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Cumulative Environmental-Health Exposure Index (IEC-ES): A hybrid framework for prioritizing Public Health and environmental interventions

EMBOLO ENYEGUE Elisée Libert

Institute of Medical Research and Medicinal Plants Study (IMPM), Cameroon

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ABSTRACT

Context: Environmental health risks arise from interacting exposures, population vulnerability, and existing disease burden, yet these domains are often assessed separately. **Objective:** This paper proposes the Cumulative Environmental–Health Exposure Index (IEC-ES), a transparent composite framework designed to support territorial prioritization of public-health and environmental interventions. **Framework:** IEC-ES combines three dimensions environmental exposure (E), human vulnerability (V), and health burden (H). Indicators are selected for relevance, availability, comparability, and actionability, converted to a common 0-2 risk scale, aggregated within dimensions, and combined using explicit weights that sum to one. Equal weighting can be used as a baseline, while context-specific weights may be tested through sensitivity analysis. **Illustrative application:** In a generic urban example, harmonized 0–2 normalization yields an IEC-ES of approximately 1.25, corresponding to moderate risk. In a sanitation-focused comparison, a high-risk neighborhood (E=1.80, V=2.00, H=2.00) reaches 1.93, whereas a second neighborhood (E=1.00, V=1.00, H=0.75) reaches 0.92 and is therefore classified as moderate risk.

**Corresponding author*

Email: elisseeembolo@yahoo.fr

Affiliation address: Yaounde/Cameroon

P.O. Box 13033

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Conclusion: IEC-ES offers a simple and interpretable structure for integrating heterogeneous environmental, social, and health information into a decision-support score. It should be used with component-level interpretation, transparent documentation of indicator choices, uncertainty analysis, and empirical validation before routine policy deployment.

What this study adds

- A single, transparent framework that combines environmental exposure, human vulnerability, and health burden for territorial prioritization.
- A harmonized 0–2 scoring system that resolves scale inconsistencies and makes risk classes directly interpretable for decision-makers.
- An operational distinction between the overall IEC-ES score and its component scores, reducing the risk of oversimplified decisions based on a single composite value.

1. Context and significance

Environmental determinants contribute substantially to population health through physical, chemical, biological, and social pathways. Air pollution, unsafe water, contaminated soil, inadequate sanitation, vector exposure, climate hazards, and unhealthy built environments interact with demographic, socioeconomic, and medical vulnerabilities. The resulting burden is rarely distributed evenly: communities with fewer resources or weaker access to services may experience higher exposure, greater susceptibility, and a reduced capacity to respond (Briggs, 2003; Landrigan et al., 2018; World Health Organization [WHO], 2016).

Established public-health indicators are indispensable but usually answer only part of the decision problem. Incidence, prevalence, mortality, years of life lost, and disability measures quantify observed outcomes, while deprivation or social-vulnerability indices describe structural disadvantage. Environmental monitoring identifies pollutant concentrations or regulatory exceedances, and geographic information systems show the spatial distribution of hazards. These approaches are complementary, yet their results are often interpreted in parallel rather than combined into a single operational prioritization framework (Murray & Lopez, 1996; Townsend, 1987; Elliott & Wartenberg, 2004).

The exposome and cumulative-risk paradigms broaden the conceptual field by recognizing that people experience multiple exposures over time (Wild, 2005). However, high-dimensional exposomic methods and advanced predictive models may require data, infrastructure, and expertise that are not consistently available to local health authorities. For routine planning, a useful index must therefore balance scientific defensibility with transparency, interpretability, and feasibility.

The IEC-ES is proposed as a pragmatic bridge between these approaches. It does not replace disease surveillance, exposure assessment, causal epidemiology, or detailed vulnerability analysis. Instead, it organizes selected indicators into three explicitly defined dimensions and produces a summary score that can help rank areas for further investigation and intervention. This orientation is consistent with environmental-health and One Health perspectives that emphasize interactions across human, animal, and environmental systems (Destoumieux-Garzón et al., 2018).

2. Central proposition and conceptual positioning

2.1 Central proposition

The central proposition is that territorial health risk is better prioritized when three distinct but interacting domains are considered together: (1) environmental exposure, (2) human vulnerability, and (3) observed health burden. A locality with modest current morbidity may still warrant attention if hazardous exposure and vulnerability are high, while a locality with similar exposure may require a different intervention when vulnerability or health burden is lower.

2.2 Relationship with existing approaches

IEC-ES is intentionally positioned as a decision-support composite rather than a causal risk estimator. Its value lies in converting heterogeneous but policy-relevant information into a common scale while preserving the underlying component scores. This makes the reasoning behind a priority ranking visible and allows the user to examine whether a high overall score is driven mainly by environmental pressure, vulnerability, health burden, or a combination of all three.

