International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 9 (September, 2024), PP 276-282

Environmental Health Risk Assessment: A Framework for Protecting Public Health

Aria Gusti*
*Department of Public Health, Faculty of Public Health, Universitas Andalas, Indonesia
Corresponding Author: Aria Gusti

ABSTRACT
Environmental Health Risk Assessment (EHRA) is a vital tool for evaluating and managing health risks from environmental hazards, such as chemical, biological, and physical agents. It follows a structured process involving hazard identification, dose-response assessment, exposure assessment, and risk characterization. These steps help estimate the likelihood and severity of adverse health effects from environmental exposures. EHRA is increasingly important due to rising industrial activities, urbanization, and agricultural practices, which contribute to pollution in air, water, soil, and food. The assessment also considers vulnerable populations, including children, the elderly, and those with pre-existing health conditions, who may be more susceptible to environmental risks. Despite challenges like data limitations and uncertainties, EHRA is essential for guiding environmental regulations and public health interventions. This paper discusses the framework, methodologies, and applications of EHRA, highlighting its role in reducing exposure to environmental hazards and protecting public health.

Keywords: *Environmental health Risk Assessment, Hazard Identification, Exposure Asessment*

Date of Submission: 09-09-2024 Date of Acceptance: 26-09-2024

I. INTRODUCTION

Environmental health risk assessment (EHRA) plays a pivotal role in understanding and mitigating the impact of environmental hazards on public health.[1] The environment in which people live, work, and play contains a myriad of chemical, physical, biological, and social factors that can influence health outcomes. Environmental pollutants, for instance, can originate from both natural processes and human activities, such as industrialization, urbanization, agriculture, and transportation. These pollutants can affect air quality, contaminate water sources, accumulate in soil, and infiltrate food chains, leading to potential health risks for humans.[2]

As society becomes more industrialized, human activities have led to an increase in the release of hazardous substances into the environment.[3] Industrial waste, emissions from vehicles, chemical run-offs from agricultural fields, and household pollutants all contribute to an array of harmful exposures. Many of these pollutants—such as particulate matter (PM), volatile organic compounds (VOCs), heavy metals, and endocrine-disrupting chemicals—have been linked to serious health problems, including respiratory diseases, cardiovascular conditions, cancers, neurological disorders, and reproductive health issues.

In addition, climate change has emerged as an urgent environmental issue that intensifies existing health risks. The changing climate exacerbates air and water pollution, alters disease vectors, and increases the frequency of extreme weather events like heatwaves, floods, and droughts.[4] These phenomena introduce new health challenges, making it more critical than ever to assess and mitigate environmental risks.

Given the complexity of environmental exposure pathways and the diverse range of potential health outcomes, EHRA is a structured and systematic approach to evaluating these risks. Its objective is not only to identify potential hazards but also to quantify the likelihood and severity of adverse health outcomes that may arise from environmental exposures. By doing so, EHRA provides the scientific basis for regulatory decisions, public health interventions, and environmental management policies aimed at reducing exposure to harmful environmental agents and protecting human health.[5]

The concept of risk assessment itself is grounded in the recognition that not all environmental exposures result in health damage.[6] The magnitude of risk depends on various factors, including the concentration of the hazardous agent, the duration and frequency of exposure, and the vulnerability of the population. EHRA seeks to understand these interactions and to evaluate whether a particular exposure constitutes a significant health threat under certain conditions.[7]

Furthermore, EHRA is instrumental in guiding environmental policy and regulation. Governments and organizations around the world rely on risk assessments to set limits on pollutant levels in the environment, establish guidelines for safe occupational practices, and implement preventive measures.[8] In the public health realm, EHRA helps prioritize interventions, allocate resources, and design targeted health promotion campaigns to protect the most vulnerable populations—such as children, the elderly, and people with pre-existing health conditions—from disproportionate exposure and harm.[9]

In light of the rising number of environmental health threats, from urban pollution to emerging chemical hazards, the need for robust and comprehensive risk assessment strategies is more pressing than ever.[10] In this paper, we will explore the framework of environmental health risk assessment, discuss its key methodologies, and examine its application in various sectors. By understanding the EHRA process, stakeholders—ranging from policymakers to community organizations—can better manage and mitigate environmental risks to ensure a safer and healthier future for all.

