Effective Environmental Public Health Surveillance Programs: A Framework for Identifying and Evaluating Data Resources and Indicators

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The complexity and multidisciplinary nature of environmental public health (EPH) surveillance call for a systematic framework and a concrete set of criteria to guide development, selection, and evaluation of environmental public health indicators. Environmental public health indicators are the foundation of a comprehensive EPH surveillance system, providing quantitative summary measures and descriptive information about spatial and temporal trends of hazard, exposure, and health effects over person, place, and time. A case-synthesis review of environmental regulatory and public health indicator models was employed to develop a framework and outline a methodological approach to EPH surveillance system development, including the selection of content areas and the corresponding data and environmental public health indicators. The framework is organized around three assessment phases: (1) scientific basis and relevance, (2) analytic soundness, and (3) feasibility, interpretation and utility. By outlining a process and identifying important constructs and criteria, the framework provides practitioners with an effective and systematic tool for making scientifically valid programmatic decisions about EPH content development. Improved decision making ensures more effective EPH surveillance systems and enhanced opportunities to understand and protect the public health from environmental threats.

KEY WORDS: **environmental health, environmental public health indicators, evaluation, framework, indicators, policy development, program management**

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Over the last several decades, increasing attention has focused on the need to improve environmental public health (EPH) surveillance capacity and to develop methods for addressing priority environmental health (EH) concerns in the United States.[1–5] Environmental public health surveillance establishes the means to assess, analyze, and disseminate appropriate data for making decisions and safeguarding human health from environmental threats.[1,6] Since the earliest organized prevention efforts, tracking of health trends and risk factors has been a cornerstone of public health practice.[7,8] Today, *EPH surveillance* is defined as the ongoing systematic collection, analysis, interpretation, and dissemination of data about environmental hazards, exposures, and health effects for action to improve health.[1,6] Environmental public health indicators (EPHIs) can serve as the foundation of a comprehensive EPH surveillance system, providing quantitative summary measures and descriptive information about spatial and temporal trends of EPH topics over person, place, and time.[9,10] Despite the growing national interest in enhanced EH surveillance programs practical strategies and tools for practitioners to use in the selection, development and evaluation of content are lacking.[11,12]

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A framework describing what criteria should be used to prioritize and guide selection of EPH surveillance system content, including appropriate data and EPHIs, is needed in the United States.[9] In today's economic and political times, practitioners are increasingly accountable for their decision making and need documentation, transparency, and consistency in all programmatic decisions. Environmental public health surveillance is multidisciplinary, and data are derived from diverse programs and agencies including environment, health, agriculture, transportation, and planning and development.[1,3,6,11] A systematic framework grounded in science, theory, and practice will greatly advance practitioners' capacity to appropriately and effectively address the public health dimensions of environmental issues.[11]

This study was undertaken to identify a methodological approach to the development and evaluation of content (including information, data, and EPHIs) for inclusion in a comprehensive EPH surveillance system. Environmental public health indicators are quantitative summary measures derived from surveillance and monitoring data. Indicators are used to translate EPH data into usable information.[13] When chosen carefully and developed on the basis of both scientific theory and knowledge, EPHIs can be valuable tools for tracking program progress, identifying emerging problem areas and policy development.[9,10] However, EPHIs are effective only when part of a larger surveillance system that can identify, gather and analyze relevant data, synthesize results, and interpret findings.[1,7,11]

A framework was developed to assist practitioners in prioritizing the selection and evaluation of EPHIs. The overarching goals of this project were to construct criteria for evaluating environmental public health indicators and to outline a stepwise process by which a prioritized list of EPHIs can be generated for use by EPH practitioners. Three case examples—(1) total trihalomethanes (disinfection by-products [DBPs]) in community water supplies, (2) mercury in fish tissue, and (3) percent low birth-weight—were identified to further explain each of the frameworks core concepts. These examples are provided to illustrate how practitioners might use the tool in making decisions about what to include or exclude from a comprehensive EPH surveillance system.

