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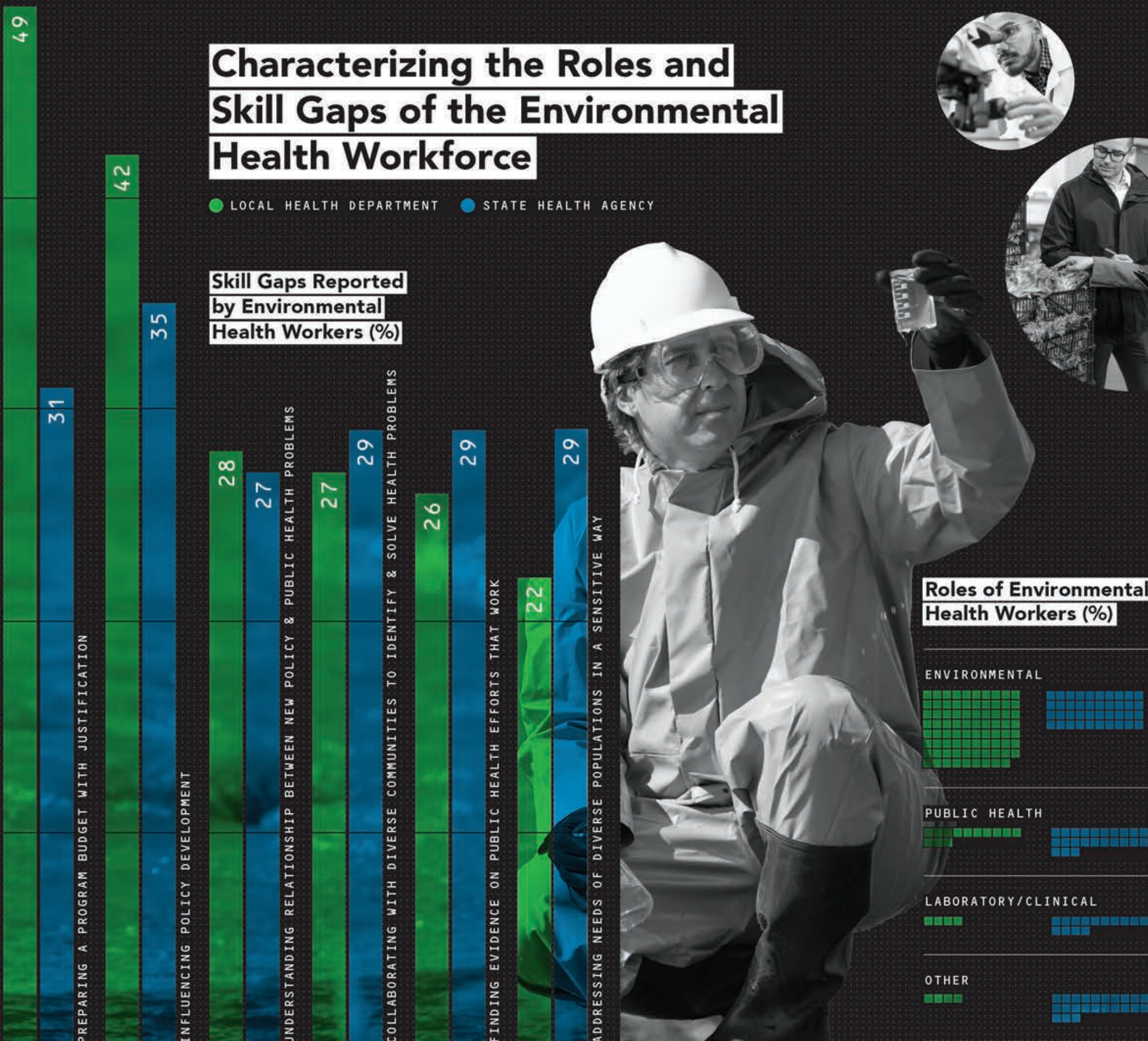
Volume 81, No. 6 January/February 2019

Characterizing the Roles and Skill Gaps of the Environmental Health Workforce



Published by the National Environmental Health Association

www.neha.org

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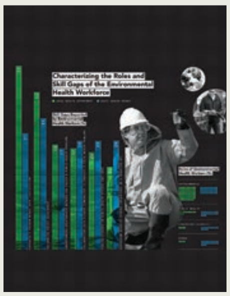

Efforts to characterize the environmental health workforce are needed in order to strengthen the field. There is a lack of information from the perspective of state and local health department workers regarding their tasks, responsibilities, and skill gaps. This month's cover article, "Characterizing the Roles and Skill Gaps of the Environmental Health Workforce in State and Local Health Departments," serves to address this gap in the literature by characterizing environmental health workers. The article also compares and contrasts these characteristics between state health agencies and local health departments.

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Official Publication

National Environmental Health Association

Journal of Environmental Health
(ISSN 0022-0892)

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Published monthly (except bimonthly in January/February and July/August) by the National Environmental Health Association, 720 S. Colorado Blvd., Suite 1000-N, Denver, CO 80246-1926. Phone: (303) 756-9090; Fax: (303) 691-9490; Internet: www.neha.org. E-mail: kruby@neha.org. Volume 81, Number 6. Yearly subscription rates in U.S.: $150 (electronic), $160 (print), and $185 (electronic and print). Yearly international subscription rates: $150 (electronic), $200 (print), and $225 (electronic and print). Single copies: $15, if available. Reprint and advertising rates available at www.neha.org/JEH. CPM Sales Agreement Number 40045946.

Full text of this journal is available from ProQuest Information and Learning, (800) 521-0600, ext. 3781; (734) 973-7007; or www.proquest.com. The *Journal of Environmental Health* is indexed by Current Awareness in Biological Sciences, EBSCO, and Applied Science & Technology Index. It is abstracted by Wilson Applied Science & Technology Abstracts and EMBASE/Excerpta Medica.

All technical manuscripts submitted for publication are subject to peer review. Contact the managing editor for Instructions for Authors, or visit www.neha.org/JEH.

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Periodicals postage paid at Denver, Colorado, and additional mailing offices. POSTMASTER: Send address changes to *Journal of Environmental Health*, 720 S. Colorado Blvd., Suite 1000-N, Denver, CO 80246-1926.

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PRESIDENT'S MESSAGE

Vince Radke, MPH, RS, CP-FS, DLAAS, CPH

My Heroes

This past October I had the privilege to attend two National Environmental Health Association (NEHA) affiliate conferences—the Iowa Environmental Health Association (IEHA) Fall Conference and the Alaska Environmental Health Association (AEHA) Annual Educational Conference. In attendance with me at the IEHA conference were Region 4 Vice-President Kim Carlton and Region 7 Vice-President Tim Hatch. Both gave presentations and represented NEHA well. Carlton gave an update on NEHA and Hatch spoke on emergency preparedness and response to the 2017 hurricanes. At the AEHA conference, Region 1 Vice-President Matthew Reighter gave two presentations. One of the presentations was an update on NEHA and the other was on the prevention of foodborne illness.

Both conferences were well attended. In Alaska, a moose showed up just outside our conference room windows (Photo 1). The quality of presentations was excellent. What was most impressive was the diversity and quality of work being done by local sanitarians/environmental health specialists. They were doing this work in collaboration with various partners (e.g., state agencies, industry, nongovernmental organizations, and others).

IEHA was starting a yearlong celebration of its 50th anniversary. I gave IEHA President Don Simmons a small gift on behalf of NEHA's board of directors (Photo 2). The Iowa conference started with a presentation by Bruce Clark, Marler Clark, The Food Safety Law Firm, on foodborne illness litigation and the burden and impact of foodborne illness suffered by individuals and their families.

Photo 1. An unexpected attendee of the Alaska Environmental Health Association's Annual Educational Conference. Photo courtesy of Vince Radke.

The Iowa conference had multiple presentations during each of the breakout sessions. Based on the program abstracts, it was difficult to decide which presentations to attend. They all sounded good. I attended a presentation titled "It Take a Village: How to Improve Your Environmental Health Program by Collaborating With Other Environmental Health Agencies Through Regional Meetings and Interagency Agreements." The presentation was given by two environmental health specialists from neighboring counties who demonstrated the power of partnerships in addressing environmental health issues in the region.

Another presentation showed the importance of partnership and collaboration between environmental health at a county public health department and the Iowa State Hygienic Laboratory to resolve issues around contamination of private wells (e.g., bacteria, nitrate, arsenic, neonicotinoid insecticides, and others). Another session highlighted the importance of data from the well log for environmental health specialist. These data, along with laboratory data, can help well drillers and environmental health specialists who are working together to determine possible well water contamination sources and to take the necessary action to correct the problem.

A session about the Iowa Onsite Waste Water Association's Homeowner Onsite System Record Keeping Folder showed the importance of having information available to quickly respond to issues with septic systems to septic system owners, contractors, and pumpers. Also, the speaker pointed out how grant money to the counties can be used to pay for this resource. Other sessions I attended provided information on a community water fluoridation program, a nuisance program, and a lead poisoning program that is a partnership between the Iowa Department of Public Health and Linn County Public Health. I was so proud of all the good work that environmental health specialists, along with their partners, are doing in their communities in Iowa. My heartfelt thanks to all of them.

At the AEHA conference I got a sense of the difficulty environmental health specialists face in Alaska. The distances they must travel, either by boat or plane because roads do not lead to many villages and small communities, make their jobs tough. There were sessions on air monitoring in Bethel, Alaska, and confined space entry if environmental health specialists were involved. The session on confined space entry spoke about the training, monitoring, and safety procedures

Photo 2. National Environmental Health Association President Vince Radke congratulates Iowa Environmental Health Association (IEHA) President Don Simmons on IEHA's 50th anniversary. Photo courtesy of Carmily Stone.

Photo 3. Vince Radke (far left) and Matthew Reighter (far right) stand with officers from the Alaska Environmental Health Association before the closing dinner and award ceremony commences. Photo courtesy of Vince Radke.

that are required before environmental health specialists can enter a confined space.

There was a session on One Health that demonstrated the importance of environmental health specialists in the areas of food safety, animal health, and zoonotic diseases. The speaker pointed out the importance of environmental health specialists working with epidemiologists, public health nurses, and public health laboratories to control disease. There was a session about new tools for those working in institutional environmental health, as well as a session on using technology and social media to increase public awareness and reporting of foodborne illness in Alaska.

Given the changing climate in Alaska, there was a discussion on the risk of ticks and tickborne pathogens in Alaska going forward. There were two other sessions that deserve mention. The first was a talk given by Dr. Jay Butler, director of the Division of Public Health at the Alaska Department of Health and Social Services, on the perspectives of communicating complex health topics like environment health issues. The other was an update on the Alaska Pacific University (APU) Environmental Health Program and the effort between AEHA and APU to establish an environmental health program at the university. This multiyear effort is moving forward. It is the hope that APU and students in Alaska will have an academic environmental health program in the next year or so.

Finally, I attended the AEHA dinner and awards ceremony on my last night in Alaska (Photo 3). It was a wonderful moment for me to see the joy and pride of those being recognized for their great work under harsh conditions.

In closing out the evening, I was sitting with three young environmental health specialists over a beer sharing environmental health war stories. They mentioned that part of their jobs was to fly to remote villages in Alaska in support of improving the health of people in the villages. One of their jobs was to vaccinate family dogs against rabies. One of the hazards of that job is dog bites; they take the necessary precautions but occasional they get bit. I was concerned and told them so. They laughed and said it was part of their job and not a big deal. They showed me their scars. We finished our beers, said good night, and headed back to the hotel.

Before falling asleep that evening, I thought about the environmental health specialists in Iowa, Alaska, and across the U.S.—my heroes!

Vince

President@neha.org

Evaluation of the Air Quality Index as a Risk Communication Tool

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Abstract **Air quality conditions in the U.S. are reported to the general public via the regulatory-based Air Quality Index (AQI). The accuracy of AQI as a risk communication tool is dependent, in part, on an assumption of equivalent health risks for each of the index pollutants. Time-series analyses of 858,030 emergency department visits from 2005–2010 for respiratory diseases in two New York counties (Bronx and Queens) were completed using a Poisson generalized linear model in order to assess the equivalency of respiratory morbidity risk for four index pollutants. Excess respiratory risk per 1-AQI unit was approximately twice as high for ozone (0.16%, 95% confidence interval [*CI*] [0.08, 0.24]) as compared with sulfur dioxide (0.09%, 95% *CI* [0.01, 0.16], nitrogen dioxide (0.07%, 95% *CI* [0.01, 0.15]), and fine particulate matter (0.07%, 95% *CI* [0.02, 0.12]). Unequal respiratory risks on a per-AQI-unit basis resulted in inconsistencies between reported AQI values and public health risks, especially during the ozone season. While still useful in reporting general air quality conditions to the public, AQI may be insufficiently precise to inform optimal daily behavior modification decisions.**

Introduction

Despite steady improvements in outdoor air pollution concentrations that have generally occurred in the U.S. over the past 15 years, approximately 75% of the adult U.S. population continues to indicate that they worry "a great deal" or "a fair amount" about air pollution (Statista, 2018; U.S. Environmental Protection Agency [U.S. EPA], 2012a, 2017). This general concern regarding air quality is more tangibly expressed by increasing public demand for information regarding daily air quality concentrations. For example, public engagement with local air quality management organizations in the Washington, DC–Baltimore metropolitan region increased more than 10-fold from 2006–2018 while air pollution concentrations decreased in the region over the same time period by approximately 25% (Clean Air Partners, 2006, 2018).

The Clean Air Act (Section 319, Part A) requires "reporting of air quality based on [a] uniform air quality index" (Air Quality Monitoring, 2011). The Air Quality Index (AQI) is a regulatory-based index with the primary purpose of communicating a nationally uniform message on air pollution concentrations relative to National Ambient Air Quality Standards (NAAQS) for five criteria pollutants: ozone (O_3), particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) (Air Quality Index Reporting, 1999). In practice, AQI is a single-pollutant index where the AQI value of the pollutant with the highest ambient concentration relative to its regulatory standard (critical pollutant) is reported to the public as the AQI value each day in metropolitan statistical areas with a population over 350,000 or in areas that are otherwise required to report AQI (U.S. EPA, 2012b).

AQI was not specifically designed to provide detailed information regarding public health risks, but it has become a commonly used tool for clinicians and patients to help inform daily behavior modification decisions. Using a regulatory-based index for risk communication, however, does have some limitations, including a general inability to inform the public regarding health risks occurring at concentrations below regulatory standards and an inability to account for the health effects of exposure to multiple pollutants (Air Quality Index Reporting, 1999). This limitation potentially is a critical issue given that it has been observed that the majority of air pollution-attributable health effects occur on days with pollution concentrations below NAAQS (Perlmutt, Stieb, & Cromar, 2017). Given the important role that behavior modification may increasingly play in managing the health impacts of air pollution (Laumbach, Meng, & Kipen, 2015), it is important that the accuracy of AQI as a risk communication tool is fully evaluated.

This study investigates the public health capabilities of AQI by testing the structural assumptions of the index. The accuracy of AQI as a risk communication tool (wherein higher index values are associated with increased public health risks) depends in part on the assumed equivalency of health risks for the five index pollutants on a per-AQI-unit basis. As such, it is important to evaluate this assumption of equivalency using real-world data. This study a) explores whether the public health risks of the index pollutants increase at a similar rate based on the AQI scale and b) assesses the impacts of

TABLE **1**

Summary of New York City Daily Meteorological and Air Pollutant Concentrations With Equivalent Air Quality Index (AQI) Values From 2005–2010 by Seasonal Average and Percentile Values

	Seasonal Average	Percentile Values				
		0.05	0.25	0.50	0.75	0.95
Year-round						
Temperature (°F)	55.6	28.4	41.9	56.0	70.7	80.0
Relative humidity (%)	62.4	39.3	50.2	61.8	74.2	86.9
O_3 (ppb, 8-hr maximum)	28.2 (31.7)	8.3 (9.7)	17.5 (20.7)	25.0 (29.5)	34.0 (40.1)	60.0 (62.4)
$PM_{2.5}$ (µg/m^3, 24-hr)	47.3 (12.9)	19.0 (4.6)	31.0 (7.4)	45.5 (11.0)	60.0 (16.4)	83.5 (27.6)
NO_2 (ppb, 1-hr maximum)	38.4 (40.5)	19.5 (20.7)	30.0 (31.8)	37.5 (39.8)	45.5 (48.2)	61.5 (63.9)
SO_2 (ppb, 1-hr maximum)	19.2 (13.5)	3.5 (2.5)	8.5 (6.0)	15.0 (10.5)	26 (18.2)	49.3 (35.4)
Non-ozone season						
Temperature (°F)	42.9	24.3	34.2	42.2	51.0	59.0
Relative humidity (%)	61.2	38.6	48.7	58.8	73.6	87.9
O_3 (ppb, 8-hr maximum)	18.3 (21.6)	5.0 (5.9)	13.5 (15.9)	18.0 (21.2)	23.5 (27.7)	30.5 (36.0)
$PM_{2.5}$ (µg/m^3, 24-hr)	48.4 (13.1)	21.0 (5.0)	34.5 (8.28)	47.5 (11.6)	59.5 (16.3)	82.5 (26.9)
NO_2 (ppb, 1-hr maximum)	37.9 (40.0)	20.5 (21.7)	30.0 (31.8)	37.0 (39.2)	44.0 (46.6)	59.5 (62.0)
SO_2 (ppb, 1-hr maximum)	25.9 (18.3)	6.5 (4.6)	14.5 (10.2)	22.5 (15.8)	34.0 (23.8)	57.0 (41.2)
Ozone season						
Temperature (°F)	68.3	49.4	61.1	70.3	76.3	82.6
Relative humidity (%)	63.7	40.2	53.1	63.6	74.7	86.1
O_3 (ppb, 8-hr maximum)	38.1 (41.7)	17.9 (21.2)	27.0 (31.9)	33.5 (39.5)	42.5 (50.2)	80.5 (69.0)
$PM_{2.5}$ (µg/m^3, 24-hr)	46.1 (12.6)	18.4 (4.4)	28.0 (6.7)	43.0 (10.3)	60.0 (16.4)	85.1 (28.3)
NO_2 (ppb, 1-hr maximum)	38.9 (41.1)	18.5 (19.6)	30.0 (31.8)	38.5 (40.8)	46.5 (49.3)	62.1 (64.4)
SO_2 (ppb, 1-hr maximum)	12.4 (8.7)	2.5 (1.8)	6.0 (4.2)	10.0 (7.0)	15.0 (10.5)	32.0 (22.4)

NO_2 = nitrogen dioxide; O_3 = ozone; $PM_{2.5}$ = fine particulate matter; SO_2 = sulfur dioxide.
Note. Equivalent AQI values for each pollutant are shown in parentheses.

this assessment on the overall accuracy of AQI as a risk communication tool.

Methods

Health Data

We obtained data from daily respiratory disease emergency department (ED) visits for years 2005–2010 for Bronx and Queens counties from the New York Statewide Planning and Research Cooperative System. These ED visits, restricted to counts of visits with diagnoses of respiratory disease, included the following ICD-9 diagnostic codes (all two-digit extensions were used): asthma (493), chronic obstructive pulmonary disease (COPD) (491, 492, 496), upper respiratory infection (URI) (460–466, 477), and pneumonia (480–486).

Pollution and Weather Data

We collected daily reported AQI values of NO_2, O_3, fine particulate matter ($PM_{2.5}$), and SO_2 for Bronx and Queens counties in New York City for years 2005–2010 from the U.S Environmental Protection Agency (U.S. EPA) Air Data to generate a daily AQI value for each pollutant (U.S. EPA, 2018). AQI values reported from 2005–2010 were based on AQI cutpoints from the 2013 NAAQS. We obtained daily meteorological variables for years 2005–2010 from the National Climatic Data Center and averaged from stations at LaGuardia and John F. Kennedy airports (National Climatic Data Center, 2015). Summary statistics for pollution and weather variables are shown in Table 1.

Evaluation of Risk Based on Changes in the Air Quality Index

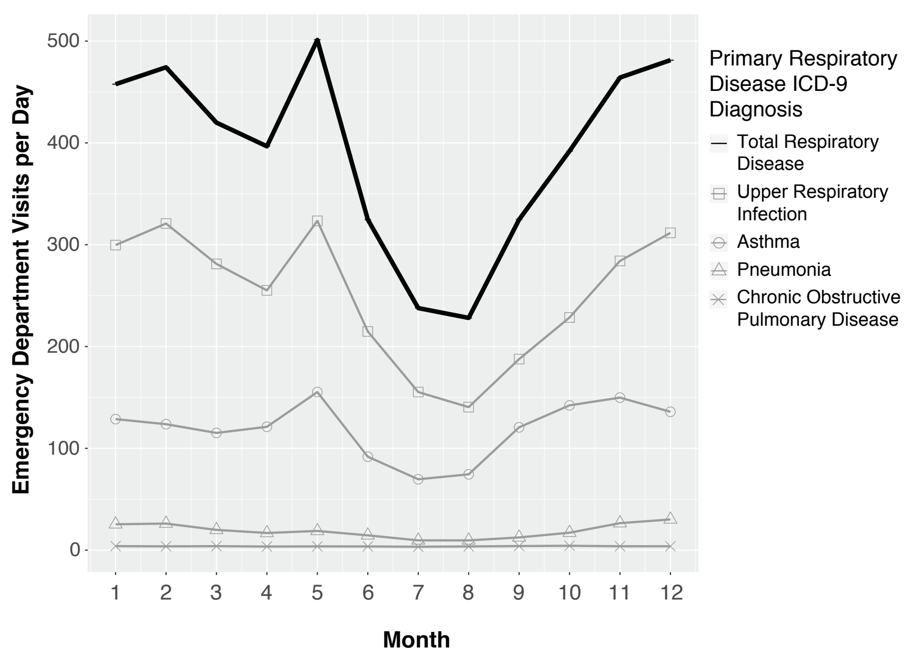
To quantitatively assess the accuracy of AQI as a risk communication tool, the excess risk of respiratory morbidity associated with a 1-unit increase in AQI value was determined for four of the five pollutants reported by AQI (NO_2, O_3, $PM_{2.5}$, and SO_2). Carbon monoxide (CO) was not included in the analysis because during our study period, concentrations were frequently below detection limit.