II. FRAMEWORK COMPONENTS

EHRA is generally conducted in four major steps:

1. Hazard Identification:

This involves recognizing potential environmental agents or hazards that could cause harm. These hazards can be biological (e.g., bacteria, viruses), chemical (e.g., heavy metals, pesticides), physical (e.g., radiation, noise), or social (e.g., socioeconomic factors affecting exposure). While EHRA is an important process for identifying and controlling environmental hazards, it may overlook systemic issues such as climate change or pollution from larger industries that require broader regulatory action beyond individual hazard identification and control.[11] Additionally, the focus on specific hazards may detract from addressing underlying root causes of environmental harm. In order to truly create a sustainable and healthy environment, it is crucial to address these systemic issues through policy and regulatory changes. Furthermore, fostering collaboration between stakeholders is essential to address these challenges effectively.

By tackling these larger issues, we can work towards creating a more resilient environment that can withstand the challenges of climate change and pollution.[12] It is important for EHRA processes to be integrated with broader environmental policies in order to truly make a lasting impact on the health and safety of our planet. For example, implementing carbon pricing policies can help reduce greenhouse gas emissions from industries, leading to cleaner air and a healthier environment. Additionally, investing in public transportation systems can decrease reliance on fossil fuel-powered vehicles, further mitigating pollution levels and promoting sustainable living practices.

2. Dose-Response Assessment

This step evaluates the relationship between the level of exposure to a substance and the incidence of health effects in exposed populations. It helps in determining safe levels of exposure. Dose-response assessment is crucial in ensuring that regulatory agencies set appropriate limits for exposure to harmful substances, taking into account the potential risks to public health.[13] By understanding how different levels of exposure can impact health outcomes, policymakers can make more informed decisions regarding regulations and guidelines. This step also highlights the need for ongoing monitoring and research to continuously evaluate the potential health risks associated with environmental hazards. This ongoing monitoring allows for adjustments to be made to exposure limits as new information becomes available. By staying informed and proactive in addressing potential health risks, regulatory agencies can better protect the public from the harmful effects of environmental hazards.

Ultimately, dose-response assessment plays a vital role in safeguarding public health and ensuring that regulations are effective in minimizing the impact of harmful substances on the population.[14] For example, in the case of air pollution, researchers may regularly monitor levels of harmful pollutants such as particulate matter and ozone in order to assess their impact on respiratory health. If new studies show that exposure to certain levels of these pollutants poses a greater risk than previously thought, regulatory agencies can quickly adjust emission limits to protect public health. This proactive approach helps prevent adverse health outcomes and improves overall air quality for the population.

3. Exposure Assessment

Exposure assessment estimates how much of a particular agent people are exposed to, the frequency of exposure, and the duration. This involves identifying the sources of exposure, pathways through which people come into contact with the hazard, and the affected population.[15] By understanding the extent of exposure, regulatory agencies can make informed decisions on how to best protect the public from harmful pollutants. By identifying sources and pathways of exposure, measures can be put in place to reduce risks and improve air quality. Through comprehensive exposure assessments, agencies can effectively monitor and regulate emissions to ensure the health and safety of the population. This data-driven approach allows for the implementation of targeted interventions to mitigate the impact of pollutants on public health. By continuously monitoring exposure levels and refining regulations based on new information, regulatory agencies can adapt to changing circumstances and protect the well-being of communities.[16]

Ultimately, these efforts contribute to a healthier environment and improved quality of life for all. For example, by utilizing air quality monitoring devices in urban areas with high levels of pollution, regulatory agencies can identify sources of emissions and implement measures to reduce harmful pollutants. Additionally, conducting regular health impact assessments can help determine the effectiveness of these interventions and guide future regulatory decisions to further improve air quality standards.

4. Risk Characterization

This is the final step, which integrates the information from hazard identification, dose-response, and exposure assessments to estimate the likelihood of adverse health outcomes.[17] The risk is expressed in terms of both the probability and severity of effects on health. This step allows decision-makers to prioritize risks and allocate resources accordingly to protect public health. By understanding the potential harm posed by different pollutants and sources of emissions, regulatory agencies can develop targeted strategies to reduce overall health risks in the population. Risk characterization also helps to communicate the potential health impacts of air pollution to the public, empowering individuals to take action to protect themselves and advocate for cleaner air in their communities (Regina and Andrea) .

