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REVIEW ARTICLE

Perspectives from the Society for Pediatric Research: contaminants of water and children's health: Can we do better?

Kamil Evy A. Bantol[1], Heather L. Brumberg[2], Shetal I. Shah[2] and Joyce R. Javier[3]

Children are uniquely susceptible to the health consequences of water contamination. In this review, we summarize the existing, robust literature supporting the importance of examining specific water contaminants (i.e., lead, pesticides, nitrates, arsenic, perchlorate) and the routes of contamination in the United States and globally. We also discuss the health effects of exposure to contaminated water and significant disparities related to access to clean water. Lastly, we offer strategies for prevention and intervention—including those focused on the individual patient level—and review the current US policy framework pertaining to regulation of these toxicants.

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IMPACT:

- A key message in this article is that exposure to water contaminants have serious and long-lasting consequences on children's health.
- This review summarizes current existing literature and adds policy recommendations supporting clean water for children.
- Information from this review has two potential impacts:
  - Guide health professionals in screening and/or treating children's health problems resulting from water contaminant exposure.
  - Guide policy makers in using evidence-based approaches to improve water quality and clean water access.

INTRODUCTION

Providing safe drinking water is a challenge both in the United States and globally. The World Health Organization (WHO) 2017 report on drinking water, sanitation, and hygiene showed that three in ten people globally lack access to clean water at home.[1] In the United States, safe drinking water is generally available in most areas.[2] However, analysis of violations to the Safe Drinking Water Act indicated that 9–45 million Americans were exposed to contaminated water between 1982 and 2015.[2] Events such as the Flint water crisis further highlight that, despite widespread availability of high-quality drinking water in the United States, more work is needed to provide safe drinking water in all communities.

Several sources of water contamination exists (Fig. 1).[3] Agriculture and urbanization significantly contributes to water pollution (Fig. 2). Runoff from farms, ranches, or animal feeding operations may contain chemicals derived from the excessive use of fertilizers and pesticides.[4] These chemicals can impact water quality, particularly in nearby rivers, lakes, and groundwater.[4] Increasing population density, a consequence of greater urbanization, also contributes to pollution.[5] Wastewater from buildings, households, and construction contain contaminants that may be discharged into groundwater or surface waters if incompletely removed by water treatment plants.[5]

Children are uniquely susceptible to the health consequences of contamination. Compared to adults, children have a higher likelihood of exposure since they consume more food and water in proportion to their body weight.[6] Stages of development also play a role in children's vulnerability to contaminants. For example, young children may be at higher risk of coming in contact with or ingesting chemicals when they are teething, putting objects in their mouth, or crawling on the ground.[7] Prenatally, exposures during crucial periods of organ development may increase their vulnerability to congenital anomalies. Postnatally, central nervous system development is affected, with animal studies showing effects on synaptic plasticity, neuronal numbers, neuron migration, and myelin deposition.[8] These factors increase children's susceptibility to the health effects of water contamination, thereby placing them at higher risk for long-term disease, disability, and death.[6,9]

The purpose of this review is to summarize the literature regarding the health outcomes of lead, pesticides, arsenic, nitrate, and perchlorate contamination of water. We summarize water standards for these chemicals by the WHO,[10] Environmental Protective Agency (EPA),[11] and Health Canada[12] (Table 1). We also discuss current policies and prevention and research opportunities that may guide pediatricians and policy makers in addressing environmental risks (Table 2). Although a wide range of contaminants can be found in water, we focus on select chemicals given their mechanisms of contamination, important implications in childhood exposure and health effects, and potential for

[1]Division of General Pediatrics, Children's Hospital Los Angeles, Los Angeles, CA, USA; [2]New York Medical College, Maria Fareri Children's Hospital at Westchester Medical Center, New York, NY, USA and [3]Division of General Pediatrics, Children's Hospital Los Angeles, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA
Correspondence: Joyce R. Javier (jojavier@chla.usc.edu)

