



REVIEW ARTICLE

Exploring the exposome: A new approach to understanding environmental influences on anthroposemiotics

Mainak Banerjee^{1*}, Mousumi Dutta² & Arghya Mandal³

¹Department of Zoology, Ram Krishna Dharmarth Foundation (RKDF) University, Ranchi 834 004, Jharkhand, India

²Government General Degree College, Kharagpur-II, Madpur, Paschim Medinipur 721 149, West Bengal, India

³Department of Environmental Studies, Mankar College, Mankar 713 144, West Bengal, India

*Email: mainak.bio@gmail.com

OPEN ACCESS

ARTICLE HISTORY

Received: 24 June 2025

Accepted: 13 May 2026

Available online

Version 1.0 : 24 August 2026

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/TCB/open_access_policy

Publisher's Note: The article processing was done by atom e-Publishing, Thiruvananthapuram, India. Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

CITE THIS ARTICLE

Mainak B, Mousumi D, Arghya M. Exploring the exposome: A new approach to understanding environmental influences on anthroposemiotics. Trends in Current Biology. 2026; 4(3): 50-54. <https://doi.org/10.14719/tcb.9429>

Abstract

A novel perspective on the intricate relationships between nature and anthroposemiotics is through the framework of the exposome, which entails a comprehensive evaluation of environmental exposures throughout an individual's lifespan. Environmental factors significantly influence anthroposemiotics, the study of signs and meaning-making in human culture; nonetheless, traditional methodologies often overlook the substantial effects of the exposome. This work aims to elucidate the significance of incorporating exposome research into the study of anthroposemiotics to enhance our understanding of nature's impact on human communication, cognition and cultural evolution. We examine the ramifications for linguistics, semiotics, anthropology and environmental studies, along with potential avenues for incorporating exposome data into anthroposemiotic research, utilising multidisciplinary literature. Embracing the exposome paradigm will enhance our understanding of the intricate interactions between individuals and their environments, facilitating innovative research methodologies and practical insights to address contemporary challenges related to sustainability, culture and communication.

Keywords

anthroposemiotics; communication; culture; environment; exposome; interdisciplinary; significance; sustainability

Introduction

Understanding the intricate interaction between humans and their environment is essential in various disciplines, including ecology and anthropology. The concept of the exposome, an all-encompassing framework that incorporates all environmental exposure during an individual's lifespan, is essential to this initiative (1). The study of anthroposemiotics examines how individuals understand signs and symbols within cultural contexts. Despite the acknowledged significance of environmental influences on human behaviour and cognition, anthroposemiotic analysis does not comprehensively incorporate exposome research. The exposome paradigm emphasises the cumulative impacts of both internal and external environmental exposures, including contaminants, dietary factors, social interactions and psychosocial stressors, among others. These exposures have diverse effects on human biology, behaviour and development (2, 3). They can also influence population-level disease patterns and individual health trajectories. Conventional approaches of studying human cognition, communication and culture often overlook the dynamic interplay between anthroposemiotics and the exposome. Anthroposemiotics examines the semiotic processes through which individuals comprehend and attribute meaning to cultural systems. Human culture is replete with signs and symbols that reflect and delineate societal values, beliefs and identities, encompassing language, art, rituals and social norms. Nevertheless, anthroposemiotics tends to minimise the impact of the environment on meaning-making processes, although acknowledging the socio-cultural framework in which these processes occur.

This work promotes a comprehensive approach that considers the exposome's influence on anthroposemiotic phenomena to address this academic divide. We want to get a comprehensive knowledge of the diverse ways in which nature influences human cognition, communication and cultural evolution. Our aim is to elucidate the complex interactions between environmental exposures and semiotic processes that produce cultural continuity and variation. Consequently, we utilise an interdisciplinary approach that integrates concepts from anthropology, linguistics, environmental studies and exposome research.