Furthermore, risk characterization enables researchers to identify gaps in knowledge and areas where further investigation is needed to fully understand the health impacts of air pollution. By continually updating risk assessments and incorporating new data, regulatory agencies can adapt their policies and regulations to effectively address emerging health concerns. Ultimately, the goal of risk characterization is to provide decision-makers and the public with the information needed to make informed choices that will improve air quality and protect public health for generations to come. For example, a risk characterization study may find that certain populations living near industrial sources of pollution are at a higher risk of respiratory illnesses due to exposure to harmful pollutants. By understanding these risks, policymakers can implement stricter emissions controls and monitoring measures to protect vulnerable communities and reduce the overall burden of air pollution-related health issues.

III. METHODOLOGIES IN ENVIRONMENTAL HEALTH RISK ASSESSMENT

A variety of methods are employed in EHRA, including:

1. Quantitative Risk Assessment (QRA)

Uses numerical values to describe the risk, often expressed in terms of probabilities and expected cases of illness or injury. Uses numerical values to describe the risk, often expressed in terms of probabilities and expected cases of illness or injury. Quantitative Risk Assessment (QRA) is often used in situations where accurate data is available, allowing for precise calculations of risk. However, an alternative semi-quantitative approach has been proposed that acknowledges the limitations of accurately expressing risk using probabilities and expected values. This approach focuses on establishing a broad qualitative risk picture, defining crude risk categorizations, and evaluating risk based on a more comprehensive perspective.[18] On the other hand, Qualitative Risk Assessment is utilized when there is uncertainty or limited data, providing a more general understanding of potential risks. Toxicological and Epidemiological Studies play a crucial role in assessing environmental risks, providing valuable information on the impact of exposures on human health and helping to prioritize interventions to protect vulnerable populations. For example, in a study assessing the risk of a chemical exposure in a community near a factory, Quantitative Risk Assessment could be used to calculate the likelihood of adverse health effects based on specific exposure levels and population demographics. Qualitative Risk Assessment could then be employed to estimate potential risks in cases where data on exposure levels or health outcomes is limited.

2. Qualitative Risk Assessment

Involves describing risks in non-numerical terms, often used when data is incomplete or when a quick risk estimation is needed. This approach relies on expert judgment and experience to evaluate the likelihood and severity of potential risks. It is particularly useful in situations where there is uncertainty or variability in the data, allowing for a more comprehensive understanding of the risks involved.[19] By combining both quantitative and qualitative risk assessments, a more holistic view of the potential dangers posed by a chemical exposure can be obtained, ultimately leading to better informed decision-making and protective measures for the community.

For example, when assessing the risks associated with a new industrial chemical, experts may consider factors such as the toxicity of the substance, the route of exposure, the duration and frequency of exposure, and the potential for exposure to vulnerable populations. This comprehensive approach can help to identify and prioritize risks, enabling decision-makers to implement appropriate control measures and mitigate potential harm. In addition, the use of expert judgment in risk assessment allows for the consideration of non-traditional risks, such as those related to social, cultural, or economic factors, that may not be captured by traditional risk assessment methods. Overall, the integration of expert judgment into risk assessment processes can enhance the accuracy and reliability of risk estimates, ultimately leading to more effective risk management strategies.

3. Toxicological and Epidemiological Studies

These studies provide data on the effects of environmental exposures on health, helping to define dose-response relationships and identifying population groups that are more vulnerable to certain hazards. For example, in a quantitative risk assessment of a chemical plant, probabilities of different accident scenarios occurring and the expected number of workers affected by each scenario would be calculated. In a qualitative risk assessment of a new product, risks such as potential allergic reactions or misuse may be described in terms of severity and likelihood. Effector mechanisms in anaphylaxis involve the activation of mast cells and/or basophils, triggered by exposure to various allergens. Risk assessment in anaphylaxis involves confirming the clinical diagnosis and considering intrinsic risk factors beyond sensitization to allergens. New approaches are being investigated to support the clinical diagnosis of anaphylaxis and distinguish sensitized individuals at risk.[20]

These assessments play a crucial role in shaping public policy and regulations to protect human health and the environment. By understanding the potential risks associated with various exposures, decision-makers can implement measures to mitigate these risks and safeguard the well-being of individuals and communities. Additionally, risk assessments can also inform the development of strategies for emergency response and preparedness in the event of an environmental incident or disaster. Overall, the data and insights provided by risk assessments are essential tools in promoting a safe and sustainable environment for all.