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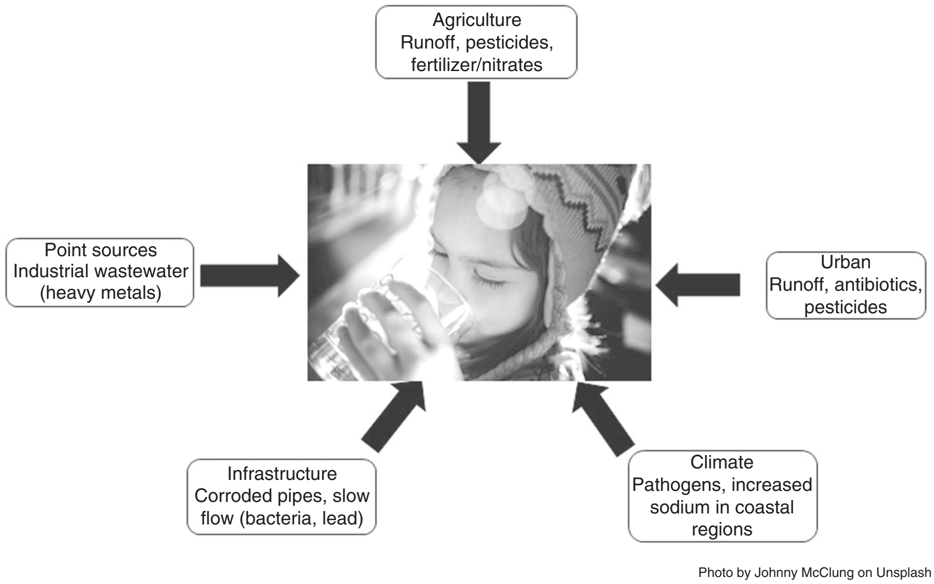

Fig. 1 Sources of water contamination. Waste from agriculture, urbanization, climate, infrastructure, and point sources contribute to contaminants found in drinking water.

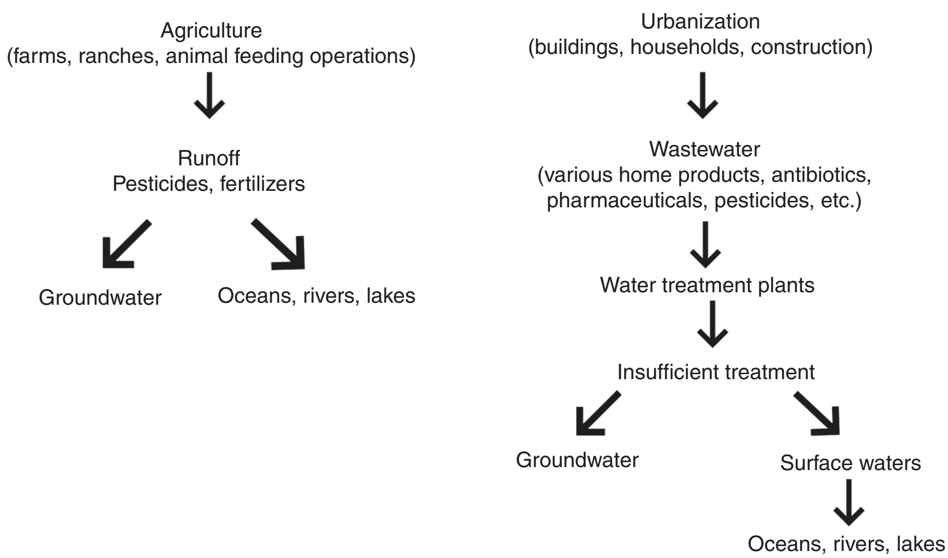

Fig. 2 Routes of water contamination. Flow chart depicting how contaminants from agricultural and urban areas end up in various bodies of water.

prevention of exposure via policy change. Information on other types of water contaminants can be found in other resources.[13] We also focus on exposures most relevant to children living in the United States.

SELECT CONTAMINANTS AND THEIR HEALTH OUTCOMES

Lead

Children are exposed to lead through various sources. These include drinking water, chips from old paint, toys, toy jewelry, playing in fields with lead-contaminated dust or soil, and imported products such as candy. The presence of other metals also plays a role in lead exposure. Among infants aged 6 and 12 months, low calcium, iron, and zinc blood levels were associated with increased lead absorption.[14] In adults, bone turnover during pregnancy, breastfeeding, and periods of calcium deficiency releases stored lead into blood, thereby affecting both maternal and fetal blood lead levels (BLLs).[8,14]