Methods

A stepwise review of published and unpublished literature was conducted to identify existing indicator models and examine criteria previously used by environmental management and public health programs to select indicators. PubMed/MEDLINE and Google were employed. Key word searches included the following: environmental indicators, ecological indicators, health indicators, and EPHIs. Models were chosen if they were developed by a scientific panel or expert working group, addressed topic areas relevant to EPH, and had a theoretical framework guiding development and use of indicator measures for EPH and/or public health practice.

Selected models were grouped into three categories: environmental regulatory, public health surveillance, and EH programs. Environmental regulatory programs include agencies that systematically collect data on the distribution of potential physical toxins and hazards in the environment. Public health surveillance programs monitor and track health and/or factors associated with health in the population. EH programs combine both models—systematic assessment of environmental hazards and monitoring of population health effects and exposures.

A data collection instrument was developed following a modified cross-case synthesis approach to facilitate the review and comparison of indicator development criteria and concepts from each model.[14] Criteria were then clustered into the conceptual constructs (eg, scientific basis, reliability, and quality) that became the key assessment phases and core elements of the resulting framework.

Results

There were a considerable number of indicator initiatives within each of the three categorical areas to develop a framework reflective of current EPH science, theory, and practice. Table 1 lists the primary indicator initiatives and scientific literature contributing to the final framework. While these public health and environmental models were all developed independently, common criteria emerged across all three models such as indicators need to relevant, accurate and reliable. Figure 1 depicts the framework and shows how the primary constructs and core elements are organized to facilitate the process of content development and evaluation.

Based on the premise that developing and evaluating surveillance programs is dynamic and iterative process, the framework outlines three assessment phases.[24,23] Phase I, *scientific basis and relevance*, involves examining the scientific basis and relevance of a particular information set. Phase II, *analytic soundness and feasibility*, requires an assessment of how feasible the information is for practitioners to collect. Furthermore, phase II also includes a review of how attributes, such as data quality and quantity, affect the validity and reliability of the measures for their intended purpose within

TABLE 1 ● Environmental regulatory, environmental public health, and public health indicator models

Ecological/environmental regulatory	Environmental public health	Public health
State of the Lakes Ecosystem Conference (SOLEC) indicators, 1999[15]	Developing Indicators for Environment and Health, 1995[19]	Healthy People 2010[26,27]
Evaluation guidelines for ecological indicators, 2000[16]	Environmental Indicators Framework and Methodologies, 1999[20]	Updated Guidelines for Public Health Surveillance, 2001[28]
National Research Council: Ecological indicators for the nation, 2000[17]	Indicators in Environmental Health: Identifying and Selecting Common Sets, 2002[21]	A Priority Rating System for Public Health Programs, 1990[29]
A SAB report: Framework for assessing and reporting on ecological condition, 2002[18]	Environmental Public Health Indicators, 2002[10]	Indicators for Chronic Disease Surveillance, 2004[30]
	EPA Draft Report on the Environment, 2003[22]	Maternal and Child Health (MCH) Model Indicators, 1997[31]
	America's Children and the Environment Measures of Contaminants, Body Burdens, and Illnesses Second Edition, 2003[23]	America's Children: Key National Indicators of Child Well-being, 2003[32]
	Making a Difference: Indicators to Improve Children's Environmental Health, 2003[24]	
	Recommendations for the Development of Children's Health and the Environment Indicators in North America, 2003[25]	

the program (ie, Do the measures truly reflect the concept that the proposed indicator is trying to capture?). Phase III, *interpretation and utility*, explores the value and usefulness of EPHIs on the basis of their ability to be used for developing targeted intervention and prevention strategies and policies. A total of seven evaluation elements are incorporated throughout the three assessment phases: EH importance, public health importance, stakeholder concern, technical capacity and practicality, data and information quality, meaningfulness for public health action, and policy development.

