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Environmental Justice Indicators for Infrastructure Prioritization

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Abstract

Infrastructure investment determines how communities experience mobility, water security, drainage, environmental quality, public space, climate resilience, and access to essential services. Conventional capital-prioritization systems commonly emphasize engineering condition, project readiness, cost, service demand, and economic efficiency. Although these factors remain necessary, they can perpetuate unequal infrastructure outcomes when historically underserved neighborhoods already experience higher environmental burdens, weaker service provision, greater socioeconomic vulnerability, and lower institutional capacity to compete for investment.

This study develops an environmental-justice indicator framework for incorporating distributive need into infrastructure prioritization. Because authenticated municipal capital-program data, environmental-exposure measurements, and community-engagement records were not supplied, the quantitative component is explicitly simulation based. Sixty synthetic infrastructure candidates are evaluated using an Environmental Justice Infrastructure Priority Index that integrates engineering need, cumulative environmental burden, social vulnerability, historic service deficit, and community-identified priority. The framework treats environmental-justice indicators as screening and decision-support evidence rather than automatic determinations of legal or distributive injustice. Simulated analysis demonstrates that inclusion of justice indicators materially changes the relative attractiveness of several projects.

An Eastside drainage and sewer renewal project receives a composite priority score of 92 because severe asset deterioration coincides with cumulative environmental exposure, socioeconomic vulnerability, longstanding service deficits, and high community priority. A technically competitive but less disadvantaged green-street project receives a substantially lower justice-adjusted score. The findings indicate that equitable prioritization requires more than adding a demographic variable to an existing engineering formula. Meaningful environmental-justice screening should evaluate cumulative burdens, population vulnerability, historical infrastructure conditions, community knowledge, and the distribution of prospective benefits. The proposed model offers a transparent basis for capital planning while emphasizing sensitivity analysis, local validation, public participation, and professional judgment.

Keywords: environmental justice, infrastructure prioritization, cumulative environmental burden, social vulnerability, infrastructure equity, GIS screening, capital planning, distributive justice

1. Introduction

Public infrastructure is not merely a collection of physical assets. Roads, public transport, water networks, drainage systems, parks, energy systems, sidewalks, flood defenses, and environmental infrastructure shape exposure to hazards and determine access to essential social and economic opportunities. Infrastructure decisions therefore have distributive consequences extending far beyond engineering performance. A neighborhood with unreliable drainage may experience recurrent property damage, transportation disruption, mold exposure, and financial stress, while another neighborhood may benefit from reliable systems that prevent these secondary burdens. Environmental-justice research has repeatedly shown that communities can experience overlapping environmental and socioeconomic disadvantages rather than isolated exposures. Sadd, Pastor, Morello-Frosch, Scoggins, and Jesdale demonstrated the usefulness of combining hazard proximity, pollution exposure, health risks, and social vulnerability into a cumulative screening structure instead of evaluating environmental burdens one source at a time.

This cumulative perspective is particularly important for infrastructure planning. Conventional project-ranking systems frequently begin with physical asset condition and expected operational benefit. Such approaches can be rational from an engineering perspective, but they may fail to capture the fact that identical infrastructure failures have unequal consequences across communities. Households with limited financial resources may have less capacity to recover from flooding, transportation interruption, water contamination, excessive heat, or energy outages. Older residents, people with disabilities, households without private vehicles, renters, and populations experiencing health vulnerabilities may similarly depend more heavily on reliable public infrastructure. Research on place-based flood vulnerability demonstrates that socioeconomic conditions influence the capacity of communities to prepare for, absorb, and recover from environmental hazards, making vulnerability information relevant to risk-management and funding decisions.

Environmental-justice screening tools provide an established methodological foundation for incorporating these conditions into spatial decision support. The California cumulative-impact approach integrates pollution burden with population characteristics, while the U.S. EPA's historical EJSCREEN framework combined nationally consistent environmental and demographic indicators to identify places potentially warranting additional investigation. Importantly, such tools were designed as screening mechanisms rather than deterministic risk assessments. EPA documentation explicitly cautioned that screening information contains uncertainty, does not include every locally relevant condition, and should be supplemented with local knowledge and further analysis. Research using CalEnviroScreen similarly demonstrates that composite indicators can identify substantial disparities in cumulative environmental-health burdens and help direct policy attention toward highly affected communities.