The EPA estimates that 20% of total lead exposures in the United States occur due to water consumption.[15] In infants, estimates can be as high as 60% since tap water is frequently used to reconstitute formula.[15] For example, a case study described an infant with plumbism due to daily intake of powdered formula that was prepared with home tap water having a first-draw lead content of 130 parts per billion (p.p.b.).[16] School-age children may also be at particular risk for lead exposure, given that only 10% of schools nationwide are required to comply with the EPA's standards for water lead levels.[17]

The presence of lead in drinking water can be attributed to plumbing materials used in cities and buildings.[15] As water leaves treatment plants, it travels through lead-based materials such as pipes and solder. Water fountains and faucets found in buildings and homes also contain equipment made from lead. The EPA mandates that anti-corrosive chemicals must be added in water to prevent these materials from oxidizing.[18] However, failure to use chemicals to control corrosion, such as the case in Flint, Michigan,

Table 1. Standards for acceptable contaminant levels.

Contaminant	World Health Organization	Environmental Protection Agency	Health Canada
Lead	10 μg/L	15 μg/L	5 μg/L
Atrazine	100 μg/L	3 μg/L	5 μg/L
Arsenic	10 μg/L	10 μg/L	10 μg/L
Perchlorate	70 μg/L	—	—
Nitrate	50 mg/L	10 mg/L	10 mg/L
Nitrite	3 mg/L	1 mg/L	1 mg/L

Notes: WHO standards for arsenic, lead, and perchlorate are provisional guidelines based on treatment performance and should not be used as health-based guidelines. The EPA's standard on lead is based on the Lead and Copper rule, which sets the action level at 15 μg/L. If 10% of tap water sampled from various homes exceed this level, actions such as public health education, additional corrosion control, and service line replacement are required.

can cause leach from lead service lines, lead solder, and brass fittings.[15,19]

There are currently no known safe BLLs. At levels of exposure below 5 μg/dL, sufficient evidence shows that children experience decreased academic achievement, lower intelligent quotient (IQ) scores, and increased risks for attention-deficit/hyperactivity disorder.[20] At <10 μg/dL, exposure can result in delayed puberty, reduced postnatal growth, and hearing difficulties.[20] Early-age lead exposure is further associated with various types of antisocial behaviors, with studies documenting a link between blood or bone lead concentrations and aggression, conduct disorder, and delinquent or criminal behaviors.[20] Finally, at levels >10 μg/dL, multiple organ systems are affected, which can result in anemia due to heme synthesis disruption, abdominal pain, vomiting, poor nerve function, and loss of muscle control.[3]

Exposure during pregnancy has implications for both maternal health and infant development. Lead exposure is also linked to spontaneous abortions, stillbirth, and preterm labor, particularly at levels above 10 μg/dL.[21–23] Relative to 0 μg/dL, maternal BLLs even at <5 μg/dL are associated with adverse birth outcomes, including reduced infant growth and low birth weight.[21,24] Effects on neurodevelopment are also well documented, with studies linking maternal BLL above 5 μg/dL during the first trimester to lower scores on the Neonatal Behavioral Neurological Assessment and Child Development Inventory.[25,26]

Pesticides

Pesticide contamination of drinking water can be attributed to its widespread use in homes and agriculture. For example, runoff from farms or gardens enter streams that may feed into water supplies.[27] Pesticides can also seep into the soil where they eventually come in contact with groundwater.[27] Although the ingestion of pesticides is predominantly from foods that have been treated with them, people may be exposed to pesticides (i.e., insecticides, herbicides, and fungicides) in some water supplies given that they may not be removed by conventional drinking water treatment technologies.[28] In a 10-year study by the US Geological Survey, pesticides were found in over 50% of sampled wells from shallow groundwater tapped beneath agricultural and urban areas with atrazine, a herbicide being the most frequently detected pesticide group in agricultural areas.[29]

When acutely exposed to pesticides, symptoms include nausea, vomiting, eye irritation, coughing, and shortness of breath.[6] Long-term exposure can result in adverse health effects.

