Cumulative impacts

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Cumulative Impacts Mapping and Analysis Platform (CI-MAP) technical support document

MINNESOTA POLLUTION CONTROL AGENCY

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Foreword

The Minnesota Pollution Control Agency would like to thank all the contributions from staff, community members and external stakeholders for helping in the development of the Cumulative Impacts Mapping and Analysis Platform (CI-MAP) through rulemaking. This tool will help identify communities disproportionately burdened by multiple sources of pollution and with neighborhood characteristics that increase vulnerability to negative impacts of pollution. The following document serves as a resource to inform how this Geographic Information System (GIS), web-based mapping application was created to help users make informed decisions.

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Introduction

The Minnesota Pollution Control Agency (MPCA or Agency) is proposing new Minnesota Rules governing cumulative impacts analyses for air permit decisions in Environmental Justice (EJ) areas as directed by Minn. Stat. § 116.065. This statute defines EJ areas and requires the MPCA to adopt rules to address the cumulative impacts of pollution during the air permitting process. An EJ area is defined in statute as one or more census tracts—small, relatively permanent subdivisions of a county or city—meeting any of the following criteria:

- 40 percent or more of the population is nonwhite
- 35 percent or more of the households have an income at or below 200 percent of the federal poverty level
- 40 percent or more of the population over the age of five has limited English proficiency
- Located within Indian Country

The main purpose of this rule is to establish the conditions that implement and govern cumulative impacts analyses and permit decisions in EJ areas. This rule applies to facilities located in or within one mile of an EJ area in the counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, or Washington (Twin Cities seven-county metropolitan area) or in a city of the first class (currently only Duluth and Rochester outside the Twin Cities seven-county metropolitan area).

Minn. Stat. § 116.065 directs the MPCA to ensure the public has access to information about factors that may make people susceptible to harm from exposure to pollutants, including environmental effects on health from exposure to pollutants and social and environmental factors such as poverty, substandard housing, food insecurity, elevated rates of disease, and poor access to health insurance and medical care.

Existing environmental regulations do not provide a specific directive to consider environmental stressors or the impact that multiple pollutants from multiple sources may have on the environment and human health, and how those pollutants and sources may interact. Bringing together different factors including environmental effects on health, social and environmental factors, demographic information, and environmental information will help, in part, to better understand the cumulative impacts experienced by people across different geographic areas. The proposed rules are needed to help bring together this information and provide a consistent methodology for the MPCA, regulated parties, and Minnesotans to better understand the potential impacts to the environment and health of a requested permit action.

These rulemaking efforts resulted in the creation of the MPCA's Cumulative Impacts Mapping and Analysis Platform (CI-MAP) that brings together multiple environmental stressors to help visualize and understand the different environmental stressors experienced by Minnesotans that may make residents of an EJ area susceptible to the harm from exposure to pollution. The MPCA's CI-MAP displays 26 environmental stressors across the state and specifically in the Twin Cities seven-county metropolitan area and cities of the first class.

This technical document describes the data and analysis procedures used to build CI-MAP's environmental stressor database. The information in this document includes:

- Criteria for data inclusion as environmental stressors in CI-MAP
- Background on community engagement and research best practices implemented in support of the development of CI-MAP

- Rationale for each environmental stressor with literature reviews to show the relevance of the data to cumulative impacts
- Reproducible methods used for calculating environmental stressor values. This includes information on the data sources as well as the steps needed to generate the data that is displayed in CI-MAP

Background and methodology

Several strategies were used to gain feedback and support for this data analysis tool. The rulemaking process provided a structure to meaningfully engage with stakeholders throughout the process and ensure that differing perspectives were considered in the development of the rule. This section discusses the primary methods undertaken to help get input and develop this tool:

1. Providing **community engagement opportunities throughout the rulemaking**, especially earlier in the process. Community engagement was a crucial aspect to developing this tool. These engagement opportunities helped to prioritize what topics or issues should be in the tool, share our methods for building this resource and test the usability of the tool. Several types of engagement opportunities were provided in this process:
    a. *Co-learning community events.* These were educational events where experts from across the United States presented on their work. This project sought experts with backgrounds on creating data screening tools that consider multiple domains (environmental, public health, and socioeconomic topics) and working in governmental organizations. Two events specifically had a tie to data tools and analyses:
        i. 1/30/24 on Cumulative Impacts Programs Across the Country
        ii. 3/26/2024 on Contents of a Cumulative Impacts Analysis
    b. Working *sessions.* The working sessions provided space for facilitated, in-depth conversations and feedback on sets of questions that the agency generated. Three sessions involved the data tools and analysis:
        i. Data Indicators Working Session Part 1 on 7/10/2024
        ii. Data Indicators Working Session Part 2 on 11/13/2024
        iii. Cumulative Impacts Analysis Contents and Substantial Adverse Impacts on 5/13/2025 and 5/20/2025 (same session, in-person and virtual options)
    c. *Community engagement at existing events and focused conversations.* MPCA community engagement staff attended community events and conducted outreach to inform the public about this rulemaking. An important aspect of engagement efforts was to share progress on the data tool and integrate input on stressor data to be included in the tool. The primary approaches to community engagement are shared below, and more specific details like dates, locations or organizations involved are provided on the publicly-available rulemaking webpage within the Cumulative Impacts Statement of Need and Reasonableness (SONAR) document:[1]
        i. Tabling events - The MPCA set up information tables at community events, public spaces, and apartment complexes to speak to residents of environmental justice areas about their daily experiences with air pollution and what they want to see included or removed from air emission regulations.

[1] https://www.pca.state.mn.us/get-engaged/cumulative-impacts-rulemaking

ii. Community conversations - Members of the public who interacted with MPCA staff at tabling events or other outreach activities were contacted and invited to participate in further conversations throughout the engagement process. These conversations involved approximately 1-3 people per conversation and often lasted for 45-90 minutes. The conversations had an expansive topic focus where people could discuss their living conditions, learn about the rule, and share their opinion on the rule's development. The MPCA had more than 85 community conversations related to cumulative impacts in the seven-county metropolitan area.

iii. Interviews - The MPCA hosted 51 interviews with community members. The interviews involved 1-2 people and had a narrow topic focus. The purpose of the interviews was to gain insight into the possible effects of the rule on various stakeholders. The MPCA identified participants' knowledge base on the rule and asked for their general thoughts on the rule. The MPCA interviewer then asked participants about specific conceptual areas of the rule. When applicable, the MPCA asked participants if and how their lived experiences informs their perception and feedback of the rule.

iv. Focus groups - The MPCA hosted focus groups with stakeholders to receive feedback on the proposed rule. The focus groups were comprised of approximately 3-10 people and have a narrow topic focus. During these interactions, MPCA staff asked participants about their general thoughts of the rule and identified their knowledge base. The MPCA staff then asked participants about specific conceptual areas to hear their perception and feedback for the rule. The MPCA also asked participants to share how their lived experiences shape what they want to see incorporated into the rule.

v. Guest Workshops, Presentations, and Events Attended - The MPCA attended community events in various capacities to conduct outreach and engagement. MPCA staff attended many community events as guests to hear from the public about their neighborhoods, interests, the impacts of pollution, and their vision for the future. MPCA staff attended events hosted in environmental justice areas related to a component of the rule. These events often focus on topics that involve potential areas of study in the cumulative impacts analysis or are hosted by a demographic group that may contribute to an area being classified as an environmental justice area. The MPCA was invited to present about the cumulative impacts rule and host guest workshops at events across the state. These engagement events often involved more than 10 individuals. These presentations or workshops often took place at schools, community centers, or other accessible places.

d. *Usability testing.* The agency created a beta version of the Cumulative Impacts Analysis tool with the stressors of interest, background text on the topics, as well as the ability to look at specific areas and download a PDF report that included all of the stressors for a given census tract.

2. **Research best practices** from existing cumulative impact and environmental justice data tools. Our agency researched different data screening tools from across the country as well as relied on academic research. These tools provided foundational documentation and methodology to incorporate in Minnesota's Cumulative Impacts Analysis tool. In particular, the Minnesota Pollution Control Agency relied upon existing work from:

   a. California's Office of Environmental Health Hazard Assessment (OEHHA) CalEnviroScreen
   b. The University of Connecticut's Environmental Justice Screening Tool
   c. Colorado's Department of Public Health & Environment EnviroScreen
   d. Maryland's Department of Environment MDEnviroScreen

e. Massachusetts's Department of Environmental Protection Cumulative Impact Analysis in Air Quality Permitting
f. Michigan's Department of Environment, Great Lakes and Energy MiEJScreen: Environmental Justice Screening Tool
g. New Jersey's Department of Environmental Protection EJMAP
h. Pennsylvania's Department of Environmental Protection PennEnviroScreen
i. Washington's Department of Health Environmental Health Disparities Map

Table 1: State data mapping tools for best practices research

State	Name of tool	Web link
California	CalEnviroScreen	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40
Connecticut	Environmental Justice Screening Tool	https://connecticut-environmental-justice.circa.uconn.edu/
Colorado	EnviroScreen	https://cdphe.colorado.gov/enviroscreen
Maryland	MDEnviroScreen	https://mde.maryland.gov/Environmental_Justice/Pages/MDEnviroScreen.aspx
Massachusetts	Cumulative Impact Analysis in Air Quality Permitting	https://www.mass.gov/info-details/cumulative-impact-analysis-in-air-quality-permitting
Michigan	MiEJScreen: Environmental Justice Screening Tool	https://www.michigan.gov/egle/maps-data/miejscreen
New Jersey	EJMAP	https://dep.nj.gov/ej/ejmap-data-documentation/
Pennsylvania	PennEnviroScreen	https://www.pa.gov/agencies/dep/public-participation/office-of-environmental-justice/pa-environmental-justice-areas
Washington	Environmental Health Disparities Map	https://doh.wa.gov/data-and-statistical-reports/washington-tracking-network-wtn/washington-environmental-health-disparities-map

Reviewing existing state data tools helped staff identify data and justification for stressors; helped staff to test functionality and accessibility; and helped stakeholders provide usability feedback.