The relationship between environmental justice and infrastructure is nevertheless more complex than identifying disadvantaged locations on a map. Infrastructure itself can reproduce or reduce vulnerability. Hendricks and Van Zandt argue that environmental-justice and hazard-vulnerability research must more explicitly consider roads, stormwater systems, sewerage, energy, greenspace, and related physical systems because underserved built environments can institutionalize unequal protection. Empirical planning studies similarly demonstrate that explicitly incorporating social indicators can alter infrastructure siting. Christman, Meenar, Mandarano, and Hearing incorporated disadvantaged-community characteristics into green stormwater infrastructure prioritization, while Zhu, Ren, and Liu developed an equity-oriented method for directing green infrastructure toward communities with greater environmental and social need. These studies suggest that equity indicators can move infrastructure planning from retrospective documentation of inequality toward prospective allocation of investment.

The present study develops an Environmental Justice Infrastructure Priority Index (EJIPI) for this prospective function. The framework asks whether infrastructure projects should receive greater priority when severe physical need coincides with cumulative environmental burden, socioeconomic vulnerability, historical service deficiency, and strong locally identified need. It does not assume that the numerically highest index score should automatically receive funding. Engineering feasibility, legal requirements, project dependencies, life-safety obligations, cost, and implementation readiness remain relevant. Instead, the proposed index creates a transparent justice lens within capital planning so that infrastructure need is not evaluated independently of the communities experiencing that need. Because no authenticated municipal project dataset has been provided, all project names, scores, rankings, and quantitative comparisons are explicitly synthetic.

2. Objectives of the Study

2.1 Development of an Environmental-Justice-Oriented Infrastructure Priority Framework

The first objective is to construct a prioritization framework capable of integrating conventional infrastructure condition with environmental and social indicators. Existing cumulative-impact methods demonstrate that pollution burden and population vulnerability can be analyzed jointly, while infrastructure-planning research shows that equity variables can influence the identification of priority intervention areas. The present study extends these principles by placing environmental-justice indicators directly inside a capital-prioritization architecture.

The resulting framework is intended to remain sufficiently interpretable for engineers, planners, public-health professionals, budget officials, elected representatives, and community stakeholders. Each component remains visible rather than being concealed within a black-box algorithm. This allows users to identify whether a project ranks highly because of engineering deterioration, environmental burden, social vulnerability, historic underinvestment, community need, or a combination of these conditions.

2.2 Evaluation of Cumulative Need Rather Than Single-Indicator Disadvantage

The second objective is to avoid defining environmental-justice priority through a single demographic characteristic. Environmental injustice can involve overlapping conditions, including pollution exposure, proximity to hazardous activities, inadequate infrastructure, health sensitivity, limited household resources, and weak access to environmental amenities.

The proposed system therefore evaluates cumulative need. Social vulnerability is interpreted as a contextual modifier of environmental and infrastructure burdens rather than a statement that communities are inherently deficient. Similarly, historical service deficit captures unequal infrastructure conditions rather than labeling residents themselves as vulnerable. This distinction is important because environmental-justice analysis should direct attention toward structural conditions and unequal protection, not stigmatize communities.

2.3 Assessment of How Justice Indicators Alter Capital Prioritization

The third objective is to examine whether a justice-adjusted prioritization model generates materially different investment rankings from a technically oriented approach. The simulation therefore compares infrastructure candidates characterized by different combinations of engineering condition, cumulative environmental burden, social vulnerability, service deficit, and community priority.

Particular attention is given to projects whose engineering scores alone would place them below competing investments but whose broader environmental-justice conditions substantially increase their priority. Such changes provide the strongest evidence of why environmental-justice indicators may matter within capital programming.