FIGURE 1 ● A Framework for Identifying and Evaluating Data Resources and Indicators for Environmental Public Health Surveillance Programs

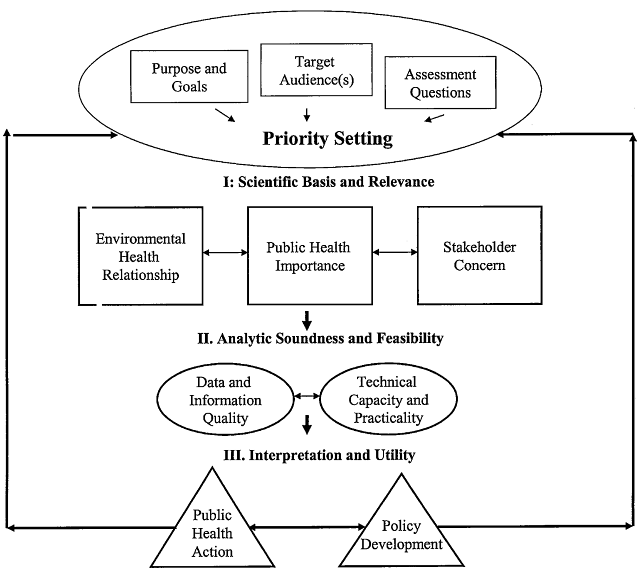

Table 2 outlines the three assessment phases and corresponding evaluation elements. The significance of each element may vary depending on results of the priority setting process and may be weighted accordingly.

Priority setting

Priority setting is required to establish programmatic goals, outline the purpose of the system, identify target audiences, and determine assessment questions that need to be addressed.[17,21,26] Once priority topic areas are identified, programs can outline relevant EPHIs and determine the resources and data available to address these priorities. With respect to the three case examples, investigators took the perspective of state-level EH practitioners and identified children's EH as a programmatic goal with a particular priority being to determine the impact of water quality on reproductive and developmental outcomes. On the basis of a review of existing environmental monitoring data, population exposure to DBPs and exposure to mercury from recreational fish tissue in susceptible subpopulations were selected as two initial EPHIs for consideration. On the health outcome side, vital statistics data were considered and percent low birth-weight also emerged as a potential EPHI. Although these EPHIs appear to address program priorities, their utility needs to be evaluated before integrating them into an EPH surveillance system.

Phase I: Scientific basis and relevance

Once programmatic goals and priorities are established, practitioners can assess the scientific basis and

TABLE 2 ● **The evaluation framework constructs, core elements, and criteria**

Construct	Core element	Criteria	References
Scientific basis and relevance	Environmental health importance	Scientific validity	10,17,19,25,33
		Strength of evidence	17,21,35
		Representativeness	10,22,24,33
		Authoritative standard	10,22,28,31
	Public health importance	Magnitude	17,21,19,26,27,29,31
		Rarity	25,28
		Vulnerable subpopulation	23,28
		Exposure potential	10,25
		Potency	10,25
		Importance	10,26,27
	Stakeholder concern	Voluntary	34,35
		Controllable	
		Beneficial	
		Equitable	
		Natural or man-made	
		Potentially catastrophic	
		Familiar	
		Trusted	
		Impacts children	
Analytic Soundness and feasibility	Technical capacity and practicality	Available	10,15,21,23,25
		Measurable	10,19,24,24
		Feasible	10,15,17,19,21
		Collectable	15,31
		Spatially and temporally scaled	15,17,24
		Trackable	10,15,24,25
		Timely	10,24
	Data and Information Quality	Accurate	10,15,24
		Reliable	15,17,21,23,25–27
		Repeatable	15,17,21,23,25–27
		Scientifically valid	21,25
		Robust	17,19,21,24,25
		Sensitive	10,15,17,23,24,26,27
		Unbiased	27,36
Interpretation and utility	(Meaningful for) Public health action	Anticipatory	15
		Available and Appropriate	10,15
		Cost-effective	17,19,24
		Spatially and temporally scaled	15,17
		Easily quantifiable	10,15,19
		Timely	10,24
	Policy development	Understandable and applicable	15,17,19,21,24,25
		Objective oriented	15,26,27
		Grounded by political will/support	17,19,21
		Relevant and informative	19,21,24,25

relevance of selected EPHIs. Environmental health importance, public health importance, and stakeholder concern emerged as the three primary constructs to consider in phase I. A scientific underpinning to support the inclusion of data into an EPH system is necessary to facilitate targeted intervention and prevention programs. Thus, the EH importance should be determined by examining what is or is not known regarding the cause-and-effect relationship between population exposure to a particular hazard and related health effects.[24,33,37] Identifying gaps in understanding along the EH continuum can help establish the scientific evidence or lack there, available to support inclusion or exclusion of a particular EPHI.[11,37]

