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Inequity Behind Levees

The Case of the United States of America

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The Case of the United States of America

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Front cover image: U.S. Customs and Border Protection, along with multiple other agencies providing support to communities impacted by the 2017 Hurricane Harvey in TX, USA. By Donna Burton

Back cover image: Aerial shot of the 2005 flood in New Orleans, LA, USA. By U.S. Coast Guard

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About UNU INWEH

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UNU-INWEH is an integral part of the United Nations University (UNU) – an academic arm of the UN, which includes 13 institutes and programmes located in 12 countries around the world, and dealing with various issues of development. UNU-INWEH was established, as a public service agency and a subsidiary body of the UNU, in 1996. Its operations are secured through long-term host-country and core-funding agreements with the Government of Canada. The Institute is located in Hamilton, Canada, and its facilities are supported by McMaster University.

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Glossary of Abbreviations

ACS	American Community Survey
ASCE	American Society of Civil Engineers
CEJST	Climate and Economic Justice Screening Tool
CEQ	Council on Environmental Quality
Dp	Disparity Percentage
FEMA	Federal Emergency Management Agency
HUSCVs	Highly Underserved and Vulnerable Communities
LA	Leveed Area
NH	Non-Hispanic
NLA	Non-Leveed Area
NLD	National Levee Database
USACE	United States Army Corps of Engineers

Executive Summary

A member of the U.S. Border Patrol Border Search, Trauma, and Rescue Team leads survivors to a safe extraction area in the aftermath of the 2017 Hurricane Harvey TX, USA. By Alexander Zamora

Levees, built predominantly as earthen embankments, are commonly used in different parts of the world to contain, control, and divert water flow to reduce the risk of flooding. Historically, levees were built several decades ago by farmers and early settlers to protect crops and livestock in fertile flood plains without rigorous design and construction standards. However, the role of these semi-engineered levees has become unintendedly critical over time despite their considerable structural deficiencies. This role change was mainly driven by factors such as changes in land use and urbanization within levee-protected regions. Some of these levees now bear the responsibility of safeguarding infrastructure in many parts of the world, including the United States of America.

Flooding patterns are increasingly exacerbated by anthropogenic climate change, posing a significant risk to the economy, safety, and well-being of various nations. The evolving risk of flooding can disproportionately affect historically underserved and socially vulnerable communities. This makes infrastructure equity an immediate concern for responsible governments.

Current levee systems in many other parts of the world may not only be structurally inadequate, but they can also increase socio-economic inequalities. Many levee systems protect underserved communities with high levels of social and economic vulnerability to floods, natural and human-made hazards, and climate change impacts. This report by the United Nations University Institute for Water, Environment and Health (UNU-INWEH) investigates the population characteristics of the communities living behind levees in the United States of America to highlight how the social, economic, and demographic disparities of population groups behind levees can make some of these communities highly vulnerable to floods and levee failures. As the world prepares to take serious mitigation and adaptation action on climate change, such inequity and injustice implications call for a major reform in current flood management practices.

Fulfilling justice and equity will not be an achievable goal if risk mitigation and climate change adaptation strategies are designed without a comprehensive assessment of diversity in the levels of vulnerability of different population groups and communities. Thus, this report intends to highlight how and why the failure of aging human-made infrastructure under climate change and natural hazards can differently affect people with various economic, social, and demographic conditions. The investigation will be focused on the United States to underline the fact that the injustice and inequity implications of human- and nature-made hazards are significant even in the Global North and advanced economies.

The average annual economic losses due to floods in the U.S. are over $32 billion in 2020's climate and are projected to increase by over 26% by 2050 due to climate change. Earthen levees, which safeguard about two-thirds of the U.S. population, are the backbone of this nation's flood protection infrastructure. Alarmingly, with an average age of 57 years, a considerable proportion of levees in the United States are operated at substandard conditions, with many of them being at the end of their service life. Consequently, targeted strategies aimed at strengthening the aging U.S. levee system are imperative to mitigate flood risk within levee-protected communities.

Key Findings:

- Historically underserved and socially vulnerable communities are substantially over-represented in levee-protected areas at the national, regional, and state levels within the United States
- Disadvantaged communities are overrepresented behind levees in 43 states with a national disparity of 40.6%.
- Regionally, the highest disparities exist in the Northeast (57.3%), followed by the West (51.3%), Southeast (38%), Midwest (29.2%), and Southwest (25%).
- In terms of race and ethnic composition, Hispanic communities are most overrepresented in leveed areas (39.9%), followed by Native American (18.7%), Asian (17.7%), and Black (16.1%) communities.
- Residents in levee-protected communities exhibit disproportionately low educational attainment (27.8%), poverty (20.4%), and disability (5.4%) when compared to residents in communities not protected by levees.
- At the national level, Black and Asian populations exhibited disproportionate representation behind high to very high-risk levees, with disparity percentages of 74.1% and 68.8%, respectively.
- Substantial overrepresentation of Native Americans was found in areas protected by non-classified levees (82.5%), and non-accredited levees (76.7%).

This investigation is focused on the major but overlooked issue of unequal vulnerability of different groups of populations and communities to natural and human-made hazards. Conventional models of managing natural and man-made hazards that are driven by economic (mainly cost minimization) objectives ignore the diversities in the social, economic, and demographic diversities of the affected population groups. Such diversities, however, result in different levels of preparedness and adaptation capacity of population groups, which lead to different levels of vulnerability.

The analysis results quantitatively describe disparities in flood risk exposure among historically underserved and socially vulnerable communities at the state, regional, and national geographical scales in the United States. The investigation reveals that average levels of social and economic disadvantage are higher among populations in leveed areas than non-leveed areas within the United States. Specifically, the study finds that members of racial and ethnic minority groups, poor households, disabled persons, and persons without high school diplomas are overrepresented in leveed communities in comparison to non-leveed communities. While the findings are alarming, they can inform decision-makers on which communities require priority for flood mitigation and adaptation actions.

Comparison of the sociodemographic and socioeconomic composition of leveed and non-leveed U.S. communities show a substantial overrepresentation of historically underserved and socially vulnerable communities in leveed areas at the state, regional, and national levels. According to the study results, Hispanics are the most overrepresented population in leveed areas yielding a disparity percentage of 39.9%, followed by Native American (18.7%), Asian (17.7%), and Black (16.1%) communities. Communities characterized by low education, poverty, and disability exhibit a disproportionately higher presentation of 27.8%, 20.4%, and 5.4% in leveed areas across the U.S. In 43 states, disadvantaged communities are overrepresented behind levees, with a national disparity percentage of 40.6%. At the regional level, the highest disparity was observed in the Northeast (57.3%), followed by the West (51.3%), Southeast (38%), Midwest (29.2%), and Southwest (25%). Regionally, in the U.S. Midwest and Southeast, respectively, 60.6% and 40.2% more Black populations live behind levees. In the Western U.S., the largest disparities are related to people with low levels of education (40.5%) and Hispanic or Latino populations (38.6%).

A rescue team leads Hurricane Harvey survivors to a safe extraction area in 2017. TX, USA. By Alexander Zamora

This study conclusively underscores an unsettling yet pronounced inequitable disposition of vulnerable and underserved communities situated behind a critical component of the flood control infrastructure systems in the United States of America. Hence, it highlights the urgent need for developing mitigation and adaptation strategies that increase the safety of the U.S. aging levees with a serious focus on equity. It is noteworthy that given the data limitations at the federal level, the disparities found within this study likely gravitate towards a conservative underestimation of the true scale of the inequity problems behind the U.S. levees. The United States has many undocumented levees (which might be up to two times more than the documented levees) that are mainly privately owned and have lower standards in terms of construction and maintenance compared to documented federal levees. Thus, the communities behind these undocumented levees may be even more exposed to levee failures and flood risk because the likelihood of a catastrophic failure is greater potentially due to their proximity to substandard levees.

The report calls for targeted action to ensure that future flood mitigation and climate change adaptation strategies prioritize those most at risk. Incorporating principles of environmental justice into future decision-making regarding flood management and infrastructure resilience under climate change has the potential to foster a more resilient and equitable society by ensuring that policy decisions take into account the concerns of the socially and economically vulnerable populations who disproportionately face human-made and natural hazards and disasters around the world.

Despite growing public attention to the hazards posed by substandard levees and climate change as well as a much-needed increase in government investments to enhance the levee systems, there is still a lack of a practical framework that embraces environmental justice and equity considerations in developing climate adaptation strategies that relate to levee-based flood management. The methodology developed and used in this investigation is scalable and can readily be applied to examine the vulnerability of different communities living behind levees and other flood control infrastructure across the world. The insights that are obtained by similar investigations in other parts of the world can pave the way to inform efforts to identify hotspots within underserved and socially vulnerable communities that warrant prioritization for enhancing the integrity and resilience of their flood protection systems.

2017 Hurricane Harvey flooding in Texas, USA. By Lance Cpl. Niles Lee, public domain image, Flickr

Introduction

Flood in 1997 forcing a break in a levee, CA, USA. By Dale Kolke, Creative Commons License, Flickr

Levees are barriers set adjacent to streams and bodies of water to contain, control, and divert water flow to reduce the risk of nearby infrastructure flooding. Levees are built predominantly as earthen embankments, protecting communities against flooding across the globe, spanning Asia, Europe, and North America.

Historically, in many parts of the world, levees were first built several decades ago by farmers and early settlers to protect crops and livestock in fertile flood plains. These levees were simply uncompacted berms of soil built without rigorous design and codified construction practices.[1] They were initially constructed with a modest elevation just sufficient to protect farmlands. However, with the decomposition of pear soils in flood plains, the elevation levels declined necessitating an increase in the height of levees.

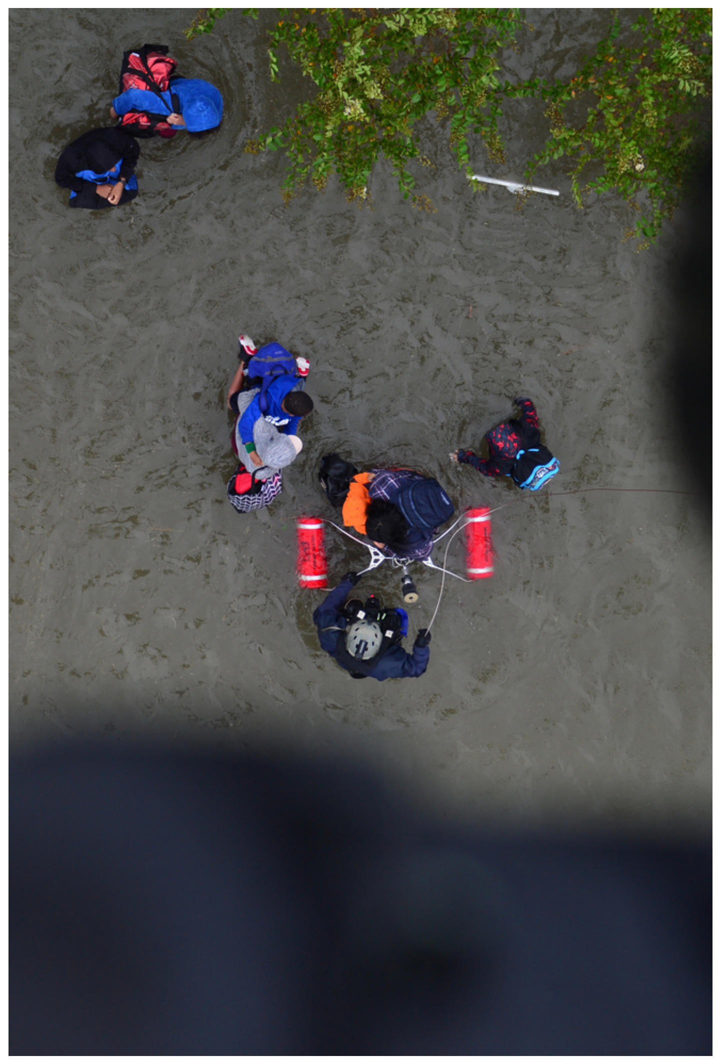
The role of semi-engineered levees around the globe has become unintendedly critical over time. The change was mainly driven by factors such as land use change and urbanization within levee protected regions. Thus, despite their considerable structural deficiencies, some of these levees now bear the responsibility of safeguarding infrastructure in many parts of the world, including the United States of America. Alarmingly, with an average age of 57 years, a considerable proportion of levees in the United States are operating at marginal conditions, described by the American Society of Civil Engineers (ASCE) as “mostly below standard, with many components at the end of their service life”.[2]

Within the United States, oversight of levees falls under the purview of the Army Corps of Engineers (USACE), with the National Levee Database (NLD)[3] recording approximately 40,000 kilometers of levee systems. Recent studies suggest that the nation’s levee network could be larger. The significance of levees within the U.S. is further highlighted by statistics indicating that approximately two-thirds of the American populace reside within tracts protected by at least one levee[2] and the NLD estimates that levees reduce risk to $2.3 trillion in property value and much of U.S. critical infrastructure systems.

