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Environmental health models: A literature review

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Abstract
Colombia and Latin America show limited implementation of environmental health projects; furthermore, the literature reveals few models of approach, conceptual frameworks, or reference guidelines to support their development. Therefore, it is necessary to contribute to the construction of general models for addressing environmental health, which may serve as the foundation for future research and practical applications. A systematic review was conducted in Scopus, Science Direct, IEEE Xplore, and Google Scholar using the search terms "Environmental health model" or "Environmental quality model" and "Framework" or "Indicators" or "Government" or "Information system". Only documents, reports, and articles describing models, guidelines, or conceptual frameworks for addressing environmental health were included. In total, 24 studies were selected and analyzed. The review identified three main elements for the development of environmental health projects. First, guidelines provide a set of steps and phases to implement such projects, based on previous experiences. Second, the context of analysis determines the scope and focus of the model or strategy. Third, the indicators to be used offer a quantitative means of evaluation. The selection of appropriate indicators for a given assessment depends on various factors, such as country, population, topography, and type of community. No general model or universally applicable set of indicators was identified; rather, indicator selection is context-dependent and varies according to the characteristics of the study area or region. This highlights the need for adaptable frameworks and the importance of integrating diverse data sources to support informed decision-making in environmental health.

Keywords
Environmental health, environmental indicators, information and communication technologies, framework, systematic review.

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Modelos de Salud Ambiental: Una revisión de la literatura

Resumen

Colombia y América Latina presentan poca implementación en proyectos de salud ambiental; además, en la literatura se encuentran pocos modelos de abordaje, marcos conceptuales o lineamientos de referencia que respalden su implementación. Por ello, se hace necesario contribuir a la construcción de modelos generales para el abordaje de la salud ambiental, los cuales pueden sentar las bases para futuras investigaciones y aplicaciones prácticas. Se realizó una revisión sistemática en Scopus, Science Direct, IEEE Xplore y Google académico utilizando los términos de búsqueda "Modelo de salud ambiental" o "Modelo de calidad ambiental" y "Marco" o "Indicadores" o "Gobierno" o "Sistema de información". Solo se seleccionaron documentos, informes y artículos que describieran modelos, lineamientos o marcos conceptuales para el abordaje de la salud ambiental. En total, se seleccionaron y analizaron 24 estudios. La revisión permitió establecer tres elementos principales para el desarrollo de proyectos de salud ambiental. En primer lugar, las guías o lineamientos brindan un conjunto de pasos y fases para llevar a cabo este tipo de proyectos basados en experiencias previas. En segundo lugar, el contexto de análisis, que determina el alcance y enfoque del modelo o estrategia. En tercer lugar, los indicadores a utilizar, que proporcionan un medio cuantitativo de evaluación. La selección del indicador apropiado para una evaluación en particular depende de diversos factores, como el país, la población, la topografía, el tipo de comunidad. No se logró identificar un modelo general ni un conjunto de indicadores universalmente aplicables; por el contrario, la selección de indicadores es dependiente del contexto y varía según las características de la zona o región de estudio. Esto resalta la necesidad de contar con marcos adaptables y la importancia de integrar diversas fuentes de datos que respalden una toma de decisiones informada en salud ambiental.

Palabras clave

Salud ambiental, Indicadores Ambientales, Tecnologías de la Información y la Comunicación, Marco Conceptual, Revisión Sistemática.

