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Environmental Justice in the Anthropocene: A Review of Methodological Biases in Impact Assessment Studies

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ABSTRACT

The Anthropocene epoch, characterized by profound human-induced alterations to Earth's systems, has amplified environmental injustices, disproportionately affecting marginalized communities through climate change, pollution, biodiversity loss, and resource extraction. Impact assessment studies, including environmental impact assessments (EIAs) and social impact assessments (SIAs), serve as critical tools for evaluating these effects and informing policy. However, methodological biases in these studies often undermine their validity, leading to incomplete or skewed representations of environmental justice issues. This narrative review critically examines the methodological biases inherent in impact assessment research within the Anthropocene context, focusing not on empirical findings but on how studies are conducted. Drawing from peer-reviewed journal articles published, the review identifies key biases such as selection bias, measurement error, geographic skew, and insufficient incorporation of participatory approaches. These biases frequently result from inadequate data collection strategies, overreliance on quantitative metrics that overlook qualitative dimensions of justice, and limited engagement with affected communities. The objectives are to map prevalent methodological flaws, explore their implications for environmental justice, and propose pathways for more equitable research practices. By highlighting these critiques, the review underscores the need for reflexive, inclusive methodologies that address procedural, distributive, and recognition justice in the face of escalating Anthropocene challenges. Ultimately, mitigating biases in impact assessments is essential for advancing environmental justice and ensuring that policies mitigate rather than exacerbate inequalities.

Keywords: *Environmental justice, Anthropocene, Methodological bias, Impact assessment, Participatory research, Cumulative impacts*

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INTRODUCTION

The Anthropocene represents a paradigm shift in understanding human-environment interactions, marking an era where anthropogenic activities have become the dominant force shaping planetary systems (Hoffman-Hall *et al*., 2024; Sayyed *et al*., 2024). This epoch is defined by accelerated climate change, habitat destruction, pollution proliferation, and biodiversity decline, all of which intersect with social inequalities to produce uneven environmental burdens (Banerjee & Schuitema, 2022; Graefen *et al*., 2023; Ovienmhada *et al*., 2024). Environmental justice (EJ), as a framework, seeks to address these disparities by ensuring fair distribution of environmental benefits and harms, meaningful participation in decision-making, and recognition of diverse cultural and social contexts (Banerjee & Schuitema, 2023; Spuler *et al*., 2025). Originating from grassroots movements in the United States during the 1980s, EJ has evolved into a global discourse, particularly relevant in the Anthropocene where global-scale impacts amplify local vulnerabilities (Dhanasekar *et al*., 2022; Spuler & Wessel, 2024).

Impact assessment studies, encompassing environmental impact assessments (EIAs), cumulative impact assessments (CIAs), and related methodologies, are pivotal in evaluating the potential consequences of development projects, policies, and environmental changes (Leonard *et al*., 2020; Efremov, 2023; Sovacool *et al*., 2023). These studies aim to predict, mitigate, and monitor impacts on ecosystems and human communities, often serving as regulatory requirements under frameworks like the U.S. National Environmental Policy Act (NEPA) or international standards (Roque *et al*., 2021; Nguyen & Hoang, 2022). In the context of EJ, impact assessments provide opportunities to identify disproportionate effects on marginalized groups, such as low-income populations, indigenous communities, and people of color (Trung *et al*., 2022; Roque *et al*., 2024). However, the efficacy of these studies is compromised by methodological biases that can distort findings, perpetuate injustices, and hinder effective policy responses (Ncube *et al*., 2023; Bezboruah *et al*., 2024; Walker *et al*., 2024).

