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Perspective

Enhancing the effectiveness of EJ mapping tools: a framework for improved reporting and presentation

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Abstract
Environmental justice (EJ) mapping tools play a crucial role in addressing disparities in environmental hazards and promoting equitable treatment for all communities. Drawing from observations of tools worldwide, with a particular focus on well-documented examples from the United States, this perspective piece aims to provide actionable recommendations to enhance the usability and impact of EJ mapping tools. Based on our collective experience and analysis, we identified key areas for improvement, including general characteristics, tool resources, and indicator selection. Our recommendations aim to increase transparency, user-friendliness, and overall effectiveness of EJ mapping tools. These insights are intended to support stakeholders globally in advancing EJ goals by facilitating the adoption of best practices in EJ mapping tool development and implementation. The accompanying checklist summarizing the recommendations will serve as a valuable resource for tool developers, policymakers, and communities seeking to address environmental disparities and promote equitable decision-making across various geographical contexts. *Clinical trial number*: Not applicable.

Keywords Environmental justice · Mapping tools · Geographical information systems · Health equity · EnviroScreen

1 Introduction

Environmental justice (EJ) is a critical concept that emphasizes the fair and equitable treatment of all individuals in the context of environmental challenges, regardless of their race, ethnicity, or socioeconomic status [1]. However, marginalized communities often bear a disproportionate burden of environmental hazards, pollution, and health risks, leading to poorer health outcomes [2]. As the EJ movement progresses, there is a growing need for effective tools to identify, visualize, and address these disparities [3].

The development and utilization of EJ mapping tools represent significant strides in addressing environmental disparities and injustices [3]. These tools serve as powerful resources for understanding, visualizing, and advocating environmental conditions, health, and socio-economic injustices. These tools help identify communities that are disproportionately impacted by pollution and environmental hazards, making this information accessible to decision-makers and affected community members [4]. Examples of prominent EJ mapping tools include the US-EPA EJScreen, California or Colorado EnviroScreen, and the Climate and Economic Justice Screening Tool (CEJST), among others developed globally [5–7]. A detailed comparative analysis of these and other EJ mapping tools can be found in our recent systematic review [8], which examines 25 tools across multiple characteristics, including spatial granularity, indicators, and functionalities. Building

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on that comprehensive analysis, this perspective focuses on synthesizing key insights and providing recommendations for improving future tool development and implementation. EJ mapping tools exhibit considerable diversity in their design, scope, and functionality. They range from national-level platforms to state or local initiatives, with varying update frequencies and visualization techniques. Some tools focus on specific environmental hazards, while others take a more comprehensive approach to assessing cumulative impacts. This diversity reflects the complex and multifaceted nature of EJ issues, as well as the varied needs of different stakeholders. Our recommendations aim to address common challenges and opportunities observed across this spectrum of tools, providing a flexible framework for improvement that can be adapted to various contexts and scales. These tools have played a crucial role in directing attention and resources toward disadvantaged communities and shaping decision-making processes at various levels [9].

It is important to note that EJ mapping tools serve diverse purposes within the environmental justice movement. While our recommendations emerge primarily from experience with tools focused on health outcomes and environmental exposures, we acknowledge the crucial role of mapping in other EJ contexts, particularly those addressing socio-environmental conflicts from a political ecology perspective. Such tools, exemplified by the EJ Atlas (https://ejatlas.org/), serve distinct but complementary purposes in giving voice to communities mobilizing against ecological distribution conflicts. These different approaches to EJ mapping reflect the multifaceted nature of environmental justice work, from quantifying health impacts to documenting community mobilization and power relations.

The concept of EJ has evolved significantly since its inception in the 1980 s. Initially focused on the disproportionate siting of hazardous waste facilities in minority communities [10], EJ has expanded to encompass a wide range of environmental and health disparities [11]. In the United States, the federal government's 1994 Executive Order 12,898 directs federal agencies to address EJ in their policies and programs [12].

As the field progressed, there was growing recognition that addressing environmental inequities required quantitative, spatially explicit approaches to identify and analyze disparities across different geographic scales. This led to the development of EJ mapping tools, with early examples emerging in the early 2000 s [13]. These tools have become increasingly sophisticated, incorporating various environmental and socioeconomic indicators to provide a more comprehensive picture of environmental justice issues, such as Cal EnviroScreen and EJ Screen [8]. These two pioneering mapping tools in the USA include one focused at the state level (Cal EnviroScreen) and the US-EPA EJ Screen, representing nationwide EJ indicators [8].

Despite the growing number of EJ mapping tools, there is significant variability in their design, functionality, and content. Differences in tool interfaces, resources provided, and the selection of indicators can pose challenges to user comprehension and application, particularly for community members and stakeholders [14]. To address these issues, we aim to provide EJ tool developers and owners with a set of actionable recommendations to improve EJ mapping tools, focusing on enhancing tool transparency, user-friendliness, and overall impact.