Theoretical framework

The intersection of anthroposemiotics and the exposome offers a comprehensive theoretical framework that elucidates the complex interplay between environmental exposures and human meaning-making processes. This study is informed by a theoretical framework that integrates core concepts from various disciplines, including environmental psychology, semiotics, cultural anthropology and exposome theory (4–6). By integrating these many perspectives, we can develop a nuanced understanding of how environmental conditions affect the creation, interpretation and diffusion of cultural symbols and meanings. The exposure theory provides a comprehensive framework for comprehending the full spectrum of environmental exposures individuals encounter throughout their lives. This framework encompasses both internal and external factors, including dietary practices, microbiota makeup, gene-environment interactions and physiological responses to stress (7). External exposures encompass factors such as air and water quality, built environments and socioeconomic conditions. The concept of "exposome signatures" emphasises the unique environmental profiles of individuals and populations, reflecting the interplay of genetic predispositions, environmental exposures and health outcomes. Anthroposemiotics concurrently offers a theoretical framework for studying how individuals interpret signs and symbols within cultural contexts (8). Anthroposemiotics, originating from semiotic theory, examines the processes of signification, interpretation and communication that form the foundation of human civilisation. Anthroposemiotics seeks to understand how symbols acquire cultural significance and influence social behaviour, encompassing the linguistic structures of spoken and written language as well as the visual representations seen in art and media. Moreover, anthroposemiotics recognises the influence of historical circumstances, social dynamics and context on semiotic practices and cultural norms (9). The integration of exposome theory with anthroposemiotics offers a novel framework for analysing the reciprocal relationship between environmental exposures and cultural interpretation. We can elucidate the processes via which nature influences human culture by considering how environmental factors impact the formation and interpretation of cultural symbols (8–10). Environmental stressors can modify the structure and content of linguistic utterances, influencing the variation and evolution of language among individuals. Cultural rituals and symbols may evolve as adaptive responses to environmental challenges, preserving ecological knowledge and enhancing community resilience (11, 12). This theoretical framework underscores the complexity and dynamism of human-environment interactions. Environmental exposure influences social structures, power dynamics, collective identities, cognitive processes and communication patterns across individual, interpersonal and societal dimensions. By employing a comprehensive approach that

considers the reciprocal interactions of the exposome and anthroposemiotics, we can develop more intricate models of linguistic diversity, cultural evolution and environmental stewardship.

Exposome and language

The significant influence of environmental factors on linguistic variety, evolution and acquisition is examined in the section on Exposome and language. Environmental influences, encompassed under the exposome concept, significantly influence language usage and development across diverse cultural contexts. Language attributes such as vocabulary, grammar and pronunciation can be affected by regional variations in temperature, topography and resource availability. The dynamic evolution of languages over time is driven by sociocultural factors, including migration patterns, urbanisation trends and globalisation (13–15). Pollution, noise and social disparity adversely affect language acquisition and proficiency. Research suggests that environmental stressors may influence cognitive development, including language processing abilities, hence affecting children's language learning outcomes. Moreover, disparities in language access and education may be intensified by environmental factors, further segregating various groups (14). By examining the intersection of language and the exposome, researchers can gain a profound insight into the complex link between linguistic diversity and environmental influences. Understanding how environmental factors affect language diversity and acquisition is crucial for language policy, education and cultural preservation efforts. By doing interdisciplinary research that synthesises insights from linguistics, anthropology and environmental studies, we can develop more complete methodologies for analysing language diversity and promoting linguistic equity across diverse socio-environmental contexts (16).

Exposome and cultural semiotics

The segment on Exposome and cultural semiotics examines how environmental exposures influence the creation, significance and transmission of cultural symbols, traditions and behaviours (17). Environmental factors are essential in influencing cultural semiotics within the framework of the exposome, as they affect the material and socio-economic conditions that lead to cultural expressions (18). Many cultural traditions often derive inspiration for their artistic expressions and symbolic significances from natural landscapes, climatic phenomena and biological resources. Environmental pressures that can jeopardise cultural heritage and disrupt traditional cultural practices including pollution, habitat degradation and climate change. Environmental degradation may threaten the preservation of cultural artefacts, sacred sites and traditional knowledge systems, hence jeopardising community resilience and the continuity of cultural identities (18–20). Cultural symbols and rituals may serve as adaptive responses to environmental challenges by promoting sustainable practices within communities and instilling ecological knowledge. Researchers can gain insights into the impact of the environment on cultural expression, identity formation and collective memory by examining the relationships between cultural semiotics and the exposome (19). To address the socio-environmental challenges confronting contemporary societies and to foster cultural diversity and resilience, it is essential to understand these relationships. By collaborating across disciplines and engaging the community, we may develop strategies for cultural revival and environmental stewardship that honour the symbiotic relationship between individuals and their natural environments.

