Surveillance in Environmental Public Health: Issues, Systems, and Sources

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ABSTRACT

This article describes environmental public health surveillance and proposes a framework to enhance its practice in the United States. Special issues for surveillance in environmental public health are examined, and examples of existing systems useful for environmental public health practice are provided. Current and projected surveillance needs, as well as potential sources of data, are examined. The proposed framework for conducting environmental public health surveillance involves data from three points in the process by which an agent in the environment produces an adverse outcome in a host: hazards, exposures, and outcomes.

Environmental health practitioners should build on efforts in other fields (e.g., infectious diseases and occupational health) to establish priorities in the surveillance of health conditions associated with exposure to environmental toxicants. For specific surveillance programs, existing data systems, as well as data gaps, should be identified. Coordinated surveillance systems can facilitate public health efforts to prevent and control disease, injury, and disability related to the interaction between people and their environment. (*Am J Public Health.* 1996;86:633–638)

Introduction

For federal, state, and local health departments, environmental health—the prevention and control of health problems related to the environment—is an essential function. The process by which an agent—biological, chemical, or physical—in the environment produces an adverse outcome in a host can be depicted in a "hazard-exposure-outcome" axis (Figure 1). While all steps in this axis are necessary for an agent to produce an adverse outcome, both the relative importance of each step and the time necessary to move from one step to the next may vary among agents.

Public health surveillance has been defined as the ongoing systematic collection, analysis, and interpretation of data on specific health events affecting a population, closely integrated with the timely dissemination of these data to those responsible for prevention and control.[1] While this definition focuses on health outcomes (e.g., diseases, disabilities, or injuries), surveillance of hazards (or risk factors) and exposures is also critical to environmental public health practice (Figure 1). Hazard surveillance is the "assessment of the occurrence of, distribution of, and the secular trends in levels of hazards (toxic chemical agents, physical agents, biomechanical stressors, as well as biological agents) responsible for disease and injury."[2] Exposure surveillance is the monitoring of individual members of the population for the presence of an environmental agent or its clinically inapparent (e.g., subclinical or preclinical) effects.

Three of the functions of a surveillance system are critical to its usefulness for environmental public health.[1] First, the system must enable measurement of specific hazards (e.g., air pollutants), exposures (e.g., blood lead), or health outcomes (e.g., asthma). Second, it must produce an ongoing data record; although one-time surveys or sporadic epidemiologic studies are valuable to public health, they are distinct from surveillance activities. Third, it must produce timely and representative data that can be used in planning, implementing, and evaluating public health activities.

The uses of surveillance data can be categorized according to timeliness. For detecting epidemics, unusual clusters of specific birth defects (by use of automated triggers defined by sentinel health events) signal instances in which public health officials should respond immediately.[3] In addition, such a system may enable detection of newly emerging conditions[4] (e.g., toxic shock syndrome and the eosinophilia–myalgia syndrome). Detection of changes in health practice could be signaled by an increase in the use of over-the-counter medications for asthma. Changes in antibiotic-resistance patterns may lead physicians to change their prescription practices or researchers to

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Editor's Note. See related editorial by Levy (p 624) and annotation by Morabia (p 625) in this issue.

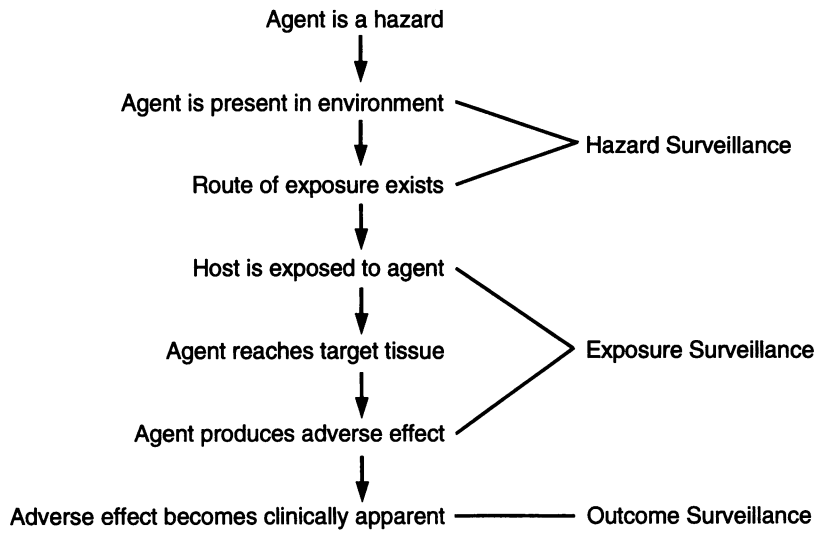

FIGURE 1—The process by which an environmental agent produces an adverse effect and the corresponding types of public health surveillance.