3. Work with the **State of Minnesota's staff with technical scientific expertise** to create stressors that reflect the needs of this rulemaking using a mixed-methods research approach.
4. Work with IT developers to create a web-based map application to view the environmental stressors database and meet the needs of the Cumulative Impacts law.

Stressors: descriptions and analysis

Criteria for environmental stressor inclusion

The Minnesota Pollution Control Agency identified 26 relevant environmental stressors based primarily on the following criteria:

1. *Clear meaning and balancing indicators across multiple impact topics* - Once specific data topics were identified based on the above methodology, the MPCA ensured there were a similar number of indicators across the data topics. Each of the indicators represents a unique stressor. Part of the process (still to be determined) will be adding up indicators to determine substantial adverse impact. Having uneven representation across topics would skew the analysis.

2. *Geographic spread* - Indicators are publicly available for all areas covered by the rule, including all Minnesota First Class Cities (cities with population > 100,000). Making a standardized and transparent process needs to have the same set of data available for all areas covered by the rule.
3. *Geographic scale/size* - Indicators are available or can be aggregated to census tract.
4. *Timeliness of publicly available data* - Indicators should be able to be updated regularly. Specific data years used will be made available in CI-MAP itself, as these will change when updates are made to CI-MAP.
5. *Historic pollution burden* - Indicators should capture past pollution burden when possible. The legislation explicitly calls out past levels of pollution, recognizing that communities may carry long-term health burdens from historical industrial activity and contamination events.
6. *Current pollution burden timeframe* - Indicators will use the most recent data available and consider "current" as encompassing up to the most recent five years of data available. Availability and update schedule will be posted on the public data tool. Some data take longer than others to be made publicly available, but we will still want to use the most recent and work toward most timely years. As an example, data on asthma emergency room visits can take more than a year to get to the Department of Health and then have to be combined over multiple years to share total numbers by zip code without compromising privacy rules.
7. *Indicator calculations* - Indicators should follow established calculations and methods, as possible and available. Using established and even nationally consistent measures helps lend credibility and reproducibility to analysis, which are important for comparing data over space and time, with other jurisdictions, and ensuring high quality data inputs for implementing cumulative impacts analysis. For example, the U.S. Environmental Protection Agency (EPA) tracks particle pollution levels as an annual and daily average so we would use the same calculation for high local air pollution levels.
8. *Relevance to human health* - The legislation specifies that the rule should pertain to cumulative impacts on human health, rather than broader impacts to the environment.

Methods for determining adverse impacts and adverse cumulative stressors

This section describes how environmental stressors are evaluated to determine whether a community is experiencing adverse impacts. The analysis relies on two types of benchmarks. A *reference value* is a stressor-specific standard or benchmark used to assess whether there are adverse impacts for a community for a given environmental stressor. When a reference value does not exist for an environmental stressor, a *geographic point of comparison* is used. The geographic point of comparison is defined as the lower of the state or county median (50th percentile) for a given environmental stressor.

Individual stressors for a given community (census tract) are considered *adverse environmental stressors* when their values exceed the reference value or exceed the geographic point of comparison. All identified adverse environmental stressors are then summed to calculate the *combined stressor total*, which reflects the overall environmental burden in a census tract. If this combined stressor total is greater than the geographic point of comparison, the census tract is determined to be experiencing *adverse cumulative stressors*.

While this section provides a broad overview of how adverse impacts and adverse cumulative stressors are determined, we strongly encourage readers to look at formal definitions in the Cumulative Impacts rule for reference values, geographic point of comparison, adverse environmental stressors, combined stressor total, and adverse cumulative stressors (see Minn. R. 7007.6010).

Data processing and software tools

Data preparation, processing, and spatial analyses were done using R, Python, and ESRI products to develop the environmental stressor database.

Environmental stressor data included in CI-MAP

Table 2: All environmental stressors included in CI-MAP. Details on data sources and preparation for every environmental stressor can be found in later sections of this document.

Stressor category	Environmental stressor	Source	Data Product
Air pollution	Cancer risk	MPCA	Minnesota Risk Screening (MNRISKS)
	Fine particulate matter	EPA	AirNow-Tech
	Ground-level ozone	EPA	AirNow-Tech
	Non-cancer risk	MPCA	Minnesota Risk Screening (MNRISKS)
Land pollution	Cleanup sites	MPCA	Remediation program data
	Solid waste	MPCA	Solid Waste program data
Water pollution	Impaired waters	MPCA	Water Quality program data
	Industrial stormwater runoff	MPCA	Industrial program data
	Groundwater threats	MPCA, MDH, MDA	Groundwater Contamination Atlas, County Well Index, Township Testing Program
Traffic factors	Populations living near busy roads	MNDOT	Traffic Forecasting and Analysis Data products
	Traffic density	MNDOT	Traffic Forecasting and Analysis Data products
Social factors	Age of residents	U.S. Census Bureau	American Community Survey (ACS)
	Cost-burdened households	U.S. Census Bureau	American Community Survey (ACS)
	Income inequality	U.S. Census Bureau	American Community Survey (ACS)
	Lack of educational attainment	U.S. Census Bureau	American Community Survey (ACS)
	People with disabilities	U.S. Census Bureau	American Community Survey (ACS)
	Unemployment	U.S. Census Bureau	American Community Survey (ACS)
Public health factors	Asthma prevalence	CDC	PLACES database
	Childhood lead exposure	MDH	Minnesota Environmental Public Health Tracking Program
	Heart disease prevalence	CDC	PLACES database
	Lack of health care coverage	U.S. Census Bureau	American Community Survey (ACS)
Neighborhood factors	Food insecurity	CDC	PLACES database
	Impervious surfaces	USGS	National Land Cover Database (NLCD)
	Lack of recreational open space	USGS	PAD-US database
	Lack of tree canopy	USGS	National Land Cover Database (NLCD)
	Permitted sites and other agency interests	MPCA	MPCA Regulated Universe data

Air pollution

Air pollution environmental stressors are determined using a mix of computer models and real-world air quality data to understand how communities may be affected. These indicators include modeled estimates of cancer and non-cancer health risks, as well as the number of unhealthy days for fine particle pollution (PM2.5) and ground-level ozone. Together, they show different ways that air pollution can make communities more susceptible to being harmed by additional pollution exposure.

Cancer risk

Description: The cancer risk score from air pollution sources is provided by the MPCA Minnesota Risk Screening (MNRISKS) model. Air pollution can easily travel through the environment from diverse sources and negatively impact public health. This stressor examines both permitted facilities and many smaller, scattered sources of pollution, such as cars and trucks on the road, off-road vehicles, and various others that can contribute to higher rates of cancer in communities. A health benchmark is a calculated health-based guideline. It represents an estimated level of air pollution below which harmful effects are less likely, even for sensitive populations, over a lifetime of exposure. A score below 1 is good; it means air pollution is below health benchmarks. A score at or above 1 means pollution is above health benchmarks. This does not necessarily mean that health effects are occurring there, but it does compel further analysis.

Indicator Measurement Units: Estimated cancer risk score

Rationale: Minnesota's MNRISKS data modeling tool provides a holistic evaluation of how communities are impacted from various sources of air pollution, such as local neighborhood sources (building heating, bonfires, lawn equipment, gas stations and more), transportation sources, industrial sources, and fires. Exposure to air pollution at high enough levels can increase the average amount of cancer cases in a community, and this stressor provides an estimated rate of cancer cases. In Minnesota, it also has been found that certain communities, such as low-income communities, Indigenous peoples, and people of color, can be disproportionately exposed to higher levels of air pollution.

Stressor Value Calculation Method:

- Cancer risk estimates were obtained from the Minnesota Pollution Control Agency's MNRISKS model (https://www.pca.state.mn.us/sites/default/files/aq9-29.pdf). The model provides estimates at the census block group level.
- Census tracts were assigned the highest cancer risk value among block groups within each tract.
- Cancer risk estimates use a cancer risk value of 1 as the reference value to determine status of a census tract as an adverse stressor.

Fine particulate matter

Description: Fine particulate matter measures the total number of days in a 10-year window when fine particle air pollution ($PM_{2.5}$) was unhealthy, with an air quality index above 100. Particulate matter pollution is measured continuously to determine if communities will be impacted by exposure. This measurement is defined by the 24-hour average. The measurement threshold is 35 micrograms per cubic meter ($\mu g/m^3$).

