Rainwater catchments in rural Alaska have the potential to produce high-quality water and high quantities of water for household use

Kaitlin Mattos, Elizabeth King, Cara Lucas, Elizabeth Hodges Snyder,
Aaron Dotson and Karl Linden

ABSTRACT

Rainwater collection is a common source of household water in developed and developing communities where treated on-site water is not available. Although rainwater catchment has been practiced for generations in rural Alaska communities, there is little data available on the quality and quantity of rainwater resources. Forty-eight rainwater samples were collected from nine communities in Alaska over 2 years. Samples were tested for physical water quality parameters, metals, and bacteria. Characteristics of household catchments were recorded. Rainwater quantity in two communities was evaluated. Overall, high-quality water was observed in rain catchments, with average total organic carbon (TOC) and turbidity being lower than or equal to those values in other published rainwater studies. pH was consistently low. Over 80% of samples were below the United States limits for metals and met international microbiological water quality standards. However, variation was observed between households, communities, indoor/outdoor bacteria samples, covered/uncovered storage containers, and over time. The quantity of rainwater available for catchment could supply 17–40% of annual household water and is projected to increase in future decades according to Alaska climate models. Best practices are recommended for rural Alaska communities to maintain the naturally high quality of rainwater and take advantage of large quantities of rainwater available on-site.

Key words | developing communities, rainwater, rural, water quality, water resources

Kaitlin Mattos
Karl Linden
Department of Civil, Environmental and Architectural Engineering,
University of Colorado at Boulder,
UCB 428, Boulder, Colorado 80309-0428,
USA

Elizabeth King
Cara Lucas
Elizabeth Hodges Snyder
Department of Health Sciences,
University of Alaska Anchorage,
3211 Providence Drive, Anchorage, Alaska 99508,
USA

Elizabeth King
Current affiliation: Alaska Native Tribal Health Consortium,
4000 Ambassador Drive, Anchorage, Alaska,
USA

Cara Lucas
Aaron Dotson (corresponding author)
Department of Civil Engineering,
University of Alaska Anchorage,
3211 Providence Drive, Anchorage, Alaska 99508,
USA
E-mail: *addotson@alaska.edu*

INTRODUCTION

Approximately 700 million people lack access to safe drinking water in developing communities around the world (World Health Organization Joint Monitoring Program 2015), and these numbers increase when considering communities that lack access to *good quality and adequate quantity* of water resources. Residents living in communities worldwide, in both developing and developed countries, that are without piped utilities or engineered water infrastructure may use rainwater catchment systems to provide water for drinking and hygiene purposes within the home (Thomas 1998; Domènech *et al.* 2012; Rahman *et al.* 2014; Elliott *et al.* 2017). While the use of natural water resources is often culturally and socially acceptable and sometimes preferred to chemically treated water in such communities, there is persistent concern about the quality of these sources, whether and how to regulate them, and how to promote best management practices (Howard & Bartram 2003; Mwenge Kahinda *et al.* 2007; Chidamba & Korsten 2015; Kim *et al.* 2016). Rainwater is often assumed to be of high quality naturally, but pathogenic microbes, metals, and volatile organic compounds are known contaminants introduced to catchment systems by biological sources (e.g. birds

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and insects, Fewtrell & Kay 2007; Chidamba & Korsten 2015), atmospheric sources (e.g. dust and sea spray, Thomas 1998; Lye 2002; Fewtrell & Kay 2007), or homeowners themselves (e.g. through the selection of roof, gutter and storage materials, Thomas 1998; Fewtrell & Kay 2007; Mendez *et al.* 2011).

Although most underserved communities are in developing nations, developed countries like the United States still lack water and sanitation coverage in many remote and rural communities. For example, an estimated 20% of rural Alaskan residences do not have access to treated water within the home. This is largely because Alaska communities are sparsely populated, difficult to access from nearby population hubs, and located in a cold climate that results in high costs and engineering challenges that must be overcome to provide traditional utility services (Alaska Department of Environmental Conservation 2017).

Without piped water in their communities, unserved/underserved rural Alaskans often have to self-haul treated water from a community watering point or untreated water/ice from melting snow, rivers, lakes, and streams (Hart & White 2006; Eichelberger 2010). Acquisition of water from these unpiped sources requires labor-intensive or expensive hauling practices that can result in the contamination of good quality source water. Alternatively, collecting rainwater on-site allows communities to take advantage of a natural resource that requires little or no haul effort and low infrastructure cost. The use of inexpensive and simple rainwater catchment systems could also allow homes to increase the quantity of water they use for hygiene purposes, which has been linked to improved health in rural Alaska (Hennessy *et al.* 2008; Thomas *et al.* 2016). Rural Alaskans in many communities have collected rainwater from household roofs in plastic tubs, trashcans, or metal drums with or without the use of gutters for decades (Hart & White 2006). Yet, while water quantity can be seasonally increased through rainwater harvesting, little is known about the quality or potential quantity of this resource as collected by existing practices.