Modelos de Saúde Ambiental: Uma Revisão da Literatura

Resumo

A Colômbia e a América Latina apresentam poucas implementações reais de projetos em saúde ambiental; além disso, poucos modelos de abordagem, marcos conceituais ou diretrizes de referência são encontrados na literatura que apoiem sua implementação. Portanto, é necessário contribuir para a construção de modelos gerais para o enfrentamento dos estudos em saúde ambiental, os quais podem estabelecer as bases para futuras pesquisas e aplicações práticas. A revisão sistemática foi realizada nas bases de dados Scopus, Science Direct, IEEE Xplore e Google Scholar, utilizando os termos de busca: "modelo de saúde ambiental" ou "modelo de qualidade ambiental" e "marco conceitual" ou "indicadores" ou "governo" ou "sistema de informação". Foram selecionados apenas documentos, relatórios e artigos que descrevem modelos, diretrizes e marcos para o enfrentamento de questões relacionadas à saúde ambiental. Um total de 24 estudos foi selecionado e analisado. A revisão da literatura possibilitou identificar três elementos principais para o desenvolvimento de projetos em saúde ambiental. Primeiro, as diretrizes, que fornecem um conjunto de etapas e fases para a execução desses projetos com base em experiências anteriores. Segundo, o contexto de análise, que determina o escopo e o foco do modelo ou estratégia. Terceiro, os indicadores a serem utilizados, que fornecem uma base quantitativa para avaliação. A escolha de indicadores adequados depende de diversos fatores contextuais, incluindo o país, a população, a topografia e o tipo de comunidade. Não foi identificado um modelo geral nem um conjunto de indicadores universalmente aplicáveis; ao contrário, a seleção de indicadores depende do contexto e varia conforme as características da área ou região de estudo. Isso ressalta a necessidade de marcos flexíveis e a importância de integrar diversas fontes de dados para apoiar a tomada de decisões informada em saúde ambiental.

Palavras chave

Saúde Ambiental, Indicadores Ambientais, Tecnologias da Informação e Comunicação, Estrutura Conceitual, Revisão Sistemática.

Introduction

Human health is influenced by a wide range of environmental factors, including air, water, noise, and other conditions. These factors affect not only physical health but also mental and psychosocial well-being. Globally, an estimated 23% of deaths (12.6 million in 2012) are attributable to environmental causes (1). More recent estimates confirm that environmental pollution remains responsible for approximately 9 million premature deaths annually, particularly in low- and middle-income countries, underscoring the persistent global burden of environmental health risks (2).

In Colombia, the situation is no different. It is estimated that 17% of the national disease burden (approximately 46,000 deaths per year) is attributable to environmental factors (3). According to a 2019 national report by the Instituto Nacional de Salud, nearly 17,549 annual deaths in the country are associated with air and water pollution, the use of solid fuels, and heavy metal exposure (4). To analyze this phenomenon, environmental health specialists study the impact of environmental conditions on human health.

Some efforts have been undertaken in Colombia. First, certain environmental issues were incorporated into the 1991 National Constitution. Second, the National Health Code was enacted to regulate gas emissions, water quality, and solid waste management (3, 5). However, these efforts have had limited impact. Few government divisions are dedicated specifically to environmental health, and most projects in this area address either health or environmental issues in isolation, which hinders holistic approaches to environmental health (6). This fragmentation is also evident across Latin America, where, despite frameworks for intersectoral health–environment action, major implementation gaps persist (7).

Several challenges contribute to this situation, including budgetary constraints, administrative barriers to accessing information, difficulties integrating heterogeneous data sources, and the absence of standardized indicators (8). The use of new data sources (e.g., satellite information, IoT sensors) and big data techniques is also limited by insufficient technical capacity, inconsistent data governance, and weak infrastructure for environmental information systems (9).

Moreover, few models or guidelines for environmental health analysis exist in the literature. Among the methods proposed (3, 5, 10), most emphasize theoretical approaches and lack technical considerations for implementation or validation. One notable exception is the Protocol for Assessing Community Excellence in Environmental Health (PACE EH), developed by the National Center for Environmental Health (NCEH), which provides a framework for conducting community-based environmental health assessments (11). PACE EH has been implemented in the United States and other countries (8, 12). More recently, newer frameworks have been suggested to integrate climate and environmental drivers with health outcomes through systems-based approaches (13), which helps to structure complex health–environment interactions for improved decision-making.

In this context, the present study represents an initial step toward unifying concepts and reviewing the state of the art on frameworks, guidelines, and information systems for environmental health assessment.

Methods

The purpose of this section is to present the analysis of previous experiences in environmental health assessment. This study aimed to identify conceptual and technical aspects that contribute to the development of the project. The review followed the *PRISMA 2020 statement: an updated guideline for reporting systematic reviews* (14, 15), selected to minimize bias and provide more reliable results to inform conclusions and decision-making. The process included five stages: (1) definition of the research question, (2) search strategy, (3) screening and eligibility, (4) data extraction, and (5) quality assessment. The review included journal articles, technical reports, and government documents.

Research Question

Before formulating the research questions, key concepts relevant to this study were standardized, given that terminology varies across authors:

- Environmental health: Refers to the effects of environmental factors on human health, resulting in illnesses or injuries. Environmental health assessment comprises all activities designed to gather data for analyzing the impact of the environment on human health. This may include pathological, biological, geographical, and social studies related to urban development, transportation, agriculture, and other factors (11).

