Annals of Global Health
VOL. 83, NO. 3–4, 2017

ISSN 2214-9996/$36.00
https://doi.org/10.1016/j.aogh.2017.10.013

ORIGINAL RESEARCH

Children's Environmental Health Indicators for Low- and Middle-Income Countries in Asia

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Abstract

BACKGROUND Given that low- and middle-income countries (LMICs) in Asia still have high child mortality rates, improved monitoring using children's environmental health indicators (CEHI) may help reduce preventable deaths by creating healthy environments.

OBJECTIVES Thus, the aim of this study is to build a set of targeted CEHI that can be applied in LMICs in Asia through the CEHI initiative using a common conceptual framework.

METHODS A systematic review was conducted to identify the most frequently used framework for developing CEHI. Due to the limited number of eligible records, a hand search of the reference lists and an extended search of Google Scholar were also performed. Based on our findings, we designed a set of targeted CEHI to address the children's environmental health situation in LMICs in Asia. The Delphi method was then adopted to assess the relevance, appropriateness, and feasibility of the targeted CEHI.

FINDINGS The systematic review indicated that the Driving-Pressure-State-Exposure-Effect-Action framework and the Multiple-Exposures-Multiple-Effects model were the most common conceptual frameworks for developing CEHI. The Multiple-Exposures-Multiple-Effects model was adopted, given that its population of interest is children and its emphasis on the many-to-many relationship. Our review also showed that most of the previous studies covered upper-middle– or high-income countries. The Delphi results validated the targeted CEHI. The targeted CEHI were further specified by age group, gender, and place of residence (urban/rural) to enhance measurability.

CONCLUSIONS Improved monitoring systems of children's environmental health using the targeted CEHI may mitigate the data gap and enhance the quality of data in LMICs in Asia. Furthermore, critical information on the complex interaction between the environment and children's health using the CEHI will help establish a regional environmental children's health action plan, named "The Children's Environment and Health Action Plan for Asia."

KEY WORDS Asia, children's environmental health indicators, diarrheal diseases, insect-borne diseases, low- and middle-income countries, respiratory diseases.

Conflicts of Interest: The authors declare that they have no conflicts of interest in this work.

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INTRODUCTION

Despite considerable progress made in reducing child mortality worldwide, 2.4 million children under age 5 years died in low- and middle-income countries (LMICs) of Asia in 2015.[1] The Millennium Development Goal 4 (MDG 4) to reduce by two-thirds the under-5 mortality rate between 1990 and 2015 remains part of the unfinished agenda in the Sustainable Development Goals (SDGs), with the Caucasus and Central Asia, Southern Asia, Southeastern Asia, Oceania, and Eastern Asia excluding China not meeting the goal.[1] Forty-seven countries will not be able to achieve the SDG target of reducing preventable deaths of children aged under 5 years of age to 25 per 1000 live births or fewer by 2030, and almost 13% of the countries are LMICs in Asia.[1]

A number of studies have identified the leading causes of under-5 mortality in LMICs are respiratory diseases, diarrheal diseases, and insect-borne diseases including malaria and dengue.[2-5] The World Health Organization (WHO) estimated that 570,000 deaths from respiratory infections; 361,000 deaths from diarrheal diseases; and over 300,000 deaths from malaria in children aged under 5 years were linked to poor environmental conditions.[6] Each of the diseases is closely linked to poor environmental conditions. Major environmental contributors to respiratory infections include household air pollution from use of solid fuels, ambient air pollution, and environmental tobacco smoke.[6] In addition, diarrheal diseases are largely attributable to poor hygiene and sanitation, as well as water pollution.[6] Climate change and inadequate management of water bodies may cause outbreaks of insect-borne diseases.[6-9]

The international community has recognized the significance of instating environmental health monitoring systems to understand the complex relationship between environmental risks and children's health. Through the Children's Environmental Health Indicators (CEHI) Initiative, launched by the World Health Organization in 2003,[10] the WHO Regional Offices integrated the CEHI framework and its core set of indicators into regional children's environmental health monitoring systems. However, regional CEHI pilots overseen by the WHO Regional Office for South-East Asia and the WHO Regional Office for the Western Pacific were considered but not initiated.[11]

Given that LMICs in Asia often lack national monitoring systems,[12,13] have unique environmental characteristics,[14,15] and have relatively high child mortality rates,[1] establishing a regional children's environmental health monitoring system may help fill gaps in data and improve understanding of the link between the environment and children's health. Scientific evidence accumulated through the system may encourage policy makers to start developing policies. For instance, the Children's Environment and Health Action Plan for Asia (CEHAPA) was proposed to promote children's environmental health by identifying existing and emerging environmental threats to children's health and preventing children from being exposed to those environmental threats. However, a set of targeted CEHI developed on the basis of a conceptual framework for LMICs in Asia is necessary to establish the regional monitoring system.