When reviewing the three case examples, several key differences in the amount of evidence supporting each EH topic emerged. For disinfection by-products (*DBPs*), several epidemiologic studies provide suggestive but still inconclusive evidence to support DBPs can cause reproductive outcomes that they may cause adverse birth outcomes such as low birth-weight in children exposed in-utero.[38–40] There is also epidemiologic evidence to support that over time maternal consumption of fish containing high levels of mercury may lead to long-term developmental effects in their children.[37,41,42] In contrast, low birth-weight is a multifactorial outcome resulting from multiple social, behavioral, and individual risk factors; the impact of environmental exposures on total percent low birth-weight within a specified geographic region is difficult to ascertain.[43] Therefore, from an EH perspective, total trihalomethanes (an indicator of DBPs) in community water and mercury in fish tissue would rank higher than percent low birth-weight.

Once the environmental health importance of EPHIs has been assessed, the public health importance can be examined. The *public health importance* refers to the magnitude of the health effect(s) related to a particular hazard, exposure, or potential risks associated with the EPHI.[28] Magnitude can be measured in terms of morbidity, mortality, or overall costs to healthcare and society.[29] Consequently, the magnitude of health outcome indicators is often easier to establish than environmental hazards or exposures. Often times, two measures of hazards and health effects may be related, but the scientific evidence supporting the magnitude of that relationship and causal pathway may or may not be known and public health importance remains uncertain. Similarly, the public health importance of a particular hazard or exposure may vary by state or region.

With regards to the three case examples, it is known that percent low birth-weight is a leading cause of infant mortality in the United States and therefore has potentially greater public health importance than drinking water disinfectants or fish tissue contamination; however, the true public health magnitude of both DBPs and mercury cannot be determined. Furthermore, a state may find they have elevated mercury levels in fish tissue taken from recreational lakes and streams; however, data about the consumption of recreational fish in the United States are unknown and levels of mercury in these fish tissue vary. Thus, it is important to clearly state what is or is not known about the relationship and the presence of a particular hazard or exposure within a region when examining public health importance.[10,11,19,24]

Beyond the scientific basis, some EPH surveillance data and EPHI are relevant in a practice setting simply because the public is concerned about a topic area but the scientific evidence to support the EH contribution is lacking.[19,21,24] The public is the primary customer of our public health efforts, and concern regarding an EPH problem can influence the importance and relevance of a particular indicator regardless of the scientific evidence. Public concern regarding an EH issue can be measured on the basis of elements of risk perception.[34,43] The importance of environmental concerns as perceived by the public will vary depending on risk conditions, such as an involuntary exposure event or natural or man-made disaster (ie, chemical exposure from industrial pollution or hurricane) is perceived as higher risk than a voluntary exposure (ie, smoking) and affected populations (ie, impact on children usually results in a higher perceived risk).[24,43] With regards to the three examples, fish tissue contaminants may be perceived as less of a threat than drinking water contaminants because not everyone eats the fish and those who do can usually change dietary habits; however, a majority of the population would be exposed to community drinking water because exposure through bathing and home use is involuntary in cases where alternative water treatments are not available.

Furthermore, the degree to which risk perception can impact the prioritization of a potential EPHI will vary based on the political climate and context of a particular concern. For example, because of very specific outbreaks of elevated drinking water contaminants in some communities, the public has been led to believe that community drinking water supplies are unsafe and have switched to bottled water use. In reality, public water supplies are continually regulated and programs are in place to ensure that the public receives safe water but there is no nationally consistent monitoring of bottled water and risks to public are unknown. Public concern raises the significance of contaminants in community water supplies above the unknown risks associated with bottled water and both need to be equally addressed despite their differing public health importance.