Prenatal exposure to pesticides is associated with poor cognitive function in school-aged children,[30] lower scores on tests that examined working memory, reasoning, comprehension and IQ among Latino agricultural families,[31] and higher rates of autism spectrum disorder.[32] Aside from neurological effects, pesticides can affect musculoskeletal development. Recent evidence suggests that maternal exposure to agricultural pesticides increases the risk of abdominal wall birth defects such as gastroschisis.[33]

Arsenic

The element arsenic is a widely distributed metalloid in the environment.[34] Existing as either organic, inorganic, or gaseous compounds, arsenic can be found in soils, rocks, food, water, and air.[34] Release of arsenic into the environment occurs through both natural and human processes. Natural processes include erosion of ores and sediments, volcanic eruptions, and the flow of groundwater through shallow aquifers containing high levels of arsenic.[34,35] In the latter case, mining and commercial use contribute to arsenic dispersal in the environmental.[36] Geography also contributes to arsenic levels. Drinking water supplies in the southwestern United States have particularly high levels of arsenic, likely due to factors such as irrigation, pH, reducing conditions, and climate that increase the solubility of arsenic in groundwater.[37,38]

Although arsenic is a known occupational hazard, water intake usually serves as a source of exposure. Infants and school-age children may be at particular risk for arsenic exposure. A report by the Environmental Integrity Project indicated that several California school districts were found to have high levels of arsenic in their water.[39] In infants, exposure depends on whether the child is breast- or formula-fed. Breastfed infants have lower arsenic exposure than formula-fed infants[40] and the use of tap water in formula has been associated with increased arsenic levels in 6-week-old infants.[40] Prenatal exposure may also occur since arsenic readily crosses the placenta.[41]

While the WHO considers its organic form as non-toxic, inorganic arsenic is associated with negative health outcomes that affect a wide range of organ systems.[42,43] For example, issues stemming from chronic arsenic exposure include dermal issues (hyperpigmentation, keratosis, and skin lesions) to hypertension and peripheral neuropathy.[43] The International Agency for Research on Cancer also considers inorganic arsenic compounds to be carcinogenic. Numerous studies have documented a strong association between arsenic exposure with skin, urinary bladder, and lung cancers, particularly among individuals exposed through elevated arsenic in drinking water.[43] Furthermore, exposure to arsenic impacts cognitive function. For example, arsenic levels above 5 μg/L resulted in lower IQ scores among children grades 3–5 living in Maine.[44]

Prenatal exposure also has various consequences, particularly on birth outcomes, development, and epigenetics. Studies have shown that increased maternal urinary arsenic levels are associated with respiratory problems in infants 12 months or younger[45] and lower birth weights among females born to obese mothers.[46] Additionally, in an analysis of cord blood samples, changes in DNA methylation and messenger RNA expression in genes encoding for binding transcription factors were associated with high maternal urinary arsenic levels.[47] These epigenetic changes have implications on birth outcomes (e.g., preterm birth) and long-term health (e.g., higher mortality and cancer).[47,48]

Perchlorate

Perchlorate is used as an oxidizing agent in rocket fuel, explosives, fireworks, road flares, or may occur naturally in groundwater or soil.[49,50] Additionally, perchlorate may be found in drinking water from bleach (hypochlorite) degradation as bleach is used to disinfect drinking water.[51] Human exposure may occur from water contamination, in vegetables via water or fertilizer, or cow and human milk, and can be assessed by spot urine analysis.[49] Analysis of the Food and Drug Association's Total Diet Study determined

Table 2. Strategies for prevention at the individual and policy level.