Time-series analysis using a Poisson generalized linear model was used to determine the association between daily counts of total respiratory disease ED visits and daily AQI values for the index pollutants from 2005–2010 in New York City. The full time-series model included linear and nonlinear terms to control for potential confounding due to temporal and meteorological variables. Specific terms included natural splines (10 *df*/year) to account for long-term trends and seasonality; same-day and average of lag 1- to 3-day temperature (3 *df*); same-day relative humidity (3 *df*); day of the week; and an indicator variable for May 2009, which was found to be an outlier during the study period. We accounted for overdispersion by using quasi-likelihood estimator. Similar methods have been previously used to assess health risks of short-term air pollution exposures (Ito, Thurston, & Silverman, 2007).

We estimated associations of air pollution and respiratory disease ED visits using single-day lag structures between 0–3 days and a simple moving average of lag 0–2 days (same-day exposure through exposures 2 days before ED visit). Risk ratio (*RR*) estimates, including 95% confidence interval (*CI*) estimates, were determined from the derived beta coefficients and corresponding standard errors using a 1 AQI-unit interval. We assessed differences in *RR* estimates via two-tailed *t*-tests. For all analyses, we used R software version 3.2.4.

FIGURE **1**

Average Daily Emergency Department Visits by Month and ICD-9 Code, Bronx and Queens Counties, New York City, 2005–2010



Reported Air Quality Index Value Versus Daily Excess Risk

Using the coefficients generated from time-series analysis, we determined the daily percent excess risk of respiratory disease ED visits for years 2005–2010 for each AQI pollutant. We calculated daily percent excess risk using the following equation:

$$100(e^{\beta_i X_{it}} - 1)$$

where β_i equals the per 1 AQI-unit coefficient of pollutant *i* generated from time-series analysis and X equals the AQI of pollutant *i* on day *t*. Daily total excess risk associated with exposure to each pollutant was determined assuming an additive effect across pollutants.

In order to evaluate whether higher AQI values are associated with higher health risks, we compared the daily excess respiratory morbidity risk as a function of the same-day AQI value for years 2005–2010. We also calculated conditional probabilities for days with higher AQI values having higher respiratory morbidity risk using ranges of ± 10, 20, and 30 AQI units.

Results

Counts of average daily ED visits by month varied throughout the year, with the highest average daily counts during May and the lowest number of ED visits occurring in June–September (Figure 1). Average daily counts per day by respiratory disease ICD-9 diagnosis (391.6 visits/day) were greatest for URI (249.9 or 63.8% of total), followed by asthma (119.0 or 30.4% of total), pneumonia (18.9 or 4.8% of total), and COPD (3.8 or 1.0% of total).

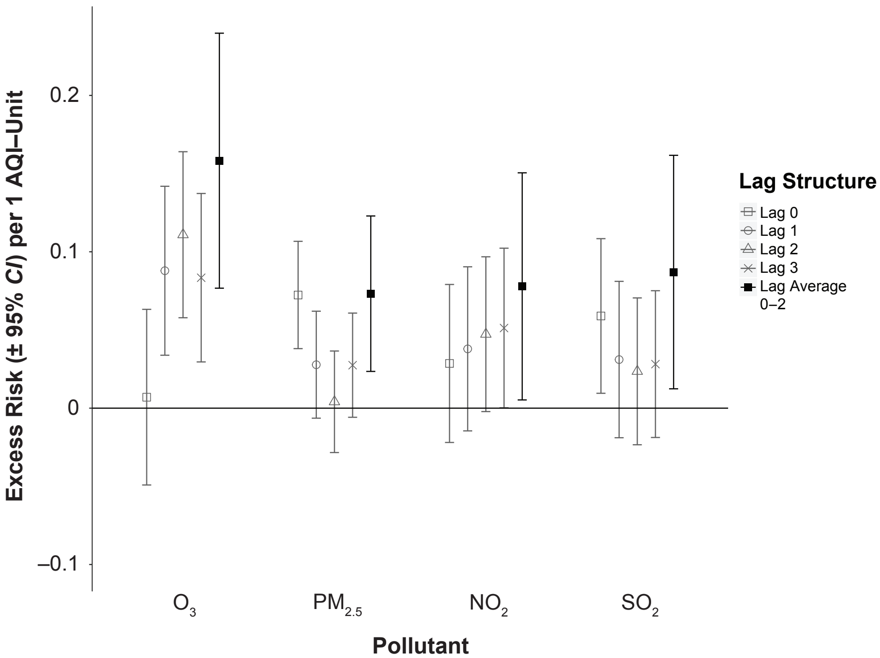
Positive associations between AQI pollutants and total respiratory disease ED visits were statistically significant at multiple lag days (Figure 2). Excess risk of total respiratory disease ED visits for a 1-unit increase in AQI were highest for O_3 (excess risk: 0.16%, 95% *CI* [0.08, 0.24]) compared with the other pollutants SO_2 (0.09%, 95% *CI* [0.01, 0.16]), NO_2 (0.07%, 95% *CI* [0.01, 0.15]), and $PM_{2.5}$ (0.07%, 95% *CI* [0.02, 0.12]) (Table 2). Qualitatively, the effect size is approximately double for O_3 as compared with NO_2, $PM_{2.5}$, and SO_2, all of which have comparable effect sizes on a per-AQI-unit basis, though the effect size is not statistically significantly different via two-tailed *t*-tests. The *p*-values for O_3 compared with SO_2, $PM_{2.5}$, and NO_2 were .21, .08, and .15, respectively.

Looking at lag structures with peak effects (i.e., lag 1–3 for O_3 and lag 0–3 for the other pollutants) for each of the pollutants shows that these differences in risk are statistically significant for O_3 compared with the other pollutants. We found that differences in excess risk were statistically significant for O_3 (excess risk: 0.22%, 95% *CI* [0.13, 0.30]) compared with SO_2 (0.10%, 95% *CI* [0.02, 0.18]) and $PM_{2.5}$ (0.09%, 95% *CI* [0.03, 0.15]) (*p*-values of .05 and .02, respectively) and were marginally significant (p = .07) when comparing O_3 and NO_2 (0.11%, 95% *CI* [0.03, 0.19]).

We evaluated the daily excess risk associated with the reported critical AQI pollutant and the excess risk associated with the pol-

FIGURE **2**

Excess Risk of Respiratory Emergency Department Visits by Air Quality Index (AQI) Pollutant on a per AQI-Unit Basis, New York City, 2005–2010



CI = confidence interval; NO_2 = nitrogen dioxide; O_3 = ozone; $PM_{2.5}$ = fine particulate matter; SO_2 = sulfur dioxide.

TABLE **2**

Association of Daily Air Quality Index (AQI) Values With Emergency Department Visits for Respiratory Disease per 1 AQI-Unit

Pollutant	% Excess Risk (95% *CI*)	β Coefficient	*SE*	Lag Structure
O_3	0.16 (0.08, 0.24)	0.001581	0.000416	Lag average 0–2
$PM_{2.5}$	0.07 (0.02, 0.12)	0.000732	0.000254	Lag average 0–2
NO_2	0.07 (0.01, 0.15)	0.000778	0.000370	Lag average 0–2
SO_2	0.09 (0.01, 0.16)	0.000870	0.000380	Lag average 0–2

CI = confidence interval; NO_2 = nitrogen dioxide; O_3 = ozone; $PM_{2.5}$ = fine particulate matter; SO_2 = sulfur dioxide.

lutant with the maximum daily excess risk in New York City for years 2005–2010. During this time, 40% of days during the non-ozone season (October–March) had higher excess risks associated with one of the noncritical pollutants, compared with the critical pollutant; during the ozone season (April–September), this value increased to 70%.

We examined in greater detail the daily excess risks for the year 2007 (median study year) (Figure 3). Similar to results from 2005–2010, we found a seasonal pattern in the difference between percent excess risk of the critical AQI pollutant versus the pollutant with the maximum daily excess risk (Panel A in Figure 3). The greatest difference in excess risk for total respiratory disease ED visits was observed during the ozone season, where the average percent change in maximum excess risk relative to the excess risk of the critical pollutant was 36.8% as compared with 11.6% during the non-ozone season. The greatest monthly average percent change in maximum excess risk relative to the excess risk of the critical pollutant occurred in April (43.9%), while the minimum percent change occurred in January (0.82%).

Panel B in Figure 3 displays the daily critical AQI pollutant as well as the pollutant with the maximum percent excess risk. O_3 was often the pollutant with the greatest maximum percent excess risk during the warmer months, even though $PM_{2.5}$ and NO_2 were often the daily critical AQI pollutant. During the colder months of the non-ozone season, more agreement was found to exist between the excess risk of the critical pollutant and the maximum percent excess risk.

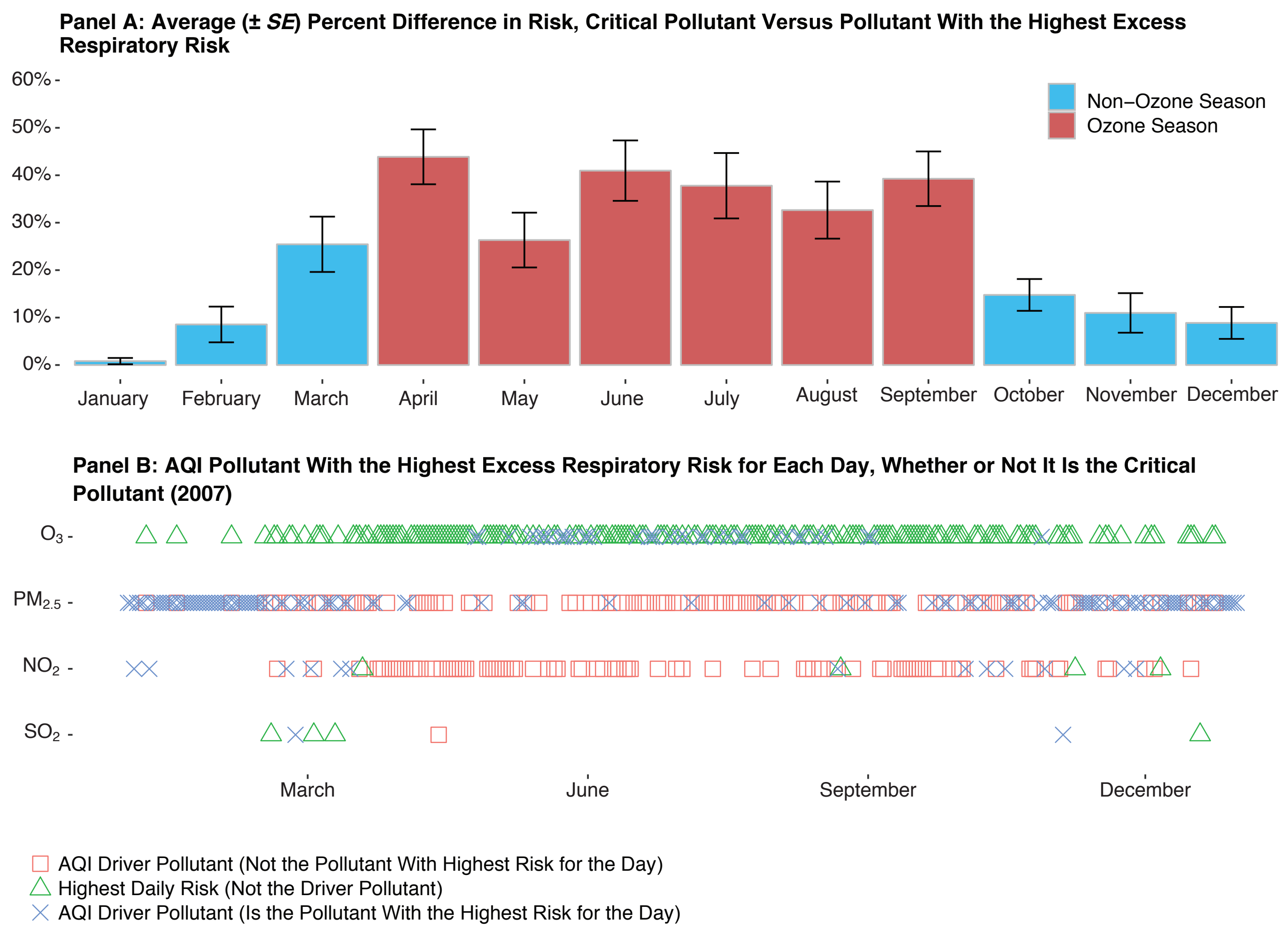
We calculated conditional probabilities to determine the likelihood that excess respiratory risk on a given day was lower than days with lower AQI values and higher than days with higher AQI values. These probabilities are shown separately for the ozone and non-ozone seasons for AQI values ± 10, 20, and 30 index units (Figure 4). During the ozone season, excess respiratory risk on days with AQI values >70 was accurate within ± 10 index units less than 50% of the time. During the non-ozone season, days with AQI values near 80 had approximately a 50% probability of excess respiratory risks being less than days with an AQI value ≥60 than days with an AQI value of 100. Also during the non-ozone season, days with index values near 70 had a 25% chance of having the daily respiratory risk fall outside of the range of risks observed on days with AQI values of 40–100. We observed similar probabilities on days with AQI values throughout the moderate range (50–100) in both the ozone and non-ozone seasons.

Discussion

U.S. EPA advises healthcare professionals who counsel patients about asthma to encourage patients to use AQI as a tool to manage respiratory health, even though AQI is not specifically designed as a health-

FIGURE **3**

Comparison of Daily Critical Air Quality Index (AQI) Pollutant and Pollutant With Highest Excess Respiratory Health Risk, New York City, 2005–2010



NO_2 = nitrogen dioxide; O_3 = ozone; $PM_{2.5}$ = fine particulate matter; SO_2 = sulfur dioxide.

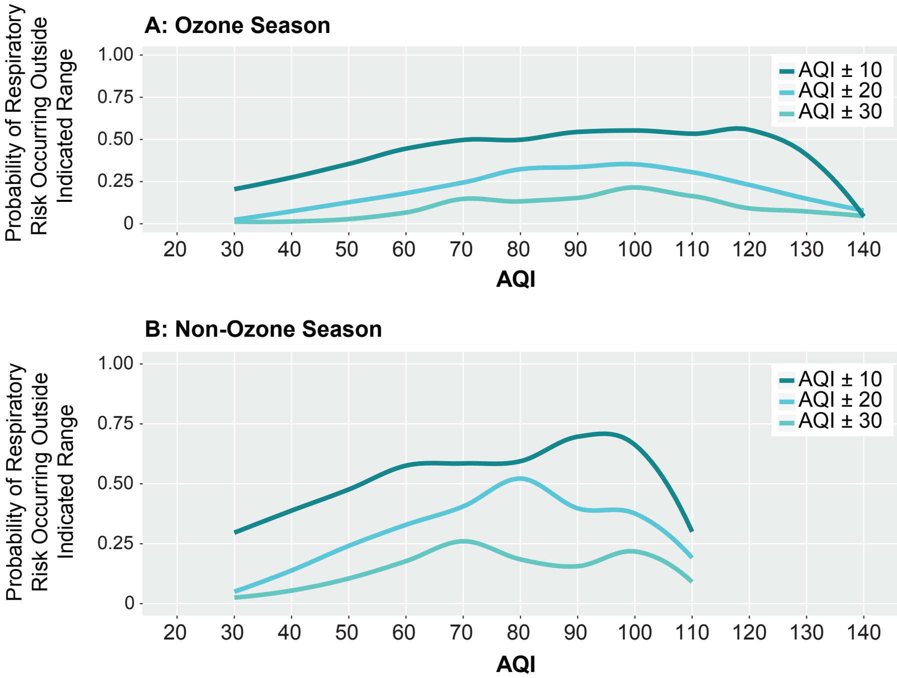
based index (U.S. EPA, 2016). In detailing how the general public can use AQI, U.S. EPA states, "the higher the AQI value… the greater the health concern" (U.S. EPA, 2014). The results of this study show that this statement is not always true. Particularly during the ozone season, it is evident that there is often a disconnect between the AQI value and the public health risks for respiratory morbidity.

A key finding of this study is that the excess respiratory risk per 1 AQI-unit is not equal across all pollutants. The excess risks for a 1 AQI-unit increase of NO_2, SO_2, and $PM_{2.5}$ are similar in magnitude (between 0.07% and 0.09%), but the excess risk for O_3 is approximately double that of the other pollutants on a per-AQI-unit basis (0.16%) (Table 2). As a result, the critical pollutant with the highest AQI value of the day, determined by which pollutant has the highest concentration relative to its regulatory standard, is not always the pollutant with the greatest respiratory health risk for the day.

The greatest discrepancies in risk from the daily critical pollutant compared with the pollutant with maximum risk generally occurred during the summer months when O_3 concentrations are highest. This discrepancy, combined with the inability of AQI to account for the health effects of the noncritical pollutants each day, explains the inconsistent health risks observed on different days despite the same reported AQI value. The ability of AQI values to consistently represent population-level respiratory risks in this study varied dramatically by season (Figure 3), and thus it would be reasonable to assume that the effectiveness of AQI as a risk communication tool might also vary by location. Additional analysis across a larger number of study locations will be needed to determine

FIGURE 4

Probability of Excess Health Risks Occurring Outside Indicated Air Quality Index (AQI) Ranges by Season, New York City, 2005–2010



the extent that these findings can be generalized to the broader U.S. population.

The present analysis used AQI values derived from 2013 definitions. We performed additional analysis using updated AQI and concentration cutpoints from the revised 2015 O_3 standard (National Ambient Air Quality Standards For Ozone, Final Rule, 2015). The new standard, however, represents only a 7% reduction (70 ppb versus 75 ppb) and the per 1-unit AQI risk of O_3 relative to the other pollutants was twofold; therefore the new AQI cutpoints associated with the revised O_3 standard had little impact on the results and conclusions of our analysis.

Due to individual variability in response to air pollution—even among healthy individuals (Brook et al., 2010; Hussain et al., 2012; Janghorbani, Momeni, & Mansourian, 2014; Laumbach, 2010)—it is difficult to accurately communicate more than generic messages as to how the public should respond based on specific AQI values, even though there is public demand for this type of guidance (AirNow-International, n.d.). Ideally, AQI would have sufficient internal accuracy to allow patients to determine their own susceptibility to levels of outdoor air pollutants. Unfortunately, the regulatory-based design of the index does not provide sufficiently consistent risk-based information to enable this type of individual optimization within the broad ranges of AQI categories. This lack of internal reliability can explain, in part, why, in a study from two U.S. cities, individuals reported modifying their behavior according to their own perceptions of air quality and not in response to official AQI advisories (Laumbach et al., 2015).

It is important to note that the current AQI is intended to communicate the health risks for any and all relevant health outcomes, and standards for criteria pollutants are set based on research of multiple health outcomes including increased mortality risk, cardiovascular morbidity, and respiratory morbidity. Of particular note are the well-described cardiovascular health impacts associated with short-term pollution exposure, in addition to the many other relevant health endpoints that have been implicated with outdoor air pollution exposures, but which we did not directly evaluate in this study (Thurston et al., 2017). While a limitation of the current study is that this analysis assessed only associations between AQI and respiratory morbidity outcomes, the results indicate that the current AQI approach might have structural limitations in communicating health risks that cannot be solved simply by continued revision of NAAQS and associated AQI cutpoints.

Even with its potential limitations as a risk communication tool, there have been some demonstrable benefits from AQI reporting. In general, risk communication systems have been shown to positively influence behavior change (i.e., avoidance behavior) in outdoor activity due to media alerts (Neidell, 2009; Neidell & Kinney, 2010). A cross-sectional study based on the 2005 Behavior Risk Factor Surveillance System examined a change in outdoor activity due to media alerts of AQI. The authors found a prevalence of change in outdoor activity of 31% in adults with lifetime asthma and 16% in adults without asthma (Wen, Balluz, & Mokdad, 2009). The increased rates of behavior modification among the at-risk subpopulation is a good sign that some patients are looking to AQI to decide how much time to spend outdoors (AirNow-International, n.d.).

Improvements in methods of risk communication associated with air quality indices could lead to more pronounced public health benefits. Accounting for the differences in health risks by pollutant would enable the creation of a more precise risk communication index. Additionally, better education among clinicians regarding the potential strengths and limitations of AQI as a risk communication tool could also facilitate improved outcomes. For example, recognizing that AQI might only provide a coarse view of the general conditions of outdoor air quality (Figure 4), clinicians could recommend that to better inform behavior modification decisions, particularly susceptible patients with an interest in managing air pollution risks look at the concentrations of all of the pollutants that are examined for AQI. Making sure clinicians are adequately trained in the use of AQI is critical, which is the most common way for patients to become familiar with air quality indices (Borbet, Gladson, & Cromar, 2018).

It is noteworthy that there have been no major changes in the overall AQI approach since its inception in 1999 (prior reporting used the Pollution Standards Index), other than changing the cutpoints of the individual pollutants used in generating the index (U.S. EPA, 2012b). This lack of updating most likely is due to the lack of scientific research focused on the utility of AQI as a risk communication tool. Even as other countries and cities have undertaken efforts to revise their air quality indices, there has been very little effort to complete post-hoc evaluations of how well these indices represent population-level health risks. Given the important role that individual behavior modification can play in reducing health burdens associated with air pollution, it is critical that AQI and other air quality indices are properly evaluated and improved using the best available scientific evidence. These improvements will be accelerated as more patient-oriented evidence becomes available and as a more rigorous approach is undertaken in providing clinical practice guidelines associated with advising patients on the use of air quality indices.

Conclusion

Recommendations for clinical practice have suggested that healthcare workers advise at-risk persons to monitor the daily AQI in order to reduce exposure to outdoor air pollution when levels are high (U.S. EPA, 2016). The underlying studies that serve as a foundation for this consensus recommendation undoubtedly assume that increasing AQI values are associated with increased health risk. Due to a lack of equivalency in health risk across the multiple index pollutants on a per-AQI-unit basis, however, this assumption might not be true. In recommending patients use AQI as part of an individualized management plan, clinicians should be aware that AQI might not provide patients with the day-to-day precision a patient needs to make optimal behavior-modification decisions.

