Challenges and opportunities for research supporting cumulative impact assessments at the United States environmental protection agency's office of research and development

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Introduction

A growing body of scientific evidence shows that in overburdened communities the cumulative impacts from exposures to combinations of chemical and non-chemical stressors throughout the life course results in poor community health status and reduced lifespan. The United States Environmental Protection Agency's (U.S. EPA's or the Agency's) Office of Research and Development (ORD) has prioritized cumulative impacts in its research portfolio, and is leading the Agency's efforts to work with overburdened communities to develop actionable science aimed at informing decisions to make their lives better, healthier, and longer. The goal of this Viewpoint is to spur research in the medical, public health, environmental science, and social sciences communities to develop scientific evidence to support decision-making that reduces disparities. We seek to focus on the exposome[1,2] or the Total Environment framework[3] to identify and prioritize those factors in the environment that characterize multiple exposures over time and across populations that result in disparate outcomes for health and well-being.[4] We emphasize that understanding and addressing factors leading to health disparities and unequal environmental burdens requires a research agenda focused on the science of cumulative impacts and that a collective and collaborative research effort is needed.

What are cumulative impacts?

Cumulative impacts are defined as the totality of exposures to combinations of chemical and non-chemical stressors and their effects on health, well-being, and quality of life outcomes.[5] Cumulative impacts consider exposures to both chemical and non-chemical stressors at each life stage throughout the life course (Fig. 1). This definition expands on a definition published by Scammell and colleagues[6] where they emphasized the negative effects from cumulative impacts. Totality of exposures can result in positive, negative, or no change to health, well-being, and quality of life outcomes. Cumulative impacts are applicable to individuals, geographically defined groups, or definable population groups.

Cumulative impact assessments

The need for cumulative impact assessments can be placed within the history and development of cumulative risk assessment, coupled with the growing recognition of the urgency for actionable science to address the needs of overburdened communities. Cumulative impacts form the basis for cumulative impact assessments that can be used to understand disparities in community health and well-being and inform decision-making at the federal, state, and local levels.[5,7,8] Cumulative impact assessments should be developed and applied with a bias for action and focused on community engagement to find solutions. Cumulative impact assessments incorporate both quantitative and qualitative information in describing outcomes, moving the scientific community beyond the traditional risk assessment process where only specific exposures and morbidities are evaluated using long-established methodologies. Using a cumulative impact assessment for decision-making in the context of addressing environmental injustice requires including information on distributions of environmental harms and benefits, and recognition and inclusion of the perspectives and knowledge of community groups via models such as community-based participatory science and health impact assessment. Transparency around the decision context is also important since decision-makers may be limited in actions they can take under their legal authorities, but broader partnerships between communities, government, and other stakeholders may present different options for action. Acknowledging limitations and forming partnerships contributes to trust-building

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Fig. 1: Schematic representation of cumulative impacts.

and identification of acceptable solutions. When doing cumulative impact assessments, social science contributions are necessary to effectively engage stakeholders, build trusting relationships, and synthesize information using mixed methods approaches.

The Total Environment framework illustrates the interrelationships among inherent characteristics, activities and behaviors, and stressors from the built, natural, and social environments that influence children's health and well-being as they progress through various stages of development.[3] We adapted the Total Environment framework to represent the complex interrelationships among components describing cumulative impacts for both human and community health.[5]

Policy drivers

The U.S. EPA's mission is to protect human health and the environment. The Agency works to ensure that all Americans have clean air, land, and water in the everyday environments where they live, learn, play, and work.[9] At the foundation of its mission are four core principles: follow the science, follow the law, be transparent, and advance racial justice and equity.[10] The U.S. EPA executes its mission based on understanding, characterizing, and reducing health and environmental risks associated with exposures to chemical and non-chemical stressors.[11]