3. Review of Literature

3.1 Cumulative Environmental Burdens and Justice Screening

Environmental-justice analysis developed partly in response to the limitations of assessing individual pollution sources separately from the social conditions surrounding exposed populations. Sadd and colleagues proposed an Environmental Justice Screening Method incorporating twenty-three indicators across hazard proximity and land use, pollution exposure and health risk, and social and health vulnerability. Their central contribution was to demonstrate how GIS-based cumulative screening can rank communities according to overlapping environmental and social burdens and thereby support targeted regulatory and planning attention.

Alexeeff and colleagues developed a related cumulative-impact framework organized around exposures, public-health effects, environmental effects, sensitive populations, and socioeconomic factors. Their method explicitly distinguished screening from quantitative community-level health-risk estimation. Instead, the purpose was to identify comparatively burdened places deserving further consideration. August and colleagues subsequently examined methodological challenges involved in combining indicators, including data quality, correlation among variables, indicator selection, weighting, and sensitivity to model structure. Their findings are highly relevant to infrastructure prioritization because composite scores can acquire false authority if the assumptions behind indicator aggregation are not disclosed or tested.

Cushing and colleagues applied statewide cumulative screening to examine environmental-health disparities and found pronounced inequalities in the distribution of environmental burdens and vulnerable populations. Their work also emphasized that screening scores can help decision makers identify locations warranting additional attention rather than quantifying individual health risk. EPA's EJSCREEN model reflected a similar philosophy. Environmental and demographic information was combined spatially to identify potentially overburdened places, but official documentation cautioned that screening outputs should be supplemented with additional evidence and community knowledge.

3.2 Social Vulnerability, Infrastructure, and Unequal Protection

Environmental exposure becomes more consequential when communities have fewer resources available for prevention, adaptation, or recovery. Social vulnerability research therefore examines factors influencing sensitivity and coping capacity. Cutter, Boruff, and Shirley's Social Vulnerability Index established a widely used multidimensional approach to understanding how socioeconomic and demographic conditions shape hazard vulnerability. Place-based adaptations of this logic continue to show that vulnerability varies geographically and is relevant to public investment decisions.

Chakraborty, Rus, Henstra, Thistlethwaite, and Scott developed a comprehensive socioeconomic index for evaluating social vulnerability in flood-risk management. Their analysis illustrates how income, housing, demographic structure, ethnicity, and other socioeconomic variables can be converted into spatially interpretable indicators relevant to planning and funding. Such indicators are particularly important where infrastructure deterioration and environmental hazards interact. A drainage failure in a financially secure neighborhood with high insurance coverage and strong municipal resources does not create an identical recovery context to the same failure in a neighborhood already experiencing housing insecurity and chronic environmental burdens.

Hendricks and Van Zandt extend this argument directly to critical infrastructure. Their review emphasizes that communities should not be described as intrinsically vulnerable when vulnerability may result from systematically neglected or underserved built environments. Roads, sewer systems, stormwater infrastructure, greenspace, and energy services can either reduce risk or embed unequal protection. This insight supports the inclusion of a historic service-deficit dimension within infrastructure prioritization. It allows the analytical framework to ask whether current capital need partly reflects long-term differences in service quality, maintenance, accessibility, or infrastructure protection.

3.3 Equity Indicators in Infrastructure and Spatial Planning

A growing body of planning research has moved beyond identifying environmental disparities to integrating equity directly into project siting. Christman and colleagues developed a GIS-based method for prioritizing green stormwater infrastructure using social factors in addition to physical suitability. Their framework identified disadvantaged areas and incorporated community capacity to determine locations in which green infrastructure could deliver more equitable benefits. The study demonstrates that infrastructure optimization changes when the beneficiaries and social context of investment are explicitly considered.

Zhu, Ren, and Liu similarly developed a green-infrastructure equity index integrating environmental conditions and community characteristics. Their results showed that areas facing greater waterlogging and poorer environmental conditions were not necessarily those emphasized by existing plans, leading the authors to recommend spatial reallocation of future green investment. Research on transportation network design reaches a comparable conclusion: infrastructure systems affect access to opportunities, and equity criteria can therefore be incorporated into network optimization rather than evaluated only after a project portfolio has been selected.

