ARTICLES AND REVIEWS

A Simplified Risk-Ranking System for Prioritizing Toxic Pollution Sites in Low- and Middle-Income Countries

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ABSTRACT

Background: In low- and middle-income countries (LMICs), chemical exposures in the environment due to hazardous waste sites and toxic pollutants are typically poorly documented and their health impacts insufficiently quantified. Furthermore, there often is only limited understanding of the health and environmental consequences of point source pollution problems, and little consensus on how to assess and rank them. The contributions of toxic environmental exposures to the global burden of disease are not well characterized.

Objectives: The aim of this study was to describe the simple but effective approach taken by Blacksmith Institute's Toxic Sites Identification Program to quantify and rank toxic exposures in LMICs. This system is already in use at more than 3000 sites in 48 countries such as India, Indonesia, China, Ghana, Kenya, Tanzania, Peru, Bolivia, Argentina, Uruguay, Armenia, Azerbaijan, and Ukraine.

Methods: A hazard ranking system formula, the Blacksmith Index (BI), takes into account important factors such as the scale of the pollution source, the size of the population possibly affected, and the exposure pathways, and is designed for use reliably in low-resource settings by local personnel provided with limited training.

Findings: Four representative case studies are presented, with varying locations, populations, pollutants, and exposure pathways. The BI was successfully applied to assess the extent and severity of environmental pollution problems at these sites.

Conclusions: The BI is a risk-ranking tool that provides direct and straightforward characterization, quantification, and prioritization of toxic pollution sites in settings where time, money, or resources are limited. It will be an important and useful tool for addressing toxic pollution problems in LMICs. Although the BI does not have the sophistication of the US Environmental Protection Agency's Hazard Ranking System, the case studies presented here document the effectiveness of the BI in the field, especially in low-resource settings. Understanding of the risks posed by toxic pollution sites helps assure better use of resources to manage sites and mitigate risks to public health. Quantification of these hazards is an important input to assessments of the global burden of disease.

Key Words: children's health, environmental health, global burden of disease, global health, hazard ranking system, hazardous waste sites, legacy pollution, low- and middle-income countries, risk assessment, toxic pollution

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INTRODUCTION

Exposure to hazardous chemicals and pollutants is both well documented and actively managed in the United States. In the 1970s, several highly publicized cases of community-level chemical exposures sparked an increased knowledge of the adverse health effects of numerous toxicants. This increased understanding, coupled with a desire to end community-level chemical exposures, led to the creation of the Comprehensive Environmental Response, Compensation and Liability Act of 1980, more commonly referred to as the Superfund Act. Thousands of contaminated sites have been evaluated through Superfund mechanisms in the United States over the past 3 decades, although quantifying and ranking these sites based on their potential human health threat remained a difficult and evolving process until the Environmental Protection Agency's (EPA) Hazard Ranking System (HRS) was

published as a federal regulation in 1990.[1] Since then, proper screening and ranking systems for chemical substances and hazards have become extremely important tools in fields such as public health and environmental science.[2]

Regulators have wrestled with environmental risk-ranking approaches since the development of an environmental consciousness. One such approach, although simplistic, compares the observed environmental level of an agent to an existing regulatory standard or commonly accepted guideline for that agent.[3] In the United States, the primary agencies with numerical standards for air, soil, and water is the EPA. However, regulatory standards do not exist for all chemical agents and often "guidelines" are listed and other methods are necessary. This approach also does not factor human exposure.

The Geo-Accumulation Index[4] and the Contamination Factor[5] are based on comparing the naturally occurring level of a metal to the observed amount in a particular media with the assumption being an order of magnitude or greater may indicate "contamination or accumulation" from an anthropogenic source.

The Hakanson index[6] is primarily an ecological risk indicator and incorporates contaminant concentration, species number, a simple toxicologic determination, and ecological sensitivity to produce a potential ecological risk index. Although more complex than other approaches, the Hakanson index is limited to aqueous sediment contamination and ecological impacts. These contaminant indices are useful, but they do not address human health or pathways of exposure.