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SPECIAL REPORT

The Effect of Hurricanes on Pathogenic Diseases

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Abstract **While hurricanes are known to cause immediate destruction through flooding and strong winds, pathogenic diseases as a result of hurricanes are less recognized. Evidence shows that airborne opportunists and waterborne diseases are more common in the environment after hurricanes, as are visits to the emergency room for respiratory and skin ailments. In addition, infections that result from overcrowding tend to increase in shelters while mosquito-borne viruses can increase in number over the long-term. Understanding the effect of hurricanes on these pathogens in the environment can help public health professionals and the public be better prepared when major hurricanes occur, as well as decrease the incidence of illness and death after a hurricane.**

Introduction

2017 was a year of extreme hurricane activity in Texas and Puerto Rico, with lasting effects that will not quickly be forgotten. Extensive flooding and damaging winds are usually the first concerns that come to mind when people think about hurricanes such as Harvey and Maria. Few people immediately think about pathogenic diseases when discussing major tropical weather systems. News reports can remind people to use caution during power outages and to not eat food that is preserved in suboptimal refrigeration temperatures. The public can be reminded to drink bottled water instead of using tap water after hurricanes. Interestingly, secondary effects from hurricane destruction do play a subtle role and are likely undetected and undiagnosed in many cases. Several scientific studies indicate that after hurricanes, there is an increase in cases of some pathogenic diseases. In addition, statistical evidence indicates increases in emergency department and physician office visits by patients reporting symptoms of a variety of conditions. Other evidence shows that the risk itself is greater for contracting certain illnesses following hurricane damage due to a greater presence of organisms in the environment during and after hurricanes in comparison with before the storm.

Potential Pathogens in the Environment After Hurricanes

Failed levees lead to damaging flooding following major hurricanes, leading to breaches in municipal water systems. This occurrence can cause mixing of sewage water and drinking water or cause increases in runoff from farmland, causing animal waste to leach into drinking water (Renaissance Computing Institute, 2012). After Hurricane Sandy, farmlands became flooded and municipal waste treatment plants were under water, which affected the coastal regions of North Carolina in 1999. A variety of animal farms flooded, resulting in hogs, turkeys, and chickens drowning and having to be burned in order to prevent the spread of disease.

Millions of gallons of manure were released into rivers, thereby contaminating water supplies. Over 300 private wells tested positive for coliform bacteria. One study indicated increases in illnesses from *Toxoplasma gondii* and adenovirus following Hurricane Sandy in severely affected areas of North Carolina (Setzer & Domino, 2004). Although *T. gondii* is carried primarily by cats, intermediate hosts include livestock, suggesting that this organism was spread to humans due to flooding of livestock farms.

Studies that determine the presence of pathogens in environmental waters after hurricanes can indicate what potential risks there are to people cleaning up or working in the aftermath of hurricanes (Sinigalliano et al., 2007). After Hurricanes Katrina and Rita in August and September of 2005, *Vibrio cholerae*, *V. vulnificus*, and, less frequently, *V. parahaemolyticus* were found in Lake Pontchartrain in Louisiana. Various *Legionella* species were also present in this lake after these hurricanes, and in a rare number of samples *L. pneumophila,* the cause of Legionnaires' disease, was present. Just after floodwaters receded, levels of these potential pathogens were higher than several months after the hurricanes. *Cryptosporidium* and *Giardia* cysts were found in canal waters in New Orleans, Louisiana, deriving from runoff around the canals. Epidemiological studies were not correlated with these findings, but the presence of these bacterial and parasitic species indicates increased health risks associated with these organisms after floods caused by hurricanes—especially for survivors who are exposed to environmental sources.

Leptospira Illnesses From Environment Causes

Another environmental organism of concern for hurricane survivors is *Leptospira*. The Centers for Disease Control and Prevention (CDC) states that leptospirosis can occur following exposure to water or soil that has been contaminated with infected animal urine or other body fluids, or by directly touching urine or body fluids from an infected animal (CDC, 2018). Leptospirosis was blamed for several deaths in Puerto Rico following Hurricane Maria, which is not the first time *Leptospira* bacteria have been reported in victims of hurricanes ("Leptospirosis cases reported in Puerto Rico," 2017). In 1996, Hurricane Hortense hit Puerto Rico and 142 dengue-negative patients were tested for *Leptospira* (Sanders et al., 1999). In this group, 4 of 72 prehurricane samples and 17 of 70 posthurricane samples were confirmed to be positive for *Leptospira*, which is a large increase in cases when comparing numbers before and after the storm.

Hurricane Mitch severely affected Honduras in 1998 and a study of 68 people with leptospirosis symptoms were tested for the disease (Naranjo et al., 2008). They found that 24 of the 68 who were tested had positive results for a variety of *Leptospira* species. They reported that 80.8% of those tested reported the presence of rodents in or around their homes, while 86.7% reported having contact with stagnant water, and 55.8% reported having contact with pets. Any or all of these risk factors likely contributed to the large number of cases of leptospirosis after Hurricane Mitch.

Skin Diseases Secondary to Hurricanes

Various people who were exposed to the devastation of Hurricane Katrina exhibited debilitating skin conditions and gastroenteritis soon after. CDC reported that 22 new cases of infection with *Vibrio* species occurred in patients in Louisiana and Mississippi after Hurricane Katrina, with 18 patients presenting with wound infections and 4 patients having symptoms of gastroenteritis (CDC, 2005). Of the 18 wound infections, 17 were speciated, with 14 being caused by *V. vulnificus* and 3 caused by *V. parahaemolyticus*; 3 of the 5 who died of necrotizing fasciitis suffered from *V. vulnificus*, while 2 contracted *V. parahemolyticus*. Underlying conditions were definitely correlated with these illnesses, with 13 of the overall patients having problems such as heart disease, diabetes mellitus, alcoholism, and renal disease. The remaining 4 of the 22 cases consisted of people suffering from nonwound *Vibrio* infections and 2 of these patients were identified as having gastroenteritis caused by nontoxigenic forms of *V. cholerae*.

Although scientific studies have not been reported on cases of necrotizing fasciitis from Hurricane Harvey as of yet, news reports claimed that two cases occurred. The first was from a 77-year-old female from Houston, Texas, who fell and had trauma to an upper extremity. The second was a 31-year-old male from Galveston, Texas, who was hospitalized after having a wound infection on his upper left arm (Astor, 2017; Nestel, 2017). Both individuals had been helping family with hurricane cleanup and, in both cases, the actual organism causing the wound infection has not been released. Another man reportedly died from sepsis contracted from the floodwaters of Hurricane Harvey.

Less severe cases of skin problems, including folliculitis, were reported following Hurricanes Katrina and Rita in a study by Noe and coauthors (2007). Rashes were reported from those working in a military base in New Orleans, Louisiana: 58 of 136 workers had a visible rash, with 8 of those being diagnosed with bacterial folliculitis. Although no species were identified for the folliculitis cases, this reported occurrence is evidence that increases in even minor skin disorders can occur after major hurricanes.

Decreased Air Quality From Water Damage

Several air sample studies were performed after Hurricanes Katrina and Rita hit Louisiana. Rao and coauthors (2007) collected air samples from inside 20 water-damaged homes in four parishes near New Orleans. The homes were classified as having mild, moderate, and heavy damage. Air samples were taken from the front yard of 11 of the homes. They found a greater number of organisms from samples taken from moderately and heavily damaged homes, with higher spore counts and endotoxin levels. After culturing samples at room temperature and at 37 °C from indoor and outdoor samples, opportunistic species such as those belonging to the genera *Penicillium* and *Aspergillus* were the most commonly isolated fungi from indoor and outdoor samples. *Cladosporium* and *Paecilomyces* species were also present both indoors and outdoors. Spores of *A. niger* were found in the highest percentage of homes from indoor samples, while spores from *Cladosporium* species were at the highest percentage from outdoor samples.

In a similar study, Chew and coauthors (2006) measured indoor and outdoor aerosols from three homes in the Gentilly district of New Orleans that were flooded after Hurricane Katrina. Similar to the findings of Rao and coauthors (2007), *Cladosporium*, *Aspergillus*, *Penicillium*, and *Paecilomyces* species were found in each of the homes from spore counts, PCR, and culturing. *Stachybotrys* species were also found from spore counts and PCR, *Alternaria* species were identified from spore counting and culturing at room temperature, and *Curvularia* species were identified from spore counting only.

In a third study, air samples were taken from the following indoor and outdoor sites in Louisiana: New Orleans, Metairie, Chalmette, and Mandeville (Solomon, Hjelmroos-Koski, Rotkin-Ellman, & Hammond, 2006). They sampled 23 outdoor and 8 indoor sites from flooded homes during October and November of 2005. *Cladosporium*, *Penicillium*, and *Aspergillus* species had the highest numbers of spore taxa present. *Alternaria* and *Stachybotrys* species, among others, were also identified through spore collections. Endotoxin levels were found to be slightly higher than levels tested in other residential areas in the U.S. The authors noted that endotoxins do not become airborne as easily as do mold spores, but that remediation processes can disturb the environment and increase endotoxin levels.

Each of these studies indicates that these opportunistic fungi increase in the environment after hurricanes due to moisture left in and around buildings. The most important question when considering the rise in levels of various opportunistic fungi is whether or not and how often these species cause disease. Mycotoxins from *Aspergillus*, *Penicillium*, *Alternaria*, and *Cladosporium* species have been shown to have a variety of detrimental effects in humans and animals, such as lung carcinogenicity, liver and kidney toxicity, and immunosuppression (da Rocha, da Chagas Oliveira Freire, Maia, Guedes, & Rondina, 2014).

Effects from direct exposure to fungal structures usually are most problematic for those with predisposing conditions such as asthma or weakened immune systems. If people do not have preexisting issues, allergic reactions are the most commonly reported health effects (CDC, 2017). Even in people who do not have allergies or asthma, however, coughing and wheezing have been reported. There are also rare conditions that are worth discussing that occur due to exposure to these opportunistic fungi.

Peritonitis, lung infections, skin and nail issues, and even cerebral disease have occurred from *Penicillium* species such as *P. marneffei*, and more rarely from *P. chrysogenum* and other species (Lyratzopoulos, Ellis, Nerringer, & Denning, 2002). Effects from *Aspergillus* species have been reported to be similar to *Penicillium* species, except that endotoxins from *A. flavus* have specifically been reported to contain a carcinogenic aflatoxin (da Rocha et al., 2014). As for *Paecilomyces*, various species have been implicated in pneumonia and *P. variotii* has been implicated in endocarditis, fungemia, and osteomyelitis, among other diseases (Steiner et al., 2013). Illnesses from *Cladosporium* species are categorized as approximately 55% respiratory, 28% superficial, and 15% deep tissues and fluids, with the most common species being *C. halotolerans* and *C. tenuissimum* (Sandoval-Denis et al., 2015). One specific report after Hurricane Katrina referenced one person suffering pneumonia from a *Cladosporium* species, but that person recovered without treatment (Benedict & Park, 2014). Clearly, these opportunistic fungi that increase due to hurricane activity can cause diseases in those exposed to them.

Respiratory Illnesses Following Hurricanes

Unfortunately, studies that isolate actual pathogenic causes of respiratory illnesses after hurricanes are not plentiful. One study performed after Hurricane Katrina, however, indicates increases in both upper and lower respiratory tract infections in children and adolescents compared with rates before the hurricane (Rath et al., 2011). The Health Survey for Children and Adolescents after Hurricane Katrina tracked those seeking care at participating sites in New Orleans during October 2005–February 2006. Self-reported exposures when comparing numbers before and after the hurricane indicated an increase in upper respiratory tract infections from 21.7% to 75.6%, while lower respiratory tract infections increased from 9.4% to 36%.

Asthma was the most common preexisting condition of these children and in general those with chronic conditions suffered more negative consequences of Hurricane Katrina. Children participating in this study reported a variety of residential environmental exposures in the form of roof and flood damage, as well as inside mold damage. Others reported drinking something unhealthy or exposure to dust, chemicals, smoke, or mold. Significant associations were made between residential exposure to mold and exposure to outdoor mold, dust, and fumes with children who had lower-respiratory-tract symptoms. Upper-respiratory-tract symptoms were also associated with exposure to dust and molds outside the home. Younger children were shown to have a greater risk of respiratory diseases following exposure to hurricane damage, with most of those reporting respiratory symptoms being younger than 11 years.

Similar respiratory ailments were reported after Hurricane Wilma, which landed in Cape Romano, Florida, in October 2005 (Sneed, Zhang, & Leguen, 2005). Increases in respiratory illnesses were reported at the Miami-Dade County Emergency Department following Hurricane Wilma's arrival. Specifically, 64% of the respiratory complaints were in children ages 0–4. Respiratory visits peaked October 25, 2005, but had returned to normal levels by October 28, 2005.

Outbreaks Due to Crowded Conditions

Norovirus infections are often associated with long-term care facilities (Rosenthal et al., 2011). The same crowded conditions of healthcare facilities that are conducive to norovirus also occur in hurricane shelters. An outbreak of norovirus occurred in a megashelter in Houston after Hurricane Katrina and a norovirus-like outbreak occurred in one of the shelters after Hurricane Sandy in New York City (Ridpath et al., 2015; Yee et al., 2007). More than 1,000 patients were treated for gastroenteritis out of more than 27,000 who were in a megashelter known as the Reliant Park Complex in Houston, Texas, after Hurricane Katrina in September 2005. Multiple strains of norovirus were identified, affecting people of all ages. After Hurricane Sandy, multiple residents of several temporary shelters reported symptoms consistent with norovirus. Following each of these outbreaks, discussions about preventions of illnesses in hurricane shelters have been ongoing.

As for major outbreaks of *V. cholerae*, it is important to note that outbreaks rarely occur in regions that do not usually have outbreaks of specific diseases. Hurricane Matthew devastated Haiti in October 2016, and the problems Haiti has already had with cholera worsened (Ivers, 2017). There were already 29,000 cases of cholera during the first 9 months of 2016, even before Hurricane Matthew added to the problem. There were 477 suspected new cases of cholera within days of the hurricane (World Health Organization, 2016). One million doses of oral cholera vaccine arrived in Haiti at the end of October 2016. Cholera was not present in Haiti before being inadvertently introduced by United Nations' peacekeepers in 2010. Massive efforts are being made to eradicate cholera from Haiti, with a focus on sanitation, water quality, and improved hygiene.

Effects on Mosquito-Borne Illnesses

The evidence for short-term increases in mosquito-borne viruses after hurricane activity is conflicting. After Hurricane Jeanne devastated Gonaives, Haiti, in September 2004, a surveillance study was performed (Beatty et al., 2007). Results indicated two patients with acute dengue fever and two with active West Nile virus infections in the region out of 116 patients with illnesses that included fever. It was noted that the two West Nile cases were a slight increase from the four previous cases that had ever been identified in the Caribbean Basin. The authors concluded that these data were consistent overall with previous data suggesting that the number of cases of mosquito-borne viruses after hurricane activity rarely increases.

Another study, however, indicated that certain mosquito-borne diseases could increase slightly after hurricane flooding and, indeed, increases much more during the year following hurricane activity. Caillouët and coauthors (2008) compared data on West Nile neuroinvasive cases during the 3 weeks before Hurricane Katrina with cases 3 weeks after the storm. In Louisiana, there were no cases 3 weeks before the storm, but there were 11 cases 3 weeks after, while in Mississippi cases rose from 0 to 10. When cases from 2006 were compared with each of the previous 4 years, cases rose from 30 each of the previous 4 years to 45 in 2006 in Louisiana. In Mississippi, cases rose from an average annual number of cases of 23 from 2002–2005 to 55 cases in 2006. The increases in cases occurred even with population losses up to 28% in Louisiana. Perhaps new data concerning mosquito-borne viruses will be collected and analyzed following Hurricanes Harvey and Maria.

Conclusion

After hurricane damage, victims and their families are likely most concerned about access to food and water, as well as storm cleanup. Evidence shows, however, that pathogens are a secondary risk. Understanding who is most at risk for these various often-opportunistic pathogens and how to avoid them will likely prevent cases in the future. Further field and statistical studies from recent and future hurricanes will likely shed more light on the incidence of aquatic and airborne pathogens, as well as those that are spread through crowded conditions and by mosquitoes.

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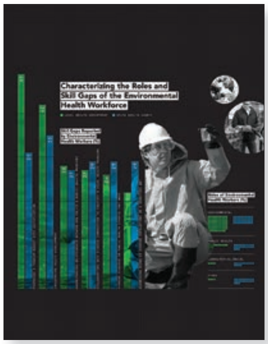

Characterizing the Roles and Skill Gaps of the Environmental Health Workforce in State and Local Health Departments

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Abstract **Efforts to characterize environmental health workers (EHWs) are needed in order to strengthen the field. Data from the 2014 Public Health Workforce Interests and Needs Survey were used to describe the self-reported roles, important daily work tasks, and skill gaps of EHWs and to compare and contrast these characteristics between state health agencies (SHAs) and local health departments (LHDs). While EHWs at SHAs and LHDs share overall similarities in terms of important daily work tasks and skill gaps, the differences could reflect that the strengths of local-level environmental work fall within communicating and community interaction, whereas state-level strengths reside in administrative, policy, and scientific functions. Our findings also highlight a need for EHWs to strengthen their skills in budget- and policy-related competencies, especially at the local level. We found that number of years in current position was a significant predictor of the number of skill gaps, suggesting the utility of a peer-learning network.**

Introduction

Environmental health workers (EHWs) make up 8% of the local, state, and federal public health workforce and constitute the largest group of governmental public health workers, after administrative or clerical personnel and public health nurses (Beck, Boulton, & Coronado, 2014). EHWs ensure that the air we breathe, food we eat, and water we drink is safe. They work in the realms of land use, community design, and housing to create health-promoting environments (Srinivasan, O'Fallon, & Dearry, 2003). Their responsibilities are broad, including assessing, communicating, and managing risks related to air quality, drinking water and food safety, industrial hygiene, healthy housing, waste management and disposal, and vector control (National Center for Environmental Health, Centers for Disease Control and Prevention [CDC], & American Public Health Association, 2001). In addition, the duties of EHWs are increasing in scope to include developing programs for climate change adaptation planning; environmental health tracking, which involves monitoring and surveillance of environmental hazards and associated exposures and health effects (CDC, 2018); and conducting health impact assessments (Association of State and Territorial Health Officials, 2011). As the environmental health workload is broadening, however, it is necessary to evaluate the capacity of EHWs.

The environmental health workforce is strained by reductions in federal funding and decreasing capacity, especially in terms of workforce training (Association of State and Territorial Health Officials, 2011, 2014), as well as a dearth of leaders who are ready to fill newly vacated positions due to high rates of turnover, retirement, and voluntary turnover from the high percentage of workers who intend to leave their positions (Herring, 2006; Sellers et al., 2015). With a fluctuating workforce and changing scope of work, it is important to understand the skills and skill gaps of the workforce, as well as to explore potential differences by level of government, as environmental health agency functions can diverge in state versus local settings. Identifying skill gaps and potential training needs—and specifying these by level of government—enables application of relevant solutions to the appropriate setting.

Prior to the 2014 Public Health Workforce Interests and Needs Survey (PH WINS), little information has been available from the perspective of individual state and local health department workers on their tasks, responsibilities, and skill gaps (Sellers et al., 2015). This article, therefore, serves to address this gap in the literature by characterizing EHWs, and comparing and contrasting the following characteristics between state health agencies (SHAs) and local health departments (LHDs): 1) main roles of EHWs, 2) tasks that EHWs report as "very important" to their daily work, and 3) self-reported skill gaps of EHWs.

FIGURE **1**

Categorized Role Classifications for Environmental Health Workers

Environmental Professionals

- Environmentalist
- Sanitarians/inspectors
- Engineers

Public Health Professionals

- Health officer
- Department/bureau director
- Program director
- Deputy director
- Public health manager/ program manager
- Other management and leadership
- Epidemiologist
- Statistician
- Public health informatics specialist
- Health educator
- Community health worker

Laboratory/Clinical Professionals

- Technician
- Laboratory aide/assistant
- Laboratory technician
- Laboratory scientist/ medical technologist
- Laboratory scientist, supervisor
- Laboratory scientist, manager
- Laboratory developmental scientist
- Registered nurse, unspecified
- Licensed practical/ vocational nurse
- Nutritionist
- Public health veterinarian

Other Professionals

- Other professional and scientific
- Other

Methods

Public Health Workforce Interests and Needs Survey

Sampling and broader survey methodologies have been written about extensively elsewhere (Leider, Bharthapudi, Pineau, Liu, & Harper, 2015). In brief, PH WINS was conducted in three sampling frames: 1) a nationally representative sample of permanent, central office employees in SHAs; 2) employees of the Big Cities Health Coalition (BCHC), a membership group of the largest metropolitan health departments in the country (National Association of County and City Health Officials, n.d.); and 3) a pilot frame of local and regional health department employees. For BCHC and local and regional health department frames, the data have importance for the localities in which they were collected and were not intended to constitute a nationally representative sample (Leider, Bharthapudi, et al., 2015). The analyses presented were stratify by setting/sample frame and were also weighted by sample frame: SHAs (n = 910) and LHDs (n = 1,001). The LHD setting includes staff from local and regional health departments, which includes 185 respondents from LHDs who are members of BCHC.

Population

The analyses in this article were limited to EHWs as defined in terms of those who are directly engaging in environmental health-subject matter related work, identified using a combination of two variables: program area and role classification. We determined EHWs to be those who meet either of the following criteria: those with the role classification of "environmentalist," excluding those in an administrative program (n = 1) or those in the program area of "environmental health," excluding those in the following roles: clerical personnel (n = 138), other business support (n = 21), information technology (n = 20), business support (n = 17), public information specialist (n = 11), grants and contracts (n = 10), students (n = 6), custodian (n = 3), and human resources (n = 3). Figure 1 characterizes the composition of this group in terms of role classifications.

Analyses

We conducted descriptive analyses for demographic information and work-related characteristics, as well as role classifications reported by EHWs, which were collapsed into the four categories shown in Figure 1.

We evaluated these demographic and job characteristic factors as predictors of skill gaps. We also conducted analyses for important daily work-related tasks and skill gaps, defined as those tasks that respondents reported being "somewhat" or "very important" to their daily work, but for which they reported low proficiency (unable to perform/ beginner). A composite variable totaling the number of skill gaps per individual EHW was created and used as the outcome. Poisson regression was used to determine predictors of skills gaps. We selected variables to be included in the model based on a manual stepwise selection process. We set the significance level at $p < .05$. All analyses for this article were conducted using STATA 14.1. PH WINS was deemed exempt by the Chesapeake Institutional Review Board.