The Maryland environmental-justice screening tool provides another relevant example because it combines environmental indicators with demographic and health information at decision-relevant geographic scales. Driver and colleagues demonstrate that locally tailored screening can provide information beyond national tools by incorporating indicators relevant to specific communities. Collectively, this literature establishes the methodological foundation for the present study while revealing a continuing need for frameworks that connect cumulative environmental-justice indicators directly with comparative infrastructure capital prioritization.

4. Research Methodology

4.1 Research Design and Synthetic Infrastructure Portfolio

The study adopts a quantitative simulation-based methodological design. No real capital improvement program, utility asset database, community-health dataset, environmental-monitoring system, procurement record, or public-engagement dataset was supplied. Consequently, the analysis does not represent an empirical evaluation of any municipality, utility, or government agency.

A synthetic portfolio of 60 proposed infrastructure projects is developed across five broad investment categories: water and sewer renewal, stormwater and flood protection, transportation accessibility, public-realm and green infrastructure, and neighborhood resilience. Each candidate project is associated with a hypothetical service area and scored on five standardized dimensions.

The simulation deliberately includes cases in which strong engineering need overlaps with high environmental-justice need and cases in which these dimensions diverge. This allows the framework to demonstrate whether justice information changes the order in which projects would be considered.

Table 1: Environmental Justice Infrastructure Priority Indicators

Dimension	Representative Indicators	Illustrative Evidence in an Empirical Application	Decision Purpose
Engineering need	Asset condition, failure probability, service interruption, safety deficiency	Asset-management databases, engineering inspections, maintenance histories	Preserves technical necessity within prioritization
Cumulative environmental burden	Air pollution, flood exposure, contaminated sites, traffic burden, heat, industrial proximity	Environmental monitoring, GIS layers, hazard databases	Captures overlapping environmental stressors
Social vulnerability	Income constraints, age sensitivity, disability, housing burden, limited mobility, health sensitivity	Census, public-health and administrative data	Represents unequal capacity to avoid or absorb infrastructure-related harm
Historic service deficit	Recurrent outages, deferred maintenance, inadequate access, historic capital spending gap	Service records, capital histories, accessibility audits	Identifies long-standing differences in infrastructure protection

4.2 Construction of the Environmental Justice Infrastructure Priority Index

Engineering need remains an essential component because environmental justice should not result in technically unnecessary projects being ranked above urgent life-safety or infrastructure-failure requirements. Cumulative environmental burden receives an equivalent weight because the model is intended specifically to identify locations in which infrastructure investment can reduce overlapping environmental disadvantage.

Social vulnerability and historic service deficit receive substantial but slightly lower weights. Community priority receives ten percent of the composite score. This weight should not be interpreted as indicating that community knowledge is less legitimate. Instead, it recognizes that participatory evidence may require separate deliberative treatment and should not be compressed entirely into a numerical model.

In an actual application, weighting should be approved through transparent institutional and community processes. Sensitivity analysis should recalculate rankings under alternative weighting scenarios so that decision makers can determine whether the portfolio is robust or highly dependent on normative weighting choices.

4.3 Screening, Validation, and Prioritization Procedure

The proposed empirical workflow begins by defining project service areas rather than relying solely on project point locations. Infrastructure benefits and burdens frequently extend along networks or across catchments, transit walksheds, water-service zones, drainage basins, or neighborhoods. Environmental and demographic indicators should therefore be aggregated using geographic units corresponding as closely as possible to the population materially affected by each investment.

Indicator values are standardized into percentile-based or normalized scores before aggregation. Missing information is not automatically assigned an average value because doing so can conceal systematic data gaps in marginalized areas. Instead, incomplete observations receive a data-quality flag and may require additional field investigation or community engagement. The composite EJIPI is then used to screen projects into broad priority categories. High scores trigger additional technical, financial, and community review rather than automatic approval. Decision makers should examine whether the score is driven by one extreme indicator or by consistent evidence across multiple dimensions.

