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Review Article

Environmental Epidemiology: Concepts, Components, and Implications for Public Health

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Abstract:

Environmental epidemiology is a subdiscipline of epidemiology that investigates how environmental factors including physical, chemical, biological, and social determinants affect human health. With the increasing complexity of environmental risks caused by industrialization, urbanization, and climate change, this field has become essential for identifying, measuring, and controlling exposures that contribute to both infectious and non-communicable diseases. This review summarizes the fundamental concepts of environmental epidemiology, focusing on the host agent environment interaction, the epidemiological triad, the web of causation, and the wheel model of disease causation. It also highlights the health impacts of major forms of pollution: contaminated water as a leading cause of gastrointestinal diseases, polluted air as a contributor to millions of premature deaths annually, and soil contamination as a source of long-term toxic risks through the food chain. By consolidating these perspectives, the review underscores the value of environmental epidemiology in clarifying causal relationships, guiding preventive strategies, and shaping evidence-based public health policies. In the context of global environmental change, strengthening environmental epidemiology through interdisciplinary approaches, improved exposure assessment, and equity-focused interventions is critical to building resilient communities and ensuring sustainable public health protection.

Keywords: Environmental Epidemiology; Epidemiological Triad; Environmental Pollution; Public Health; Exposure Response.

1. Introduction

Environmental epidemiology is a scientific discipline that examines how environmental factors including physical, chemical, biological, and social determinants affect the health of individuals and populations. Over the past few decades, environmental exposures have become increasingly complex due to rapid industrialization, urbanization, and climate change, all of which have intensified the prevalence of pollution in water, air, and soil (1). According to the World Health Organization (WHO), an estimated 24% of global deaths are linked to modifiable environmental factors, including unsafe water, poor sanitation, and air pollution (2). Moreover, air pollution alone is responsible for approximately 7 million premature deaths annually, primarily from respiratory and cardiovascular diseases (3). These data highlight the urgency of addressing environmental determinants of health as part of global public health priorities.

Unlike traditional epidemiology, which often focuses on direct host pathogen interactions, environmental epidemiology emphasizes the broader ecological and social context in which diseases arise. Its primary objective is to identify exposure effect relationships, demonstrate causal links through dose response associations, and provide a scientific basis for preventive interventions. This discipline also incorporates innovative tools such as biological markers for exposure monitoring, allowing for more accurate assessments of health risks.

Despite its growing importance, significant knowledge gaps remain in environmental epidemiology. Long-term low-level exposures are often difficult to quantify, the synergistic effects of multiple pollutants are challenging to separate, and the health impacts of climate change introduce new complexities (4,5). Vulnerable populations such as children, the elderly, and residents of low- and middle-income countries face disproportionate risks, underscoring the need for equity-focused environmental health policies. For example, the Lancet Commission on Pollution and Health (2022) reported that pollution is responsible for over 9 million deaths per year, with the heaviest burden borne by disadvantaged populations (6).

Given these challenges, this review article aims to synthesize the fundamental concepts of environmental epidemiology, including its components (host, agent, and environment) and conceptual models of disease causation. It also highlights the impact of environmental pollution specifically water, air, and soil contamination on public health. By consolidating these perspectives and incorporating global evidence, the article underscores the critical role of environmental epidemiology in guiding public health interventions, shaping environmental regulations, and strengthening community resilience in the face of global environmental change.

2. Main Body / Subheadings

Definition of Environmental Epidemiology

Environmental epidemiology is a subdiscipline of epidemiology that investigates the influence of environmental exposures on human health. It focuses on understanding the interactive dynamics between populations and their physical, chemical, biological, and social surroundings that pose potential health risks (7). Unlike occupational epidemiology, which often deals with high-level exposures in workplace settings, environmental epidemiology also addresses low-level, chronic exposures affecting entire populations. Recent methodological advances include the use of biological markers (biomarkers) to assess internal dose and biological effect, allowing more precise monitoring of exposure pathways and disease outcomes (8).

Benefits of Environmental Epidemiology

The benefits of environmental epidemiology are twofold. First, it provides scientific evidence for causality between environmental exposures and disease outcomes, which can be translated into effective public health policies (9,10). Second, it helps identify vulnerable groups who are disproportionately affected by environmental hazards. In an era of increasing environmental pollution, the discipline plays a strategic role in evaluating the health impacts of contaminants in air, water, and soil, enabling governments to design targeted interventions and regulations. Furthermore, it contributes to risk assessment frameworks, ensuring that exposure thresholds are grounded in epidemiological evidence rather than theoretical estimates alone.