Contaminant	Recommendations: Individual level	Recommendations: Research/policy level
Lead	1. Pediatricians should screen asymptomatic children based on requirements at the federal, local, and state level and based on risk factors[21] 2. Pediatricians can review all possible sources of lead when conducting their histories, including dust and paint in the home or child care settings, whether the home was built before 1978, contaminated soils, lead-lined water pipes, and traditional remedies (e.g., Azarcon in Hispanic and Ghasard in Indian communities)[113] 3. Homes with possible lead hazards should be inspected and repaired[113] 4. Hand washing in children should be emphasized to remove lead dust[113] 5. Caregivers should remove shoes/workplace clothing before entering house and launder the work clothing separate[21] 6. If there is concern about lead in tap water, caregivers should run cold water for 1–2 minutes before formula preparation[21]	• Reduce exposures by reducing the Dust Lead Health Standard to 10 μg/ft^2 for floors and 100 μg/ft^2 for window sills under authority grant via the Toxic Substances Control Act[114] • Reduce the lead action level to trigger public health intervention by the Centers for Disease Control and other public health agencies to 3.5 μg/dL[87]
Pesticide	1. Pediatricians should recommend families to avoid use of pesticides by using baits, traps, or gels instead of spray and dusts[6] 2. If possible, families can consider purchasing organic produce, particularly fruits and vegetables that are known to have high levels of pesticides (strawberries, spinach, potatoes, etc.)[6] 3. Washing hands with soap and water after playing outdoors and before meals is recommended[6]	• Federal prohibition of chlorpyrifos with strong enforcement[115] • Strong enforcement of existing prohibitions on use enacted at the state level[93] • Add assessments of new pesticides and others not yet studied[29]
Arsenic	1. Pediatricians should recommend families to wash their hands before eating, limit contact with soil, prevent children from putting objects in their mouth, and store chemicals out of children's reach[116] 2. In areas with water arsenic levels above the recommended limit, pediatricians may also advise families to switch to cleaner water sources[116] 3. It is also important to note that unlike lead, some toxic chemicals, such as arsenic, are not easily transferred via breastmilk	• Setting of a maximal permissible level of inorganic arsenic in rice and rice-containing products[100]
Perchlorates and nitrates	1. Test well water for perchlorate and nitrates[117] 2. Optimize thyroid function by preventing iodine deficiency via adequate intake via diet (including iodized salt and avoiding processed foods) and vitamins[117] 3. Increase dietary intake of antioxidants, such as vitamin C and polyphenols, to mitigate nitrate effects[60] 4. On a broader, community level, perchlorate and nitrate can be decreased by water treatment through strategies, such as reverse osmosis or anion exchange[51,118] 5. Another key strategy would be avoidance of Chilean fertilizer and preventing contamination from fireworks or rocket fuel.[51] 6. Increase awareness of methods for use and storage of bleach for treating water, which can degrade into perchlorate. Safer bleach is kept in cool temperatures, out of direct sunlight, diluted, and maintained at well controlled pH between 11 and 13. It is also best to avoid use of older bleach products[51]	• Create a national standard for safe perchlorate levels in drinking water[104] • Robust federal testing of public and private water sources for nitrates[108] • Emulate the European Nitrate Directive and designate "nitrate-vulnerable areas" subject to strict enforcement/ regulation of agricultural practices[60] • US$600,000 of proposed federal funding to provide technical support to states to prioritize areas at high risk for nitrate contamination[109]
All contaminants	1. If further support is needed, pediatricians should refer to Pediatric Environmental Health Specialty Units (PEHSUs). Available throughout all US regions, PEHSUs have environmental health experts who can provide consultations and educational resources to families.[119]	• Legislation requiring the EPA to issue comprehensive regulations on >10 contaminants per year to prevent bureaucratic delays[103]

that 74% of food samples tested had detectable amounts of perchlorate.[52] Furthermore, the source of exposure by age was highest with baby food and formula/dairy products in infants 6 months to 11 months, dairy products in children 2, 6, and 10 years, and vegetables and dairy in adolescents and adults.[52]

In US residents 6 years and older, based on data from the National Health and Nutrition Examination Survey, Blount et al.[49] found that all subjects had detectable amounts of perchlorate, suggesting pervasive exposure to at least small amounts. Interestingly, there were little differences by race and ethnicity.[53]

Perchlorate competitively inhibits thyroid uptake of iodide via the sodium-iodide symporter.[54] It is the same symporter expressed in human mammary tissue that allows perchlorate to enter human milk.[49] Perchlorate has a much higher affinity for the symporter than other substances, which may inhibit thyroid uptake of iodine (i.e., nitrates).[51] Exposure of women at least 12 years of age to perchlorate has also been linked to increased thyroid-stimulating hormone, regardless of intake of iodine and decreased total thyroxine levels when intake of iodine is <100 μg/L.[55] This effect on thyroxine level in women of reproductive age could translate into the fetus and infant impact, especially in breastfeeding infants, as lower thyroid hormone levels in mothers have been associated with lower IQ and poorer neurodevelopment in their progeny.[51] This is due to the fetus in the first trimester being dependent on maternal thyroid hormones for proper development. Exposures at other times of fetal or early childhood also impact growth.[56] Taylor et al.[57] found that mothers with suboptimal thyroid function with perchlorate levels in the top 10% had a higher risk of having offspring with lower IQ at 3 years of age, especially verbal IQ, irrespective of levothyroxine therapy.

