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Rural children's exposure to well water contaminants: Implications in light of the American Academy of Pediatrics' recent policy statement

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Introduction

In May, 2009, the American Academy of Pediatrics (AAP) issued a policy statement recommending that pediatric health care providers ask families whether they drink water from a well at home. They also recommend regular biologic and chemical testing of private wells that supply drinking water to U.S. children. The recommendations call for annual testing for nitrates and total coliforms and for less frequent testing for inorganic compounds, gross radioactivity, and lead (Rogan & Brady, 2009a). Policy justification was based on children's susceptibility to waterborne illnesses, the severity of illness resulting from children's ingestion of contaminated water, and the lack of regulation addressing private wells.

In general, children are more vulnerable to the health effects of waterborne contaminants than adults because they drink more water per kilogram of body weight, have a lifetime of potential exposure, and have immature metabolic pathways (aAAP Committee on Environmental Health, 2003a). For example, infants are particularly susceptible to developing methemoglobinemia from exposure to nitrates, due to their increased capacity to convert nitrate to nitrite and their decreased levels of cytochrome b5 reductase, an enzyme that converts methemoglobin back to hemoglobin (Faustman, Silbernagel, Fenske, Burbacher, & Ponce, 2000; Ward, et al., 2005).

Health effects from drinking water contaminants are diverse and depend upon the type of contamination. Bacteria, viruses, and parasites tend to cause gastrointestinal illnesses (bAAP Committee on Environmental Health, 2003b). This is particularly problematic in children who become dehydrated more quickly than adults when they have diarrhea (Rogan & Brady,

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2009b). Other contaminants, such as radon, arsenic, chromium, and trichloroethylene, are carcinogenic (bAAP Committee on Environmental Health, 2003b). Nitrates, as mentioned previously, can cause methemoglobinemia in infants (Ward, et al., 2005). Scientists are only beginning to study complex mixtures of drinking water contaminants and their additive or synergistic effects on health (Ryker & Small, 2008).

According to the Environmental Protection Agency (EPA), approximately 15% to 20% of households in the U.S. rely on private wells for their drinking water (EPA, 2006, 2008). Private wells are not regulated. Most states make testing of private wells the responsibility of homeowners, although homeowners frequently do not test their well water and if they do they do not necessarily correctly interpret the test results (Jones, et al., 2006; Shaw, Walker, & Benson, 2005). The results of focus groups and a direct-mail survey in Ontario, Canada indicated persons using private well water often believed their water quality was very good (Jones, et al., 2005). Direct mail respondents were concerned about bacterial and chemical contaminants but only 8% frequently tested their water (Jones, et al., 2006). Perceived high quality of well water, knowledge of what to test for and the costs associated with testing are often cited as reasons for not testing private well water (Jones, et al., 2006).

The National Water-Quality Assessment Program recently reported that more than one in five domestic wells sampled contained one or more non-microbial contaminants at a concentration greater than a human health benchmark. Microbial contaminants were detected in as many as one-third of a subsample of wells (DeSimone, 2009). Few studies report well water quality in the rural West among low income families. A recent study in Arizona sampled water from the wells of 10 small systems and 39 private individual wells (Marrero-Ortiz, Riley, Karpiscak, & Gerba, 2009). Forty three percent of the wells were positive for total coliforms, 16% for fecal coliforms and 4% for *Escherichia coli*. Thirty one percent of the wells contained arsenic above the current drinking water standard of 0.010 milligrams per liter. Per the AAP recommendation, common economic activities in the rural West (e.g. extractive mining, smelting, and agriculture), regional radon, and illegal dumping warrant water quality tests for metals, pesticides, radon and volatile organic compounds (See Appendix 1. Flowchart for Testing Well Water) (Rogan & Brady, 2009a). Many of these tests are prohibitively expensive for low income families.

The U.S. EPA suggests testing well water annually for total coliform, nitrates, dissolved solids and pH (EPA, 2002). Arsenic occurs naturally in well water in many regions of the U.S. Local health departments are a reliable source of information regarding what contaminants should be evaluated when testing well water. For example, in regions where there is a high level of agriculture, nitrates, pesticides and coliforms should be monitored in well water (EPA, 2009).