Historically, environmental regulations set limits for individual chemicals, typically in a single environmental medium (air, water, or soil). Though the U.S. National Environmental Policy Act (NEPA) of 1969 mandated consideration of cumulative effects[12] due to major governmental actions, it did not provide guidance on analytical considerations. Subsequent environmental policy has typically conformed to the single pollutant paradigm. Some environmental laws and management guidance have referenced cumulative impacts, but there is a general lack of guidance on how to evaluate and apply cumulative impacts.[6,13] The U.S. EPA's Office of the General Counsel recently released its Cumulative Impacts Addendum to EPA Legal Tools to Advance Environmental Justice, a first-ever collection of examples of the Agency's legal authorities to identify and address cumulative impacts through a range of actions (e.g., permitting, regulations, grants).[14] As of July 2023, 22 states have developed or are in the process of developing legislation, mapping tools, and guidance

documents to incorporate cumulative impacts into decision-making.[15,16] For example, New Jersey's Environmental Justice Statute makes explicit that site decisions will be considered through the lens of cumulative and disproportionate impacts, with the goal of correcting the legacy of siting sources of pollution in overburdened communities.[17]

In response to calls to reduce health disparities experienced by overburdened communities, President Biden signed four Executive Orders ([EOs]: 13985,[18] 14008,[19] 14091[20] and 14096[21]) to advance racial equity and support for underserved communities and to address the climate crisis and environmental justice. These EOs provide a framework for stimulating action across the United States to address health inequities caused by disproportionate exposures to chemical stressors exacerbated by non-chemical stressors using cumulative impact assessments. Federal action necessitates the development and adoption of scientific data and tools to inform decisions that reduce health disparities experienced by overburdened communities.

The U.S. EPA is working to expand upon its traditional approach to environmental decision-making based on the source-to-outcome continuum for chemical agents and selected receptor characteristics such as life stage to one that considers individual and community vulnerability by including non-chemical stressors.[22–24] This move recognizes that socio-demographics, place, exposure, and outcomes are highly associated. For example, research shows that the legacy of redlining and other discriminatory housing policies continues to be associated with poorer air quality, urban heat islands, and adverse health status,[25,26] that people of color are exposed to significantly higher levels of air pollutants,[27] and people of color and those with low income in the United States are more likely to live in areas facing higher risks of most climate damage impacts.[28]

What makes a community?

We all recognize a community when we see it: the place we live with our families, where our friends and relatives visit, and where we share a sense of togetherness with others. Where we live influences our health, well-being, and quality of life both contemporaneously and for years to come. Factors contributing to this life experience include community history, how the land was used before it became a community, land use and annexation policies, availability of public services and infrastructure (e.g., mobility solutions), proximity to food, education, health care, employment, and green space, and how the community may change over time (i.e., cumulative impacts). These factors influence the mix of assets and stressors for individuals and the community as a whole. Many people, throughout the course of their lives, live, learn, work, and play in communities with polluted environments, shaped by policies and decisions made long before they moved into their homes. In some communities in the United States, decreased lifespan is linked to zip code because of a legacy of disparity in built, natural, and social environments and the resulting impacts on health, well-being, and quality of life.[29]

Chemical and non-chemical stressors

People are exposed to myriad chemical and non-chemical stressors during their typical, everyday activities in all locations where they spend time. These exposures are critical determinants of individual and public health.[30] Chemical stressors are defined as exogenous environmental compounds, and are found in the air people breathe, the water, beverages, and foods people consume, and the products used in and around homes, places of business, and recreational areas. Chemical stressors include contaminants measured in air, water, soil, and consumer products such as particulate matter, metals (e.g., Pb), residential and agricultural pesticides, perfluorinated compounds, polychlorinated biphenyls, phthalates, and others. Non-chemical stressors, also described as social determinants of health, are defined as positive and negative influencing factors found in the built, natural, and social environments including but not limited to climatic stressors, relationships and social connectivity, public safety, access to resources such as nutritious food, health care, education, housing, and recreational facilities/parks/green space, and transportation, drinking water, sewage, and other components of public infrastructure. Chemical and non-chemical stressors aggregate and accumulate over time from one or more sources in the built, natural, and social environments, affecting health, well-being, and quality of life.[3]

Traditionally, the scientific community reductively studies one stressor or group of stressors at a time, linked to one or more health outcomes.[1,31–34] In the real world, however, people are exposed to multiple chemical and non-chemical stressors at each life stage throughout their life course (i.e., their exposome). The interactive and cumulative nature of multiple stressors impact health, well-being, and quality of life outcomes. In overburdened communities, disproportionate impacts may arise from unequal environmental conditions and stressor burdens. Hence, a systems approach to understanding the complex interrelationships among chemical and non-chemical stressors is warranted, consistent with recent recommendations by the National Academies of Sciences, Engineering, and Medicine[35] that the U.S. EPA adopt a systems-based One-Environment-One-Health approach.