Exposome and cognitive semiotics

In Exposome and Cognitive Semiotics, we examine how environmental exposure influences the cognitive processes fundamental to perception, memory, conceptualisation and semiotic interpretation. Contaminant exposure, socioeconomic factors and psychosocial stressors are examples of environmental influences that may affect cognitive performance, as outlined in the exposome paradigm (20–22). Contextual factors greatly influence how individuals perceive and interpret symbols, encode and retrieve memories and construct conceptual frameworks within cultural environments. The deterioration of attention, memory and executive functioning has been linked to environmental stressors such as noise and air pollution. Additional factors influencing cognitive biases and perceptual distortions that impact individuals' comprehension of cultural symbols and social interactions include psychosocial stressors and socioeconomic disparities (21). Cultural schemas and collective cognition are significantly shaped by environmental conditions, which also affect the common values, worldviews and beliefs of communities. Researchers can gain understanding of how environmental exposures influence cognitive processes and cultural interpretation by examining the intersection of the exposome and cognitive semiotics. Understanding these processes is essential for reducing cognitive disparities, enhancing psychological well-being and fostering cultural resilience to environmental disruptions (22).

Methodological considerations

To guarantee the validity and robustness of findings, the integration of anthroposemiotic analysis with exposome research necessitates meticulous consideration of certain methodological factors. Firstly, sophisticated methodologies for amalgamating diverse datasets, such as linguistic corpora, cultural artefacts and environmental monitoring data are essential for data integration and analysis. Statistical approaches like structural equation modelling elucidate complex relationships among variables, while multilevel modelling techniques facilitate the examination of individual and population-level connections between environmental exposures and anthroposemiotic phenomena (22). Interdisciplinary collaboration is crucial as it integrates knowledge from environmental science, languages, semiotics, anthropology and epidemiology. Collaboration guarantees that research outcomes are culturally pertinent and enhances methodological rigour. Comprehending temporal and socio-cultural processes necessitates longitudinal and contextual research; ethnographic approaches and community engagement are essential for capturing nuances and accurately interpreting data (23). It is imperative to prioritise ethical considerations, including securing informed consent and respecting cultural traditions (24). The application of indigenous research methods promotes equitable relationships and respectful engagement with communities. Stringent validation protocols and transparent scientific methodologies ensure validation and reproducibility, enhancing the reliability and clarity of study outcomes. Addressing these methodological issues fosters knowledge progress and guides interventions for environmental sustainability and societal well-being. It facilitates the production of sophisticated insights into the reciprocal interaction between environmental exposures and cultural meaning-making processes.

Physiological aspects of exposome

The exposome includes all environmental exposures and individual experiences over their lifetime, comprising both external and

internal variables. These exposures encompass tiny chemicals and metabolic byproducts (endogenous exposures), non-chemical stressors such as climate change and radiation and intricate combinations like air and water pollution. Investigating the exposome necessitates consideration of intrinsic biological reactions, including oxidative stress, interactions between external agents and metabolic pathways, DNA repair mechanisms and the accumulation of mutations (24–26). Simultaneously analysing numerous exposures provides a more thorough comprehension of the impact of environmental factors on human health (26). Researchers often utilise two contrasting methodologies to characterise the exposome: the bottom-up strategy, which initiates with specific exposures and the top-down approach, which commences with biological responses to deduce potential exposures. Advanced data processing techniques are crucial for exposome sequencing, facilitating the detection of correlations among environmental exposures, the genome and illness outcomes, especially in chronic disorders with unidentified causes. Research indicates that genetic variants contribute to only a little fraction (about 10–30 %) of the diversity in chronic disease risk, underscoring the substantial impact of environmental factors and gene-environment interactions. Genetic research has elucidated the underlying molecular underpinnings of allergy disorders. This methodology can also be utilised for various illnesses, including type II diabetes and obesity. A multitude of environmental and behavioural risk factors—such as urbanisation, air pollution, occupational exposures, virus infections, smoking and dietary habits—have been associated with the onset of asthma and allergy disorders. These relationships highlight the necessity of assessing the comprehensive spectrum of environmental exposures in the examination of illness aetiology (27). The exposome has transitioned from a theoretical notion to an emerging reality in health research. The combined use of epidemiological, bioinformatic and toxicological methodologies is enhancing the comprehension of public health effects that are only partially elucidated by genetic sequencing. To maximise this promise, public health research must progressively integrate these technologies into population-based cohort studies. Effective exposome characterisation will provide the concurrent assessment of genetic and environmental factors within a unified study framework, hence permitting a more thorough exploration of gene-environment interactions (28). This signifies a substantial paradigm change in scientific study, transitioning from the conventional one-to-one exposure-outcome model to a more comprehensive view of health as the product of numerous, interacting exposures. The emergence of exposomic methods enables the development of novel study designs that capture this complexity (29). This method may ultimately clarify the enduring controversy regarding the respective roles of nature (genetic inheritance) and nurture (environmental influence) in human health (30). An individual's distinct traits and health consequences result from the intricate interaction of genetic and many non-genetic elements. Although a minor fraction of disorders can be exclusively linked to genetic variation, research into non-genetic factors has traditionally been constrained, frequently concentrating on isolated or narrowly defined exposures. To rectify this deficiency, the notion of the exposome has arisen, offering a more holistic framework for comprehending human health (31). The exposome includes all physical, chemical, biological and psychosocial exposures a human experience from conception onwards, together with the internal biological reactions that influence their health impacts. Recent