Even though rainwater is widely used globally, most published studies focus on warm weather regions (e.g. Thomas 1998; Lye 2002; Jordan *et al.* 2008; Imteaz *et al.* 2011; Marcynuk *et al.* 2013; Rahman *et al.* 2014). To the authors' best knowledge, there is only one published study on rainwater in Alaska which examined lead, copper, and zinc (Hart & White 2006), but it did not focus on rural areas and overall water quality was not discussed. The study described here examines water quality from 48 rainwater catchment samples and estimates the quantity of rainwater available for household use in rural Alaska. Because environmental data is difficult and expensive to collect in remote Alaska, this study incorporates citizen science data collected in 2015 and data collected by researchers at the University of Alaska Anchorage (UAA) in 2016 and considers the benefits and challenges of using citizen science networks to collect water quality data in remote places.

METHODS

Study site description

This research was conducted in nine communities from four regions (Southwest, Far North, Interior, and Southeast, Figure 1) in Alaska. Of 200 communities in rural Alaska, approximately 20% are considered 'unserved' with respect to piped water and sanitation, while nearly 80% are served by piped water, individual well and septic, or closed pump and haul systems. Unserved communities range in size between 12 and 193 households with an average of four people per home (Alaska Department of Environmental Conservation 2017). The majority of residents in rural communities identify as Alaska Native and are of indigenous descent. Because rural communities are difficult and expensive to travel to, communities participating in this study were chosen by convenience. Samples were collected by trained personnel during trips that were scheduled for other projects and purposes. Due to the small size of underserved rural Alaska communities and to protect individual anonymity within the communities, community names are not provided.

Rain catchment characteristics and rainwater quality

In 2015, samples were collected through a citizen science network, and in 2016, samples were collected by UAA researchers. The 2015 samples were collected and preserved by volunteer traveling professionals in eight rural

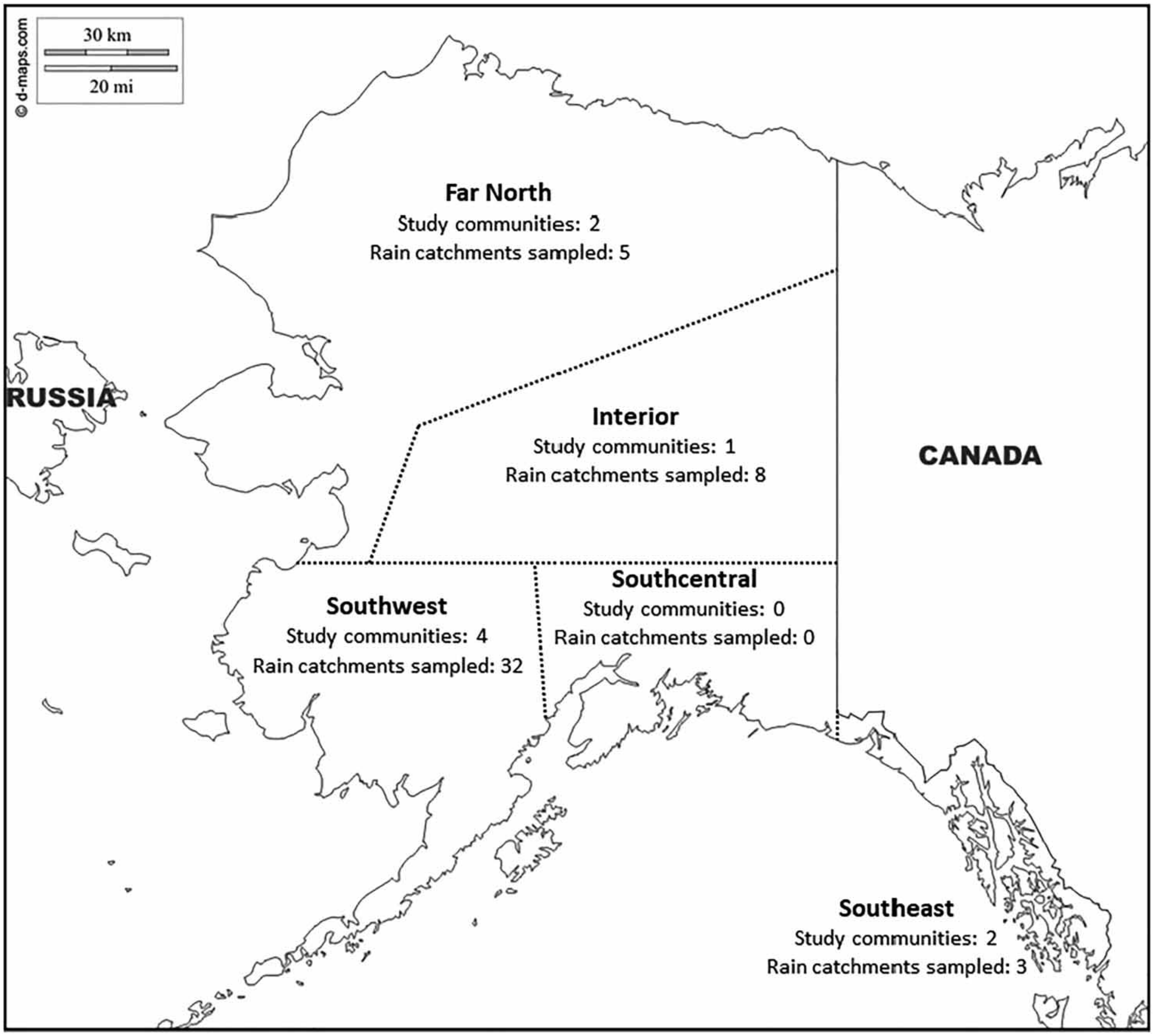

Figure 1 | Household rain catchments sampled in nine communities in four regions of Alaska.