Research approach

The Office of Research and Development (ORD), the U.S. EPA's scientific research arm, provides the data, tools, and information that form the scientific

foundation the Agency relies on to fulfill its mission.[36] ORD has prioritized cumulative impacts research to advance understanding of the complex interrelationships between chemical and non-chemical stressors in support of community health and environmental justice. However, advancement of this understanding requires broader engagement by the scientific community.

Identification of research needs

The U.S. EPA has emphasized that broad engagement with stakeholders is essential for building responsive, equitable programs. In 2021 ORD held listening sessions and workshops to identify research needs related to cumulative impacts.[5] Participants in the listening sessions included more than 170 entities representing state and local governments and tribal nations. Building from the listening sessions, the subsequent workshops included a community panel and focused discussions between U.S. EPA scientists and policy makers to address research needs for cumulative impact assessments across multiple decision contexts.

This process identified three focus areas for research: (1) stressor identification and characterization; (2) analytical methods for combined analyses of quantitative and qualitative data; and (3) data generation. With regard to the first of these, there is a plethora of research on individual exposures to both chemical and non-chemical stressors.[5] There is much less research exploring the interrelationships between exposures to chemical and non-chemical stressors and health, well-being, and quality of life outcomes.

Research priorities

The highest priority analytical research need is for methods to combine quantitative and qualitative data to conduct a cumulative impact assessment. In recent decades, social science researchers have made significant progress in developing mixed methods; however, mixed methods in the context of environmental decision-making remains an underdeveloped field. Efforts to characterize environmental health disparities have led to a proliferation of indices for health, well-being, and quality of life.[37] For example, CalEnviroScreen (https://oehha.ca.gov/calenviroscreen) and EJScreen (https://www.epa.gov/ejscreen) have been used to prioritize resource allocation. However, future applications are being contemplated for rule-making, permitting decisions, and other actions.

Linking indicators of multiple burdens of chemical and non-chemical stressors to cumulative impacts using molecular epidemiological data will enable progress to be made in assessing cumulative impacts. For example, exposomal studies including a deeper understanding of biomarkers from diverse populations (including biomarkers of allostatic load) can be used to identify associations between exposures and impacts. There has been highly productive research on the relationships between neighborhood environment and epigenetic aging, as well as research on the relationships between access to greenspace and allostatic load.[38,39]

Assessing cumulative impacts to inform decisions is a data-intensive process that requires environmental monitoring and health data at multiple geographic scales, including state, city, and census tract level and health and environmental data at multiple temporal resolutions. Different decisions require different data inputs to be suitably fit-for-purpose, ranging from fine-grained quantitative data, to community science activities, to qualitative local perspectives.[40,41]

Thus, a brief summary of priority research needs includes:

- Developing fit-for-purpose approaches to quantify community assets, vulnerabilities, and health burdens for use in decision-making;
- Incorporating holistic approaches to characterize exposures to multiple stressors and understanding how changes in the environment can modify exposures to stressors and resultant health outcomes;
- Identifying, characterizing, and evaluating environmental exposures, health disparities, and well-being impacts most prevalent in overburdened communities and identifying community-focused actions to effect change; and,
- Evaluating the impacts of policies and interventions aimed at both reducing vulnerability and increasing environmental benefits in overburdened communities.

These priorities are large challenges and will benefit from engagement of the broader scientific community. To this end, the U.S. EPA's STAR grant program has awarded 49 grants worth more than $58 million through eight different solicitations to fund research addressing different aspects of cumulative impacts (https://www.epa.gov/healthresearch/funding-resources-and-partnerships).