advancements in monitoring technologies and analytical techniques have markedly enhanced the significance of the exposome in environmental and biological research. This transition has facilitated the identification of causal relationships between intricate environmental exposures and various health outcomes. Exposure to chemical combinations, whether deliberate or involuntary, has been linked to the onset of different illnesses and metabolic problems (31). Exposome-wide association studies (EWAS) performed in extensive cohorts, including the UK Biobank, have demonstrated that all-cause mortality correlates more significantly with the exposome than with genetic variables (32). Notwithstanding these encouraging advancements, the investigation of the exposome continues to be intrinsically difficult. The dynamic, multifactorial characteristics and the variety of exposures over the human lifespan necessitate comprehensive, interdisciplinary methodologies. A thorough comprehension of the exposome's influence on health necessitates collaboration among specialists in analytical chemistry, toxicology, epidemiology, environmental science, clinical medicine, data science and many omics fields. This comprehensive paradigm is crucial for elucidating the intricate links between environmental exposures and disease.

The exposome presents a revolutionary approach for elucidating disease mechanisms, guiding precision and preventative medicine and delivering a comprehensive insight into the influence of the environment on human health as environmental and biomedical sciences progress.

Implications and future directions

The integration of exposome research with anthroposemiotic analysis has significant implications for scholarly inquiry and practical use. This multidisciplinary approach enhances our understanding of the complex interplay between cultural dynamics and environmental exposures. By elucidating how environmental factors affect cultural symbols, language and cognitive processes, researchers can aid in formulating policies and initiatives that promote environmental sustainability and cultural resilience. The findings of integrated exposome-anthroposemiotic research possess practical implications for public health, language revitalisation and conservation efforts. Educational interventions for marginalised groups may be informed by an understanding of how environmental stressors affect language acquisition and cultural practices. Examining the cultural significance of environmental symbols and rituals can enhance conservation initiatives that employ community-based approaches alongside traditional ecological science. Potential research directions include longitudinal studies to examine the lasting impacts of environmental exposures on cultural changes, as well as cross-cultural comparisons to identify both universal and context-specific patterns. Moreover, by employing advanced computational methods such as network analysis and machine learning, we can enhance our ability to mimic complex environmental-cultural interactions. Integrating anthroposemiotic analysis with exposome research offers effective strategies for addressing contemporary challenges at the intersection of culture, cognition and environment.

Conclusion

To sum up, the combination of anthroposemiotic analysis and exposome research presents a viable multidisciplinary method for comprehending the complex interactions between cultural

dynamics and environmental exposures. Researchers can provide light on the mutually reinforcing link between humans and their environment by investigating how environmental influences influence language, cultural symbols and cognitive processes. This integrated paradigm informs policies and initiatives targeted at enhancing human well-being and environmental sustainability, with implications for public health, education and conservation. In order to advance our understanding of the exposome-anthroposemiotic nexus and turn research findings into workable solutions for addressing current issues at the nexus of culture, cognition and the environment, it is imperative that interdisciplinary collaboration, methodological innovation and community engagement continue. Researchers may learn how environmental influences influence cultural symbols, rituals and practices, as well as the cognitive processes that underlie semiotic interpretation and meaning making, by using this integrated approach. We may better understand how environmental changes affect human health, behavior and social well-being by clarifying these complex interactions. Furthermore, this research has practical ramifications for environmental preservation, public health and education that go well beyond the confines of academia. Understanding the processes by which cultural variety, language development and cognitive resilience are influenced by environmental exposures might help us design treatments and policies that advance both environmental sustainability and human well-being. Research in this area will not advance unless ongoing multidisciplinary cooperation, methodological innovation and community participation are fostered. We can address urgent societal issues at the nexus of culture, cognition and the environment by adopting a holistic approach that incorporates a variety of viewpoints and methodologies, ultimately promoting a more peaceful and sustainable coexistence between people and their surroundings.