Limited information is available about well water quality among rural low-income families. Further, little is known about attitudes and protective actions employed by this population to abate risks. To elucidate contextual and logistical issues pertaining to the AAP recommendations, we report cross-sectional findings from an intervention study titled "Environmental Risk Reduction through Nursing Intervention and Education" (ERRNIE). The purpose of this paper is to report sample proportions from well water quality tests conducted for each household, precautionary actions taken by parents, and feasibility and risk communication issues that arose during the course of the study. This information is intended to provide primary care providers with practical advice they can use to help families obtain valid and actionable well test results.

Methods

The study population included low-income, rural families with at least one child under the age of seven living in one of two western counties in the United States. Participants were recruited through local health department contacts and community settings in Gallatin County, Montana (population 89,824, 26 person/sq. mi) and Whatcom County, Washington (population 196,529, 79 persons/sq. mi). Both counties have high growth rates (2000–2008 population increase = 32% for Gallatin County and 18% for Whatcom County) and have experienced significant demographic and socio-economic changes (i.e., gentrification) since 2000.

Inclusion criteria were: 1) household income level ≤250% federal poverty level, 2) plan to reside in current residence for the next year, 3) at least one child under age seven in the home, and 4) water from a non-municipal source (e.g. private well or community water system with fewer than 15 connections). The latter criterion was included to focus the study on families living on water systems with limited regulations for testing. Exclusion criteria were: 1) no family member who is able to read and speak English, 2) participation in the data collection of the pilot study, and 3) the presence of overriding severe health problems that would preclude the ability to participate in study activities.

The enrollment period extended from July, 2006 to December, 2009. Potential subjects were screened over the telephone using a script. If eligible, an appointment was set up for the initial data/sample collection visit. Consent forms and questionnaires were sent by mail before the visit. Study procedures were approved by the Institutional Review Boards of the two universities affiliated with the research.

Questionnaires were used to collect sociodemographic and health characteristic data from the primary adult and any children under age seven residing in the home. Respondents were asked to indicate their level of concern regarding multiple contaminants. The Precaution Adoption Process Model was used to explore respondents' stage of behavioral change in terms of taking precautionary actions to limit their children's exposure to contaminated well water (Weinstein & Sandman, 2002). Respondents were asked to indicate which stage they were in: 1) unaware of issue, 2) unengaged by issue, 3) decided not to act, 4) decided to act, 5) already taken action. Respondents were also asked to indicate if, in the past month, they had taken four specific actions to reduce contaminants: used a water filter, let water run before using it, switched to bottled water, and/or found out more about health risks from contaminated water. They were also asked whether they had ever tested their well water.

Trained data collectors, supervised by a water quality specialist, took water samples from the faucet of kitchen sinks after any in-home water treatment had occurred. If possible, aerators were removed prior to sampling. Faucet ends were disinfected with alcohol and the water was allowed to flow from the faucet for five minutes prior to sampling. With the exception of microbiological samples in Washington, samples were placed into insulated shipping containers with frozen ice-packs and sent via overnight transit to the Montana State Public Health Laboratory, Helena, Montana. Microbiological samples in Washington, and any follow-up microbiological samples in both counties, were taken immediately to a state- and EPA-approved local laboratory to ensure analysis within 30 hours of collection. Sample collection, storage, and handling were in accordance with standard methods for drinking water analyses, Standard Method 1060 –Collection and Preservation of Samples, and Standard Methods 9060A and B –Collection and Preservation and Storage, respectively, of samples for microbiological examination (American Public Health Association, 1998). Sample bottles were provided by the laboratory for each group of tests performed, along with detailed instructions regarding how to fill the different containers and holding times (American Public Health Association, 1998).

Water samples were analyzed for the full range of regulated contaminants. Threshold values used to interpret water quality results were based on the Maximum Contaminant Levels (MCL) set forth in the National Primary Drinking Water Regulations (USEPA, 2002). A more stringent standard was used for naturally occurring fluoride (2 mg/L) and nitrate if the water was being consumed by a formula fed infant less than six months old (5 mg/L as N). Pesticides, herbicides, and volatile organic compounds were grouped as synthetic organic compounds (SOC) and the threshold for action was any SOC present.

