A report by Chang et al. (2004) investigated roof runoff from commonly used roofing materials in Nacogdoches, TX and found that pH, electrical conductivity, and zinc were the only three variables significantly affected by roofing materials. Research conducted in Wisconsin compared runoff from parking lots, lawns and driveways, and roofs and found that roofs produce significant zinc loads in commercial and industrial land uses (Bannerman, 1993).

Pathogens from fecal matter deposited by animals and atmospheric deposition on roof surfaces could lead to contamination of roof runoff (Evans et al., 2006). Research on microbial contamination of roof runoff is limited in the United States. Research conducted outside the United States on rainwater harvesting systems used for indoor uses has shown microbial contamination at levels that could pose a significant health risk for consumption or non-potable contact (Albrechtsen, 2002; Simmons et al., 2001). One study conducted in northeastern Greece showed that first flush diverters did little to reduce pathogen levels in rainwater collection systems (Gikas et al., 2012). The same study showed that first flush diverters adequately treated physiochemical parameters such as sediment, total phosphorus, anions, and cations to potable standards for the region. Some evidence exists that water quality within a rainwater harvesting tank may vary with increasing tank depth, with pathogens being concentrated on the water surface, and heavy metals settling at the bottom of the tank (Spinks, et al. 2003). Although these studies help shed light on the water quality of harvested rainwater, additional research was needed that specifically addresses the safety of harvested rainwater for irrigating gardens grown for consumption.

To further our understanding of how to safely utilize harvested rainwater for vegetable gardens, this study examined levels of five contaminants in harvested rain water draining off asphalt shingled roofs; PAHs, lead, zinc, total coliform (TC). *Escherichia coli (E.coli)* analysis was added after three sampling rounds. In addition, we examined whether there is a significant difference between levels of contaminants draining roofs in different land uses, specifically, suburban versus urban communities. The results of this research will help to develop guidelines for best management practices for applying harvested rainwater to backyard and community vegetable gardens.

Methodology and Analysis

This project analyzed roof runoff from asphalt shingled roofs that was collected in plastic 55 gallon rain barrels. Samples were collected from both urban and suburban locations in order to determine if surrounding land use had an impact on water quality. Figure 1 shows the experimental setup and site locations of the rain barrels. Rain barrels were installed in two medium density housing suburban communities in southern New Jersey (Collingswood and Mount Holly), and a high density housing urban community in central New Jersey (New Brunswick). Sampling locations were chosen based on the New Jersey Department of Environmental Protection (NJDEP) 2007 Land Use/Land Cover data, ability to access the site, and permission from the property owner.

The experimental design for this study used clusters of three individual 55 gallon rain barrels (one per dwelling) sited at each of four locations for a total of 12 rain barrels. Two cluster locations were in the urban community and two were in the suburban community. A cluster approach was employed to ensure that each cluster of three rain barrels captured the same rainfall event and were exposed to similar atmospheric deposition rates. The rain barrels/dwellings within each cluster were located within ¼ mile of each other.

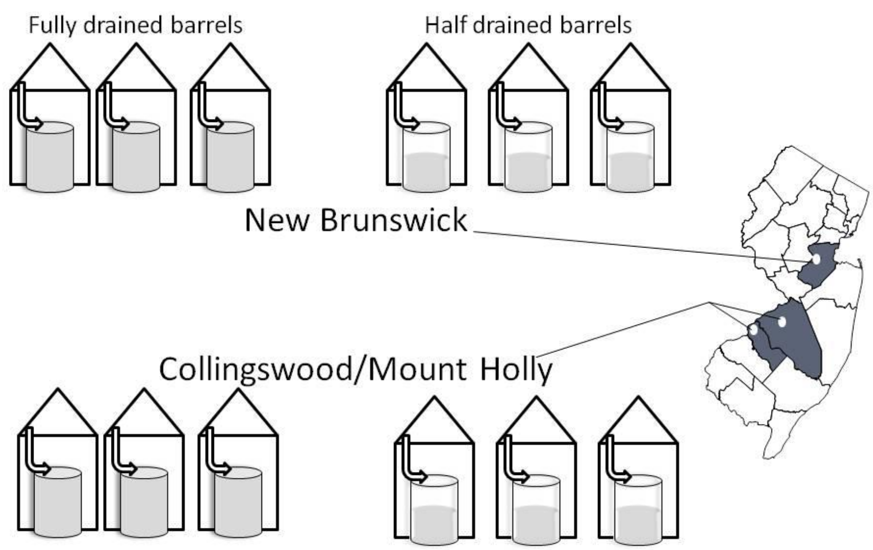

Figure 1. Experimental setup and site locations.