alter their priorities. Data from the Environmental Protection Agency, the US Bureau of the Census, and the National Health Interview Survey can be used to relate risk of illness among defined populations (e.g., asthma in children) to air quality.[5]

In the United States, decisions affecting public health policy and allocation of resources usually are made yearly in conjunction with government budgets. Timely annual data summaries would provide immediate estimates of the magnitude of a health problem, thus assisting policymakers to modify priorities and plan intervention programs.[6] These same data would be useful to those assessing control activities and would help researchers establish priorities in applied epidemiology and laboratory research. In addition, reviewing surveillance data annually can facilitate the testing of hypotheses related to prevention and intervention efforts (e.g., ocular injuries associated with fireworks).[7] As intervention programs are evaluated and priorities are set, policymakers must evaluate the effects of the programs on populations (e.g., protective measures to reduce the threat of lead toxicity in workplaces[8]).

Surveillance data should be retained in readily accessible archival form, not only to document the evolving health status of a population but also to help us understand the predictors of disease and injury. These data should be of the best possible quality and should be made available for research, including that conducted by individuals not affiliated with the government. Carefully maintained archival data can provide the most accurate portrayal of the natural history of a disease in a population. For example, mortality attributed to smoking in women in the United States has now surpassed mortality attributed to breast cancer. To measure effectively the long-term effects of public policies or social changes, researchers must have access to archival surveillance and health information systems. For example, the effect of programs encouraging women to stop smoking could be apparent from archival data on lung cancer mortality.[9] In addition, archival surveillance information can be used to validate interim data.

The surveillance of infectious diseases, chronic diseases, injuries, and occupational health has been treated elsewhere.[10–12] In this paper, we focus on those aspects of environmental public health surveillance that have not been considered adequately (e.g., exposure to environmental toxicants). First, we address special issues related to environmental public health surveillance. Second, we present a framework for categorizing systems for environmental public health surveillance and illustrate the framework with examples. We also list selected data sources for those conducting environmental public health surveillance (see Table 1).

Special Issues in Environmental Public Health Surveillance

While not unique to environmental public health, four issues are of particular concern to those who practice in this arena. First, our ability to identify the specific environmental causes of many adverse outcomes is limited. This is especially true for adverse outcomes that occur long after exposure and are caused by an agent that does not persist in the body; does not produce an easily detected, unique effect or marker; or does not occur in a setting (e.g., occupational) where there is a readily identifiable, significant hazard. Although adverse outcomes have been linked to many biological and physical agents, very few of the millions of known chemical agents have been studied adequately.[13] Although the causes of some adverse outcomes may be unique (e.g., mercury poisoning, which causes acrodynia among children), many adverse outcomes have multiple causes, some of which may not be environmental.[14]

Second, data collected for other purposes may not be sufficient for environmental public health surveillance.[15] For example, data from vital records or disability claims rarely contain sufficient information to meet a case definition for a condition caused by an environmental exposure. Other limitations of such data sources may include lack of timeliness of data collection or data availability, incomplete data on outcomes, nonrepresentativeness of the population, and problems with data quality[16] (Table 1).

Third, although all public health decisions are made in a social context, in environmental public health, public alarm is quite common and may often be out of proportion to the hazard itself.[17] Thus, sentiment rather than science may influence environmental public health policy disproportionately.