Our perspective on improving EJ mapping tools is informed by the conceptual dimensions of EJ: distribution, recognition, and procedural justice [15, 16]. As researchers with experience in developing and assessing health equity and environmental justice tools through collaborations with public health organizations, governmental bodies, and community stakeholders, we offer this perspective to advance the field of EJ mapping tools. Our recommendations are grounded in well-established theoretical frameworks of environmental justice that have shaped both academic discourse and practical applications in the field. Scholars such as Schlosberg [15] and Fraser [16] have identified three fundamental dimensions of environmental justice that inform our approach. Distributional justice focuses on the fair allocation of environmental burdens and benefits, which is directly addressed by EJ mapping tools through their visualization of environmental hazards and community vulnerabilities. Recognition justice emphasizes the need to acknowledge and respect the diversity of communities affected by environmental issues, which can be reflected in the selection and representation of indicators in EJ tools. Procedural justice concerns the fair and inclusive decision-making processes, which EJ mapping tools can support by providing transparent, accessible information to all stakeholders.

These theoretical concepts underpin our action-based framework for improving EJ mapping tools. By enhancing the general characteristics, tool resources, and indicators used in these tools, we aim to better capture and represent these dimensions of EJ. For instance, improving spatial granularity in EJ tools can enhance our understanding of distributional justice at various scales. These practical improvements directly advance environmental justice goals: multilingual interfaces and comprehensive guides increase accessibility for diverse communities, while transparent methodologies enable meaningful participation in environmental decision-making processes. Together, these features help ensure that EJ mapping tools serve their fundamental purpose of identifying and addressing environmental disparities through an equity lens. This framework is grounded in our practical experience and observations and is designed to provide actionable recommendations for tool developers, policymakers, and community stakeholders. While a comprehensive review

of these tools is beyond the scope of this paper, our recommendations are informed by our understanding of the current landscape of EJ mapping tools, including their strengths, limitations, and potential for improvement.

Based on this knowledge, we have identified three key areas that are crucial for enhancing the effectiveness of EJ mapping tools: general characteristics, tool resources, and indicators. These areas consistently emerge as critical components that define the functionality, usability, and impact of EJ mapping tools in practice [17, 18]. Our recommendations focus on these areas, aiming to provide a framework that can guide the improvement of existing tools and the development of new ones.

By offering this perspective, we hope to stimulate discussion and inspire innovation in the field of EJ mapping, ultimately contributing to more effective tools that can better support decision-making and community empowerment in the pursuit of EJ. While recognizing ongoing debates about global frameworks, we note that our recommendations align with broader sustainability efforts, including SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 16 (Peace, Justice and Strong Institutions) [19] These connections highlight how improved EJ mapping tools can contribute to addressing environmental disparities through targeted interventions and policies at multiple scales, from local to global. However, we emphasize that the primary value of these recommendations lies in their potential to advance environmental justice at the community level, where mapping tools can have the most direct impact on identifying and addressing local environmental inequities.

2 Key elements of existing EJ mapping tools

Based on our collective experience and observations of EJ mapping tools worldwide, we have identified three key areas that are crucial for enhancing the effectiveness of these tools: (1) General Characteristics, which cover the foundational aspects of the tools; (2) Tool Resources, which focus on the supporting materials and features that enhance usability; and (3) Indicators, which address the specific data points and metrics used in the tools (Fig. 1). These elements consistently emerge as critical components that define the functionality, usability, and impact of EJ mapping tools in practice.

Our insights are drawn from our experience in the field of EJ and extensive engagement with various EJ mapping tools globally, rather than from a formal systematic review. This perspective aims to synthesize our practical knowledge and observations to provide a clear and logical structure for tool developers and users to consider when improving or creating EJ mapping tools.

While a comprehensive review of individual tools is beyond our scope, it's worth noting some illustrative examples. For instance, the U.S. EPA's EJScreen tool demonstrates comprehensive geographic scope by covering the entire United States, including territories [20]. The California EnviroScreen balances the number of indicators well, providing a comprehensive view without overwhelming users [21]. The Colorado EnviroScreen exemplifies good practices in data accessibility by offering downloads in multiple formats with clear metadata [22]. These examples, among others globally, have informed our recommendations for improving EJ mapping tools. For comprehensive documentation and analysis of these and other EJ mapping tools, including their detailed characteristics, functionalities, and access information, see our systematic review of 25 EJ mapping tools in the United States [8]. Here we focus on synthesizing key insights and recommendations from our analysis of these tools.

2.1 General characteristics

EJ mapping tools exhibit a wide range of general characteristics, including variations in geographic scope, spatial granularity, and user interface design. Some tools cover individual states, while others provide nationwide or even US territory data [4, 14]. Most tools are maintained by state governments, with fewer being managed by federal agencies, academic institutions, or third-party organizations. Spatial granularity also varies, with some tools offering a single level of detail (e.g., census tract) and others providing multiple levels (e.g., county, census tract, and census block) for more tailored analyses. Improving spatial granularity in EJ tools enhances our ability to analyze distributional justice at various scales, from neighborhoods to regions. User interfaces differ in their user-friendliness and accessibility features, catering to diverse user needs. Additionally, some tools create and display summary units, such as composite indexes or scores, while others present raw data without aggregation or offer both options.