The objective of this study was to build a set of targeted CEHI that can be applied in LMICs in Asia through the CEHI initiative using a common conceptual framework. We first conducted a systematic review to perform a qualitative analysis of the selected studies. Following the analysis, indicators from the framework were used to form a set of targeted CEHI. Indicators from several authoritative sources were also included in the set. A panel of national and international experts then validated the set of CEHI.

METHOD

Systematic Review (SR).

Literature Search. The methodological guideline upon which this study was based is the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).[16] An iterative approach was adopted in the search and the review strategies. We conducted an electronic database search employing Pubmed, CIHANL Plus, Scopus, ProQuest Atmospheric Science Collection, ScienceDirect, Springer, Web of Science Core Collection, African Index Medicus, Latin American and Caribbean Health Sciences Literature, Index Medicus for the Eastern Mediterranean Region, Western Pacific Region Index Medicus, Index Medicus for the South-East Asian Region, and WHO Library & Information Networks for Knowledge Database. Language was restricted to English where possible, and no date restriction was imposed. The search terms were a combination of the following key words: children's environmental health indicators, children's environmental health, indicator*, child*, environment, health*, framework*, model*, and tool*. Grey literature was included due to the limited number of studies. Studies were excluded if 1) the population of concern did not include children; 2) at least one of the health

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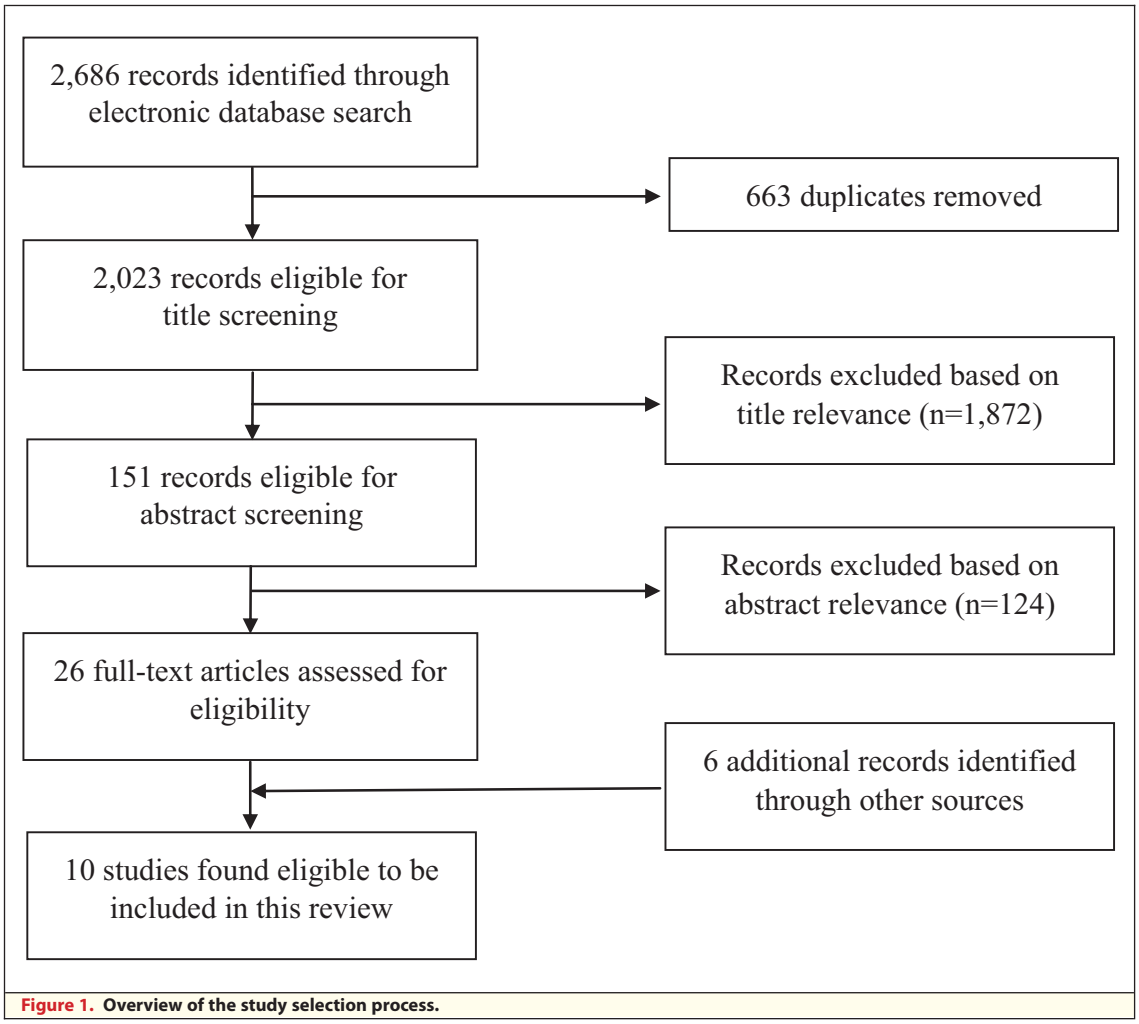