communities and transported to university and certified private laboratories. Volunteers with existing travel plans in remote rural communities were recruited to carry a sampling kit, obtain a convenience sample of one or more rainwater catchment tanks during their planned trip, and record catchment characteristics (such as roof material, collection system, collection vessel, water quantity, cleanliness, and presence of nearby wood burning, e.g. chimney smoke, wood pile, and steam bath). Detailed sampling instructions following the methodology described below were provided to volunteers (as described in King 2016). After sampling was complete, volunteers were asked to self-rate the accuracy with which the sampling protocols were followed. Samples were stored in coolers with ice packs for 0–4 days at approximately 4°C before being transported to Anchorage for analysis.

In 2016, rainwater catchment samples were collected by university researchers from households in one community in the Southwest region and one community in the Interior region during 2-day trips to each community. In the

Southwest community, most homes had rain catchment tanks, so sampling was conducted at approximately every fifth home in each of three sections of the community ($n = 21$). In the Interior community, most homes that usually catch rainwater had deconstructed their systems for the winter at the time of the visit, so all homes that still had active systems were sampled ($n = 8$). At each home chosen for rainwater samples, observations of catchment characteristics were recorded in similar categories as the 2015 study. The approximate number and size of collection vessels around each home was determined and one vessel was arbitrarily chosen for sample collection. In <10% of homes, a resident gave instructions on which vessel to sample from based on the age of the water or the vessel being actively drawn from for use in the home. In 2016, turbidity measurements were taken within an hour of sampling with a portable field turbidimeter (HACH 2100Q). All other samples were transported back to Anchorage in coolers with ice packs at approximately 4°C and analyzed within 48 h of collection.

The sampling protocol provided to volunteers in 2015 and followed by university researchers in 2016 was as follows: homeowner permission and contact information for communicating results were obtained prior to sampling. Water samples (designated 'outside sample') were taken wearing fresh nitrile gloves by dipping a 250 mL (milliliter) sterile sample bottle into the surface of the collection vessel and pouring the water into each container in the sampling kit. Scoops or pitchers connected to the catchment vessel or provided by the homeowner were used instead where available. Bacteria samples were collected and transported in the sterile 100 mL plastic bottles provided with test kits. Photos were taken of each collection system. In 2016 at each home, residents were also asked if they currently had rainwater in use in a storage vessel inside the home, and if they would consent to a water quality sample for bacterial analysis. Where consented, these samples were taken by filling a sample bottle directly from a pitcher or vessel that the residents use on a regular basis (designated 'inside sample'). Although this sampling method allows the possibility that water quality parameters are influenced by the cleanliness of the pitchers or vessels used in sampling, the authors determined that this method was appropriate because it represented the most realistic measure of the quality of water used in the homes.

Upon arrival in Anchorage, samples were submitted to a certified laboratory for analysis of conductivity (analytical method SM21 2510B), pH (analytical method SM21 4500-H B), TOC (analytical method SM 5310B), and metals (analytical method SW6020A). Metals assessed by the certified laboratory included aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, boron, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc. All samples were analyzed for ultraviolet absorbance at 254 nm (nanometer) wavelength on a Cary 60 UV-Vis spectrophotometer and converted to ultraviolet transmittance (UVT).

The most probable number (MPN) of *Escherichia coli* was measured using the Aquagenx Compartment Bag Test (CBT, Sobsey 2017) as validated for limited resource settings (Stauber *et al.* 2014; Wang 2015). Prior to analysis, samples were allowed to warm to 20–22°C and the chromogenic *E. coli* media were added and allowed to dissolve for 25–60 min until the ampule containing the media turned white. Samples were incubated at 37°C for 20–22 h and enumerated according to the provided CBT MPN table (Sobsey 2017).

Water quality results that were above maximum contaminant levels (MCLs) (U.S. Environmental Protection Agency 2009) or secondary MCLs (U.S. Environmental Protection Agency 2015) for drinking water were summarized in written letters and sent to participating homeowners. Information was provided on typical water quality results from tap water sources and how to contact UAA researchers if they had further questions.