Indicator Measurement Units: Number of days with $PM_{2.5}$ concentration measurements above air quality index of 100

Rationale: Fine particulate matter has several public health impacts from short and long-term exposure. Due to their small size, particles can be inhaled, travel to the lower respiratory tract, cross the lung-blood barrier, and can easily go through the blood to any organ and system in the human body.[2] Short-term negative health outcomes can include pneumonia, irregular heartbeat, heart attacks, and death. Longer term health impacts are even more consequential, including increased risk of Alzheimer's disease, asthma, autism spectrum disorder, chronic kidney disease, lung disease, dementia, depression, ischemic heart disease, lung cancer, liver cancer, colorectal cancer, breathing problems, stroke, type 2 diabetes, Parkinson's disease and death.[3]

Stressor Value Calculation Method:

- Data for days exceeding the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ were downloaded from EPA's AirNow Tech https://www.airnowtech.org/.
- At each monitoring site, we counted the number of days over a ten-year period when $PM_{2.5}$concentrations exceeded the relevant NAAQS. Each census tract was then assigned the result from the nearest monitoring station.

Ground-level ozone

Description: Ground-level ozone measures the total number of days in a 10-year window when ozone concentration measurements were unhealthy, with an air quality index above 100. Ozone pollution is measured continuously to determine if communities will be impacted by exposure to this pollution. This measurement is defined by the maximum 8-hour concentration over the day. The measurement threshold is 71 parts per billion (ppb).

Indicator Measurement Units: Number of days with ozone concentration measurements above air quality index of 100

Rationale: The effects of ozone exposure on respiratory health have long been studied. Both experimental and observational studies have demonstrated ozone's ability to decrease lung function, incite allergic and inflammatory responses, and promote airway hyperreactivity.[4] Studies have also associated chronic ozone exposures with the onset of asthma and long-term lung function reduction.[5] Furthermore, ozone exposure has been linked to increased mortality, hospitalizations, primary care doctor visits, and school absences.[6]

Stressor Value Calculation Method:

- Data for days exceeding the National Ambient Air Quality Standards (NAAQS) for ground-level ozone were downloaded from EPA's AirNow Tech https://www.airnowtech.org/.

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[2] Minnesota Department of Health. 2024. Air Quality in Minnesota, Fine particles. https://data.web.health.state.mn.us/air_pm. U.S. Environmental Protection Agency. (2024b). Learn about Lead. https://www.epa.gov/lead/learn-about-lead.

[3] American Lung Association. (2024b). Particle Pollution. https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/particle-pollution. Lin, C.-k. C., Yuan-Ting; Lee, Fu-Shiuan; Chen, Szu-Ta; Christiani, David. (2021). Association between exposure to ambient particulate matters and risks of autism spectrum disorder in children: a systematic review and exposure-response meta-analysis. Environmental Research Letters, 16(6). https://doi.org/10.1088/1748-9326/abfcf7. Rojas-Rueda, D., Morales-Zamora, E., Alsufyani, W. A., Herbst, C. H., AlBalawi, S. M., Alsukait, R., & Alomran, M. (2021). Environmental Risk Factors and Health: An Umbrella Review of Meta-Analyses. Int J Environ Res Public Health, 18(2). https://doi.org/10.3390/ijerph18020704.

[4] U.S. EPA. 2013. Final Report: Integrated Science Assessment of Ozone and Related Photochemical Oxidants. EPA/600/R-10/076F. Washington, DC U.S. EPA. http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492.

[5] American Lung Association. (2024a). Ozone. https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/ozone#how

[6] Basu et al. A Time-Stratified Case-Crossover Study of Ambient Ozone Exposure and Emergency Department Visits for Specific Respiratory Diagnoses in California (2005–2008), Environmental Health Perspectives, Volume 124, Issue 6, 2015.

- At each monitoring site, we counted the number of days over a ten-year period when ozone concentrations exceeded the relevant NAAQS. Each Census tract was then assigned the result from the nearest monitoring station.

Non-cancer risk

Description: The non-cancer risk score from air pollution sources is provided by the MPCA MNRISKS model. Air pollution can easily travel through the environment from diverse sources of pollution to negatively impact public health. This stressor examines both permitted facilities and many smaller, nonpermitted and dispersed sources of pollution, such as cars and trucks on the road, off-road vehicles, and dozens of categories of nonpoint sources, those that cannot be traced to a specific source. All these can contribute to higher rates of poor health. A health benchmark is a calculated health-based guideline. It represents an estimated level of air pollution below which harmful effects are less likely, even for sensitive populations, over a lifetime of exposure. A score below 1 is good; it means air pollution is below health benchmarks. A score at or above 1 means pollution is above health benchmarks. This does not necessarily mean that health effects are occurring there, but it does compel further analysis.

Indicator Measurement Units: Estimated non-cancer risk score

Rationale: Minnesota's MNRISKS data modeling tool provides a holistic evaluation of how communities are impacted from various sources of air pollution, such as local neighborhood sources (building heat, bonfires, lawn equipment, gas stations and more), transportation sources, industrial sources, and fires. Several negative health impacts other than cancer have been found from exposure to air toxics, such as cardiovascular diseases, respiratory diseases, irritation (watery eyes or a scratchy throat), nerve damage, organ damage, and birth defects. In Minnesota, it also has been found that certain communities, such as low-income communities, Indigenous peoples, and people of color, can be disproportionately exposed to higher levels of air pollution.

Stressor Value Calculation Method:

- Non-cancer risk estimates were obtained from the Minnesota Pollution Control Agency's MNRISKS model (https://www.pca.state.mn.us/sites/default/files/aq9-29.pdf). The model provides risk estimates at census block group level.
- Census tracts were assigned the highest cancer risk value among block groups within each tract.
- Non-cancer risk estimates use a non-cancer risk value of 1 as the reference value to determine status of a census tract as an adverse stressor.

Land pollution

Land pollution environmental stressors are assessed using information about contaminated sites and solid waste facilities to understand how communities may be affected. These indicators include the presence and severity of cleanup sites, as well as the number and type of nearby solid waste facilities and their levels of activity. Together, they reflect different ways that land-based pollution and waste management can make communities more susceptible to being harmed by additional pollution exposure.

Cleanup sites

Description: The MPCA Remediation Division works to protect human health and the environment by investigating pollution and responding to pollution caused or potentially caused by petroleum or hazardous substances. These cleanup sites are under the oversight of these MPCA programs: Petroleum, Brownfields, Superfund, Closed Landfill, Resource Conservation and Recovery Act (RCRA), Integrated Remediation, and Emergency Response.

Indicator Measurement Units: Pollution cleanup sites percentile

Rationale: At these cleanup sites, the remediation programs investigate and evaluate risks by gathering data from groundwater, surface water, soil, and air to define the extent and magnitude of pollution and to evaluate all potential ways that humans may be exposed to pollution. When humans are exposed to pollution, some of the impacts can be observed through low birth weights, increases in liver disease, increased blood lead levels in children, as well as cognitive and behavioral problems.[7] Action is taken by the MPCA to protect human health and the environment when pollution is found above health-based guidance values and there is a way for humans to be exposed.

More information on cleanup sites can be found on the MPCA's Remediation and redevelopment website, https://www.pca.state.mn.us/air-water-land-climate/remediation-and-redevelopment.

Stressor Value Calculation Method:

- Obtained list of remediation sites from internal MPCA database
- Allocated points based on cleanup site, type and activity. The breakdown of points was by facility type and status to indicate different levels of severity and impact to human public health outcomes:
  - Site Assessment sites received 0 points for closed, completed or inactive/retired; 6 points for active/existing.
  - Brownfield and Superfund sub-area sites received 1 point for closed, completed or inactive/retired; 9 points for active/existing.
  - Superfund, Emergency Response, Integrated Remediation, and RCRA Remediation sites received 2 points for closed, completed or inactive/retired; 12 points for active/existing.
  - Closed Landfill Program facility sites received 12 points.
- After point assignment, a buffer analysis was run to identify where cleanup sites intersect with census tracts. Census tracts intersecting within a 250-meter buffer around a cleanup site location get assigned 100% of the points for a given cleanup site. Census tracts intersecting within a 500-meter buffer around a cleanup site location get assigned 50% of the points for a given cleanup site. Census tracts intersecting within a 750-meter buffer around a cleanup site location get assigned 25% of the points for a given cleanup site. Census tracts intersecting within a 1,000-meter buffer around a cleanup site location get assigned 10% of the points for a given cleanup site.
- Points assigned to census tracts during buffer analysis were summed giving a total number of clean-up site points per census tract. This was the cumulative cleanup sites pollution score value.
- Lastly, cleanup sites' pollution scores were converted to state-wide percentiles by ranking all census tracts.

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[7] Baibergenova A, Kudyakov R, Zdeb M, Carpenter DO (2003). Low birth weight and residential proximity to PCB-contaminated waste sites. Environ Health Perspect 111(10):1352-7.

Solid waste

Description: Solid waste activities are based on MPCA reports of waste activity and disposal sites. The solid waste environmental stressor is based on information from permits for solid waste facilities and reports about waste activity. Communities could be considered stressed if there are more solid waste facilities, and if those facilities have larger volumes of waste, or higher perceived risks, compared to their county or the rest of Minnesota.