The impending impacts of climate change are projected to further strain already deteriorating levee systems by accentuating both flood patterns and sea level rise.[4,5] In 2020, average flood-induced losses within the United States exceeded 32 Billion U.S. Dollars (USD).

These losses can disproportionately afflict highly underserved and socially vulnerable communities.[6,7] Projections indicate an increase of 26% in these flood-related losses by the year 2050. Moreover, the increase in projected losses are attributed solely to climate change.[7] The increasing flooding risk is further elevated by the observed sea level rise.[8,9]

Given these impending challenges, there is an emerging need to devise and operationalize flood and failure risk mitigation and adaptation strategies that prioritize underserved communities, given their heightened susceptibility to flood-related losses due to preexisting social and economic barriers. A holistic approach to climate change adaptation mandates a transdisciplinary and transectoral approach to concurrently account for and mitigate the evolving risk of flooding in a changing climate, the short- and long-term integrity of levees, and the socioeconomic conditions of leveed communities.



Survivors rescued from flood waters in the aftermath of 2017 Hurricane Harvey in, TX, USA. By Alexander Zamora, public domain image

The recent $1.2 trillion Infrastructure Investment and Jobs Act in the U.S. aims to fortify the nation's infrastructure, including flood protection systems, primarily emphasizing climate adaptation and environmental justice.[10] In parallel, the Justice40 initiative of the United States mandates the federal administration to allocate 40% of its climate and clean energy investments to communities impacted by environmental injustice (e.g., communities of color and low-income neighborhoods). Although recent interest and support for climate adaptation and environmental justice is promising, an assessment by the ASCE's Task Committee on Future Weather and Climate Extremes[11] indicates that the investment requisites for U.S. infrastructure exceed $27 trillion without climate change impacts. This suggests that the infrastructure law provides a mere 4.4% of the capital to address the dual challenges of climate change and impact inequality. Consequently, an imperative question needs to be answered: Which infrastructure projects and communities should be prioritized for allocating these limited resources?

The recent breach of the Pajaro Levee in the U.S. state of California in March 2023 has underscored, with renewed urgency, issues in equity associated with the repair and maintenance of levee systems. The community behind the Pajaro Levee was economically disadvantaged. Media reports suggest that proactive measures were not taken primarily due to cost considerations, the perceived low value of land behind the levee, and communities' lack of wealth and political influence.[12] This unfortunate event is a stark reminder of the pressing need to address equity challenges within levee systems. It also highlights the need to consider economic and non-economic realities when deciding to fund infrastructure projects.

Fulfilling justice and equity will not be an achievable goal if risk mitigation and climate change adaptation strategies are designed without a comprehensive assessment of diversity in the levels of vulnerability of different population groups and communities.

Thus, this report intends to highlight how and why the failure of aging human-made infrastructure under climate change and natural hazards can affect people with different economic, social, and demographic conditions. The investigation will be focused on the United States to underline the fact that the injustice and inequity implications of human- and nature-made hazards are significant even in the Global North and advanced economies. The report examines differences in the sociodemographic and socioeconomic composition between a spectrum of leveed-protected and non-protected U.S. communities. In addition, it analyzes the concentration of communities designated as "disadvantaged" based on the Climate and Economic Justice Screening Tool (CEJST) of the Council on Environmental Quality (CEQ) within the Executive Office of the U.S. President.[13]

1 Vahedifard, F., Azhar, M., & AghaKouchak, A. (2022). Adaptation strategies for levees under a changing climate: Toward environmental justice and equity to evolving levee risk. GEOSTRATA Magazine, ASCE, 26(3), 50–56. https://doi.org/10.1061/geosek.0000422

2 ASCE. (2021). Report card on America's infrastructure: Levees. The American Society of Civil Engineers (ASCE). Retrieved from https://infrastructurereportcard.org/wp-content/uploads/2017/01/Levees-2021.pdf

3 NLD. (2023). National levee database (NLD). U.S. Army Corps of Engineers (USACE). Retrieved from https://levees.sec.usace.army.mil

4 Moftakhari, H. R., Salvadori, G., AghaKouchak, A., Sanders, B. F., & Matthew, R. A. (2017). Compounding effects of sea level rise and fluvial flooding. Proceedings of the National Academy of Sciences of the United States of America, 114(37), 9785–9790. https://doi.org/10.1073/%20pnas.1620325114

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8 Buchanan, M. K., Oppenheimer, M., & Kopp, R. E. (2017). Amplification of flood frequencies with local sea level rise and emerging flood regimes. Environmental Research Letters, 12(6), 064009. https://doi.org/10.1088/1748-9326/aa6cb3

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10 Infrastructure Investment and Jobs Act. (2022). President Biden's bipartisan infrastructure law. Retrieved from https://www.whitehouse.gov/ bipartisan-infrastructure-law/

11 Task Committee on Future Weather and Climate Extremes. (2021). In M. R. Tye & J. P. Giovannettone (Eds.), Impacts of future weather and climate extremes on United States infrastructure: Assessing and prioritizing adaptation actions. American Society of Civil Engineers. (print): 9780784415863. https://doi.org/10.1061/9780784415863

12 Rust, S. (2023). Before disastrous flood, officials knew Pajaro River levee could fail but took no action. Los Angeles Times. Retrieved from https://www.latimes.com/california/story/2023-03-12/authorities-knew-the-levee-could-fail

13 CEQ. (2022). Climate and Economic Justice Screening Tool (CEJST), ver. 1.0, released November 22, 2022. Council on Environmental Quality (CEQ). Retrieved from https://screeningtool.geoplatform.gov CFR. (2023). 44 CFR. § 65.10. Title 44, section 65.10. Code of Federal Regulations.

Why are underserved communities more vulnerable to flood impacts?

Aerial shot of the 2005 flood, post Hurricane Katrina in LA, USA. By Lieut. Commander Mark Moran, Creative Commons License, Flickr

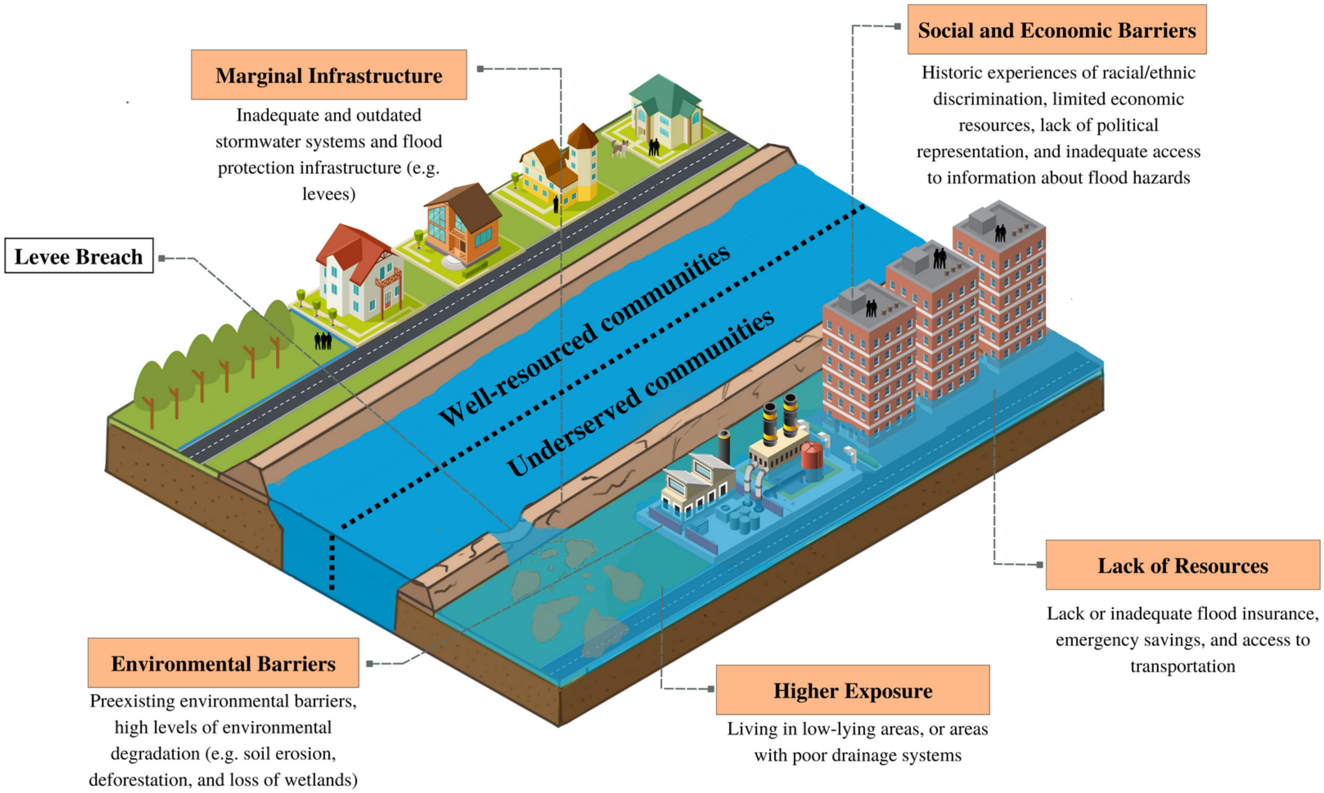

Figure 1. Primary factors elevating the risk of levee failures and flooding among historically underserved and socially vulnerable communities.

Historically underserved and socially vulnerable communities (also known as HUSVCs) include individuals from communities historically marginalized due to factors such as their racial identity, ethnic origin, heightened levels of economic disadvantage, age, gender identity, and/or disability status.[14] Many studies have examined the interplay between flood risk and social vulnerability in the United States. For instance, the evaluation of the spatial variability of vulnerability in the Sacramento Delta region in the State of California has revealed an overlap between regions of elevated flood risk and social vulnerability.[6] Another study has shown that 100-year flood zones in Miami, Florida, contain a disproportionately large share of non-Hispanic Black and Hispanic residents.[15] Examination of the contiguous U.S. has also underscored the overrepresentation of low-income communities within 100-year flood zones.[16] Similarly, some areas in the U.S. South have been identified where persons in socially and economically disadvantaged communities, especially mobile home residents and members of racial-ethnic minority groups, are exposed to a heightened risk of flooding.[17] Another study in Los Angeles, California inferred that communities with a large proportion of non-Hispanic Black residents or residents who identify with other historically disadvantaged racial and ethnic groups bore a disproportionate share of flood risks.[18] A recent study estimated that average annual flood-related losses in the U.S. reached $32 billion in 2020's climate while the economic burden disproportionately fell upon persons within underserved and socially vulnerable communities.[7]

Texas Army National Guardsmen rescue flood survivors stranded by the 2017 Hurricane Harvey flooding, TX, USA. By Sgt. 1st Class Malcolm McClendon, public domain access, Flickr

Historically underserved and socially vulnerable communities bear increased flood risk from levee breaches for the following reasons:

Social and Economic Barriers:
These communities face an array of social and economic challenges that exacerbate their flood vulnerability. These span discriminatory practices, political disenfranchisement, and limited access to timely information on impending flood risks and levee breaches.

Environmental Barriers:
These communities often reside in areas with high levels of environmental degradation spanning soil erosion, deforestation, and loss of wetlands. These factors can exacerbate the impacts of flooding.

Marginal Infrastructure:
These communities are often located in areas with dated, aging, and/or substandard infrastructure which includes inadequate stormwater management systems and levee systems.

Lack of Resources:
Resources at the disposal of these communities are often inadequate to plan for and recover from flood events. Some examples include a lack of comprehensive flood insurance, a lack of emergency funds, and limited transport availability for evacuation.