Rainwater quantity estimates

To evaluate the future possible contributions of rainwater to household water use in rural Alaska, theoretical rainwater catchment volumes were calculated for the two communities sampled in 2016. Estimates of total roof catchment area were made by measuring and averaging the square footage of at least 10 houses in each community using the measurement tool on Google Earth. Monthly rainfall and average temperature from 1981 to 2010 were obtained from the Alaska Climate Research Center (2017) for Bethel and Galena where data was available to represent the Southwest and Interior communities, respectively. Low estimates of annual rainfall were obtained by adding up the monthly rainfall values for all months where the average temperature was above 0°C (assuming in months with an average temperature below 0°C, the precipitation fell as snow, not rain). High estimates of annual rainfall were obtained by taking the total rainfall indicated directly on the Alaska Climate Research Center website for each location to estimate maximum possible rain catchment volumes. Total annual rain catchment estimates were calculated by multiplying the respective high and low annual rainfall estimates by the measured average roof square footage in each community and assuming a household size of four persons and a water demand of 15 gallons per person per day. Rain catchment estimates for individual months with an average temperature above 0°C were also calculated.

RESULTS AND DISCUSSION

Rain catchment characteristics

All catchment systems sampled in both years collected rainwater from roofs made of metal roofing, except two homes in the Southeast that used asphalt shingles. All but one system collected rainwater from the primary dwelling, with the exception of capturing rain from the roof of a shed. Ninety percent of homes used standard open gutters made of metal or plastic on at least one side of the roof to increase catchment area. Most of the homes with gutters used downspouts, but some had strings tied from the gutter to guide the water into the collection vessel. No standard first flush apparatuses were observed, but several homes had clothing (e.g. socks) or cloth covering the end of their downspout or the top of the catchment vessel to serve as a filter for debris. Alternatives to gutter systems included catching runoff where it collected into a drip on the corner of the roof or simply placing buckets out in the open. Over 85% of the catchment vessels sampled were plastic or metal containers <100 gallons in volume – most frequently plastic trashcans, tubs/bins, or 5-gallon buckets. Three homes used >100-gallon cistern-like containers. Two of these homes used large plastic-lined cisterns, and one home collected water in a 15-foot long skiff that sat upright underneath a gutter at the edge of the house. Most homes in all communities left their catchment vessels uncovered, but approximately 25% used rigid plastic, wood, or mesh cloths as a cover. The lack of covers in the Southwest may have been due to active rain collection happening, while observations were being recorded in 2016, but this was not verified.

Rainwater quality

Between the 2015 and 2016 sampling periods, 48 samples from nine communities in four regions were analyzed for TOC, conductivity, pH, metals, and bacteria. Four communities in the Southwest, two communities in the Far North, one community in the Interior, and two communities in the Southeast were sampled (Figure 1). The 2015 citizen science study produced 19 samples collected between September 5 and December 20 from eight communities: four in the Southwest, two in the Far North, and two in the Southeast. In 2016, 21 rainwater samples were collected from one Southwest community on October 1 between 10:30 am and 5:30 pm, while it was overcast and actively raining. Eight rainwater samples were collected from the Interior community on 15–16 October 2016 between 2 pm and 7 pm each day. One Southwest community was sampled in both years. The water quality results are summarized in Table 1.

TOC, pH, and turbidity

Rainwater quality had a high variation between samples in this study but was generally comparable with or of higher water quality than samples from other rainwater studies, as noted below. TOC and all metals parameters, except manganese, sodium, and zinc, were tested below the limit of quantification (LOQ, see Table 1) in over 50% of samples (Figure 2). Average TOC (1.84 ± 1.67 mg/L) was lower than several other studies (Villarreal & Dixon 2005; Despins *et al.* 2009; Farreny *et al.* 2011). pH was the parameter most commonly in violation of drinking water standards: 63% of samples had a pH outside of the acceptable range (6.5–8.5). pH was similar to samples in Villarreal & Dixon (2005, pH range: 5.2–7.9) and open sky samples in Yaziz *et al.* (1989, average pH 5.9), but lower than Farreny *et al.*

Table 1 | Rainwater catchment water quality characteristics

Water quality parameter	Quantification limit (LOQ)	Number of samples below LOQ	Number of samples above LOQ	Mean ± standard deviation of samples above LOQ (range)	National primary or secondary drinking water MCL
TOC (mg/L)	0.5 mg/L	26	22	1.84 ± 1.67 (0.539–5.710)	DBP treatment level = 2.0
Conductivity (μS/cm)	1.0 μS/cm	n/a	n/a	38.13 ± 34.74 (3.300–217.00)	Not specified
Turbidity (NTUs)	n/a	*N* = 29 samples from 2016 only		1.99 ± 3.49 (0.31–18.40)	5 NTUs
UVT (%)	n/a	*N* = 29 samples from 2016 only		94.5 ± 6.0 (79.0–98.9)	Not specified
pH	n/a	n/a	n/a	6.1 ± 0.7 (3.6–7.1)	6.5–8.5
Aluminum	200	46	2	479 ± 221 (259–700)	50–200
Antimony	3	47	1	6.5 (n/a)	6
Barium	3	37	11	14.0 ± 12.8 (3.1–41.8)	2,000
Cadmium	2	45	3	27.7 ± 19.4 (3.0–50.3)	5
Calcium	500	36	12	1,652 ± 1,318 (505–4,790)	Not specified
Chromium	4	47	1	8.1 (n/a)	100
Cobalt	1	47	1	1.1 (n/a)	Not specified
Copper	6	42	6	165 ± 221 (11–605)	1,000
Iron	500	46	2	1,455 ± 75 (1,380–1,530)	300
Lead	1	37	11	5.77 ± 5.63 (1.25–21.20)	Action level = 15 μg/L
Magnesium	500	30	18	1,152 ± 629 (645–3,440)	Not specified
Manganese	2	15	33	9.11 ± 9.01 (2.18–34.20)	50
Nickel	2	41	7	2.76 ± 0.46 (2.18–3.46)	Not specified
Potassium	1,000	47	1	2,040 (n/a)	Not specified
Sodium	1,000	14	34	5,685 ± 5,030 (1,110–28,300)	Not specified
Zinc	25	5	43	1,851 ± 2,259 (25–9,890)	5,000

Total *N* = 48, units of μg/L unless otherwise specified (drinking water MCLs from U.S. Environmental Protection Agency 2015).