- Indicator: A numerical representation describing environmental and health conditions (e.g., solid waste, SOx emissions, PM10). Indicators synthesize measurement data and enable transparent reporting of results.
- Index: A summary measure derived from a mathematical formula that establishes a quantitative value within a defined context (e.g., water, air) and area of analysis (e.g., urban).
- Model: The organization of indicators and indices into hierarchical levels of abstraction. Models standardize and structure values to estimate environmental health status.

Based on these definitions, the following research questions were posed:

1. Is there a general model or indicator for studying environmental health? This question seeks to identify how models and indicators are applied in environmental health assessments. Although Colombia has some indicators, the focus is on analyzing how they are calculated or applied in other countries.
2. What variables are considered in environmental health studies? This question aims to identify the main variables included in environmental health assessments.
3. Which institutions are involved in environmental health research? This question explores how different organizations collaborate in such projects.
4. What types of data sources are used in environmental health projects? This question seeks to identify the range of data sources employed.

Search Strategy

Primary data sources included scientific journals, conference proceedings, government documents, and technical reports. The keywords selected were *"Environmental health model," "Assessment," "Framework," "Indicators," "Government,"* and *"Information system."* PubMed was not included, as it focuses primarily on clinical studies.

Potential biases were considered throughout the review process:

- Geographic limitation: None applied.
- Databases included: Scopus, IEEE Xplore, ScienceDirect, and Google Scholar.
- Type of documents: Literature reviews and systematic reviews.
- Language: Articles published in English and Spanish.
- Access: Only free, open access, or otherwise accessible full texts.
- Gray literature: Not included.

Because each database returns results differently, simple search strings with up to two keywords, combined with variations of the phrase *"environmental health,"* were used. Table 1 presents the consolidated results from the initial search.

Table 1. Bibliographic search output by keyword and source

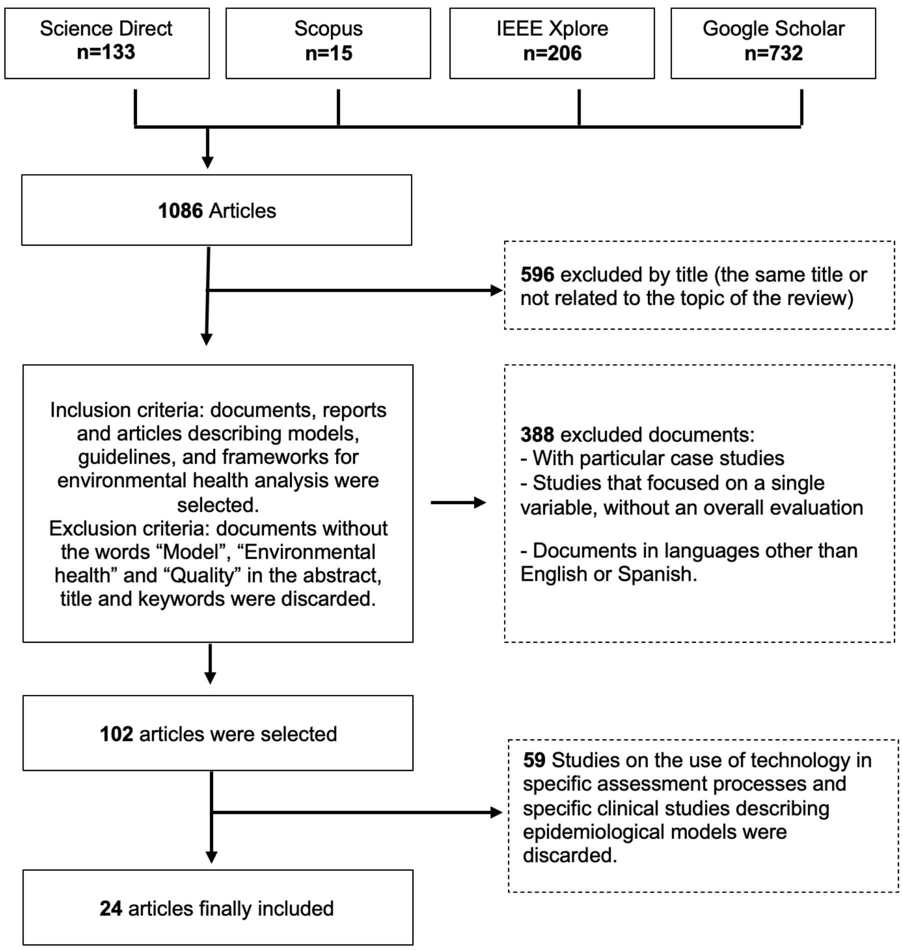
Term 1	*Term 2*	*Google Scholar*	*Scopus*	*Science Direct*	*IEEE Xplore*	*Total*
Environmental Health Model	Assessment	94	4	23	43	164
	Framework	85	1	14	11	111
	Indicators	63	1	14	6	84
	Government	74	3	8	15	100
	Information System	26	0	5	17	48
Environmental Quality model	Information System	45	1	5	35	86
	Indicators	177	2	30	35	244
	Government	168	3	34	44	249