Methodological biases refer to systematic errors in research design, data collection, analysis, or interpretation that lead to inaccurate or incomplete conclusions (Walker *et al*., 2022; FigueroaValverde *et al*., 2023; LeFevre *et al*., 2023). In impact assessment research, such biases may arise from selective

sampling, inadequate measurement tools, cultural insensitivities, or failure to account for cumulative effects over time (Okoro *et al*., 2023; Oyshi *et al*., 2025). For instance, quantitative approaches dominant in EIAs often prioritize measurable indicators like pollutant levels while neglecting qualitative aspects such as community perceptions of risk or cultural losses (Fitero *et al*., 2023; Kalyan *et al*., 2023). Geographic biases further exacerbate issues, with studies disproportionately focusing on certain regions or ecosystems, leaving gaps in understanding global Anthropocene dynamics (Haeffner *et al*., 2021; Rutten *et al*., 2022).

The novelty of this review lies in its emphasis on critiquing the conduct of impact assessment studies rather than synthesizing their substantive findings. While previous reviews have summarized EJ outcomes in specific contexts, such as ocean governance or urban planning (Siddiqi *et al*., 2022; Radonic *et al*., 2023; Ovienmhada *et al*., 2024), few have systematically dissected the methodological underpinnings that shape these outcomes. This focus is timely, as the Anthropocene demands robust, unbiased assessments to address intersecting crises like climate injustice and environmental racism (Ross *et al*., 2021; Banerjee & Schuitema, 2022; Xie *et al*., 2023).

The objectives of this review are threefold: (1) to provide a thematic overview of methodological biases in EJ-focused impact assessment studies; (2) to analyze how these biases manifest in the Anthropocene, particularly through interactions with global environmental changes; and (3) to highlight strategies for bias mitigation to enhance the equity and reliability of future research. By limiting sources to peer-reviewed journal articles, the review captures recent advancements and critiques, ensuring relevance to contemporary challenges. The structure proceeds thematically, eschewing traditional empirical sections in favor of subheadings that explore conceptual, practical, and ethical dimensions of bias.

Conceptualizing methodological biases in environmental justice research

Methodological biases in environmental justice (EJ) impact assessments are inherently multifaceted, often stemming from the conceptual frameworks that guide research design (Walker *et al*., 2022; Hultström *et al*., 2023). In the Anthropocene, where human activities are deeply intertwined with natural processes, simplified models can fail to capture the complexity of socio-ecological systems, giving rise to biases that distort understanding and policy guidance (Cissé *et al*., 2024; Hoffman-Hall *et al*., 2024). For instance, studies focused on distributive justice—concerned with the fair allocation of environmental risks and benefits—frequently rely on spatial analyses. While these methods provide important insights, they can introduce selection bias by aggregating data at coarse scales, masking intra-community disparities and overlooking localized vulnerabilities (Shrestha *et al*., 2022; Banerjee & Schuitema, 2023).

A critical methodological challenge is the conflation of different bias types, such as confounding and measurement biases, which can skew causal inference regarding environmental impacts (Banerjee & Schuitema, 2023). Quasi-experimental designs, commonly used in impact assessments, are particularly prone to post-intervention selection biases. For example, in climate impact studies, environmental degradation often triggers migration, which alters population composition and consequently biases vulnerability analyses toward the remaining residents (Banerjee & Schuitema, 2022; Oyshi *et al*., 2025).

Recognition justice—emphasizing acknowledgment of diverse knowledge systems—is another area where methodological biases are prevalent. Research frameworks often privilege Western scientific paradigms, neglecting local or Indigenous knowledge systems. This is evident in ocean-related impact assessments, where insufficient integration of Indigenous knowledge leads to incomplete evaluations of marine injustices and ecological vulnerabilities (Ross *et al*., 2021; Ovienmhada *et al*., 2024; Spuler *et al*., 2025). Systematic reviews reveal a strong geographic bias, with a predominance of studies originating from the Global North. This Eurocentric orientation risks perpetuating narrow perspectives on Anthropocene injustices and marginalizing voices from the Global South, where environmental risks and socio-economic vulnerabilities are often most acute (Haeffner *et al*., 2021; Flacke *et al*., 2022; Chang & Vivekanand, 2024).