ORD's research approach

ORD's research on cumulative impacts is organized into five strategic areas (Fig. 2):

(1) Establish the decision context and partner/stakeholder engagement. Approaches within this area focus on partners and stakeholders (e.g., identify and establish trust), problem identification, policies, and decisions that cumulative impacts can inform. We have piloted a series of health impact assessments that have engaged communities and other stakeholders (https://www.epa.gov/healthresearch/health-impact-assessments). Based on a partnership between ORD and EPA Region 2, the

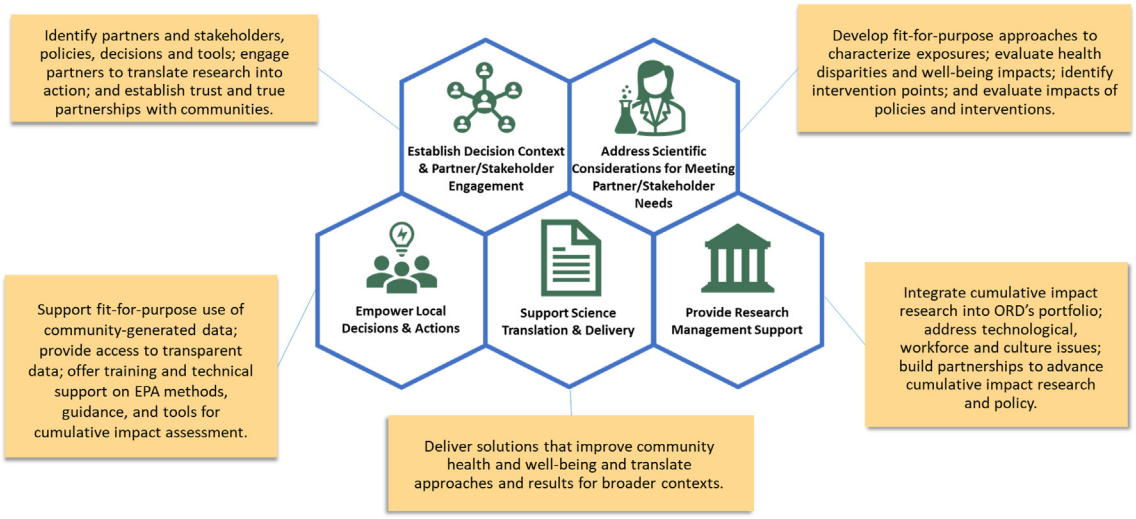

Fig. 2: Five strategic areas for ORD's research on cumulative impacts. Figure 2 is a modified version of Figure 3 of the U.S. EPA report on cumulative impacts research published elsewhere. Source: U.S. EPA. Cumulative Impacts Research: Recommendations for EPA's Office of Research and Development. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-22/014a, 2022. https://www.epa.gov/healthresearch/cumulative-impacts-research.

U.S. EPA has also established the Community-Engaged Research Collaborative for Learning and Excellence (CERCLE) in Edison, NJ as a model for addressing community challenges nationwide. Through CERCLE, the Agency will partner with underserved communities to co-produce actionable information and sustainable solutions.

(2) Address scientific considerations for meeting partner/stakeholder needs. Work within this area focuses on developing all the components incorporated into a cumulative impact assessment. These components include exposure information, asset and vulnerability identification, what methods and approaches will be used to ensure the cumulative impact assessment is fit-for-purpose, and what health, well-being, and quality of life outcomes will be considered. Much of the scientific research needed to advance cumulative impacts research is found here. For example, we are conducting redlining research to understand health disparities, allostatic load research to understand vulnerability, and biochemical, ecological, and social capacity research to understand mitigation options for reducing cumulative impacts. ORD researchers are working to identify which combinations of stressors should be prioritized to reduce existing environmental health disparities and understand how co-occurring stressors interact.