Core Components of Environmental Epidemiology

Environmental epidemiology is traditionally guided by three interrelated components, often represented in the epidemiological triad:

a. Agent: Refers to the factor responsible for causing disease. It may include biological organisms (bacteria, viruses, parasites), chemical pollutants (heavy metals, pesticides, industrial effluents), or physical factors (radiation, noise, temperature extremes) .
b. Host: Refers to individuals or populations that are exposed to agents. Host susceptibility is determined by demographic characteristics (age, sex, ethnicity), biological status (immunity, genetics, comorbidities), and behavioral factors (diet, occupation, lifestyle).
c. Environment: Encompasses external conditions that affect exposure likelihood and health outcomes. This includes physical environments (air, water, soil), biological settings (population density, vector habitats), and socioeconomic environments (income, education, occupational safety) .

Together, these elements form the foundation for analyzing disease causation and distribution in environmental epidemiology.

Conceptual Models of Disease Causation

a. Epidemiological Triad

The classic epidemiological triad conceptualizes disease occurrence as the result of interactions between host, agent, and environment (10). An imbalance among these three elements increases the likelihood of disease. For example, air pollution (agent), combined with poor urban air quality (environment), disproportionately affects elderly individuals with pre-existing respiratory conditions (host).

b. Web of Causation

This model emphasizes that most diseases arise from multiple interrelated factors rather than a single cause. It highlights that interventions can disrupt the disease process by targeting one or more links in the causal chain. For instance, cardiovascular disease risk can be mitigated by reducing exposure to fine particulate matter (PM2.5), improving access to clean food and water, and promoting healthier lifestyles.

c. Wheel Model

The wheel model illustrates the interaction between genetic susceptibility and environmental influences (11–13). The genetic core represents host factors, while surrounding environmental sectors (biological, physical, social) influence disease risk. In hereditary diseases, genetic contributions may dominate, while in communicable diseases like malaria, environmental factors such as vector density and sanitation play greater roles.

Environmental Pollution and Health

Water Pollution

Water pollution occurs when biological, chemical, or physical contaminants degrade water quality. Polluted water is a major source of diarrheal diseases, accounting for approximately 485,000 deaths annually worldwide (WHO, 2023) (1). Common sources include industrial effluents, agricultural runoff, and domestic sewage. Heavy metals such as lead, mercury, and arsenic in water supplies are linked to neurotoxicity, kidney damage, and increased cancer risk.

Air Pollution

Air pollution is one of the leading environmental risk factors globally. Pollutants include gases such as carbon monoxide, sulfur dioxide, nitrogen oxides, ozone, and particulate matter (PM2.5 and PM10) (14,15). The WHO estimates that air pollution contributes to 29% of all lung cancer deaths, 24% of stroke deaths, and 43% of chronic obstructive pulmonary disease (COPD) deaths. Urbanization and fossil fuel combustion remain the primary drivers. Children and the elderly are particularly vulnerable, and long-term exposure is associated with systemic inflammation, cardiovascular disease, and reduced life expectancy.

Soil Pollution

Soil pollution refers to the contamination of soil by hazardous substances, including pesticides, plastics, radioactive materials, and industrial waste (16). Contaminated soil reduces agricultural productivity and introduces toxins into the food chain. For instance, pesticide residues are linked to endocrine disruption, while radioactive waste increases cancer risk. Informal waste disposal in low-income countries exacerbates soil contamination, disproportionately affecting marginalized populations.

3. Conclusion

Environmental epidemiology offers a critical framework for understanding how environmental exposures shape human health by integrating the interactions of agents, hosts, and environments, while conceptual models such as the epidemiological triad, web of causation, and wheel model highlight the multifactorial nature of disease causation. Its application is particularly urgent in addressing water, air, and soil pollution, which remain major public health challenges globally, contributing to infectious diseases, chronic conditions, and long-term toxic risks through the food chain. By providing evidence-based insights into exposure–effect relationships, environmental epidemiology not only clarifies causal links but also informs policies, guides preventive interventions, and identifies vulnerable populations most at risk. In an era of climate change, industrialization, and rapid urbanization, strengthening this discipline through interdisciplinary approaches, advanced exposure assessment, and equity-driven policies is essential for building resilient communities and ensuring that environmental health is firmly embedded in the foundation of global public health strategies.

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