The HRS is a scoring system used by the EPA's Superfund program to assess the relative threat associated with releases of hazardous substances in multiple environments such as uncontrolled landfills, locations of toxic chemical spills, mining sites, and abandoned industrial areas. It is the primary screening tool for determining whether a site should be included in the EPA's national priority list. The HRS evaluates sites based on the following pathways:

- Ground water migration
- Surface water migration
- Soil exposure
- Air migration

The HRS uses a complex procedure that incorporates components addressing the likelihood of a chemical release, the waste characteristics, and possible "targets" affected. Although this has been an effective tool for assessing and ranking hazardous waste site contamination and exposures in the United States, there are a number of reasons why it has not been applied in many low- and middle-income countries (LMICs).

First, many countries lack the infrastructure and functional capacity to evaluate and respond to community-level exposures of toxic pollutants in the way that the EPA does in the United States. Although this weakness will be addressed in the future, the capacity is presently out of reach in many resource-poor settings.

Second, because there are many abandoned "legacy" sites that continue to expose entire communities or populations in LMICs to life-threatening pollutants, these sites have to be addressed urgently, while authorities also have to deal with current sites that have the likelihood or potential to release contaminants in the future. In this context, the Blacksmith Index (BI) can address contamination issues from either legacy or ongoing active sites while requiring much less data and resources to apply than the full HRS.

Third, the costs of hazard ranking systems such as the EPA's tool remain a major impediment for many low-income countries. Given the need to obtain adequate understanding of the pollutants and to carry out sample collection, laboratory testing, and data analysis, the system can be prohibitively expensive, even if the capability is available.

Finally, application of a complex and sophisticated HRS requires considerable detailed knowledge of the site, the chemicals, possible exposure pathways, and the potentially affected population—all of which are typically not available in most low-resource settings.

Therefore, an HRS such as that developed and implemented by US EPA cannot be readily applied in most of these countries. The reality is that there are many legacy sites in LMICs but insufficient resources or time to carry out the complex studies required to apply an advanced system. In identifying and attempting to prioritize many sites in different countries, it became apparent that a modified and simplified assessment formula was required.

METHODOLOGICAL APPROACH

Basis for Establishing an Environmental Health Site Ranking System Specific to LMICs

In establishing the BI for toxic exposures in LMICs, Blacksmith staff and advisors identified the essential components of the EPA's HRS and developed a system that retains the key elements but is much more amenable to expedited data collection. Such changes were necessary as much of the data needed for the HRS are not available in LMICs or cannot be obtained in a cost-effective manner. There are some other key differences in the BI, for the purposes of making the approach more readily applicable. For instance, the EPA largely focuses on pollutants at the source and calculates migration to and impact on possible receptors, for example, area wells. In comparison, the BI relies on samples taken directly at soils or wells in source or target areas without

specifically addressing the migration potential. As a result, the BI misses the potential future contamination and focuses solely on current or past contamination at receptors.

The current HRS used by the EPA has not changed much in its essentials from the system initially created in the late 1980s, likely due to the fact that most significant contamination sites in the United States have been assessed since the Superfund was created. There is also a need to maintain historical consistency when ranking sites. There are 3 general criteria to the system:

1. Characteristics of the waste (pollutant);
2. Likelihood that a site has released, or has the potential to release, hazardous substances into any of the following exposure pathways: groundwater migration, surface water migration, soil exposure, and/or air migration; and
3. Identification of people or sensitive environments affected by the release (population).

The formula uses a structured-value numerical algorithm model combining these components to compute an overall score between 0 and 100. Currently, any site scoring at least 28.50 is eligible for the national priorities list for cleanup (i.e., the Superfund list).

The EPA's HRS was designed and implemented as part of a regulatory compliance program intended to create and address a comprehensive list of cleanup sites throughout the United States. It requires extensive data collection and sampling of multimedia environments (air, water, soil, and food), which typically are costly. Because the objective of Blacksmith's Toxic Sites Identification Program (TSIP) is to identify and screen potential hazardous waste sites that present health implications rather than list potential contaminated sites based on predicted pollutant migration patterns, the formula for the BI HRS was modified and targeted specifically to focus on health threats rather than environmental contamination. Table 1 summarizes key characteristics of the 2 systems.