A water quality decision tool was developed for use by study staff to determine follow up actions for abnormal results. For example, if the initial sample taken by our staff was positive for total coliforms, we immediately contacted the family to let them know the results, the recommended course of action, and instructions on how to collect a water sample (materials provided) and deliver it to a laboratory previously established to perform repeat testing. Follow-up for results without possible acute health effects was performed by study staff or the local environmental health department in each county.

Descriptive statistics for categorical data are presented as frequencies and percents and for continuous data as means and standard deviations. The Chi-square test was used to examine the associations between prior well testing and action with demographic variables (level of education, income, and homeowner status). T tests were used to compare means for continuous demographic variables (age, years of education) between prior well testing and action groups. All significance testing was performed using SAS (9.1) software (Cary, NC). Two-sided p-values are reported.

Results

Sixty six percent of those households referred to the study were eligible to participate. Of those, 59% enrolled in the study. Baseline data were collected on 188 households, which included 188 primary adult respondents and 320 children (Table 1). In general, primary adult respondents were non-Hispanic, white women who had completed high school. A little over half owned their home and reported an annual household income between $25,000 and $49,999. Most had private health insurance, although a significant number had no health insurance or were on Medicaid. Like their parent, most children were non-Hispanic and white. A little over half of the children were covered under private health insurance, and approximately one third were enrolled in Medicaid. Among those children that were 12 months old or younger, 41% were fed either formula (27%) or a combination of formula and breast milk (14%).

About 27% of homes had at least one contaminant present in their water at levels beyond the stated thresholds, and 3% had two contaminants present. In order of frequency, abnormal contaminant results identified include (Table 2): total coliforms (18%), arsenic (6%), synthetic organic chemicals (6%), nitrates (2%), fluoride (2%) and *E. coli* (<1%). No samples were positive for copper or lead. Synthetic organic chemicals that were detected included (number of households where contaminant was detected): trihalomethanes (2), petroleum product present of an unknown type (2), aldrin/dieldrin (1), picloram (1), chlordane (1), phthalic anhydride (1), bis (2 ethylhexyl) phthalate (4). All were detected in trace amounts less than the MCLs. Repeat test results for microbial contaminants demonstrated that 89% of the households that were re-tested due to positive coliforms (n=27) were positive on the re-test (n=24).

Prior to testing, respondents were asked their level of concern regarding multiple contaminants or sources of contaminants in their drinking water (n varied between 185 and 188). In order of frequency, respondents were most concerned about contamination from bacteria/germs (n=188, 85%), nitrates (n=185, 78%), their own septic system (n=186, 68%), pesticides (n=185, 66%), their neighbor's septic system (n=185, 58%), lead from their pipes (n=187, 55%), and arsenic (n=187, 51%).

When asked about taking precautions to limit their children's exposure to contaminated well water (n=182), only a few respondents reported that they were undecided (2%) or had decided not to take precautions (2%). Approximately one quarter had never thought about taking precautions (24%). Most respondents replied that they had either decided to take action (48%) or had already taken action (24%).

Demographic variables, including age (33.3 vs. 32.6 years), level of education (years of school: 14.3 vs. 13.8 years), level of income (<25K vs. 25–50K vs. >50K: 70.2%, 73.5%, 75.8% reported action) and homeowner status (own vs. rent: 71.1% vs. 75.4% reported action) did not significantly differ between those who had either decided to take action or had taken action and those who were undecided, decided not to, or who never thought about taking precautions (all statistically non-significant, p-values not shown).

When all respondents were asked about four specific actions they had taken in the past month (n varied from 156–186), the most frequent affirmative response was that they used a water filter (n=182, 44%) (type of filter was not specified). A substantial proportion also reported that they had let the water run for a few minutes in the morning before using it (n=181, 39%), and/or had switched to bottled water (n=182, 35%). Few affirmatively replied that they had tried to find out more about health risks (n=181, 17%). Few indicated that they had taken any other action (n=156, 15%) in the past month. Approximately one third (n=186, 31%) of respondents reported that they had (ever) previously tested their well water for contamination. Higher levels of education, income, and age, as well as homeowner status, were significantly associated with previous well water testing (Table 3).