Results

Characteristics

A total of 1,911 EHWs responded to PH WINS, representing 23,229 EHWs across all settings: 910 (9%) in SHAs and 1,001 (9%) in LHDs. Based on the weighted sample in each of the two settings, EHWs were mostly White (81% SHA, 79% LHD), with a bachelor's degree as their highest educational attainment (54% SHA, 70% LHD), with slightly more males than females (53% SHA, 52% LHD) (Table 1). Roughly half of EHWs across settings hold supervisory positions (52% SHA, 43% LHD) (Table 1) and have spent ≤5 years in their current position (49% SHA, 42% LHD) (Figure 2). About one third have spent ≥21 years in public health practice (38% SHA, 31% LHD), with 3–5% planning to retire from their current position within 1 year (Figure 2). Most EHWs are between 31–65 years of age (86% SHA, 87% LHD).

TABLE **1**

Environmental Health Worker Demographics for State Health Agencies (SHAs) and Local Health Departments (LHDs)

Demographic	SHA		LHD	
	%	95% *CI*	%	95% *CI*
Sex				
Male	53	47, 58	52	48, 57
Female	47	42, 53	48	43, 52
Supervisory status				
Non-supervisor	48	45, 52	57	52, 62
Supervisor	52	48, 55	43	38, 48
Annual salary				
<$45,000.00	16	13, 19	44	38, 51
$45,000.01–$55,000.00	20	18, 23	17	12, 22
$55,000.01–$65,000.00	21	18, 25	20	14, 27
$65,000.01–$75,000.00	14	12, 16	9	7, 12
>$75,000.01	29	25, 33	10	7, 13
Race/ethnicity				
White	81	77, 84	79	75, 83
Black	6	4, 9	10	8, 13
Hispanic	5	4, 5	4	2, 5
Asian	4	2, 7	2	1, 4
Other	4	3, 6	5	3, 7
Highest educational degree				
Doctorate	9	7, 12	4	2, 9
Master's	30	26, 34	19	15, 23
Bachelor's	54	50, 57	70	66, 73
No bachelor's	7	6, 9	7	5, 10
Age (years)				
≤30	10	7, 13	11	10, 14
31–50	42	39, 46	53	48, 59
51–65	44	40, 48	34	28, 40
>66	4	2, 5	1	1, 3

CI = confidence interval.
Note. SHA estimated population size: 3,578–3,826. LHD estimated population size: 1,881–2,036.

Role Categories

A substantial proportion of EHWs in each setting are environmentalists (23% SHA, 51% LHD). The proportion of EHWs reporting the role of public health manager/program manager is relatively consistent in both settings (5–6%). Figure 3 shows the breakdown of EHWs by role groupings into environmental professionals, public health professionals, laboratory/clinical professionals, and other.

Important Daily Work Tasks

Similar proportions of EHWs in both settings reported the following competencies as "very important" to their daily work, with a threshold of at least 50%: gathering reliable information, communicating to varied audiences, communicating persuasively, applying evidence-based approaches, and managing change (Table 2). Furthermore, nearly one third of all EHWs across all settings (29% or more) rated each of the 18 competencies listed on the survey instrument as "very important" to their daily work tasks (Table 2).

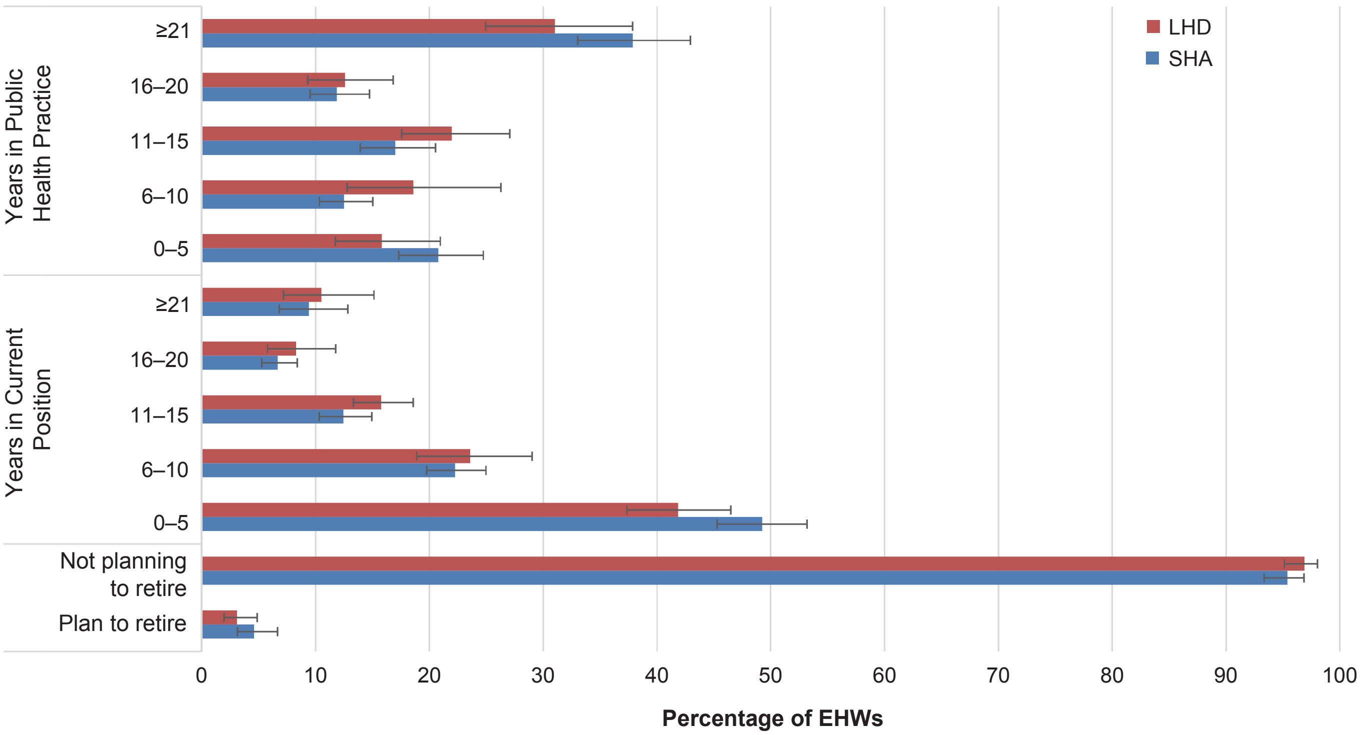
Skill Gaps

The greatest percentage of EHWs in both settings had zero skill gaps (42% SHA, 38% LHD), with little variation between settings (Figure 5). For those EHWs who had skill gaps, the average number of skill gaps reported was relatively similar in both settings: 4.73 in SHAs (95% confidence interval [*CI*] [4.12, 5.35]), 4.70 in LHDs (95% *CI* [4.19, 5.22]).

The top self-reported skill gaps, reported by over 30% of EHWs in both settings, were "influencing policy development" and "preparing a program budget with justification" (Figure 4). Of note, these most prevalent skill gaps were not among the top five important daily work tasks. Similar proportions of EHWs (ranging from 7–22%) across settings reported skill gaps for these top important tasks: 1) communication-related competencies, ≤16% of EHWs reported skill gaps and 2) applying evidence and managing change, at least 16% of EHWs reported skill gaps (Table 2, Figure 4).

FIGURE **2**

Environmental Health Worker (EHW) Experience and Plan to Retire by Setting

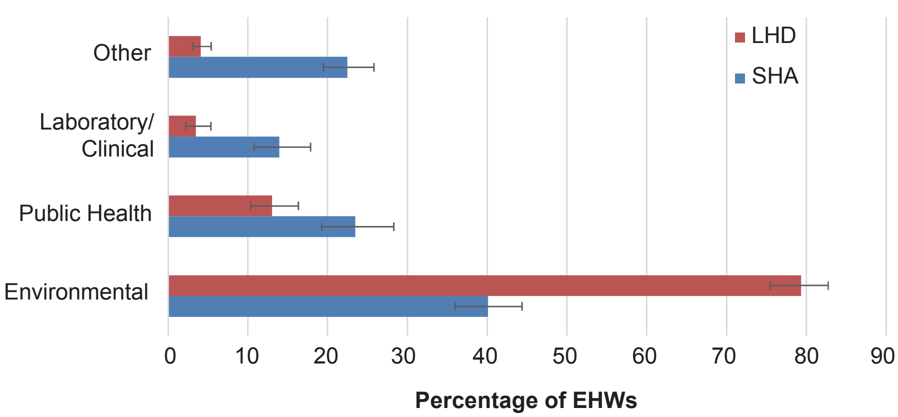


LHD = local health department; SHA = state health agency.

Note. "Plan to retire" refers to plans to retire within 1 year of responding to the survey. SHA estimated population size: 3,701–3,787; LHD estimated population size: 1,962–2,007.

FIGURE **3**

Environmental Health Workers (EHWs) in Each Role Group by Setting



LHD = local health department; SHA = state health agency.

Note. See Figure 1 for role classifications within each group. SHA estimated population size: 3,793; LHD estimated population size: 2,025.

Differences Between State Health Agencies and Local Health Departments

Earnings

Annual earnings for EHWs vary across settings: 44% of EHWs at LHDs make <$45,000 per year, compared with 16% at SHAs. And 43% of EHWs at SHAs make >$65,000, compared with only 19% of EHWs at LHDs (Table 1).

Role Categories

Sanitarians/inspectors make up a greater proportion of EHWs at the local level (26%) than at the state level (10%). A greater percentage of EHWs at SHAs report scientific and undefined roles (other, other professional and scientific, engineer, epidemiologist) compared with local settings (Figure 3). Compared with the local level, the state level has more epidemiologists (0% LHD, 6% SHA) and engineers (2% LHD, 8% SHA).

TABLE **2**

Very Important Daily Work Tasks and Skill Gaps Reported by Environmental Health Workers in State Health Agencies (SHAs) and Local Health Departments (LHDs)

Daily Work Task	Very Important				Skill Gap			
	SHA[a]		LHD[b]		SHA[c]		LHD[d]	
	%	95% *CI*	%	95% *CI*	%	95% *CI*	%	95% *CI*
Gathering reliable information to answer questions	77	73, 80	81	77, 85	7	5, 10	7	5, 10
Communicating ideas/information in a way that different audiences can understand	64	60, 68	77	71, 82	11	7, 17	10	8, 13
Communicating in a way that persuades others to act	56	52, 60	76	71, 80	16	13, 19	9	6, 12
Applying evidence-based approaches to solve public health issues	49	45, 54	58	53, 62	22	19, 25	17	13, 22
Managing change in response to dynamic, evolving circumstances	49	44, 53	50	46, 55	16	12, 22	19	15, 25
Interpreting public health data to answer questions	48	44, 53	49	44, 54	16	13, 19	20	16, 25
Engaging staff within your health department to collaborate on projects	46	42, 50	42	35, 49	18	14, 23	15	11, 20
Engaging partners outside your health department to collaborate on projects	43	39, 47	43	36, 51	19	15, 25	22	17, 29
Applying quality improvement concepts in your work	38	34, 42	46	40, 51	25	20, 30	24	18, 31
Anticipating the changes in your environment (physical, political, environmental) that might influence your work	38	33, 44	47	42, 51	26	21, 31	24	21, 29
Understanding the relationship between a new policy and many types of public health problems	35	31, 40	44	37, 50	27	24, 31	28	22, 34
Assessing the broad array of factors that influence specific public health problems	38	35, 42	39	34, 44	25	21, 29	21	15, 28
Addressing the needs of diverse populations in a culturally sensitive way	34	29, 40	44	40, 48	29	23, 36	22	18, 26
Collaborating with diverse communities to identify and solve health problems	34	30, 38	42	37, 47	29	24, 35	27	21, 33
Finding evidence on public health efforts that work	35	31, 39	38	33, 44	29	25, 34	26	21, 32
Ensuring that programs are managed within current and forecasted budget constraints	36	32, 39	35	30, 41	26	21, 31	36	28, 46
Influencing policy development	30	26, 34	30	25, 36	35	31, 39	42	35, 50
Preparing a program budget with justification	29	26, 32	30	26, 35	31	25, 38	49	40, 59

CI = confidence interval.
[a]SHA estimated population size: 3,617–3,705.
[b]LHD estimated population size: 1,887–1,980.
[c]SHA estimated population size: 1,575–3,554.
[d]LHD estimated population size: 758–1,932.
Note. Tasks in shaded rows were reported as very important by 50% of environmental health workers in one or both settings.

Daily Work Tasks

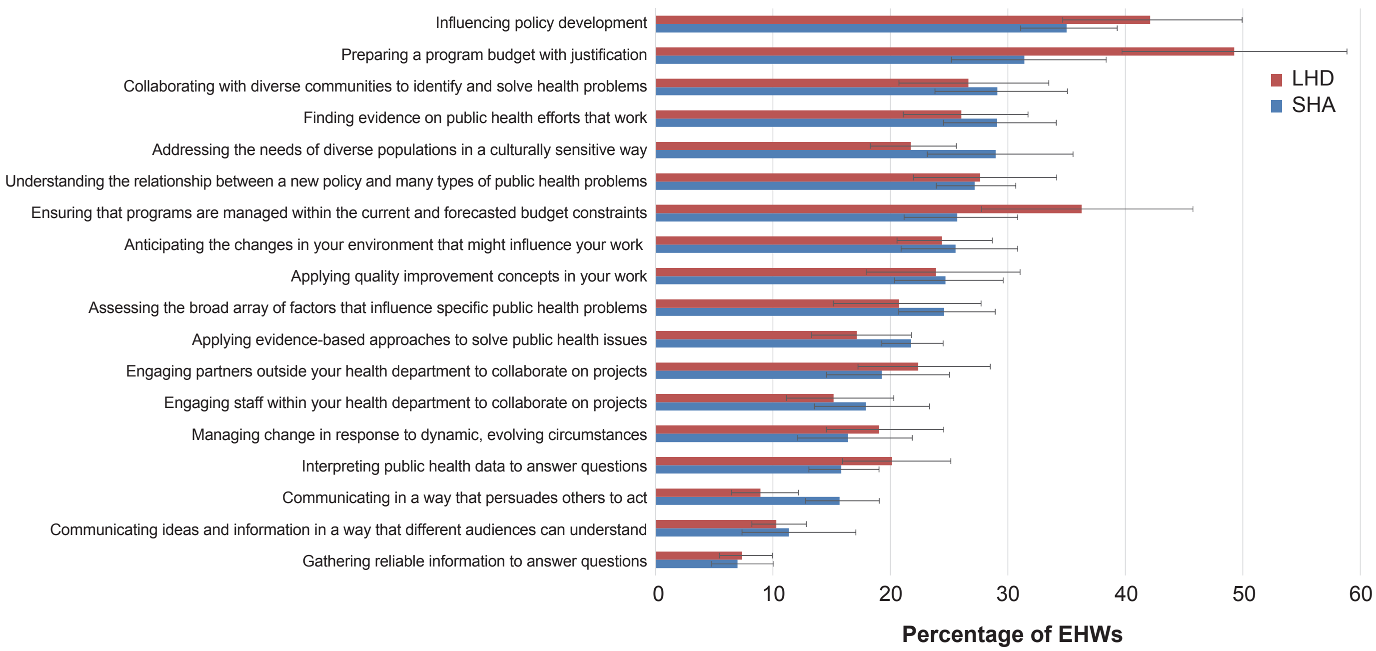
There were overall similarities in the competencies of EHWs in each setting reported as "very important" to their daily work. The exception, however, was "communicating in a way that persuades others to act," for which more EHWs at LHDs than at SHAs reported this as "very important" (76% LHD, 56% SHA).

Skill Gaps

A greater percentage of state-level EHWs reported a skill gap than local-level EHWs for competencies related to working with diverse communities; finding, assessing, and applying evidence; and communicating. There was at least a 20% difference for communicating persuasively, addressing the needs of diverse populations, and applying evidence-based approaches (Table 2, Figure 4). Moreover, a greater percentage of local-level EHWs reported a skill gap than state-level EHWs for competencies related to budgeting, interpreting data, influencing policy, managing change, and external collaboration. There was at least a 20% difference for both budgeting competencies and for interpreting public health data (Table 2, Figure 4).

FIGURE **4**

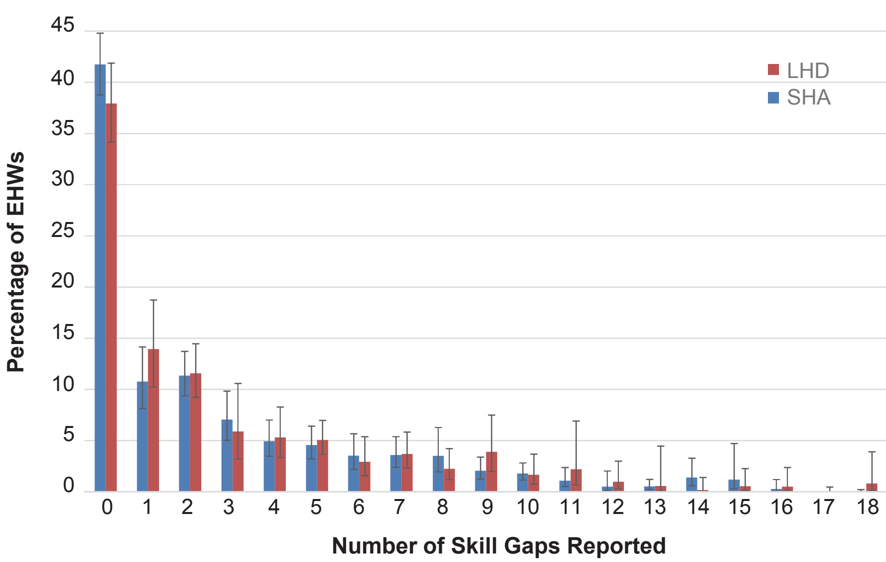
Skill Gaps Reported by Environmental Health Workers (EHWs)



LHD = local health department; SHA = state health agency.
SHA estimated population size: 1,575–3,554; LHD estimated population size: 758–1,932.

FIGURE **5**

Number of Skill Gaps Reported by Environmental Health Workers (EHWs)



LHD = local health department; SHA = state health agency.
SHA estimated population size: 3,826; LHD estimated population size: 2,036.

Regression Results for Skill Gaps

The resulting incidence rate ratios (IRRs) predicting the number of skill gaps for an EHW for each predictor are presented in Table 3. One predictor, years in current position, was statistically significant at the state level, as were four significant predictors of number of skill gaps at the local level: years in current position, annual salary, status of plans to retire, and role category.

Regression Results: State Health Agencies

At SHAs, EHWs with ≥21 years of experience in their current position had a 64% lower rate of skill gaps (IRR: 0.36, 95% *CI* [0.18, 0.72]) than those with ≤5 years in their current position.

Regression Results: Local Health Departments

At LHDs, EHWs with 6–10 years in their current position had a 37% lower rate of skill gaps (IRR: 0.63, 95% *CI* [0.43, 0.92]) than those who have been in their position for ≤5 years.

TABLE **3**

Poisson Regression Results for Predictors of Skill Gaps of Environmental Health Workers by Setting

		State Health Agency (SHA)			Local Health Department (LHD)		
		IRR	95% *CI*	*p* > *t*	IRR	95% *CI*	*p* > *t*
Role	Environmental professional	reference					
	Public health professional	1.21	0.84, 1.74	0.30	1.77*	0.32, 3.17	0
	Laboratory/clinical professional	0.67	0.42, 1.06	0.08	0.88	-0.29, 0.39	0.77
	Other professional	1.13	0.66, 1.92	0.65	1.27	0.48, 0.63	0.64
Annual salary	<$45,000.00	reference					
	$45,000.01–$55,000.00	1.13	0.66, 1.95	0.65	1.21	0.78, 1.86	0.39
	$55,000.01–$65,000.00	0.86	0.57, 1.29	0.45	1.52*	1.02, 2.27	0.04
	$65,000.01–$75,000.00	1.01	0.48, 2.08	0.99	1.09	0.46, 2.56	0.84
	>$75,000.00	1.09	0.55, 2.16	0.80	1.42	0.83, 2.44	0.19
Plan to retire	Planning to retire by 2015	reference					
	Not planning to retire by 2015	0.93	0.42, 2.07	0.85	3.16*	1.39, 7.17	0.01
Race/ethnicity	White	reference					
	Black	0.84	0.35, 2.00	0.69	0.72	0.41, 1.27	0.25
	Hispanic	0.98	0.74, 1.30	0.87	0.62	0.24, 1.63	0.32
	Asian	1.74	0.83, 3.66	0.14	0.78	0.22, 2.80	0.69
	Other	0.83	0.36, 1.94	0.66	0.80	0.29, 2.19	0.65
Highest educational degree attainment	Doctorate	reference					
	Master's	1.34	0.92, 1.96	0.13	0.88	0.33, 2.35	0.79
	Bachelor's	1.33	0.92, 1.92	0.13	0.70	0.25, 1.99	0.49
	No bachelor's	1.66	0.90, 3.04	0.10	0.37	0.12, 1.12	0.08
Supervisory status	Non-supervisor	reference					
	Supervisor	0.93	0.66, 1.31	0.68	1.11	0.81, 1.53	0.49
Years in current position	0–5	reference					
	6–10	0.96	0.69, 1.32	0.78	0.63*	0.43, 0.92	0.02
	11–15	0.66	0.40, 1.08	0.09	0.78	0.47, 1.30	0.33
	16–20	0.74	0.37, 1.46	0.38	0.94	0.56, 1.57	0.79
	≥21	0.36*	0.18, 0.72	0.01	0.72	0.30, 1.70	0.44
Years in public health practice	0–5	reference					
	6–10	0.80	0.49, 1.30	0.36	0.97	0.58, 1.60	0.90
	11–15	0.99	0.58, 1.69	0.97	0.79	0.36, 1.75	0.56
	16–20	0.68	0.34, 1.39	0.29	0.81	0.38, 1.71	0.57
	≥21	0.86	0.39, 1.87	0.69	1.07	0.63, 1.83	0.80

IRR = incident rate ratio; *CI* = confidence interval.
*Significant at $\alpha = .05$.
Note. SHA estimated population size: 3,285; LHD estimated population size: 1,726.

