Sentinel Human Health Indicators: To Evaluate the Health Status of Vulnerable Communities

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ABSTRACT

The presence of toxic substances in the Great Lakes (GL) basin continues to be a significant concern. In the United States, some 70,000 commercial and industrial compounds are now in use. More than 30,000 are produced or used in the Great Lakes ecosystem. These substances include organochlorines (e.g., polychlorinated biphenyls (PCBs), dioxins, furans, dieldrin, etc.), heavy metals such as methylmercury, and alkylated lead, and polycyclic aromatic hydrocarbons (e.g., benzo[a]pyrene). The IJC has identified 42 locations in the GL basin of the United States and Canada as Areas of Concern (AOCs) because of high concentrations of these toxic substances. In 1990 the U.S. Congress amended the Great Lakes Critical Programs Act to create The Agency for Toxic Substances and Disease Registry (ATSDR) Great Lakes Human Health Effects Research Program (GLHHERP) to begin to address these issues. This program characterizes exposures to contaminants via consumption of GL fish and investigates the potential for short- and long-term adverse health effects. This paper reviews the GLHHERP program and indicators established to monitor and address the risks posed by these substances to vulnerable populations in the Great Lakes ecosystem.

RÉSUMÉ

La présence de substances toxiques dans le bassin hydrographique des Grands Lacs constitue encore une préoccupation importante. Aux États-Unis, on utilise quelque 70 000 composés chimiques à des fins commerciales et industrielles. Plus de 30 000 d'entre eux sont produits ou employés dans l'écosystème des Grands Lacs. Les composés organochlorés (p. ex. les diphényls polychlorés [BPC], les dioxines, les furannes, la dieldrine, etc.), les métaux lourds comme le méthylmercure, ainsi que l'alkylplomb et les hydrocarbures aromatiques polycycliques (p. ex. le benzo[a]pyrène) en font partie. La CMI a désigné 42 endroits dans le bassin des Grands Lacs aux États-Unis et au Canada comme secteurs préoccupants en raison de la présence de fortes concentrations de ces substances toxiques. Aux États-Unis, le Congrès a modifié en 1990 la Great Lakes Critical Programs Act en vue de créer l'Agency for Toxic Substances and Disease Registry, responsable de l'application du Great Lakes Human Health Effects Research Program (GLHHERP), et qui a commencé à régler les problèmes causés par les substances toxiques. Le GLHHERP définit les expositions aux contaminants liées à la consommation de poissons provenant des Grands Lacs et se penche sur leurs effets nocifs à court et à long terme. Les auteurs examinent le programme GLHHERP et les indicateurs retenus pour surveiller et contrer les risques que posent de telles substances pour les populations à risque de l'écosystème des Grands Lacs.

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The Great Lakes contain some 5,500 cubic miles of water, covering 94,000 square miles and have a shoreline of over 10,000 miles. They are the largest system of fresh surface water on earth, comprising roughly 18% of the world supply. Approximately 10% of the U.S. population and 25% of the Canadian population live in the region.[1] For over 200 years, the Great Lakes basin has been used as a resource for industry, agriculture, shipping, and recreation. By the early 1960s, eutrophication, overfishing, and the widespread presence of toxic substances had all contributed to a decline in the environmental quality of this basin. The physical nature of the basin and the long retention time of chemicals in the lakes combine to make this huge freshwater resource a repository for chemicals and their by-products. Despite their size, the lakes are especially sensitive to pollution. Less than 1% of their total volume flows out of the St. Lawrence River each year, leaving toxic substances to accumulate in the sediment.[2]

Results from epidemiologic investigations suggest that adverse human health effects, i.e., reproductive, developmental, behavioural, neurologic, and immunologic, may result from exposure to Great Lakes pollutants.[3-5] Given the implications of this association, the U.S. Congress amended the Great Lakes Critical Programs Act in 1990 to investigate this human health concern.

The Agency for Toxic Substances and Disease Registry (ATSDR) Great Lakes Human Health Effects Research Program (GLHHERP) was initiated in 1992, and is designed to characterize exposure to contaminants via consumption of Great Lakes fish, and investigate the potential for short- and long-term adverse health effects. In implementing this program, ATSDR identified 1) a research strategy and 2) a suite of indicators to determine human risk from exposure to Persistent Toxic Substances (PTSs) in the Great Lakes basin.