Higher Exposure:
These communities often reside in low-lying regions or areas with poor drainage capacities increasing their exposure to flooding.

These factors operate together to make the effects of levee breaches and flooding worse for individuals who belong to underserved and socially vulnerable communities. This points to the need for plans and support tailored to aid these communities. A prerequisite for equitable levee adaptation strategies involves examining the disparities that exist within leveed communities. However, so far, no studies have quantified socioeconomic and sociodemographic disparities within leveed areas on a large scale.

14 FEMA. (2021). Equity action plan. Federal Emergency Management Agency (FEMA). Retrieved from https://www.fema.gov/sites/default/files/documents/fema_equity-action-plan.pdf

15 Chakraborty, J., Collins, T. W., Montgomery, M. C., & Grineski, S. E. (2014). Social and spatial inequities in exposure to flood risk in Miami, Florida. Natural Hazards Review, 15(3), 04014006. https://doi.org/10.1061/(asce)nh.1527-6996.0000140

16 Qiang, Y. (2019). Disparities of the population exposed to flood hazards in the United States. Journal of Environmental Management, 232, 295–304. https://doi.org/10.1016/j.jenvman.2018.11.039

17 Tate, E., Rahman, M. A., Emrich, C. T., & Sampson, C. C. (2021). Flood exposure and social vulnerability in the United States. Natural Hazards, 106(1), 435–457. https://doi.org/10.1007/s11069-020-04470-2

18 Sanders, B. F., Schubert, J. E., Kahl, D. T., Mach, K. J., Brady, D., AghaKouchak, A., et al. (2022). Large and inequitable flood risks in Los Angeles, California. Nature Sustainability, 6(1), 47–57. https://doi.org/10.1038/s41893-022-00977-7

A levee in Santa Ana, CA, USA, with an industrial zone in the right, a coastal estuary in the middle and Pacific Highway in the left. By Amir AghaKouchak

Social, Economic, and Demographic Disparities as the Basis of Inequity and Injustice

California flood in 1997 forcing a break in the west levee of the Sutter Bypass, CA, USA. By Dale Kolke, Creative Commons License, Flickr

According to the U.S. National Levee Database (NLD), an estimated 36 million persons, or approximately 11% of the total U.S.A. population reside in leveed areas. However, the actual population living behind levees in the United States of America can be potentially much larger because of the existence of undocumented levees, which can be extensive. Some studies suggest that the United States potentially has 3 times more levees than what has been documented by the federal government.[19]

his UNU investigation limits its scope to studying what has been documented by the Government of the U.S. by relying on the records of the NLD.

Thus, the findings will be an underestimation of the inequity and injustice implications of the real status.

Figure 2 shows the percentage of the total population within each state that resides in leveed areas. Figure 3 illustrates the population distribution behind levees that are and are not accredited by the U.S. Federal Emergency Management Agency (FEMA). Table I-2 offers insights into the population behind levees. To better understand the inequality in the levels of vulnerability of different communities living behind levees, we need to examine the social, economic and demographic disparities of the communities living and not living behind levees.

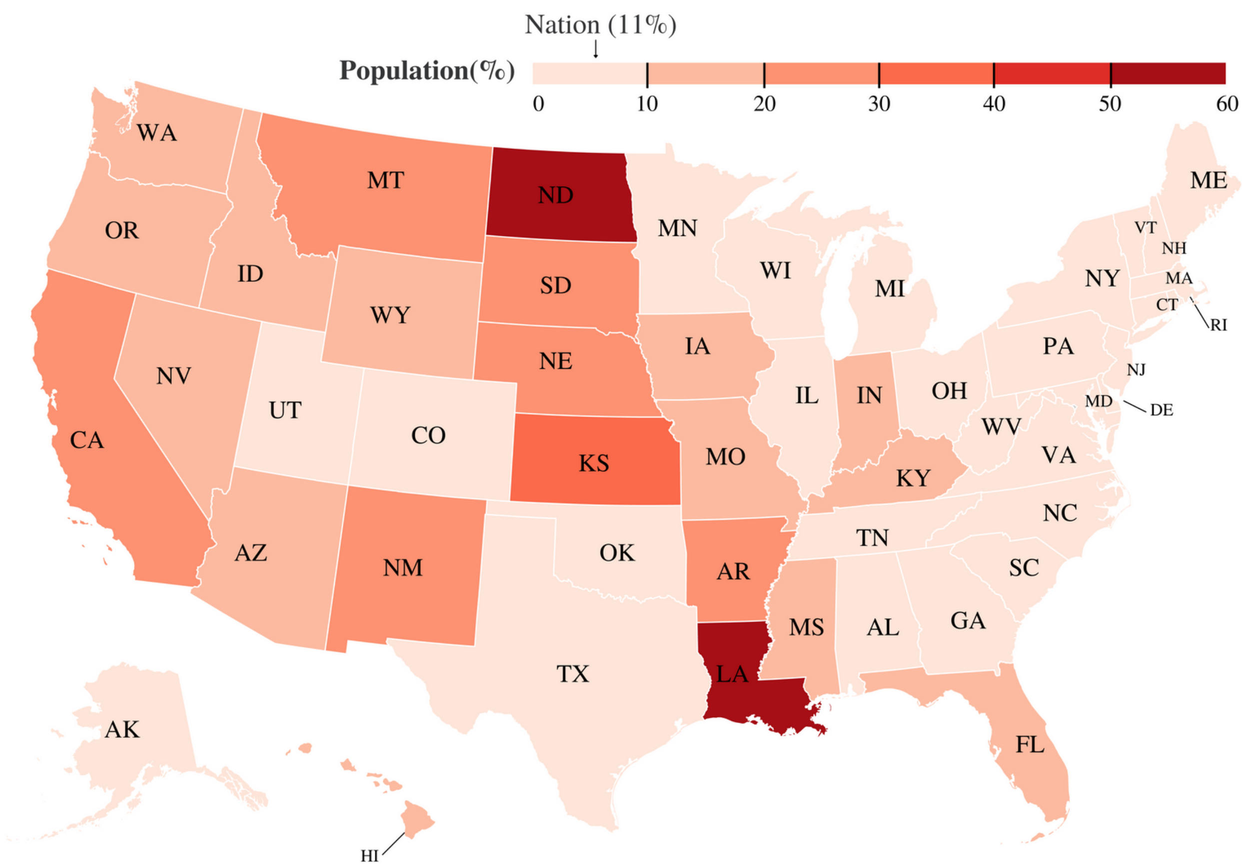

Figure 2. The percentage of population in each state residing in leveed areas

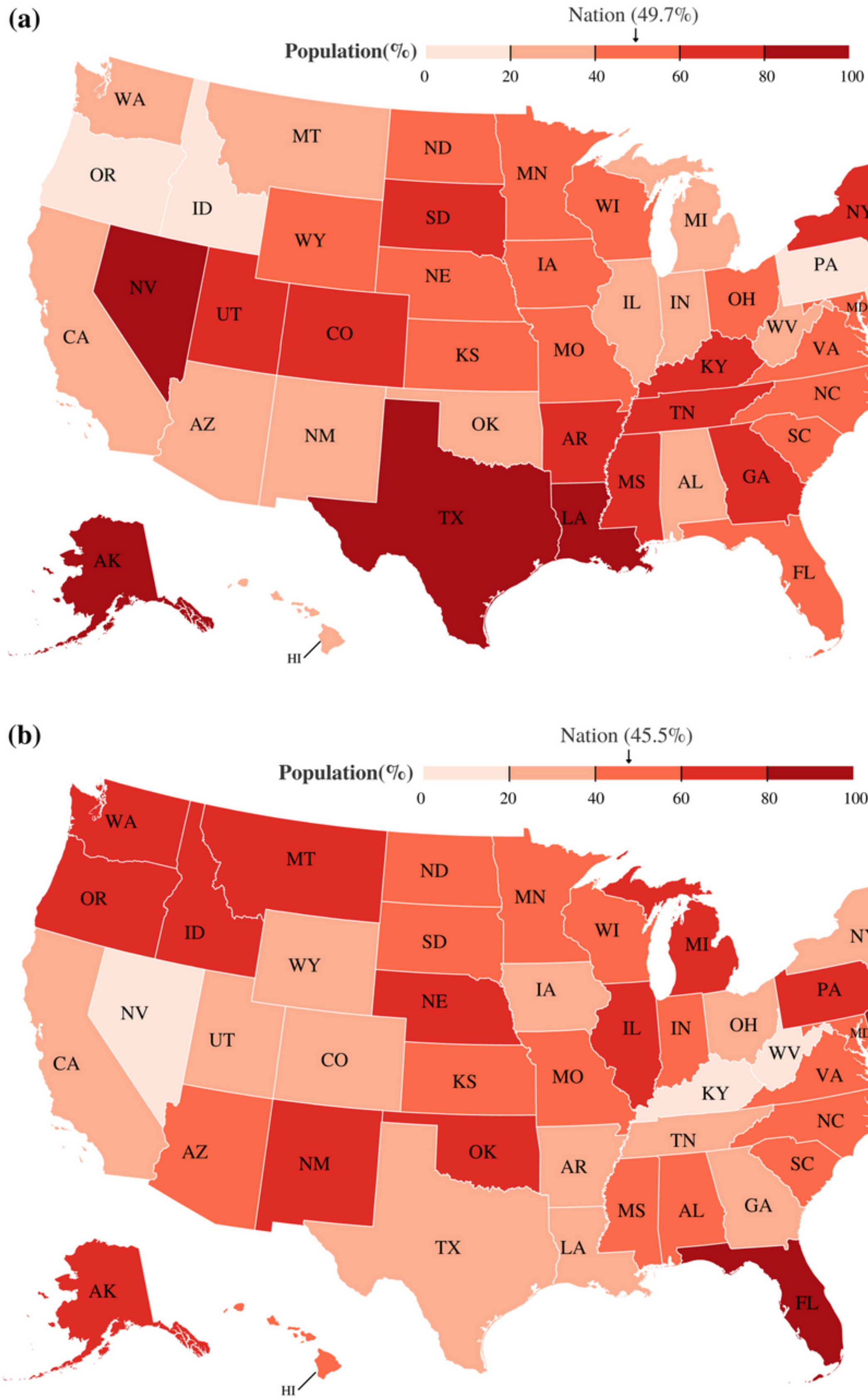

Figure 3. Comparison of the proportion of a) FEMA-accredited and b) non-FEMA-accredited levees with the proportion of populations behind these levees within each state

What is Disparity?

Disparity is defined in multiple ways and its definition often varies depending on the sector objectives of the investigates. In health, disparities are often measured by comparing rates such as difference in illness or death risks between vulnerable and less vulnerable groups.[20,21,22] Previous study on the relationship between social and economic disparities and environmental hazards use a distance-based approach. This method examines the proximity of vulnerable groups in areas with and without environmental risk sources.[23,24] Similarly, previous study on the interplay between flood risk and social vulnerability often employ spatial analysis. Typically flood layers, like the 100-year flood zones are layered over markers of social vulnerability. This helps in identifying areas of convergence of both flood risk and vulnerability.[7,16,17,25,26]

This report uses the heightened exposure to flooding as a metric to define disparity. Specifically, regions safeguarded by levees inherently bear a more pronounced susceptibility to floor-related risks compared to non-leveed areas. This definition is founded in established methodologies from previous works in this space.[7] While there is increasing interest in inequities of flood risk and vulnerability, few studies quantify the extent to which disadvantaged groups are disproportionately presented behind levees and in high flood-risk areas within the same geographical area. The disparity metric employed in this analysis helps fill this gap in prior research on differential exposure to flood risk among underserved and socially vulnerable communities. To quantify disparity for each vulnerability attribute, this study analyzes tract-level data for leveed communities for geographical level (i.e., state, region, national). Here, disparity (Dp) represents in percentage the disproportionate overrepresentation of a particular vulnerable group in leveed areas relative to non-leveed areas within the same geographic level. tract-level data for leveed communities for geographical level (i.e., state, region, national). Here, disparity (Dp) represents in percentage the disproportionate overrepresentation of a particular vulnerable group in leveed areas relative to non-leveed areas within the same geographic level.

Detailed information about the study method and analysis components can be found in Appendix I.