Furthermore, annual salary served as a statistically significant predictor for skill gaps for EHWs at LHDs. In terms of annual salary, compared with EHWs who make <$45,000, EHWs who make $55,000.01–$65,000 reported a 52% higher rate of skill gaps (IRR: 1.52, 95% *CI* [1.02, 2.27]), while holding the other variables constant in the model (Table 3). Additionally, EHWs at LHDs who were not planning to retire by 2015 had a rate of skill gaps more than 3 times higher (IRR: 3.16, 95% *CI* [1.39, 7.17]) than those planning to retire by 2015 (Table 3).

Finally, EHWs at LHDs who hold a role as a public health professional reported a 77% higher rate of skill gaps (IRR: 1.77, 95% *CI* [1.22, 2.55]) compared with those who hold environmental professional roles. While not statistically significant, EHWs with laboratory/clinical professional roles in both settings reported a lower rate of skill gaps (SHA IRR: 0.67, 95% *CI* [0.42, 1.06]; LHD IRR: 0.88, 95% *CI* [0.35, 2.18]) compared with those who hold environmental professional roles (Table 3).

Regression Results: Comparing Settings

While not statistically significant, diverging trends were seen in terms of education at SHAs versus LHDs. At SHAs, EHWs with educational attainment of no bachelor's, bachelor's, and master's reported higher rates of skill gaps compared with EHWs with doctorates. Whereas at LHDs, EHWs at each of the other highest educational attainment levels reported lower rates of skill gaps compared with EHWs with doctorates (Table 3).

Discussion

The diversity of means by which governments provide environmental health services to their jurisdictions poses a challenge to elucidating the roles and responsibilities of EHWs employed within governmental public health and to understanding potential differences between state and local levels (Salinsky, 2010). To these ends, we found that while EHWs at both levels share tasks they rate as "very important" to their daily work and their skill gaps, they diverge around strengths, which might be related to level of government.

Our findings indicate that the strengths of local-level environmental health work fall within communicating and community interaction, while state-level strengths reside in administrative, policy, and scientific functions. Communicating persuasively, applying quality improvement concepts, anticipating changes in one's environment, understanding policy–health relationships, and addressing the needs of diverse populations are very important to a greater relative percentage of EHWs at LHDs than at SHAs. Moreover, except for influencing policy, fewer EHWs at LHDs than SHAs have skill gaps for these tasks.

Strengths of state-level EHWs are related to budgeting, interpreting data, influencing policy, managing change, and external collaboration, as fewer state-level EHWs than local-level EHWs have skill gaps for these competencies. Further differences exist for LHDs in terms of pay and education, with a larger proportion of EHWs earning less at LHDs and a larger proportion with bachelor's degrees as their highest educational attainment at LHDs compared with at SHAs.

Comparison With Previously Published Public Health Workforce Interests and Needs Survey Findings

EHWs are similar to the overall state-level workforce in terms of the breakdown between age categories and supervisory status, yet EHWs differ in terms of race, sex, job experience, and plans to retire (Sellers et al., 2015). The environmental health workforce is less racially diverse than the overall state-level workforce, indicating that engaging and recruiting underrepresented groups into the study and practice of environmental health needs to be elevated as a priority. Unlike the rest of the state-level public health workforce, which is 72% female (Sellers et al., 2015), the environmental health workforce is 48% female. EHWs have more experience than the overall state-level public health workforce: a greater percentage of EHWs (11% LHD, 9% SHA) have spent ≥21 years in their current position, in contrast with the overall state-level public health workforce (5%) (Sellers et al., 2015). A notably smaller percentage of EHWs (3% LHD, 5% SHA) reported planning to retire within 1 year of taking the survey, compared with the 27% of the overall state-level public health workforce who reported planning to retire (Sellers et al., 2015). These differences create opportunities for sharing expertise among EHWs with varying levels of experience.

Important Daily Work Tasks and Skill Gaps

EHWs are skilled in the tasks they report to be most important to their work, however, they also have gaps in areas important to the field of environmental health. Gathering information, communicating clearly and persuasively, applying evidence-based approaches, and managing change were identified by at least 50% of EHWs in either setting as "very important" tasks. Not only was "gathering reliable information to answer questions" the top-rated "very important" task across settings, it was also the competency for which the smallest percentage of EHWs across all settings reported as a skill gap. Along the same lines, ≤20% of EHWs reported a skill gap for the top five competencies (those for which at least 50% of EHWs in at least one setting rated as "very important" to their daily work).

Over 30% of EHWs across all settings, however, reported skill gaps for "influencing policy development" and "preparing a program budget with justification," which aligns with the skill gaps for the state-level public health workforce (Sellers et al., 2015). Additionally, while there were relatively similar proportions of EHWs reporting skill gaps for most competencies in both settings, there was a slightly greater percentage of EHWs at LHDs reporting skill gaps related to managing programs within budget constraints, preparing a budget, influencing policy, interpreting data, managing change, and external collaboration. These skills, however, are especially necessary for effective environmental health work, as some of the most impactful environmental health successes rely upon data-driven, collaborative, adaptive work—and a broad range of policies, from water and food regulations to workplace safety standards. These findings highlight a need for EHWs to strengthen their skills in these budget- and policy-related competencies, especially at the local level.

Moreover, we found that EHWs at LHDs have a strength in communicating persuasively that is not similarly shared at the state level, as it was rated "very important" by a greater proportion of EHWs at LHDs (76% LHD, 56% SHA) and shown as a skill gap for a greater proportion of EHWs at SHAs (16% SHA, 9% LHD).

The nature of state-level work might explain why more state EHWs have skill gaps in a) working with diverse communities and b) communication when compared with local EHWs, where these skills are regularly practiced; however, mastering these skills could help those state health workers interact with local EHWs more efficiently.

Predicting Skill Gaps

Experience

Our finding that those not planning to retire at LHDs have a rate of skill gaps over 3 times higher than those planning to retire is concerning because these EHWs with a relatively higher rate of skill gaps will remain in the workforce. One potential explanation is that those planning to retire have eliminated skill gaps through experience and learning during their time working in public health. This finding raises concerns, however, about losing personnel with valuable knowledge, skills, and abilities.

Across settings, these findings suggest that those with more years of experience in their current position have a significantly lower rate of skill gaps than those with less experience. While to be expected, this finding demonstrates that work experience is an important factor in gaining the skills most relevant to environmental public health work. Taken along with the fact that the highest percentage of EHWs in each setting have held their current position for ≤5 years (42–49%), these findings imply that a substantial portion of EHWs (i.e., those newest in their positions) are those with the highest rate of skill gaps and that there is an opportunity for EHWs to address skill gaps within the first 5 years of starting their position.

Furthermore, only 9–11% of EHWs have held their current position for >21 years, and these are the EHWs who have a relatively lower rate of skill gaps. Moreover, the significance of years in current position as a predictor of rate of skill gaps, along with the finding that neither years in public health practice nor highest educational attainment was a significant predictor, suggest that the experience in EHWs' present positions offer the unique opportunity to gain the skills that are important to their work, as opposed to their time and experience in the field of public health more broadly defined, or their academic training. A peer-learning network matching EHWs with varying levels of experience could help address these disparities in skill levels. Organizations such as the National Environmental Health Association offer the opportunity for such a learning network for their members.

Role

While 13% of EHWs at LHDs hold public health professional roles, these EHWs reported a significantly higher rate of skill gaps than those EHWs with environmental professional roles. This finding further supports the characterization of environmental health work at the local level as more relevant to environmental health-specific functions/practice rather than broader scientific/public health programmatic functions. This finding also suggests that EHWs with public health professional roles at LHDs can benefit from additional training in competencies relevant to their work. In order to address these skill gaps, those who hold the title public health professional would benefit from employee exchanges with those holding the title EHW in order to gain field experience. Additionally, peer-to-peer learning might be helpful in setting up a "ride-along" program for transference of skills.

Earnings

While nearly half (44%) of EHWs at LHDs make <$45,000 per year, these EHWs have a significantly lower rate of skill gaps than EHWs who make $55,000.01–$65,000. This discrepancy raises some questions in terms of adequate compensation for work performance at the local level and might indicate that agencies with more funds available to pay EHWs also have more resources for training, or attract EHWs with higher skill levels due to higher pay. Thus, this finding might be symptomatic of the funding structures that segregate the functions of state and local governmental public health.

Limitations

A major limitation of this study is that while the SHA frame is a nationally representative sample, the LHD frames are not nationally representative. There are limits, therefore, to the generalizability of these findings. The data from these pilot frames, however, have importance at a local level. While we used several different fielding methods to gather the local pilot data, the weights for each approach were appropriately calculated (Leider, Harper, Bharthapudi, & Castrucci, 2015). While differential nonresponse bias was a concern for PH WINS, we used complex survey methodology and sample weighting to address this issue, with the nonresponse-adjusted weights constituting the sampling weights for the state and local frames (Leider, Harper, et al., 2015).

Recommendations

A peer-learning network could help institutional knowledge from being lost in governmental environmental health. EHWs with more experience in their positions could be available as a resource to early-career EHWs. Adopting a model of "peer-to-peer mentor circles" (Kuhn & Castaño, 2016), in which small groups of early- and mid/late-career EHWs who have similar work responsibilities form a supportive network, could efficiently use the expertise already present in health departments without relying upon a potentially burdensome one-to-one mentor–mentee model.

Targeted but adaptable trainings and programs to address the most prevalent skill gaps should serve to complement peer learning. One approach to address the substantial proportion of EHWs with gaps for policy- and budget-related skills would be through a management or leadership training program that prepares new managers to a) communicate with policy makers and b) formulate budget documents. This program could be adjusted to fit the differing needs at state and local levels, as well as become a part of systematized trainings that could be offered to EHWs at a national level to address skill gaps in the first 5 years of employment.

A national repository could house trainings and a corresponding curriculum to address basic workforce competencies for EHWs, especially for more specialized roles at the local level. These skill gaps are not only unique to EHWs but also are prevalent in the overall governmental public health workforce—as such, these programs and trainings could be made available and developed to be adaptable to professionals throughout the field. Furthermore, environmental health curricula at academic institutions could be evaluated for their applicability to the skills most important for work at local and state health departments, so that graduates of these programs are well equipped to address the needs in these settings.

In order to identify why EHWs at LHDs with lower salaries have fewer skill gaps, as well as elucidate which environmental health activities receive the most funding or lack funding, future studies could explore how environmental health work is funded at the state and local level, identifying how resources are distributed across agencies and how these practices and funding structures might change to better serve local needs.

Conclusion

Overall, the shared top tasks and skill gaps across settings for EHWs suggest that they have similar functions and training needs in each level of governmental public health. The distribution of EHWs' roles in each setting suggests broad similarities across settings, but with some differences in terms of fewer, more specialized, and defined roles for EHWs at local levels with a broader scope of responsibilities at the state level—which might be due to the differences in funding mechanisms for state and local environmental health.

The top tasks important to an EHW's daily work include gathering information, communicating clearly and persuasively, applying evidence-based approaches, and managing change. Nearly one third of EHWs across settings, however, report a skill gap related to policy- and budget-related competencies. Work experience as an EHW is an important factor in gaining the skills most relevant to environmental public health work at state and local levels, suggesting the need for opportunities for EHWs to gain the skills that are important to their work and to bolster and preserve institutional knowledge, potentially through a peer-learning network.

Acknowledgements: We would like to acknowledge the de Beaumont Foundation for funding and conducting, in partnership with the Association of State and Territorial Health Officials, the Public Health Workforce Interests and Needs Survey. We would also like to acknowledge the de Beaumont Foundation and the Association of Schools and Programs of Public Health for supporting the Philanthropy Fellowship that allowed for this research to be conducted.

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DIRECT FROM CDC ENVIRONMENTAL HEALTH SERVICES

Shannon McClenahan

Brian Hubbard, MPH

Safe Water for Community Health Update

Editor's Note: **NEHA strives to provide up-to-date and relevant information on environmental health and to build partnerships in the profession. In pursuit of these goals, we feature this column on environmental health services from the Centers for Disease Control and Prevention (CDC) in every issue of the *Journal*.**

In these columns, authors from CDC's Water, Food, and Environmental Health Services Branch, as well as guest authors, will share insights and information about environmental health programs, trends, issues, and resources. The conclusions in these columns are those of the author(s) and do not necessarily represent the official position of CDC.

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The contamination of drinking water in private wells, especially near former military (National Research Council, 2009) and industrial sites (Worley et al., 2017), has become an issue of increasing concern to the public. Even as the media highlights these examples of contamination, some 34 million Americas rely on well water possibly affected by common hazards (National Groundwater Association, 2016). Bacterial and chemical contamination and naturally occurring contaminants such as arsenic and uranium affect water quality in one of every five wells throughout the U.S. (DeSimone, Hamilton, & Gilliom, 2009). The U.S. Environmental Protection Agency's Safe Drinking Water Act does not cover private wells. In response, the Centers for Disease Control and Prevention's (CDC) Safe Water for Community Health (Safe WATCH) program addresses private wells and other federally unregulated drinking water sources and systems by strengthening state and local safe drinking water programs.

Since 2015, Safe WATCH has funded 14 state and 5 county health departments to use the 10 Essential Environmental Public Health Services (Essential Services) to improve services for community residents relying on federally unregulated drinking water (Figure 1). While some programs have activities spanning the full range of the Essential Services, other programs focus on only a few Essential Services at a time (Figure 2). The following examples highlight grantees who increased sampling, quantified risk, enhanced and enforced policies, and developed and improved educational and outreach programs.

- **Connecticut Department of Public Health (CTDPH)** held seven water fairs in cooperation with its local area health departments. During these fairs, CTDPH overcame cost- and knowledge-related barriers to arsenic and uranium testing by distributing 719 free water testing kits. The public returned 86% (618) of the water testing kits for analysis. The public health lab identified 34 households where arsenic or uranium exceeded maximum contaminant levels. CTDPH provided follow-up letters to residents explaining the results and offering information on treatment options.
- **Delta County, Colorado Health Department** responded to 530 requests from residents to provide free well water sampling. The Safe WATCH grant supported the first coordinated effort in the six-county region of the West Central Public Health Partnership (WCPHP), led by the Delta County Health Department, to assess drinking water quality and identify risks associated with private wells. Members of WCPHP have promoted free water sampling through brochures, newsletter advertisements, social media, newspaper articles, and a video advertisement created with the University of Colorado Boulder (see sidebar). The well water quality data are now being used to develop GIS contaminant risk maps for the region.
- **New Jersey Department of Health (NJDOH)** staff identified communities at risk for arsenic and radionuclide contamination of well water. They implemented targeted outreach events that included well water testing in those communities. Test results were shared with policy makers and helped support a proposal to expand the State Private Well Testing Act (PWTA) rules to include arsenic and radiological (gross alpha) testing statewide, with a possible adoption of the

FIGURE 1

Grantee Participation in the 10 Essential Environmental Public Health Services (*n* = 19)

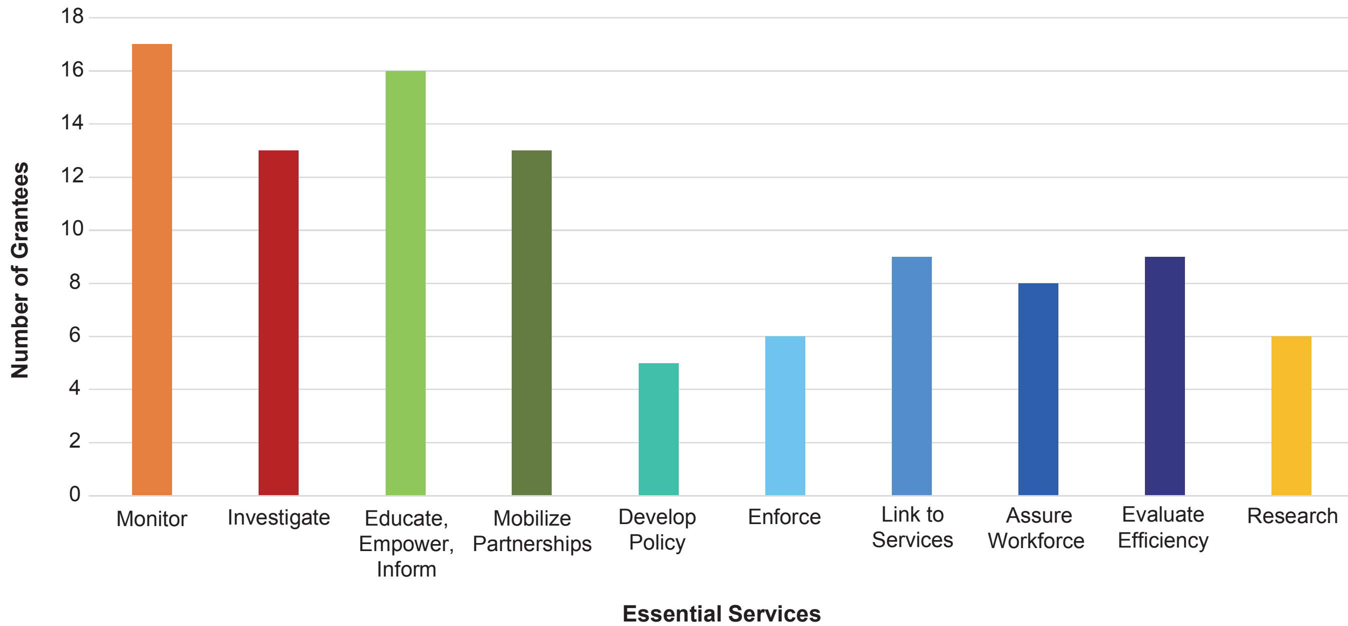
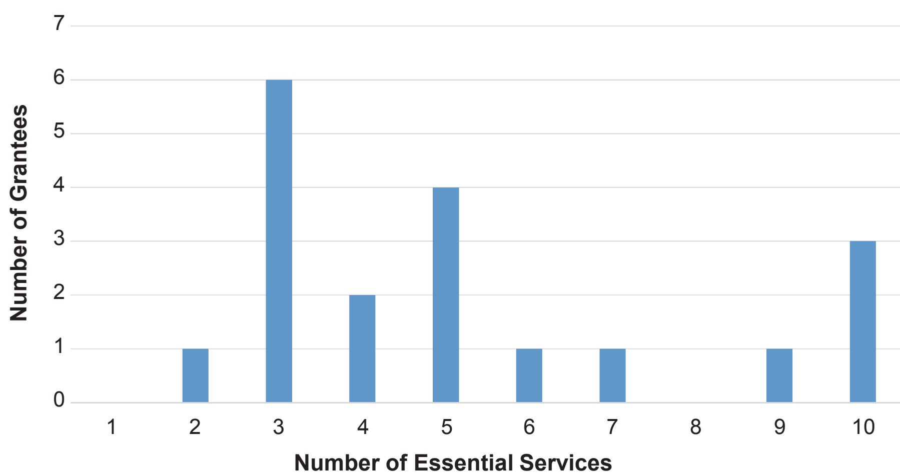


FIGURE 2

Number of 10 Essential Environmental Public Health Services Being Addressed by Grantees (*n* = 19)



revised PWTA rules by 2018. Currently, the PWTA requires tests for radionuclides only in the southern region of the state and arsenic only in the northern region of the state.

- **New Mexico Department of Health (NMDOH)** collected data and water samples from 1,482 wells during 18 water fair events. In June 2017, the New Mexico Office of the State Engineer implemented recently passed legislation requiring bar-coded well identification tags for all newly constructed wells. These bar codes allow for quick electronic scanning and well identification across agencies, which is helpful for the development and maintenance of a private well database. In summer 2017, NMDOH formed a work group to support the tagging of 3,000 existing wells.
- **New York State Department of Health (NYSDOH)** implemented a strategy for responding to private well water contamination and illness associated with concentrated animal feeding operations (CAFOs) and flooding in Federal Emergency Management Agency (FEMA) 100- and 500-year flood zones. GIS maps from partners were used to show well locations in karst topography near CAFOs and in FEMA flood zones. New maps showing vulnerable wells were then created. Staff analyzed regulations and outreach materials from other states addressing flooding and CAFO issues. NYSDOH will develop educational information for homeowners to prepare for and recover from CAFO contamination events.
- **Vermont Department of Health (VDH)** updated health advisory levels to enforceable drinking water standards for the Department of Environmental Conservation's Groundwater Protection Rule and

Strategy. VDH implemented a marketing campaign addressing well testing barriers that featured 12 articles in the *Burlington Free Press* and resulted in 1.8 million digital ad displays across websites and social media. Additional outreach was provided through an online statewide neighborhood network called the Front Porch Forum. The digital ads directed patrons to the VDH drinking water informational page to learn about well testing. The campaign received attention from local news that led to a live interview with the drinking water engineer, prompting additional requests from residents to have their wells tested.

Safe WATCH partners closed gaps in their safe drinking water programs by addressing priorities related to the Essential Services. The Safe WATCH program continues to organize and provide access to the experiences, tools, and promotional materials developed by state and local partners on the Safe WATCH website (www.cdc.gov/nceh/ehs/safe-watch/index.html). CDC will support grantees through 2020 and work towards the long-term goal of assuring access to safe drinking water to protect the health of the public.

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Check out the Safe Water for Community Health (Safe WATCH) website for updated tools and promotional materials: www.cdc.gov/nceh/ehs/safe-watch/index.html

Links to Grantee Resources

- West Central Public Health Partnership: www.wcphp.org/well-water-testing
- Delta County/University of Colorado Boulder television spot: www.colorado.edu/hometowns/western-slope
- New Mexico regulation for mandatory well tags listed under rules and regulations for well driller licensing, as well as construction, repair, and plugging of wells: www.ose.state.nm.us/STST/wdRules.php
- New Jersey Private Well Testing Act: www.nj.gov/dep/watersupply/pw_pwta.html
- Vermont drinking water testing: www.healthvermont.gov/lab/drinking-water

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INTEGRATING PUBLIC HEALTH IN LAND REUSE AND REDEVELOPMENT

Editor's Note: The National Environmental Health Association is publishing a three-part series that highlights collaboration and partnerships with the Agency for Toxic Substances and Disease Registry (ATSDR) and redevelopment stakeholders to promote environmental health and land reuse as environmental and public health practices. This series will serve as a guide for identifying new and existing resources that can be adopted at the local environmental health level to safely reuse environmentally impacted land to improve community health outcomes. The conclusions in this series are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention and ATSDR.