Such conceptual biases not only distort empirical findings but also reinforce existing power imbalances, as marginalized perspectives are frequently excluded from study design and conceptualization (Korpilo *et al*., 2022; Spuler & Wessel, 2024). Addressing these issues requires reflexive approaches that critically interrogate the assumptions underlying research frameworks and actively incorporate pluralistic epistemologies (Korpilo *et al*., 2023; Thazha *et al*., 2023; Sayyed *et al*., 2024).

Biases in data collection and measurement strategies

Data collection in EJ impact assessments is equally susceptible to methodological biases that undermine data quality, validity, and representativeness (Bodner *et al*., 2023a; Bezboruah *et al*., 2024). Measurement biases, including misclassification or mismeasurement of exposures and outcomes, are common in quantitative studies (Banerjee & Schuitema, 2023). For example, cumulative impact assessments relying on proxy indicators—such as residential proximity to industrial facilities—can misrepresent actual exposure levels, particularly for populations that are mobile or have complex activity patterns, leading to systematic underestimation of risks (Leonard *et al*., 2020; Brimacombe & Bodner, 2023).

Qualitative data collection, while crucial for capturing lived experiences, is also vulnerable to bias. Confirmation bias can occur when researchers selectively gather or interpret evidence that aligns with their preexisting assumptions (Haeffner *et al*., 2022; Kalyan *et al*., 2023). Participatory research aims to counteract this, yet implementation biases often arise when community involvement is tokenistic, failing to meaningfully empower participants or integrate their perspectives into study outcomes (Korpilo *et al*., 2022; Roque *et al*., 2022).

Temporal biases are particularly relevant in Anthropocene studies. Short-term data collection may overlook cumulative, long-term environmental impacts, such as biodiversity loss, gradual soil degradation, or progressive climate hazards, thereby underrepresenting slow-onset vulnerabilities (Leonard *et al*., 2023; Hoffman-Hall *et al*., 2024). Geographic sampling biases further exacerbate these limitations, as studies tend to focus on accessible or well-resourced sites, leaving many regions—such as remote, deep-sea, or underdeveloped areas—underrepresented (Haeffner *et al*., 2021; Ovienmhada *et al*.,

2024). For example, marine EJ research is often concentrated on coastal zones, while offshore and deep-sea ecosystems, which are also vulnerable to industrial and climatic pressures, remain largely understudied.

Mixed-methods approaches, which integrate quantitative and qualitative data, are increasingly advocated to address these biases. However, their application is inconsistent, with a persistent quantitative dominance that may continue to marginalize community narratives and nuanced environmental experiences (Walker *et al*., 2022; Yu *et al*., 2022). Overall, these methodological challenges highlight the need for standardized protocols that emphasize inclusive sampling, robust data validation, and transparent documentation of assumptions and limitations to produce equitable and reliable EJ assessments (Bodner *et al*., 2023a; Oyshi *et al*., 2025).

Analytical biases and interpretation challenges

The analytical phases of impact assessments are particularly vulnerable to biases that can significantly affect both scientific inference and policy recommendations (Savita *et al*., 2022; Banerjee & Schuitema, 2023). Among the most pervasive are confounding biases, which occur when unaccounted-for variables distort observed causal relationships. These biases are especially common in non-randomized study designs, which dominate environmental and EJ research due to practical and ethical constraints (Oyshi *et al*., 2025). In the context of environmental justice, socioeconomic confounders—such as income inequality, housing segregation, or employment status—can obscure or exaggerate disparities in exposure among racial or marginalized communities, leading to misleading conclusions (Ross *et al*., 2021; Shrestha *et al*., 2022). Detection and reporting biases further compromise analytical rigor. Outcome assessment biases, for example, emerge when subjective judgments influence impact ratings, often reflecting the assessor's perspective rather than objective conditions (Leonard, 2021; Bezboruah *et al*., 2024). In the complex Anthropocene context, where environmental and social impacts are multidimensional and interlinked, synthesis biases in meta-analyses can compound errors. Aggregating heterogeneous studies without careful consideration of methodological differences can amplify inaccuracies, producing biased generalizations that may misinform policy (Haeffner *et al*., 2021; Walker *et al*., 2022).