4. Geographical Information Systems (GIS)

GIS is increasingly used to map exposure data, identify hotspots of environmental contamination, and analyze the spatial distribution of health outcomes in relation to social vulnerability and environmental burdens. Spatial health inequalities, such as unequal distribution of resources, play a key role in affecting health outcomes. GIS tools and data analysis can help in understanding why some geographical areas experience poorer health than others.[21] Additionally, mapping and modeling human exposure to uraniferous mine waste using GIS can inform the selection of sampling sites for epidemiological studies on uranium exposure in residents.[22] Environmental health related socio-spatial inequalities can identify 'hotspots' of environmental burdens and social vulnerability, revealing spatial patterns of inequalities within a city.[23] This information can guide the development of targeted intervention strategies to reduce health disparities.

IV. APPLICATION OF EHRA IN VARIOUS CONTEXTS

EHRA has been applied in numerous settings, including:

1. Urban and Industrial Areas

Industrial activities release pollutants into the environment, necessitating the assessment of air quality, water contamination, and soil pollution.[24] Airborne pollutants like particulate matter (PM2.5), volatile organic compounds (VOCs), and heavy metals are commonly assessed to understand their health risks. EHRA is crucial in urban settings where high population density and traffic congestion can exacerbate air pollution levels. In industrial areas, EHRA helps to monitor the impact of factory emissions on nearby communities and ecosystems. By analyzing the levels of pollutants in the air, water, and soil, EHRA can provide valuable data for decision-makers to develop strategies for pollution control and public health protection. For example, in a study conducted in a highly industrialized area, EHRA found elevated levels of heavy metals in the air near a factory that was emitting pollutants. This data prompted local authorities to enforce stricter regulations on the factory to reduce its emissions and protect the health of nearby residents. Additionally, EHRA identified areas with high concentrations of VOCs in urban settings, leading to targeted efforts to reduce traffic congestion and improve air quality through measures such as promoting public transportation and implementing green spaces.

2. Agricultural Communities

The use of pesticides and herbicides in agricultural settings presents significant health risks, particularly for rural populations.[25] EHRA helps assess these risks by analyzing pesticide exposure through food, water, and air. By working closely with farmers and agricultural workers, EHRA is able to provide recommendations for safer alternatives and practices to minimize exposure to harmful chemicals. This proactive approach helps protect the health of agricultural communities and ensures sustainable farming practices for future generations. Through education and outreach programs, EHRA also raises awareness about the potential health impacts of pesticide use and advocates for policies that promote organic farming and environmentally-friendly agricultural practices. For example, EHRA may work with a group of farmers in a rural community to implement integrated pest management techniques, reducing the need for harmful pesticides. By educating the farmers on alternative methods such as crop rotation and natural predators, EHRA helps them transition to more sustainable practices that protect both their health and the environment.

3. Climate Change and Natural Disasters

EHRA plays a key role in understanding the health impacts of climate change and environmental disasters such as floods, wildfires, and droughts.[10] These events often exacerbate existing environmental hazards or introduce new ones, requiring comprehensive risk assessments. EHRA works to develop adaptation strategies and emergency response plans to mitigate the health risks associated with these events. By conducting research and providing training on climate change resilience, the organization helps communities prepare for and respond to natural disasters in a way that minimizes their impact on public health. Through collaboration with local authorities and other stakeholders, EHRA aims to build a more resilient and sustainable future for vulnerable populations facing the increasing threats of climate change. For example, in a flood-prone region, EHRA would conduct a risk assessment to identify vulnerable populations such as elderly individuals living in low-lying areas. They would then work with local authorities to develop evacuation plans and establish early warning systems to ensure these individuals can safely evacuate before the flood hits. By providing training on disaster preparedness and resilience building measures, EHRA helps these communities mitigate the health risks associated with floods and other climate-related disasters.