Discussion

The AAP policy statement is timely given the recent focus on children's environmental health and initiation of the National Children's Study (U.S. Department of Health and Human Services, 2010). This study helps to decrease the gap between understanding citizen perceptions of well water contamination and measured contamination in the areas studied. Respondents' concerns about microbials were well aligned with the detection of total coliforms, relative to other contaminants, and coincided with a recent study suggesting that private well use was associated with an increased rate of enteric infections in children (Denno, et al., 2009). Likewise, respondents' lack of concern for lead contamination was consistent with the low level of lead detected in the water. In contrast, respondents were not particularly concerned about arsenic relative to other contaminants, yet high arsenic was detected second only to coliforms in frequency. Even in an arsenic hot spot, 40% of survey respondents in another study were not concerned about arsenic in their water (Shaw, et al., 2005). Respondents in this study did report concern about nitrate contamination, although few households tested positive for nitrates above the current MCL. There is, however, continued study and debate in the scientific community regarding nitrate's MCL, with some suggesting that it is too conservative and others arguing to lower it (Ward, et al., 2005).

Microbial and chemical contaminants found in sampled wells for this study were relatively low compared with national level data (DeSimone, 2009; EPA, 1984, 1990) (Table 4). Arsenic was an exception and was found at rates similar to findings in the National Water-

Quality Assessment Program. The lower proportion of microbiological and nitrate contamination detected may be related to the changing landscape (from agriculture to housing) in the counties where the households were tested. However, while only 2 percent of the wells sampled had nitrate levels greater than the drinking water standard of 10 mg/L as N, 11 percent had values greater than 5 mg/L, a level indicative of contamination from human sources since natural nitrate levels rarely exceed 2 mg/L as N (Mueller & Helsel, 1996). Arsenic, a naturally occurring contaminant, would not be expected to change based on changing land practices. Low detection of copper and lead contamination is likely related to the fact that first draw samples were not taken.

The number of contaminants that co-occurred with at least one other contaminant in this study was similar to national estimates, 3% and 4% respectively, although the national estimate excluded microbial contaminants and used a higher threshold for fluoride. Strikingly, the U.S. Geological Survey found that 73% of wells sampled had mixtures of two or more contaminants at concentrations greater than one-tenth of their human-health benchmarks (DeSimone, 2009). Risk communication is complicated by the fact that little is known about the health effects of chemical mixtures (Carpenter, Arcaro, & Spink, 2002).

Most families had never tested their well water and many had never thought about taking precautions. Results suggest that young families with lower incomes and less education, as well as renters, are least likely to have ever tested their well water. Interventions should be targeted to these subpopulations to enhance regular well water testing.

Almost half of respondents reported that they had decided to take precautions to limit their children's exposure to contaminated water, and approximately one quarter reported that they had already taken some sort of action. This is hopeful considering over 40% of respondents' children are formula fed. However, many of the protective actions taken have limitations related to impurity abatement or significant cost/access concerns, highlighting the complexities associated with preventing and mitigating environmental health risks from well water contamination (Rogan & Brady, 2009b). The EPA has a website called "Private Drinking Water Wells" that outlines precautions families can take to ensure the protection and maintenance of their drinking water supplies (EPA, 2006).

Implications for Practice

Findings have implications for providers in terms of communicating and interpreting results to families. Sources of contamination, variable action levels, and recommendations for further testing are confusing issues for families. Well water contamination is complex and highly variable. For example, bis (2-ethylhexyl) phthalate was detected at levels above the MCL (0.006 mg/L) in several homes. The most likely source is polyvinyl chloride pipe or other plastic components in the water system serving the home, such as components of a water softener. When water tests positive for total coliforms the source can be the water coming from the well or it can be from bacteria growing on the surfaces of pipes in the home's plumbing system (Besner, Gauthier, Servais, & Camper, 2002). Explaining to families that contamination may come from the well itself, reflecting contamination in the groundwater, or the home's plumbing is important when considering mitigation options.