Interpretation biases add another layer of complexity. Cultural biases, rooted in dominant epistemologies, and cognitive biases, such as short-termism, shape how findings are understood and prioritized (Haeffner *et al*., 2022). Short-termism—the tendency to focus on immediate outcomes—can undermine assessments of slow-onset phenomena like sea-level rise, biodiversity loss, or soil degradation, obscuring long-term vulnerabilities (Banerjee & Schuitema, 2022; Ovienmhada *et al*., 2024). In international or cross-cultural contexts, cognitive biases in risk perception influence compliance with EJ standards, particularly in construction, industrial, or urban development projects, where local perceptions of environmental risk may diverge from formal assessments (Salite *et al*., 2021).

Table 1. Examples of Biases in Data Collection and Analysis

Section/Phase	Bias Example	Context in Anthropocene	Consequences
Data Collection	Confirmation bias in qualitative gathering, aligning with preconceptions.	Short-term data overlooking cumulative impacts like biodiversity loss or soil degradation.	Tokenistic participation; underrepresents lived experiences and slow-onset vulnerabilities.
Measurement Strategies	Use of proxy indicators (e.g., proximity to facilities) misrepresenting exposures.	Mobile populations or complex activity patterns in pollution or climate studies.	Systematic underestimation of risks; neglects qualitative aspects like risk perceptions.
Analytical Phase	Confounding biases from unaccounted socioeconomic variables.	Non-randomized EJ research on racial disparities in exposure.	Exaggerates or obscures causal links; misinforms policy on inequalities.
Interpretation	Cultural and cognitive biases, such as short-termism.	Focus on immediate outcomes ignoring long-term phenomena like sea-level rise.	Undermines assessments of multidimensional impacts; reinforces power imbalances.
Cumulative Assessments	Intersecting biases from confounding multiple exposures.	Layered injustices like pollution and limited healthcare in marginalized communities.	Distorts risk estimates; perpetuates procedural and recognition deficits.

Mitigating these analytical and interpretive challenges requires rigorous methodological practices. Robust sensitivity analyses, transparent reporting of assumptions and uncertainties, and explicit recognition of potential confounders are critical for producing reliable, equitable assessments. Unfortunately, many studies fall short in implementing these measures, perpetuating biased narratives and potentially reinforcing inequities rather than addressing them (Bodner *et al*., 2023a; Bodner *et al*., 2023b).

Geographic and demographic biases in study focus

Geographic biases in EJ and environmental impact research reflect broader inequalities in research funding, infrastructure, and accessibility. There is a marked skew toward studies conducted in developed regions, leaving many vulnerable areas of the Global South underrepresented (Haeffner *et al*., 2021; Flacke *et al*., 2022). This imbalance has significant consequences in the Anthropocene, where climate change, biodiversity loss, and pollution disproportionately affect under-resourced regions. For example, ocean EJ research is heavily concentrated in temperate zones, often overlooking tropical and equatorial regions where communities face acute climate injustices and ecosystem degradation (Banerjee & Schuitema, 2022; Ovienmhada *et al*., 2024; Spuler & Wessel, 2024).

Demographic biases further compound these gaps. Research frequently neglects intersectional factors, including gender, age, indigeneity, and disability, which are crucial for understanding the differential impacts of environmental change (Ross *et al*.,

2021; Spuler *et al*., 2025). Participatory frameworks are designed to counter such biases, yet they often fall short in practice. Participant recruitment tends to favor accessible, educated, or socially connected individuals, limiting the representativeness of findings and marginalizing those most affected (Korpilo *et al*., 2022; Roque *et al*., 2022).