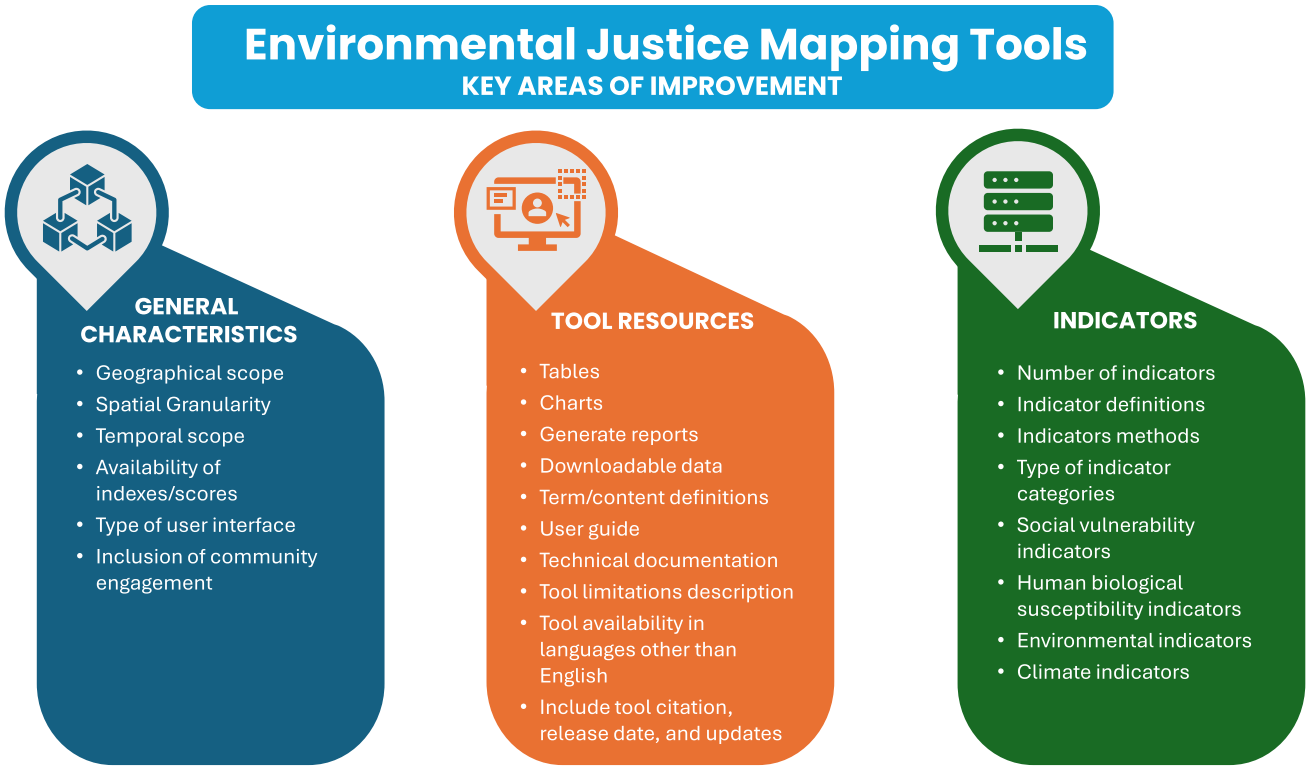

Fig. 1 Key areas for improvement in environmental justice mapping tools, derived from observations of existing tools and forming the basis of our recommendations

2.2 Tool resources

Tool resources play a vital role in supporting users as they navigate and interpret the data provided by EJ mapping tools. Common resources include online tables, charts, report-generation capabilities, and downloadable data. Providing comprehensive and accessible resources supports SDG 16 (Peace, Justice, and Strong Institutions) by promoting transparency and enabling informed decision-making by all stakeholders. Most tools offer user guides or technical documentation to help users utilize the tool's features effectively. However, the transparency regarding tool limitations varies, with some tools explicitly communicating potential biases, data gaps, or methodological constraints, while others lack clear documentation. Language accessibility is another important aspect, with some tools offering resources and interfaces in Spanish or providing translation options. Still, this feature is not consistently available across EJ mapping tools in the United States. Providing comprehensive user guides and multilingual interfaces addresses recognition justice by making tools more accessible to diverse communities.