Phase II: Analytic soundness, technical capacity, and feasibility

A surveillance program built solely on scientific basis and relevance may not be practical or feasible. Thus, phase II, *analytic soundness, technical capacity, and feasibility*, focuses on the practical issues that impact the ability to systematically collect good-quality data to develop valid and reliable EPHIs.

Analytic soundness, technical capacity, and feasibility involve assessment of the data properties, such as data quality and accuracy, evaluation of the strengths and weaknesses of the data (eg, are the data of sufficient quality to generate a valid estimate), as well as an understanding of the feasibility of collecting and analyzing data over time. Furthermore, the technical data assessment offers opportunities to highlight areas for enhancing EH capacity and make the case for collecting data and developing measures that are readily available and are of good quality.[10,20,24] Basic criteria for assessing the technical capacity and practicality of EPH data and measures include availability, measurability, collectibility, spatial and temporal scale as well as whether the data are timely, accessible, and linkable.[10,20,21,24]

With regards to the three case examples, collection and analysis of fish tissue samples are costly and time-consuming. Thus, obtaining fish tissue data with appropriate spatial resolution on a routine basis for use as an EPHI would be very difficult. In contrast, all states are required under the federal Safe Drinking Water Act to routinely monitor for DBPs in drinking water systems and these data are often readily available (http://www.epa.gov/safewater/sdwa/index.html). Similarly, access to vital statistics data on low birth-weight is easy and very accessible for most state health departments. Therefore, from a technical capacity and feasibility standpoint, low birth-weight and DBPs might rank higher than mercury contamination in fish. At the same time, this does not mean that the quality of the data for generating public health assessments is equal.

Data and information quality can be assessed by reviewing the analytic properties of datasets being used to generate the EPHI. An *analytic property* refers to the quality, accuracy, validity, sensitivity, and reliability of the data.[21,35] The *robustness and the sensitivity* of the EPHIs refer to their ability to reflect true changes in spatial and temporal trends that are relevant to public health decision making.[17,21] High-quality data are well documented, and methods for collecting the information can be easily reproduced.[19] The quality of the data is also influenced by any potential sources of bias.[35]

For example, how data are collected can introduce bias to any EPHI measure. For example, environmental monitoring data are collected on the basis of regulatory standards without consistent monitoring intervals (ie, some localities may monitor on a quarterly basis and others annually). These regulatory standards were set to balance technology and public health protection, not to assure systematic, representative samples of population exposures. Consequently, some community water systems are required to monitor for DBPs quarterly whereas other systems may only be required to monitor DBPs on an annual basis. Thus, a comparison of the two systems' DBP monitoring results will not be accurate or reliable if one system monitors more frequently than another or reporting requirements change. Environmental public health indicators must be evaluated with these potential sources of bias in mind and their potential impact on the accuracy, validity, and reliability of analytic results and corresponding interpretations must be considered.[21,35]

Phase III: Interpretation and utility

Phase III, *interpretation and utility*, focuses on the overall goal of an EPH surveillance program: improving health outcomes related to environmental exposures by using evidence-based decision making.[36,44] The final interpretation and utility of data and EPHIs depend on their proposed use and on specific assessment questions that the surveillance program is intended to address.[24] Public health surveillance is developed with the intention that action arrives from the monitoring and assessment of key measures over time.[28] Therefore, one measure of program utility is its ability to be used by EPH practitioners to design and measure intervention and prevention strategies and track the success of these programs over time.[10] An EPH surveillance system that is meaningful for determining appropriate public health actions must be anticipatory, available, appropriate, cost-effective, temporally and spatially scaled, easily quantifiable, and timely.[10,15,17,19,24] Furthermore, EPH surveillance programs can enhance EPH practice if they can convey a meaningful and simplified message that is easily understood by policy makers and relevant stakeholders.[10,15,24,45] The overall utility of the EH surveillance data and measures for evidenced based policies is their applicability to community interests, concerns, and overall goals.[20,27,44]