Cumulative impact assessments, essential for capturing the multi-layered consequences of Anthropocene processes, are also affected by geographic and demographic biases. Incomplete historical data, unrecorded exposures, and overlooked legacy injustices distort the understanding of cumulative risks, particularly in communities with long-standing environmental vulnerabilities (Leonard *et al*., 2020; Brimacombe & Bodner, 2023). This geographic-demographic mismatch not only hampers scientific accuracy but also undermines the equitable distribution of environmental protections, highlighting the urgent need for targeted research in underrepresented regions and populations (Flacke *et al*., 2022; Hoffman-Hall *et al*., 2024).

Participatory approaches and their methodological limitations

Participatory research has been widely recognized as a crucial avenue for advancing procedural justice in environmental justice (EJ) assessments. By involving communities directly in the research process, participatory approaches aim to ensure that affected populations have a voice in decisions that influence their environments and well-being. Such involvement, in principle, enhances inclusivity, transparency, and democratic decision-making. However, despite these advantages, participatory research is not immune to biases and methodological limitations (Korpilo *et al*., 2022).

One notable challenge is the presence of power imbalances within participatory settings. In many cases, dominant stakeholders—such as government agencies, corporations, or vocal community members—can overshadow marginalized voices, leading to performance biases where the perspectives of less powerful participants are underrepresented or ignored (Roque *et al*., 2022; Graefen *et al*., 2023). This dynamic not only compromises the fairness of the process but also risks skewing research findings toward the priorities of more influential actors.

In studies addressing the Anthropocene, participatory methods often struggle to integrate diverse ontologies and epistemologies. Recognition biases arise when dominant worldviews—typically those aligned with Western scientific paradigms—are prioritized over local, Indigenous, or alternative ways of knowing (Sayyed *et al*., 2024; Spuler *et al*., 2025). As a result, research outcomes may fail to capture the full spectrum of community experiences and environmental understandings, limiting the relevance and legitimacy of the findings.

Methodologically, participatory approaches face practical constraints that can limit their scalability. Resource limitations, time constraints, and logistical challenges often confine participatory studies to small-scale, localized cases (Yu *et al*., 2022; Kalyan *et al*., 2023). While such studies provide rich, context-specific insights, their findings are not always generalizable, which can hinder broader policy application. Moreover, critical interpretive syntheses suggest that although participatory tools enhance inclusivity, they carry the risk of co-optation: without genuine empowerment, participation can be tokenistic, serving institutional agendas more than community interests (Dhanasekar *et al*., 2022; Korpilo *et al*., 2022).

In formal impact assessment frameworks such as the National Environmental Policy Act (NEPA), additional procedural barriers further restrict the incorporation of EJ principles. These include limited windows for public input, complex technical language, and formalized processes that privilege stakeholders with resources and expertise (Roque *et al*., 2021; Efremov, 2023). Addressing these challenges requires hybrid methodologies that combine participatory approaches with rigorous bias identification and mitigation strategies, ensuring that participation genuinely advances equity rather than merely fulfilling procedural obligations (Bodner *et al*., 2023b; Korpilo *et al*., 2023).

Intersecting biases in cumulative impact assessments

Cumulative impact assessments (CIAs) are designed to capture the complex synergies and interactions of multiple environmental and social stressors, particularly in Anthropocene contexts where ecosystems and human communities are deeply intertwined. Despite their importance, CIAs are highly susceptible to intersecting biases, which can undermine the accuracy and fairness of assessments (Leonard *et al*., 2020; Brimacombe & Bodner, 2023).

One form of bias arises from confounding multiple exposures. Communities facing layered injustices—such as industrial pollution, socio-economic marginalization, and limited healthcare access—may experience overlapping environmental risks that standard assessment methods fail to disentangle (Shrestha *et al*., 2022; Banerjee & Schuitema, 2023). Consequently, risk estimates may be biased, underestimating the cumulative burden borne by vulnerable populations.