(2011, pH 7.59 ± 0.07) and Despins *et al.* (2009, pH 7.3 ± 1.0) and higher than Reimann *et al.* (1997), catchment average range: 4.0–5.0), showing a large variation in pH across rainwater studies and geographies. Turbidity varied between the two communities in 2016 when turbidity was measured (Southwest: 1.05 ± 0.44 Nephelometric Turbidity Units [NTU], minimum = 0.31, maximum = 2.17; Interior: 4.48 ± 5.8 NTU, minimum = 0.31; maximum = 18.4). Turbidity was similar to values reported in Despins *et al.* (2009, low values = 0.9 ± 0.5 NTU, high values = 2.6 ± 3.1 NTU), Mendez *et al.* (2011, range: 1.0–20 NTU), and open sky samples reported in Yaziz *et al.* (1989, range: 2.0–5.0 NTU).

Metals

Eight samples out of 48 (17%) were above the National Primary or Secondary Drinking Water Regulations for some of the metal parameters tested. In catchments where certain metals were detected, they were often orders of magnitude greater than other studies (e.g. Fe, Mg, Ba, Na, Ca, and Zn were higher than reported in Reimann *et al.* 1997; Zn was higher than reported in Hart & White 2006; Fe, Mg, Ba, and Zn were higher than reported in Morrow *et al.* 2010). However, most published rain research has sampled more sophisticated rain catchment systems and documented the impact that roof materials (Yaziz *et al.* 1989), first flushes (Mendez *et al.* 2011), settling (Morrow *et al.* 2010), and sampling and analysis technique (Reimann *et al.* 1997) can have on water quality parameters. We hypothesize that approved roof coatings (Hart & White 2003b) and first flush apparatuses would greatly decrease the occurrences and concentrations of metals in rural Alaska rainwater catchments. Other anomalies in individual samples could be attributed to debris in the sample. In samples from the

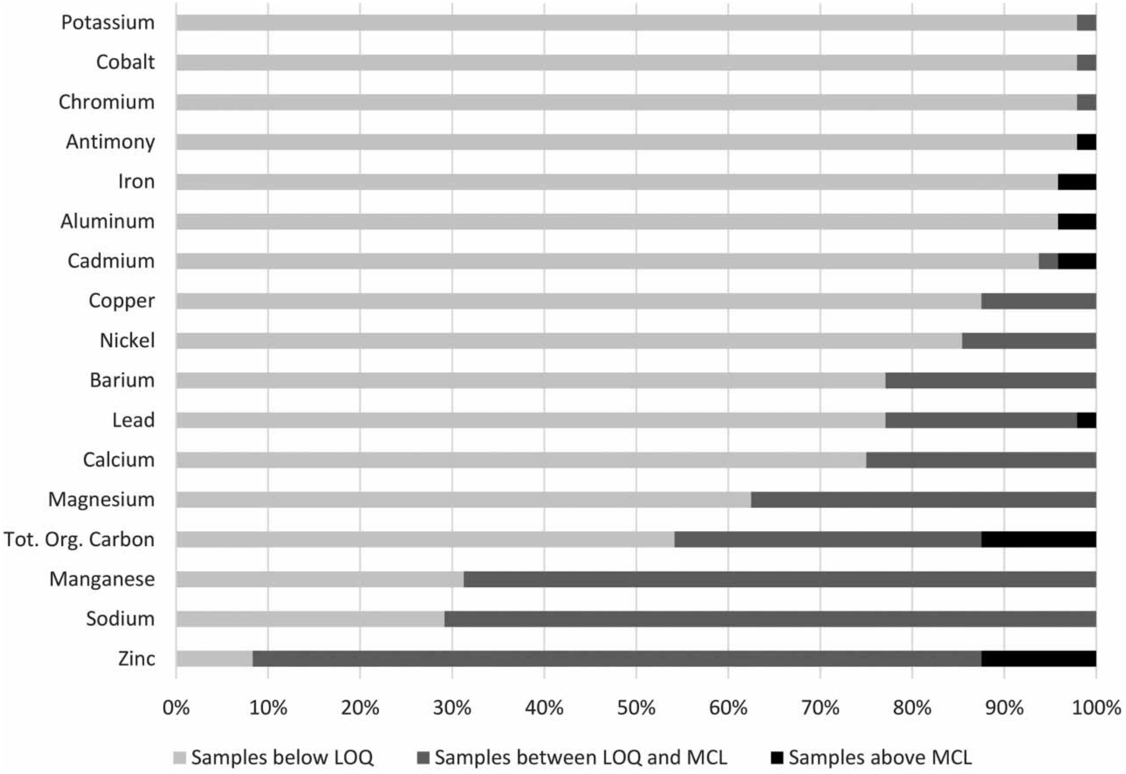

Figure 2 | Water quality parameters for which at least one rainwater sample was above the quantification limit [LOQ]. LOQs and MCLs are listed in Table 1. None of the 48 samples were above the LOQ for arsenic, beryllium, boron, mercury, molybdenum, selenium, silver, thallium, or vanadium.