Figure 1. **Overview of the study selection process.**

outcomes did not include insect-borne diseases, respiratory diseases, and diarrheal diseases; 3) indicators used in the study could not be found even in the extended search; 4) indicators were not organized using a framework; and 5) the study was not targeted above national level[17] because our intention was to propose a set of CEHI that can later be implemented at the regional level.

Study Selection. A total of 2684 records were identified with 472 from Pubmed, 136 from CIHANL Plus, 708 from Scopus, 19 from ProQuest Atmospheric Science Collection, 152 from ScienceDirect, 67 from Springer, 343 from Web of Science Core Collection, 11 from African Index Medicus, 104 from Latin American and Caribbean Health Sciences Literature, 175 from Index Medicus for the Eastern Mediterranean Region, 287 from Western Pacific Region Index Medicus, 197 from Index Medicus for the South-East Asian Region, and 13 from WHO Library & Information Networks for Knowledge Database. Six hundred sixty-three duplicates were eliminated. Two independent reviewers screened the remaining records by title and abstract relevance, and 26 records were selected for full-text review (Figure 1). Due to the limited number of eligible papers, an additional search was conducted. Thus, a hand search of the reference lists and an extended search of Google Scholar were performed. Six more records identified from the additional search were included for the quantitative analysis.

Selection and Validation of Indicators.

Selection of Indicators. After finding the most common conceptual framework for developing CEHI, the core set of indicators designed for the framework was adopted as a primary reference of targeted CEHI. Furthermore, we thoroughly reviewed a list of the existing indicators from agencies including the World Bank, the United Nations Statistics

Division, WHO, the United Nations Children's Fund, and the United States Agency for International Development, because the indicators from those agencies are considered to be scientifically sound, robust, and internationally compatible.[18-21] After the selection, we modified the indicators to ensure they were relevant to LMICs in Asia. Suggestions for disaggregation by age group, gender, and place of residence (urban/rural) were added when they were appropriate.

Validation of Indicators. After the initial selection of CEHI, a Delphi approach was adopted to seek the opinions of experts on the CEHI. The Delphi process was conducted to give the indicators greater credibility.[22] The experts were solicited based on their extensive research and field experiences on children's environmental health in Asian countries. Because the opinions of experts on the CEHI were sought via electronic mail, we were able to receive feedbacks from the experts without geographical boundary. The experts were asked to review the selected CEHI and comment on the following items: the relevance and significance of the selected environmental topics in LMICs in Asia and the feasibility and effectiveness of the indicators. The experts could also provide suggestions on how the selected CEHI could be modified in order to be more age-, gender-, or place of residence–specific, and be more pertinent to children's environmental health situations in LMICs in Asia.