Methodological analyses of EJ literature reveal a disproportionate focus on distributional outcomes, such as exposure levels and pollutant concentrations, while procedural and recognition dimensions are frequently neglected (Haeffner *et al*., 2021; Flacke *et al*., 2022). In policy contexts, the language of public participation often limits true empowerment. Most legislation favors consultative or advisory participation over collaborative engagement, reinforcing procedural biases and reducing the potential for community-driven solutions (Nguyen & Hoang, 2022; Efremov, 2023).

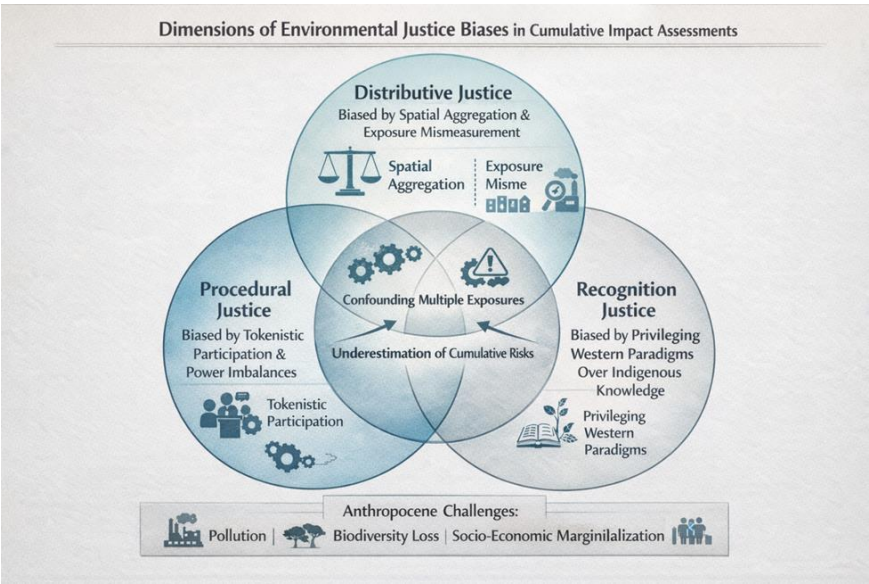

Figure 1. Intersecting Dimensions of Environmental Justice Biases

The convergence of these biases amplifies social and environmental vulnerabilities. Addressing them requires integrated frameworks that simultaneously account for distributional, procedural, and recognition dimensions, providing a holistic approach to bias mitigation in CIAs (Walker *et al*., 2022; Bodner *et al*., 2023a).

Ethical implications of biases in anthropocene research

The ethical stakes of bias in EJ and Anthropocene research are substantial. Biases embedded in assessment design, execution, and interpretation can perpetuate harm, further marginalizing already vulnerable populations (Banerjee & Schuitema, 2022; Hoffman-Hall *et al*., 2024). Cognitive biases in research, such as short-termism or confirmation bias, can exacerbate these harms by prioritizing immediate outcomes over long-term justice (Salite *et al*., 2021; Haeffner *et al*., 2022).

Ethical frameworks in EJ research emphasize the necessity of bias-aware study designs that explicitly prioritize equity and inclusivity (Flacke *et al*., 2022; Korpilo *et al*., 2023). However, prevailing tendencies toward simpler study designs—driven by resource limitations or methodological conservatism—often undermine these ideals, compromising the credibility and ethical integrity of research (Savita *et al*., 2022; Trung *et al*., 2022).

To uphold ethical standards, transparency and accountability must be central to participatory and cumulative impact research. This includes documenting methodological choices, power dynamics, and decision-making processes, as well as actively addressing and reporting potential biases. By doing so, assessments can fulfill their intended purpose of promoting justice rather than inadvertently entrenching inequality (Ross *et al*., 2021; Spuler & Wessel, 2024).