Nitrates

Nitrates can be found in well water as a result of human or animal waste and fertilizer contamination of the water.[58,59] It can also occur when excess nitrogen is deposited via fossil fuel combustion and nitrogen-fixing plants, including soybeans.[60] About half of the nitrogen deposited in land and used in agriculture moves to surface and groundwater.[60] The maximum contaminant levels are monitored in public water supplies, but potentially less closely monitored with private wells.[60,61]

Nearly 14% of the US population has private wells, with 6% of these having elevated nitrate levels in comparison with 2% elevated nitrate levels in public supply wells.[60] The location of the well is also important: 21% of the private wells in agricultural regions had elevated levels in comparison with 6% of private wells overall.[60]

One of the primary concerns related to high levels of nitrate (NO_3^-) is methemoglobinemia in infants.[61] Methemoglobin is formed in the presence of nitrites (converted from ingested nitrates) and leads to methemoglobinemia when it is >10% of all the hemoglobin.[34,61] Babies 4 months and younger are especially susceptible to nitrate-induced methemoglobinemia since fetal hemoglobin more easily oxidizes into methemoglobin.[34]

Nitrates compete with iodine uptake by interfering with the sodium iodide-symporter in the thyroid, thus disrupting thyroid function.[56,61] However, perchlorate has a higher affinity for the thyroid than nitrate.[54,62] Four of five studies in a 2018 review by Ward et al.[60] demonstrated increased risk for subclinical hypothyroidism with exposure to drinking water nitrates among women, pregnant women, and children. One study linked thyroid cancer with nitrate intake.[60]

A recent review examined pregnancy outcomes in association with maternal intake of nitrates. The studies assessed demonstrated mixed results regarding spontaneous abortions, prematurity, small for gestational age, and low birth weight.[60,61] Further, in examining congenital anomalies in the context of maternal drinking water nitrate intake, five of six studies reviewed found an increased risk of neural tube or central nervous system defects.[60]

Nitrate is converted to nitrite in the human body and then may undergo nitrosation with amines and amides to N-nitroso compounds (NOCs).[34,61,63] Since most NOCs are carcinogens, the International Agency for Research on Cancer to classify nitrates and nitrites when nitrosated as Group 2A ("probably carcinogenic to humans").[34,63] The nitrate ingested from water is quickly absorbed via the gastrointestinal tract and transported through blood, which perfuses the salivary glands.[60] In saliva, the nitrate is concentrated as high as 20 times more than blood, and some salivary nitrate is converted by oral bacteria into nitrite.[60] The saliva is then swallowed exposing the gastrointestinal tract again to nitrates and nitrites to be converted to NOCs.[60] NOC conversion can be inhibited by dietary intake of compounds, such as Vitamin C or polyphenols.[60] There is, to this end, emerging evidence with four of five studies suggesting an associated risk of colorectal or colon cancer.[60]

DISPARITIES RELATED TO ACCESS TO CLEAN WATER AND THEIR HEALTH EFFECTS

Significant disparities related to clean water access and the health effects of exposure to contaminated water exist. One prime example of this is the water crisis in Flint, where poorer communities were disparately affected with higher resultant lead levels. Further, low-income and minority communities may be more malnourished and iron deficient,[64] making toxicity more likely due to increased gastrointestinal absorption of lead and other heavy metals.[65,66]

Despite advancements in water infrastructure, access to clean water continues to be a challenge in many US households.[67] Mack and Wrase[67] found that almost 12% of US households make US $32,000 or less, meaning that they spend a large proportion of their income paying for water services. These households are concentrated in low-incomes states and metropolitan areas with a high percentage of people who are disabled, uninsured, and unemployed. Hanna-Attisha et al.[68] found that during the Flint water crisis, the highest predicted BLLs occurred in areas that have had significant demographic change, an increase in poverty, and an increase in vacant properties.

Racial and ethnic disparities have also been described by several studies examining water contamination. For instance, American Indians and Alaska Natives continuously face contamination of drinking and recreational water, in addition to environmental hazards from mining, military, and agricultural exposures.[69] Average BLLs are also usually highest among Black children, particularly those from low-income families.[70] Recent events beyond the Flint water crisis highlight this disparity, with reports indicating poor water quality in New York City and Newark among predominantly low-income, Black communities and schools.[71,72] Within the Latino community, a study examining the water systems in California's San Joaquin Valley showed that Latino families disproportionately had higher nitrate levels in their drinking water compared to non-Latino whites and non-Latino people of color.[73] Further, immigrant Latinos living in "colonias"—unincorporated areas along the US–Mexico border—are at particular risk for water contamination, given the lack of infrastructure available to regulate their water and sewage systems.[74] Water contamination also affects Asian American communities. In 1979, groundwater running along the San Gabriel Valley, an area with a large Asian American community, was found to be contaminated with volatile organic compounds.[75,76] The EPA has ordered the private companies responsible to treat the area's contaminated wells and groundwater, but treatment is not expected to end until 2030.[75,77]