Indicator Measurement Units: Solid waste percentile

Rationale: Solid waste facilities can pose a variety of environmental and human health challenges. Studies have shown that they can release pollution into the air, such as methane, carbon dioxide, and nuisance odors.[8] These facilities may have accidents such as fires and/or they may mismanage wastes resulting in generation of leachate and potential for groundwater contamination. Leachate is created when liquid percolates through a solid waste and contaminants are dissolved into the liquid. Solid waste leachate can enter groundwater if it is improperly managed or if the landfill does not have a leachate collection system. Negative human health outcomes may be associated with solid waste facilities if mismanagement results in releases that reach receptors.[9]

Stressor Value Calculation Method:

- Solid waste data was sourced from MPCA.
  - Staff reviewed information on gas capture, landfill, construction, demolition, leachate, tires, transfer areas, waste-to-energy, and disposal sites across the state of Minnesota.
- Staff allocated solid waste points to each permitted facility. These points will be assigned to communities in the next step.
  - Category 1: Landfills –
    - Less than 4,000 annual cubic yards of waste: 4 points
    - 11,999-4,000 annual cubic yards of waste: 5 points
    - 36,999-12,000 annual cubic yards of waste: 6 points
    - 77,999-37,000 annual cubic yards of waste: 7 points
    - Over 78,000 annual cubic yards of waste: 8 points
  - Category 2: Solid waste disposal site (closed, closing, inactive, or a site that did not report any amounts of waste or activity described in the other categories): 1 point per site
  - Category 3: Transfer or processing facilities
    - Under 5,600 tons per year: 1 point
    - 56,000-5,600 tons per year: 3 points
    - Over 56k tons per year: 6 points

[8] Lou X, Nair J (2009). The impact of landfilling and composting on greenhouse gas emissions–a review. Bioresource Technology 100(16):3792-8. Ofungwu J, Eget S (2006). Brownfields and health risks--air dispersion modeling and health risk assessment at landfill redevelopment sites. Integr Environ Assess Manag 2(3):253-61. Weitz KA, Thorneloe SA, Nishtala SR, Yarkosky S, Zannes M (2002). The impact of municipal solid waste management on greenhouse gas emissions in the United States. Journal of the Air & Waste Management Association 52(9):1000-11.

[9] Roelofs D, de Boer M, Agamennone V, Bouchier P, Legler J, van Straalen N (2012). Functional environmental genomics of a municipal landfill soil. Front Genet 3:85. Mataloni F, Badaloni C, Golini MN, Bolignano A, Bucci S, Sozzi R, et al. (2016). Morbidity and mortality of people who live close to municipal waste landfills: a multisite cohort study. International Journal of Epidemiology 45(3):806-15.

- Category 4: Tire waste facilities
    - Under 59 tons per year: 2 points
    - Over 59 tons per year: 4 points
- Category 5: Gas capture facilities
    - Under 6.7 million cubic meters per year: 2 points
    - 6.7 million cubic meters or more per year: 4 points
- Category 6: Waste-to-energy facilities
    - Under 157k tons per year: 4 points
    - Over 157k tons per year: 8 points
- Category 7: Facilities generating leachate
    - Under 3.9 million gallons per year: 1 point
    - 6.3 to 3.9 million gallons per year: 3 points
    - Over 6.3 million gallons per year: 6 points

- Staff applied the above points in whole or in part to communities based on their proximity to the facilities. Staff determined this proximity by drawing distance buffers around facilities (buffer analysis) and comparing them to census tracts. Staff assigned 100% of a solid waste facility's points to census tracts within 250 meters; 50% to those within 500 meters; 25% to those within 750 meters; and 10% to those within 1,000 meters. (For example, a landfill with over 78,000 annual cubic yards of waste (eight points) that generates over 6.3 million gallons per year of leachate (six points) within 500 meters of a census tract (50%) would score seven points.)
- Staff summed assigned points, giving each census tract a cumulative solid waste pollution score value.
- Lastly, solid waste pollution scores were converted to state-wide percentiles by ranking all census tracts.

Water pollution

Water pollution environmental stressors are assessed using data on the condition of surface and groundwater and potential pollution from industrial runoff. These indicators include impaired lakes, rivers, and streams, potential risks from industrial stormwater, and threats to groundwater. Together, they capture different ways that water pollution can make communities more susceptible to being harmed by additional pollution exposure.

Impaired waters

Description: Impaired waters scores are based on pollution found in lakes, rivers and streams in a community, and whether it harms human health.

Indicator Measurement Units: Impaired waters percentile

Rationale: The more water impairments there are, and whether or not they can impact human health, determines the overall impairment score. Minnesota has large and complex watershed systems across the state, and pollution can easily travel into waterways from various regulated facilities. Surface water quality is key to healthy ecosystems, safe public recreation, as well as crucial for communities like our Tribal partners that rely on fishing for food sovereignty and engaging in important cultural practices. Impaired waters can have contaminants such as polychlorinated biphenyls (PCBs), heavy metals (e.g., mercury), pesticides, polyaromatic hydrocarbons (PAHs), and various PFAS forever chemicals. Minnesota continues to make positive trends, with most sampled waters improving or not changing in the latest water quality reports, which can be explored further on the MPCA's impaired waters list web page.[10]

Stressor Value Calculation Method:

- Intersected the current MPCA impaired waters list (updated every two years, located on the MPCA external website) with census tracts.
- Summarized the number of lake and stream/river per census tract per impairment. The count removed any impact of the magnitude of lake area or length of impaired waters. Impairments are summarized at the designated use level, not the parameter level.
- Used the summarized data to create standardized categories for designated use impairments. Impairments were separated into two overall groups, based on whether the impairment has direct human health impacts or not. The impaired categories were combined to create one impaired score that reflected the type and number of impairments per census tract.
- Designated use impairments were defined as having either direct human impact (fish consumption or drinking water) or do not have direct human impacts (aquatic life, recreation, wild rice production). The number of water body IDs per census tract per category was standardized to "multiple water bodies", "one water body", or "none". Direct counts of the number of impaired waters per census tract are not appropriate to use for multiple reasons. The counts do not reflect the preponderance of impairments so much as reflecting the amount of sampling effort per area (highly variable) and the number of water bodies in an area (also highly variable). The number of water body IDs that are impaired also do not reflect the total number of water bodies in an area, just the water bodies that have been assessed. Below is the scoring framework in Table 3:

Table 3. Impaired score assigned to specific levels of environmental and direct human impacts.

Environmental impacts	Direct human impact	Impaired score
None	None	0
One water body	None	1
Multiple water bodies	None	2
None	One water body	3
One water body	One water body	4
Multiple water bodies	One water body	5
None	Multiple water bodies	6
One water body	Multiple water bodies	7
Multiple water bodies	Multiple water bodies	8

- After obtaining impaired waters score per a census tract, the score was weighted by the population of the census tract by multiplying impaired score by census tract population creating a weighted impaired waters score per a census tract.
- Lastly, impaired waters scores were converted to state-wide percentiles by ranking all census tracts.

[10] Minnesota's impaired waters list. Minnesota Pollution Control Agency. (n.d.). https://www.pca.state.mn.us/air-water-land-climate/minnesotas-impaired-waters-list

Industrial stormwater runoff

Description: The industrial stormwater runoff stressor captures potential exposure to stormwater runoff leaving industrial facilities.

Indicator Measurement Units: Industrial stormwater runoff exceedances

Rationale: Industrial stormwater runoff can contain pollution that is comprised of a variety of chemicals that can impact the environment or human health by direct exposure by ingestion or skin contact as well as indirect exposure through contaminants transferred to the food chain. This pollution has been found to be linked to the development of chronic diseases (metabolic, endocrine issues impacting human glands and hormones, respiratory issues) as well as cancer. Several studies have shown communities of color and low-income populations are disproportionally affected by pollution as they tend to live in closer proximity to industrial areas, thereby leading to increased exposure.

Stressor Value Calculation Method:

- Industrial stormwater monitoring results from a five-year period were sourced from MPCA databases. For each industrial stormwater permit, monitoring outcomes were classified as either meeting or not meeting applicable limits (benchmark values or effluent limits) for multiple parameters. For parameters with benchmark values, results were considered to not meet limits (i.e., an exceedance) if the rolling average of four monitoring results exceeded the benchmark. For parameters with effluent limits, results were considered to not meet requirements based on individual monitoring results. It should be noted that a single exceedance of an applicable benchmark value is not a violation of the MPCA Industrial Stormwater permits.
- Instances of monitoring results not meeting limits were summed for each facility within the five-year window.
- Next, facility locations were intersected with census tracts.
- Exceedance counts (instances of monitoring results not meeting limits) were then summarized per a census tract, combining counts across facilities for a given census tract.

Groundwater threats

Description: Groundwater threats are based on data on groundwater contamination and reliance on domestic wells.

The groundwater threats score reflects contamination exceedances and areas of concern from the MPCA Groundwater Contamination Atlas, township nitrate testing results, and the presence of active domestic wells. Communities could be considered more stressed if they have a higher number of contamination exceedances, overlapping areas of concern, and a greater reliance on domestic wells compared to the rest of Minnesota.

Indicator Measurement Units: Groundwater threats percentile

Rationale: Contaminated groundwater is a public health risk as 75% of Minnesotans rely on groundwater as a drinking water source.[11] However, reliance on groundwater varies geographically. In major population centers such as Minneapolis and St. Paul, many residents receive drinking water from

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[11] 2025 Groundwater Policy Report. (2025). Minnesota Environmental Quality Board. https://www.eqb.state.mn.us/sites/eqb/files/2025_groundwater_policy_report.pdf

surface water systems. In contrast, residents in rural areas are more likely to rely on groundwater from municipal wells or private wells.