RESULTS

Results From the Systematic Review. Of all records identified from the searches, 10 studies applied a structured framework in the course of developing or selecting CEHI. Six studies were conducted at the national level, and 4 studies were conducted at the regional level. Dates of publication fell into a 15-year range, from 2001 to 2016. However, most of the studies were published before 2010 (80%). It is also noted that all of the selected studies had a cross-sectional design. The studies adopted either the Driving-Pressure-State-Exposure-Effect-Action (DPSEEA) framework[18] or the Multiple-Exposures-Multiple-Effects (MEME) model.[21] Given the similarities in the main features of the studies, we synthesized the findings and qualitatively analyzed them by region (Table 1).[20,23-31]

Regional Representation. Studies were categorized by the WHO regional classification to examine whether there was a regional difference in the number of publications. Three studies represented the Americas (the United States, the United States–Mexico border region, and the joint study of the United States, Canada, and Mexico),[23-25] four studies represented Europe (Romania, Greece, and two pan-European studies),[27-30] two studies represented the Western Pacific (Australia and New Zealand),[20,31] and one study represented the Eastern Mediterranean (Oman and Tunisia).[26]

Although the study conducted in the Eastern Mediterranean region included Tunisia, a developing country or LMIC,[32,33] indicators used in the assessment of the status of children's environmental health in Tunisia were not published.[26] Because inclusion criteria stated that a study would be excluded when indicators used in the study could not be found even in the extended search, all the studies considered in the selection of the CEHI framework for this study only included developed, that is, upper-middle-income countries or high-income countries (HICs).[32,33]

Exposure-Side and Health-Side Indicators. As the MEME model is a modification of the DPSEEA framework with a focus on children, they share several environmental topic areas and health outcomes. Thus, similar exposure-side and health-side indicators were shown in the studies because they had either adopted the DPSEEA framework or the MEME model. Furthermore, studies conducted in the same region shared common goals in exposures and health outcomes. For instance, the studies conducted in Europe shared common exposure-side and health-side indicators under the four Children's Environmental Health Action Plan for Europe (CEHAPE) Regional Priority Goals (RPGs),[27-30] among which RPG 1 is to prevent children from contracting gastrointestinal diseases by ensuring access to safe water and adequate sanitation and RPG 3 is to improve indoor and outdoor air quality to reduce the risk of respiratory illness in children.[27-30]

In spite of the similarities, variations in health outcomes still exist in the same region; diseases or disorders included in health-side indicators vary from country to country. For instance, the study included only the United States focused on addressing neurodevelopmental disorders and noncommunicable diseases (NCDs) including cancer and asthma.[23] However, the core set of indicators in the study conducted in the US-Mexico border region included mortality rate in children aged under 5 years from diarrheal disease.[24] In addition, health-side indicators used in Oman have different emphases from those in other regions, with collecting information on acute respiratory illness and diarrhea history, rather than

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Table 1. Qualitative Analysis of Studies Included in the Systematic Review

WHO Region	Countries	Exposures	Health Outcome Indicators	Framework Presented	Reference
Americas	USA	- Air quality - Water, sanitation, and hygiene	- Percentage of children with asthma - Percentage of children having an asthma attack in the previous 12 months, by race/ethnicity and family income - Children's emergency room visits for asthma and other respiratory causes - Children's hospital admission for asthma and other respiratory causes	Revised DPSEEA	[23]
	USA-Mexican border region	- Air quality - Water, sanitation, and hygiene	- Incidence of morbidity due to acute respiratory infections in children under 5 - Estimated death rates due to acute respiratory infections in children under 5 - Diarrhea mortality in children under 5 - Diarrhea morbidity in children under 5	DPSEEA	[24]
	USA, Canada, Mexico	- Air quality - Water, sanitation, and hygiene	- Percentage of children exposed to air pollution exceeding national standards - Prevalence of asthma cases - Hospitalizations due to respiratory distress - Number of outbreaks of diarrheal disease - Morbidity (number of childhood illnesses attributed to waterborne disease) - Mortality (number of childhood deaths attributed to waterborne disease)	MEME	[25]
Eastern Mediterranean	Oman, Tunisia*	- Indoor air quality - Water, sanitation, and hygiene	- Acute respiratory illness among children aged under 5 years (last 2 weeks: fever, cough, & shortness of breath) - Diarrhea history	MEME	[26]
Europe	Greece, Romania	- Air quality - Water, sanitation, and hygiene	- Infant mortality from respiratory diseases - Prevalence of asthma and allergies in children - Outbreaks of waterborne diseases	DPSEEA	[27,28]
	Europe	- Air quality - Water, sanitation, and hygiene	- Infant mortality due to respiratory diseases - Diarrhea morbidity in small children	DPSEEA	[29]
	Europe	- Air quality - Water, sanitation, and hygiene	- Infant mortality due to respiratory diseases - Prevalence of asthma and allergies in children - Hospital admissions and emergency room visits due to asthma in children - Outbreaks of waterborne diseases in children - Incidence of priority diseases in children	DPSEEA	[30]
Western Pacific	Australia	- Housing and shelter† - Food safety and supply security - Solid waste† - Natural hazards† - Air quality - Water, sanitation, and hygiene - Disease-carrying vectors - Social/work environments†	- Mortality rate for children aged under 5 years as a result of acute respiratory illness - Morbidity rate for children aged under 5 years as a result of acute respiratory illness - Prevalence of chronic respiratory illnesses in children aged 0-14 years - Diarrhea mortality rate in children aged under 5 years - Approximate rate of insect-borne diseases in children aged 0-14 years	MEME	[31]
	New Zealand	- Water, sanitation, and hygiene	- Number of cases of proven waterborne diseases	DPSEEA	[20]