4. Vulnerable Populations

Certain groups such as children, the elderly, and individuals with pre-existing health conditions are more susceptible to environmental risks. Children, the elderly, and individuals with pre-existing health conditions are more susceptible to environmental risks due to factors such as physiological immaturity in children, compromised physiological capacity in the elderly, and underlying health conditions in individuals with pre-existing diseases.[26] EHRA is tailored to account for vulnerable populations, ensuring protective measures are in place to mitigate health impact. EHRA works closely with local health authorities and community leaders to identify and prioritize the needs of these vulnerable populations. Through targeted outreach and education campaigns, EHRA aims to increase awareness and empower these individuals to take proactive steps to protect their health during disasters. By addressing the unique challenges faced by vulnerable populations, EHRA is able to enhance the overall resilience and well-being of communities at risk. For example, EHRA may work with a low-income neighborhood that is prone to flooding, helping residents create emergency plans and access resources like emergency shelters. They may also collaborate with local health clinics to provide vaccinations and medical supplies to vulnerable populations during a disease outbreak. Through these efforts, EHRA helps ensure that those most at risk have the support they need to stay safe and healthy in times of crisis.

V. CHALLENGES IN ENVIRONMENTAL HEALTH RISK ASSESSMENT

Several challenges persist in conducting EHRA effectively:

1. Data Limitations

In many cases, insufficient data on exposure levels, health effects, and vulnerable populations complicates the risk assessment process. Limited resources, both in terms of funding and expertise, can also hinder the ability to conduct thorough EHRA.[27] Additionally, the lack of standardized methodologies and guidelines for conducting EHRA across different regions and sectors further adds to the complexity of the process. Despite these challenges, it is important to continue improving EHRA practices to better protect human health and the environment.While data limitations can pose challenges, advancements in technology and data collection methods have greatly improved the availability and accuracy of information for conducting EHRA. Additionally, collaborations between researchers and stakeholders can help fill in gaps in data and enhance the overall effectiveness of the assessment process.

Moving forward, it will be crucial for organizations to prioritize data sharing and collaboration in order to address these challenges and improve EHRA practices. By working together, researchers and stakeholders can ensure that EHRA processes are more comprehensive and accurate, ultimately leading to better protection of human health and the environment. Additionally, ongoing advancements in technology and data collection methods will continue to play a key role in enhancing the effectiveness of EHRA and mitigating potential risks to society.

2. Uncertainty in Risk Estimates

Estimating risks involves inherent uncertainties due to the complexity of environmental exposure pathways and the variability in human responses to different hazards.[28] Methods for addressing these uncertainties, such as sensitivity analysis, are critical. While data limitations and uncertainty in risk estimates are valid challenges, EHRA can still be conducted effectively by utilizing alternative data sources, expert judgment, and robust sensitivity analysis techniques to account for these limitations and uncertainties. It is important to acknowledge these challenges but not let them hinder the overall effectiveness of EHRA.

By incorporating multiple sources of information and expertise, EHRA practitioners can improve the accuracy and reliability of their assessments. Additionally, ongoing research and advancements in modeling techniques can help to reduce uncertainty and improve the overall quality of EHRA results. Collaboration between experts in different fields, such as toxicology, epidemiology, and environmental science, can also enhance the robustness of EHRA by incorporating a variety of perspectives and knowledge bases. Ultimately, by acknowledging and addressing these challenges head-on, EHRA can continue to be a valuable tool for assessing and managing environmental health risks.

3. Communication of Risk

Once risks are characterized, communicating them to the public and decision-makers is crucial but challenging.[29] Effective risk communication must balance scientific uncertainty with the need for timely action. It must be transparent, clear, and tailored to the audience's level of understanding. This can involve using visual aids, plain language, and engaging with stakeholders to ensure that risks are clearly understood. Additionally, building trust and credibility with the audience is essential for effective risk communication. It is important to acknowledge uncertainties while also providing practical guidance for mitigating risks and making informed decisions. Ultimately, successful risk communication can empower individuals and communities to take action to protect themselves and others.