A final validation stage incorporates engineering feasibility, cost effectiveness, regulatory obligations, project dependencies, displacement or gentrification risk, operational capacity, and community feedback. The methodology therefore separates screening priority from final capital authorization.

5. Analysis

5.1 Distribution of Environmental-Justice Infrastructure Need

The synthetic portfolio produces substantial variation across the five dimensions. Several projects with severe engineering deterioration also serve areas characterized by high pollution burden and socioeconomic vulnerability. These projects remain high priority under both conventional and justice-adjusted evaluation.

More analytically significant are projects in which engineering need is moderate but environmental-justice conditions are severe. The North Corridor transit-access project, for example, has a lower engineering contribution than the West District water-main renewal project. Its total EJIPI nevertheless becomes substantially higher because mobility disadvantage, environmental burden, historic access deficits, and community priority reinforce the technical case for intervention.

The opposite pattern also occurs. Some technically attractive projects serve areas with lower cumulative burden and comparatively strong existing infrastructure provision. Such projects are not deemed unnecessary; rather, their relative ranking changes when scarce public investment is evaluated through a distributive-justice lens.

5.2 Comparative Infrastructure Priority Scores

Table 2: Simulated Infrastructure Prioritization Using Environmental-Justice Indicators

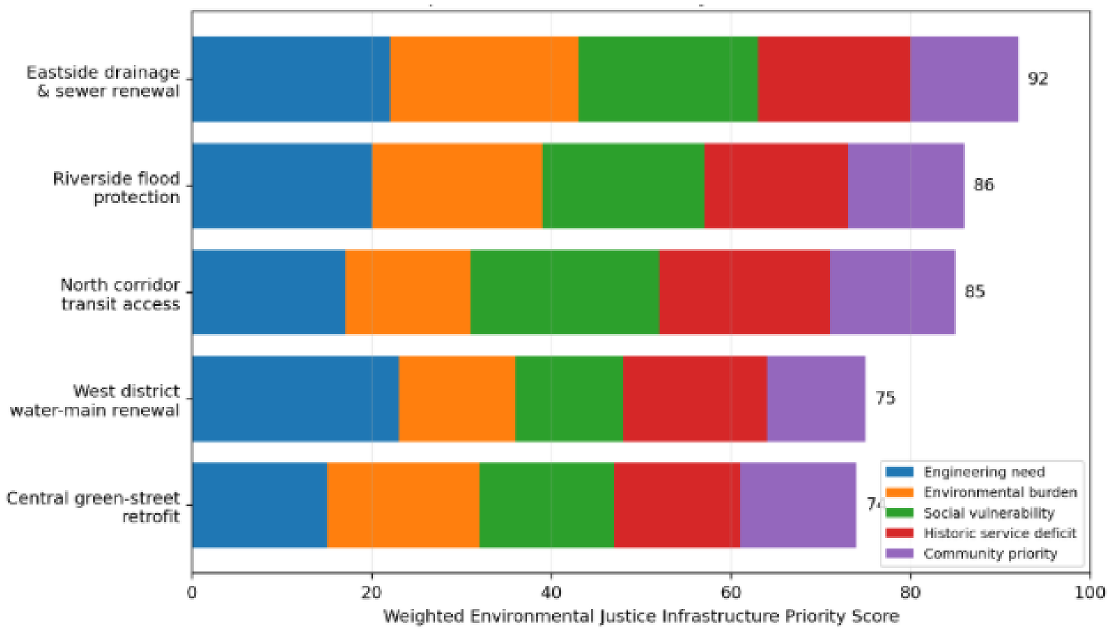
Infrastructure Candidate	Engineering Need	Environmental Burden	Social Vulnerability	Historic Service Deficit	Community Priority	EJIPI Score
Eastside drainage and sewer renewal	22	21	20	17	12	92
Riverside flood protection	20	19	18	16	13	86
North Corridor transit access	17	14	21	19	14	85
West District water-main renewal	23	13	12	16	11	75
Central green-street retrofit	15	17	15	14	13	74

Eastside drainage and sewer renewal obtains the highest score because no single criterion dominates the result. Severe technical need coincides with substantial environmental burden, socioeconomic vulnerability, historical service deficiency, and strong community concern. The project consequently represents the type of cumulative condition that environmental-justice prioritization is designed to reveal.

