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Collaborative response to arsenic-contaminated soil in an Appalachian Kentucky neighborhood

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ABSTRACT

The aim of this study was to identify factors associated with an increased exposure to arsenic-contaminated soil in a Kentucky neighborhood as part of collaborative public health response. An exposure assessment survey was administered to residents and toenail clippings and soil samples analyzed for arsenic concentration. The associations between exposure variables and arsenic concentrations were evaluated using a multivariate-generalized estimating equation. An ecological assessment of cancer incidence in the community was also conducted using standardized incidence ratio maps. Median toenail arsenic was 0.48 micrograms/gram (µg/g), twice the expected regional level of 0.2 µg/g. Mean residence surface soil arsenic level was 64.8 ppm. An increase of 1 ppm of residence concentration was significantly associated with a 0.003 µg/g rise in toenail levels. Concentrations for respondents who engaged in digging were 0.68 µg/g significantly higher compared to individuals who did not. No significantly elevated rates of lung or bladder cancer were observed in the affected ZIP codes. Living in areas with high soil arsenic contamination might lead to (1) increased exposure; (2) elevated residence soil arsenic concentrations and (3) the action of digging in the soil was associated with elevated toenail arsenic levels. Based upon elevated soil levels identified, residents were recommended to move from the contaminated environment until remediation was complete. Additional recommendations included regular health-care follow-up.

KEYWORDS

Arsenic; environmental contamination; exposure assessment; Kentucky

Introduction

Arsenic is a naturally occurring metal found in soil and rock. Historically, arsenical compounds were used as lumber preservatives, sometimes in the form of ammoniacal copper arsenate (ACA) (ATSDR 2017). Human contact with arsenic may occur through ingestion or inhalation of contaminated soil, or by residing in an area with high natural soil levels of arsenic (Bradham et al. 2018). Appalachian Kentucky has naturally-occurring arsenic associated with the region's coal seams (Johnson et al. 2011; NREPC 2004). The concentration of natural arsenic in soil generally ranges from 1 to 40 parts per million (ppm). Chronic exposure to arsenic might lead to adverse health outcomes, including increased risk of lung, bladder, and skin cancers (ATSDR 2017)

Surface soil samples of the area collected as part of a collaborative public health and environmental state response from a 19-household residential neighborhood in Appalachian Kentucky exhibited extremely elevated concentrations of soil arsenic up to 31,000 ppm. This neighborhood is located on the former site of a lumber treatment facility that anecdotally improperly disposed of ACA in the 1980s. When the initial contamination was discovered in August 2016 through routine Superfund monitoring, surface soil samples were collected which confirmed contamination, soil remediation was initiated and a multidisciplinary response team from state and local health departments, emergency management, and academic institutions conducted an exposure assessment to soil and an ecological assessment of cancer incidence as part of a public health investigation (Kentucky SOS 2016)

Methods

To identify factors associated with an increased exposure to arsenic-contaminated soil, an in-person, onsite

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survey was administered to all 84 residents on the single affected street identified through surface soil sample testing within one week of identification of contamination. Parents provided responses for children when necessary. The survey was developed *ad hoc* based upon known factors associated with exposure to arsenic, including (1) occupation, diet, or activities; (2) known symptoms associated with exposure to arsenic and medical history; and (3) types of contact with soil at the residence.

Toenail clippings were used to assess possible arsenic exposure that may have occurred in the months prior, as many residents had already moved off-site within the same week after being notified of elevated arsenic levels and when the survey was conducted such that individuals were no longer acutely exposed. Toenails specifically were selected to represent this longer-term exposure. Clippings were self-collected at time of survey in a single day using sterile, single-use clippers, with response team observation. Surface soil samples were collected at a depth of 0 to 9 in. per Energy and Environment Cabinet protocol. Arsenic concentration was analyzed in washed nail clipping and soil samples by inductively coupled plasma-mass spectrometry using methods described in detail by several investigators (Button et al. 2009; Hinwood et al. 2003; Johnson et al. 2011). Multiple (4–24) discrete random soil measurements were collected per residence, and mean surface soil arsenic concentration per residence calculated. Toenail arsenic concentration for each resident was compared to expect baseline regional arsenic concentration of 0.2 μg/g, based upon concentrations previously published from a similar population of Appalachian Kentucky residents, where Johnson et al. (2011) detected values of 0.29 μg/g to be the 90th percentile of toenail arsenic levels in this similar reference population (Karagas et al. 2000)

Statistical analyses

Continuous variables were described using medians and interquartile ranges. Categorical variables were described using percentages and 95% confidence intervals. The associations between exposure variables and arsenic concentrations were evaluated using a multivariate-generalized estimating equation. The generalized estimating equation was employed in order to account for clustering within residences. Confidence intervals and *p*-values were calculated utilizing bias-corrected and accelerated bootstrapping (5,000 resamples) stratified within residence. Analyses were conducted using SPSS (v. 25, Armonk, NY).