Research strategy

ATSDR's GLHHERP is a strategy based on the five traditional elements of disease prevention: 1) identification of a pattern of disease or other adverse health effects, 2) evaluation of the causal factors potentially contributing to these patterns of dis-

ease and adverse effects, 3) interventions to control or mitigate the causal factors, 4) dissemination of information, and 5) development of an infrastructure.[6] This research strategy has been endorsed by the Council of Great Lakes Research Managers and has been adopted by the International Joint Commission (IJC) as a framework for the study of human and ecosystem health in the Great Lakes basin.

Indicators of potential risk

The research program has identified a set of indicator categories to determine risk. They include 1) vulnerable, i.e., susceptible populations, 2) exposure, 3) pathways of exposure, 4) sensitive human health end points, 5) body burden levels, 6) sociobehavioural data, 7) sociodemographic data, and 8) knowledge of health advisories. Taken together, these indicators categories assess the potential for adverse human health effects from exposure to PTSs in the basin. What follows is a brief description of each category.

Vulnerable Populations

Several human populations who may be at particular risk because of exposure to Great Lakes pollutants via fish consumption have been identified. Predisposition to toxic injury in these populations can be due to behaviour, nutritional status, physiology, or other factors. These populations include subsistence fish anglers, American Indians, Asian Americans, pregnant women, fetuses, nursing infants whose mothers consume contaminated Great Lakes sport fish (GLSF), young children, the elderly, the urban poor, and those with compromised immune function.[7]

Exposure

In the United States, some 70,000 commercial and industrial compounds are now in use and more than 30,000 are produced or used in the Great Lakes basin. The "critical Great Lakes pollutants" identified by the IJC are polychlorinated biphenyls (PCBs), dichlorodiphenyl trichloroethane (DDT), dieldrin, toxaphene, mirex, methylmercury, benzo[a]pyrene (a member of a class of substances known as polycyclic aromatic hydrocarbons [PAHs]), hexachlorobenzene (HCB), furans, dioxins, and alkylated lead. They are persistent, and many are lipophilic so that they bioaccumulate in biota and biomagnify up the food web.[2,8] The ATSDR GLHHERP focused on these 11 critical pollutants as well as other toxic chemicals of concern, e.g., arsenic, cadmium.

The IJC has identified 42 "Areas of Concern" (AOC) in the United States and Canada in which toxic substances exceed limits or guidelines of the U.S.-Canada Great Lakes Water Quality Agreement. Thirty-one of these 42 areas are within the borders of the United States.[9]

Pathways of Exposure/Body Burden Levels

Potential pathways of human exposure to Great Lakes pollutants include inhalation of air; ingestion of water, foodstuffs, or contaminated soil; and dermal contact with water or airborne particulates. Analyses indicate the majority of human exposure to chlorinated organic compounds (80-90%) comes from food, a lesser amount (5-10%) from air, and minute amounts (less than 1%) from water.[10]

Most available data on human exposure to toxic substances in the Great Lakes come from analyses of contaminant levels in drinking water and sport fish. Investigators have also demonstrated that blood serum levels of these contaminants are significantly increased in consumers of Great Lakes sport fish compared to people who do not eat such fish or who consume very small amounts.[11]

Sensitive Human End Points

Exposure to contaminants via consumption of Great Lakes fish over an extended period of time allows for continuous exposure that may increase the potential for adverse human health effects. The program has identified sensitive human health end points to be assessed which included behavioural, reproductive, developmental, neurologic, endocrinologic, and immunologic measures. Future assessment may examine genetic end points if warranted by the research findings.

Sociobehavioural and Sociodemographic Data

The Health Belief Model (a model for the value expectancy theory) has been used to examine why people do or do not take preventive actions to reduce their risk. According to this theory, how people think and respond to risk largely depends on their health beliefs and knowledge of the risk, weighed against the barriers and benefits of taking preventive action.[12] Motivation to comply with health advisories includes value of health, and structural and demographic variables; these variables influence individual health beliefs and preventive behaviours.[13] Structural variables can include knowledge of a disease or hazard. Demographic variables can include age, gender, ethnicity, income, and education.