DPSEEA, Driving-Pressure-State-Exposure-Effect-Action; MEME, Multiple-Exposures-Multiple-Effects.

* Could only confirm exposures.

† As the study adopted multiple environmental risks in one disease, exposures associated with at least one of the three leading causes of child mortality in the environment-health matrix were included.[21]

on prevalence, morbidity rate, or mortality rate of respiratory diseases or diarrheal diseases.

Except for the Australian study, where insect-borne diseases were included as a priority health issue in children's environmental health, insect-borne diseases were not identified as prioritized health outcomes in the studies.

Specification of Indicators by Age Group, Gender, and Place of Residence. Exposure-side indicators were not child specific in most of the studies, although health-side indicators tended to be more child specific. For instance, the studies conducted in the European region had a limited number of child-specific exposure-side indicators. Compared to the European region's initiative, the North American region's initiatives have a number of child-specific exposure-side indicators. For example, Kyle et al stated they would target children aged under 7 years when investigating percentage of environmental tobacco-smoke exposure in children.[23] However, some studies from the Americas did not specify the target age range in health-side indicators. Thus, it was difficult to find detailed information on which age group was regarded as "children." The study conducted in Australia clearly defined the age group in both exposure-side and health-side indicators.[31] Gender and place of residence were not well disaggregated in all of the studies.

Selection of a Model. The selected studies for systematic review showed that the DPSEEA framework and the MEME model were the most frequently used frameworks for developing CEHI. As mentioned above, the MEME model is both a condensed and extended version of the DPSEEA framework. However, compared to the DPSEEA framework, the MEME model emphasizes children and the MEME relationships, which more accurately illustrate the complex association between environment and health.[21,34] Therefore, we employed the MEME model as a conceptual framework for the targeted CEHI for LMICs in Asia. We then modified the indicators created for upper-middle-income countries or HICs, because the indicators might not be suitable for LMICs in Asia due to differences in health priorities and types of environmental exposures.

Results of the Delphi Process and Modification of the Indicators. The panelists confirmed that selected environmental threats, air pollution, water pollution, and climate change are the priority concerns in LMICs in Asia. Furthermore, the panelists provided open-ended comments that can improve the measurability and the specificity of the CEHI. Based on the comments received from the panelists, we further revised the indicators. Thus, the indicators were disaggregated by age group, gender, and place of residence, as shown in Table 2.[14,24,25,27-30,35-39]

DISCUSSION

Summary of the Findings. Despite a vast number of studies identified through the literature search, only a small number of studies met the inclusion criteria. The systematic review summarized a small number of studies to highlight the frameworks commonly used to develop CEHI and reveal the gaps in the current studies. Because development of environmental health indicators was often led by governments or international organizations, related documents were usually published as gray literature. This may explain why a limited number of studies were detected through academic database searches.

Another possibility is that national, regional, and global initiatives of CEHI have been rarely followed into research. The limited number of longitudinal studies in all regions may suggest an absence of periodic monitoring using CEHI, which may relate to a lack of publications of follow-up studies using data obtained from children's environmental health monitoring systems. Even though national or international organizations collect exposure and health data using their own methodologies, public access to the comprehensive methodology for the indicator-development process may be limited.