2.3 Indicators

EJ mapping tools incorporate a wide range of indicators, with significant variation in both the number and types of indicators included. While some tools focus on a targeted set of core indicators to maintain simplicity, others incorporate dozens of indicators to capture the complex nature of environmental justice issues. The number of indicators selected often reflects a balance between comprehensiveness and usability, with tools typically including between 10 and 30 indicators across various categories [8]. The selection of diverse indicators reflects the interconnected nature of EJ issues, addressing multiple SDGs simultaneously. For instance, environmental quality indicators relate to SDG 3 (Good Health and Well-being) and SDG 6 (Clean Water and Sanitation), while social vulnerability indicators align with SDG 10 (Reduced Inequalities). Social vulnerability indicators often include income level, race/ethnicity, education status, and employment status. Human biological susceptibility indicators encompass age, life expectancy, and disease prevalence, including both communicable and non-communicable diseases. Environmental indicators address various aspects of

environmental quality, such as air, water, and soil pollution, as well as biological, chemical, physical, and natural hazards and assets. Climate-related indicators, although less common, are increasingly being incorporated to examine the intersection between EJ and climate change, providing information on short-term, medium-term, and long-term climate risks. While most tools include data sources for indicators, fewer provide indicator methodologies or rationales for indicator selection, which can limit transparency. Definitions of indicators are typically provided to clarify their meaning and significance within the tool. The careful selection and clear definition of indicators supports procedural justice by enabling stakeholders to make informed decisions based on transparent, relevant data.

3 General recommendations for EJ mapping tool development and maintenance

EJ mapping tools provide a powerful means of understanding and addressing environmental inequalities. To maximize their impact and accessibility to all users, it is essential to consider multiple aspects of their design, display, and operation, and to apply best practices in terms of tool interface, resources, and indicator selection (Table 1).

The following recommendations are designed to be actionable and adaptable to various contexts. While the specific implementation may vary depending on the scale and purpose of each EJ mapping tool (e.g., state-level vs. national tools), these guidelines provide a framework for improvement that can be tailored to individual needs and resources. Building on the key elements discussed earlier, our recommendations are organized into three categories: General Characteristics, Tool Resources, and Indicators. Each category addresses specific aspects of EJ mapping tools that can be enhanced to better serve the goals of EJ.

3.1 General characteristics

The following recommendations aim to optimize the foundational elements of EJ mapping tools, enhancing their ability to provide comprehensive and nuanced insights into EJ issues.

3.1.1 Geographic scope

EJ mapping tools should clearly indicate their geographic scope, such as national, state, county, or city level [9]. This information helps users assess the relevance of the tool to their specific areas of interest and contextualize findings within local or regional contexts. Tools should also specify whether they include data for US territories and Federally Recognized Tribes, acknowledging the unique EJ challenges faced by these communities [14]. For example, the U.S. EPA's EJScreen tool effectively demonstrates a comprehensive geographic scope by covering the entire United States, including territories like Puerto Rico and the U.S. Virgin Islands [18]. This broad coverage allows for consistent EJ assessments across diverse regions. Considering geographic scope and spatial granularity aligns with SDG 11 (Sustainable Cities and Communities) by enabling analysis at various scales, from neighborhoods to entire regions.

3.1.2 Spatial granularity

To accommodate diverse analytical needs and enable more nuanced assessments, EJ mapping tools should offer multiple levels of spatial granularity [4]. Providing options such as county, census tract, and census block levels allow users to zoom in or out to the desired level of detail, facilitating tailored analyses and interventions at different scales. Consistency and compatibility across spatial levels are crucial for comparing data at various granularities. Offering multiple levels of spatial granularity allows for more nuanced assessments of distributional justice, enabling users to identify environmental inequities at various scales, from neighborhoods to regions. The Washington Environmental Health Disparities Map exemplifies effective use of multiple spatial granularity levels. It allows users to view data at the census tract, zip code, and county levels, enabling both broad overview assessments and detailed local analyses [23].

3.1.3 Temporal focus

Effective EJ mapping tools should clearly define their temporal focus, specifying the timeframe of the data and analyses presented [3]. Users need to understand whether the data pertains to historical, current, or projected conditions and

Table 1 Checklist of recommendations for enhancing environmental justice mapping tools

Aspect	Recommendations	Yes/no
Geographic scope	Clearly indicate geographic scope (national, state, county, or city level)	
Spatial granularity	Offer multiple levels of spatial granularity (e.g., county, census tract, census block)	
Temporal focus	Define the temporal focus (historical, current, projected) and update frequency	
Number of indicators	Balance comprehensiveness and usability by prioritizing the most relevant indicators	
Availability of Indexes/scores	Include indexes or scores with flexibility to access aggregated and raw data	
User interface	Prioritize user-friendly interfaces with clear navigation and accessibility features	
Inclusion of community engagement	Report mechanisms for soliciting and incorporating community feedback	
Tables and charts	Include clear tables and charts with intuitive labels and customization features	
Generate reports	Allow users to generate customizable reports in various formats	
Downloadable data	Offer downloadable data in multiple formats with clear documentation	
Term definitions	Provide comprehensive and accessible definitions of key terms	
User guides	Ensure user guides are comprehensive, well-structured, and regularly updated	
Technical documentation	Create detailed technical documentation outlining methodologies and limitations	
Tool limitations description	Describe tool limitations clearly, including potential biases and uncertainties	
Tool availability in languages besides English	Translate interface elements and resources into commonly spoken languages	
Tool citation release date and update information	Provide update schedules and release dates for transparency and reliability	
Indicator definitions	Include clear definitions and metrics for all indicators used	
Indicator methods	Document methodologies for selecting and including indicators	
Indicator categories	Categorize indicators into social vulnerability, biological susceptibility, environmental factors, and climate indicators	
Cumulative impacts	Incorporate cumulative impact assessments and document methodologies	
Future directions	Involve community-based research and establish a framework for ongoing evaluation and refinement	