While public water systems are required to meet the requirements of the federal Safe Drinking Water Act, maintenance and water-quality testing of private wells is not regulated by the state or federal government. These are the responsibility of the well owner and are often overlooked, with the Minnesota Department of Health (MDH) finding less than 20% of well users test their drinking water as frequently as MDH recommends.[12] In some areas, local geology makes groundwater more sensitive to pollution.[13] Due to these factors, people who use private wells as a drinking water source can be vulnerable to pollution from nearby sources. Common contaminants of concern in Minnesota include arsenic, coliform bacteria,[14] manganese,[15] nitrate,[16] trichloroethylene[17] [18] and per- and polyfluoroalkyl substances (PFAS, often called "forever chemicals" [19] [20]). Contaminants found in groundwater can be anthropogenic (pollutants that are human made) or geogenic (chemicals that occur naturally in groundwater).[21] Drinking groundwater that is contaminated above drinking water standards or guidance may pose some level of health risk.[22]

Stressor Value Calculation Method:

- Groundwater contamination exceedance data for wells and boreholes were obtained from the Minnesota Pollution Control Agency (MPCA) Groundwater Contamination Atlas (GWCA): https://gisdata.mn.gov/dataset/env-mn-gw-contamination-atlas
- Township-level nitrate testing results were obtained from the Minnesota Department of Agriculture (MDA) nitrate well testing program: https://gisdata.mn.gov/dataset/env-nitrate-well-test
- Information on active domestic wells in Minnesota was obtained from the Minnesota Department of Health County Well Index database: https://gisdata.mn.gov/dataset/water-well-information-non-pws

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[12] Minnesotans with private wells urged to test their drinking water for five common contaminants. (2024). Minnesota Department of Health. https://www.health.state.mn.us/news/pressrel/2024/wellsprivate031124.html

[13] Groundwater pollution sensitivity. (2025). Minnesota Department of Natural Resources. https://www.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity.html

[14] 14 Minnesotans with private wells urged to test their drinking water for five common contaminants. (2024). Minnesota Department of Health. https://www.health.state.mn.us/news/pressrel/2024/wellsprivate031124.html

[15] Manganese in Drinking Water. (2021). Minnesota Department of Health. https://www.health.state.mn.us/communities/environment/water/docs/contaminants/mangnsefctsht.pdf

[16] Nitrate in Well Water. (2025, August 1). Minnesota Department of Health. https://www.health.state.mn.us/communities/environment/water/wells/waterquality/nitrate.html.

[17] Trichloroethylene (TCE). (2025). Minnesota Pollution Control Agency. https://www.pca.state.mn.us/pollutants-and-contaminants/trichloroethylene-tce

[18] Toxicological Profile for Trichloroethylene. (2019). U.S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/toxprofiles/tp19.pdf

[19] Smalling, K. L., Romanok, K. M., Bradley, P. M., Morriss, M. C., Gray, J. L., Kanagy, L. K., Gordon, S. E., Williams, B. M., Breitmeyer, S. E., Jones, D. K., DeCicco, L. A., Eagles-Smith, C. A., & Wagner, T. (2023). Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: Comparison of underserved private-well and public-supply exposures and associated health implications. Environment International, 178(178), 108033–108033. https://doi.org/10.1016/j.envint.2023.108033

[20] PFAS. (2025). Minnesota Pollution Control Agency. https://www.pca.state.mn.us/pollutants-and-contaminants/pfas

[21] 2025 Groundwater Policy Report. (2025). Minnesota Environmental Quality Board. https://www.eqb.state.mn.us/sites/eqb/files/2025_groundwater_policy_report.pdf

[22] Guidance Values and Standards for Contaminants in Drinking Water. (2025). Minnesota Department of Health. https://www.health.state.mn.us/communities/environment/risk/guidance/gw/index.html

- Each GWCA well or borehole location was spatially assigned to a U.S. Census tract. The total number of GWCA exceedances was then summed for each census tract.
- For township-level nitrate testing results, census tracts were spatially intersected with township boundaries. When a census tract intersected multiple townships, the highest (i.e., most conservative) nitrate testing category among intersecting townships was assigned to the census tract. Nitrate testing results were reported as categorical percentages (≥10%, 5–<10%, <5%). To enable quantitative analysis, categories were assigned ordinal scores as follows: ≥10% = 3, 5–<10% = 2, and <5% = 1.
- Active domestic wells were identified from the County Well Index database. Each well location was spatially assigned to a census tract, and the total number of active domestic wells was calculated for each census tract.
- Census tracts with no GWCA exceedances, nitrate testing results, or active domestic wells were assigned a value of zero for the corresponding data category.
- Census tract values for GWCA exceedances, nitrate testing scores, and active domestic well counts were transformed into ranked percentiles ranging from 0 to 100.
- A groundwater threats score was calculated for each census tract as the arithmetic mean of the three percentile values.
- An additional weighting of 5% was applied to the groundwater threats score for census tracts that spatially intersected a GWCA “Area of Concern” polygon and also contained one or more active domestic wells.

Transportation factors

Transportation-related environmental stressors are measured using data that reflect how close people live to heavy traffic and how much traffic moves through their neighborhoods. These indicators include the percentage of people living near busy roads and overall traffic density within a census tract. Together, they capture different ways that transportation patterns and roadway use can make communities more vulnerable to harm when exposed to pollution.

Population living near busy roads

Description: The percent of residents living near roads with average annual daily traffic greater than 10,000 vehicles.

Indicator Measurement Units: Percent of residents near busy roads

Rationale: Major roads and highways can bring air pollutants and noise into nearby neighborhoods, resulting in a variety of negative health effects on communities, including noise, vibration, injuries, and local land use changes such as increased numbers of gas stations. Studies have shown that low-income communities and people of color make up the majority of residents in high-traffic areas. In addition, schools that are located near busy roads are more likely to be in low-income neighborhoods. Minnesota also has significant historical impacts from real estate redlining practices that segregated neighborhoods with more highway traffic.[23]

[23] Delegard, K., & Corey, M. (2024). Mapping Racial Covenants in the United States: A Technical Toolkit. White Paper. Digital Humanities Advancement Grants. National Endowment for the Humanities. https://apps.neh.gov/publicquery/AwardDetail.aspx.

Stressor Value Calculation Method:

- Methods adapted from: https://cdn.ymaws.com/www.cste.org/resource/resmgr/EnvironmentalHealth/EHIndicatorAQ31.pdf. First, we obtained 2020 U.S. Census Data with block group polygons, census tract polygons, Minnesota county polygons, a traffic segment layer with an average annual daily traffic attributes from the Minnesota Department of Transportation.
- Selected all road segments having >10,000 cars/day (average annual daily traffic).
- Calculated area of each block group.
- Buffered selected road segments by 300m.
- Intersect buffered road segments with block group polygons.
- Dissolved (or collapsed) resulting intersected polygons on block group unique identifier so that there is no more than one polygon per block group unique identifier.
- Calculated area of resulting dissolved polygons; this is the area of each block group that is within 300m of busy roads.
- Joined in the total area and total population attributes from original block group data table with the block group area within the buffer table.
- Divided the area of block group near busy roads by the total block group area; this is the proportion of block group area within 300m of busy roads.
- Multiplied the proportion of block group area within 300m of busy roads and the total block group population; this is the number of people exposed in the block group.
- Divided the number of people exposed (calculated in the previous step) by the total population and multiplied by 100; this is the total percent of the block group population living within 300m of busy roads.
- Summed the number of people exposed in the block group per census track unique identifier; this is the total population of census tract living within 300m of busy roads.
- Divided the total population of census tract living within 300m of busy roads by the total census tract population and multiplied by 100; this is the percent of the census tract population living within 300m of busy roads.

Traffic density

Description: Census tract annual average daily traffic (AADT) volume.

Indicator Measurement Units: Average vehicles per day

Rationale: Transportation pollution is a source of several notable air pollutants, such as particles, nitrogen oxides, black carbon, and noise.[24] Living near lots of traffic may also be related to health impacts such as heart disease, respiratory disease, and premature death.[25] Residents near higher density of traffic also experience social isolation, traffic incidents and low physical activity levels.[26]

[24] American Lung Association. (2024c). Who is Most Affected by Outdoor Air Pollution? https://www.lung.org/clean-air/outdoors/who-is-at-risk

[25] Münzel, T., Kröller-Schön, S., Oelze, M., Gori, T., Schmidt, F. P., Steven, S., Hahad, O., Röösli, M., Wunderli, J.-M., Daiber, A., & Sørensen, M. (2020). Adverse Cardiovascular Effects of Traffic Noise with a Focus on Nighttime Noise and the New WHO Noise Guidelines. Annual Review of Public Health, 41(Volume 41, 2020), 309-328. https://doi.org/https://doi.org/10.1146/annurev-publhealth-081519-062400

[26] Salvo, G., Lashewicz, B. M., Doyle-Baker, P. K., & McCormack, G. R. (2018). Neighbourhood built environment influences on physical activity among adults: a systematized review of qualitative evidence. International journal of environmental research and public health, 15(5), 897.

Stressor Value Calculation Method:

- Obtained traffic segment information including annual average daily traffic volume (AADT) from Minnesota Department of Transportation
- Intersected each road segment piece with a census tract
- Calculated length of each road segment piece within each tract
- Calculated an AADT "load" per road segment within a tract by multiplying AADT volume by road segment proportion
- Lastly, we calculated AADT "load" per a census tract by summing AADT contributions from road segments within a census tract

Social factors

Social factor environmental stressors reflect characteristics of communities that can make people more vulnerable to environmental harms or less able to be resilient to them. These indicators include age, housing cost burden, educational attainment, income inequality, disability status, and unemployment. Together, they capture different social and economic conditions that can make communities more vulnerable to harm when exposed to pollution.