Interior in 2016, high concentrations of metals could be due to the freezing of the water and the method of breaking up the ice to collect a sample.

This study captured samples from one community in the Southwest over both years (2015 $n = 7$, 2016 $n = 21$) in the same season and was, therefore, able to look at some temporal variation in rainwater samples. Most parameter values were similar between years. Both sample years had low TOC (only 25% of samples had detectable levels >0.5 mg/L), slightly acidic pH (2015 mean = 5.3, 2016 mean = 6.0, two-sample t-test $p = 0.12$), detectable levels of sodium and zinc in >85% of samples, and rare occurrences of barium, cadmium, calcium, copper, and lead. Manganese was present in 50% of samples in each year. Only three parameters were different between the 2 years: conductivity was higher in 2016 (mean = 49.96 μS/cm) than in 2015 (mean = 20.56 μS/cm, two-sample t-test $p < 0.0001$), magnesium was more common in 2016 (detected in over half of samples compared with 0 samples with detectable levels >500 μg/L in 2015), and nickel was less common in 2016 (detected in 0 samples compared with 75% of the samples >2 μg/L in 2015). Rainwater quality is very likely to be non-homogeneous with respect to time and geography, so more comprehensive and systematic analyses would need to be applied to future research and monitoring if increased data confidence is required, especially with respect to contaminants of high concern.

Bacteria analyses

The bacteria samples from the 2015 citizen science study were processed several days outside of the recommended holding time and 0 MPN/100 mL was observed for all samples. The results are believed to be invalid and are not presented here. Over half of the 2016 samples from both communities ($n = 28$ outside samples, $n = 24$ inside samples, Figure 3) tested negative for *E. coli*, and <15% of inside and outside samples had sufficiently high MPN/100 mL of *E. coli* to be classified as 'high risk' according to the World Health Organization (>10 MPN/100 mL, Sobsey

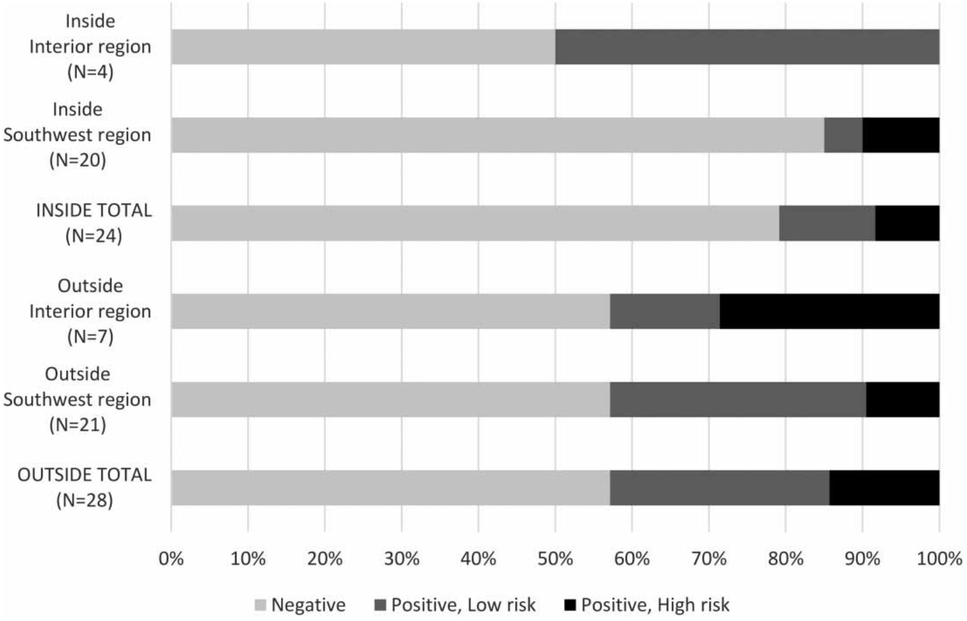

Figure 3 | 2016 *E. coli* results from rainwater catchment samples. Risk level based on World Health Organization recommendations.

2017). ‘High-risk’ results could be due to the hardware being used in the catchment system or to the spread of bacteria into water from human or animal contact or wind. Uncovered vessels had a significantly higher concentration of *E. coli* (p-value = 0.03) than covered vessels.