POLICY IMPLICATIONS AND RECOMMENDATIONS

Overview and approach to regulation

Generally, federal policy on contaminants vacillates between degrees of stringency of regulation based on political climate. Relaxation of national standards on air and water protections runs the potential risk of increase exposure of water sources to contaminants. Actions on environmental regulations should be undertaken deliberately, with solicited input from pediatric stakeholders and attention to the impact changes in regulation may have on child health. Proposed changes to environmental reforms should follow the standard federal procedure for rule-making, which is designed to allow for expert opinion. Executive orders should be limited because they may limit solicited input.[78,79] Overall regulation related to water quality standards should seek to ensure broad protections for federally protected bodies of water. Actions to limit the scope of federally protected water supplies should themselves be curtailed.[80]

Ensuring agencies such as the EPA received adequate resources is critical toward optimizing child health protections. Thus, budgets for these agencies should not be reduced, especially during periods of environmental de-regulation.[81] Officers charged with specifically addressing the health of children and studying the impact of policies on child health, such as the EPA's Office of Child Health Protections, the National Institutes of Child Health and Development, and the National Institute of Environmental Health Sciences should be safeguarded from budget reductions in order to be sufficiently resourced to carry out research, which informs further policy development.[82]

In assessing the potential risks of an exposure, agencies should have available all relevant scientific data that has been peer-reviewed. Rules restricting the types of peer-reviewed studies that can be considered in evaluating regulations on health should be discouraged.[83–85]

Lead

As data indicate that there is no safe level of lead in children, policies should move toward reducing sources of lead exposure via all portals of entry.[86,87] The newly released EPA water standards[11] (15 μg/L) are not sufficiently low to protect children. The AAP policy statement summarized studies that found blood lead concentrations below 5 μg/dL (50 p.p.b.), is a causal risk factor for impaired cognition, higher rates of neurobehavioral disorders, and lower birth weight in children.[20,88] Newly released guidance from Health Canada recommends that the maximum acceptable concentration for total lead in drinking water is 0.005 mg/L (5 μg/L).[89] States also have authority to set specific lead levels, which trigger public health investigations and access to special services. New York has proposed to lower this action level from 10 μg/dl to better comply with current data and CDC recommendations, which is considering lowering the level of concern to 3.5 μg/dl.[90] Although concerns exist as to whether laboratories can discern levels this low and still be within standard testing errors, there remain fiscal implications related to increased costs for evaluation and treatment; it is clear that enforcement of this policy is a reasonable and long-term cost-effective approach to reducing childhood lead exposure.[90] All states should consider this regulation.

Pesticides

The US EPA is mandated to consider contributions of exposures from drinking water when establishing standards for pesticides in foods. Although not found in water, clinicians and policy makers should know about policy related to organophosphates due to their known adverse health effects.[91] The EPA regulates organophosphate pesticide exposures due to their known adverse health effects.[91] Proposed changes to regulation regarding use of organophosphate pesticides have been repeatedly delayed.[92–94] In August of 2017, the federal courts ordered the EPA to enforce the ban on the pesticide within 60 days.[95] As regulatory practices continue to unfold, rules on the limitations on use should be based on current data, including calculations of cumulative risk, which include inhalation exposures.[96] While legislation to ban use of the pesticide nationally has been introduced, the delay in regulation of these compounds suggests that lawmaking at the state level may result in faster reductions in childhood exposures (Senate Bill 921).[97] Hawaii banned use of the pesticide within the state in 2018, and New York, California, Oregon, and Connecticut are also considering similar legislation (Hawaii Bill SB3095 and National Resources Defense Council).[98,99]