By actively listening to the concerns and feedback of stakeholders, risk communicators can address misconceptions and build consensus on appropriate risk management strategies. In times of crisis, such as natural disasters or public health emergencies, clear and timely communication is crucial to prevent panic and ensure that accurate information is disseminated. Establishing a two-way dialogue with the audience can also help to foster a sense of transparency and accountability, which is key to maintaining trust in the long term. In order to effectively communicate risks, it is important to tailor the message to the specific needs and preferences of the audience, taking into account factors such as cultural background, language proficiency, and literacy levels. By engaging with stakeholders in a respectful and inclusive manner, risk communicators can build stronger relationships and facilitate more effective risk management outcomes.

VI. CONCLUSION

Environmental health risk assessment provides a structured approach to understanding and managing the health risks associated with environmental hazards. Through its four core steps include hazard identification, dose-response assessment, exposure assessment, and risk characterization. EHRA offers valuable insights into the potential health impacts of environmental factors. The continued advancement of EHRA methodologies and tools, such as GIS and computational modeling, will enhance the accuracy and utility of these assessments, enabling policymakers and public health professionals to make informed decisions that protect populations from environmental health risks.

REFERENCES

[1] Carter P. Environmental Health Risk Assessment for Global Climate Change and Atmospheric Greenhouse Gas Pollution. In: Leal Filho W, Azul AM, Brandli L, Özuyar PG, Wall T, editors. Climate Action, Cham: Springer International Publishing; 2020, p. 413–23. https://doi.org/10.1007/978-3-319-95885-9_95.

[2] Özkara A, Akyıl D. Environmental Pollution and the Effects of the Pollutants on the Ecosystem. Türk Bilimsel Derlemeler Dergisi 2018;11:11–7.

[3] Ali H, Khan E, Ilahi I. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. J Chem 2019;2019:1–14. https://doi.org/10.1155/2019/6730305.

[4] Aadil Gulzar, Tajamul Islam, Ruquia Gulzar, Tabasum Hassan. Climate Change and Impacts of Extreme Events on Human Health: An Overview. Indonesian Journal of Social and Environmental Issues (IJSEI) 2021;2:68–77. https://doi.org/10.47540/ijsei.v2i1.180.

[5] Manno M. Biological monitoring for environmental health risk assessment. Environmental Geochemistry, Elsevier; 2024, p. 101–19. https://doi.org/10.1016/B978-0-443-13801-0.00021-9.

[6] Backhaus T, Faust M. Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework. Environ Sci Technol 2012;46:2564–73. https://doi.org/10.1021/es2034125.

[7] Kavlock RJ, Daston GP, DeRosa C, Fenner-Crisp P, Gray LE, Kaattari S, et al. Research needs for the risk assessment of health and environmental effects of endocrine disruptors: a report of the U.S. EPA-sponsored workshop. Environ Health Perspect 1996;104:715–40. https://doi.org/10.1289/ehp.96104s4715.

[8] Clahsen SCS, van Kamp I, Hakkert BC, Vermeire TG, Piersma AH, Lebret E. Why Do Countries Regulate Environmental Health Risks Differently? A Theoretical Perspective. Risk Analysis 2019;39:439–61. https://doi.org/10.1111/risa.13165.

[9] Briggs DJ. A framework for integrated environmental health impact assessment of systemic risks. Environmental Health 2008;7:61. https://doi.org/10.1186/1476-069X-7-61.

[10] Carter P. Environmental Health Risk Assessment for Global Climate Change and Atmospheric Greenhouse Gas Pollution. In: Leal Filho W, Azul AM, Brandli L, Özuyar PG, Wall T, editors. Climate Action, Cham: Springer International Publishing; 2020, p. 413–23. https://doi.org/10.1007/978-3-319-95885-9_95.

[11] Manno M. Biological monitoring for environmental health risk assessment. Environmental Geochemistry, Elsevier; 2024, p. 101–19. https://doi.org/10.1016/B978-0-443-13801-0.00021-9.

[12] Lu Y, Khan ZA, Alvarez-Alvarado MS, Zhang Y, Huang Z, Imran M. A Critical Review of Sustainable Energy Policies for the Promotion of Renewable Energy Sources. Sustainability 2020;12:5078. https://doi.org/10.3390/su12125078.