(3) Empower local decisions and actions through science. Work within this area provides solutions through training and technical support focused primarily on Agency methods and tools. This category also includes community-generated data and information. We have developed many resources to support participatory science, including a quality assurance toolkit, equipment loan programs, and policy guidelines and checklists for participatory science projects. Research is exploring the use of qualitative data in decision-making (e.g., NEPA) to characterize different types of decisions and evaluate data demands and barriers for including qualitative information in these decisions.

(4) Support science translation and delivery. Work within this area includes translating approaches and results and increasing usability and user-centered design for scientific tools and products to meet community needs. For example, the Equitable Resilience Builder tool engages community members in resilience planning to generate solutions that advance equity.[42] This tool contains activities for listening to local voices (e.g., trauma-informed engagement strategies, storytelling, participatory mapping) and guidance on holding collaborative workshops to assess hazards, vulnerability, and resilience and to identify actions to strengthen resilience in ways that address the needs of those made vulnerable by social and environmental inequalities.

(5) Provide research management support for cumulative impact assessment. The fifth strategic area recognizes that research organizations need support and resources to make progress in a new research arena. These organizational infrastructure components include hiring of scientists—in particular, social scientists—to support highly

interdisciplinary systems-based approaches; providing internal support for career development and promotion of scientists in a wide range of disciplines; tools to incorporate participatory science (e.g., community-based data and information) into decision-making; enhancing the workforce with unique scientific skill sets by expanding STEM education and outreach; and, innovative hiring practices to recruit and retain a talented and diverse scientific workforce.

These strategic areas emphasize the importance of the decision context, and embedding the scientific research within that context, while including relevant partner and stakeholder engagement, translation, and delivery.[5]

ORD's identification of research needs, and strategic approach to developing the science of cumulative impacts, can serve as input for researchers at other institutions grappling with research related to cumulative impacts and cumulative impact assessments.

Challenges to implementing cumulative impacts research

Cumulative impacts research is the here and now for the scientific community. To address the public health challenges affecting communities now and into the future, ORD needs to lead the way in the science of cumulative impacts. While this is easy to say, implementation will be a challenge. Researchers struggle with issues related to data availability and scale, methods of combining quantitative and qualitative data, and how to apply systems frameworks in a decision context. We suggest that cumulative impacts research be integrated across research disciplines as well as across policy domains. We need to act with a bias toward action and focus the research around those needs most critical to informing environmental justice decisions. Only through harnessing scientific insights from across the environmental, medical, public health, and social sciences disciplines, community engagement, and policy collaborations through a whole-of-government approach, can we effectively identify and address cumulative impacts.

Conclusions

ORD is prioritizing cumulative impacts research to address the multiple stressors to which people and communities are exposed, and studying how combinations of stressors affect health, well-being, and quality of life at each developmental stage throughout the course of one's life. Cumulative impacts research builds from the traditional risk assessment approach to include combinations of chemical and non-chemical stressors, changing climate, multiple health endpoints, community engagement, and mixed methods analytical approaches that incorporate both quantitative and qualitative data to inform decisions in the best interest of the community. By moving cumulative impacts research to the mainstream of scientific study, the scientific community can more accurately represent the everyday environment where people live, learn, work, and play, and help inform policy decisions to improve community health and well-being, especially for those most burdened.

Contributors

NST: Conceptualization, Writing—original draft, Writing—review and editing, Visualization, Supervision, Project administration; **AMG:** Writing—review and editing, Visualization; **SH:** Writing—review and editing, Visualization; **SHJ:** Writing—review and editing, Visualization; **ETL:** Writing—review and editing, Visualization; **SLM:** Writing—review and editing, Visualization; **SJP:** Writing—review and editing, Visualization; **HCF:** Conceptualization, Writing—review and editing, Visualization, Supervision, Funding acquisition.

Declaration of interests

Nicolle S. Tulve, Ph.D.: Discloses her role as the Chair, Membership Committee, International Society of Exposure Science, Volunteer Position.

Sarah L. Mazur, M.P.P.: Discloses her role as a co-chair of the Environmental Justice Subcommittee formed by Executive Order 14,096. Sarah serves in this role as part of her official U.S. EPA duties and the subcommittee is convened under the auspices of the White House.

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