In many samples, there was disagreement between the inside and outside samples in the level of risk, despite homeowners indicating that they came from the same source. Nine outside samples in the Southwest tested positive for *E. coli*, and only two of these homes also tested positive for *E. coli* in the inside sample. Three outside samples in the Interior tested positive for *E. coli*, and only one of these homes also tested positive for *E. coli* in the inside sample. Discrepancies between inside and outside samples could be due to the household practice of point-of-use treatment, contamination of individual catchment or storage containers, or variation in water age. Point-of-use water treatment was not observed or described by homeowners at any home in this study, but may have been in use in some instances and should be evaluated more effectively in future studies.

‘Cadmium house’ case study

The most alarming sampling results from this study came from a single home in the Southwest community that was sampled both in 2015 and 2016 and had high levels of cadmium both years (15–25 times the MCL). This home also had low pH, low levels of *E. coli* in the outside sample in 2016, and detectable levels of barium both years, although barium was not above the MCL. No catchment characteristics or sample collection anomalies were recorded that might explain these high contaminant levels.

In both years, the homeowner was informed about the sample results and was contacted by public health officials upon the request of UAA, who answered questions and encouraged the family to stop using their rainwater until further analysis could be done. The homeowner did not report taking any action based on these results. This case study raises concerns about irregularities in rainwater catchment quality that could impact human health and that may not be detected or explained easily without intensive monitoring. Furthermore, there are not currently designated authorities to conduct this monitoring, communicate with homeowners about issues that are detected, or regulate the use of rainwater catchment systems. The scientific and ethical roles and responsibilities of researchers in communicating the results and enforcing appropriate drinking water quality standards at individual households are unclear for studies like this. For example, most studies do not report discussing water quality results with the participants (e.g. Hart

& White 2006; Despins *et al.* 2009), but Clasen *et al.* (2008) chose to report medical issues directly to health authorities when they were encountered in household water quality testing.

Rainwater quantity estimates

Houses in the community in the Southwest surveyed in 2016 were approximated to have an average of 750 ft^2 of the roof catchment area. Low and high estimates for total theoretical rain catchment volume per year assuming 100% capture efficiency are shown in Table 2. The low estimates were 70% and 60% of the high estimate volumes for the Southwest and Interior communities surveyed, respectively. Rain catchment was estimated to be able to provide 27–40% of annual household water needs for the Southwest community and 13–22% of the annual household water needs for the Interior community, assuming that households had the capacity to store 100% of their capture in the seasons when rainfall would occur. Anecdotal evidence from community members supported the notion that rainwater is a major resource for rural Alaska communities. In the Southwest, some community members reported using rainwater exclusively in the spring and summer and for 50% of water needs in the home in the fall. However, many community members indicated in a community forum and informally during sampling that they would like to collect more rainwater but needed good roofing material, sturdy gutters, and more storage containers to expand their systems. Community members said that rainwater was a key water source in their homes and a preferred source of drinking and washing water. Individuals in the Interior community reported collecting 50–120 gallons of rainwater per month in the spring, summer, and fall, and this volume was limited by the quality and lack of gutters and holding tanks. The quantities of rainwater stored and used as a percentage of annual need are also dependent on household size, which was not asked in the present study. Conversations with some community members in the Interior suggested that rainwater was widely used during the warmer months, but that residents were concerned that visiting officials, including researchers, would not approve of the practice.

Table 2 | Rainwater catchment potential in high and low rainfall scenarios.

	Rain (in.)	Average roof area (ft^2)	Volume of rain (galloon/ year)	Days of water supplied by rain[a]	% of year supplied by rain[a]
Southwest					
High	18.54	750	8,670	144	40
Low	12.87		6,020	100	27
Interior					
High	12.37	625	4,820	80	22
Low	7.45		2,902	48	13

[a] Days of water supplied assumed 60 gallons used per household per day.

For the estimated quantities of rainwater calculated above to be harvested, homes would have to make use of all available roof area by installing gutters and downspouts in appropriate locations. Monthly variation in rainfall would require collection vessel volume totaling approximately 1,500 gallons for the Southwest community and 900 gallons for the Interior community. Furthermore, appropriate greywater/wastewater disposal methods would have to be implemented alongside rain catchment system expansion to manage the increased volume of the water to be disposed.

This study estimated rainfall capture based on 1981–2010 weather data. However, rural Alaska weather patterns are experiencing rapid changes that could drastically increase annual rainfall. For example, one Southwest community studied here is projected to experience one additional month of temperatures above freezing in the spring by 2060 and a second additional month of temperatures above freezing in the fall by 2090. Furthermore, changing climate is projected to increase monthly precipitation by approximately 15% in the next 80 years based on an intermediate projection (‘medium representative concentration pathways’, University of Alaska Fairbanks 2018). Rainwater collection as a percent of total household water needs is already significant in some communities, and it is projected to continuously increase for most parts of rural Alaska in future decades.