Across the entire sample, 10.7% of data were missing. For toenail arsenic concentrations, data were missing because either participants provided nails that were too small to analyze, or these individuals already moved off-site by the time of collection. There were no instances of arsenic concentrations falling below the detection limit. Ten complete datasets were imputed using fully conditional specification. All available data were employed as predictors in the imputation model.

In order to conduct an ecological assessment of cancer incidence in the community, Kentucky Cancer Registry diagnosis residence and demographic data were used for all individuals with lung or bladder cancer during 2000–2013 in the region to create standardized incidence ratio maps in QGIS 2.8 (Open Source Geospatial Foundation Project), with discrete Poisson spatial scan statistics at ZIP code and census tract using SaTScan™ 9.4 (Information Management Services Inc.) to detect potential cancer clusters. (Kulldorff 1997)

Results

All 88 (100%) subjects from 19 affected households completed the survey. The descriptive statistics for the sample are presented in Table 1. The median age of respondents was 26.1 years (IQR: 10.5– 39.9). Thirty-three (39%) were aged <18 years. The majority of the sample was female (52.9%) while 41.6% identified as Hispanic. The median time spent living at the residence was 9.2 years (IQR: 3.9– 16.1). The median toenail arsenic concentration was 0.43 μg/g (IQR: 0.12–0.9) and median residence concentration was 64.8 ppm (10.3– 100.6). 63.7% of participants exhibited concentrations >0.2 μg/g and 19.7% contained concentrations >1 μg/g.

The associations between exposure variables and toenail arsenic concentrations are presented

Table 1. Respondent characteristics (N = 88).

Characteristic	% or M	95% CI or IQR
Respondent characteristics		
Hispanic; %, 95% CI	41.6	17.4 – 70.8
Female; %, 95% CI	52.9	40.7 – 64.9
Age (years); M, IQR	26.1	10.5 – 39.9
Toenail concentration (μg/g); M, IQR	0.43	0.12 – 0.90
Occupational history		
Ever worked in agriculture/farming; %, 95% CI	29.5	20.8 – 40
Ever worked in industrial processing plant; %, 95% CI	8.1	4.1 – 15.4
Ever worked in power plant; %, 95% CI	4.7	2.1 – 10.2
Ever worked in cement manufacturing; %, 95% CI	9.4	5.2 – 16.6
Tobacco use		
Current smoker; %, 95% CI	22.7	12.7 – 37.4
Previous smoker; %, 95% CI	33.0	19.4 – 50.2
Exposure to potential arsenic sources		
Eat homegrown fruits/vegetables; %, 95% CI	51.1	33.8 – 68.2
Agricultural pesticides; %, 95% CI	84.1	75.2 – 90.3
Arsenic treated wood; %, 95% CI	9.1	3.3 – 22.5
Drinking well water; %, 95% CI	0	0 – 5.0
Soil exposures		
Gardening; %, 95% CI	24.9	16.4 – 35.9
Digging; %, 95% CI	39.8	27.1 – 54
Mowing; %, 95% CI	38.9	27.4– 51.9
Weeding; %, 95% CI	26.9	17.8 – 38.6
Pets that split time between indoors/outdoors; %, 95% CI	22.7	10.4 – 42.7
Outdoor sports; %, 95% CI	48.6	37.6 – 59.6
Play with pets; %, 95% CI	38.7	21.1 – 59.8
Residential soil concentration (μg/g); M, IQR	64.8	10.3 – 100.6
Time at residence (years); M, IQR	9.2	3.9 – 16.1

% – Percentage
95% CI – 95% Confidence Interval
M – Median
IQR – Interquartile Range

Table 2. Adjusted associations between exposure variables and toenail concentrations of arsenic (ug/g; N = 88).

Characteristic	B	95% CI	p
Respondent characteristics			
Hispanic	0.95	0.04 – 1.85	.04
Female	0.000	−0.63 – 0.63	1
Age	−0.01	−0.04 – 0.01	.31
Occupational history			
Ever worked in agriculture/farming	−0.41	−1.03 – 0.21	.19
Ever worked in industrial processing plant	0.63	−0.17 – 1.43	.12
Ever worked in power plant	−0.28	−1.20 – 0.64	.55
Ever worked in cement manufacturing	−0.50	−1.12 – 0.11	.11
Tobacco Use			
Current smoker	0.68	−0.32 – 1.67	.18
Previous smoker	−0.21	−1.08 – 0.66	.64
Exposure to potential arsenic sources			
Eat homegrown fruits/vegetables	0.54	−0.20 – 1.29	.15
Agricultural pesticides	−0.07	−0.78 – 0.64	.84
Arsenic treated wood	0.88	−0.96 – 2.72	.35
Soil exposures			
Gardening	−0.66	−1.56 – 0.24	.15
Digging	0.68	0.06 – 1.30	.03
Mowing	−0.06	−0.57 – 0.45	.80
Weeding	0.15	−0.51 – 0.81	.65
Pets that split time between indoors/outdoors	0.40	−0.37 – 1.17	.31
Outdoor sports	−0.03	−0.52 – 0.47	.92
Play with pets	−0.33	−1.17 – 0.51	.44
Residential soil concentration	0.003	0.002 – 0.004	<.001
Time at residence	0.007	−0.03 – 0.05	.72