All three case examples, DBPs in drinking water, mercury contaminants in fish tissue, and percent low birth-weight, can be tracked over time and used to identify appropriate interventions; however, the environmental measures may be easier to use for identifying public health actions because guidelines for determining how much fish is safe to eat at certain levels or what constitutes a safe level of contaminants in drinking water are well established. Therefore, preventing adverse exposures through changes in drinking water treatment and maintenance or dissemination of fish consumption advisory awareness may be easier to develop than reducing the attributable fraction of low-birth-weight births resulting from undeterminable environmental exposures. Consequently, the first two EPHIs may rank higher than low birth-weight in interpretation and utility because the information derived from these indicators can be used to take direct public health actions and provide tangible results.

Tables 3 and 4 show the summary ranking of the three examples and how the framework can be used to consistently document decisions over time. The tables provide a simple, qualitative, high, medium, and

TABLE 3 ● Framework implementation, ranking by core element

Core evaluation element	Relative ranking of indicators: Disinfection by-products in public drinking water supplies	Mercury in fish tissue	Percent low birth weight
Environmental health importance	Medium	High	Low
Public health importance	U/D	U/D	High
Stakeholder/public concern	Medium	High	Low
Technical capacity and feasibility	Medium low	Low	High
Data information quality	Medium low	Medium	High
Public health action (meaningful)	Medium	High	U/D
Policy development	High	High	Low

Abbreviation: U/D, undetermined.

low ranking to evaluate each indicator for each core element within the three assessment phases. For example, under phase I, low birth-weight ranked high for public health importance but low for EH and public concern, in contrast, DBPs and mercury in fish tissue ranked high for EH importance but could not be evaluated for public health importance. The table provides an opportunity to document and review the decision-making process throughout. A more sophisticated quantitative scoring method could also be applied but is beyond the scope of this article.

Discussion

Given the broad range of issues facing EPH practitioners, selecting data and EPHIs to serve as the foundation for a comprehensive EPH surveillance program can be daunting. Priority setting by its very nature has both subjective and objective components.[24] Environmental public health practitioners must justify their decision making, policies, and intervention and prevention efforts[33]; therefore, there is a need for well-established criteria and concrete methods to assist practitioners with the development of valid, reliable, and consistent EPH surveillance data and EPHIs.[19] This evaluation framework meets these objectives by providing practitioners with a methodological approach for making evidence-based decisions regarding the future selection, development, and use of data and EPHIs in EPH surveillance and practice.

This framework provides a core set of constructs and criteria to ensure that EPH surveillance programs are utilized effectively to meet the needs of primary audiences including the public, policy makers, and EPH practitioners. Environmental public health priorities are dynamic and evolve over time and EPH resources are often limited. The framework ensures that EPH surveillance systems address emerging priorities by engaging key stakeholders throughout the developmental process.

Without this capability, EPH surveillance systems cannot accurately facilitate action to mitigate problems or make effective, evidence-based policies.[46]

Although further research and application of the framework are needed, this framework offers opportunities to develop consistent, comparable, and meaningful EPH surveillance systems. Implementation of the framework using the three case examples suggests that there may not be one clear decision about which indicators to include or eliminate within a program. Having clear programmatic priorities or goals, such as needing to build a program that identifies existing and emerging hazards (eg, DBPs or mercury) rather than replicating measures already used by other programs (eg, percent low birth-weight), will assist in final decision making.

Environmental public health surveillance programs are complex and can be challenging for public health practitioners to develop, because of their cross-disciplinary nature. As EPH surveillance programs evolve, this framework provides a tool to bridge the gap among the current complex web of agencies and differing mandates by facilitating the systematic linkage of environmental exposure and health outcome data. This linkage offers tremendous opportunities to advance our nation's ability to prevent disease, develop evidence-based EPH policies, and further our understanding of the impact of environment on health.

TABLE 4 ● Framework Implementation, summary evaluation

Topic area	Scientific basis and relevance	Analytic soundness and feasibility	Interpretation and utility
Disinfection by-products in public drinking water supplies	Good	Good	Good
Mercury in fish tissue	Good	Fair	Good
Percent low birth-weight	Poor	Excellent	Fair

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