Samples were collected from each barrel over a four month period from July - October. Six sets of samples were collected in south Jersey and eight from central Jersey for a total of 84 samples. Half of the central and half of the southern barrels were drained down completely prior to a rain event, while the other half were drained down by 50 percent. The partial draw down was done to mimic homeowner system usage and test whether there is a buildup of pathogenic bacteria when residual water is left in the barrel. Water samples were collected 3 – 7 days after a rain event in order to replicate the expected time frame that a homeowner/community gardener would wait before using the collected runoff.

Samples were initially analyzed for PAHs, Pb, Zn, and TC. After three rounds of sampling (36 samples), no PAHs were detected and PAH analysis was dropped. At this point, due to some samples showing high levels of TC bacteria, E. coli analysis was added to the rest of the samples. While TC is a commonly used screening tool for pathogens, *E. coli* analysis is a better indicator of human health risk (Santo Domingo, 2010). The presence of *E. coli* indicates the potential presence of human pathogens, i.e. viruses, and is important information if rain barrel water is used to water a vegetable garden.

Samples for PAHs were collected in two 1-liter amber glass bottles and preserved at 4°C. Samples for Pb and Zn were collected in one 250 ml plastic container, preserved with HNO3 and chilled to 4°C. The TC samples were collected in a 125 ml plastic container, preserved with 0.008% $Na_2S_2O_3$ and chilled to 4°C. All samples were submitted to New Jersey State certified laboratories for analysis.

A two-tailed, sample t-test was used to determine whether there was a significant difference between levels of contaminants draining roofs in different land uses. A two-tailed, sample t-test was also used to determine whether there was a significant difference between pathogen levels in barrels that were drained halfway and barrels that were fully drained. A significance level of $p < 0.05$ for all statistical tests was used.

Because of the high number of non-detects in the dataset, some form of data correction was employed to conduct the analyses. For TC data, non-detects were replaced with half the detection limit (i.e. for each <1.0/100 mL, a value of 0.5/100 mL was used in the analyses). This method was chosen since only 7% of the data values were below the detection limit (USEPA, 2000).

For Zn and Pb, the ‘trimmed mean’ method was utilized where a percentage of the lowest and highest measurements from the data set are removed to more accurately determine the mean value. Of the total samples analyzed, 25% of the Zn samples and 50% of the Pb samples were below the detection limit. For environmental samples, where 15-50% of the samples are not detected, a 15% trimming is recommended and was used for these analyses (USEPA, 2000).

Due to the low number of *E. coli* samples collected, no analysis was conducted on the data.

Results

The water quality data was compared to both drinking water and irrigation standards as seen in Table 1.

Table 1: Water quality standards.

Parameter	**NJ Drinking Water Standards**[a]	**Federal Irrigation Standards**
Lead	15.0 µg/L	5,000 µg/L[b]
Zinc	5,000 µg/L	2,000 µg/L[b]
TC (counts/100 mL)	n/a	n/a
E.coli (counts/100 mL)	0/100 mL	geometric mean= 126/100 ml[c] single sample maximum= 235/100 ml[c]

[a]NJAC, 2011

[b]USEPA, 2004

[c]USFDA, 2011

Both Pb and Zn were compared to USEPA reclaimed water guidelines for agriculture irrigation (USEPA, 2004) because no other federal irrigation standards exist for these parameters. Descriptive statistics for Pb and Zn concentrations after data correction are presented in Table 2. Zn values did not violate any of the water quality standards in either the suburban sites or the urban sites. Results from the raw Zn data from all sites ranged from <20 to 869 µg/L. Mean Zn concentrations at urban sites were significantly higher than suburban sites ($p>0.05$). Atmospheric Zn can come from tire dust and industrial processes (Councell, 2004). Both increased traffic in urban areas and industrial processes involving metals near urban centers may be accounting for the differences seen in the data sets.

Raw Pb values ranged from <3 µg/L to 107 µg/L and three of the urban sites violated state drinking water standards only, with values ranging from 20.6 µg/L to 107 µg/L. The main source of Pb is most likely from atmospheric deposition due to industrial processes, manufacturing industries and waste incineration (EPA, 2006a). Pb results showed no statistical difference between urban and suburban land uses.