North Corridor transit access provides a different pattern. Its engineering contribution is lower than that of West District water-main renewal, yet its final priority is ten points higher. This change results primarily from greater social vulnerability and historical service deficit. The example demonstrates how a conventional engineering-only ranking can understate infrastructure needs when the principal problem is inadequate access rather than imminent asset failure.

5.3 Composition of Justice-Adjusted Infrastructure Priority

Graph 1: Simulated Composition of Environmental-Justice Infrastructure Priorities



The graph illustrates how different forms of need combine within the five representative projects. Eastside drainage and sewer renewal records the strongest cumulative score at 92, followed by Riverside flood protection at 86 and North Corridor transit access at 85. West District water-main renewal and Central green-street retrofit receive scores of 75 and 74, respectively.

The stacked composition is analytically important because the final score alone does not explain why a project receives priority. North Corridor's score is driven less by pure engineering condition and more by social vulnerability and historic infrastructure deficit. Eastside, by contrast, demonstrates simultaneously high need across nearly every dimension.

6. Discussion

6.1 Moving From Equal Treatment to Need-Responsive Infrastructure Investment

The first implication is that equal infrastructure decision rules do not necessarily generate equitable outcomes. A system that applies the same engineering threshold to every neighborhood may appear procedurally neutral while ignoring unequal baseline conditions. Communities that have experienced prolonged underinvestment may require substantially greater deterioration before a conventional benefit-cost or asset-condition threshold triggers action.

Environmental-justice screening addresses this problem by incorporating contextual need. Sadd and colleagues demonstrate why cumulative environmental and social conditions should be analyzed together rather than through isolated hazard indicators. Alexeeff and colleagues similarly show that screening can distinguish places experiencing higher combined burdens and help agencies direct protective activities accordingly. Infrastructure planning can adopt the same logic: a physically deteriorated asset located in an already overburdened community can reasonably receive greater urgency because failure compounds existing disadvantage.

The North Corridor example demonstrates the converse point. Infrastructure injustice may also arise from absence rather than deterioration. A neighborhood that has never received adequate pedestrian accessibility, public transport connectivity, drainage protection, or greenspace cannot always produce a high "asset failure" score because the relevant infrastructure is insufficient or missing. Historic service deficit therefore becomes a necessary complement to conventional engineering condition.

6.2 Composite Indicators Require Transparency and Local Validation

The second implication is methodological. Composite indicators are useful because they summarize complex information, but their apparent numerical precision can obscure normative decisions concerning indicator selection, transformation, weighting, geography, and missing data.

August and colleagues identify these methodological issues explicitly in cumulative environmental-health screening and emphasize indicator relevance, data quality, correlations, and sensitivity to model structure. EPA's EJSCREEN documentation similarly cautioned against interpreting screening information as definitive risk assessment and recommended supplementary local analysis. These principles should be retained when environmental-justice indicators are connected with public investment.

The EJIPI should therefore not become an opaque formula whose output is treated as self-justifying. Every project score should include an indicator profile, data-quality assessment, explanation of weighting, and geographic definition. Decision makers should be able to see whether a high score arises from multiple mutually reinforcing conditions or one unusually high variable.

Sensitivity analysis is equally important. If a project falls from first to fifteenth place after a minor change in weighting, its ranking is inherently unstable and should be interpreted cautiously. Projects remaining consistently high across reasonable weighting alternatives provide stronger evidence of robust cumulative need.