Yes/No column is provided for tool developers and managers to assess their mapping tools against these recommendations, facilitating practical implementation of the framework

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the frequency of updates (e.g., real-time, annual, or specific intervals). Transparency regarding the temporal dimension is essential for assessing the relevance and currency of the information provided.

3.1.4 Availability of indexes/scores

Incorporating indexes or scores can help distill complex data into accessible metrics for users [9]. These summary measures facilitate easier interpretation and comparison of environmental disparities across different areas. However, tools should offer flexibility in their presentation, allowing users to access both aggregated indices and raw data for more detailed analysis, while ensuring transparency in the calculation methodologies. The use of composite indices in EJ mapping tools is a subject of ongoing debate. Proponents argue that they simplify complex information for decision-makers [24], while critics contend that they may obscure important nuances in the data [25]. When incorporating indexes or scores, tool developers should consider these perspectives and provide transparency in their methodologies.

3.1.5 User interface

EJ mapping tools should prioritize user-friendly interfaces that enhance accessibility and usability for a diverse range of users and stakeholders, including those with visual impairments [3]. The interface design should be intuitive, with clear navigation and interactive features that facilitate data exploration and analysis. Consistency and compatibility across different devices and platforms are essential to ensure access for all users. Addressing the needs of users with visual impairments through accessible design features, such as alternative text for images, compatibility with screen readers, color-blind accessible color schemes, and adjustable font sizes, is crucial for inclusivity and usability.

3.1.6 Inclusion of community engagement

Effective EJ mapping tools rely heavily on community engagement, which requires active participation from communities throughout the tool's conception, development, and update processes [1]. To ensure the authenticity and relevance of these tools, developers should report how they integrate mechanisms for soliciting and incorporating community feedback at every stage, such as user surveys, community forums, or advisory boards. Transparent reporting on community engagement efforts demonstrates a commitment to accountability and inclusivity, strengthening trust and collaboration among stakeholders. Effective community engagement must recognize and address existing power relations between stakeholders. This includes acknowledging historical inequities, ensuring meaningful participation of marginalized communities throughout the tool development process, and creating mechanisms for community control over data and narratives. Special attention should be paid to involving grassroots organizations, indigenous communities, and other historically excluded groups who often lead environmental justice struggles [25–27]. This deeper engagement supports the tool's effectiveness in not just measuring environmental impacts, but in empowering communities to advocate for environmental justice.

3.2 Tool resources

These recommendations focus on improving the supporting materials and features that make EJ mapping tools more accessible and useful to a diverse range of users.

3.2.1 Tables and charts

Tables and charts should be included to present data in a clear and organized manner, with intuitive labels and visual features that facilitate easy navigation and interpretation [14]. Customization features, such as filtering, sorting, or rearranging data, and interactive elements, like zooming or toggling between different chart types, enable users to explore the data in more detail. Optimizing tables and charts for readability across various devices and screen sizes ensures accessibility for all users. Tooltips or explanations providing additional context or definitions for data points can aid in understanding the information presented.

3.2.2 Generate reports

EJ mapping tools should allow users to generate reports, enabling the effective documentation and communication of findings [4]. Customizable report templates that allow users to select specific data, analyses, and visualizations are essential. The report generation process should be intuitive and user-friendly, with clear prompts and instructions guiding users through each step. Options for formatting and styling reports to align with users'preferences should be available. Generated reports should be well-organized and visually appealing, with concise summaries, descriptive captions, and relevant contextual information to facilitate understanding for diverse audiences. Tools should support the export of reports in multiple formats, such as PDF or Word documents, to ensure compatibility and ease of sharing.

3.2.3 Downloadable data

To optimize the use of EJ mapping tools, downloadable data should be offered with flexible options in various formats, including CSV and Excel. The download process should be straightforward and accessible, with clear instructions and options for selecting specific datasets, variables, and geographical extents to customize the downloaded data. Data documentation, including information on data sources, methodology, and any relevant limitations, should be provided alongside the downloadable datasets to ensure data integrity and quality. Regular updates and maintenance of the data repository are essential to ensure users have access to the most current and accurate information available. The Colorado EnviroScreen tool demonstrates best practices in data accessibility by offering downloads in multiple formats (CSV, Excel, and shapefile), accompanied by clear metadata and usage guidelines [22]. This approach caters to users with varying technical expertise and data needs.