Blacksmith Index HRS Formula

The formula for the BI HRS provides a numerical value for the estimated public health risk associated with any site where an initial site screening (ISS) has been carried out as part of the TSIP. The ISS is a procedure carried out by trained investigators to collect essential site data during a short site visit, using standardized protocols.[7]

The BI is based on the widely accepted "source-pathway-receptor" model of risk assessment illustrated in Figure 1. These 3 indicators are the greatest considerations when calculating the BI value of any given site. The BI has taken a more methodical and scientific data-driven approach than many other simplified ranking or labeling schemes that leave more room for interpretation.[8]

Table 1. Comparison of HRS Approaches

HRS scale	Pathway/Media Considered	Impacted Population Evaluated	Pollutants Identified and Evaluated	Likelihood of Future or Continuing Release	Migration Potential Evaluated	Simplified Formula for All Routes of Exposure?	Spatial Attenuation Considered	Persistence Considered?
US EPA	Soil, water, air, food, others	Extensive evaluation	Evaluates multiple pollutants if present	Evaluates	Considers migration from source	No	In migration potential calculations	Generally assumes no degradation
Black-smith Index	Soil, water, sometimes air or food	Focus on population nearby & users of water	Evaluates most prevalent pollutant	Focus on current contamination at receptor areas	Focus on pollutants at receptor areas	Yes	Simplified factor for attenuation due to distance from source	Additional weight (factor) for persistent pollutants

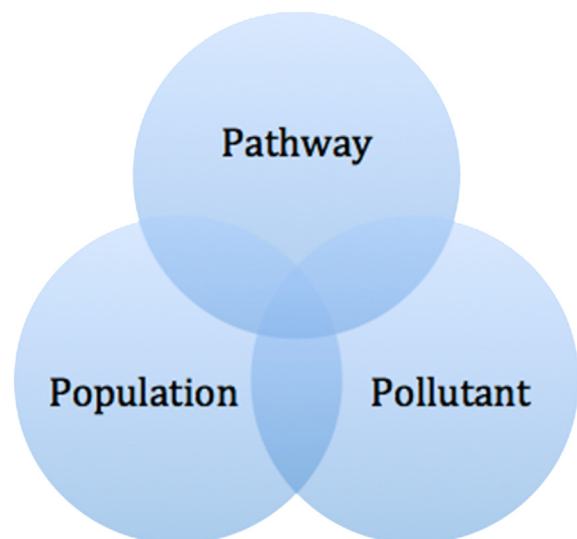EPA, Environmental Protection Agency; HRS, hazard ranking system.

Figure 1. The pollutant-pathway-population model used by the Toxic Sites Identification Program's hazard ranking system.

The BI is defined as follows:

$$BI_{SITE} = Highest\ among\ BI_1,\ BI_2...BI_n,\ BI_{add\_pop}$$

$n = number\ of\ sectors\ sampled\ and\ reported\ in\ the\ ISS$

$$BI_{1...n} = [\log_{10}(sector\ pop)]$$
$$+ \left[\log_{10}\left(\frac{sector\ test\ result}{screening\ threshold}\right)\right] + PF$$

$$BI_{add\_pop} = [\log_{10}(add.\ est.\ pop.)]$$
$$+ \left[\log_{10}\left(\frac{worst\ sector\ test\ result}{screening\ threshold} xSAF\right)\right]$$
$$+ PF$$

These formulas can also be written as follows:

$$BI_{SITE} = Highest\ among\ BI_1,\ BI_2...BI_n,\ BI_{add\_pop}$$

$n = number\ of\ sectors\ sampled$

$$BI_{1...n} = [\log_{10}(a)] + \left[\log_{10}\left(\frac{b}{c}\right)\right] + f$$

$$BI_{add\_pop} = [\log_{10}(y)] + \left[\log_{10}\left(\frac{z}{c}xj\right)\right] + f$$

Where: a - population in a sector
b - average test result (contaminant specific)
c - screening threshold level (contaminant-specific)
f - persistence factor
j - spatial attenuation factor
y - additional population exposed
z - worst (maximum result or high-risk sector) sector test result

The values are relative and are intended to provide a basis for setting priorities across sites. In particular, the contamination severity is calculated as b/c, which is the contaminant-to-screening level ratio for the specific contaminant that dominates the site. The BI is reported on a simplified scale of integer values from 0 to 10, to avoid the appearance of unjustifiable precision.