The selected studies reveal geographical underrepresentation of LMICs, which explains the lack of systematic monitoring of children's environmental health using CEHI in LMICs. Given the lack of participation in the CEHI initiatives, LMICs in Asia in particular need to be equipped with scientific measures to identify short- and long-term effects of the environment on children's health. Through this study, LMICs in Asia can initiate the process to adopt a common set of targeted CEHI, which can provide a base for a children's environmental health monitoring system. Monitoring and evaluation of children's environmental health status using CEHI would provide critical evidence of the current children's environmental health status and help devise further inputs for promoting children's environmental health.

Specifically, repeated data gathering through an improved monitoring system using CEHI may help to track progress on children's environmental health and build prevention and intervention strategies, such as CEHAPA. Without CEHI, the causes of the higher mortality rate in LMICs in Asia would persist and prevail due to the absence of knowledge, which may impede the achievement of SDG Target 3.2, to,

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Table 2. A Set of Targeted CEHI for LMICs in Asia

Issue	Indicators from the DPSEEA and the MEME	Suggestions for Specification	Reference*
1. Socioeconomic-Demographics Context			
Exposure	Number of children aged 0-14 years living in poverty	Disaggregated by age group (aged under 5 years), gender, and place of residence	
	Population density	Disaggregated by gender and place of residence	
	Annual net rate of population growth	Birth registration	35
	Percentage of people aged less than 16 or greater than 65 years	Disaggregated by age group (aged under 5 years), gender, and place of residence	
	Annual net rate of change in the proportion of people living in urban areas	Children aged under 5 years living in urban area - Disaggregated by gender	
Health Outcome	Annual death rate of infants aged under 1 year	Neonatal mortality rate, infant mortality rate, and under-5 mortality rate (per 1000 live births) - Disaggregated by gender and place of residence	
	Life expectancy		
Action		Establishment of National Environmental Health Action Plan for Children	36
2. Respiratory diseases			
Exposure	Percentage of children aged 0-4, 5-9, and 10-14 years living in damp housing (1, leaking roof; 2, damp walls/ floors/foundations; and 3, rot in window frames or floor)	Disaggregated by place of residence	
	Mean annual exposure of children aged 0-14 years to O_3, CO, PM_{10}, $PM_{2.5}$, SO_2, NO_2, and lead in the ambient air in urban areas	Disaggregated by age group (aged under 5 years) and place of residence	
	Percentage of children aged 0-14 years living in households using coal, wood, or kerosene as the main source of heating and cooking fuel	Disaggregated by age group (aged under 5 years), gender, and place of residence	
	Number of children aged 0-14 years living in proximity to heavily trafficked roads	Disaggregated by age group (aged under 5 years) and place of residence Number of children aged 5 years living in proximity to unpaved roads	
	Number of children aged 0-14 years living in households in which at least one adult smokes on a regular basis	Disaggregated by age group (aged under 5 years) and gender Children aged under 5 years living in proximity to industrial factory/power generator/hazardous waste sites/landfills/agricultural areas using pesticides	
Health Outcome	Incidence of morbidity due to respiratory diseases in children aged under 5 years	Disaggregated by gender and place of residence	
	Annual mortality rate due to respiratory diseases in children aged under 5 years	Disaggregated by gender and place of residence	
	Prevalence of chronic respiratory illnesses in children aged 0-14 years	Disaggregated by age group (aged under 5 years), gender, and place of residence	25,27-30
Action	Capability to implement air quality management	Enactment of Clean Air Act	14
	Number of cities that have air quality monitoring system	Disaggregated by place of residence	
	Daily (or hourly) concentrations of PM_{10}, SO_2, NO_2, and O_3 at a representative sample of monitoring stations	Add CO, $PM_{2.5}$ - Disaggregated by place of residence	
	Attributable change in numbers of households relying on biomass fuels or coal as the main source of heating or cooking	Attributable change in numbers of households with children aged 5 years - Disaggregated by place of residence	
	Consumption of lead-free gasoline as a percentage of total gasoline consumption		
	Attributable change in tobacco consumption	Enactment of Smoking Ban Policy	24,27-30

(*continued on next page*)