3.2.4 Term definitions

Clear and concise definitions of key terms and content are vital components of EJ mapping tools to ensure effective communication and understanding among users [3]. Developers should prioritize the inclusion of comprehensive definitions covering a range of relevant terms related to the environment, health, justice, equity, and cumulative impacts. These definitions should be easily accessible within the tool interface and presented in a user-friendly format to create a common understanding between stakeholders.

3.2.5 User guides

User guides allow users to maximize the effectiveness and usability of EJ mapping tools [14]. To ensure their efficacy, user guides should be comprehensive, well-structured, and easily accessible within the tool interface. These guides should provide clear instructions on navigating the tool's features, interpreting data outputs, and conducting analyses. Additionally, user guides should offer troubleshooting tips, best practices to address common challenges or questions, and frequently asked questions. Regular updates to user guides, reflecting any changes or improvements to the tool, ensure that users have access to the most accurate and relevant information.

3.2.6 Technical documentation

Developers should prioritize the creation of comprehensive technical documentation that outlines the tool's methodologies, including data sources and analyses conducted [4]. This documentation should provide clear explanations of the techniques used, enabling users to understand how data is processed and interpreted within the tool. Addressing limitations or uncertainties associated with the tool's methodologies helps users make informed decisions about the reliability and applicability of the tool's outputs. Technical documentation should be easily accessible within the tool interface and regularly updated to reflect any changes or improvements.

3.2.7 Tool limitations description

Providing a clear and transparent description of the limitations of EJ mapping tools ensures that users understand the scope and applicability of the tool's results [3]. Developers should include a dedicated section within the tool documentation that outlines the potential constraints, biases, and uncertainties associated with the tool's methodologies and

data sources. This description should address factors such as data availability, spatial resolution, temporal coverage, and assumptions made during analysis. By acknowledging these limitations upfront, users can make informed decisions about the suitability of the tool for their specific needs and interpret the results with appropriate caution. Regular reviews and updates to the limitation description reflect improvements or changes to the tool's functionalities, methodologies, or data sources.

3.2.8 Tool availability in languages besides English

Developers should prioritize the translation of interface elements, user guides, technical documentation, and other resources into languages commonly spoken by the target user population [14]. Cultural sensitivity should be maintained throughout the translation process to accurately convey the intended meaning of terms and concepts. Implementing automatic translation services within the tool interface can further enhance language accessibility for users, allowing them to interact with the tool in their preferred language without barriers. By expanding language support, EJ mapping tools can empower a broader range of stakeholders.

3.2.9 Tool citation, release date, and update information

Ensuring transparency regarding the tool's update schedule, release time, and any planned future updates enhances users'confidence in the tool's reliability and applicability over time [4]. Articulating the release and update dates fosters trust among users, facilitating the effective use of the tool for decision-making and supporting ongoing efforts to address environmental injustices across different temporal contexts. Establishing a routine schedule for tool updates is crucial for maintaining data accuracy and relevance.

3.3 Indicators

Our recommendations for indicators aim to ensure that EJ mapping tools capture the full complexity of EJ issues while remaining clear and interpretable.

3.3.1 Number of indicators

EJ mapping tools should strike a balance between comprehensiveness and usability when determining the number of indicators to include [14]. For instance, the California EnviroScreen tool effectively balances comprehensiveness and usability by including a carefully selected set of 21 indicators across four main categories: exposures, environmental effects, sensitive populations, and socioeconomic factors [8, 21]. This number of indicators provides a comprehensive view of EJ issues without overwhelming users. The tool achieves this balance by (a) focusing on indicators with strong scientific support for their relevance to EJ, (b) combining related indicators where appropriate (e.g., combining various air pollutants into a single'air quality'indicator), and (c) providing clear explanations and visualizations for each indicator to enhance usability. This approach allows the tool to capture a wide range of EJ factors while maintaining ease of use and interpretation. While covering a diverse range of factors contributing to EJ disparities is important, prioritizing the most relevant and impactful indicators within the context of EJ is crucial to avoid overwhelming users and hindering data interpretation and decision-making.

3.3.2 Indicator definitions

EJ mapping tools should include comprehensive definitions of indicators used in the analysis. These definitions should specify the metrics and factors encompassed by each indicator, ensuring that users have a clear understanding of the data being presented. Consistent and well-defined indicators contribute to the credibility and usability of the tool, enabling users to accurately understand, interpret, and analyze the data.