Socioeconomic and Sociodemographic Disparity Across the United States of America

The study examined the sociodemographic and socioeconomic disparities of the population in leveed and non-leveed areas using the 2015-2019 American Community Survey (ACS). Figure 4 shows sociodemographic disparities in leveed areas versus non-leveed areas at the state and national levels. The percentage of persons who identified as Hispanic or Latino/a (any race) is higher in leveed areas at all geographical levels (national and regional). At the national level, this group emerged as the most disproportionately represented in leveed areas. The disparity percentage for persons identifying as Hispanic is notably high at Dp = 39.9%, surpassing figures for persons who identified as non-Hispanic (NH) Native American (Dp = 18.7%), NH Asian (Dp = 17.7%), or NH Black (Dp = 16.1%). The study also examined tract-level comparison of the race/ethnicity composition of the population in leveed versus non-leveed areas at the regional and national levels (Figure 5). There is a notable presence of the NH Black population in the Midwest and Southeast behind almost all levee categories. Particularly, there is a high proportion of NH Black communities behind levees in the Midwest and Southeast rated as having a high or very high risk of eventual flooding.

Regional results further demonstrate that considerable sociodemographic disparities exist in flood risk exposure. Areas in the Southeastern region of the U.S.A. have the highest overrepresentation of Hispanics in leveed area (Dp = 60.2%). This pattern is also present in the Western (Dp = 38.6%), Midwestern (Dp = 37.4%), and Southwestern (Dp = 25%) regions of the country. In contrast, the NH Black population exhibits a notable overrepresentation in LA within the Midwestern (Dp = 60.6%), Southeastern (Dp = 40.2%), and Western (Dp = 13.6%) regions. The NH Asian population showed disparities in the Southwestern (Dp = 26.3%) and Western (Dp = 16.9%) regions whereas NH Native Americans were overrepresented in the Midwestern (Dp = 24.1%), Northeastern (Dp = 14.2%), and Southwestern (Dp = 9.5%) regions.

Nationally, Hispanic populations are the most overrepresented racial and ethnic subpopulation group in all LA. The disparity measure is more than two times higher for the Hispanic population (Dp = 39.9%) in comparison to the NH Native American (Dp = 18.7%), NH Asian (Dp = 17.7%), and NH Black (Dp = 16.1%) populations. Disparities within regions between Hispanic and non-Hispanic groups are even more pronounced than those at the national level. At the regional level, the undertaken analyses show that the amount of disproportionately higher representation in leveed communities among Hispanics is much higher in the Southeastern (Dp = 60.2%) region, followed by the Western (Dp = 38.6%), Midwestern (Dp = 37.4%), and Southwestern (Dp =25.0%) regions. The analysis also reveals that the NH Black population are overrepresented in leveed areas within the Midwestern (Dp = 60.6%), Southeastern (Dp = 40.2%), and Western (Dp = 13.6%) United States. Regional disparities in overrepresentation in levee-protected communities among the NH Asian population are primarily found within the Southwestern (Dp = 26.3%) and Western (Dp = 16.9%) United States. Moreover, NH Native American populations exhibited disproportionately higher representation in levee-protected areas within the Midwestern (Dp = 24.1%), Northeastern (Dp = 14.2%), and Southwestern (Dp = 9.5%) United States.

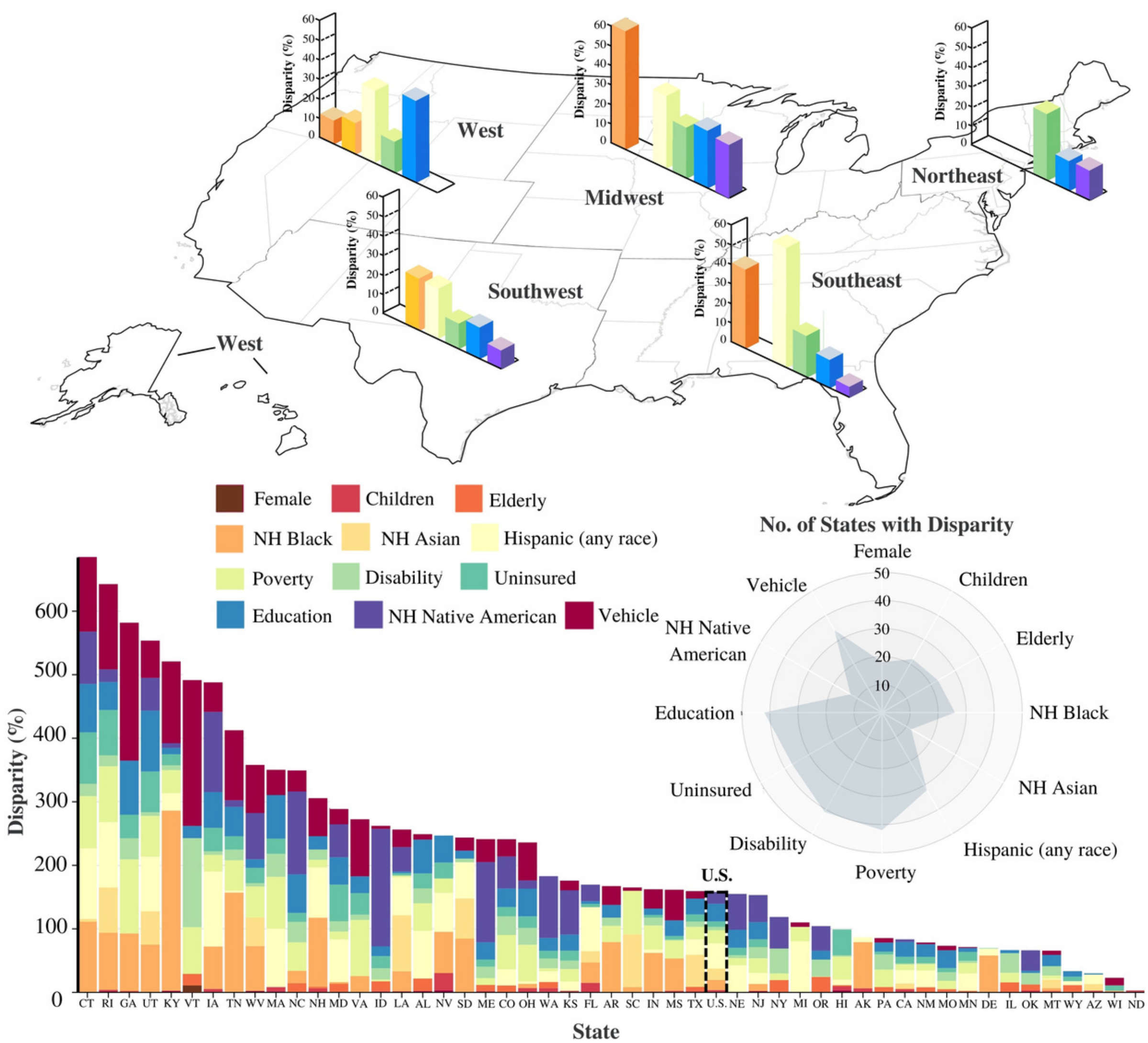

Figure 4. Disparities of levee-protected communities at the state, region, and national levels. For each attribute and geographic level (i.e., state, regional, or national), the disparity represents the percentage of the associated population disproportionately overrepresented in the levee-protected areas relative to non-leveed areas within the same geographic level.

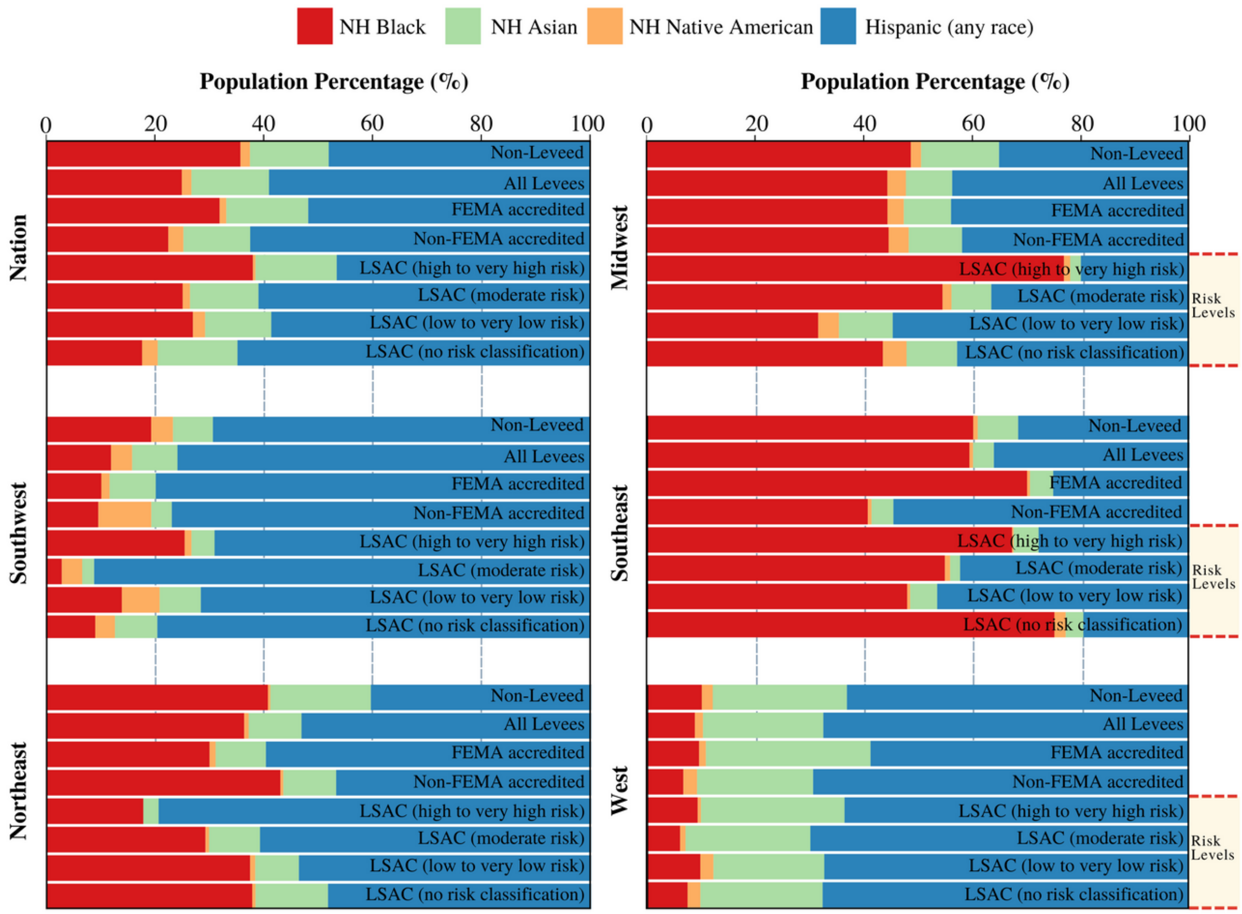

Figure 5. Tract-level compositions of race and ethnicity compositions in population of leveed versus non-leveed areas at the regional and national levels.

At the national and regional levels, levee-protected communities in the U.S.A. exhibited low levels of educational attainment and high levels of poverty. The most pronounced socioeconomic disparities nationally were found with respect to educational attainment (Dp = 27.8%) and poverty status within levee-protected communities (Dp = 20.4%). At the regional scale, notable disparities in poverty status were observed in Northeastern (Dp = 33.1%), Midwestern (Dp = 25.2%), Southeastern (Dp = 21.7%), Western (Dp = 15%), and Southwestern (Dp = 12.5%) regions. Educational disparities among levee-protected communities were highest in the Western United States (Dp = 40.5%) followed by the Midwestern (Dp = 29.4%), Southwestern (Dp = 16.2%), Northeastern (Dp = 14.1%), and Southeastern (Dp = 13.7%) regions of the country.

Across the United States, the study found that uninsured (Dp = 8.6%) and disabled (Dp = 5.4%) populations are overrepresented in leveed areas. However, subsequent analyses showed that regional disparities in health insurance coverage rates and disability prevalence within levee-protected communities deviated from their respective national averages. For instance, the share of persons residing in levee-protected communities in the Midwestern (Dp = 29.4%) and Western (Dp = 11.3%) regions exceeded the national average. Similarly, overrepresentation of disabled persons in levee-protected communities also exceeded the national average in the Northeastern (Dp = 30.1%), Southwestern (Dp = 15.2%), and Midwestern (Dp = 9.8%) regions of the United States. National and/or regional disparities in the gender or age composition of residents within levee-protected communities were limited.