Table 1. Positioning of IEC-ES relative to selected existing approaches

Approach	Primary focus	Typical limitation for local prioritization	IEC-ES contribution
Epidemiological indicators	Observed morbidity, mortality, incidence, prevalence	May be reactive and may not represent upstream exposure or vulnerability	Adds environmental and vulnerability domains to observed health burden
Socioeconomic / deprivation indices	Poverty, deprivation, social vulnerability	Do not directly measure environmental hazards or health outcomes	Links structural vulnerability to exposure and health information
Environmental / regulatory assessment	Pollutants, hazards, thresholds	Often factor-specific; population susceptibility may be external to the metric	Integrates environmental pressure with vulnerability and health burden
GIS risk mapping	Spatial distribution of hazards and outcomes	May remain descriptive without a transparent prioritization rule	Provides a comparable summary score while retaining mapped components

Exposome / high-dimensional models	Multiple lifetime or molecular exposures	Data- and resource-intensive for routine local planning	Offers a lower-complexity operational framework using available indicators
IEC-ES	Exposure + vulnerability + health burden	Requires transparent indicator selection, validation, and sensitivity testing	Explicit, modular, interpretable prioritization framework

Note. The table summarizes conceptual differences; it does not imply that IEC-ES is superior for all analytical purposes. Specialized epidemiological, environmental, and spatial methods remain necessary for causal inference and detailed assessment.

3. Construction of the IEC-ES

3.1 Dimension E: Environmental exposure

The environmental-exposure dimension represents conditions that can increase contact with health hazards. Candidate indicators may include ambient and household air pollution, drinking-water quality, soil contamination, proximity to uncontrolled waste, vector breeding conditions, flooding or heat exposure, and other locally relevant environmental pressures. Indicator selection should be limited to variables with a plausible relationship to health and a clear direction of risk.

3.2 Dimension V: Human vulnerability

The vulnerability dimension describes characteristics that influence susceptibility, exposure opportunity, or the ability to prevent and respond to harm. Examples include the proportion of young children and older adults, poverty or deprivation, overcrowding, inadequate housing, limited access to health services, malnutrition, pregnancy, chronic disease, low health literacy, and other context-specific social or biological vulnerabilities.

3.3 Dimension H: Health burden

The health-burden dimension represents observed population outcomes that may be relevant to the environmental-health problem under assessment. Depending on the application, indicators may include disease incidence or prevalence, environmentally related consultations, avoidable hospitalizations, mortality, outbreak occurrence, vaccination or prevention gaps, or established burden-of-disease measures. The label H (health burden) is used consistently here to avoid confusion with the term sensitivity.

3.4 Indicator-selection criteria

Each candidate indicator should be evaluated before inclusion. Four criteria are proposed:

Relevance: the indicator has a defensible relationship with the health or environmental problem being prioritized.

Availability: data can be obtained at the intended spatial and temporal scale with sufficient completeness.

Comparability: the indicator can be interpreted consistently across the units being compared or can be standardized appropriately.

Actionability: a high value can reasonably inform a prevention, environmental, health-service, or policy response.

The indicator set should also be screened for redundancy. Closely correlated variables that measure the same construct can unintentionally double-count one domain and distort the composite score. The final set should therefore be documented with definitions, units, data sources, reference periods, direction of risk, missing-data rules, and the rationale for inclusion.

3.5 Harmonized normalization to a 0–2 risk scale

To ensure consistency across the index and its risk classes, all final indicator values are converted to a 0–2 scale, where 0 represents the most favorable reference condition, 1 an intermediate condition, and 2 the most adverse condition. For a quantitative indicator in which higher values represent higher risk, min–max normalization is:

$$x^* = 2 \times (x - x_{min}) / (x_{max} - x_{min})$$

where x is the observed value and xmin and xmax are defensible reference bounds. Values outside the reference range should be capped at 0 or 2 unless a different rule is prespecified. For protective indicators, where higher values indicate lower risk, the direction is reversed:

$$x^* = 2 \times (x_{max} - x) / (x_{max} - x_{min})$$

Qualitative and semi-quantitative indicators may be coded directly as 0 (favorable), 1 (intermediate), or 2 (adverse) using explicit operational definitions. If z-scores or other transformations are used during exploratory analysis, they must ultimately be mapped to the prespecified IEC-ES scale before aggregation.