Acknowledgements

Authors gratefully acknowledged to Department of Zoology, Ram Krishna Dharmarth Foundation (RKDF) University Ranchi, Department of Physiology, Government General Degree College, Kharagpur II and Department of Environmental Studies, Mankar College, Mankar, for the help and facilitates provided during that work.

Authors' contributions

Each author significantly contributed to manuscript preparation. MB culminate the idea and draft the layout of the manuscript and MD and AM wrote about several aspects of this study with special emphasize on physiological correlations.

Compliance with ethical standards

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical issues: None

References

- Robinson H, Dave N, Barzilay R, Wagner A, Kells N, Keller AS. The effect of the “exposome” on developmental brain health and cognitive outcomes. *Neuropsychopharmacology*. 2026;51(1):169–84. <https://doi.org/10.1038/s41386-025-02180-6>
- Scholz S, Schirmer K, Schlechtriem C, Brack W, Armitage JM, Kools SAE, et al. The eco-exposome concept: Supporting an integrated assessment of mixtures of environmental chemicals. *Environ Toxicol Chem*. 2022;41(1):30–45. <https://doi.org/10.1002/etc.5242>
- Rappaport SM, Smith MT. Environment and disease risks. *science*. 2010;330(6003):460–1. <https://doi.org/10.1126/science.1192603>
- Pronk A, Loh M, Kuijpers E, Juraschek SP, Chadeau-Hyam M, Nawrot TS, et al. Applying the exposome concept to working life health: the EU EPHOR project. *Environ Epidemiol*. 2022;6(2):e185. <https://doi.org/10.1097/EE9.0000000000000185>
- Merra G, Gualtieri P, La Placa G, Frank G, Della Morte D, De Lorenzo A, et al. The relationship between exposome and microbiome. *Microorganisms*. 2024;12(7):1386. <https://doi.org/10.3390/microorganisms12071386>
- Guillien A, Ghosh M, Gille T, Dumas O. The exposome concept: how has it changed our understanding of environmental causes of chronic respiratory diseases? *Breathe*. 2023;19(2). <https://doi.org/10.1183/20734735.0044-2023>
- Bellentani F, Arkhipova D. The built environment in Social Media: towards a Biosemiotic Approach. *Biosemiotics*. 2022;15(2):193–213. <https://doi.org/10.1007/s12304-022-09497-5>
- Lyu Y. Decoding the Environmental Etiology of Non-communicable Diseases. *Biomedical and Environmental Sciences*. 2025;38(11):1327–8. <https://doi.org/10.3967/bes2025.171>
- Deguen S, Amuzu M, Simoncic V, Kihal-Talantikite W. Exposome and social vulnerability: an overview of the literature review. *International journal of environmental research and public health*. 2022;19(6):3534. <https://doi.org/10.3390/ijerph19063534>
- Wang Z. The effect of the environment on depression and underlying genetic influence in adolescents and young adults. 2025. <https://helda.helsinki.fi/server/api/core/bitstreams/577bcde0-a73b-4ef2-af6c-8aa0071dc33d/content>
- Santana del Pino Á, Quintana-Montesdeoca MDP, Simbaña-Rivera K, Zumbado M, Luzardo OP, Henríquez-Hernández LA, et al. Defining the external exposome of newborns from La Palma Island, Spain: characteristics of realistic mixtures and its role on Precision Public Health. *Int J Hyg Environ Health*. 2026;273:114761. <https://doi.org/10.1016/j.ijheh.2026.114761>
- Yu Z, Yang G, Lin T, Zhao B, Xu Y, Yao X, et al. Exposure ecology drives a unified understanding of the nexus of (urban) natural ecosystem, ecological exposure and health. *Ecosyst Health Sustain*. 2024;10:0165. <https://doi.org/10.34133/ehs.0165>
- Batista ER. Reimagining alternative socioecological futures: Transformative narratives for a Second Scientific Revolution. *Environmental Science & Policy*. 2026;176:104319. <https://doi.org/10.1016/j.envsci.2026.104319>