For a more detailed analysis of disparities for national and regional geographical levels, the investigation delved into within-state disparities as shown in Figure 4. It is clear that historically underserved and socially vulnerable communities were predominantly overrepresented in leveed areas. Educational attainment levels and poverty status, respectively displayed disparities in 42 out of 50 states. Disparities related to disability status (41 states), health insurance coverage status (37 states), and access to personal vehicles (34 states) were also uncovered in most states. Evidence that levee-protected communities are disproportionately NH Black (26 states), elderly (23 states), or contain large child populations (22 states) was somewhat mixed at the state-level whereas relatively few states exhibited disparities related to gender (18 states), NH Native American populations (13 states), and NH Asian populations (12 states) within levee-protected communities.

Focusing in on some pronounced state-level disparities, NH Black communities in the states of Kentucky and Tennessee displayed disparities of 283.7% and 156.3%, , respectively. Households in the states of Vermont and Georgia without access to personal vehicles revealed disparities of 229.5% and 217.2% respectively. NH Native American populations in the states of Idaho, North Carolina, and Maine were overrepresented in leveed areas by 184.8%, 130.4%, and 126.2%, respectively.

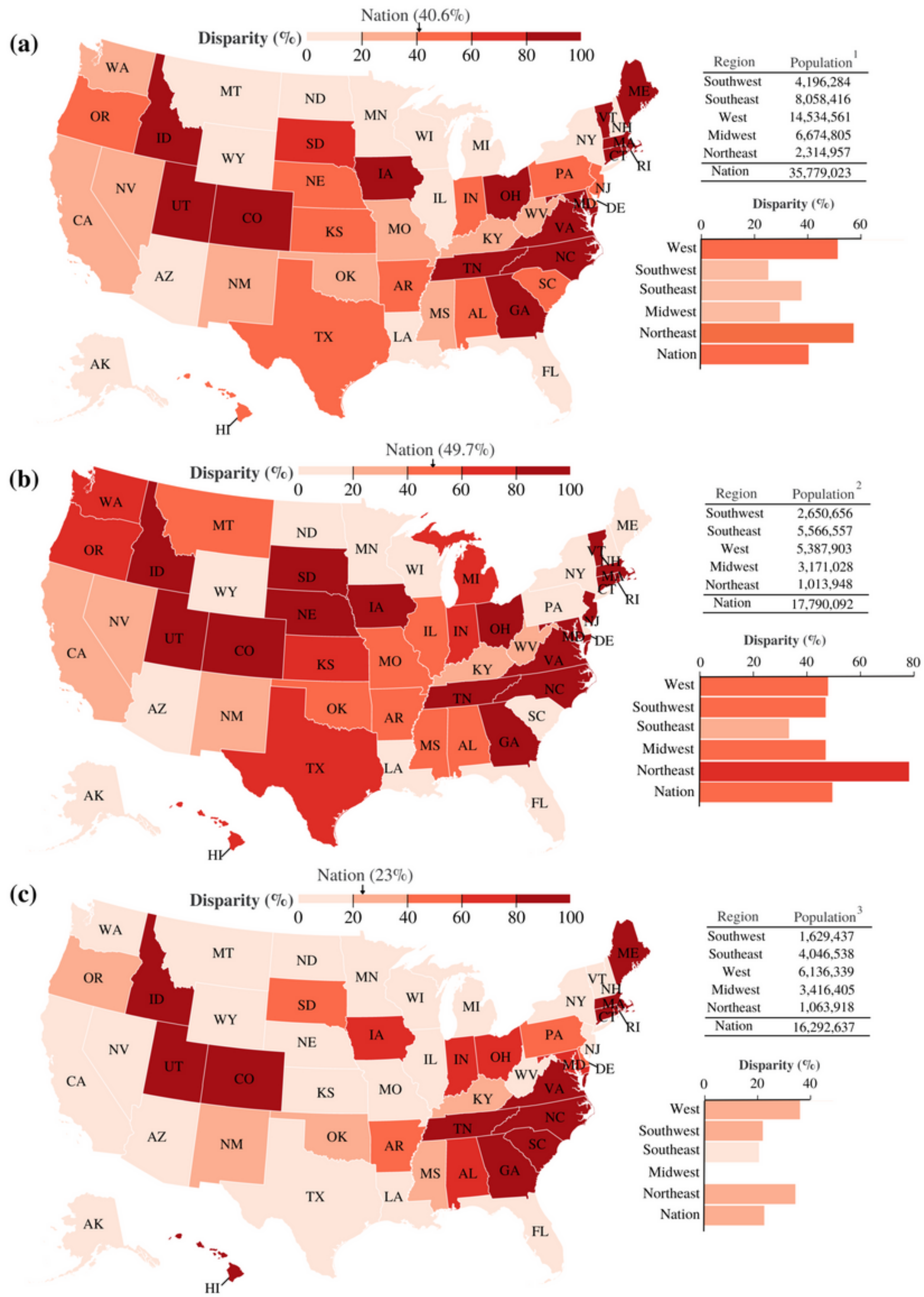

Figure 6. Disparity (%) in populations designated as "disadvantaged" using the Climate and Economic Justice Screening Tool (CEJST) between leveed vs. Non-leveed areas for different FEMA-accredited levees within the National Levee Database: (a) all levees, (b) FEMA-accredited levees, and (c) non-FEMA-accredited levees. The disparities in the figure are capped at 100% and indicate the percentage of disadvantaged populations that are overrepresented in leveed areas compared to non-leveed areas within the same geographic level.

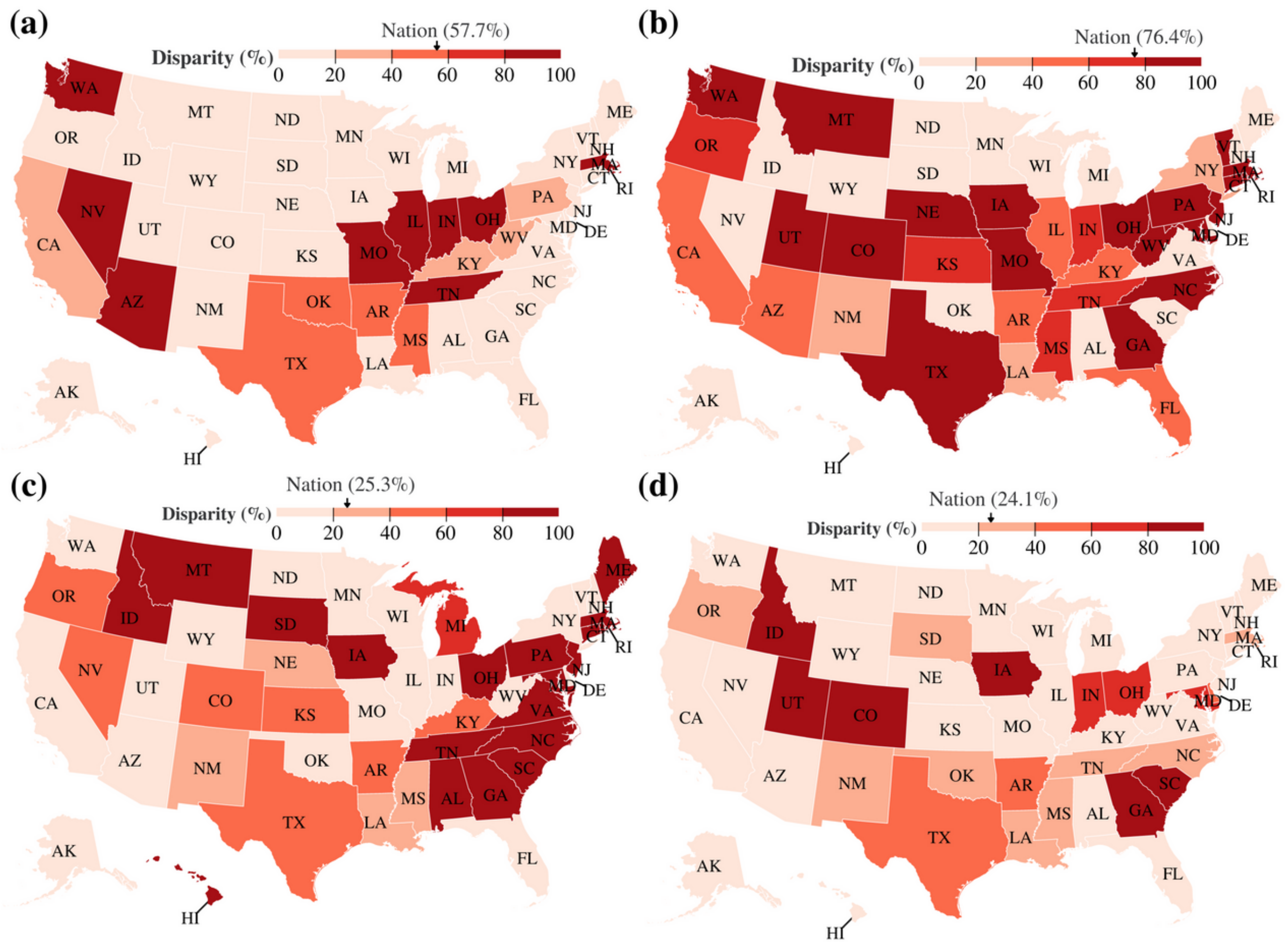

Figure 7. Disparity (%) in populations identified as "disadvantaged" using the Climate and Economic Justice Screening Tool (CEJST) in leveed versus non-leveed areas for different levee risk classifications within the U.S, National Levee Database: a) levees classified as high to very high risk, b) levees classified as moderate risk, c) levees classified as low to very low risk and d) levees with no risk classification. The disparities in the figure are capped at 100% and indicate the percentage of disadvantaged populations that are overrepresented in leveed areas compared to non-leveed areas within the same geographic level.

The State of Vermont exhibited a 140.2% disparity for disability prevalence within leveed areas while Iowa had a 117.9% disparity among Hispanic populations within leveed areas. Low-income communities were overrepresented behind major levee systems in the State of Georgia by 116.6%. In the State of Utah, communities with low levels of educational attainment in leveed areas have a disparity of 95.7%. The State of Louisiana's NH Asian community and Connecticut's population without health insurance coverage were overrepresented in leveed areas by 88.3% and 80.9% , respectively.

Disparities Based on Levee Risk Classification Levels and FEMA Certification

Beyond an analysis of socioeconomic and sociodemographic disparities across all levees, the study deepened it's scope to scrutinize disparities for a further six categories of levee-protected areas. The investigation considered areas safeguarded by a) FEMA-accredited levees, b) non-FEMA-accredited levees, c) levees categorized as high to very high risk, d) those designated as moderate risk, e) levees assessed as low to very low risk, and f) levees without a risk classification. The results illustrated in Figures 6 and 7 show the disparities existing among the population situated behind these levee categories relative to non-leveed areas.

The investigations revealed pronounced overrepresentation of Hispanic populations across all levee categories. The level of disparities was highest behind moderate-risk levees (Dp = 86.8%), followed by high to ver-

-y high-risk levees (Dp = 58.7%), levees with no risk classification (Dp = 50.7%), FEMA-accredited levees (Dp = 49.9%), non-FEMA-accredited levees (Dp = 45.3%), and low to very low-risk levees (Dp = 34.4%). Nationally, NH Black and NH Asian populations showed substantial overrepresentation behind high to very high-risk levees, registering disparity percentages of 74.1% and 68.8% , respectively. Additionally, NH Native American populations exhibited overrepresentation in regions protected by levees with no risk classification (82.5%) and non-FEMA-accredited levees (Dp = 76.7%). Disparities based on poverty levels ranged between Dp = 9.6% to 29.3% across various levee categories.