Source: own elaboration.

Screening and Eligibility

Independent searches were conducted in each of the four selected databases. The titles, abstracts, keywords, and conclusions of the retrieved documents were reviewed to determine their relevance. The process of inclusion and exclusion of studies is illustrated in the flowchart presented in Figure 1.

Figure 1 Flowchart of the literature review



Source: own elaboration.

Results

The analysis of the selected articles was conducted according to the predefined classification categories and the research questions formulated. The results are presented in Table 2.

Table 2. Results of content classification from the literature review

Author	Variable	Actor	Implementation	Data Source	Mean
(Garc, C.A. *et al* 2013)	MA	G	N	N.A	J
(Escobar, 2016)	MA	U	Y	GO	J
(Li *et al.* 2008)	A	U	Y	PRI	J
(Corvalán, 1999)	W	WHO	Y	N.A	J
(Boulos *et al.* 2011)	TR, A, Tm	U	Y	OWN	J
(Dianelys *et al.* 2011)	MA	U	N	N.A	J
(Hubbard *et al.* 2005)	A, W	NGO	Y	OWN	J
(WHO 1999)	MA	WHO	N	NGO	TR
(Schütz *et al.* 2008)	MA	WHO	N	NGO	TR
(Garc, C. A. 2012)	A	G	N	OWN	J
(Rubio *et al.* 2016)	A	U	Y	OWN	J
(ENHIS 2005)	MA	WHO	Y	NGO	TR
(Knol *et al.* 2010)	MA	P	N	N.A	TR, J
(Fitzpatrick *et al.* 2010)	MA	U	N	N.A	J
(Health Ministry 2012)	MA	G	N	N.A	TR
(Tascomi 2018)	MA	G	Y	GO	TR
(Huang and Mingquing 2010)	MA	U	N	N.A	C
(Liu *et al.* 2012)	MA	G	N	GO	J
(Briggs 2008)	MA	G	N	GO-OWN	J
(Rodriguez *et al.* 2008)	A	U	Y	GO	TR
(Renalds *et al.* 2010)	H.Q	U	N	N.A	J
(Wang and Mchugh 2011)	A	G,U	Y	GO	J
(Vrijheid *et al.* 2016)	A	G, U	N	N.A	J
(Tarcan and Varol 2002)	MA	U	Y	OWN	J

Multivariable Analysis (MA), *Air* (A), *Water* (W), *Traffic* (TR), *Housing quality* (HQ); *Government* (G), *University* (U), *World Health Organization (*WHO), *Non-governmental organization* (NGO), *Private entity* (P); *Yes* (Y), *No* (N); *Non-governmental organization* (NGO), *Government organization* (GO), *Private* (PRI), *no implementation* (N.A); *Journal* (J), *Technical Report* (TR), *Conference paper* (C).

Source: own elaboration.

Overall Indicators for Environmental Health Assessment

Some overall indicators integrating multiple variables for environmental health assessment were identified in the literature (16). One model, for example, proposes the calculation of an urban quality index based on several indicators. Similarly, a World Health Organization (WHO) study defined diverse indicators for environmental health (17), while Schütz *et al.* (18) presented a Latin American and Caribbean initiative that examined the most representative "conceptual frameworks" in this field.