Families need clear explanations regarding developmentally appropriate action levels and other sources of exposure. EPA MCLs, state standards, and precautionary action levels are confusing in that relevant action levels are dependent on the population drinking the water and other exposure sources of the contaminant. For example, the MCL for fluoride is too high for water being consumed by children less than nine years of age, since fluoride at that level can damage children's teeth (EPA, 2006). Thus the secondary MCL (2 mg/L) was used to evaluate risks for young children. Even at this level, risk of adverse effects is still dependent on the child's nutritional status and fluoride from other sources, such as ingestion of fluoridated toothpaste.

Recommendations for further testing are dependent on the contaminant. While the presence of coliforms does not mean that pathogens are present, the absence of coliforms is not "absolute evidence" that fecal contamination is not present (Rogan & Brady, 2009b). For example, a coliform test will not detect the presence of viruses. It was useful to explain to families that further testing allows more information to be gathered upon which to make an informed decision on a plan of action. In the mean time, recommendations were made such that families take precautionary action including using water from another source and disinfecting the well and home plumbing system using sodium hypochlorite (bleach) (Gallatin Local Water Quality District, 2003; Minnesota Department of Health, 2009). Although chlorination takes time and may yield undesirable byproducts, it is a low cost, protective way to eliminate pathogenic bacteria and viruses unless, of course, the ground water itself is contaminated. In cases where the ground water is contaminated and the source of contamination cannot be identified, most homeowners have limited choices that do not involve significant financial outlays for alternatives such as drilling a new well, installing home treatment systems or purchasing bottled water.

Interpreting results for arsenic may be more straight-forward. Arsenic is a well-established carcinogen. However, adverse effects are chronic and mitigation is expensive, thus appropriate actions are less clear. Again, recommendations must take into account the economic reality of the family, such that if they cannot afford an arsenic removal system, a more practical solution may be to collect water from a municipal source. Discussions about health risks were difficult when the result was just below the action level. Recommendations were made to stop using the water from a professional standpoint, and explanations were given about the increased risks associated with a lifetime of exposure of contaminated drinking water.

Finally, the one third of participating families that rented their homes had to consider whether or not to inform their landlords of abnormal results. Resource-poor families have few housing options and could face eviction if their landlord-tenant relationship is stressed. That said, if nothing was done, the possibility that another family could move in and their children may face the same risks had to be considered. These situations were handled on a case-by-case basis, often working with the local health department's environmental health staff.

Limitations

Findings from this study provide a snapshot of well water contaminants present in two Western counties in the U.S. Cross sectional data is limiting in that it does not capture changes over time. Future analyses will examine whether attitudes and actions changed in response to the results reported to families from the household testing conducted in this study. Second, the sample was not randomly selected, thus the findings are not generalizable. However, the findings provide insight into behavioral, contextual and logistical factors associated with testing private wells and communicating risk. Third, the lack of first draw samples most likely precluded detection of lead and copper. Future studies will assess the source of water used for drinking and preparing formula, the type of water filter reportedly being used, and any follow up actions taken among those respondents that reported previous testing.

Conclusion

This study enhances understanding of the level and types of precautionary actions taken by a select sample of low-income families on private wells to protect their children against the health effects of drinking water contaminants. Detection of most contaminants was low with coliforms and arsenic being the most frequently detected. Families were concerned about the presence of bacterial contaminants but were not so concerned about arsenic. Few families routinely test their well water. Sociodemographic factors are associated with regular well water monitoring. To implement the AAP recommendations and promote children's environmental health, families, health care providers, and public health professionals will need to work together to understand the complexities associated with testing, interpreting and mitigating well water contamination. However, within these caveats, the policy represents a proactive approach to children's environmental health and will inevitably strengthen connections among primary care providers, public health personnel, and local water quality laboratories.

Abbreviations

AAP	American Academy of Pediatrics
EPA	Environmental Protection Agency
ERRNIE	Environmental Risk Reduction through Nursing Intervention and Education
MCL	Maximum Contaminant Level
SOC	Synthetic Organic Compound

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Table 1

Characteristics of the study population.