The study also examined disparities in the representation of "disadvantaged" populations within various levee categories and non-leveed areas, employing the Climate and Economic Justice Screening Tool (CEJST) of the Executive Office of the U.S. President's Council on Environmental Quality, as illustrated in Figure 6a. At the national level, communities classified as "disadvantaged" showcased a disproportionate overrepresentation in leveed areas by 40.6%. Examining disparities regionally, the Northeastern U.S. stood out at Dp = 57.3%, followed by the Western (Dp = 51.3%), Southeastern (Dp = 38%), Midwestern (Dp = 29.2%), and Southwestern (Dp = 25%) regions of the country. State-level analyses uncovered disparities in levee-protected areas for socially vulnerable groups in the vast majority of states (i.e., 43 out of 50 states). It is noteworthy to spotlight states such as Vermont with a disparity of 643.9%, Utah (Dp = 243.7%), Connecticut (Dp = 201.1%), Rhode Island (Dp = 195.2%), Georgia (Dp = 180.9%), Iowa (Dp = 166.5%), and Colorado (Dp = 134.1%).

Additionally, disparities within areas protected by FEMA-accredited levees were compared to non-leveed areas (Figure 6b). At the national scale, the disparity was found to be 49.7%. The highest regional disparity was observed in the Northeastern U.S. (Dp = 78.2%), followed by the Western (Dp = 47.8%), Midwestern (Dp = 46.9%), Southwestern (Dp = 46.7%), and Southeastern (Dp = 33.1%) portions of the country. Notably, at the state-level, the states of Vermont (Dp = 643.9%), Utah (Dp = 261.2%), Rhode Island (Dp = 245.2%), Connecticut (Dp = 199.4%), Iowa (Dp = 195.6%), Georgia (Dp = 195.1%), and Maryland (Dp = 186.1%) exhibited notably high disparities. The study also examined disparities within areas protected by non-FEMA-accredited levees in comparison to non-leveed areas (Figure 6c). Disparities were negligible when we compared results from analyses that included all levees regardless of their FEMA rating and analyses that only included FEMA-accredited levees.

At the national level, disparities were 23%. Disparities were largest in the Western U.S.A, (35.7%) followed by the Northeastern (34.4%), Southwestern (22.2%), and Southeastern (20.8%) United States. Assessing socioeconomic and sociodemographic disparities, NH Native American populations in the states of Alabama and Idaho were overrepresented by 383.6% and 353.5% , respectively. Hispanic populations exhibited the highest disparities in the states of Alabama (Dp = 236.5%) and Massachusetts (Dp = 136%) whereas the State of Tennessee exhibited notably elevated disparities among the NH Black population (Dp = 162.7%).

The analysis reveals that non-FEMA-accredited levee systems constitute 73.5% of the total levee systems, protecting 45.5% of the population behind levees. On the other hand, FEMA-accredited levee systems account for 15.9% of the total levee systems, providing protection to 49.7% of the population residing behind levees.

Additional analyses were performed to determine disparities among disadvantaged subpopulations in areas safeguarded by levees of varying risk classifications encompassing high to very high, moderate, low to very low, and no classification categories relative to non-leveed areas. Figure 7 show disparities in populations identified as disadvantaged in leveed versus non-leveed areas for different levee risk classifications, including levees classified as high to very high risk (Figure 7a), levees classified as moderate risk (Figure 7b), levees classified as low to very low risk (Figure 7c), and levees with no risk classification (Figure 7d). The disparities in the figure are capped at 100% and indicate the percentage of disadvantaged populations that are overrepresented in leveed areas compared to non-leveed areas within the same geographic level.

Findings reveal national disparity percentages (Dp) of 57.7%, 76.4%, 25.3%, and 24.1% for areas protected by high to very high-risk, moderate-risk, low to very low-risk, and non-classified levees, respectively. Examining regional disparities, high to very high-risk levees exhibited the highest disparities in the Midwest (Dp = 125.2%), Northeast (Dp = 66.4%), West (Dp = 65.3%), Southwest (Dp = 55.7%), and Southeast (Dp = 30%). In communities behind moderate-risk levees, notable disparities were observed in the U.S. Northeast (107.6%), West (80.9%), Midwest (80.5%), Southeast (69.6%), and Southwest (61.1%). Disparities for communities behind low to very low-risk and non-classified levees were particularly significant in the Northeastern (85.5%) and Southeastern (50.8%) United States, respectively.

Figure 8 presents the proportion of levees of varying categories and the corresponding proportion of the total population residing behind each type of levee. State-level examination of communities residing behind high to very high-risk levees uncover substantial sociodemographic and socioeconomic disparities. Among these, the NH Native American population in the states of Ohio and West Virginia showed disparity values of 706.1% and 143%, respectively. Within Hispanic populations, the states of Massachusetts and Washington display disparity percentages of 608.6% and 113%, respectively. Disparity percentages in NH Black populations in states like Kentucky (Dp = 430.4%), West Virginia (195.6%), and Illinois (Dp = 157.2%) were notably high. Furthermore, NH Asian populations in Louisiana exhibited disparity percentages of 192.3%. In addition, discerning disparities between communities situated behind levees without a FEMA classification and areas that are not protected by levees. Notable disparities are noticeable for NH Native American populations in the states of Florida (Dp = 631.0%), Kentucky (396.4%), Louisiana (342.7%), and Georgia (247.7%). Hispanic populations in the states of Michigan (Dp = 142%) and Tennessee (Dp = 138%) also exhibited very high disparity percentages. The NH Black population in the State of Georgia (Dp = 144.8%) and the NH Asian population in the State of South Dakota (Dp = 113.8%) also exhibited very high disparity percentages in this investigation.

To provide a comprehensive understanding of the levee systems' impact on the population, the study looked into proportion of levee systems based on their risk classification and the corresponding proportion of the levee population behind each type of levee.

Nationally, high to very high-risk levee systems constitute only 1% of the total levee systems. However, 23.7% of the population residing in leveed areas lives behind these levee systems. Similar patterns are observed for moderate and low to very low-risk levees, accounting for 4.0% and 24.7% of all levees, respectively. The corresponding proportions of the levee-protected population are 19.3% and 33.7% who are residing behind thes levee systems. Additionally, the analysis reveals that most levee systems (70.3%) are non-classified levees, yet they are responsible for protecting 45.7% of the population residing behind levees.

Disparities Based on Disadvantaged Designations

Comparative analyses at the state-level revealed that "disadvantaged" populations, broadly construed, were overrepresented between leveed areas LA and non-leveed areas NLA (Figure 9). The results show that disadvantaged populations were overrepresented in leveed areas versus non-leveed areas in 43 out of 50 states. For instance, in the State of Vermont, the entirety (100%) of the population in leveed areas was socially and/or economically disadvantaged whereas only 13.4% of the population in non-leveed areas was socially and/or economically disadvantaged. Socially and/or economically disadvantaged populations were also much more common in leveed areas (95.2%) than non-leveed areas (33.9%) of the State of Georgia. It is also noteworthy that disadvantaged groups are also overrepresented by large margins in leveed areas versus non-leveed areas within the states of Vermont, Georgia, Rhode Island, Connecticut, Maine, North Carolina, and Tennessee.

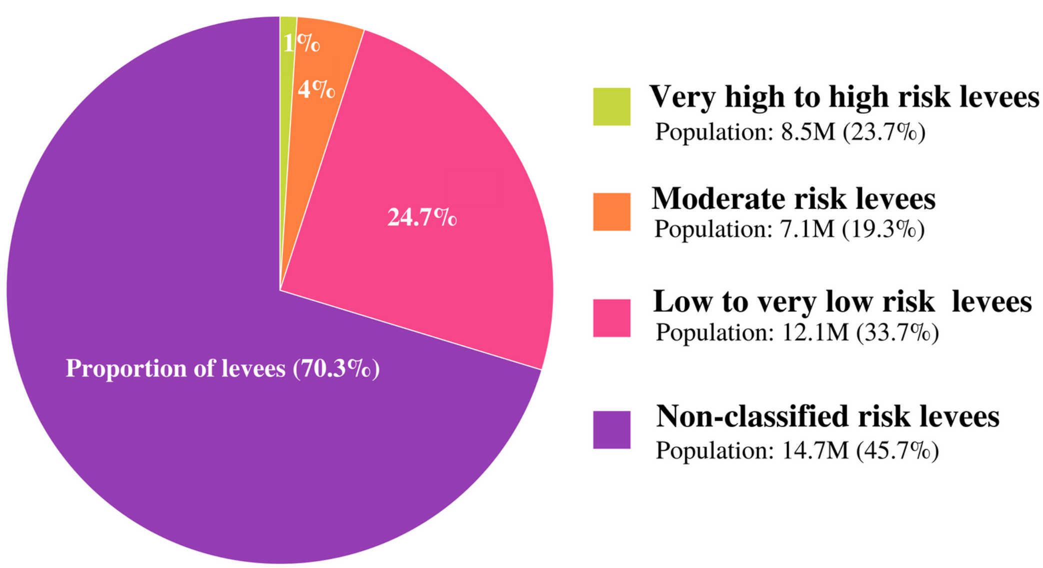

Figure 8. The proportion of levees with different risk classifications along with the proportion of the total population living behind these levees in the United States of America.

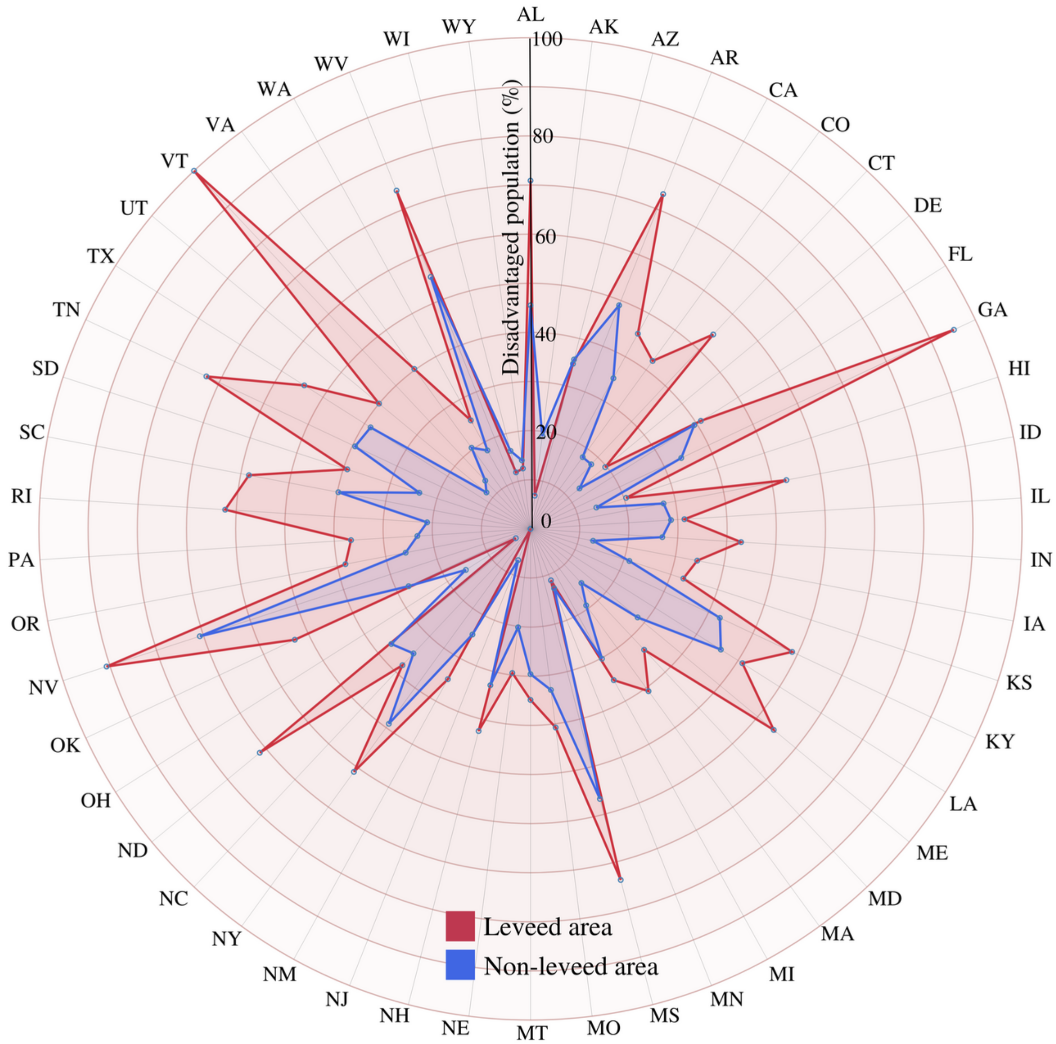

Figure 9. Comparison of population fraction (%) of disadvantaged communities in leveed areas versus non-leveed areas in different states of the United States of America.