Table 2: Descriptive statistics for Pb and Zn concentrations after data correction

	Suburban Barrels						**Urban Barrels**					
Parameter	HD1[a]	HD2	HD3	FD4	FD5	FD6	HD1	HD2	HD3	FD4	FD5	FD6
Pb (µg/L)												
Mean	3.5	3.2	2.5	3.6	3.7	2.0	1.5	3.0	3.1	2.2	5.1	2.6
Stdev	1.7	2.5	0.8	2.1	2.8	1.1	0.0	2.5	1.3	1.4	1.2	2.1
n[b]	3	4	6	5	4	4	4	5	6	4	3	4
Zn (µg/L)												
Mean	32.2	23.8	40.2	27.4	38.8	27.9	31.4	71.8	78.7	19.0	55.8	49.8
Stdev	21.9	12.2	8.7	18.0	25.0	14.4	23.5	57.1	49.5	8.1	18.6	36.3
n	4	3	4	6	3	6	4	5	6	3	3	5

[a] HD= half drained after sampling, FD= fully drained after sampling

[b]n= number of samples after data correction

TC concentrations violated the drinking water quality standards at all sites for all samples (Table 3). Currently thereexists no irrigation standard for TC. Samples from all locations ranged from <1 cfu to 9000 cfu. TC levels showed no statistically significant differences between urban and suburban land uses. The geometric mean of TC in urban land uses, however, was more than double (366 cfu/100 mL) the suburban land uses (153.7 cfu/100 mL). The maximum TC measured was 9,000 cfu/100 mL for urban lands and 2,600 cfu/100 mL for suburban land uses. For TC, there was no statistical difference between the fully-drained and half-drained barrels in the suburban land uses and the urban sites. There were also no statistical differences between the fully-drained and half-drained TC levels within the land uses (full vs. half for suburban and full vs. half for urban).

Table 3. Descriptive statistics for total coliform.

	Suburban Rain Barrels						**Urban Rain Barrels**					
	HD1[a]	HD2	HD3	FD4	FD5	FD6	HD1	HD2	HD3	FD4	FD5	FD6
Min	0.5	35.0	0.5	52.0	0.5	0.5	0.5	120.0	160.0	120.0	12.0	16.0
GeoMean	209.4	306.3	171.1	412.9	144.8	50.7	294.2	257.5	989.4	711.1	518.6	215.6
Max	2,600.0	2,300.0	2,600.0	1,900.0	1,100.0	360.0	5,000.0	760.0	9,000.0	6,200.0	7,600.0	580.0
Stdev	870.5	787.2	893.8	604.4	352.4	124.4	1,716.9	210.4	3,354.2	2,138.2	2,882.7	213.8
n	6	6	6	6	6	6	6	6	6	6	5	6

[a] HD= half drained after sampling, FD= fully drained after sampling

E. coli was detected and violated state drinking water standards (0/100ml) in 66% of the samples collected (n= 47). In January 2013, the Food and Drug Administration released their proposed standards for “Growing, Harvesting, Packing and Holding of Produce for Human Consumption” (USFDA, 2011). The standard calls for maximum *E. coli* levels in agriculture irrigation water of $\leq$126 cfu/100 ml for the geometric mean (n=5) and $\leq$235 cfu/100ml for any single sample. *E. coli* sample results ranged from non-detect - 1800 cfu /100 ml. Samples exceeded the single sample limit (235 cfu/100 mL) four times out of the 47 samples collected (9%). Even though a low percentage of samples exceeded the irrigation limit, caution is still warranted considering the potential impact of *E.coli* contamination on human health. In this study, potential sources of pathogens were wildlife (birds, small mammals/squirrels) that had access to the roofs that were monitored or living in trees adjacent to the homes.

Recommendations and Conclusions

Results from this study showed heavy metals were well below the EPA irrigation thresholds for reclaimed water and posed minimal risk for irrigating a vegetable garden. Results also showed the majority of water samples to be below recommended irrigation guidelines for *E. coli.* Regardless, the researchers recommend chemical treatment of rain barrel water before irrigating a garden grown for consumption, in addition to cultural practices, to reduce the risk of exposure to harmful pathogens. Rain barrel users should make sure to clean the barrel with a 3% bleach solution before collecting water to irrigate a vegetable garden. Household, unscented bleach with a 5-6% chlorine solution can be added at the rate of 1/8 teaspoon per gallon (8 drops). Prior to irrigating a vegetable garden, water in a typical 55 gallon rain barrel should be treated with approximately 1 ounce of bleach. Wait approximately 24 hours after the addition of bleach to allow the chlorine to dissipate before using the water. It should be noted that household bleach is not labeled for use in water treatment by the Food and Drug Administration, although it is frequently recommended for emergency disinfection of drinking water (USEPA, 2006b).

Implementing good cultural practices is also important for reducing the pathogen contamination. Harvested rainwater from a rain barrel should only be used for non-foliar applications on vegetable gardens possibly through drip irrigation. Water should be applied in the morning. Harvesting should not take place right after watering in order to benefit from leaf drying and ultraviolet light disinfection.

Additional research is needed to determine whether installation of a first flush diverter would be effective for reducing pathogens in the storage container to levels appropriate for produce irrigation. A first flush diverter is often utilized with large cisterns which divert the first flush volume of contaminated roof runoff away from the tank. One study conducted in northeastern Greece showed that a first flush diverter may not be effective for reducing pathogen levels and should not be the sole treatment technique (Gikas, 2012).

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