Part 1: A 5-Step Land Reuse and Redevelopment Model: Resources to Spur Local Initiatives

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Background

People who live near or access land reuse sites such as brownfields often experience disproportionate exposure to environmental pollution that can result in poor health outcomes, including higher rates of chronic disease, toxic exposures (e.g., mercury or lead-based paint) that result in adverse health effects, and cancer (de Leon & Schilling, 2017; Massey, 2004; New Jersey Department of Health and Senior Services, 2007). To address health risks and exposures related to land reuse sites, for over a decade the Agency for Toxic Substances and Disease Registry (ATSDR) internally integrated a public health model in land reuse and redevelopment—the 5-Step Land Reuse Strategy to Safely Reuse Land and Improve Health (5-Step Land Reuse Model).

In June 2015, ATSDR introduced the 5-Step Land Reuse Model during a 3-day training facilitated by the American Public Health Association. The purpose of the training was to introduce the 5-Step Land Reuse Model as a national model that could expand resources for health-focused land reuse at the local level.

The 5-Step Land Reuse Model Training

Over 65 individuals participated in the training. Participant came from ATSDR's Brownfields and Reuse Opportunity Working Network (BROWN), community partnerships, and grantees (an ATSDR funding program from 2008–2016). The authors represent each of these participant groups. The training was based around the 5-Step Land Reuse Model shown in Figure 1. A brief description of the training based on each of the model's steps is provided below.

Step 1: Engage With the Development Community

Participants shared and practiced using community engagement techniques, such as plain language (www.plainlanguage.gov) and community engagement games. ATSDR grantees shared successful community engagement techniques, such as funding of *promotores de salud* (community health workers), in which community members educate and engage their communities about land reuse sites, environmental concerns, and associated health outcomes.

Step 2: Evaluate Environmental and Health Risks

This session was grounded in environmental health basics that included definitions and significance of exposure sources, media, pathways, toxicology, and cancer and noncancer risks. Participants learned about and practiced using the following tools:

- health impact assessment (Centers for Disease Control and Prevention [CDC], 2016),
- Protocol for Assessing Community Excellence in Environmental Health (CDC, 2017),
- Healthy Community Design Checklist (CDC, 2013),
- ATSDR Brownfields/Land Reuse Action Model (ATSDR, 2015),
- ATSDR Land Reuse Site Screening Tool (ATSDR, 2018), and
- community-based participatory research (Zubaida, Grunbaum, Gray, Franks, & Simoes, 2007).

Step 3: Communicate Risk or Health Issues to the Development Community

This session emphasized the importance of health risk communication in community buy in for redevelopment. Expert risk communicators described basics of overall health communication, led role-playing scenarios that result in positive or negative risk communication, and provided examples of real-world community-based risk communication activities they perform.

Step 4: Redesign the Community With Health in Mind

This session described redevelopment planning approaches to maximize health outcomes across physical, social, and economic health spectrums. Examples such as energy efficiency, stormwater management, tree planting, nonmotorized transportation (e.g., bicycling infrastructure), and agriculture to improve food access and build local economies were provided and supported by case examples and best practices. In addition, BROWN provided targeted technical assistance to each community partnership.

FIGURE 1

The Agency for Toxic Substances and Disease Registry 5-Step Model to Safely Reuse Land and Improve Health (5-Step Land Reuse Model)

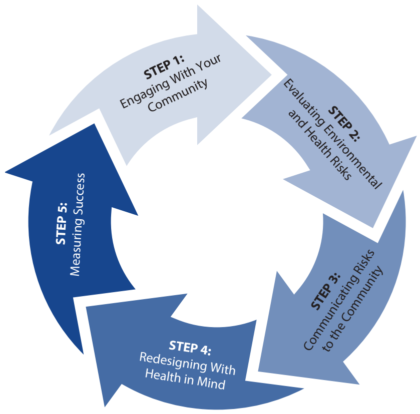

TABLE 1

Issue and Corresponding Redevelopment Indicator Examples

Issue	Indicator
Pollution of river	Water quality monitoring data
Contaminated properties	Inventory of the number of contaminated properties and types and nature of contamination
Odor from waste transfer facility/rodents	Odor survey, rodent control data
Habitat concerns	Wildlife survey, environmentally friendly lighting installations, habitat preservation efforts
Lead from past industrial activities and older housing stock	Blood-lead level data, age and condition of housing and commercial/industrial properties, inventory of lead emissions
Air pollution	Asthma and/or other respiratory ailment incidence rates, number of major highways and proximity to them, number and type of industrial facilities emitting pollutants into the atmosphere
Lack of access to green space and recreation	Number of parks and acreage of open/green spaces, number of people using parks, types of recreation observed
Lack of access to fresh foods and vegetables	Number of urban gardens, number of grocery stores in the neighborhood
Lack of access to medical care	Number and type of clinics and healthcare providers in the redevelopment area
Neighborhood blight and economic condition	Number of vacant homes and land, number of boarded homes and/or properties, number of foreclosures, number of closed businesses or inactive commercial activity

Step 5: Measure Success: Environment and Health Change

This session emphasized the importance of evaluating how environmental remediation or restoration can lead to changes in health and environment over the course of redevelopment. The ATSDR Action Model was highlighted as a redevelopment tool for including measurable indicators as benchmarking outcomes. Example indicators are shown in Table 1.

Outcomes: The 5-Step Land Reuse Model as a National Resource

The 2015 training provided a rich repository of land reuse and redevelopment resources, success stories, lessons learned, and opportunities for collaboration. Shortly after the training, ATSDR developed the Land Reuse Toolkits to elevate the 5-Step Land Reuse Model for public use. ATSDR incorporated the input of the training participants who essentially represented the five personas of the toolkits: community champions, community planner, municipal agency, environmental or health professional, and developer. ATSDR included in each toolkit resources from the training and from a book authored by BROWN members, *Land Reuse and Redevelopment: Creating Healthy Communities* (Berman & Whitehead, 2018).

The 2015 training also launched participant collaborations. One collaboration resulted in a European Union Erasmus award for a 2018–2019 faculty and student exchange on health-focused land reuse between universities in Romania and the U.S. In another collaboration, two BROWN members and two community partnerships successfully applied for a Robert Wood Johnson Foundation Culture of Health Leaders Program advocating for "healthfields" (i.e., safe reuse of land to reduce exposures and achieve environmental and community health improvements). They received $380,000 for individual healthfields projects in target communities over 3 years (2016–2019).

Recently, ATSDR and the National Environmental Health Association (NEHA) collaboratively designed an online certificate program in environmental health and land reuse based on the 5-Step Land Reuse Model. The certificate program includes environmental health basics of epidemiology, land reuse and redevelopment, risk assessment, risk communication, and toxicology. The certificate program is scheduled to launch in 2019 and will be provided free of charge for continuing education by ATSDR with a dual certificate offered by NEHA.

Conclusion

The June 2015 training participants represented interest groups frequently at the table in community-driven land reuse and redevelopment projects. Ultimately, the training led to several participant collaborations, the development of the Land Reuse Toolkits, and the creation of the ATSDR and NEHA environmental health and land reuse certificate program. Overall, the training met ATSDR's goal to elevate the internal 5-Step Land Reuse Model into a national model to support local health-focused redevelopment projects.

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Did You Know?

NEHA is pleased to announce the 2019 National Environmental Public Health Internship Program. The program enables students to gain a firsthand perspective on the day-to-day responsibilities of environmental health professionals. Local, state, and tribal environmental health departments can apply to host one of the internships. The deadline for student and health department applications is January 18. Learn more at www.neha.org/professional-development/students/internships.


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EH CALENDAR

UPCOMING NEHA CONFERENCES

July 9–12, 2019: NEHA 2019 Annual Educational Conference & Exhibition, Nashville, TN. For more information, visit www.neha.org/aec.

July 13–16, 2020: NEHA 2020 Annual Educational Conference & Exhibition, New York, NY.

July 12–15, 2021: NEHA 2021 Annual Educational Conference & Exhibition, Spokane, WA.

NEHA AFFILIATE AND REGIONAL LISTINGS

California
April 8–11, 2019: Annual Educational Symposium, hosted by the California Environmental Health Association, Ventura, CA. For more information, visit www.ceha.org.

Florida
July 30–August 2, 2019: Annual Education Meeting, hosted by the Florida Environmental Health Association, Howey in the Hills, FL. For more information, visit www.feha.org/events.

Georgia
June 12–14, 2019: Annual Education Conference, hosted by the Georgia Environmental Health Association, Stone Mountain, GA. For more information, visit www.geha-online.org.

Idaho
March 12–14, 2019: Annual Education Conference, hosted by the Idaho Environmental Health Association, Boise, ID. For more information, visit https://ieha-idaho.com.

Indiana
April 11, 2019: Spring Conference, hosted by the Indiana Environmental Health Association, Greenwood, IN. For more information, visit www.iehaind.org/Conference.

Kansas
February 6–8, 2019: KEHA/KSFA Conference, hosted by the Kansas Environmental Health Association and Kansas Small Flows Association, Lawrence, KS. For more information, visit www.keha.us.

Kentucky
February 11–13, 2019: Annual Conference, hosted by the Kentucky Environmental Health Association, Lexington, KY. For more information, visit http://kyeha.org/events.

New Jersey
March 3–5, 2019: Educational Conference & Exhibition, hosted by the New Jersey Environmental Health Association, Atlantic City, NJ. For more information, visit www.njeha.org.

Ohio
April 11–12, 2019: 73rd Annual Educational Conference, hosted by the Ohio Environmental Health Association, Worthington, OH. For more information, visit www.ohioeha.org.

Oregon
February 26–28, 2019: Annual Educational Conference, hosted by the Oregon Environmental Health Association, Newport, OR. For more information, visit www.oregoneha.org.

Utah
May 8–10, 2019: Spring Conference, hosted by the Utah Environmental Health Association, Cedar City, UT. For more information, visit www.ueha.org/events.html.

TOPICAL LISTING

Public Health
April 23–24, 2019: Iowa Governor's Conference on Public Health, Des Moines, IA. For more information, visit www.ieha.net/IGCPH.

JEH QUIZ

FEATURED ARTICLE QUIZ #4

Characterizing the Roles and Skill Gaps of the Environmental Health Workforce in State and Local Health Departments

Available to those holding an individual NEHA membership only, the *JEH* Quiz, offered six times per calendar year through the *Journal of Environmental Health,* is an easily accessible means to accumulate continuing-education (CE) credits toward maintaining your NEHA credentials.

1. Read the featured article carefully.
2. Select the correct answer to each *JEH* Quiz question.
3. a) Complete the online quiz found at www.neha.org/publications/journal-environmental-health,

   b) Fax the quiz to (303) 691-9490, or

   c) Mail the completed quiz to
   JEH Quiz, NEHA
   720 S. Colorado Blvd., Suite 1000-N
   Denver, CO 80246.

   Be sure to include your name and membership number!
4. One CE credit will be applied to your account with an effective date of January 1, 2019 (first day of issue).
5. Check your continuing education account online at www.neha.org.
6. You're on your way to earning CE hours!

Quiz Registration

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JEH Quiz #2 Answers
October 2018

1. c	4. a	7. c	10. a
2. a	5. b	8. c	11. b
3. d	6. d	9. a	12. c

➔ Quiz deadline: April 1, 2019

1. Environmental health workers (EHWs) make up __ of the local, state, and federal public health workforce.
   a. 4%
   b. 6%
   c. 8%
   d. 10%

2. The article compared the following characteristics between state health agencies (SHAs) and local health departments (LHDs):
   a. main roles of EHWs.
   b. tasks the EHWs report as "very important" to their daily work.
   c. self-reported skill gaps of EHWs.
   d. all the above.

3. The highest percentage of EHWs in both settings (i.e., SHAs and LHDs) reported a __ as their highest educational degree.
   a. bachelor's
   b. master's
   c. doctorate

4. EHWs in both settings were mostly
   a. Black.
   b. White.
   c. Hispanic.
   d. Asian.

5. About __ of EHWs in both settings have spent ≥21 years in public health practice.
   a. one quarter
   b. one third
   c. one half
   d. two thirds

6. The percentage of EHWs in SHAs and LHDs that reported zero skill gaps was __, respectively.
   a. 7% and 6%
   b. 11% and 14%
   c. 38% and 42%
   d. 42% and 38%

7. The average number of skill gaps reported by EHWs in LHDs was
   a. 4.12.
   b. 4.70.
   c. 4.73.
   d. 5.22.

8. The top self-reported skill gaps, reported by over 30% of EHWs in both settings, were "influencing policy development" and "preparing a program budget with justification."
   a. True.
   b. False.

9. Sanitarians/inspectors make up a __ proportion of EHWs at the local level than at the state level.
   a. lesser
   b. similar
   c. greater

10. The daily work task indicated as "very important" by the greatest percentage of EHWs in both settings was
    a. gathering reliable information to answer questions.
    b. communicating ideas/information in a way that different audiences can understand.
    c. communicating in a way that persuades others to act.
    d. applying evidence-based approaches to solve public health issues.

11. A greater percentage of __ EHWs reported a skill gap than __ EHWs for competencies related to budgeting, interpreting data, influencing policy, managing change, and external collaboration.
    a. local-level; state-level
    b. state-level; local-level

12. EHWs at LHDs who were not planning to retire by 2015 had a rate of skill gaps more than __ times higher than those planning to retire by 2015.
    a. 2
    b. 3
    c. 4
    d. 5

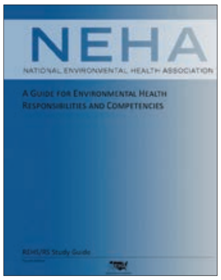
RESOURCE CORNER

Resource Corner highlights different resources that NEHA has available to meet your education and training needs. These timely resources provide you with information and knowledge to advance your professional development. Visit NEHA's online Bookstore for additional information about these, and many other, pertinent resources!

NEHA BOOKSTORE
www.neha.org/store

REHS/RS Study Guide (4th Edition)

National Environmental Health Association (2014)



The Registered Environmental Health Specialist/Registered Sanitarian (REHS/RS) credential is NEHA's premier credential. This study guide provides a tool for individuals to prepare for the REHS/RS credential exam and has been revised and updated to reflect changes and advancements in technologies and theories in the environmental health and protection field. The study guide covers the following topic areas: general environmental health; statutes and regulations; food protection; potable water; wastewater; solid and hazardous waste; zoonoses, vectors, pests, and poisonous plants; radiation protection; occupational safety and health; air quality; environmental noise; housing sanitation; institutions and licensed establishments; swimming pools and recreational facilities; and disaster sanitation.

308 pages / Paperback
Member: $149 / Nonmember: $179

Control of Communicable Diseases Manual (20th Edition)

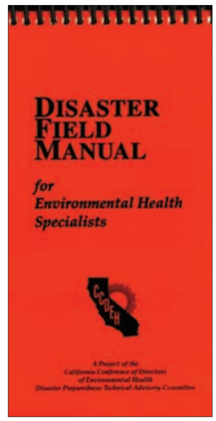
Edited by David L. Heymann, MD (2015)

The *Control of Communicable Diseases Manual (CCDM)* is revised and republished every several years to provide the most current information and recommendations for communicable-disease prevention. *CCDM* is designed to be an authoritative reference for public health workers in official and voluntary health agencies. The 20th edition sticks to the tried and tested structure of previous editions. Chapters have been updated by international experts. New disease variants have been included and some chapters have been fundamentally reworked. This edition is a timely update to a milestone reference work that ensures the relevance and usefulness to every public health professional around the world. *CCDM* is a study reference for NEHA's Registered Environmental Health Specialist/Registered Sanitarian and Certified Professional–Food Safety credential exams.

729 pages / Paperback
Member: $59 / Nonmember: $64

Disaster Field Manual for Environmental Health Specialists

California Association of Environmental Health Administrators (2012)

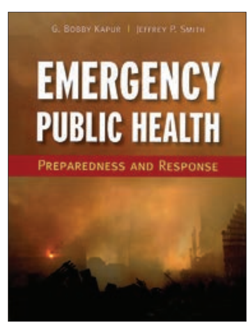


This manual serves as a useful field guide for environmental health professionals following a major disaster. It provides an excellent overview of key response and recovery options to be considered as prompt and informed decisions are made to protect the public's health and safety. Some of the topics covered as they relate to disasters include water, food, liquid waste/sewage, solid waste disposal, housing/mass care shelters, vector control, hazardous materials, medical waste, and responding to a radiological incident. The manual is made of water-resistant paper and is small enough to fit in your pocket, making it useful in the field. Study reference for NEHA's Registered Environmental Health Specialist/Registered Sanitarian credential exam.

224 pages / Spiral-Bound Hardback
Member: $37 / Nonmember: $45

Emergency Public Health: Preparedness and Response

G. Bobby Kapur and Jeffrey P. Smith (2011)



Emergency Public Health provides a unique and practical framework for disaster response planning at local, state, and national levels. The book systematically addresses the issues in a range of environmental public health emergencies brought on by natural calamity, terrorism, industrial accident, or infectious disease. It features historical perspectives on a public health crisis, an analysis of preparedness, and a practical relevant case study on the emergency response. Study reference for NEHA's Registered Environmental Health Specialist/Registered Sanitarian credential exam.

568 pages / Paperback
Member: $114 / Nonmember: $124

SUPPORT THE NEHA ENDOWMENT FOUNDATION

The NEHA Endowment Foundation was established to enable NEHA to do more for the environmental health profession than its annual budget might allow. Special projects and programs supported by the foundation will be carried out for the sole purpose of advancing the profession and its practitioners.

Individuals who have contributed to the foundation are listed below by club category. These listings are based on what people have actually donated to the foundation—not what they have pledged. Names will be published under the appropriate category for one year; additional contributions will move individuals to a different category in the following year(s). For each of the categories, there are a number of ways NEHA recognizes and thanks contributors to the foundation. If you are interested in contributing to the Endowment Foundation, please call NEHA at (303) 756-9090. You can also donate online at www.neha.org/about-neha/donate.

Thank you.

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Baltimore City Health Department, Office of Chronic Disease Prevention
https://health.baltimorecity.gov/programs/health-resources-topic

Bureau of Community and Children's Environmental Health, Lead Program
www.houstontx.gov/health/Environmental/community_childrens.html

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City of Independence
www.ci.independence.mo.us

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http://cityofracine.org/Health

City of St. Louis Department of Health
www.stlouis-mo.gov/government/departments/health

Coconino County Public Health
www.coconino.az.gov/221/Health

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www.iapmort.org

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Jefferson County Public Health (Colorado)
http://jeffco.us/public-health

Kanawha-Charleston Health Department
http://kchdwv.org

LaMotte Company
www.lamotte.com

Louisiana State Board of Examiners for Sanitarians
www.lsbes.org

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www.maricopa.gov/631/Environmental-Services

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Multnomah County Environmental Health
https://multco.us/health

Nashua Department of Health
http://nashuanh.gov/497/Public-Health-Community-Services

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www.env.nm.gov

New York City Department of Health and Mental Hygiene
www1.nyc.gov/site/doh/index.page

North Bay Parry Sound District Health Unit
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Nova Scotia Environment
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Oklahoma Department of Environmental Quality
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Oneida Indian Tribe of Wisconsin
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Note. As of October 1, 2018, NEHA no longer offers organizational memberships. We will continue to print this section in the Journal to honor the membership benefits due to these listed organizations until their memberships expire. For more information about NEHA membership, visit www.neha.org/membership-communities/join.

SPECIAL LISTING

The board of directors includes NEHA's nationally elected officers and regional vice-presidents. Affiliate presidents (or appointed representatives) comprise the Affiliate Presidents Council. Technical advisors, the executive director, and all past presidents of the association are ex-officio council members. This list is current as of press time.

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GRAND SESSION KICKOFF
Anne Godfrey, CCMI FCIM
Chief Executive,
Chartered Institute of Environmental Health,
London, UK

CLOSING SESSION
Dr. Grayson C. Brown
Executive Director,
Puerto Rico Vector Control

KEYNOTE SPEAKER: *To Be Announced*

EDUCATIONAL SESSIONS

Network with your peers and environmental health leaders and learn about the latest trends and environmental health topics. Over 200 educational sessions will be offered focusing on a variety of issues including hurricane disaster relief efforts, food safety emerging issues such as retail and home restaurants, developments in climate and health, infectious and vectorborne diseases, healthy communities, water, and more.

EXHIBITION

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NEHA.ORG/AEC/EXHIBITION

NEHA NEWS

Government Affairs 2019: What's in Store for Environmental Health

By Joanne Zurcher (jzurcher@neha.org)

Happy New Year! The new year holds a lot of promise in Washington, DC, for environmental health professionals and the National Environmental Health Association's (NEHA) Government Affairs. The last 3 years of building a presence in Washington, DC, has made this work easier and more challenging at the same time. Our success has made influencers, members of Congress, and Administration staff expect excellence from NEHA, and we are working hard to ensure your voice is heard by all.

There's a new Congress in 2019 with Democrats in control of the House of Representatives and Republicans solidly in charge of the Senate. President Donald Trump and his Administration will be busy trying to work with a divided Congress.

The first order of business is welcoming the new members of Congress to Washington, DC, for the opening day of the 116th Congress on January 3. It is an exciting time when the new members of Congress are sworn in. The only vote that day is for the Speaker of the House, which as of this writing, is expected to be Representative Nancy Pelosi (D-California). This day is one of my favorites on Capitol Hill, as many of the freshman class personally welcome you to their offices. It is also move-in day for them and they have no idea where anything is in the buildings.

What an interesting group of new members of Congress—the largest class of women to be elected to Congress, the first two Muslim women to be elected (Representatives Ihan Omar and Rashida Tlaib), the first two Native American women to be elected (Representatives Sharice Davids and Debra Haaland), and the youngest woman to ever be elected (Representative Alexandria Ocasio-Cortez). Additionally, the first sibling (Representative Greg Pence) of a sitting vice president rounds out this interesting group.

On the Senate side, there are new Senators from Arizona (Kyrsten Sinema), Florida (Rick Scott), Indiana (Mike Braun), Mississippi (Cindy Hyde-Smith), Missouri (Josh Hawley), Nevada (Jacky Rosen), North Dakota (Kevin Cramer), Tennessee (Marsha Blackburn), and Utah (Mitt Romney).

Once opening day has come and gone, NEHA Government Affairs begins to educate the new members of Congress and their staff about NEHA. We work to remind them of the importance of having a credentialed environmental health workforce, investing in environmental health work, and making sure they know what a resource NEHA and our membership are to them.