3.6 Within-dimension aggregation and weighting

For each dimension, the normalized indicators are aggregated using an arithmetic mean or another prespecified weighted mean. The simplest baseline assigns equal weight to indicators within each dimension. Alternative indicator weights may be justified by evidence, expert consensus, statistical analysis, or policy priorities, but the weighting procedure should be reported transparently and examined through sensitivity analysis, consistent with good practice for composite indicators (Nardo et al., 2005).

3.7 Overall IEC-ES score

Let E, V, and H denote the three-dimension scores, each on the 0–2 scale. The overall index is:

$$\text{IEC-ES} = \alpha E + \beta V + \gamma H, \quad \text{with} \quad \alpha + \beta + \gamma = 1$$

Equal weighting is obtained with $\alpha = \beta = \gamma = 1/3$. Context-specific scenarios may emphasize one dimension (for example, environmental exposure) provided that the weights remain non-negative, sum to one, and are justified before results are interpreted. Because the weighted average of 0–2-dimension scores also lie between 0 and 2, the risk classes remain directly interpretable.

Table 2. Operational interpretation of the IEC-ES score

IEC-ES score	Risk class	Operational interpretation
0.00–0.66	Low	Maintain prevention and routine surveillance; investigate adverse component scores if present.
0.67–1.33	Moderate	Targeted prevention, environmental improvement, and strengthened monitoring are warranted.
1.34–2.00	High	Prioritize multisectoral intervention and investigate the drivers of the high score urgently.

The cut-points above are pragmatic operational categories proposed for the framework. They require empirical calibration against real outcomes before being treated as validated clinical or regulatory thresholds.

4. Illustrative applications

The following examples are illustrative and are used to demonstrate calculation and interpretation. They should not be presented as evidence of empirical validation unless the authors provide the underlying datasets, sampling procedures, data sources, and validation analyses.

4.1 Generic urban example

A hypothetical urban area is characterized using environmental, vulnerability, and health indicators. Quantitative indicators are normalized to 0–2; qualitative indicators are coded as 0, 1, or 2. Equal weighting is used within each dimension and across the three dimensions.

Table 3. Harmonized scoring for the generic urban example

Dimension	Indicator	Observed value	Reference / coding	0–2 score	Risk direction
E	PM2.5 (µg/m³)	30	5–50	1.11	Higher = worse
E	Drinking-water condition	Partially non-potable	Ordinal	1.00	Intermediate
E	Open dumping	Frequent	Ordinal	2.00	Adverse
V	Population <5 y or >65 y (%)	28	5–35	1.53	Higher = worse
V	Access to health care	Limited	Ordinal	1.00	Intermediate
V	Chronic comorbidity burden	Moderate	Ordinal	1.00	Intermediate
H	Environment-related consultations (%)	18	2–25	1.39	Higher = worse

H	Avoidable hospitalizations	Moderate	Ordinal	1.00	Intermediate

The resulting dimension scores are E = (1.11 + 1.00 + 2.00)/3 = 1.37; V = (1.53 + 1.00 + 1.00)/3 = 1.18; and H = (1.39 + 1.00)/2 = 1.20. With equal dimension weights, IEC-ES = (1.37 + 1.18 + 1.20)/3 = 1.25. According to Table 2, the area is therefore classified as moderate risk. The component profile suggests that environmental pressure is the largest of the three dimensions, although all three require attention.

4.2 Sanitation-prioritization example

A second illustrative scenario compares two densely populated neighborhoods facing fecal–oral disease risk. The objective is to determine which area should receive earlier sanitation action when resources are limited. The framework considers access to improved latrines, open defecation, contaminated stagnant water, microbiological drinking-water quality, solid-waste management, child vulnerability, poverty, population density, hygiene knowledge, acute diarrhea, waterborne disease incidence, digestive-disease consultations, and recent outbreak occurrence.

Table 4. Illustrative indicator scores for two neighborhoods exposed to fecal–oral disease risk

Dimension	Indicator	Neighborhood A	Neighborhood B
Environmental exposure	Access to improved latrines	2	1
Environmental exposure	Open defecation	2	1
Environmental exposure	Contaminated stagnant water	2	1
Environmental exposure	Microbiological drinking-water quality	2	1
Environmental exposure	Solid-waste management	1	1
Human vulnerability	Children <5 years	2	1
Human vulnerability	Household poverty	2	1
Human vulnerability	Population density	2	1

Human vulnerability	Hygiene knowledge	2	1
Health burden	Acute diarrhea prevalence	2	1
Health burden	Waterborne disease incidence	2	1
Health burden	Digestive-disease consultations	2	1
Health burden	Recent outbreak	2	0

The dimension-level values specified in the source example are E = 1.80, V = 2.00, and H = 2.00 for Neighborhood A, and E = 1.00, V = 1.00, and H = 0.75 for Neighborhood B. With equal weights, the corresponding IEC-ES values are 1.93 and 0.92.