Age of residents

Description: The percent of people who are either 5 years and younger or 65 years and older.

Indicator Measurement Units: Percent of people who are either 5 years and younger or 65 years and older

Rationale: Children are often more vulnerable to pollutants because of differences in behavior and biology, which can lead to greater exposure and/or unique times of susceptibility during development. Older adults are more vulnerable because pollution exposure can worsen existing health issues.

Research has linked air pollution to negative health outcomes in children since they breathe more air relative to their size.[27] There are strong correlations to air pollution and increased asthma conditions, increased medication use, missed school days, and higher mortality rates due to respiratory infections.[28] Several studies of older adults link long-term exposure to air pollution with higher rates of chronic diseases and premature deaths. Short-term exposure to pollution also has been found to impact health outcomes for older adults.[29]

[27] Kulkarni, N. and Grigg, J. 2008. Effect of air pollution on children. Pediatrics and Child Health 18 (5). Pp 238-243.

[28] Alhanti, B.A., Chang, H.H., Winquist, A., Mulholland, J.A., Darrow, L.A. and Sarnat, S.E. 2016. Ambient air pollution and emergency department visits for asthma: a multi-city assessment of effect modification by age. Journal of Exposure Science and Environmental Epidemiology 26, 180–188. Kulkarni, N. and Grigg, J. 2008. Effect of air pollution on children. Pediatrics and Child Health 18 (5). Pp 238-243. Ko, F.W.S, Tam, W., Wong, T.W, Lai, C.K,W., Wong, G.W.K, Leung, T,-F., Ng, S.S.S. and Hui, D.S.C. 2007. Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. Clinical and Experimental Allergy, 37, pp. 1312–1319. Lelieveld, J., Haines, A, and Pozzer, A. 2018. Age-dependent health risk from ambient air pollution: a modelling and data analysis of childhood mortality in middle-income and low-income countries. Lancet Planet Health 2: e292-300.

[29] Keita Ebisu, Brian Malig, Sina Hasheminassab, Constantinos Sioutas, Age-specific seasonal associations between acute exposure to PM2.5 sources and cardiorespiratory hospital admissions in California, Atmospheric Environment, Volume 218, 2019.

Stressor Value Calculation Method:

- Obtained five-year estimates for number of people that are younger than 5 or 65 and older provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
  - ACS Table: S0101 - Age and Sex
  - ACS Field names: C01_002, C01_030, C01_001
- Calculated percent of residents under 5 and over 65 for each census tract as:
  (people under 5 (C001_002) + people over 65 (C01_030)) / total population (C01_001) * 100

Cost-burdened households

Description: The percent of households that are spending greater than 30% of total income on housing costs, including mortgage or rent payments.

Indicator Measurement Units: Percent of households that are spending greater than 30% of total income on housing costs, including mortgage or rent payments

Rationale: Communities in Minnesota commonly experience financial costs that impact household budgets and bring significant stress. Recent data estimates that 641,549 Minnesota households qualified as cost-burdened households, with the majority being represented by people of color.[30] Overburdened communities often coexist with numerous commercial facilities and industrial sites, both large and small. Many manufacturing sites, former dry cleaners, and gas stations were abandoned without a responsible party to clean up for future use. Neighborhoods comprised of cost-burdened households and communities of color bear the brunt of legacy pollution. Superfund sites are also disproportionately located in neighborhoods of people living under the poverty level, communities of color, and people who are linguistically isolated.[31] Children from cost-burdened and minority families are especially vulnerable to health risks because they spend more time playing on contaminated soil and live in houses that have lead paint or high dust levels. They may be exposed to higher levels of contaminants in utero and from breast milk because their mothers are also disproportionately exposed. Children from cost-burdened households commonly have inadequate diets that may increase the absorption of toxic chemicals from their digestive system.[32]

Stressor Value Calculation Method:

- Obtained five-year estimates for number of people who rent or own a home, have an annual income less than 75,000 USD and spend 30% or more of their income on housing provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
  - ACS Table: B25106 - Tenure by Housing Costs as a Percentage of Household Income in the Past 12 Months
  - ACS Field names: B006, B010, B014, B018, B028, B032, B036, B040

[30] Minnesota Housing Partnership. 2024. 2024 State of the State's Housing Profile with Key Minnesota Findings and Trends. https://mhponline.org/wpcontent/uploads/2024_State_Profile_Findings_FINAL.pdf

[31] Brender, Jean D., Maantay, Juliana A., and Chakraborty, Jayajit. 2011, Residential Proximity to Environmental Hazards and Adverse Health Outcomes, American Journal of Public Health 101, S37_S52, https://doi.org/10.2105/AJPH.2011.300183

[32] Gochfeld, M., & Burger, J. 2011. Disproportionate exposures in environmental justice and other populations: the importance of outliers. American journal of public health, 101 Suppl 1(Suppl 1), S53–S63. https://doi.org/10.2105/AJPH.2011.300121.

- Calculated percent of households within each census tract with annual income less than 75,000 USD that are spending greater than 30% of total income on housing costs (as either mortgage or rent payments) as:
  Less than $20,000 (B25106_006, B25106_028) + $20,000 to $34,999 (B25106_010, B25106_032) + $35,000 to $49,999 (B25106_014, B25106_036) + $50,000 to $74,999 (B25106_018, B25106_040)/Total population (B25106_001) * 100

Educational attainment

Description: The percent of people 25 years and older without a high school diploma.

Indicator Measurement Units: Percent of people 25 years and older without a high school diploma

Rationale: Educational attainment, how far a person gets in school, is an important independent predictor of health. Several studies have associated it with susceptibility to the health impacts of environmental pollutants. People with less education in the U.S. have a lower life expectancy,[33] are more likely to be obese,[34] and are more likely to experience psychiatric disorders.[35] Research has also found that people who do not graduate high school are more frequently suffering from at least one chronic health condition, such as asthma, diabetes, heart disease, high blood pressure, stroke, hepatitis, and stomach ulcers.[36] People without a high school education appear to be at higher risk of death associated with particulate air pollution.[37] Community members with lower educational attainment may be less aware of environmental hazards and climate risks as well as lack access to health information or services.

Stressor Value Calculation Method:

- Obtained five-year estimates for number of people 25 and older with a high school diploma provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool [tidycensus package in R](#).
  - ACS Table: S1501 – Educational Attainment
  - ACS Field names: C01_014, C01-006
- Calculated percent of the population 25 and older without a high school diploma within each census tract as:
  (Total population (C01_006) - the number of people with a high school diploma or higher (C01_014)) / Total population (C01_006) * 100

[33] Sasson I (2016). Trends in life expectancy and lifespan variation by educational attainment: United States, 1990–2010. Demography 53(2):269-93.

[34] Cohen AK, Rai M, Rehkopf DH, Abrams B (2013). Educational attainment and obesity: a systematic review. Obesity Reviews 14(12):989-1005.

[35] Erickson J, El-Gabalawy R, Palitsky D, Patten S, Mackenzie CS, Stein MB, et al. (2016). Educational attainment as a protective factor for psychiatric disorders: findings from a nationally representative longitudinal study. Depression and Anxiety 33(11):1013-22.

[36] U.S. Department of Health and Human Services (HHS). (2024b). Social Determinants of Health. https://odphp.health.gov/healthypeople/priority-areas/social-determinants-health

[37] Pope III, C. A., Lefler, J. S., Ezzati, M., Higbee, J. D., Marshall, J. D., Kim, S. Y., ... & Burnett, R. T. (2019). Mortality risk and fine particulate air pollution in a large, representative cohort of US adults. Environmental health perspectives, 127(7), 077007.

Income inequality

Description: Income inequality in a community, measured using the Gini index. This economic index ranges between one and zero, where one is complete inequality, and zero is perfect equality.

Indicator Measurement Units: Gini Index (unitless, but expressed in percentages)

Rationale: Studies have shown that societies with more extreme social hierarchy or income differences can experience social relations that are less supportive and face higher levels of conflict or even violence.[38] Communities facing higher levels of income inequality can experience negative health impacts to overall life expectancy, higher rates of interpersonal violence and mental illness. Additionally, communities with greater levels of income inequality often have higher mortality rates for people with less income and wealth.[39] Research in the U.S. is even showing that income distribution has a stronger association to higher mortality rates than the median income for a given state.[40] Minnesota continues to experience large income and wealth inequality stemming from historical racial redlining and discriminatory practices across different institutions. Minnesota has the third-largest racial-wealth gap in the U.S., with the median net worth (people in the middle) of Black households at $0, compared to $211,000 for white households and $18,000 for Latino households.[41]

Stressor Value Calculation Method:

- Obtained five-year estimates for Gini index of income inequality provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
    - ACS Table: B19083 – Gini Index of Income Inequality
    - ACS Field names: 001E
- Lastly, GINI index values were converted to state-wide percentiles by ranking all census tracts.

People with disabilities

Description: The percent of people with a disability. This stressor shows how many people in a community have impaired or low vision, are deaf or are hard of hearing, have limited or incomplete physical mobility, or are experiencing developmental disabilities. People with disabilities can be more sensitive to environmental pollution.