Screening thresholds used in the BI are taken from published data for well-established systems. (The screening threshold is typically the level below which the risk associated with that contamination is regarded as acceptably low.) The most common issue is soil contamination and therefore default screening thresholds relate to soil. A simple hierarchy is used to select values for use in BI, with EPA regional screening levels (RSL) being the initial point of reference.[9] (RSLs are based on the more stringent of carcinogenic and noncarcinogenic risk estimates. The BI uses RSL values except for a small number of substances where the RSL is based on carcinogenic risk and the substance is classified by the International Agency for Research on Cancer as other than groups 1 or 2A [known or probable carcinogen]. In this case, the noncarcinogen value is used, on the basis that the carcinogenic value is unduly stringent for a substance of unproven impact.)

If no EPA RSL can be found, threshold levels are then chosen from Canadian guidelines associated with human health, or failing that UK, or Australian values. The World Health Organization and Occupational Safety and Health Administration standards have been used for screening threshold values when appropriate, such as for food or industrial air exposure levels.

A new sector-sampling protocol implemented in the TSIP program provides more nuanced information on population and concentration of the pollutant. With this approach, the site is divided into separate areas based on type of land use (such as residential, agricultural, etc.) and proximity to the source site, and aggregated samples are taken for each area. Distinct population estimates are prepared for each sector and added together to determine the population at risk at the site as a whole.

In cases where the exposure pathway is a result of contaminated water (such as in a well or pond) used for potable or other human use (bathing, washing), the same formula is used. Samples are taken of the water source and the result used as the "sector" result ("b" in the formula above) and the population being the number of people who use the contaminated water source. The screening value used is that for potable water.

The final calculated index for the site is the largest among the different sector's indices, including an index calculated for the "estimated additional population at risk." To calculate this value, it is assumed that the population is exposed at the level of the "worst sample test result" multiplied by a "spatial attenuation factor" (SAF). Additionally, a "persistence factor" is used to account for heavy metals and organic pollutants, or

POPs, which persist in the environment over time. The importance and utility of both these factors are discussed here.

For those sites where the sampling result is between 1 and 2 times the screening threshold level, the formula for the BI defaults to an index value of 1. This adjustment ensures that those sites where contamination levels are just above the screening threshold level with low populations at risk are not labeled as 0 sites, leaving people with the impression that they are safe, uncontaminated, or will not adversely affect human health. Furthermore, this algorithm is needed to assure that a site with sampling results marginally over the screening levels but with large potentially exposed populations do not receive an inappropriately high index score. An example illustrating this type of index score can be found in case study 1. Note that a situation where there may be high contamination but no people at risk for exposure, such as a desert site far from any inhabited areas, will not receive consideration of the BI simply because the index is intended as a ranking tool for sites where public health is at risk.

The SAF and Persistence Factor

The BI for any given site is calculated on the number of people affected by the contamination and the severity of pollution at the sampled area. In many cases, there are additional people exposed to toxic pollutants in areas nearby or down gradient (i.e., downwind or downstream) of the sampled areas and sources. Investigators estimate the number of additional people that may be exposed in unsampled areas. However, the level of exposure for these additional people is very difficult to determine and would usually require extensive sampling and evaluation to develop an accurate estimate. In general, their level of exposure will be less than the individuals at the areas sampled simply because investigators are instructed to conduct sampling at areas ("sectors") likely to present the worst exposure. This usually means collecting composite samples in sectors outside the source area but where people are likely to be exposed, such as residential or occupied areas adjacent to the source site. At the same time, risk to additional exposed people, beyond areas sampled, should be considered when developing an index for a site.

To account for this additional population, they are included in a separate "sector" for which the BI calculation procedure reduces the severity factor by an SAF. The SAF reflects that the further people are from the worst contaminated location, and the less time they spend at that location, the lower their exposure. Because of the numerous factors and the great variety of situations in which toxic contamination occurs, it is not possible to apply more than a generalized attenuation factor to the severity of pollution experienced by people at a great distance from the source. Therefore, the SAF is simply an allowance for this reduced exposure, separated into categories based on the pathway and media that are relevant to the site (i.e., air, surface water, ground water, or food).

Some guidance on the attenuation of pollution versus distance from a site can be taken from the US EPA's instructions on how to calculate hazard ranking scores for potential Superfund sites.[10,11] As those calculations show, the attenuation is very significant within a short distance for air pollutants or soil contamination, whereas the attenuation is significantly less for ground water. (It must be noted that the attenuation of contaminants in water is highly dependent on local surface water and ground water flow, as well as other factors such as the pollutant solubility and sorption to soils, such that there is really no good way to estimate this attenuation absent extensive hydrogeologic information, other than to note that it occurs.)