Characteristics	Primary Respondents (Total n=188)	Children Living in Home (Total n=320)
Age at Enrollment: Mean (Range)	33.1 (18 – 53)	3.0 (2 weeks – 6.9 years)
Gender (%)		
Male	7	49
Female	93	51
Hispanic Ethnicity (%)		
No	95	91
Yes	5	9
Race (%)		
Am. Indian/Alaska Native	4	3
Asian	<1	0
Black or African American	<1	0
White	92	92
Other	3	0
More than one race	<1	5
Health Insurance (%)		
Medicaid	15	29
Private	55	55
None	22	6
Other	3	7
Not known	0	<1
Highest Level of Education (%)		
Grade school or Junior High	1	
High School	26	
Trade School or College	63	
Graduate school	10	
Income in the Past Year* (%)		
0 – $24,999	27	
$25,000–$49,999	55	
$50,000 or >	18	
Homeowner Status (%)		
Own home	55	
Rent home	34	
Other	11	
Description of Child’s Diet among Children aged 12 months or younger (%)		
Both breast milk and formula		14
Breast milk		58
Formula		27

*Income was left blank by four respondents. Income eligibility was verified prior to enrollment.

Table 2

Prevalence of well water contaminants.

Contaminant	Abnormal Threshold	Percent Abnormal (95% CI) *	Range
Coliforms	any present	18 (12, 23)	
E. coli	any present	<1 (0, 2)	
Nitrates (mg/L)	> 10 mg/L**	2 (0, 4)	12.8 – 15.4 mg/L
Lead (mg/L)	> 0.015 mg/L	0	
Copper (mg/L)	>1.3 mg/L	0	
Arsenic (mg/L)	>0.01 mg/L	6 (3, 10)	0.012 – 0.07 mg/L
Fluoride (mg/L)	> 2 mg/L	2 (0, 4)	2.12 – 7.85 mg/L
SOCs	any present	6	

SOCs synthetic organic chemicals

* n = 188, except n = 165 for fluoride. After study initiation the laboratory changed their protocol to include fluoride in their battery of tests.

** > 5 mg/L for any formula fed infant less than 6 months in household

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Table 3

Associations between demographic attributes and respondents who reported previous well water testing

Attribute	Previous Testing	No previous Testing	Test Statistic	p-value
Age: Mean (SD)	35.5 (6.3)	32.1 (6.6)	t=3.31, df=184	0.0011
Education: Mean (SD)*	14.85 (2.2)	13.9 (2.3)	t=2.94, df=184	0.0037
Income in the Past Year: **	n=56	n=126	χ^2 = 9.4, df=2	0.0092
0 – $24,999	17%	83%		
$25,000–$49,999	32%	68%		
$50,000 or >	48%	52%		
Homeowner status***	n=57	n=129	χ^2 = 23.1,df=1	<0.0001
Own home	42%	58%		
Rent home	8%	92%		

SD=standard deviation

*Education was also evaluated as a non parametric statistic, p-value was < 0.01.

**Income was left blank by four respondents. Income eligibility was verified prior to enrollment.

***Based on reported income and respondent descriptions, those respondents in the category of “other” were reclassified as homeowners.

Table 4

Comparison of contaminants found exceeding human health benchmarks in ERRNIE study with national studies.

Contaminants (Abnormal threshold)	DeSimone* (2009)	NSA (1984)/ NPS (1990)	ERRNIE
Total coliforms (any present)	33.5	42.1	18
E. Coli (any present)	7.9	19.8	<1
Nitrates (>10 mg/L as N)	4.4	4.1	2
Lead (>0.015mg/L)	<1	n/a	0
Copper (>1.3 mg/L)	0.06	n/a	0
Arsenic (Varies)	0.6 (>50μg/L)	0.8 (> 50μg/L)	n/a
	6.8 (>10μg/L)	n/a	6 (>10μg/L)
Fluoride (>2 mg/L)	4	n/a	2
Pesticides/Herbicides (varies)	3 (> 0.2 μg/L)	4.2 (NPS)	4 (> 0.2 μg/L) 6 (any present)

NSA National Statistical Assessment of rural water conditions

NPS National Pesticide Survey

ERRNIE Environmental Risk Reduction through Nursing Intervention and Education

*Samples collected directly from the well.