The first major hurdle for the year will be working with our champions—Representative Brenda Lawrence (D-Michigan) and newly reelected Senator Debbie Stabenow (D-Michigan) to reintroduce the Environmental Health Workforce Act in both chambers. As you might know, at the start of every Congress, all the legislation that didn't become law in the previous Congress needs to be reintroduced for it to be considered by either chamber. This legislation is critical to ensuring that there is a credentialed environmental health workforce in every state. The new Democrat Majority brings along opportunities for increased movement on this legislation. NEHA Government Affairs is extremely hopeful that we can find a legislative vehicle to help pass this critical legislation.

President Trump's State of Union Address will follow in late January and then it's off to the races for the fiscal year (FY) 2020 appropriations process. As of writing, all of FY 2019 has not been signed into law and there could be work to still do on FY 2019. NEHA Government Affairs will work diligently to increase funding for the Centers for Disease Control and Prevention (CDC), specifically for CDC's National Center for Environmental Health/Agency for Toxic Substances and Disease Registry, and the Food and Drug Administration.

While all this work is going on, NEHA's Government Affairs will be pressing Congress to pass a hurricane and disaster supplemental appropriations bill in an effort to pay for the environmental health crisis due to the 2018 California wildfires and Hurricanes Florence and Michael.

Then it will be time to plan NEHA's 3rd Annual Hill Day. This exciting day brings NEHA's board of directors to Washington, DC, to meet with members of Congress and their staff to elevate the voice of environmental health professionals. Republicans and Democrats get to hear personal stories from NEHA's board about why they do the work they do every single day. We will keep you posted on this fun day as it gets closer.

Before you know it, it will be time to join us in Nashville for the 2019 Annual Educational Conference & Exhibition! NEHA's Government Affairs will do a recap of this exciting year and answer all your political questions.

In the meantime, please don't be a stranger to NEHA's Government Affairs. If something is going on in your state legislature that you like or don't like, let us know. If there is an issue that we need to take to the Hill, I would love to hear from you, our members.

The last 3 years have been quite a roller coaster. NEHA's Government Affairs will continue to represent environmental health professionals in Washington, DC, and ensure that the environmental health profession always has a seat at the table.

2019 HUD Secretary's Awards for Healthy Homes

The U.S. Department of Housing and Urban Development (HUD), in partnership with NEHA, announces the fifth annual Secretary's Awards for Healthy Homes. These awards recognize excellence in making indoor environments healthier in four categories: public housing/multifamily housing, policy and education innovation, cross program coordination, and research. Nominations must show measurable benefits in the health of residents and be available to low-to-moderate income communities. Applications open January 11 on the NEHA and HUD websites. The deadline to submit an application is March 1. Previous year's award winners are ineligible to apply. The awards will be presented at the NEHA 2019 Annual Educational Conference & Exhibition, July 9–12, in Nashville, Tennessee (www.neha.org/aec).

NEHA **NEWS**

NEHA Staff Profile

As part of tradition, NEHA features new staff members in the *Journal* around the time of their 1-year anniversary. These profiles give you an opportunity to get to know the NEHA staff better and to learn more about the great programs and activities going on in your association. This month we are pleased to introduce you to one NEHA staff member. Contact information for all NEHA staff can be found on page 47.

Reem Tariq

Eager to move out of my childhood home in Kuwait, I relocated to America at the cusp of adulthood to venture out on my own. Frolicking from one city to the next, I finally settled upon the idyllic rolling hills of Pullman, Washington, to get my bachelor's degree in genetics and cell biology at Washington State University. Upon graduating, I explored a spectrum of vocational experiences ranging from teaching at a local college of nursing in South India to corporate photography in Texas. I decided to enroll in graduate school at East Tennessee State University (ETSU) based on my quest for a meaningful career in environmental health sciences.

I learned about NEHA through my experience of participating in the National Environmental Public Health Internship Program in summer 2017. That year I attended my first NEHA Annual Educational Conference & Exhibition and fell in love with the way the association operated. Soon after graduating from ETSU, I joined NEHA in February 2018 as a project coordinator in NEHA's Program and Partnership Development department. As a project coordinator, my work is primarily focused on developing and maintaining projects in private water, environmental public health tracking, and undertaking student and academic outreach. My work at NEHA is everything I expected and more. Above all, I enjoy building programs and relationships with partners with the collective goal of providing a healthful environment for all.

In my spare time I enjoy cooking complex recipes and failing to get them right, undertaking the esteemed hikes of Northern Colorado, reading fantastical fiction and historical accounts, and writing poetry to make sense of it all. If you have any questions about the work I do at NEHA, please feel free to reach out to me at rtariq@neha.org.

DirecTalk
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rest for the wicked, I immediately return to Denver at the conference's conclusion.

These visits provide an opportunity for us to personify NEHA. I want the global community to know we are not an abstraction or a vacuous corporate entity. I want people to know we engage in professional capacity building with enthusiasm, love, and purpose. We desire our network to feel that commitment and to be energized by it.

NEHA is also a member of the International Federation of Environmental Health (IFEH). This federation provides a global meeting place for environmental health professionals to meet and discuss issues of common concern. Based in the UK, 43 countries participate in IFEH events. NEHA Past-President Adam London attended its most recent conference in New Zealand. We hope to begin working on joint policy statements, white papers, and other documents that will advance the art and science of practice. Together, we may be able to accomplish things that perhaps each nation cannot do alone.

A conference attendee asks a question during a National Environmental Health Association food safety training program in Dubai. Photo courtesy of David Dyjack.

National Environmental Health Association (NEHA) Entrepreneurial Zone Director Rance Baker delivers a message during a NEHA training program at the Dubai International Food Safety Conference. Photo courtesy of David Dyjack.

When I travel, many in my social network express worry about my health and safety. Their concerns are predicated on strange food, unfamiliar customs, and nefarious characters. I don't see it that way. Working with our international partners freshens our approaches and understanding of the world around us. What happens in the Zika forest of Uganda has implications for the U.S. and its residents. Our situational awareness is greatly enhanced when we have personal connections with essential partners. What at first might appear as strange is simply new. New friends. New insights. New professional networks.

Speaking of new, it's a new day and time to deliver a new presentation.

Dave

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Did You Know?

NEHA's board of directors recently approved a policy statement on food safety for cottage foods and home-based restaurants. This policy statement and others on food, water, preparedness, cannabis, vector control, body art, and climate change can be found at www.neha.org/publications/position-papers.

DirecTalk MUSINGS FROM THE 10TH FLOOR

David Dyjack, DrPH, CIH

Going Mobile

Silence punctuated by an air of expectation. No pressure, I kept reminding myself. It was a question I had anticipated but the focused stares of the search committee were nonetheless unnerving. It was December 2014 and I was a late round candidate for the National Environmental Health Association (NEHA) executive director position. The question was, "What will be your priorities if you are selected for the NEHA leadership role?" My response was heartfelt and I would tender the same response today if asked again. First, treat environmental health as a contact sport. Second, remove the profession's invisibility cloak. And third, project global leadership, including cultivation of the NEHA brand, services, and products to an international constituency. My three-legged stool.

Many, including you, may question the wisdom or rationale of reaching out beyond our own borders, particularly when we have so many challenges at home. I see it differently. There is a lot to learn by being engaged with our global counterparts. I continue to be amazed by the insights and innovation of professionals who share our values, passion, and scientific orientation. A good example is the Zika virus. The Jamaican public health community informed me during a visit there in October 2015 that Zika was present on the island, which was not publicized because of governmental concerns for the hospitality and tourist industry. When I returned home I tweeted, I e-mailed, I called. No one paid me any attention or they felt that Jamaica was irrelevant. Sadly, at the end of calendar year 2015, Puerto Rico declared its first locally transmitted case. For the better part of 90 days our country lost an opportunity to get ahead of that mess.

We engage in professional capacity building with enthusiasm, love, and purpose.

Since 2015, NEHA staff and board members have been to Azerbaijan, Bangladesh, Canada, Taiwan, Tasmania and mainland Australia, New Zealand, Ireland, France, Jamaica, Portugal, Malawi, and several U.S. territories including Guam, U.S. Virgin Islands, and Puerto Rico. A local or international sponsor covered the travel cost in about half of these visits. Each trip had a purpose, which involved preparation and action. In many cases we were the keynote speaker at a conference. In other cases we had been asked to provide technical expertise, such as the visit to Taiwan. There is only one truly effective way to learn what is important to people—it is to show up in person, share a meal, and become part of the narrative. No offense to my colleagues who spend hours connecting electronically, it just isn't the same.

That's why each year we invite our counterparts to attend our Annual Educational Conference (AEC) & Exhibition. Australia, the United Kingdom (UK), Canada, Jamaica, and Ireland, among others, are encouraged to jump on a plane and participate in our AEC. We provide them opportunities to speak to you, meet North American environmental health influencers, and possibly take a holiday. We recognize humans are hard wired for social interaction and we plan accordingly.

As I write this column, I'm sitting in an espresso bar in Trelawny, Jamaica. NEHA President Vince Radke and I will both have an opportunity to share some thoughts with our Caribbean colleagues. Then things will get really interesting. Radke then travels later this week to Australia to speak at the Environmental Health Australia conference. Yours truly departs in 48 hours for the United Arab Emirates, where NEHA will host a plenary session at the Dubai International Food Safety Conference. NEHA will also deliver courses in instructor skills training and special processes in retail food. These face-to-face classes provide an opportunity for NEHA to showcase our continuing professional education capabilities. We hope some of the 3,000 attendees, mostly from the Middle East and North Africa, will consider becoming NEHA members and acquire our credentials.

My time in Dubai will be limited to a few days. From there we literally jet off to Geneva, Switzerland, to keynote a session at the Global Conference on Air Pollution and Health convened at the World Health Organization. I will speak on the knowledge, skills, and attitudes required for the environmental health workforce as we protect the health and wellness of our communities in a time of extreme climate perturbations. As there is no

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HEALTH SPACE

Health Risks Associated With Arsenic and Cadmium Uptake in Wheat Grain Irrigated With Simulated Hydraulic Fracturing Flowback Water

Linsey Shariq, PhD
Civil and Environmental Engineering
University of California, Davis

Abstract **The expansion of hydraulic fracturing throughout the U.S. has lead to increased flowback and produced water (FPW) production. One reuse option for FPW is agricultural irrigation. Reusing this waste stream to produce crops, however, has uncertain human health implications. A greenhouse experiment was performed to evaluate the plant uptake and health risks associated with consuming wheat *(Triticum aestivum)* irrigated with simulated flowback water containing FPW constituents arsenic and cadmium. The experiment also evaluated the impacts of tetrasodium ethylenediaminetetraacetic acid (EDTA), a common hydraulic fracturing fluid additive and metal chelator, on plant uptake. Arsenic and cadmium were applied at concentrations of 77 and 12 µg/L, respectively, based on documented flowback water sample medians. EDTA was applied at 37 mg/L, the median reported injection concentration. Arsenic and cadmium were extracted from harvested grain and quantified using inductively coupled plasma mass spectrometry (ICP-MS). Results indicated that EDTA did not significantly increase plant uptake of the applied metals. Treated grain was found to contain 6.5 times higher arsenic and 1.4 times higher cadmium concentrations than control grain. Health risk evaluations revealed elevated carcinogenic and noncarcinogenic risks associated with the ingestion of arsenic in treated wheat grain.**

Introduction

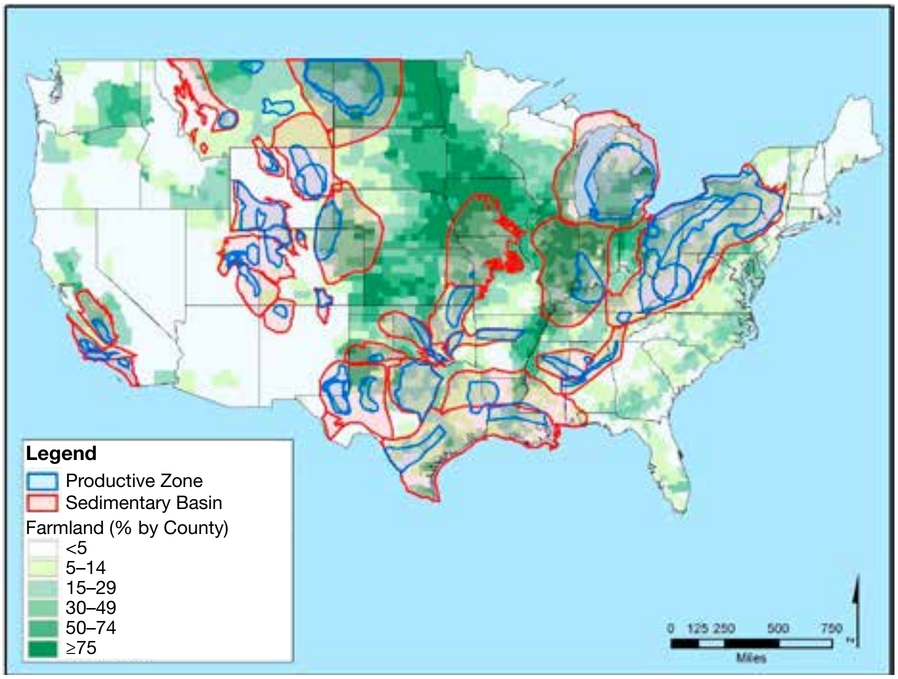
Hydraulic fracturing is a well stimulation technique used to improve the flow of oil and gas from petroleum-bearing rock formations. A fluid mixture containing water, proppant, and chemical additives is injected into a well at high pressure to fracture the rock. Hydraulic pressure is then removed, allowing oil, gas, and formation water to flow into the well through the fractures held open by the proppant. The portion of the injected fluid that returns to the surface once pressure is released is called flowback water. The native formation water that also surfaces during the extraction is generally referred to as produced water (Thurman, Ferrer, Blotevogel, & Borch, 2014). Average injection water volumes range from <2,600 m^3 per directional well stimulation to 19,425 m^3 per horizontal gas well stimulation (Gallegos, Varela, Haines, & Engle, 2015). Following well stimulation, the quantity of flowback water ranges from 10–70% of the original injection volume (American Petroleum Institute, 2010). The combination of flowback and production water (FPW) returning to the surface can reach as high as 14,300 m^3 per well over the first 5–10 years of production (Kondash, Albright, & Vengosh, 2017).

The potential for large quantities of FPW production combined with the widespread spatial overlap between domestic extraction sites and agricultural land (Figure 1) have sparked interest in FPW reuse for agricultural irrigation, especially in drought-stricken areas. Small operations reusing treated and diluted enhanced oil recovery (EOR)-produced water for irrigation are already underway in California (Brost, 2002), and researchers have studied the reuse of coalbed methane FPW for irrigation in Wyoming (Engle, 2011). Additionally, natural gas production in the U.S. is estimated to grow by 65% in the next 30 years, accounting for 39% of the domestic energy production by 2050 (U.S. Energy Information Administration, 2018). The overlap of land uses and predictions of continued energy growth make the evaluation of FPW reuse safety an increasingly important research topic for sustainable water management.

Hydraulic fracturing FPW can contain both additive chemicals and naturally occurring constituents (California Council on Science and Technology [CCST], 2015; Thurman et al., 2014). Recent analytical laboratory studies have shown that of the median 14 addi-

FIGURE **1**

Spatial Overview of Hydraulic Fracturing Source Rock and Agricultural Land in the United States



Source: U.S. Department of Agriculture (2012) and U.S. Energy Information Administration (2016).

tive chemicals used in each hydraulic fracture (U.S. Environmental Protection Agency [U.S. EPA], 2015), biocides and surfactants are identifiable in some FPW samples (Ferrer & Thurman, 2015; Thurman et al., 2014). In addition to chemical additives, naturally occurring contaminants can also be present in FPW (Abualfaraj, Gurian, & Olson; 2014, CCST, 2015; Lester et al., 2015). These naturally occurring constituents include metals, radionuclides, and polycyclic aromatic hydrocarbons. Several constituents brought up from the subsurface in the hydraulic fracturing process, such as the metals evaluated in this research, can potentially pose a health risk when water is not tested or treated appropriately for its end use (Vengosh, Jackson, Warner, Darrah, & Kondash, 2014).

Currently, there is limited published literature addressing the health implications associated with FPW reuse for agricultural irrigation. This investigation is designed to quantify the plant uptake and health impacts associated with concentrations of the naturally occurring toxic metals arsenic and cadmium, which are found in hydraulic fracturing flowback water. Results from this study can be combined with future research evaluating additive chemical uptake in plants to obtain a more thorough understanding of hydraulic fracturing FPW agricultural reuse safety.

Methods

Constituent and Crop Selection

A literature review of regional hydraulic fracturing FPW samples formed the basis for constituent and concentration selection. At the time of this experiment, the most extensive compilation of flowback water observations (219 flowback water samples) was documented by four agencies in Pennsylvania, West Virginia, and New York from March 2008–December 2010 (Abualfaraj et al., 2014). Researchers in California also published analytical results from 48 FPW samples (CCST, 2015) and researchers in Colorado published analytical results from one flowback water sample (Lester et al., 2015). Constituents were assessed based on the availability of health data, severity of toxicity, and whether their concentrations were near or exceeded either the national drinking water standards or agricultural water quality thresholds in California (Table 1). Based on the evaluated parameters, arsenic and cadmium were selected for the experiment.

The selected concentrations of 77 µg/L for arsenic and 12 µg/L for cadmium represent the median of 219 arsenic samples and 218 cadmium samples reported in the Northeastern regional study (Abualfaraj et al., 2014). The selected concentrations fall within the concentration range of the 48 FPW samples reported in California (CCST, 2015) and within 15% of the arsenic concentration reported in Colorado (Lester et al., 2015). The widely used corrosion inhibitor tetrasodium ethylenediaminetetraacetic acid (EDTA) was also selected as a constituent of concern based on its ability to act as a chelating agent potentially able to increase the uptake of cationic metals into plants (Chen, Li, & Shen, 2004). EDTA was added to irrigation water at a concentration of 37 mg/L based on the median use concentration reported in the U.S. EPA chemical disclosure registry FracFocus (U.S. EPA, 2015).

The selected chemicals were applied through irrigation water to the staple crop wheat. The incorporation of a staple crop was an integral experimental parameter because it is not easily removed from the human diet. Additionally, due to the high consumption rate of a staple crop, small amounts of chemical contamination can pose a risk to human health. Organic hard red spring wheat (*Triticum aestivum*) from the Sustainable Grains Company was chosen as the target crop primarily because wheat was reported as the single most consumed grain crop by humans and livestock worldwide (Pimentel & Pimentel, 2008). Additionally, previous research shows that wheat can accumulate selected metals including arsenic (Bhattacharya, Samal, Majumdar, & Santra, 2010) and cadmium (Mortvedt, Mays, & Osborn, 1981). Wheat is also a representative member of the Poales plant order, having the ability to move organic contaminants such as EDTA from their roots to their shoots through acropetal translocation (Collins & Willey, 2009). Hard red spring wheat was specifically selected

TABLE **1**

Regulatory Limits, Flowback Concentrations, and Health Information for Selected Naturally Occurring Metals

Constituent	Maximum Drinking Water Contaminant Level (µg/L)[a]	Agricultural Water Quality Threshold (µg/L)[b]	Pennsylvania, West Virginia, and New York Median Flowback Water Sample Concentration (µg/L)[c]	Colorado Flowback Water Sample Concentration (µg/L)[d]	California Flowback and Recovered Water Sample Concentration Range (µg/L)[e]	Health and Toxicity Information (LD_{50} Units: mg/kg)[f]
Arsenic	10	100	77	67	ND–1,300	LD_{50} mouse oral: 145 Carcinogen: confirmed Endocrine disruptor: suspected
Cadmium	5	10	12	NA	ND–83	LD_{50} mouse oral: 225 Carcinogen: probable Endocrine disruptor: suspected

NA = not available; ND = not detected.
[a]U.S. Environmental Protection Agency, 2018.
[b]California Water Boards, 2017.
[c]Abualfaraj, Gurian, & Olson, 2014.
[d]Lester et al., 2015.
[e]California Council on Science and Technology, 2015.
[f]Bergman, Heindel, Jobling, Kidd, & Zoeller, 2012; U.S. National Library of Medicine, 2012, 2018.

because it is the dominant type of spring wheat in the U.S., representing 12.6 of the 13.5 million acres of spring wheat planted in 2015 (U.S. Department of Agriculture [USDA], 2015).

Experimental Design and Protocol

The greenhouse experiment consisted of a completely randomized design (CRD) with three treatments and eight replications per treatment. A random number generator was used to develop the CRD grid. The experimental treatments consisted of a control, treatment 1, and treatment 2. The control plants were irrigated with reverse osmosis fertilized water with no hydraulic fracturing flowback water constituents. Treatment 1 plants were irrigated with reverse osmosis fertilized water collected at the greenhouse and amended with arsenic, cadmium, and EDTA in the laboratory. Treatment 2 plants were irrigated with reverse osmosis fertilized water collected at the greenhouse and amended with only arsenic and cadmium in the laboratory.

Ron's Mix soil, available through the University of California, Davis (UC Davis) Orchard Park greenhouse facility, was used throughout the experiment. Sample analysis of the base soil indicated that the total arsenic and cadmium concentrations in the soil were 3.84 and 0.253 mg/kg, respectively. Grains were planted 4 cm apart using templates at a depth of 5 cm. Individual experimental units were planted with 59 seeds and grain was aggregated from the mature wheat plants in each experimental unit after 76 days of growth before laboratory analyses.

Water sample analysis of base water indicated total arsenic and cadmium concentrations were lower than the method detection limits of 0.010 and 0.0020 mg/L, respectively. Fertilizers Growmore 4-18-38, CALCINIT (a calcium nitrate amendment), and magnesium sulfate were injected into the water at 1.3% with Dosatron injectors to yield a concentration of 100-200-100 mg/L of nitrogen-phosphorus-potassium. Control water was collected before each irrigation event and brought to the laboratory for amendment with the chemicals of interest.

Stock solutions were prepared for each chemical additive and stored at 4 °C until use. A 60 mg/L arsenic stock solution was prepared from arsenic (As(V)) TraceCERT standard for ICP. A 20 mg/L cadmium stock solution was prepared from cadmium nitrate tetrahydrate. A 30 g/L EDTA stock solution was prepared from EDTA tetrasodium salt dehydrate. For treatments 1 and 2, 1.283 mL of arsenic stock solution and 0.60 mL of cadmium stock solution were diluted with reverse osmosis fertilized water to 1 L to achieve the desired concentration of 77 µg/L arsenic and 12 µg/L cadmium. Treatment 1 was further amended with 1.233 mL of EDTA stock solution per liter of reverse osmosis fertilized water to achieve 37 mg/L.