The SAF calculation takes the geometric mean of the EPA factors for the source to 0.5 miles, and rounds up. The values used in the BI SAF, based on exposure and pollutant classification, are presented in Table 2.

The persistence factor is based on the environmental half-life values (in days) for POPs and other pollutants from the Centers for Disease Control and Prevention's Agency for Toxic Substances & Disease

Table 2. Summary of Spatial Attenuation Factor Values					
	Water (Adjustment Based on Type of Water Body)	**Soil (Adjustment Based on Type of Land Body)**	**Food (Adjustment Based on Type of Land Body)**	**Air (Gases, Vapors, Mists)**	**Dermal**
SAF values	Pond, small lake, small river = 0.9	Dumpsite, industrial, mixed use = 0.2	Agricultural = 0.5	Air pollutant inhalation = 0.3	Dermal contact = 0.3
	Large lake, large river = 0.5	Residential/ school = 0.5	Dumpsite, industrial, mixed use = 0.5		
	Estuaries = 0.2	Natural areas = 0.1	Residential/ school = 0.7		
	Ocean = 0.1	Agricultural = 0.2	Natural areas = 0.1		
	Wetland = 0.6				
	Ground water = 0.5-0.9 depending on climate				

SAF, spatial attenuation factor.

Registry' database.[12] Those pollutants with a half-life in soil of more than 365 days are given an additional point when calculating their final index value. Heavy metals and other nondegradable elements also are given this additional point for persistence.

This refined BI calculation has been applied to at least 3000 sites in 48 countries.[13,14]

RESULTS

Overview of Site-Specific Case Studies

Four specific case studies are presented to demonstrate the process for developing the final index value associated with each site. Factors including pollutant, pathway, population impacted, test result, SAF, and persistence factor are all taken into account in calculating the final index value. A summary of the case studies is given in Table 3. The results of the case studies are discussed here.

Case Study 1: Arsenic in Peru

Pollution from mine tailings at a site in Puno, Peru, has been affecting local people, livestock, and agriculture with elevated levels of several heavy metals. Arsenic was deemed to be the key pollutant because it was the most common and had the highest concentration, although cadmium, lead, copper, and chromium were also detected in the sampling. Arsenic and the other contaminants are released into the Ramis River, which serves as a main source of drinking water for an estimated 15,000 local residents. The drinking water standard for arsenic in drinking water is 10 ppb (μg/L) and the composite samples analyzed at this site had a value of 13 ppb. The relatively low test results at this site—but still above the screening level—resulted in the site being given a default score of 1 out of a possible 10.

Case Study 2: Mercury, Lead, and Total Chromium in Ghana

Artisanal gold mining in Eastern Ghana has led to contamination of soil, sediment, and water with mercury, arsenic, and total chromium due to an antiquated extraction process for the gold. The site is located close to a school and other sensitive ecosystems that are being adversely affected by the high levels of pollutants. Composite sampling in the adjacent miners' village was carried out for the 3 pollutants. Mercury yielded a test result of 50 ppm of in soil, the screening threshold level is 10 ppm; arsenic was found at a concentration of 3.3 ppm in soil, the screening threshold level is 0.61 ppm; and total chromium was found at a concentration of 532 ppm, the screening threshold level is 220 ppm. Because mercury, lead, and total chromium are persistent in the environment, they all received an additional point on the scale to account for their continued potential to harm local residents. It was estimated by reviewing local population statistics that 5000 people are directly at risk for dermal contact, with another 600 likely being indirectly affected. Mercury is often a major issue at artisanal small-scale gold mining sites and in this case the test result for mercury was highest in relation to the screening threshold level of the 3 pollutants sampled. Therefore, mercury was chosen as the primary pollutant. This information yielded a score of 5 out of a possible 10 on the index scale as a result of choosing the highest value among all the sectors. The test result was calculated as follows:

$$\text{Mercury}: BI_1 = \left[\log_{10}\left(5,000\right)\right] + \left(\log_{10}\left(\frac{50}{10}\right)\right)$$
$$+ 1 = 5.38 \text{ rounds down to } 5$$