Knowledge of Fish Advisories

A thorough understanding of the target audience is necessary to effectively communicate risk through fish advisories. Communicating risk can increase the likelihood and willingness of a population to adhere to advisories. Therefore, the research program also chose to assess the knowledge and awareness of fish advisories in vulnerable populations.

Research findings

The Great Lakes Human Health Research Program has made significant progress in identifying, evaluating, and reporting public health findings through the use of the listed indicators. These findings indicate the following:

Exposure Data

- Communities of concern are still exposed to PTSs including PCBs, dioxins, furans, chlorinated pesticides, i.e., DDT, and mercury.[14-21]
- Levels of some contaminants in Great Lakes sport fish are above the advisory limits set by state and federal governments.[19,22]
- Residents in the basin ate more fish than that estimated for the U.S. population.[14,18,20,23]
- Sport fish-eaters consume 2-3 times more fish than the general U.S. population.[14,16,18,20,24]
- Fish consumption appears to be the major pathway of exposure for some PTSs.[15,20]
- Body burden levels of some PTSs in vulnerable populations are 2 to 4 times higher than those of the general U.S. population.[14,16,18]
- A significant trend of increasing body burden is associated with increased fish consumption.[14,20,25]

- Men consume more fish than women; men and women eat Great Lakes sport fish during most of their reproductive years.[14,20,21,23,26]
- Maternal consumption of Lake Ontario Great Lakes fish increases the risk of prenatal exposure to the most heavily chlorinated PCBs.[15]

Sociobehavioural and Demographics Data

- An estimated 4.7 million people consumed Great Lakes sport fish in a given year; 43.9% of the respondents were women.[27]
- Knowledge of and adherence to health advisories for Great Lakes sport caught fish vary across different populations.[20,26,27]
- Fifty percent of respondents to the survey who had eaten Great Lakes sport fish were aware of the health advisory for fish, and awareness differed significantly by race, sex, educational level, fish consumption, and state of residence.[27]
- Ninety-seven percent of American Indian men were aware of local advisories against consuming Great Lakes sport fish, however 80% of the men ate fish.[20]
- Eighty percent of minorities who had eaten Great Lakes sport fish were unaware of the fish advisory, and awareness was especially low among women.[27]
- Fish is an essential component of diets of minority populations and American Indians; they consume fish that tend to have higher levels of contaminants.[20,26]

Health Effects

- Conception rate and the incidence of a live birth are lower in some women who are sport fish consumers.[23]
- An association was found between men who consumed large amounts of sport fish and the risk of delayed conception in their spouses.[24]
- Significant menstrual cycle reductions were indicated in women who reported consuming more than 1 meal per month of contaminated Great Lakes sport fish.[28]
- In the Oswego Newborn Study, neurobehavioural and developmental deficits have been observed in newborns (12 to 24 hours after birth and again 25 to 48 hours after birth) of mothers who consumed approximately 2.3 meals per month of contaminated Lake Ontario fish.[21]
  - Significant relationships were identified between the most highly chlorinated PCBs performance impairment on the habituation and autonomic tests of NBAS (neurobehavioural assessment scales) at 25-48 hours after birth. No significant relationship was found between PCBs of lesser chlorination, DDE, hexachlorobenzene, mirex, lead or mercury on any NBAS performance test.[29]
  - Initial test results for memory, verbal, and perceptual performance among 3 years old in the Oswego study indicate their score is lower than children from mothers who consumed low amounts or no GL sport fish.[30]
  - The relationship between prenatal exposure to PCBs and performance on the Fagan Test of Infant Intelligence (FTII) was also assessed in the Oswego infants at 6 months and again at 12 months. The results indicated a significant relationship between exposure to PCBs and poor performance on the FTII. No significant relationship was found between exposure to DDE or methylmercury on any tests of the FTII.[31]
- Self-reported liver disease, diabetes, and muscle/joint pain may be associated with exposure to PCBs and other contaminants via fish consumption.[32]
- PCB concentrations were significantly associated with poorer pegboard performance (a test to evaluate visual motor coordination and spatial orientation).[33]
- PCBs and dichlorodiphenyl dichloroethene (DDE) were markedly elevated in an adult fish-eating cohort. Exposure to PCBs, not DDE, was associated with lower scores on several measures of memory and learning.[34]