RESULTS AND DISCUSSION

The thematic exploration of methodological biases in environmental justice (EJ) impact assessment studies reveals a pervasive pattern of systematic errors that compromise the integrity of research in the Anthropocene. These biases, ranging from conceptual oversimplifications to analytical distortions, not only skew empirical outcomes but also perpetuate structural inequalities by marginalizing vulnerable communities in decision-making processes (Hoffman-Hall *et al*., 2024; Sayyed *et al*., 2024). In an era where human-induced environmental changes intensify disparities, the failure to address these flaws undermines the core principles of EJ—distributive, procedural, and recognition justice (Sovacool *et al*., 2023; Ovienmhada *et al*., 2024). For instance, selection biases in data collection often exclude indigenous perspectives, leading to incomplete assessments of cumulative impacts from resource extraction and climate adaptation projects (Leonard *et al*., 2020; Leonard, 2021). This exclusion is particularly acute in the Global South, where geographic biases favor urban or accessible sites, ignoring rural and remote areas disproportionately affected by biodiversity loss and sea-level rise (Flacke *et al*., 2022).

The implications of these biases extend beyond academic validity to real-world policy and governance. Impact assessments inform critical decisions in sectors like energy transition and water management, yet biased methodologies can result in policies that exacerbate environmental racism and socioeconomic vulnerabilities (Banerjee & Schuitema, 2022; Banerjee & Schuitema, 2023; Oyshi *et al*., 2025). In the context of just transition plans, for example, perceptual biases among stakeholders can overlook the lived experiences of affected workers, leading to inequitable distribution of benefits from low-carbon initiatives (Banerjee & Schuitema, 2022). Similarly, in stormwater infrastructure and urban planning, biases in green infrastructure assessments fail to advance EJ, perpetuating cycles of infrastructure decay and health disparities in marginalized neighborhoods (Banerjee & Schuitema, 2023; Oyshi *et al*., 2025). The Anthropocene's interconnected crises amplify these issues, as short-term analytical biases ignore long-term cumulative effects, such as compounded heat exposure in prison landscapes or water insecurity post-disasters (Roque *et al*., 2021; Ovienmhada *et al*., 2024).

Ethical considerations further highlight the urgency of bias mitigation. Methodological assumptions in bias adjustment for climate models involve value judgements that can inadvertently prioritize certain knowledge systems over others, raising questions about usable information for EJ advocacy (Spuler *et al*., 2025). Western cultural biases in conservation studies undermine indigenous stewardship practices, treating them as monolithic and ignoring diverse epistemologies (Leonard *et al*., 2020). This recognition deficit not only distorts impact evaluations but also erodes trust between researchers and communities, hindering participatory approaches essential for resilient adaptation (Roque *et al*., 2022; Radonic *et al*., 2023; Roque *et al*., 2024). Moreover, cognitive biases in observational studies, akin to those in public health, can lead to negative effectiveness interpretations if not addressed, paralleling skewed EJ outcomes (Bodner *et al*., 2023a).

Interdisciplinary integration offers a pathway to redress these biases. Socio-hydrology and water governance research emphasize representation justice, advocating for inclusive agendas that capture human agency and methodological pluralism (Haeffner *et al*., 2021; Yu *et al*., 2022). Public participation GIS tools demonstrate potential in assessing multiple EJ dimensions, incorporating landscape values and sensory data to counter geographic skews (Korpilo *et al*., 2022; Korpilo *et al*., 2023). However, challenges persist in scaling participatory methods, where power imbalances can introduce new biases if partnerships are short-term or tokenistic (Radonic *et al*., 2023). Community-based participant-observation and digital participatory methods provide promising models, enabling real-time EJ measurement and household perceptions in underrepresented regions (Shrestha *et al*., 2022; Roque *et al*., 2024).