Fourth, biological markers are likely to become critical elements of environmental exposure surveillance, just as they are critical to surveillance of infectious diseases.[18] Like most infectious biological agents, some chemical agents and noninfectious biological agents can be measured directly or produce a specific immune response in their host that usually persists after the adverse outcome (e.g., chronic renal problems linked to cadmium exposure or various allergenic dusts).[19,20]

TABLE 1—Selected US National Data Sources That Support Environmental Public Health Surveillance

Title	Category	Scope	Responsible Organization(s)	Source(s) of Data	Dates	Limitations of Data
Aerometric Informational Retrieval	H	National	Environmental Protection Agency	Air monitoring sites	1970–present	T
Ambulatory Sentinel Practice Network for North America	O	National[a]	Ambulatory Sentinel Practice Network	Family physicians	1981–present	T, I, R, N
Drug Abuse Warning Network	E, O	National	National Institute on Drug Abuse	Emergency rooms, medical examiners/coroners	1972–present	I, R, Q
Hazard Substances Emergency Events Surveillance System	H, O	5 states	Agency for Toxic Substances and Disease Registry	State agencies, hospitals, fire/police departments	1990–present	T, I, R, Q, N
Hazardous Materials Information System	H, O	National	Department of Transportation	Highway patrol	1971–present	I, R, N
Medical Examiner/Coroner Information Sharing System	E, O	National[a]	Centers for Disease Control and Prevention	Medical examiners/coroners	1990–present	T, R, Q
Medicare Provider Analysis and Review	O	National	Health Care Financing Administration	Office-based medical practices, hospital discharge data	1992–present	T, I, R, Q, N
McAuto	O	National[a]	McDonnell-Douglas Corp	Hospital discharge abstracts	1982–present	T, I, R, Q, N
National Ambulatory Medical Care Survey	O	National	National Center for Health Statistics	Ambulatory care providers	1974–1981, 1985, 1990	T, I, N
National Disease and Therapeutic Index	E, O	National	IMS Inc	Office-based medical practices	1960–present	T, I, N
National Exposure Registry	H, E	National	Agency for Toxic Substances and Disease Registry	Personal interviews	1989–present	T, R, Q, N
National Health Assessment and Nutrition Examination Survey	E, O	National	National Center for Health Statistics	Population survey respondents	1971, 1976, 1982, 1988	T, N
National Health Interview Survey	H, O	National	National Center for Health Statistics	Household interview respondents	1957–present	T, I, N
National Hospital Discharge Survey	O	National	National Center for Health Statistics	Hospital discharge abstracts	1965–present	T, I, N
Professional Activities Study	O	National	Commission of Professional and Hospital Activities	Hospital discharge abstracts	1953–present	T, I, R, Q, N
Surveillance, Epidemiology, and End Results Program	O	National[a]	National Cancer Institute, National Institutes of Health	Cancer registry	1973–present	T, R, N
Toxic Release Inventory	H	National	Environmental Protection Agency	Industry	1987–present	T, Q
Vital records	O	National	National Center for Health Statistics, states	Death certificates, birth certificates	1925–present	I, Q
Water Data Storage and Retrieval System	H	National	Department of the Interior, US Geological Survey	Multiple soil and water sites	1880–present	T

Note. References to these systems are available from the authors on request. H = hazard; E = exposure; O = outcome; T = not timely; I = incomplete data on outcomes; R = not representative; Q = poor data quality; N = useful at national, regional, or state level only.
[a]Includes selected states or localities only.

A Framework for Environmental Public Health Surveillance

To address these issues, we propose three types of surveillance for use in environmental public health: hazard surveillance, exposure surveillance, and outcome surveillance. If a clear link has been documented between a hazard and an adverse health outcome, there is a route of exposure to the hazard, and the hazard can be readily monitored in the environment, then hazard surveillance offers the best potential for early intervention and prevention. If the hazard cannot be monitored readily but there is a marker for exposure to the hazard, then exposure surveillance would provide information to inform the earliest opportunity for intervention. Finally, if an important public health outcome has a suspected (but undocumented) relationship to an environmental hazard, then outcome surveillance, in combination with etiologic studies, is warranted.

It is important to emphasize that these types of surveillance are complementary, and the optimal strategy for preventing or reducing the impact of a specific public health problem often dictates the use of all three types of surveillance. For example, outcome surveillance may be used to document the disease burden in the population.[10] Hazard surveillance may be used to identify new relationships between hazards and outcomes. Exposure and outcome surveillance may also provide valuable information for evaluating the effectiveness of hazard reduction programs.[21] We illustrate this framework with examples of each type of surveillance from environmental public health practice.