Indicator Measurement Units: Percent of people with a disability

Rationale: Studies have found that people with disabilities in the U.S. frequently live near environmentally hazardous sites, such as superfund or remediation sites, solid waste facilities, and high-traffic roadways.[42] People with disabilities also have less capacity to respond to emergency events like

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[38] Wilkinson, R. G. (2020). Income inequality, social cohesion, and health: clarifying the theory—a reply to Muntaner and Lynch. In The political economy of social inequalities (pp. 347-365). Routledge.
[39] Avanceña, A. L., DeLuca, E. K., Iott, B., Mauri, A., Miller, N., Eisenberg, D., & Hutton, D. W. (2021). Income and income inequality are a matter of life and death. What can policymakers do about it?. American Journal of Public Health, 111(8), 1404-1408.
[40] McKay, L.C.. 2023. The state of income inequality: New dataset helps identify where income gaps are narrowing—and where they are growing. For All, Fall 2023 issue. https://www.minneapolisfed.org/article/2023/the-state-of-income-inequality
[41] Anderson, K., & Madsen, S. R. (2024). The Current Status of Utah Women & Girls: A Research Synopsis. Utah Women & Leadership Project White Paper, 9, 1.
[42] U.S. Environmental Protection Agency. (2024d). Climate Change and the Health of People with Disabilities. https://www.epa.gov/climateimpacts/climate-change-and-health-people-disabilities

floods or wildfires. Additionally, people with disabilities are more likely to have chronic health conditions than people without disabilities.[43]

Stressor Value Calculation Method:

- Obtained five-year estimates for number of civilian noninstitutionalized population with a disability provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
  - ACS Table: S1810 – Disability Characteristics
  - ACS Field names: C02_001, C01_001
- Calculated percent of people with a disability within each census tract as:
  Total civilian noninstitutionalized population with a disability (C02_001) / total civilian noninstitutionalized population (C01_001) * 100

Unemployment

Description: The percent of adults who are unemployed.

Indicator Measurement Units: Percent of adults who are unemployed

Rationale: Unemployment can result in negative health consequences. People who are unemployed can suffer from depression, anxiety, low self-esteem, demoralization, worry, and physical pain. Unemployed individuals also have more stress-related illnesses, such as high blood pressure, strokes, heart attacks, heart disease, and arthritis.[44] In addition, experiences such as perceived job insecurity, downsizing or workplace closure, and underemployment also have implications for physical and mental health.[45]

Stressor Value Calculation Method:

- Obtained five-year estimates for percent of people unemployed provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
  - ACS Table: S1701 – Poverty Status in the Past 12 Months
  - ACS Field names: C01_027, C01_031
- Calculated percent of people unemployed within each census tract as:
  Civilian labor force 16 years and older who are unemployed (C01_031) / total civilian labor force 16 years and over (C01_027) * 100

Public health factors

Public health-related environmental stressors reflect the overall health conditions of a community and how these conditions may affect residents' well-being. These indicators include asthma and heart disease prevalence, childhood lead exposure, and access to health care coverage. Together, these data

[43] Krahn, G. L., Walker, D. K., & Correa-De-Araujo, R. (2015). Persons with disabilities as an unrecognized health disparity population. American journal of public health, 105(S2), S198-S206.
[44] Silver, S. R., Li, J., & Quay, B. (2022). Employment status, unemployment duration, and health-related metrics among US adults of prime working age: behavioral risk factor surveillance system, 2018–2019. American journal of industrial medicine, 65(1), 59-71.
[45] Scribner, R. A., Simonsen, N. R., & Leonardi, C. (2017). The social determinants of health core: taking a place-based approach. American journal of preventive medicine, 52(1), S13-S19.

show how public health factors can make communities more vulnerable to harm when exposed to pollution.

Asthma prevalence

Description: Asthma prevalence among adults.

Indicator Measurement Units: Estimated percent of people with asthma

Rationale: Asthma symptoms can be made worse by air pollution coming from traffic, facility pollution, pesticides and wildfire smoke.[46] Asthma increases people's sensitivity to pollutants, such as particulate matter, ozone, nitrogen dioxide and diesel exhaust.[47] Studies have linked asthma to increased susceptibility to respiratory diseases like pneumonia and influenza, especially if residents do not have regular access to medical care or asthma medication.[48] Asthma can also reduce quality of life by limiting daily activities and can lead to premature death.[34]

Stressor Value Calculation Method:

- Obtained Minnesota census tract asthma prevalence estimates from the Centers for Disease Control and Prevention (CDC) PLACES database (https://www.cdc.gov/places/index.html)
  - Category: Health Outcomes
  - Measure: Current asthma among adults

Childhood lead exposure

Description: The census tract percent elevated blood lead levels compared to statewide. Test results are for children under the age of 6 years and tested in a five-year window. Elevated blood lead levels (EBLLs) are defined here as 5+ mcg/dL. In 2023, the reference value for an EBLL was lowered to 3.5 mcg/dL in Minnesota and will be reflected in this indicator in the future.

Indicator Measurement Units: Census tract percent elevated blood lead levels compared to statewide

Rationale: Lead can be found in older homes and buildings that contain lead-based paints or water pipes made with lead.[49] There is no safe level of lead, and lead exposure in children and pregnant women is a serious public health concern. Lead exposure in children can lead to developmental disabilities and impact parts of the brain.[50] Greater exposure during early childhood may additionally result in decreased brain volume later in adulthood.[51] Other organs and systems that can be negatively impacted include the muscles and bones, lungs, stomach and digestive system, heart and blood vessels, and

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[46] World Health Organization (WHO). (2024b). Asthma. https://www.who.int/news-room/fact-sheets/detail/asthma#:~:text=Asthma%20is%20a%20major%20noncommunicable,help%20to%20reduce%20asthma%20symptoms.

[47] Guarnieri M, Balmes JR (2014). Outdoor air pollution and asthma. The Lancet 383(9928):1581-92.

[48] Kloepfer KM, Olenec JP, Lee WM, Liu G, Vrtis RF, Roberg KA, et al. (2012). Increased H1N1 infection rate in children with asthma. Am J Respir Crit Care Med 185(12):1275-9.

[49] "Common Sources of Lead in the Home- EH: Minnesota Department of Health." Www.health.state.mn.us, 24 Sept. 2024, www.health.state.mn.us/communities/environment/lead/fs/common.html.

[50] CDC. (2024, April 16). Lead Exposure Symptoms and Complications. Childhood Lead Poisoning Prevention; CDC. https://www.cdc.gov/lead-prevention/symptoms-complications/index.html

[51] Yeter, D., Banks, E. C., & Aschner, M. (2020). Disparity in risk factor severity for early childhood blood lead among predominantly African-American black children: The 1999 to 2010 US NHANES. International Journal of Environmental Research and Public Health, 17(5), 1552. https://doi.org/10.3390/ijerph17051552

immune system, which fights infection.[52] Research has found disproportionate lead exposure levels for Black children, people living in poverty or older housing, as well as for people who have not received a high school diploma or GED.[53][54]

More information on sources of lead exposure can be found on the Minnesota Department of Health's website, https://www.health.state.mn.us/communities/environment/lead/fs/common.html

Stressor Value Calculation Method:

- Child lead exposure data were obtained from the Minnesota Department of Health's Blood Lead Information System.
- "Percent elevated" is defined as the proportion of tested children with an elevated blood lead level (EBLL) of 5+ mcg/dL. Because universal lead testing was not implemented in Minnesota until 2022, this indicator reflects only children who were tested and should not be generalized to all children in the state.
- Blood lead test results were geocoded to census tracts. For each census tract, the 95% confidence interval for its percent elevated value was compared to the 95% confidence interval for the statewide percent elevated value. These census tract results, defined as "Census tract percent elevated blood lead levels compared to statewide", were classified as:
  - **Significantly higher or lower than the state** if the confidence intervals did not overlap, or
  - **Not significantly different from the state** if the intervals overlapped.
- Among tracts significantly higher than the state, additional categories were assigned based on magnitude. Tracts were classified as **1–2 times higher** or **3 or more times higher**, with the latter defined as having a lower confidence interval bound greater than three times the statewide point estimate.
- Any census tracts that contained higher than the state as their values were given an adverse impact flag.

Lack of health care coverage

Description: The percent of people without health care coverage.

Indicator Measurement Units: Percent of people without health care coverage

Rationale: Most people without health insurance are from families with low incomes (with typically one person working in the family), people of color, and undocumented immigrants.[55] Many people in the U.S. are without health insurance, with 8.3% of residents being uninsured as of 2021, though recent

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[52] Farace, C., Fenu, G., Lintas, S., Oggiano, R., Pisano, A., Sabalic, A., Solinas, G., Bocca, B., Forte, G., & Madeddu, R. (2020). Amyotrophic lateral sclerosis and lead: A systematic update. NeuroToxicology, 81, 80-88. https://doi.org/https://doi.org/10.1016/j.neuro.2020.09.003

[53] Yeter, D., Banks, E. C., & Aschner, M. (2020). Disparity in risk factor severity for early childhood blood lead among predominantly African-American black children: The 1999 to 2010 US NHANES. International Journal of Environmental Research and Public Health, 17(5), 1552. https://doi.org/10.3390/ijerph17051552

[54] David C. Wheeler, Resa M. Jones, Mario Schootman, Erik J. Nelson, Explaining variation in elevated blood lead levels among children in Minnesota using neighborhood socioeconomic variables, Science of The Total Environment, Volume 650, Part 1, 2019, Pages 970-977, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.09.088.