Policy implications underscore the need for reflexive practices in impact assessments. Frameworks like the WAMPUM adaptation for tribal nations illustrate how incorporating indigenous frameworks can mitigate biases in water security evaluations (Leonard, 2021). Similarly, satellite data applications for EJ require community organizer input to ensure data justice, avoiding top-down geospatial distortions (Ovienmhada *et al*., 2024; Sayyed *et al*., 2024). In coastal flooding and urban resilience, adaptive capacity building through participatory monitoring addresses biases in vulnerability assessments (Bezboruah *et al*., 2024). Ultimately, confronting these biases demands a shift from quantitative dominance to hybrid methodologies that value qualitative narratives and ethical accountability (Haeffner *et al*., 2022; Bodner *et al*., 2023b).

Table 2. Strategies for Bias Mitigation

Strategy Category	Proposed Approaches	Relevant Biases Addressed	Benefits for EJ Research
Reflexive Methodologies	Interrogate assumptions; incorporate pluralistic epistemologies.	Conceptual, recognition, and cultural biases.	Enhances equity; integrates Indigenous and feminist perspectives.
Participatory Tools	Use public participation GIS, community-based observation, and hybrid methods.	Selection, procedural, and power imbalance biases.	Ensures inclusive data; counters tokenism and improves legitimacy.
Standardized Protocols	Implement bias correction in models; transparent reporting of uncertainties.	Measurement, confounding, and analytical biases.	Produces reliable assessments; addresses ethical usability in climate models.
Targeted Research	Prioritize underrepresented regions via funding and networks; use digital innovations.	Geographic and demographic biases.	Reduces skews; promotes data justice in Global South and vulnerable populations.
Integrated Frameworks	Develop open-source tools for bias detection; conduct longitudinal studies.	Intersecting and cumulative biases.	Fosters holistic EJ; supports resilient governance and policy applications.

The Anthropocene demands that EJ research evolves to confront intersecting biases holistically. By critiquing how studies are conducted, this review illuminates pathways for more equitable assessments, ensuring that marginalized voices shape responses to global environmental challenges (Ross *et al*., 2021; Walker *et al*., 2024). Failure to do so risks entrenching injustices, while proactive mitigation can foster transformative policies aligned with sustainable development goals.

CONCLUSION

This narrative review has critically examined methodological biases in EJ impact assessment studies within the Anthropocene, emphasizing the processes of research conduct over substantive findings. Key biases— including selection, measurement, geographic, analytical, and participatory limitations—systematically undermine the validity and equity of assessments, perpetuating disparities in environmental burdens (Hoffman-Hall *et al*., 2024; Spuler & Wessel, 2024; Spuler *et al*., 2025). These flaws manifest through oversimplified frameworks, inadequate community engagement, and failure to account for cumulative and intersectional effects, particularly affecting indigenous, low-income, and racialized communities (Leonard *et al*., 2020; Sovacool *et al*., 2023; Walker *et al*., 2024).

Mitigating these biases requires a multifaceted approach. First, adopt reflexive methodologies that interrogate assumptions and integrate pluralistic knowledge systems, such as indigenous conservation practices and feminist perspectives (Leonard *et al*., 2020; Sovacool *et al*., 2023). Second, enhance participatory tools like public participation GIS and community-based observation to ensure inclusive data collection and analysis (Korpilo *et al*., 2022, 2023; Roque *et al*., 2024). Third, standardize bias correction protocols in climate and impact models, incorporating value judgements for ethical usability (Spuler & Wessel, 2024; Spuler *et al*., 2025). Fourth, address geographic skews by prioritizing underrepresented regions through targeted funding and collaborative networks (Flacke *et al*., 2022).

Future research should focus on developing integrated frameworks for bias detection, perhaps through open-source tools for real-time evaluation (Shrestha *et al*., 2022; Spuler &

Wessel, 2024). Longitudinal studies tracking bias evolution in policy applications, such as just transitions and water security, are essential (Roque *et al*., 2021; Banerjee & Schuitema, 2022, 2023). Additionally, explore digital innovations for EJ, ensuring they avoid new biases in data justice (Ovienmhada *et al*., 2024; Sayyed *et al*., 2024). Ultimately, advancing bias-free methodologies will bolster EJ in the Anthropocene, promoting resilient, equitable environmental governance.

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