Table 2. Continued

Issue	Indicators from the DPSEEA and the MEME	Suggestions for Specification	Reference*
3. Diarrheal diseases			
Exposure	Population living in informal settlements	Number of children aged 5 years living in informal settlements - Disaggregated by place of residence	
	Drinking water supplies failing national microbiological water quality standards		
	Percentage of the population with access to an adequate amount of safe drinking water in the dwelling or within a convenient distance from the dwelling	Number of children aged 5 years living in households with access to an adequate amount of safe drinking water in the dwelling or within a convenient distance from the dwelling - Disaggregated by place of residence	[37]
	Percentage of households receiving piped water to the home	Number of children aged under 5 years living in households with access to treated water - Disaggregated by place of residence	[37]
	Proportion of the population with access to adequate excreta disposal facilities	Number of children aged 5 years living in households with access to adequate excreta disposal facilities - Disaggregated by place of residence	[37]
	Percentage of population served by regular waste collection services	Number of children aged 5 years living in households served by regular waste collection services - Disaggregated by place of residence	
	Number of resident children aged 0-14 years living in disaster-affected areas	Disaggregated by age group (aged under 5 years)	
		Number of children aged under 5 years living in proximity to a river not meeting national microbiological water quality standards - Disaggregated by place of residence	
Health Outcome	Incidence of outbreaks of water-borne diseases	Incidence of outbreaks of water-borne diseases in children aged under 5 years - Disaggregated by gender and place of residence	
	Diarrhea morbidity rate in children aged under 5 years	Disaggregated by gender and place of residence	
	Diarrhea mortality rate in children aged under 5 years	Disaggregated by gender and place of residence	
	Recurrence rate of outbreaks of diarrheal disease among children aged under 5 years	Disaggregated by gender and place of residence	
Action	Density of water quality monitoring network	Number of cities that have water quality monitoring system - Disaggregated by place of residence	
	Attributable change in the number of households lacking basic services	Attributable change in numbers of households with children aged under 5 years - Disaggregated by place of residence	
	Effectiveness of hazardous waste policies and regulations		
	Children aged 0-4 years able to obtain rehydration therapy within 24 hours of need	Disaggregated by place of residence	
4. Insect-borne diseases			
Exposure		Annual precipitation	[38]
		Global humidity index	[38]
		Changes in mean temperature	[39]
		Changes in sea level	[39]
		Extreme weather events such as wildfire, flood, and drought: frequency and intensity	[38,39]
	Population growth rate in areas endemic for insect-borne diseases	Disaggregate by age group (aged under 5 years and above)	
	Total area of insect-vector habitats	Disaggregated by place of residence	

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Table 2. Continued

Issue	Indicators from the DPSEEA and the MEME	Suggestions for Specification	Reference*
	Children aged 0-14 years living in areas endemic for insect-borne diseases	Disaggregated by age group (aged under 5 years) and place of residence	
	Children aged 0-14 years living in households providing suitable conditions for insect-borne disease transmission	Disaggregated by age group (aged under 5 years) and place of residence	
		Number of children aged under 5 years living in households spraying the interior walls against mosquitoes	[37]
		- Disaggregated by place of residence	
		Number of children aged under 5 years living in households with mosquito nets	[37]
		- Disaggregated by place of residence	
Health Outcome	Prevalence of insect-borne diseases in children aged 0-14 years	Prevalence of insect-borne diseases in children aged under 5 years	
		- Disaggregated by gender and place of residence	
	Mortality rate of children aged under 5 years due to insect-borne diseases	Mortality rate due to insect-borne diseases in children aged under 5 years	
		- Disaggregated by gender and place of residence	
Action	At-risk children aged 0-14 years covered by effective, integrated vector-control and management systems	Disaggregated by age group (aged under 5 years) and place of residence	

CEHI, children's environmental health indicators; DPSEEA, Driving-Pressure-State-Exposure-Effect-Action; LMIC, low- and middle-income country; MEME, Multiple-Exposures-Multiple-Effects.
* Indicators whose reference is not stated are from either the DPSEEA framework or the MEME model.

"by 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births."[40] A regional CEHI initiative in Asia that embraces LMICs should be initiated to identify key threats to children's environmental health.