[13] Barlow S, Renwick AG, Kleiner J, Bridges JW, Busk L, Dybing E, et al. Risk assessment of substances that are both genotoxic and carcinogenic. Food and Chemical Toxicology 2006;44:1636–50. https://doi.org/10.1016/j.fct.2006.06.020.

[14] Ferguson A, Penney R, Solo-Gabriele H. A Review of the Field on Children's Exposure to Environmental Contaminants: A Risk Assessment Approach. Int J Environ Res Public Health 2017;14:265. https://doi.org/10.3390/ijerph14030265.

[15] Paustenbach DJ, Madl AK, Massarsky A. Exposure Assessment. Human and Ecological Risk Assessment, Wiley; 2024, p. 157–261. https://doi.org/10.1002/9781119742975.ch5.

[16] Jain A, Leka S, Zwetsloot GIJM. Managing Health, Safety and Well-Being: Ethics, Responsibility and Sustainability. Springer Dordrecht; 2018. https://doi.org/https://doi.org/10.1007/978-94-024-1261-1.

[17] Sexton K, Callahan MA, Bryan EF. Estimating exposure and dose to characterize health risks: the role of human tissue monitoring in exposure assessment. Environ Health Perspect 1995;103:13–29. https://doi.org/10.1289/ehp.95103s313.

[18] Aven T. A semi-quantitative approach to risk analysis, as an alternative to QRAs. Reliab Eng Syst Saf 2008;93:790–7. https://doi.org/10.1016/j.ress.2007.03.025.

[19] Ramalhinho AR, Macedo MF. International Journal Of Conservation Science Cultural Heritage Risk Analysis Models: An Overview. n.d.

[20] Simons F, Frew A, Ansotegui I, Bochner B, Golden D, Finkelman F, et al. Risk assessment in anaphylaxis: Current and future approaches. Journal of Allergy and Clinical Immunology 2007;120:S2–24. https://doi.org/10.1016/j.jaci.2007.05.001.

[21] Ozdenerol E. Spatial Health Inequalities. CRC Press; 2016. https://doi.org/10.1201/9781315371894.

[22] Winde F, Hoffmann E, Espina C, Schüz J. Mapping and modelling human exposure to uraniferous mine waste using a GIS-supported virtual geographic environment. J Geochem Explor 2019;204:167–80. https://doi.org/10.1016/j.gexplo.2019.05.007.

[23] Shrestha R, Flacke J, Martinez J, Van Maarseveen M. Environmental Health Related Socio-Spatial Inequalities: Identifying "Hotspots" of Environmental Burdens and Social Vulnerability. Int J Environ Res Public Health 2016;13:691. https://doi.org/10.3390/ijerph13070691.

[24] Edo GI, Itoje-akpokiniovo LO, Obasohan P, Ikpekoro VO, Samuel PO, Jikah AN, et al. Impact of environmental pollution from human activities on water, air quality and climate change. Ecological Frontiers 2024. https://doi.org/10.1016/j.ecofro.2024.02.014.

[25] Tudi M, Li H, Li H, Wang L, Lyu J, Yang L, et al. Exposure Routes and Health Risks Associated with Pesticide Application. Toxics 2022;10:335. https://doi.org/10.3390/toxics10060335.

[26] Makri A, Stilianakis NI. Vulnerability to air pollution health effects. Int J Hyg Environ Health 2008;211:326–36. https://doi.org/10.1016/j.ijheh.2007.06.005.

[27] Ashbolt NJ, Amézquita A, Backhaus T, Borriello P, Brandt KK, Collignon P, et al. Human Health Risk Assessment (HHRA) for Environmental Development and Transfer of Antibiotic Resistance. Environ Health Perspect 2013;121:993–1001. https://doi.org/10.1289/ehp.1206316.

[28] Ramsey MH. Uncertainty in the assessment of hazard, exposure and risk. Environ Geochem Health 2009;31:205–17. https://doi.org/10.1007/s10653-008-9211-8.

[29] Health M of. Guidelines for Environmental Health Risk Assessment (EHRA). Jakarta: Directorate General of Disease Control and Environmental Health; 2013.