Success stories

The significant research findings from the ATSDR GLHHERP have resulted in a number of success stories by using different public health strategies, e.g., regulatory and community-based. For example, recent health findings were instrumental in the implementation of a Uniform Great Lakes Sport Fish Advisory used by all 8 Great Lakes states as well as other states. As well, among a population of high fish-consuming American Indian men, the ATSDR used various risk communication strategies to make them aware of the risks of consuming contaminated fish.[35] As a result, the men reduced their consumption rate from an average of 98 meals per year to 28 in the first year of the study and even lower during the second year. A reduction in consumption led to lower PCB serum levels. A similar trend was also found among women of this group.[20,36]

Public health implications

The levels of pollutants in the environment have declined dramatically since the 1970s and 1980s, however, more recent trends are less clear, indicating a possible plateau as well as an increase in pollutants from outside the basin via atmospheric transport. However, there is a success story in that regulatory agencies, health agencies and industry have all worked together to put technologies in place to reduce emissions into the environment. Despite this, the body burden levels of some PTSs in vulnerable populations are still 2 to 4 times higher than those of the general U.S. population. We also recognize that body burdens of key pollutants in the general population have been identified at levels that are within an order of magnitude that produces health effects in experimental settings.[37]

It is clear that vulnerable populations are at risk for adverse health effects because of elevated exposures as well as possibly intrinsic physiological sensitivity. Nursing infants, subsistence and sport fishermen, and the elderly are among these vulnerable groups. The nursing infant may experience exposure rates anywhere from 40 to 50 times that of the general population.[38] Therefore, the developing fetus is intensely sensitive to the effects of these chemicals during certain critical "windows" of development. If these chemicals are endocrine disruptors, these effects may have transgenerational impacts. These identified health end points in the GLHHERP constitute sensitive as well as sentinel indicators for assessing human health status in vulnerable communities.

Another complication is the possibility that these subtle effects are occurring on a wide-scale basis and in populations where the effects resist conclusive demonstration

through epidemiologic methods. The tobacco experience suggests it may be impossible, or nearly impossible, to have absolute consensus on the issue of causality. But in terms of public health practice, Gilbertson[39] has posited that the weight of evidence be used as a causality surrogate to address the challenges posed in moving from science to service. Nevertheless, even in the face of that uncertainty, society is confronted with potential public health issues that must be addressed.

The public health case for action is based on the shift in the distribution curve of a measure of functional capacity such as IQ. If the population as a whole is affected, the proportion of the population that falls into the gifted and handicapped categories is significantly altered. The public health implications of such a shift are profound. A recent re-examination of 212 children from the Lake Michigan Maternal/Infant Cohort Study indicated neurodevelopmental deficits assessed in infancy and early childhood still persist at age 11.[40] The study results indicated that the most highly exposed children, those with prenatal exposures equivalent to at least 1.25 µg/g in maternal milk, 4.7 ng/milliliter in cord blood, or 9.7 ng/milliliter in maternal serum:

- were three times as likely to have low average IQ scores ($p<0.001$);
- were twice as likely to be at least 2 years behind in reading comprehension;
- have poorer short- and long-term memory; and
- have difficulty paying attention.

These intellectual impairments are attributed to in utero exposure to PCBs; and concentrations of PCBs in maternal serum and milk at delivery in this study were slightly higher than in the general U.S. population. Because of these findings, the case for action is also based on the rights of individuals and communities to know the risks to which they are exposed. Given such effects on fetal development, one must ask, "Has the fetus become the unfortunate mining canary for human exposure to toxicants in the environment?"[17]

The Great Lakes research program has already initiated steps to reduce the impact of these findings. The program has emphasized disease prevention through mobilization of the research community to pursue appropriate public health interventions, and communication efforts for defined populations and vulnerable communities.

CONCLUSIONS

Given the significant implications of these research findings, the critical importance of primary prevention is apparent. This entails both pollution prevention as well as the model of disease prevention as key strategies to interdict exposure pathways. In addition, we must consider the health benefits gained from fish consumption while also evaluating the potential health implications. The counter-balancing risks and benefits pose a significant challenge in the development of health education and risk communication, as well as in assuring the best science is responsibly and rapidly translated into public health practice. Despite these challenges, pollution prevention strategies remain the key to reducing toxic chemical exposures.

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