- Misra BB. The chemical exposome of human aging. *Frontiers in genetics*. 2020;11:574936. <https://doi.org/10.3389/fgene.2020.574936>
- Piot M, Mestdagh M, Riese H, Weermeijer J, Brouwer JMA, Kuppens P, et al. Practitioner and researcher perspectives on the utility of ecological momentary assessment in mental health care: A survey study. *Internet Interv*. 2022;30:100575. <https://doi.org/10.1016/j.invent.2022.100575>
- Gago-Ferrero P, Cousins I, Ghassabian A, Lamoree M, Schlenk D, Toms LM, et al. The exposome and human health. *Environ Sci Technol*. 2025;59(2):991–2. <https://doi.org/10.1021/acs.est.4c13478>
- Salama M. The exposome: A new paradigm in public health research. *Mansoura Journal of Forensic Medicine and Clinical Toxicology*. 2023;31(2):1–2.
- Batmunkh B, Enkhbat M, Erdenebaatar E. Digital paradigm of public health. *Frontiers in Public Health*. 2026;14:1793593. <https://doi.org/10.3389/fpubh.2026.1793593>
- Amini H, Amini M, Wright R. Climate change, exposome change and allergy: a review. *Immunology and allergy clinics of North America*. 2023;44(1):1. <https://doi.org/10.1016/j.iac.2023.09.003>
- Nelson HS. Textbook of Diagnostic and Therapeutic Procedures in Allergy. Vedanthan PK, Van Bever H, Murali MR, editors. CRC Press; 2024 Apr 16.
- Shaffer RM, Lee AL, Nachman R, Christensen K, Bateson TF. A perspective from US Environmental Protection Agency (EPA) scientists: how your epidemiologic analyses can inform the human health risk assessment process. *Environmental Health Perspectives*. 2025;133(3–4):045001. <https://doi.org/10.1126/science.1192603>
- Wild CP. The exposome: from concept to utility. *International journal of epidemiology*. 2012;41(1):24–32. <https://doi.org/10.1093/ije/dyr236>
- Vineis P, Chadeau-Hyam M, Gmuender H, Gulliver J, Herceg Z, Kleinjans J, et al. The exposome in practice: design of the EXPOsOMICS project. *Int J Hyg Environ Health*. 2017;220(2 Pt A):142–51. <https://doi.org/10.1016/j.ijheh.2016.08.001>
- Vrijheid M, Slama R, Robinson O, Chatzi L, Coen M, van den Hazel P, et al. The human early-life exposome (HELIX): project rationale and design. *Environ Health Perspect*. 2014;122(6):535–44. <https://doi.org/10.1289/ehp.1307204>
- Go YM, Jones DP. Redox biology: interface of the exposome with the proteome, epigenome and genome. *Redox biology*. 2014 ;2:358–60. <https://doi.org/10.1016/j.redox.2013.12.032>
- Jones DP. Redox theory of aging. *Redox biology*. 2015;5:71–9. <https://doi.org/10.1016/j.redox.2015.03.004>
- Siroux V, Agier L, Slama R. The exposome concept: a challenge and a potential driver for environmental health research. *European Respiratory Review*. 2016;25(140):124–9. <https://doi.org/10.1183/16000617.0034-2016>
- Clark SN, Anenberg SC, Brauer M. Global burden of disease from environmental factors. *Annual review of public health*. 2025;46(1):233–51. <https://doi.org/10.1146/annurev-publhealth-071823-105338>
- Rappaport SM. Genetic factors are not the major causes of chronic diseases. *PloS one*. 2016;11(4):e0154387. <https://doi.org/10.1371/journal.pone.0154387>
- Manrai AK, Cui Y, Bushel PR, Hall M, Karakitsios S, Mattingly CJ, et al. Informatics and data analytics to support exposome-based discovery for public health. *Annu Rev Public Health*. 2017;38:279–94. <https://doi.org/10.1146/annurev-publhealth-082516-012737>
- Vuong AM, Yoltan K, Braun JM, Lanphear BP, Chen A. Chemical mixtures and neurobehavior: a review of epidemiologic findings and future directions. *Reviews on environmental health*. 2020;35(3):245. <https://doi.org/10.1515/reveh-2020-0010>
- Argentieri MA, Katsonis P, Katsanis N, Goldstein DB, Leal SM, Vasileiou G, et al. Integrating the environmental and genetic architectures of aging and mortality. *Nat Med*. 2025;31(3):1016–25. <https://doi.org/10.1038/s41591-024-03483-9>