Table 5. Comparative IEC-ES interpretation for the sanitation example

Area	**E**	**V**	**H**	**IEC-ES**	**Correct risk class**	**Priority**
Neighborhood A	1.80	2.00	2.00	1.93	High	Immediate sanitation and public-health action
Neighborhood B	1.00	1.00	0.75	0.92	Moderate	Targeted prevention, surveillance, and progressive improvement

This comparison illustrates the intended decision logic. Neighborhood A is clearly prioritized because all three dimensions are high. Neighborhood B remains important but falls within the moderate class, not the low-risk class. The component scores should guide the intervention package: sanitation, safe water, hygiene promotion, surveillance, and health-service preparedness can be weighted according to the local drivers of risk.

5. Implications for research, policy, and practice

For local governments and health authorities, the main utility of IEC-ES is transparent prioritization under resource constraints. Rather than distributing limited resources uniformly, decision-makers can identify territories in which environmental pressure, vulnerability, and health burden converge. The same structure can support discussion across health, sanitation, environment, urban planning, and social-service sectors because each component remains visible.

For surveillance systems, IEC-ES can serve as a complementary layer rather than a replacement. Routine epidemiological data, environmental monitoring, census indicators, and service-access data can be linked at a common geographic scale and refreshed periodically. A dashboard or GIS implementation could then display the overall index alongside E, V, and H to prevent the composite score from obscuring its drivers.

For research, the next priority is empirical validation. The index should be tested against observed outcomes, alternative indicator sets, different geographic scales, and multiple weighting scenarios. Reliability, temporal stability, predictive or concurrent validity, sensitivity to missing data, and the consequences of correlated indicators should be quantified. Such work is necessary before fixed thresholds are used for regulatory or high-stakes decisions.

For One Health applications, the architecture is extensible. Animal-health or ecosystem indicators could be introduced where they are conceptually justified, but expansion should not occur merely to increase the number of variables. The strength of a composite index depends on a coherent causal and decision framework, not on maximal data accumulation.

6. Alternative viewpoints, uncertainties, and limitations

Composite indicators inevitably simplify complex systems. Two areas can obtain the same IEC-ES value through very different combinations of E, V, and H. For this reason, the overall score should never be interpreted without the component profile and, where possible, the individual indicators.

Indicator selection and weighting introduce judgment. Expert-informed weights may reflect local priorities but can also introduce subjectivity; statistically derived weights may be unstable when data are sparse or may reflect correlation rather than policy importance. Equal weighting is transparent but does not imply equal causal importance. Sensitivity analysis should therefore be a routine part of application (Nardo et al., 2005).

Data quality is a central constraint. Environmental, demographic, and health data may differ in spatial resolution, reference period, completeness, or ascertainment. Aggregating mismatched datasets can create false precision. Users should document temporal alignment, geographic correspondence, missing-data treatment, and uncertainty before comparing areas.

The proposed 0–2 classes are operational rather than clinically validated thresholds. A high score indicates priority for assessment and action within the framework; it does not estimate an individual probability of disease and should not be interpreted as proof of causality. Empirical calibration is required to establish whether specific cut-points predict meaningful health or intervention outcomes.

Finally, the illustrative examples in this paper are demonstrations of calculation. They should not be described as statistical validation, field evidence, or robustness testing unless those analyses are documented with reproducible methods and data.

7. Conclusion

The IEC-ES provides a coherent way to organize environmental exposure, human vulnerability, and health burden into a transparent 0–2 composite score for territorial prioritization. Its practical strength is not the replacement of specialized risk assessment, but the integration of multiple decision-relevant domains in a format that can be interpreted by health authorities, municipalities, and multisectoral partners. The framework becomes more defensible when indicator definitions, normalization rules, weights, data sources, and uncertainty are documented explicitly and when the overall score is always examined together with its components. The corrected illustrative applications show that consistent scaling changes interpretation: the generic urban example is moderate risk (IEC-ES ≈ 1.25), Neighborhood A is high risk (1.93), and Neighborhood B is moderate risk (0.92). Future work should validate the index empirically, test alternative weighting and threshold schemes, and evaluate whether IEC-ES-guided prioritization improves the efficiency and equity of environmental-health interventions.

Declarations

Ethics approval and consent to participate: Not applicable to the conceptual framework and illustrative, non-empirical examples presented in this version.

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