The irrigation procedure began immediately after planting and continued until 2 days before harvest. Water requirements for each pot were preliminarily calculated using guidelines for spring wheat growth (McMullen, 2003), then adapted to ensure no leakage from the pots was observed. Each experimental unit was irrigated with 1.2 L twice a week for the first 3 weeks, then 3 times a week for the remaining 7.5 weeks for a total of 29 irrigation applications. A cumulative 34.8 L of irrigation water was applied to each experimental unit throughout the experiment.

TABLE 2

Equation Parameter Definitions and Values

Parameter	Definition of Parameter (Units)	Values
ADAF	Age-dependent adjustment factor	0–<2 years: 10; 2–<16 years: 3; >16 years: 1 (U.S. Environmental Protection Agency [U.S. EPA], 1989)
AT	Averaging time (days)	0–2 years: 730; 2–6 years: 1,460; 6–10 years: 3,650; adult: 25,550 (U.S. EPA, 1989)
BW	Body weight (kg)	0–6 years: 15; >6 years: 70 (Barton et al., 2005; U.S. EPA, 1989)
CF	Concentration in grain (mg/kg)	See Table 3
CR	Cancer risk (incremental individual lifetime cancer risk)	–
ED	Exposure duration (years)	0–<2 years: 2; 2–<6 years: 4; 6–<16 years: 10; 16–<30 years: 14; adult: 70 (U.S. EPA, 1989)
EF	Exposure frequency (days/year)	365
FI	Fraction ingested	–
HQ	Hazard quotient	–
IR	Ingestion rate (kg/day)	2–<16 years: 0.085 (U.S. Department of Agriculture [USDA], 2017) >16 years: 0.165 (USDA, 2016)
RfD	Reference dose (mg/kg-day)	Arsenic: 0.0003 (Watts, 1998) Cadmium: 0.001 (Office of Environmental Health Hazard Assessment, 2000)
SF	Oral slope factor (mg/kg-day)	Arsenic: 1.5 (Watts, 1998)

TABLE 3

Arsenic and Cadmium Summary Statistics

Constituent	Treatment	# of Replicates	Mean	Median	*SD*	Range
Arsenic (mg/kg)	Control	8	0.053	0.051	0.007	0.046–0.068
	Treatment 1	8	0.346	0.344	0.035	0.306–0.400
	Treatment 2	8	0.321	0.324	0.044	0.259–0.402
Cadmium (mg/kg)	Control	8	0.123	0.102	0.041	0.099–0.208
	Treatment 1	8	0.175	0.176	0.008	0.161–0.188
	Treatment 2	8	0.174	0.170	0.013	0.161–0.200

Metal Analysis

Wheat plants were sampled when they reached maturity on the 76th day. Maturity was determined by the complete loss of green coloring from the flag leaf and the glumes representing a 95% maximum kernel dry weight (Hanft & Wych, 1982). Metal extraction was performed on grain from each of the 24 experimental units by the UC Davis Analytical Laboratory using Method 590 (UC Davis Analytical Laboratory, 2017–2018). This method utilizes a nitric acid/hydrogen peroxide closed vessel microwave digestion system for the dissolution of 0.4 g of grain material. The postdigested solution was diluted to 12 mL with triple deionized water. The 24 samples were analyzed using Agilent Series 7500 ICP-MS with ASX-520 auto-sampler. Samples were run alongside 13 standard dilutions prepared from SPEX CertiPrep ICP-MS Multi-Element Solution 2A ranging from 0.1 µg/L to 1.0 mg/L. To ensure accuracy, the standard curve R^2 correlation coefficient values were evaluated to verify that each was above 0.995 (USDA, 2018). Samples were run with three duplicates, one per treatment and two blanks. The average blank ion count was subtracted from the sample ion count before concentration calculation.

Selenium concentrations for both ^{77}Se and ^{82}Se were used to correct ion counts for arsenic to account for polyatomic interferences. Equation 1, published in U.S. EPA Method 200.8, was applied to the arsenic results. The *C* variables represent the calibration blank subtracted counts for the indicated mass (U.S. EPA, 1994).

Equation 1

$$^{75}\text{As corrected ion count} = (^{75}C) - (3.127)\,[(^{77}C) - (0.815)(^{82}C)]$$

Results from the ICP-MS were indicated in µg of constituent per 0.4 grams of plant material in 12 mL solution. Results were converted into mg of constituent per kg of grain in preparation for toxicological evaluation.

Health Risk Evaluation

Analytical measurements were used to evaluate the carcinogenic and noncarcinogenic health risks associated with the consumption of exposed crops. Equation 2 was used to estimate the elevated cancer risk (*CR*) and Equation 3 was used to estimate the noncarcinogenic hazard quotient (*HQ*) (U.S. EPA, 1989). Table 2 provides a list of parameter definitions and values for the equations.

Equation 2

$$CR = \frac{CF*IR*FI*EF*ED}{BW*AT}*ADAF*SF$$

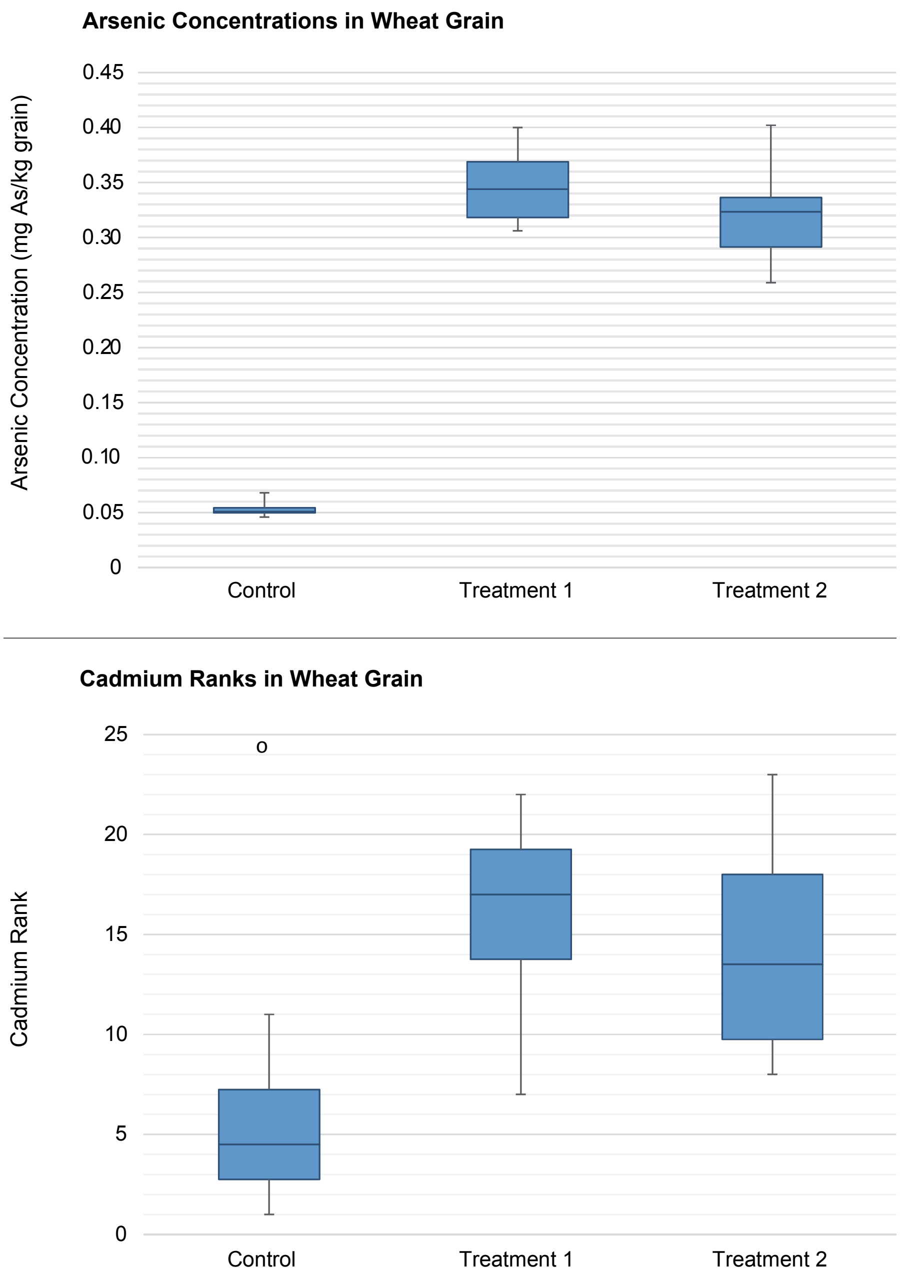
Equation 3

$$HQ = \frac{(CF*IR)/BW}{RfD}$$

Risk calculation variables ingestion rate (*IR*) and exposure frequency (*EF*) were based on U.S. Department of Agriculture (USDA) data. The 2011 USDA estimate for annual adult consumption of wheat per capita was 132.5 pounds (USDA, 2016). This consumption statistic was converted into risk equation units to identify the adult *IR* as 0.165 kg/day and *EF* as 365 days. Child consumption was estimated from the USDA grain consumption guidelines. The lowest published value of 0.085 kg/day represents the total grain consumption for a

FIGURE 2

Distribution of Arsenic and Cadmium



2- to 3-year-old child (USDA, 2017). As this guideline is inclusive of all grains, not solely wheat, this low value was used to conservatively estimate all child toxicological risks from ages 2 to <16 years old.

Variations in fraction ingested (*FI*) were evaluated to account for the fraction of wheat consumed that is likely exposed to the selected chemicals of concern. Without the *FI* variation, 100% of the wheat consumed is assumed to be exposed to the arsenic and cadmium at flowback water concentrations. Calculations were made to identify the specific *FI* at which no adverse risk was identified.

HQ values above 1 indicate that harmful risks from individual chemical ingestion cannot be ruled out. A *CR* value of 10^{-6} indicates that one person out of 1 million equally exposed people would contract cancer if exposed continuously (U.S. EPA, 1989). While *CR* levels of $<10^{-6}$ are deemed negligible, risks from 10^{-4} to 10^{-6} are generally considered acceptable and levels $>10^{-4}$ are large enough to initiate remedial action (U.S. EPA, 1991).

Results

Constituent Uptake in Wheat Grain

Arsenic and cadmium concentrations were measured in harvested grain to quantify constituent uptake from the irrigation water. Summary statistics including the mean, median, standard deviation, and range of concentrations are presented in Table 3.

Statistical results showed significant differences between treatments for arsenic and cadmium. The arsenic parametric analysis of variance (ANOVA) indicated a significant difference in sample means ($p < .0001$). Cadmium ranks from the Kruskal–Wallis nonparametric ANOVA were also found to be significantly different ($p = .0158$). The distributions between treatments are displayed in Figure 2.

The Tukey mean separation test for arsenic indicated that the mean grain concentrations were significantly higher in both treatments than in the control, but there was no significant concentration difference between the treatments themselves. The Tukey test for cadmium ranks indicated that the treatment 1 rank was significantly higher than the control, but the differences between treatment 1 and treatment 2, and treatment 2 and the control were not significant (Table 4).

The ICP-MS analysis also yielded results for four additional micronutrients within the calibration standard range: copper, nickel, sodium, and iron. Statistical analyses were performed on these results to evaluate whether the addition of EDTA impacted the uptake of these micronutrients in the wheat grain. The nonparametric ANOVAs performed on the copper and nickel mean ranks and the weighted least squares ANOVA performed on sodium concentrations indicated significant differences between treatments. The parametric ANOVA performed on iron concentrations indicated no significant difference between treatments. Tukey test results showed that copper and nickel control grain concentra-

TABLE 4

Tukey Means Separation Test Results for Arsenic and Cadmium Uptake in Wheat Grain

Arsenic Comparison			Cadmium Comparison		
Minimum Significant Difference: 0.0409			Minimum Significant Difference: 7.6527		
Treatment	Mean (mg/kg)	Tukey Grouping	Treatment	Mean Rank	Tukey Grouping
Treatment 1	0.346	A	Treatment 1	16.125	A
Treatment 2	0.321	A	Treatment 2	14.375	AB
Control	0.053	B	Control	7.000	B

TABLE 5

Micronutrient Summary Statistics

Constituent	Treatment	# of Replicates	Mean	Median	*SD*	Range
Copper (mg/kg)	Control	8	9.195	7.971	3.143	7.603–16.816
	Treatment 1	8	8.590	6.925	4.862	6.686–20.621
	Treatment 2	8	6.468	6.402	0.343	6.030–7.082
Iron (mg/kg)	Control	8	26.147	26.151	1.467	23.580–28.655
	Treatment 1	8	25.254	24.937	1.412	23.754–28.176
	Treatment 2	8	24.969	24.885	2.291	22.277–27.847
Nickel (mg/kg)	Control	8	4.512	4.124	1.112	3.183–6.755
	Treatment 1	8	2.580	2.257	1.121	1.882–5.274
	Treatment 2	8	2.057	1.975	0.252	1.808–2.562
Sodium (mg/kg)	Control	8	9.960	9.922	1.504	7.794–12.455
	Treatment 1	5	20.023	19.742	4.969	12.869–24.464
	Treatment 2	7	19.339	17.282	6.458	10.945–28.018

tions were significantly higher than both treatment concentrations, while sodium control grain concentrations were significantly lower than both treatment concentrations. Nickel and sodium showed no significant difference between treatments; however, grain copper concentrations for treatment 1 were significantly higher than treatment 2 (Table 5).

Health Risk Assessments

A carcinogenic risk assessment was performed for arsenic concentrations (Table 6) and noncarcinogenic risk assessments were performed for both arsenic and cadmium concentrations (Table 7). Cadmium does not have an associated carcinogenic oral slope factor; therefore, it was evaluated for noncarcinogenic risk only. The *FI* value represents the percentage of annual consumption from this grain source that is potentially safe to consume because the calculated risk value is lower than the critical value.

Using the remediation threshold of 10^{-4}, *CR* associated with the consumption of arsenic was elevated for all treatments, including the control. The arsenic-associated carcinogenic health risks from consuming treatment 1 and 2 grains were approximately 6.5 times higher than the control grain. The noncarcinogenic risk assessment results for arsenic indicate that both treatments were associated with elevated health risks for children and adults, while the control treatment risks were <1.

The noncarcinogenic risk results for cadmium consumption indicate the *HQ* for control plants was <1 for adults and children. Cadmium levels in treatment 1 grain were associated with a child *HQ* on the threshold of elevated risk. This risk can be lowered to below the threshold *HQ* of 1 by reducing the consumption of treatment 1 grain to <99.65% of annual wheat grain intake. Treatment 2 cadmium concentrations were associated with adult and child *HQ*s <1.

Discussion

Implications for Human Health

Experimental results indicate that consumption of wheat irrigated with simulated hydraulic fracturing flowback water is associated with elevated carcinogenic and noncarcinogenic risks for both adults and children based on arsenic exposure. The cumulative impact of applying hydraulic fracturing FPW widely on multiple crops could increase this health risk from contaminants such as arsenic.

The carcinogenic risk assessment for arsenic indicated a slightly elevated health risk from control grain consumption. The low amount of arsenic in the greenhouse irrigation water suggests that soil was the main contributor to the arsenic found in the control grain. The 3.84 mg/kg arsenic concentration in the experimental soil, however, was lower than the 7.5 mg/kg mean domestic soil arsenic concentration (Mandal & Suzuki, 2002). The mean arsenic concentration in control wheat grain, 0.053 mg/kg, was also within the same order of magnitude as the 0.02 mg/kg average domestic wheat grain arsenic concentration (Zhao et al., 2010). While the uptake of naturally occurring arsenic in edible crops continues to be an important topic of research, the approximate 6.5-fold risk increase from hydraulic fracturing FPW irrigation is an additional risk that can be minimized through regulations and treatment measures if the practice of reuse becomes widespread.

The results presented here reflect health risks associated with the consumption of whole experimental grain. Studies suggest, however, that arsenic distribution can vary within the grain. Arsenic concentrations in wheat bran have been documented as 2–3 times higher (Zhang, Liu, Tian, & He, 2009) and 3.8–4.7 times higher (Zhao et al., 2010) than wheat flour. Cadmium concentrations have similarly been reported to be 2–3 times higher in wheat bran than in milled grain and flour (Oliver, Gore, Moss, & Tiller, 1993). These reports suggest that milling wheat before consumption could reduce the health risks associated with metal ingestion from contaminated wheat.

TABLE 6

Carcinogenic Risk Results From Ingestion of Arsenic in Experimental Grain

Arsenic Treatment	*CR* (>16 years)	*FI* at which *CR* < 1 x 10^{-4}	*CR* (6–<16 years)	*FI* at which *CR* < 1 x 10^{-4}	*CR* (2–<6 years)	*FI* at which *CR* < 1 x 10^{-4}	*CR* (<2 years)	*FI* at which *CR* < 1 x 10^{-4}
Control	**1.80 x 10^{-4}**	55.46%	**2.79 x 10^{-4}**	35.88%	**1.30 x 10^{-3}**	7.69%	**4.34 x 10^{-3}**	2.31%
Treatment 1	**1.22 x 10^{-3}**	8.22%	**1.88 x 10^{-3}**	5.32%	**8.77 x 10^{-3}**	1.14%	**2.92 x 10^{-2}**	0.34%
Treatment 2	**1.15 x 10^{-3}**	8.73%	**1.77 x 10^{-3}**	5.65%	**8.26 x 10^{-3}**	1.21%	**2.75 x 10^{-2}**	0.36%

CR = cancer risk; *FI* = fraction ingested.
Note. Bolded values indicate *CR* > 1 x 10^{-4}.

TABLE 7

Noncarcinogenic Risk Results From Ingestion of Arsenic and Cadmium in Experimental Grain

Additive Metal and Treatment	Median Concentration (mg metal/kg grain)	*HQ* (>6 years)	*FI* at which *HQ* < 1 (>6 years)	*HQ* (<6 years)	*FI* at which *HQ* < 1 (<6 years)
Arsenic					
Control	0.051	0.40	100%	0.96	100%
Treatment 1	0.344	**2.70**	36.88%	**6.50**	15.31%
Treatment 2	0.324	**2.54**	39.16%	**6.12**	16.25%
Cadmium					
Control	0.102	0.24	100%	0.58	100%
Treatment 1	0.176	0.41	100%	1.00	99.65%
Treatment 2	0.170	0.40	100%	0.96	100%

HQ = hazard quotient; *FI* = fraction ingested.
Note. Bolded values indicate *HQ* values >1.

The addition of EDTA to treatment 1 irrigation water did not result in a significantly increased uptake of arsenic or cadmium in wheat grain compared with treatment 2. Furthermore, the addition of EDTA did not significantly increase the uptake of ancillary micronutrients (i.e., sodium, iron, or nickel) in treatment 1 grain. The concentration of copper was found to be significantly higher in treatment 1 grain compared to treatment 2; however, copper concentrations in control grain were higher than both. Therefore, the overall influence of EDTA on the selected metals of concern and micronutrients was not found to be consequential to human health in this experiment.

Policy Recommendations

While national regulations do not currently cover FPW reuse for irrigation, individual state discharge requirements could apply to FPW reuse. In California, for example, reuse of FPW for agriculture is subject to site-specific waste discharge requirements and agricultural water quality thresholds for irrigation. Thresholds, however, do not have regulatory enforcement and do not cover the many additive organic constituents. Additionally, based on the experimental results, the 100 µg/L agricultural water quality threshold for arsenic in California (California Water Boards, 2017) is not stringent enough to protect human health from potential carcinogenic and noncarcinogenic impacts from arsenic consumption.

Arsenic was applied to treated plants at a concentration of 77 µg/L, lower than the agricultural water quality threshold, and the health risk assessment indicated elevated risk. Further experiments applying a range of arsenic concentrations to a variety of grain and produce should be conducted to determine an enforceable water quality objective that is able to reduce health risks to an acceptable level.

The current cadmium agricultural water quality threshold of 10 µg/L in California is lower than the 12 µg/L applied to the treated plants. The results of this experiment indicate that the health risk from cadmium for children is on the cusp of elevated noncarcinogenic health risk. Reused FPW therefore should be monitored to ensure that irrigation water concentrations meet the agricultural water quality thresholds for cadmium. Site-specific waste discharge requirements should also be looked at as an important regulatory tool for setting conservative water quality levels until crop uptake studies and risk assessments can be thoroughly evaluated and translated into enforceable agricultural water quality objectives.

It is important to note that oil and gas extraction practices other than hydraulic fracturing use additive chemicals. Chemicals such as biocides, corrosion and scale inhibitors, breakers, buffering agents, clay stabilizers, crosslinkers, friction reducers, solvents, and surfactants are used in hydraulic fracturing as well as in conventional extraction and EOR (Taylor, Fram, Landon, Kulongoski, & Faunt, 2014). Because EOR FPW reuse for agricultural irrigation is currently occurring in Kern County, California, specific investigation into EOR wastewater quality is warranted. Unfortunately, unlike hydraulic fracturing, conventional and EOR chemical usage disclosures are not readily available. Staff from the California Regional Water Boards have addressed this data gap by issuing California Water Code section 13267 directives requiring operators to disclose chemical usage. The regional water boards also convened a food safety expert panel to provide input on chemical disclosures and to help direct research aimed at evaluating crop safety (California Water Boards, 2018).

Conclusion

The evaluation of FPW reuse for agricultural irrigation is a new topic of inquiry with a wide range of future research possibilities. The presented research begins to evaluate reuse safety by quantifying the plant uptake of naturally occurring metals found in FPW. A thorough evaluation of reuse safety must also include oil field additive chemicals. This effort will require analytical method development, research into chemical degradation byproducts, and development of health information for lesser-known additive chemicals.

Once this information is developed, greenhouse experiments can be used to evaluate uptake potential in crops with minimal environmental impact. With irrigated agriculture the largest water user in 40% of the shale plays worldwide (Reig, Luo, & Proctor, 2014), and drought-stricken agricultural areas exploring nontraditional water sources for their irrigation needs, now is the optimal time to investigate these research questions and develop appropriate treatment options to ensure that FPW reuse for agricultural irrigation is safe for consumer health.

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