After finding that the DPSEEA framework and the MEME model were the most commonly used CEHI frameworks, we decided to use the MEME model as the conceptual framework and modified the existing indicators to address the priority health outcomes in LMICs in Asia and enhance the measurability. Notably, the limited consideration of insect-borne diseases in the existing CEHI may be the substantial barrier to recognizing climate change as one of the children's environmental health challenges. As shown in Table 1, none of the selected studies concerned climate change in the exposure-side indicators, although growing evidence indicates that the global burden of disease attributable to climate change has increased over the past decades.[41] Given that little information is available even in HICs on the impact of climate change on transmission of insect-borne diseases, it can be inferred that health consequences of climate change are examined to even a lesser extent in LMICs. Because children in LMICs are among the most vulnerable populations to climate change whose health is most likely to be adversely affected,[41,42] extension of the current CEHI to embrace climate change as a key environmental threat may help to enhance the understanding of how climate change affects children's health. Furthermore, various public health interventions at different stages of the framework can be made on the basis of information obtained through modification of CEHI.

After the modification, the comments on the targeted CEHI by experts were collected to make the indicators valid and relevant to LMICs in Asia. In addition, on the basis of the open-ended feedback from the experts, the measurability and specificity of previous studies was improved by further disaggregating the indicators by age group, gender, and place of residence. Indicators without disaggregation may not be useful to improve understandings of susceptibility of a specific population because they cannot accurately measure the frequency and the dose of exposures to the health of a specific population, and the proportion of a specific population exposed to environmental risks. For instance, the risk of being exposed to an environmental hazard and the risk of experiencing an adverse health outcome in the same exposure can vary by gender due to physiological differences and behaviors impacted by social norms.[43] Hence, indicators that are not disaggregated by gender may not effectively capture the actual health impacts of an exposure.

The targeted CEHI proposed in Table 2 will allow the examination of associations between children's health and the environment, taking into consideration social, economic, and political dimensions. The results of the Delphi review supported the relevance, suitability, feasibility, and effectiveness of the indicators.

Strength of Our Research. To the best of our knowledge, this is the first study that reviewed CEHI studies to identify a common framework for developing CEHI and the first to develop a set of targeted CEHI for LMICs in Asia. A regional CEHI pilot can be initiated using the targeted CEHI developed in this study to collect data on children's environmental health. The data can be used to create CEHAPA.

Although the number of responses to the Delphi survey may seem small, a well-chosen panel with similar understandings on children's environmental health in LMICs in Asia can overcome its size.[44] Given that there are not many experts on children's environmental health in Asia, the panelists, children's environmental health experts with sufficient national or international research and field experiences, added reliable validation to the CEHI with a broad consensus on the suitability of the selected indicators, which supports the relevance, adequacy, and feasibility of the CEHI.

Limitations and Further Research. The study has the following limitations, some of which offer directions for future research. Due to the complex interconnectedness of environmental risks and adverse health outcomes, it was beyond the scope of this study to trace all the underlying exposures. For instance, the environmental risks included in this study do not include chemicals, pesticides, and electronic waste, which are emerging issues in LMICs[45-47] due to rapid industrialization and urbanization.

It was outside the scope of this study to examine the children's environmental health status of individual countries by a review of available data. However, when the regional CEHI initiative begins, the targeted CEHI can be used to assess children's environmental health status in the region. Furthermore, additional exposures and multiple health effects should be included in future studies.

CONCLUSION

In the current study, a systematic review was conducted to identify a common conceptual framework for developing CEHI. Using the result of the systematic review, we adopted the MEME model as a main reference of the targeted CEHI designed for LMICs in Asia to support efforts to create a healthy environment and reduce preventable deaths of children. The absence of the regional CEHI in Asia is likely to contribute to a lack of evidence of children's environmental health status in LMICs in Asia. Hence, there is a dire need for LMICs to develop and adopt effective and efficient monitoring through reliable scientific measures such as CEHI.

The targeted CEHI proposed in this study will refine the focus of data collection, increase the availability of data, and improve the quality of data. The accumulated scientific evidence through the CEHI can be used to raise public awareness on the importance of healthy environments. Application of the targeted CEHI will also support decision making, prioritize resource allocation, and help the establishment of CEHAPA, which ultimately helps LMICs in Asia to move toward promotion of children's environmental health and reduction in the number of preventable deaths caused by environmental risks.

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