Hazard Surveillance: Air Pollutants

Environmental air monitoring data from more than 4200 state and local monitoring sites in the United States are collected and published routinely for six air pollutants covered by national air quality standards (carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide).[22] These data are used to monitor compliance with standards for these six pollutants under the Clean Air Act.[23] The data are also used to enforce emission control laws for cars,[24] and, in some cities, they provide the basis for hazard alerts or press releases to encourage restricted work and other outdoor activity on days when pollutants are forecast to exceed federal standards. Better collaboration between state air pollution agencies and state and local health departments could lead to even more effective use of these environmental public health surveillance data.

Exposure Surveillance: Childhood Lead Poisoning

The results of blood lead testing among children are used to monitor exposure to lead and to assess the effectiveness of programs designed to reduce environmental lead hazards.[25] The use of these data for program management is illustrated by the system implemented by the New Mexico Department of Health.[26] The New Mexico prevention program developed legislation, documented lead poisoning outside high-risk metropolitan areas, and provided hypotheses to investigators seeking to identify sources of lead other than paint (e.g., traditional medicines and ceramic ware). Complementary data from repeated administrations of the National Health and Nutrition Examination Survey have documented the national impact of reduction of lead in gasoline on the incidence of lead poisoning.[27]

Outcome Surveillance: Birth Defects

The Metropolitan Atlanta Congenital Defects Program and the national Birth Defects Monitoring Program, together with data from 28 state birth defect monitoring programs, are used to monitor trends in specific birth defects or combinations of defects.[28] Because there is population-based ascertainment of both case and control subjects, these data facilitate epidemiologic research and have been used to study the teratogenicity for several exposures of potential public health concern, including exposure to spray adhesives,[29] airport noise,[30] and military service in Vietnam.[31]

Combination of Data Sources

Environmental public health surveillance often requires more information than is available from a single source and is complicated by the limited availability of incidence data, incomplete case ascertainment, and changes in record keeping. The combination of monitoring data for environmental hazards and data from vital records, recurrent exposure surveys, registries, and office records may be necessary to assess the occurrence of and trends in environmental hazards and their related outcomes.

The national surveillance system for asthma illustrates the use of multiple data sources for outcomes to monitor a particular health problem. This system uses data from vital records, the National Hospital Discharge Survey, the National Ambulatory Medical Care Survey, and the National Health Interview Survey to show an increase during the 1980s in the burden of asthma in the United States as measured by morbidity, mortality, and disability, especially among urban and minority populations.[32]

An example of a surveillance program combining hazard, exposure, and outcome data is that for environmental lead and its effects. Lead is one of the six priority air pollutants monitored all over the country[33]; surveys of selected housing stock are done regularly in some cities to identify housing with a lead hazard,[34] and lead is monitored in the air in some workplaces.[35,36] Exposure to lead is monitored in blood screening programs for children[37] and in workers at risk.[38] Vital statistics systems can be used to identify deaths due to lead poisoning.[39]

Discussion

In the United States, all states monitor food, air, and water, as mandated by law. The exposure levels set by this legislative mandate, however, may still permit environmentally related illness.[40,41] According to a recent survey, only eight state health departments have responsibility for environmental public health; in other states, departments of the environment or of natural resources are separate from the health department.[42] Furthermore, lead poisoning and pesticide poisoning are the only two environmental health conditions for which states routinely conduct surveillance in the general population.[43] Unless the interaction between practicing public health professionals and their counterparts in environmental public health is fostered, the use of surveillance data for disease prevention and health promotion may be constrained.[44]