Arsenic

While arsenic has been a source of concern in food products and water sources, there has not been significant regulatory action on regulating arsenic levels. Currently, a pending bill in Congress would direct the Food and Drug Administration to set a maximum permissible level of inorganic arsenic for rice and rice-containing products.[100] Another important consideration is the challenges in making water safe in public drinking water versus private wells. For instance, in the United States, arsenic is not federally regulated in private wells. Nigra et al.[101] describe a decline in urinary arsenic among public water users, but not private well users, in the US population between 2003 and 2014.[101]

Perchlorate

The EPA reference dose for perchlorate in drinking water is 7 μg/kg/day. The recommended drinking water equivalent level for consideration is calculated at 24.5 p.p.b.—a level that would trigger clean-up efforts under the Comprehensive Environmental Response Compensation and Liability Act of 1980.[102] However, EPA efforts to create a drinking water regulation for perchlorate have been ongoing for almost two decades.[94,103] Over that time, significant new data has been accumulated about the potential dangers of perchlorate at low levels.[103] Regulation and guidance on this issue should be expedited, and levels of safety and concern must consider the impact of levels in the 1st and 2nd trimesters of pregnancy, newer guidelines defining hypothyroxinemia based on age and pregnancy status and model iodine intake.[104] States, however, have created their own tolerances. California limited water levels to 6 p.p.b. and Massachusetts to 2 p.p.b.[94]

Nitrates

The maximum level for nitrate contamination is set by the EPA at 10 mg nitrate-N/L.[105] The percentage of public water systems in violation of this EPA standard has been increasing from 0.28% in 1994 to 0.32% in 2016.[106] However, the number of people reliant upon systems that exceed this standard has decreased from an estimated 1.5 million to 200,000.[106,107] Regulation of nitrate has been successful in Europe, which in 1991 enforced specific agricultural practices in areas deemed "nitrate vulnerable."[60] Levels of nitrate across Europe have averaged 4 mg Nitrate-N/L since the 1990s.[60] In 2016, the EPA released proposals to protect water quality from contaminants, emphasizing nitrates.[108] The memo called for a $600,000 increase in funding to provide technical support to states and water authorities, prioritizing areas at greatest risk for nitrate contamination.[109] Similar to the European Nitrate Directive, the EPA suggested an incremental approach to increased regulation.[109] Based on this, major EPA actions should consider mimicking effective European regulation and adhere to the agency's internal recommendations to move toward a goal of 100% compliance of public water systems with acceptable nitrate levels.

Research gaps

More research is needed to understand the impact of the toxins at different stages of exposure. These exposures include during preconception, pregnancy, through breastfeeding, and across the lifecourse. Also, more studies are needed to study contaminants in combination or in mixtures as few are only exposed to a single toxin, but rather several at the same time in various mixtures. Finally, emerging chemical risks need to be further explored, including perfluoroalkyl and polyfluoroalkyl substances (PFAs). PFAs, which enter drinking water via the manufacturing of items, such as nonstick cookware, clothing, stain repellants, and electronic equipment, have been associated with developmental effects and cancer.[110]

In order to tackle complex, research questions, "team science" has become increasingly common across all fields of research. For example, the National Academy of Sciences, Engineering, and Medicine Gulf Research Program is an independent, science-based program that was created as part of the settlement aftermath of the Deepwater Horizon disaster, the largest offshore oil spill in US history. Its goal is to expedite advances in science, practice, and capacity to generate long-term benefits for the Gulf of Mexico region and the nation.[111] Such unique cross-sector collaborations can foster the societal transformation necessary to achieve decreases in water contamination.

CONCLUSION

Recent environmental disasters suggests higher levels of water contamination than are acceptable.[112] The Flint water crisis particularly demonstrates this issue, with studies showing the 90th percentile of water lead levels at 25 p.p.b. As an essential resource, contaminant-free water is an environmental right. Initiatives are needed to mitigate contamination, including more research on acceptable levels of contaminants, demographic risk factors, and the mechanism by which contaminants create harm. More research will allow us to both better understand which populations are at risk and provide treatments for exposed individuals. This is particularly true given the unique vulnerabilities of children and fetuses who may disproportionally suffer harm from exposure. Further, changes at the policy level are important in addressing water contamination. Current federal regulations on these toxicants are bureaucratic and lead to incremental and slow change. However, recent federal actions taking into account the most current data seem to have over-ruled several administrative actions, which may adversely impact contaminant levels. As pediatricians, we must therefore advocate for opportunities for research dollars, family and community safety, and legislative policies to support a safe environment.

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ADDITIONAL INFORMATION

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