$$\text{Arsenic}: BI_2 = \left[\log_{10}(5,000)\right] + \left(\log_{10}\left(\frac{3.3}{0.61}\right)\right)$$
$$+ 1 = 5.42 \text{ rounds down to } 5$$

$$\text{Total chromium}: BI_3 = \left[\log_{10}(5,000)\right]$$
$$+ \left[\log_{10}\left(\frac{532}{220}\right)\right] + 1$$
$$= 5.07 \text{ rounds down to } 5$$

$$BI_{add\_pop} = \left[\log_{10}(600)\right] + \left[\log_{10}\left(\frac{50}{10} \times 0.5\right)\right] + 1$$
$$= 4.16 \text{ rounds down to } 4$$

$$BI_{SITE} = Highest \ among \ BI_1, \ BI_2 \ldots BI_n, \ BI_{add\_pop} = 5$$

Table 3. Summary of Site-Specific Case Studies						
Site	**Pollutant**	**Pathway**	**Population Impacted**	**Test Result (Key Pollutant)**	**Screening Threshold Level**	**Final Index Value**
Peru	Arsenic	Ingestion (water)	15,000	13 ppb	10 ppb[15]	1
Ghana	Mercury	Dermal contact (soil)	5,600	40 ppm	10 ppm[9]	5
Kazakhstan	Lead	Inhalation (gas/vapor)	40,000	3399 ppm	400 ppm[9]	7
India	Chromium	Ingestion (food)	60,000	4752 ppm	5.6 ppm[9]	8

Case Study 3: Lead in Kazakhstan

An industrial town in Kazakhstan is located in close proximity to a large copper smelter. High levels of air pollution with lead and other heavy metals are affecting local residents. Soil sampling was carried out in a local residential area because inhalation of contaminated soil or vapor is believed to be the most common route of exposure at this site. Based on local census data, it is estimated that 40,000 people are at risk for inhaling substances, vapors, or particles highly contaminated with lead. Composite sampling revealed a test result of 3399 ppm of lead in soil; the screening threshold level is 400 ppm. Because lead is persistent in the environment, an additional point was added to account for the continued potential to harm local residents. The test result was calculated as follows:

$$BI_1 = BI_{SITE} = [\log_{10}(40,000)] + \left[\log_{10}\left(\frac{3,399}{400}\right)\right]$$
$$+ 1 = 6.52 \text{ rounds up to } 7$$

With only 1 sample sector of test results to choose from, the index value calculated was used for the index value of the entire site. In this case, composite sampling gave a good overview of the conditions across a large area.

Case Study 4: Hexavalent Chromium in India

Sewage and waste from a number of tanneries located in an industrial area of India are polluting rivers, waterways, soil, and fields that are irrigated for agriculture. Tannery workers and their families are directly exposed to several contaminants, most notably hexavalent chromium. An estimated 60,000 local residents face chronic chromium exposure in the area through dermal contact, ingesting contaminated crops, or drinking water from wells that are heavily contaminated with chromium. Skin problems, stomach ailments, and an excess burden of diseases attributable to environmental factors have been documented at the site. Composite soil sampling in an adjacent residential area yielded an average test result of 4752 ppm hexavalent chromium in soil. The screening threshold level is just 5.6 ppm. The test result was calculated as follows:

$$BI_1 = BI_{SITE} = [\log_{10}(60,000)] + \left[\log_{10}\left(\frac{4,752}{5.6}\right)\right]$$
$$+ 0 = 8.45 \text{ rounds down to } 8$$

In this case, a persistence factor does not apply because hexavalent chromium in soil can reduce to the less toxic trivalent chromium form under anaerobic soil conditions, facilitated by low pH and the presence of reducing agents such as iron or sulfur. Information was not available regarding soil conditions, but a reducing context is possible based on experience at other poorly controlled tannery operations. The calculated index value of 8 is very high even without a persistence factor–high enough to indicate that this site is of major concern with respect to public health risk. If the persistence factor were deemed to apply, then the index number would come out to 9.[15]

DISCUSSION

Variation and Sensitivity

The case studies presented here demonstrate the range and wide application of the BI and show the strengths and relative ease of calculating index values with this simplified HRS. To examine the receptiveness of the results to different circumstances or measurements, 1 or more variables in each of the examples are altered and the resulting changes in the BI are examined. This allows the relative receptiveness or reactivity of the index to be demonstrated, despite the limited data collection required.