Population density was found to be lower in leveed areas that contain large disadvantaged communities (130 persons per square kilometer) when compared to those leveed areas where the population is largely not disadvantaged (166 per square kilometer). A national disparity percentage of 40.6% suggests that disadvantaged populations exhibit disproportionately higher representation in leveed areas compared to non-leveed areas by 40.6%. The results suggest that while the non-disadvantaged people living in the leveed areas of the U.S.A. may be more densely populated, disadvantaged populations constitute a disproportionately larger proportion of the total population.

Correlation Between Race, Ethnicity, and Poverty in Leveed Areas of the United States of America

Spearman's correlation tests were performed to explore potential relationships between race and ethnicity and poverty status and residence in leveed areas of the United States of America. Table 1 shows these results at the state-level. This table generally indicate that leveed areas with a large share of self-identified Hispanics also tend to have higher levels of poverty (i.e., a positive correlation shown in red). Leveed areas with large NH Native American and NH Black populations also exhibit similar associations with poverty status. On the other hand, high-poverty areas tend to have fewer NH Asian and NH White residents across most states (i.e., a negative correlation is shown in blue). Although these analyses are highly descriptive and are not meant to imply causation, they demonstrate the multifaceted nature of the social and economic disadvantages that persons living within levee-protected communities often encounter. These findings shed light on the relationship between tract-level racial and ethnic composition and poverty status within leveed areas and provide insights for further investigation and understanding of the underlying dynamics.

Table 1. Spearman's correlations between race and ethnic identity and the proportion of individuals with incomes 200% below the U.S. federal poverty line in leveed areas by state

State	NH-Native American	NH-Asian	Hispanic (Any race)	NH-Black	NH-White
Alaska	0.20	0.44	0.46	0.37	-0.41
Alabama	0.41	-0.35	0.42	-0.39	-0.17
Arkansas	-0.04	-0.08	-0.04	0.37	-0.45
Arizona	-	-	-	-	-
California	-	-	-	-	-
Colorado	0.42	-0.30	0.65	0.35	-0.66
Connecticut	0.11	-0.37	0.65	0.42	-0.65
Delaware		0.09	0.60	0.07	-0.40
Florida	-	-	-	-	-
Georgia	0.06	-0.32	-0.43	0.39	-0.39
Hawaii	-	-	-	-	-
Iowa	0.14	0.13	0.53	0.59	-0.64
Idaho	0.38	-0.32	0.04	0.02	-0.27
Illinois	0.05	-0.26	0.03	0.54	-0.46
Indiana	0.02	-0.38	0.19	0.44	-0.44
Kansas	-	-	-	-	-
Kentucky	-	-	-	-	-
Louisiana	-	-	-	-	-
Massachusetts	0.03	-0.40	0.77	0.50	-0.73
Maryland	0.06	-0.38	-0.02	-0.22	0.20
Maine	0.63	0.77	0.32	-0.77	-0.20
Michigan	-	-	-	-	-
Minnesota	-	-	-	-	-
Missouri	0.04	-0.26	0.07	0.37	-0.37
Montana	0.46	-0.25	0.10	-0.10	-0.32
North Carolina	0.64	0.07	-0.07	0.74	-0.74
North Dakota	0.28	0.12	0.25	0.08	-0.32
Nebraska	0.04	-0.21	0.50	0.16	-0.48
New Hampshire		0.46	0.45	0.22	-0.21
New Jersey	0.08	-0.30	0.45	0.27	-0.42
New Mexico	-0.03	-0.34	0.47	-0.17	-0.59
Nevada	0.15	-0.41	0.70	0.07	-0.67
New York	0.13	-0.20	0.28	0.37	-0.34
Ohio	-	-	-	-	-
Oklahoma	0.03	-0.08	0.39	0.52	-0.65
Oregon	0.26	-0.27	0.17	-0.04	-0.15
Pennsylvania	-	-	-	-	-
Rhode Island	-0.30	-0.23	0.63	0.58	-0.55
South Carolina	-	-0.48	0.16	0.63	-0.50
South Dakota	0.45	0.12	0.59	0.40	-0.69
Tennessee	-	-	-	-	-
Texas	-	-	-	-	-
Utah	-	-	-	-	-
Virginia	-0.19	-0.49	-0.18	0.47	-0.36
Vermont	-	-	-	-	-
Washington	0.35	-0.29	0.48	0.08	-0.34
Wisconsin	-	-	-	-	-
West Virginia	-0.07	-0.32	0.08	0.22	-0.22
Wyoming	-0.09	-0.13	0.51	-0.16	-0.41
Mississippi	-	-	-	-	-

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Conclusions

A man walking on the Levee in Alviso, 2015, CA, USA. By Don DeBold, Creative Commons License, Flickr

This investigation was focused on the major but overlooked issue of unequal vulnerability of different groups of populations and communities to natural and human-made hazards. Conventional models of managing natural and man-made hazards that are driven by economic (mainly cost minimization) objectives ignore the diversities in the social, economic, and demographic diversities of the affected population groups. Such diversities, however, result in different levels of preparedness and adaptation capacity of population groups, which lead to different levels of vulnerability.

As the first step to understanding the potential inequity and injustice implications of current flood management practices, this study intended to highlight the socioeconomic and sociodemographic disparities among flood-prone populations. Using the United States of America as a case country, the study showed that the inequity and injustice implications of current flood management practices can be also significant in advanced economies of the Global North. As the world prepares to take serious mitigation and adaptation action on climate change, such inequity and injustice implications call for a major reform in current flood management practices.

Throughout history, levees have protected humans from floods in many parts of the world. But the levees that were originally designed and built without rigorous structural and safety standards for protecting farmlands and animal livestock from floods are not suitable for protecting the lives and assets of humans in densely populated areas of the modern world. To holistically address issues of equity within the context of levee systems, it is imperative to identify socially and economically vulnerable communities, which stand to benefit the most from mitigation and adaptation actions.

The analyses presented herein combined high-quality data from the U.S. Census Bureau and the National Levee Database to quantitatively describe disparities in flood risk exposure among historically underserved and socially vulnerable communities at the state, regional, and national geographical scales within the United States. The investigation revealed that average levels of social and economic disadvantage are higher among populations in leveed areas than non-leveed areas within the United States. Specifically, the study found that members of racial and ethnic minority groups, poor households, disabled persons, and persons without high school diplomas are overrepresented in leveed communities in comparison to non-leveed communities. While the findings are alarming, they can inform decision-makers on which communities require priority for flood mitigation and adaptation actions.

Ensuring flood control infrastructure resilience in a changing global climate while tackling existing inequities is a complicated, multi-faceted problem. Close collaborations among experts of different disciplines, various stakeholders, and the authorities responsible for maintaining and operating flood protection infrastructure, are required to comprehensively address this issue. Efforts to adapt to the risk of natural and human-made disasters and the impacts of climate change will not be successful unless the adaptation measures aim to address inequity in the impact of infrastructural failure on underserved and vulnerable communities. Climate adaptation of infrastructure design and operations should concomitantly consider both social and engineering factors to achieve a resilient and equitable outcome. Engagement of decision makers with the public throughout the design and implementation of mitigation and adaptation process is essential to addressing resilience and equity considerations concurrently. Incorporating principles of environmental justice into climate adaptation for flood control infrastructure ensures that concerns of vulnerable populations are included in the decision making, fostering a more resilient, equitable, and inclusive society for all.

Institutional responses, including economic assistance programs administered by state and federal agencies, play a crucial role in recovery efforts after a natural disaster occurs. It is noteworthy, however, that economic aid disbursed by such agencies (e.g. FEMA in the United States) to disaster-stricken communities can be associated with increased wealth inequality within these communities, especially among their disadvantaged groups.[27]

This study conclusively underscored an unsettling yet pronounced inequitable disposition of socially vulnerable and undeserved communities situated behind levee systems in the United States of America. Hence, it highlighted the urgent need for developing mitigation and adaptation strategies that increase the safety of the U.S. aging levees with a serious focus on equity. The study assessed the levee systems only as cataloged by the U.S. Corps of Engineers in the National Levee Database. Nonetheless, its known that the National Levee Database, despite being a comprehensive database, captures only a fractional representation of the U.S. national levee systems.[19] Given this constraint, the disparities found within this study likely gravitate towards a conservative underestimation of the true scale of the problem.

Undocumented levees are mainly privately owned and have lower standards in terms of construction and maintenance compared to documented federal levees. This suggests that the communities behind these undocumented levees may be even more exposed to levee failures and flood risk because the likelihood of a catastrophic failure is greater potentially due to their proximity to substandard levees. Yet, the study used the National Levee Database because it is the most common and reliable data source used in analyses examining issues related to the U.S. levee system.

Despite growing public attention to the hazards posed by substandard levees and climate change as well as a much-needed increase in investments by governments to enhance" the levee systems, there is still lack of a practical framework that embraces environmental justice and equity considerations in developing climate adaptation strategies that relate to levee-based flood management. The methodology developed and used in this investigation is scalable and can readily be applied to examine the vulnerability of different communities living behind levees and other flood control infrastructure across the world. The insights presented in the report pave the way to inform efforts to identify hotspots within historically underserved and socially vulnerable communities of the United States that warrant prioritization for enhancing the integrity and resilience of their flood protection systems.

Aftermath of the 2017 Hurricane Harvey in TX, USA. By Camera well travelled, Creative Commons License, Flickr

27 Howell, J., & Elliott, J. R. (2019). Damages did: The longitudinal impacts of natural hazards on wealth inequality in the United States. Social Problems, 66(3), 448–467. https://doi.org/10.1093/socpro/spy016

Appendix I-Methods and Input Data

This section describes the input data and methods used in this study to examine the inequity behind the areas protected by levees in the United States of America, caused by social, economic, and demographic disparities.

Socioeconomic and Sociodemographic Data

The study identified communities disproportionately overrepresented in the leveed areas of the United States of America. For this purpose, the 2015-2019 American Community Survey (ACS) results were used for obtaining socioeconomic and sociodemographic data at the census tract level. The ACS is a nationally representative survey conducted annually in intercensal years by the U.S. Census Bureau. The ACS collects information on various demographic, social, and economic characteristics of the U.S. population.

The study used the 2015–2019 5-year ACS sample to increase the stability of tract-level estimates for small subpopulation groups. Twelve socio-economic attributes that had been considered as vulnerability attributes by several studies (Table I-1) were selected for this analysis. These attributes include the proportion of the population in each respective tract that is female, under age 18 (children), ages 65 and older (elderly), non-Hispanic Black (NH Black), non-Hispanic Native American (NH Native American), non-Hispanic Asian (NH Asian), Hispanic (Hispanic), poverty (personal income below the U.S.A. poverty line in the last 12 months), disability (persons with any form of disability), uninsured (persons without health insurance), education (persons ages 25+ without a high school diploma), and vehicle (households without access to a personal vehicle). The analysis considered racial minority groups, including NH Hispanics, NH Blacks, NH Asians, Hispanics (any race), and NH Native Americans, as historically underserved and socially vulnerable communities (HUSVCs).

The HUSVC indicators align with those used in previous literature and are available via various screening tools used to assess social vulnerability, such as the Social Vulnerability Index by the U.S. Centers for Disease Control and Prevention.[28]

Levee Database

In addition to ACS, the United States Army Corps of Engineers' National Levee Database (NLD) was used in this study. The NLD maintains a database of levees across the United States (Figure I-1), which includes leveed areas, levee extent, levee systems, and levee length (Table I-2). At the time of this study, the NLD consisted of 6,734 levee systems spanning 33,450 km across the United States of America. The NLD defines leveed areas as, "the regions of the floodplain from which water is kept out by the levee system".[3] Figure I-1a and I-1b in shows the map of levee systems and leveed areas in Florida and Louisiana.

The NLD classifies levees into two types: FEMA-accredited and non-FEMA-accredited levees (FEMA is the U.S. Federal Emergency Management Agency). The FEMA-accredited levees are those that FEMA recognizes as meeting the requirements cited in the U.S. National Flood Insurance Program regulations.[29] Specifically, for a levee system to be considered accredited, it has to meet the following criteria:

(a)The levee meets the definition of a levee or levee system in accordance with the code of U.S. federal Title 44 CFR Section 59.10 regulations;
(b) The levee has an identifiable owner;
(c) The levee is operated, maintained, and inspected as a levee;
(d) The levee is hydraulically independent of other flood control structures; and
(e) The levee meets the full requirements stated in Title 44 CFR Section 65.10 certified by a registered professional engineer.