Local validation is necessary because nationally or regionally standardized datasets cannot capture every condition important to individual communities. Driver and colleagues demonstrate how locally designed environmental-justice tools can incorporate context absent from broader screening systems. Community knowledge can similarly reveal recurrent flooding, inaccessible infrastructure, unrecorded industrial nuisances, unsafe crossings, poor maintenance, or service unreliability that administrative databases do not represent accurately.

6.3 From Screening Scores to Procedurally Just Capital Planning

The third implication is that distributive prioritization alone cannot deliver complete environmental justice. A city could allocate more projects toward disadvantaged areas while designing those projects without meaningful community participation, generating displacement pressures, or failing to maintain the completed infrastructure. Environmental justice therefore includes procedural and recognitional dimensions in addition to distribution.

Community-priority evidence in the EJIPI is intended to create a direct connection between resident experience and project screening. However, assigning community participation a numerical score is insufficient. Infrastructure agencies should also provide accessible opportunities for residents to influence project design, identify unintended effects, propose alternatives, and evaluate implementation after construction.

Infrastructure benefits must also be examined carefully. Green infrastructure, transit improvements, parks, and neighborhood revitalization can deliver important environmental benefits but can also contribute to land-value increases that place pressure on economically vulnerable residents. Equity-oriented planning should therefore ask not only where infrastructure is installed but whether existing communities can remain and benefit from the resulting improvement.

Christman and colleagues demonstrate how social indicators can be integrated into green stormwater siting rather than treated as a post-project evaluation issue. Zhu, Ren, and Liu similarly show that spatial equity indices can expose discrepancies between planned infrastructure allocation and areas experiencing greater need. Hendricks and Van Zandt extend the argument by emphasizing that infrastructure vulnerability is embedded in broader patterns of unequal urban protection. The appropriate planning response is therefore not simply to “add an equity score,” but to redesign capital governance so that environmental justice influences project identification, prioritization, design, budgeting, delivery, and evaluation.

7. Conclusion

Environmental justice provides a necessary extension to conventional infrastructure prioritization because physical asset condition alone cannot represent the unequal consequences of infrastructure deficiency. Communities experience roads, drainage systems, water networks, public transport, greenspace, flood defenses, and environmental infrastructure within very different social and environmental contexts. A technically identical infrastructure problem can therefore create substantially different burdens depending on cumulative pollution, household resources, health sensitivity, mobility, historic investment patterns, and access to alternative services.

The Environmental Justice Infrastructure Priority Index proposed in this study integrates five dimensions: engineering need, cumulative environmental burden, social vulnerability, historic service deficit, and community priority. Within the synthetic analysis, Eastside drainage and sewer renewal receives the highest composite priority score of 92 because severe engineering deterioration coincides with multiple dimensions of environmental and social disadvantage. North Corridor transit access demonstrates a different but equally important outcome: despite lower engineering need, its justice-adjusted priority exceeds a technically stronger water-main project because the affected population experiences greater social vulnerability and longstanding infrastructure-access deficits.

These results are methodological demonstrations rather than measured findings from a real capital program. Environmental-justice indexes should not automatically determine funding, nor should high scores be interpreted as legal findings of discrimination or quantitative estimates of health harm.

Screening should instead identify locations and projects warranting closer attention. Final decisions require engineering evaluation, financial analysis, regulatory obligations, project dependencies, community consultation, and assessment of unintended consequences. The transparency of the scoring system is therefore as important as the resulting ranking.

Future empirical research should apply the framework to authenticated municipal infrastructure portfolios and examine whether justice-adjusted prioritization changes the spatial distribution of capital investment. Longitudinal studies could evaluate whether communities receiving higher-priority investment subsequently experience measurable improvements in service reliability, environmental exposure, accessibility, flood protection, health-supportive infrastructure, and resident satisfaction. Research should also examine weighting sensitivity, geographic scale, missing-data bias, community-defined indicators, and the risk that infrastructure improvements contribute to displacement. Environmental-justice indicators are most valuable when they do more than describe existing inequality: they should help public institutions make infrastructure decisions that progressively reduce unequal environmental burdens and unequal levels of protection.

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