3.3.3 Indicator methods

Developers should provide clear documentation outlining the methodologies used to select and include indicators. This documentation should include detailed descriptions of data sources, data collection methods, and any limitations

associated with the indicators'data. The rationale behind indicator selection should be articulated, highlighting the factors considered when determining the significance of each indicator in assessing EJ issues. Transparency in indicator methodologies reflects a comprehensive understanding of the factors contributing to EJ. While there is general agreement on the importance of comprehensive indicator selection, debate exists regarding the optimal set of indicators. Some researchers argue for a broad, inclusive approach [28], while others advocate for a more focused set of scientifically robust indicators [29]. The challenge lies in balancing comprehensiveness with data quality and availability. Tool developers must carefully consider these trade-offs when selecting indicators.

3.3.4 Indicator categories

Categorizing indicators into key domains, such as social vulnerability, biological susceptibility, environmental factors, and climate indicators, offers a structured approach to understanding the multifaceted nature of EJ issues and guiding intervention strategies [4].

3.3.5 Social vulnerability indicators

Social vulnerability indicators are crucial for shedding light on the socioeconomic factors that impact communities'ability to cope with environmental hazards [2]. A comprehensive description of all social vulnerability indicators, covering a broad spectrum of socioeconomic variables such as income, education, minority groups, transportation accessibility, housing, community infrastructure, social capital, and historical discrimination patterns, can offer valuable insights into systemic inequities and inform targeted interventions aimed at addressing disparities. Disability should also be considered as a factor of social vulnerability due to limited access to services, facilities, products, and social opportunities.

3.3.6 Human biological susceptibility indicators

Human Biological Susceptibility Indicators refer to factors that influence an individual's or population's vulnerability to environmental hazards based on human biological characteristics [8]. These may include age, pre-existing health conditions, and genetic predispositions. Human biological susceptibility indicators are essential for assessing individual-level factors contributing to differential health impacts from environmental exposures [1]. Recommendations include reporting and describing all human biological susceptibility indicators, incorporating demographic variables such as age, and data on health outcomes (morbidity and mortality). A clear definition and justification of the chosen health indicators, such as hospitalization, incidence, prevalence, mortality, and life expectancy, can provide more robust assessments of biological susceptibility and inform targeted interventions to protect vulnerable populations. The health data should also include a clear definition using the International Classification of Disease (ICD) codes.

3.3.7 Environmental indicators

Environmental indicators are critical for identifying areas with elevated environmental risks and assets (e.g., tree canopy, biodiversity) [14]. Clear reporting and definition of these indicators are essential, providing a comprehensive vision of assessed environmental variables such as pollution levels, environmental risk, historically damaged facilities, and positive environmental indicators like access to green spaces or availability of renewable energy sources. Incorporating data on EJ metrics, such as proximity to environmental hazards or distribution of environmental benefits, can help prioritize interventions in communities facing the greatest environmental burdens.

3.3.8 Climate-related indicators

Climate indicators should focus on understanding the impacts of climate change on communities and developing strategies to enhance resilience and adaptation [3]. Recommendations for enhancing these indicators include incorporating localized climate projections and vulnerability assessments to account for regional variations in climate impacts. Integrating socio-economic data with climate indicators can provide insights into the intersectionality of climate-related risks and inform equitable adaptation strategies that address the needs of vulnerable populations. However, before implementing these recommendations, more tools should provide even simple climate-related data, such as information on an area's short-term, medium-term, and long-term climate risks, as most EJ tools currently do not include this indicator

type. The Climate and Economic Justice Screening Tool (CEJST) effectively incorporates climate indicators by including factors such as projected flood risk and wildfire risk. These forward-looking indicators help communities plan for future EJ challenges [30]. The integration of climate change indicators into EJ mapping tools is an evolving area with varying approaches. Some argue for the inclusion of future climate projections [31], while others emphasize the importance of current vulnerability indicators [32]. The debate centers on how to effectively represent both current and future EJ concerns in a single tool.

3.3.9 Cumulative impacts

EJ mapping tools should incorporate indicators and methodologies that account for the cumulative impacts of environmental stressors on communities. Cumulative impacts refer to the combined effects of multiple environmental hazards, such as air and water pollution, toxic waste, and climate change, on the health and well-being of individuals and communities over time [33]. These impacts are often disproportionately borne by marginalized and disadvantaged communities, contributing to persistent health disparities and environmental injustices [34]. By integrating cumulative impact assessments into EJ mapping tools, policymakers and communities can better understand and address the compounding effects of environmental stressors, facilitating more targeted and effective interventions to promote EJ [24, 35]. Assessing cumulative impacts is also crucial for addressing SDG 13 (Climate Action), as it helps identify communities most vulnerable to the compounded effects of environmental stressors and climate change. Developers should prioritize the inclusion of cumulative impact indicators, such as the EJ Screening Method (EJSM) [24], and provide clear documentation of the methodologies used to assess and visualize these impacts within the tool.

4 Future directions

An area for exploration is the incorporation of community-based research into mapping tool development and updates [1]. This collaborative approach emphasizes the involvement of both researchers and community members throughout the research process, ensuring that EJ mapping tools are culturally sensitive and relevant to affected areas and community members who may be using the tool. Involving communities in the development and implementation of EJ mapping tools can enhance community empowerment and capacity-building efforts.