Organizations Involved in Environmental Health Research

Most initiatives were led by universities, while government participation was relatively limited (29%). Academic institutions accounted for 50% of the projects reviewed, government entities for 29%, and international organizations such as the

WHO for 20%. This distribution suggests that, although the concept of environmental health has been widely discussed, its presence in government agendas remains low. Furthermore, few projects involved university–government partnerships, even though such alliances—particularly those including community participation—are essential to achieving societal impact.

Implementation of Models and Frameworks

Of the 24 documents reviewed, only 11 (46%) described methodological or technological prototypes, while the remaining 54% did not present evidence of implementation. This finding reflects the predominance of theoretical work in environmental health, alongside more recent efforts to design and test practical solutions.

Variables Analyzed

Most studies examined multiple variables simultaneously, with air quality being the most frequently analyzed. Of the 24 documents, seven focused on air, two on water, one on traffic, one on temperature, and 13 on multiple variables. For instance, Escobar (10) proposed a Colombian model based on regional indicators; Hubbard *et al.* (12) applied the PACE-EH protocol, which emphasizes community participation; Corvalán *et al.* (19) proposed a cause–effect model for identifying relevant issues; and WHO (20) outlined a framework for a unified set of indicators.

While many studies prioritized air quality, others broadened the scope. For example, Puente *et al.* (29) conducted an environmental evaluation emphasizing air pollution, whereas Renalds *et al.* (30) considered housing quality as a key dimension of environmental health. This review highlights the trend toward integrating environmental variables with health outcomes, though additional aspects—such as waste management, urban infrastructure, and public space—also warrant inclusion.

Data Sources

Data sources varied considerably across studies, influencing accessibility and implementation. Government databases were used in 25% of projects, non-governmental organizations in 13%, and private or closed databases in 4%. Notably, 25% of projects generated their own data. For example, Rubio *et al.* (24) described a sensor-based system to evaluate chemical vapors, incorporating neural network classifiers for air quality assessment.

Most projects required integrating heterogeneous data sources, which entailed substantial technical effort. Nonetheless, 38% of the projects reviewed were never implemented, underscoring the persistent gap between theoretical frameworks and practical application.

Technological Approaches

From a technological perspective, most studies focused on systems to visualize or integrate environment–health relationships. Li *et al.* (21), for example, proposed a platform unifying geographic information systems, databases, and specialized tools through data mining techniques. Tascomi (22) developed a web-based system (PHP, Apache Server, PostgreSQL), while Wang *et al.* (23) presented an architecture based on metadata analysis.

Recent studies incorporated artificial intelligence techniques. Neural networks were applied to analyze toxic chemical vapors and odors using sensor networks composed of low-cost devices (24, 25). Other works simulated IoT-driven data flows and conducted trend analyses on emerging technologies for environmental health (26, 27)(19, 20).

Regarding the variables analyzed, of the 24 documents reviewed, seven focused on air, two on water, one on traffic, one on temperature, and 13 examined multiple variables in different contexts. For example, one information system was developed to visualize air quality by location and its associated health outcomes (23, 28). Corvalán, Kjellstrom, and Smith (19) presented a cause–effect analysis of water quality and its potential health implications, while Puente *et al.* (29) described an environmental evaluation emphasizing air pollution. This review revealed a prevailing trend toward analyzing environmental variables in relation to health outcomes. However, additional aspects should be incorporated into environmental health assessments, such as the number of trees planted, waste management, kilometers of paved roads, and encroachment on public spaces. For instance, Renalds *et al.* (30) highlighted housing quality as a key component of environmental health assessment.

Data sources were also identified as a critical factor, influencing accessibility and feasibility. Sources varied by case study and variable analyzed. Government databases were used in 25% of projects, while 13% relied on non-governmental organizations;

for example, Wang *et al.* (23) integrated data from multiple sources, including NGOs funding the project. Only one study (4%) employed private or closed databases that were not publicly accessible. Notably, 25% of projects generated their own data. For instance, Rubio *et al.* (24) described a system for evaluating chemical vapors using a sensor network that incorporated a neural network–based classifier to determine air quality. These findings underscore the diversity of data sources, as well as the substantial efforts required to integrate heterogeneous datasets. Finally, it was observed that 38% of projects were never implemented.

Discussion

This review identified key elements for the assessment and evaluation of environmental health. Environmental Health Indicators (EHIs) are essential tools for quantifying environmental conditions and their impacts on human health. Based on primary data obtained through environmental monitoring, EHIs enable comparative assessments across temporal, spatial, and demographic dimensions, contributing to the estimation of health outcomes from exposure to hazards such as air, water, and soil pollution (17).