Best practices for rainwater use

Some of the hesitation to accept and promote the widespread use of rain catchment systems by regulatory bodies is related to the large number of small, individual systems that would need to be inspected and maintained. Proper construction and maintenance has been shown to be connected to functionality and water quality (Domènech *et al.* 2012) and is, therefore, an important concern for rural areas where the construction and maintenance of such systems is likely to be uncoordinated using variable materials, and systems are unlikely to be regularly cleaned, monitored, or tested. Although rainwater can be very clean, as shown in this study, the quality is localized and can vary based on the surrounding environment, climate, geography, season, and catchment system characteristics. For example, in the present study, four of the six TOC samples above the regulatory standard (2.0 mg/L) were from the Interior in 2016 when catchments had already begun to freeze and large amounts of debris were observed in the tanks. One-third of the collection vessels had visible leaves, insects, sediments, and debris inside the containers, and uncovered vessels had significantly higher levels of *E. coli* than covered vessels.

To ensure the safe use of this preferred and often high-quality on-site water resource, government agencies, tribal authorities, and community health practitioners must consider ways to encourage the adoption of several best practices for rainwater catchment. Water Safety Plans – where a team of stakeholders evaluate hazards and risks for a specific water supply system and plan barriers and controls, monitoring and maintenance based on those specific concerns (Bartram *et al.* 2009) – are growing in popularity and may be a useful approach to encourage safe use of rainwater in communities that have the capacity to create and implement such a plan (Lane *et al.* 2018). While some resources have been developed to encourage proper construction of cold climate rainwater catchment systems (Hart & White 2003a; Stensrod & Gosbak 2008), this study suggests that even basic practices with low time and cost inputs could improve rainwater catchment quality. We recommend the following practices:

(1) All parts of the catchment system must be cleaned and inspected at least monthly by the homeowner to reduce debris and contaminants from entering catchment containers.

(2) Household waste and other contaminants must be kept away from catchment system components.

(3) Gutters, downspouts, and storage containers must be screened or covered to reduce debris entering the water supply. First, flush apparatuses are recommended to be installed.

(4) Sanitary practices must be observed when drawing water from the storage tank and bringing it into the home.

(5) Point-of-use water treatment options are advised. UV disinfection could be a promising alternative to chlorine (which is difficult to ship and expensive) since the UVT of water samples was very high (>85%) and the power grid in most communities is relatively stable. Treatment can be considered for consistently low pH rainwater to decrease acidity.

(6) Rainwater is advised to be periodically tested for bacteria, metals, and other priority contaminants, and action should be taken if any parameter readings fall outside of the EPA drinking water regulations.

(7) Gutters must be installed on all sturdy parts of the roof and sufficient catchment containers provided to maximize catchment volume.

Use of citizen scientists

This study used volunteer citizen scientists during the first year of data collection to overcome a lack of funding to send researchers out to remote communities. While citizen scientists greatly expanded the number and geographic range of samples evaluated (King 2016), some data was lost or unusable due to the unavailability of resources and a lack of in-depth knowledge to properly execute the protocol. For example, microbiological parameters were drastically different in samples collected by academic scientists compared with those taken by citizen scientists. An earlier Alaska rainwater study employed a third type of sampling – asking homeowners to sample their own tanks and ship the samples to labs for analysis – and also had a low detection of microbes (Hart & White 2006), possibly due to differences in storage conditions and sample holding times. Using a citizen science approach could help overcome the hurdles of cost and feasibility of travel when collecting samples in remote locations; however, citizen scientists must be carefully trained and observed, and proper material and logistical support will need to be provided to ensure that accurate and useable data is collected. For example, since microbiological parameters are very sensitive to contamination and have a shorter holding time than many chemical and physical water quality parameters, it is advisable to avoid microbiological sampling in this type of citizen science context. Citizen science and homeowner sampling programs should be carefully designed and executed if they are to be employed for monitoring purposes.

Limitations

Due to the logistical and financial complications of collecting field data in rural Alaskan communities, this study made use of convenience sampling and voluntary participation in the study. Results may not be fully representative of rainwater quality across all communities, but this study represents a larger sample than has previously been collected in Alaska. Due to the use of simplified methods to accommodate multiple data collectors and challenging travel conditions, the present study was unable to collect information on point-of-use water treatment, household size, socioeconomic characteristics, household education information, seasonality of rainwater quality and quantity, and in-depth observation of environmental conditions.

CONCLUSION

This study represents a broad data reconnaissance effort to examine the quality and quantity of rainwater available to rural Alaska communities, many of which do not have adequate water resources for household use to promote a healthy lifestyle.

Overall, rainwater has been shown to be a high-quality water source that is available in varying quantities in most rural Alaska communities. Almost 80% of the samples tested in nine communities were safe to drink based on EPA primary drinking water regulations. Additionally, rainwater was expressed to be a culturally and socially acceptable and preferred water source in all the communities sampled in this study. The use of rainwater collected on-site has the opportunity to greatly increase the quantity of water that households use for hygiene purposes without the additional cost, effort, and risks that come with hauling water in from other sources. Even in relatively dry and cold areas like the Interior, rainwater could provide 60 gallons of water per household per day for over 20% of the year, which represents a 10-fold increase in water use compared with household water usage in unserved communities that self-haul water from off-site. This increase in water could contribute to declines in enteric, skin, and respiratory infections, and if rainwater catchment systems can be properly designed, maintained, and monitored, they can provide a low-cost and efficient alternative to traditionally engineered systems in rural communities.

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DECLARATIONS OF INTEREST

None declared.

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