Our recommendations address several key limitations in existing EJ mapping tools. First, by standardizing spatial granularity requirements and promoting multiple analysis levels, we enhance the tools'ability to identify fine-scale environmental justice concerns that might be masked at broader geographic scales. Second, our emphasis on comprehensive indicator selection and cumulative impact assessment helps capture the complex, interconnected nature of environmental and climate justice issues that single-indicator approaches often miss. Third, by promoting consistent documentation and transparent methodologies, we enable better cross-tool comparisons and more robust validation of findings. These improvements collectively strengthen our ability to identify and address environmental justice concerns by: (a) enabling more precise identification of affected communities through improved spatial resolution; (b) capturing complex environmental justice dynamics through comprehensive indicator frameworks; (c) facilitating evidence-based decision-making through enhanced data transparency and accessibility; (d) supporting longitudinal analysis through standardized temporal tracking; and (e) empowering community participation through improved tool accessibility and documentation. Implementation of our recommendations will necessarily vary depending on the scale, purpose, and context of each tool. For example, state-level EJ tools may prioritize different elements compared to national tools, based on local needs and data availability. Our framework is intentionally flexible to accommodate these variations while maintaining core principles that promote overall improvement in EJ mapping tools. This adaptability ensures that our recommendations can support stakeholders in advancing environmental justice goals across diverse geographical and institutional contexts.

As EJ mapping tools continue to evolve and new challenges emerge, it is essential to establish a framework for ongoing evaluation and refinement of these tools. Regular assessments of tool effectiveness, user feedback, and community impact should be conducted to identify areas for improvement and ensure that the tools remain relevant and responsive to the needs of diverse stakeholders. This iterative process of evaluation and refinement should involve close collaboration with affected communities, researchers, and policymakers to foster a culture of continuous learning and adaptation. By institutionalizing this process, EJ mapping tools can remain at the forefront of efforts to address environmental disparities and promote equitable decision-making in the face of changing social, economic,

and environmental contexts. As we continue to refine and improve EJ mapping tools, it's essential to regularly reassess their alignment with the SDGs and emerging EJ challenges. This ongoing process will ensure that these tools remain effective in supporting global sustainability goals.

Future research could further explore EJ issues in global contexts, beyond the United States [31]. An exemplary initiative in this direction is the EJ Atlas (EJAtlas, https://ejatlas.org/), which maps and documents cases of environmental injustice worldwide, and also allows for tracking community mobilizations on socio-environmental conflicts in a collaborative process. Such global perspectives can inform the development of more comprehensive and adaptable EJ mapping tools that address diverse environmental and social contexts across different countries and regions. This expanded geographical scope can identify opportunities for international collaboration to address evolving EJ challenges, and ideas from international EJ mapping tools could also inform the development and improvement of tools in the United States.

While we believe these recommendations can significantly improve EJ mapping tools, we acknowledge certain limitations. The diversity of EJ issues across different geographical and social contexts means that no single set of recommendations can be universally applicable. Additionally, data availability and quality can vary greatly, potentially limiting the implementation of some recommendations. Future research should explore how these recommendations can be adapted to different contexts and how to overcome data limitations.

5 Conclusion

This perspective offers an action-based framework for enhancing the effectiveness of EJ mapping tools, grounded in the conceptual dimensions of EJ: distribution, recognition, and procedural justice. Our recommendations, focusing on general characteristics, tool resources, and indicators, aim to capture and operationalize these dimensions in practical, actionable ways.

By optimizing the general characteristics of EJ mapping tools, such as geographic scope and spatial granularity, we enhance their capacity to address distributional justice, providing a more nuanced understanding of how environmental burdens and benefits are allocated across communities. Improving tool resources, including user guides and multilingual interfaces, supports recognition justice by making these tools more accessible to diverse communities. Refining the selection and presentation of indicators, coupled with transparent methodologies, contributes to procedural justice by enabling informed participation in environmental decision-making processes.

Our practical framework provides specific, implementable recommendations that are designed to be flexible and adaptable, acknowledging the diverse contexts in which EJ mapping tools are developed and used. By implementing these recommendations, we can create more powerful, accessible, and impactful tools that better serve the multifaceted nature of EJ issues.

As EJ mapping tools continue to evolve, their potential to drive positive changes in environmental policy and community advocacy grows. These tools can play a crucial role in identifying areas of concern, informing policy decisions, and empowering communities to advocate for EJ.

The path forward requires collaboration among researchers, policymakers, community leaders, and tool developers. By working together to implement and further refine this action-based framework, we can create EJ mapping tools that more effectively capture the complexities of EJ and support equitable decision-making.

In presenting this perspective, we hope to stimulate further discussion and innovation in the field of EJ mapping. As these tools continue to evolve, guided by the principles of distributional, recognition, and procedural justice, they have the potential to play an increasingly vital role in our collective efforts to create a more equitable and sustainable future for all communities.

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