Table I-1. Vulnerability attributes

Group	Description	ID
Sex	Female	Female
Age	Persons aged under 18	Children
	Persons aged 65 and over	Elderly
Race & Ethnicity	Non-Hispanic African Americans	NH Black
	Non-Hispanic Asians	NH Asian
	Non-Hispanic American Indian and Alaskan Native	NH Native American
	Hispanic (any race)	HP (any race)
Socioeconomic	Persons over 25 years and having less than a high school diploma	Education
	Persons without health insurance	Uninsured
	Persons with income below the poverty level in the past 12 months	Poverty
	Households with no vehicles	Vehicle
Health	Persons with any form of disability	Disability

The rigorous screening required for a levee to be accredited ensures that its protected areas have a lower flood risk than non-accredited ones. In contrast, the non-FEMA-accredited levees do not meet the FEMA's accreditation criteria or have not undergone the accreditation process. These levees may not meet the required standards to provide adequate flood protection. Consequently, areas protected by unaccredited levees may be at higher flood risk.

The NLD also classifies levees by different risk classification levels based on the levee safety action classification (LSAC) of the U.S. Army Corps of Engineers (USACE). Levees are classified using the following factors: the probability of the levee being subjected to loading (hazard), the current state of the levee (structural vulnerability), and the consequences of levee failure (exposure). The risk levels ranges are very high, high, moderate, low, and very low. Each of these levels corresponds to the measures and actions that must be taken to mitigate the risks associated with a potential levee failure. For example, for levees classified as very high risk, the USACE recommends immediate actions to be taken to implement risk reduction measures, increase monitoring frequency, communicate risk to the public, and recommend purchasing flood insurance. The detailed actions and measures to be taken for each risk classification are summarized in Table I-3. Additionally, tracts surrounded by disadvantaged communities are considered disadvantaged if they meet an adjusted low-income threshold at or above the 50th percentile.

Disadvantaged Communities

The study used the Climate and Economic Justice Screening Tool (CEJST) of the United States President's Executive Office's Council on Environmental Quality to identify "disadvantaged communities" at the census tract level. CEJST serves as a tool for federal agencies to identify disadvantaged communities to operationalize the White House's Justice40 program. This tool identifies tracts nationwide where communities face significant burdens across various categories, including climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development. The CEJST ranks each burden using percentage thresholds where the cutoff values are at or above the 90th percentile for most burdens, while the cutoff for the low-income indicator was at or above the 65th percentile.

According to the CEJST, communities are identified as "disadvantaged" if: (a) they are in a census tract that meets the thresholds for at least one of the tool's categories of burden; or (b) they are on land within the boundaries of Federally Recognized Tribes of the United States.

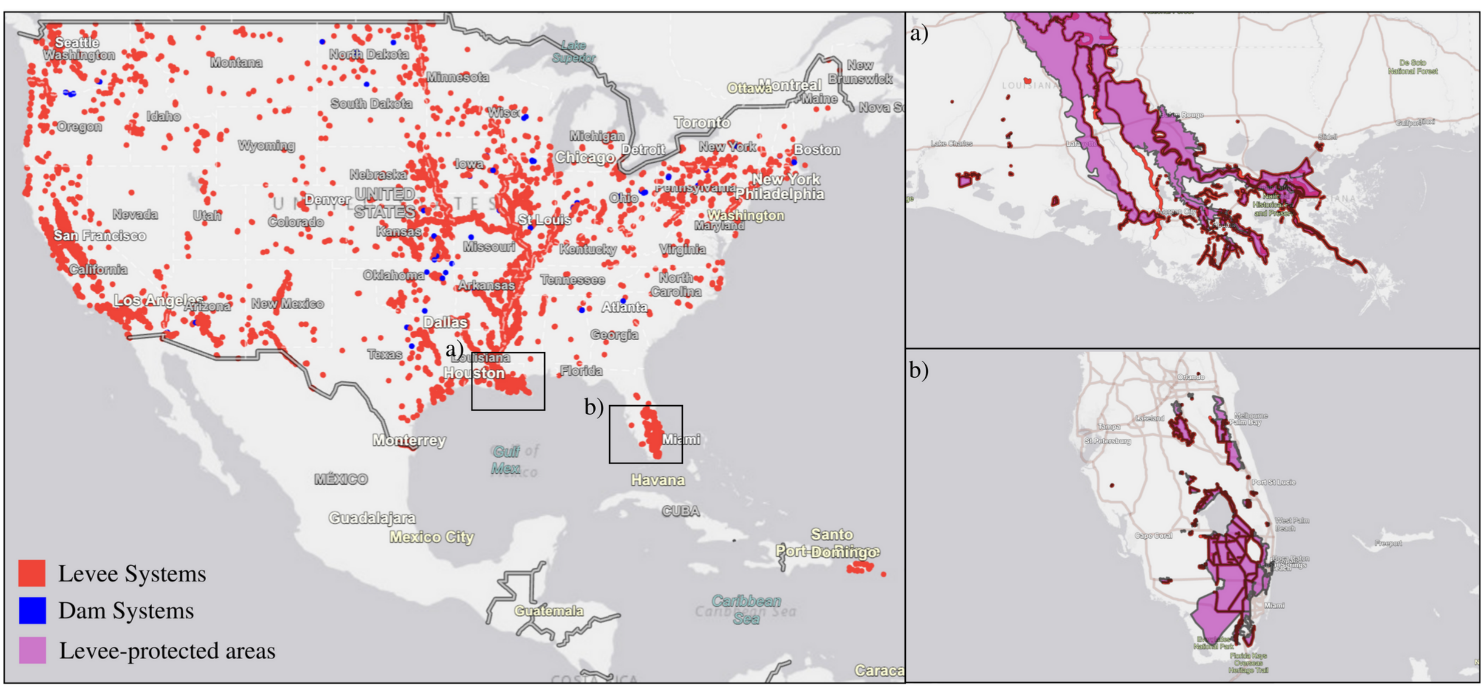

Figure I-1. The U.S. National Levee Database[3]

Disparity Calculation

To quantify disparity for each vulnerability attribute the study analyzed tract-level data for leveed communities for geographical level (i.e., state, region, national). Here, disparity (Dp) was defined in percentage as the disproportionate overrepresentation of a particular vulnerable group in leveed areas (LA) relative to non-leveed areas (NLA) within the same geographic level. For example, to determine the disparity of the NH Black population in State A, one can use the following equation:

$$D_p = \left[\frac{NH\ Black\ population\ in\ LA\ in\ State\ A - NH\ Black\ population\ in\ NLA\ in\ State\ A}{NH\ Black\ population\ in\ NLA\ in\ State\ A}\right] x100$$

In this question, the differences between the proportion of the population in leveed areas that is NH Black and the proportion of the population in non-leveed areas that is NH Black within a given state (State A) is divided by the proportion in non-leveed areas. For example, should the leveed areas of state A comprise a total population of 100, with 20 being NH Black, this would infer that 20% of the population in leveed ares is NH-Black. Conversely, if the non-leveed areas of state A houses 1000 persons of which 100 are NH Black, then the proportion of NH Black in non-leveed areas of that state is 10%. Given these proportions in leveed and non-leveed areas, the disparity percentage (Dp) using the above equation is 100%. This denotes that NH Black group is overrepresented in leveed areas by 100% relative to its representation in non-leveed areas within State A. This analysis applied this approach across varying geographical scales (state, regional, and national). The study obtained the proportions of vulnerable groups using tract-level data for both leveed areas (8107 tracts nationally) and non-leveed areas (64,772 tracts nationally) of the United States to comprehensively understand the spatial distribution of disparities for these groups within each geographical unit.

The American Flag flies above the 1993 flood that inundated homes in MO, USA. By SSGT. Paul Griffin

28 CDC. (2020). Social vulnerability index, centers for disease control and prevention, agency for toxic substances and disease registry, geospatial research, analysis, and services program. In CDC/ATSDR social vulnerability index 2020 database US. Retrieved from https://www.atsdr.cdc.gov/placeandhealth/svi/data_documentation_download.html

29 Federal Emergency Management Agency. (2020). Guidance for flood risk analysis and mapping. Retrieved from https://www.fema.gov/sites/default/files/documents/fema_levee-guidance.pdf

Table I-2. The extent of levees in each U.S. state[3]

State	Population behind Levees	Number of Levee Systems	Total Levees (km)
California	10,993,661	1705	7757.8
Mississippi	449,662	108	953.2
Florida	2,863,208	89	1686.0
Texas	2,373,075	244	1767.1
Louisiana	2,788,936	270	3156.8
Arkansas	707,155	98	3285.0
Tennessee	218,452	19	99.8
Missouri	748,581	286	2806.8
Illinois	1,069,815	559	3464.0
Arizona	1,096,517	132	470.1
Iowa	606,305	177	1190.5
Kansas	1,061,119	349	1180.3
New Mexico	490,108	128	546.3
Oklahoma	236,584	75	155.1
Washington	1,140,604	346	975.3
Oregon	501,377	214	31.5
Nevada	567,656	14	381.5
Idaho	340,692	137	125.4
Montana	234,519	76	98.9
Utah	257,864	41	78.9
Wyoming	85,169	31	92.4
Colorado	198,941	59	503.9
Nebraska	430,789	126	283.0
South Dakota	196,128	99	327.5
North Dakota	437,568	205	323.6
Minnesota	415,139	129	48.9
Wisconsin	202,112	28	140.4
Michigan	166,613	53	510.5
Indiana	788,389	106	108.1
Kentucky	566,720	34	24.4
Alabama	39,239	8	32.5
Georgia	65,616	6	274.4
Ohio	552,247	147	27.8
South Carolina	41,910	5	88.0
North Carolina	74,379	23	14.9
Virginia	131,670	19	32.8
West Virginia	111,469	18	20.4
Maryland	109,074	19	229.4
Pennsylvania	810,632	198	60.3
New York	453,270	96	30.4
New Jersey	271,056	101	5.6
Delaware	24,781	5	1.1
Massachusetts	332,109	51	2.5
Rhode Island	102,807	8	80.5
Connecticut	170,457	21	15.1
New Hampshire	25,405	6	7757.8
Vermont	4,485	1	953.2
Maine	10,881	5	1686.0
Alaska	66,784	35	1767.1
Hawaii	147,294	25	3156.8
Total	**35,779,023**	**6,734**	**33,489**

Table I-3. Levee safety action classification in the United States of America[3]

Risk Rating	Actions for levee systems and leveed areas	Risk characteristics
Very High	Implement risk reduction measures, increase monitoring, communicate risk, verify plans/maps, ensure awareness of warnings/evacuation, and recommend flood insurance.	Inundation risk from breach/malfunction, coupled with the potential for loss of life, economic, and environmental consequences, leads to very high risk.
High	Implement interim risk reduction measures, increase monitoring frequency, communicate risk, verify emergency plans and flood maps, ensure community awareness of warnings and evacuation procedures, and recommend flood insurance.	Inundation risk from breach/malfunction, coupled with the potential for loss of life, economic, and environmental consequences, leads to high risk.
Moderate	Implement appropriate interim risk reduction measures, verify current risk information, establish routine monitoring, ensure up-to-date maintenance, communicate risk, verify emergency plans and flood maps, ensure community awareness of warnings and evacuation procedures, and recommend flood insurance.	Inundation risk from breach/malfunction, coupled with the potential for loss of life, economic, and environmental consequences, leads to moderate risk.
Low	Implement routine monitoring, update risk information, conduct appropriate interim measures, ensure up-to-date maintenance, communicate risk, verify emergency plans and flood maps, ensure community awareness of warnings and evacuation procedures, and recommend flood insurance.	Inundation risk from breach/malfunction, coupled with the potential for loss of life, economic, and environmental consequences, leads to low risk.
Very Low	Continue routine monitoring, including maintenance and risk monitoring, communicate risk, verify emergency plans and flood maps, ensure community awareness of warnings and evacuation procedures, and recommend flood insurance.	Inundation risk from breach/malfunction, coupled with the potential for loss of life, economic, and environmental consequences, leads to very low risk.

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