A landmark study by the World Health Organization in Latin American cities demonstrated that the choice of indicators can substantially alter urban risk classifications. This underscores the need to contextualize EHIs and to critically assess the methodological assumptions underlying their use (17, 31). Similar dynamics have been documented in industrial regions, where the health impacts of pollutants have been evaluated using environmental risk models (32–34).

The literature has proposed various models and indicators to address environmental health. In Colombia, for instance, the Urban Environmental Quality Index evaluates urban sustainability through aggregated indicators at intermediate (Level II) and advanced (Level III) scales (10). Other frameworks, such as the Driver–Pressure–State–Impact–Response (DPSIR) and its ecological–based variant (EBM-DPSER), integrate environmental and human dimensions, proving especially useful in coastal or environmentally vulnerable areas (35).

To manage the complexity of these frameworks, hierarchical models have been proposed, classifying indicators into three levels: primary (e.g., fecal coliforms, COPD cases), aggregated (e.g., water quality indices, green space coverage), and composite indicators. This structure enhances comparability across regions and supports the design of evidence-based public policies (10, 17).

Among structured methodological approaches, the PACE-EH protocol—developed by the Florida Department of Health—stands out. It introduces a participatory methodology for identifying and prioritizing environmental health issues at the community level. The protocol involves community profiling, team formation, development of contextual indicators, and integrated action planning, thereby enabling adaptation to local contexts and fostering social appropriation of knowledge (36).

Other models include the Health Risk Assessment framework of the U.S. Environmental Protection Agency (EPA), which evaluates risk through hazard identification, exposure assessment, dose–response analysis, and risk characterization (37). This model has been widely applied in both urban and industrial contexts worldwide. Similarly, the Environmental Health Risk Assessment (EHRA) model has been developed for coastal chemical industries, emphasizing toxic emissions and water contamination, and involves hazard identification, risk quantification, and health impact assessment (38).

Contemporary approaches also incorporate economic and social components, as in the ecological–economic–social (EES) model, and employ artificial intelligence tools for predictive risk analysis. These methods aim to capture the complexity of coupled socio-environmental systems, which are characterized by non-linear dynamics, feedback mechanisms, and adaptive responses that are difficult to model with traditional tools (39). Emerging methods also integrate geospatial analysis and spatial statistics to assess environmental health inequalities. Such approaches generate exposure maps by combining on-site data, sociodemographic variables, emission sources, and territorial features, thereby revealing disparities and guiding targeted interventions (40, 41).

In Colombia, although progress has been made in developing EHIs, institutional gaps and limited intersectoral coordination persist. Recent studies reveal divergent perceptions of environmental health problems among policymakers, academics, and communities, which reduces the effectiveness of implemented strategies (42).

Despite significant advances in frameworks and models, several challenges remain. These include data fragmentation, difficulties integrating information across scales and sectors, and limited institutional capacity for implementing adaptive solutions. Overcoming these challenges will require stronger integration between science, policy, and citizen participation, along with the adoption of emerging technologies to enhance the accuracy, relevance, and usability of indicators.

The application of artificial intelligence is a promising trend in this field. Studies have demonstrated the use of artificial neural networks to analyze toxic vapors and odors through low-cost sensor networks linked via Internet of Things (IoT) technologies (24, 25). Others have presented simulations and technological analyses, providing insight into future trends in environmental health assessment (26, 27).

Finally, this review found that 38% of projects never reached the implementation stage, limiting their impact on public policy and community action. It also highlights the need to incorporate additional variables into environmental health assessments, such as housing quality, waste management, vegetation cover, road infrastructure, and public space use (30).

Conclusions and Future Work

This literature review found no general model or universal indicator for assessing environmental health. Instead, indicators are context-dependent and vary according to the characteristics of the study area or region. The review identified three key elements—guidelines, context of analysis, and indicators—that can inform the design of future environmental health frameworks.

Nonetheless, significant challenges remain, particularly in integrating diverse data sources to generate reliable information for evidence-based decision-making. Advancing this field will require stronger collaboration among government institutions, academic entities, and communities to identify environmental variables that affect health and to develop solutions that address both individual and collective needs.

Declarations

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