The following changes are used to test the receptiveness of the cases just presented and are discussed here: increasing the sample concentration results in Peru; decreasing the population in Ghana; changing the pollutant in Kazakhstan; and adding an additional sample sector in India.

Arsenic in Peru

A case study of water contamination by arsenic in Peru yielded an index value of 1 because the test result was less than twice the screening threshold level. To understand how the index value might have changed if the test result had been just over this threshold for using the index formula, consider a hypothetical test result of 21 ppb. This yields the revised result:

$$BI_1 = BI_{SITE} = [\log_{10}(15,000)] + \left[\log_{10}\left(\frac{21}{10}\right)\right]$$
$$+ 0 = 4.4 \text{ rounds down to } 4$$

Hypothetically, increasing the test result to above the pragmatic cutoff of twice the screening value results in an increase of 3 points in the BI. The change of more than 60% in the concentration moves the index from the minimum value of 1 to a still low value of 4.

Mercury, Lead, and Total Chromium in Ghana

A case study of soil, sediment, and water contamination with multiple pollutants was presented. The contamination was due to an antiquated extraction process from small-scale gold mining. The test result of 50 ppm mercury in soil combined with a relatively small affected population of 5600 people yielded a final index value of 5. To understand how this value might have changed if the population affected were significantly larger, a

hypothetical population of 250,000 people is put into the formula.

$$BI_1 = BI_{SITE} = [\log_{10}(250,000)] + \left[\log_{10}\left(\frac{50}{10}\right)\right]$$
$$+ 1 = 7$$

Although an affected population of 250,000 people might seem unlikely, it is possible within plausible assumptions. Once informal settlements encroach on industrial areas in a densely populated urban area without adequate water and sanitation, the possibility of a large chemical exposure becomes likely. The final test result would increase by 2 in this hypothetical scenario due to the significantly increased number of people that are being affected by the contamination.

Lead in Kazakhstan

A case study of lead pollution around a large smelter was presented. Lead is very stable and persistent in the environment and consequently an additional point is added by the formula to account for the potential long-term effects of the contamination on the affected population. If the persistence factor were not used, the resulting index value would appear as follows:

$$BI_1 = BI_{SITE} = [\log_{10}(40,000)]$$
$$+ \left[\log_{10}\left(\frac{3,399}{400}\right)\right] + 0$$
$$= 5.52 \text{ rounds up to } 6$$

If persistence in the environment were not taken into account, the index value associated with the lead contamination at this site would decrease by 1 point from the high initial value of 7.

Hexavalent Chromium in India

A case study of hexavalent chromium pollution in India was presented. With only 1 sample available for this site, the index value was calculated on the basis of a single sector covering the whole site. However, the final site index value might have come out differently if several samples were available. If a hypothetical second sample were taken at this site yielding a significant but lower test result, the final value still would not have changed because the highest test result is used for the site as a whole. However, if the second sample were higher, the already high index value of 8 might increase to a 9. This would be largely dependent on the population and test results but would not significantly alter the high priority that the site would deserve.

CONCLUSION

Assessment models and algorithms vary in complexity and utility. A balance must be achieved between practicality of data collection, simplicity of implementation, and the usefulness of the final result or application. The modified HRS presented in this article has advantages for use in LMICs for a number of reasons. First, due to its relatively simple formula and minimal amount of data needed for application, the BI can be implemented with limited funds or resources. Second, it provides a quick and robust ranking of current and legacy polluted sites, which is important in LMICs where the issue of toxic pollution has often been neglected for many years. Third, the focus on current public health risk, as opposed to environmental risk or potential future risk is appropriate because of the relative urgency of such risks in LMICs. Many polluted sites are in or adjacent to highly populated and often poor neighborhoods, where the health effects can be severe.

A simplified formula such as the one presented here can be a valuable tool to quantify and rank the risks of toxic polluted sites where time, money, or expertise are limited and where more sophisticated risk calculation methods, such as used by the US EPA, are not practical. Use of this simplified formula can help prioritize and guide needed interventions and therefore help to address the issue of toxic pollution in LMICs.

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