For example, environmental public health surveillance should take advantage of what has been learned by those conducting surveillance in occupational health. First, there is a need to establish outcomes on the basis of their public health importance and amenability to prevention or control measures. Thus, the National Institute for Occupational Safety and Health has focused its surveillance efforts on 10 leading work-related diseases and injuries.[45] Second, the most successful use of surveillance in prevention and control of occupational diseases

and injuries has been in those situations in which there is a clearly recognized relationship, usually demonstrated through epidemiologic or laboratory studies, between a hazard and an adverse outcome (e.g., lead-based paint and blood lead levels).[46] Third, a combination of hazard, exposure, and outcome surveillance is optimal once a relationship has been established between a specific hazard and a specific outcome. Hazard surveillance should form the foundation of prevention and control efforts,[2,47] and exposure and outcome surveillance can serve to identify failures of—and the need to institute, modify, or enforce—prevention and control programs.[36] Finally, data from outcome surveillance can be used to identify increases in diseases or injuries of unknown or previously unrecognized causes and, when used in conjunction with data from hazard or exposure surveillance, may suggest relationships to specific hazards that warrant further study (e.g., house dust and childhood asthma).[48]

National, state, and local health and environmental agencies should move rapidly to establish effective systems of environmental public health surveillance. As an initial step, local, state, and national environmental health practitioners should identify health conditions associated with exposure to environmental hazards and determine, through a consensus, which conditions and hazards should have priority in surveillance efforts. While priority setting is always challenging and sometimes contentious, the national experience with the development of health status indicators suggests that such endeavors can be undertaken effectively.[49] That experience also illustrates the need to retain the flexibility to modify priorities over time.

Next, health officials need to identify useful existing data systems, as well as gaps in these data systems that need to be filled by new sources. In addition to the effort to establish health status indicators, the process used by the Occupational and Environmental Health Committee of the Council of State and Territorial Epidemiologists may serve as a model, both for setting priorities and for identifying gaps on existing data systems.[50] Finally, analytic methods to aid in the identification of associations between environmental hazards and adverse health events need to be explored aggressively.[51] Development of this "public health surveillance infrastructure" could produce a coordinated system for preventing and controlling disease, injury, and disability related to the interaction between people and their environment. □

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Comment: Toward a Coordinated System for the Surveillance of Environmental Health Hazards

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ABSTRACT

The rapid increases in the numbers and quantities of chemicals released into the environment have been accompanied by a lack of adequate prerelease testing for adverse health outcomes. Environmental health surveillance is used both to track changes in exposures that are known to have adverse health effects and to identify previously unrecognized hazards. Surveillance data can directly aid in the design of interventions to reduce the level of hazardous agents in the environment or the opportunities for human contact with them. Components of an ideal environmental health surveillance system are discussed. For well-recognized hazards, databases related to exposure alone are adequate. However, for uncovering previously unrecognized associations, linkage between exposure and outcome databases that are collected or aggregated at the same geographic scale and for regions of relatively homogeneous exposures are needed. (*Am J Public Health.* 1996; 86:638–641)

Introduction

The enormous number and variety of chemicals that have been introduced into the environment in the last few decades have caused considerable concern among the populations of both developed and developing countries. Annual releases of toxic pollutants into the air amount to over 2 billion pounds, with a similar amount released into surface water, land or underground.[1] In 1988, 22 air pollutants exceeded the health reference level (a level considered "safe" by the US Environmental Protection Agency [EPA]) at more than 25% of sites studied.[2] Agents of concern are found not only in industrial emissions and pesticides applied in agriculture, to buildings, and on roadsides, but also in food additives and constituents of commercial products such as carpets, furniture, household cleaning agents, art supplies, toys, and cosmetics. For most chemicals other than drugs and food additives, testing for long-term or chronic health effects is not required in the United States and is rarely done. A program of testing for carcinogens has produced an important database covering hundreds of chemicals,[3] but this number is a minute fraction of agents released into the environment. Even so, this number is far higher than the number of chemicals that have been tested for reproductive toxicity, neurologic effects, cardiovascular impact, etc. In the absence of adequate prerelease testing, systematic monitoring for adverse health effects would seem rational and appropriate.

Surveillance in environmental health is a strategy for identification of hazards in the environment that cause substantial death, disease, or disability, in order to facilitate the goal of prompt removal or reduction of exposures to the offending agents. Kline et al.[4] suggest a distinction between surveillance and monitoring: surveillance is the ongoing collection of data of all kinds on exposures or outcomes through time, while monitoring denotes the scrutiny of surveillance or other data for signals of excessive exposure or health effects that serve as indicators of effect, in

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