B – Adjusted Regression Coefficient.
95% CI – 95% Confidence Interval.
p – *p* value.

in Table 2. An increase of 1 ppm of residence concentration was associated with a 0.003 μg/g (95% CI: 0.002– 0.004, $p < .001$) increase in toenail concentrations. Concentrations for respondents identified as Hispanic were 0.95 μg/g (95% CI: 0.04–1.9, $p = .04$) higher than for respondents identified as White. Concentrations for respondents who engage in digging were 0.68 μg/g (95% CI: 0.06– 1.3, $p = .03$) higher compared to respondents who do not engage in this activity. No respondents were exposed to well water.

Commonly reported diagnoses by a health-care professional included chronic lung disease (19%) and skin problems (19%). Three (4%) residents reported a cancer diagnosis (skin, lung, other). No significantly elevated rates of lung or bladder cancer were observed for the census tract or ZIP code. Although power to detect elevated rates was limited, especially for bladder cancer, there were fewer cases of each cancer than expected (i.e., SIR<1) in the census tract, based upon statewide rates adjusted for age and gender. The ZIP code-level SIRs for bladder and lung cancer were both numerically elevated (i.e., SIR<1.2), but the analysis did not have sufficient power to detect such small differences in rates.

Discussion and conclusion

Residing in an area with high soil arsenic contamination might lead to increased exposure (ATSDR 2017). Compared to baseline concentrations of 0.2 μg/g from previous studies in the region, the majority of residents exhibited elevated concentrations of toenail arsenic and some individuals contained extremely elevated levels (Johnson et al. 2011). As no participants were exposed to well water, these elevated concentrations likely originated from soil exposure. Increased residence soil arsenic concentration and engaging in digging were positively associated with elevated toenail concentrations, which would be expected given the potential to be exposed to soil containing higher arsenic concentrations. In addition, respondents identified as Hispanic displayed higher toenail arsenic concentrations than respondents categorized as White. Potentially this may have been the case due to unaccounted for exposure variables that were not captured in the survey.

It is crucial for persons to avoid exposure to arsenic-contaminated soil. Given the magnitude of the possible exposure to high soil levels and ongoing, extensive remediation, it was recommended immediately following the survey identifying potential factors associated with enhanced exposure that residents avoid further soil contact and move from the site until state-facilitated soil remediation was complete. All residents elected to move.

Previous studies demonstrated that individuals residing in areas near industries using arsenic compounds exhibited higher levels of arsenic than expected in the general population. (Kim et al. 2016; Ochoa-Martinez et al. 2016; Vimercati et al. 2016) Recommendations have highlighted the need for preventive measures to reduce exposure, as well as continued health status monitoring and biomonitoring of those exposed particularly children. (Kim et al. 2016; Ochoa-Martinez et al. 2016; Vimercati et al. 2016)

Individual toenail analysis results were shared with residents two months after the remediation commenced and residents had moved from the site for increased situational knowledge and to guide additional medical care seeking. An arsenic exposure reference document was distributed to area physicians at that time to assist with regular follow-up of residents. Public health authorities recommended ongoing resident health monitoring and repeat toenail biomonitoring within the following year to assess effectiveness of the public health intervention, further arsenic exposure, and changes in health status after moving off-site.

Limitations include use of toenail clippings, which are not a standardized metric for arsenic health outcomes. External contamination of toenails might also have contributed to elevated levels (Button et al. 2009; Hinwood et al. 2003; Slotnick et al. 2007). Public health recommendations cannot be made based upon these toenail levels alone, and the recommendations for moving were based upon soil levels. In addition, soil sampling was completed by a collaborating agency in order to guide the remediation process and was not necessarily collected in a way to assess only surface concentrations for human soil exposure. The depth at which samples were taken, sampling method, or analysis used was not dictated by us. Further, the strength of the association between soil concentration and toenail arsenic level may have been affected by variation in sampling depth.

One success of this public health response was the collaborative nature of multiple stakeholder agencies. The local health department contacted residents less than a week after the discovery of elevated soil arsenic level. Swift action taken by local and state health departments to assess factors associated with exposure to arsenic-contaminated soil increased rapport with the community and enabled quick data collection. This facilitated interventions to stop ongoing exposure including education regarding exposure risks and recommendations to move from site and enabled provision of recommendations for health-care follow up. In addition, toenail arsenic concentration provided residents another data point to consider when seeking health care follow up.

Public health implications

Exposure to arsenic may be costly because of the risk of cancers, including lung cancer. Estimation of individual monthly costs for lung cancer at diagnosis ranged from $2,687 to $9,360 (Cipriano et al. 2011). This public health investigation cost public health agencies approximately $6,000. This is a low-cost investment; if even one cancer is diagnosed earlier, there is potential for decreased morbidity and lifetime cost.

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Human Participant Protection

This public health response underwent Human Subjects Review by the Centers for Disease Control and Prevention and received non-research determination.

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