[55] Bernstein, H., Gonzalez, D., & Karpman, M. (2021). Adults in low-income immigrant families were deeply affected by the COVID-19 crisis yet avoided safety net programs in 2020. Washington, DC: Urban Institute.

years have seen slight improvements in coverage rates.[56] Financial burdens associated with health care may reduce uninsured populations' ability to engage in the environmental decision-making process. Further, individuals without insurance have barriers to accessing preventative care following adverse environmental events, increasing risk of sickness and death.[57]

Stressor Value Calculation Method:

- Obtained five-year estimates for number of people uninsured provided by the American Community Survey (ACS) from the United States Census Bureau using an application programming interface (API) tool tidycensus package in R.
  - ACS Table: S2701 – Selected Characteristics of Health Insurance Coverage in the United States
  - ACS Field names: C04_001, C01_001
- Calculated percent of people uninsured within each census tract as:
  Uninsured Civilian noninstitutionalized population (C04_001) / total civilian noninstitutionalized population (C01_001) * 100

Heart disease prevalence

Description: Heart disease prevalence among adults.

Indicator Measurement Units: Estimated percent of people with heart disease

Rationale: The term "heart disease" refers to several conditions. Heart disease is a common public health issue in Minnesota and across the U.S. It is the second-leading cause of death, behind cancer, contributing to 17% of all deaths in Minnesota as of 2022.[58] This disease happens when the heart's blood supply is blocked or interrupted by plaque buildup in the major blood vessels.[59] According to the American Heart Association, there is strong evidence that air pollution contributes to cardiovascular sickness and death, including exposure to environmental stressors.[60]

Stressor Value Calculation Method:

- Obtained Minnesota census tract heart disease prevalence estimates from the Centers for Disease Control and Prevention (CDC) PLACES database (https://www.cdc.gov/places/index.html)
  - Category: Health Outcomes
  - Measure: Coronary heart disease among adults

Neighborhood factors

Neighborhood factors reflect features of the local environment and infrastructure that can affect residents' quality of life and exposure to environmental stressors. These indicators include access to

[56] Keisler-Starkey, K., & Bunch, L. N. (2020). Health insurance coverage in the United States: 2019. Washington, DC: US Census Bureau, 5.

[57] McKenzie, B., Lehnert, E., Berens, A., Lewis, B., Bogović, S., Mirsajedin, A., ... & Kashani, M. (2022). Technical Documentation for the Environmental Justice Index 2022.

[58] Minnesota Department of Health/Cardiovascular Health Unit analysis of Vital Statistics 2013-2022. Minnesota Center for Health Statistics, MDH.

[59] American Heart Association (AHA). (2024). Understand Your Risks to Prevent a Heart Attack. https://www.heart.org/en/health-topics/heart-attack/understand-your-risks-to-prevent-a-heart-attack.

[60] Blaustein, J. R., Quisel, M. J., Hamburg, N. M., & Wittkopp, S. (2024). Environmental Impacts on Cardiovascular Health and Biology: An Overview. Circulation Research, 134(9), 1048-1060.

food, recreational spaces, and tree canopy; the extent of impervious surfaces; and the presence of regulated facilities. Together, they provide a picture of how neighborhood conditions can make communities more vulnerable to harm when exposed to pollution.

Food insecurity

Description: The percent of people who do not have access to enough food, or food of adequate quality, to meet basic nutritional needs.

Indicator Measurement Units: Estimated percent of people with food insecurity

Rationale: Food insecurity is a serious issue for residents of Minnesota and can lead to several public health challenges. Research has found that children are especially vulnerable to food insecurity, which can lead to acute health problems. Food-insecure adults are at a greater risk of developing chronic conditions, such as coronary heart disease, diabetes, obesity and cancer.[61] Environmental pollution can make symptoms from these medical conditions more severe. Food insecurity also disproportionately impacts residents that are more likely to be vulnerable and face negative impacts from environmental pollution, such as children, people of color, immigrant communities, LGBTQ+ individuals, people with disabilities, people who are formerly incarcerated, and single-parent households.[62]

Stressor Value Calculation Method:

- Obtained Minnesota census tract food insecurity estimates from the CDC PLACES database (https://www.cdc.gov/places/index.html)
  - Category: Health-Related Social Needs
  - Measure: Food insecurity in the past 12 months among adults

Impervious surfaces

Description: The percent of surface area that is covered with processed materials or structures (pavement, concrete, rooftops, and other constructed materials) that generate surface runoff.

Indicator Measurement Units: Estimated percent of tract with impervious surfaces

Rationale: Impervious surfaces can create a host of challenges for the environment and human health. Having more pavement, concrete, roofing and other constructed materials can exacerbate heat, worsen flooding, and transport surface pollution into waterways to impact water quality.[63] Studies have looked at the relationship between water quality and impervious surfaces in watersheds to find that areas with more processed materials or structures instead of vegetation have higher concentrations of pollution like inorganic nitrogen and phosphorus. Research has found that even paving over 10% to 20% of a

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[61] Thomas MMC, Miller DP, Morrissey TW. Food insecurity and child health. Pediatrics. 2019;144(4):e20190397. doi: https://doi.org/10.1542/peds.2019-0397

[62] U.S Department of Health and Human Services. Food Insecurity. Healthy People 2030. Accessed April 4, 2023. https://health.gov/healthypeople/priority-areas/social-determinants-health/literature-summaries/food-insecurity. Feeding America. Map the Meal Gap 2024. May 2024. Accessed September 12, 2025. https://www.feedingamerica.org/sites/default/files/2024-05/MMG%202024%20Executive%20Summary%20%281%29.pdf

[63] Sharon L. Harlan, Anthony J. Brazel, Lela Prashad, William L. Stefanov, Larissa Larsen, Neighborhood microclimates and vulnerability to heat stress, Social Science & Medicine, Volume 63, Issue 11, 2006, Pages 2847-2863, ISSN 0277-9536, https://doi.org/10.1016/j.socscimed.2006.07.030. Jesdale, B. M., Morello-Frosch, R., & Cushing, L. (2013). The racial/ethnic distribution of heat risk-related land cover in relation to residential segregation. Environmental health perspectives, 121(7), 811–817. https://doi.org/10.1289/ehp.1205919.

landscape can negatively impact water quality. A typical dense suburb could have, on average, 50% land cover while dense urban areas can reach much higher rates.[64]

Stressor Value Calculation Method:

- Obtained fractional impervious surface of the conterminous United States (CONUS) raster data product from the Annual National Land Cover Database (NLCD) produced by the Multi-Resolution Land Characteristics (MRLC) Consortium https://www.mrlc.gov/
- Clipped the CONUS raster to Minnesota state boundaries
- Used zonal statistics to calculate the average pixel value (percent impervious surfaces) within each census tract

Lack of recreational open space

Description: The percent of census tracts lacking recreational space, such as public-access parks, trails, and forests.

Indicator Measurement Units: Estimated percent of tract with lack of recreation space

Rationale: Recreational space provides a wealth of benefits for communities. It protects water resources, preserves biodiversity and wildlife habitats, provides greenways for residents, enhances urban centers, and supports recreational opportunities.[65] Trees filter the air while providing shade on hot days, children can more easily play and socialize, and trails allow people to exercise and access the outdoors. Studies have shown access to nature is unequal, particularly for lower-income communities and communities of color.[66] Publicly available open space encourages walking, biking, and other outside physical activity that, according to the Centers for Disease Control and Prevention, helps people live longer and have lower negative health risks for heart disease, stroke, type 2 diabetes, depression, and some cancers.[67]

Stressor Value Calculation Method:

- Downloaded the most recent PAD-US data set offered by the United States Geological Survey. The PAD-US is America's official national inventory of U.S terrestrial and marine protected areas that are dedicated to recreation, preservation of biological diversity, and cultural uses. This dataset contains federal, state , county, and city owned recreational spaces.
- Filtered down the entire PAD-US database based on the following criteria:
  - Only areas that are publicly accessible or have restricted access (such as wildlife management areas and waterfowl production areas)
  - Areas where the designation includes the terms: "parks", "trails", "recreation areas", "forests", "scenic areas", "wild areas", "fishing", "hunting"

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[64] Polycarpou, L. (2010). No more Pavement! Columbia Climate School Climate, Earth and Society. The problem of impervious surfaces. State of the planet.

[65] de Keijzer C, Gascon M, Nieuwenhuijsen MJ, Dadvand P. Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. Curr Environ Health Rep. 2016 Dec;3(4):468-477. https://doi.org/10.1007/s40572-016-0116-x.

[66] Lorien Nesbitt, Michael J. Meitner, Cynthia Girling, Stephen R.J. Sheppard, Yuhao Lu, Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities, Landscape and Urban Planning, Volume 181, 2019,Pages 51-79,ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2018.08.007.

[67] Keegan, T. H., Shariff-Marco, S., Sangaramoorthy, M., Koo, J., Hertz, A., Schupp, C. W., ... & Gomez, S. L. (2014). Neighborhood influences on recreational physical activity and survival after breast cancer. Cancer Causes & Control, 25(10), 1295-1308.

- After generating a final list of recreational spaces, we dissolved the individual PAD-US geometries to remove overlaps
- Recreation spaces were then intersected with Minnesota census tracts
- Next, we calculated the area of recreational space per a census tract
- Percent recreation space per a tract was done using the following formula: 100 * (tract recreation area / total census tract area)
- Finally, percent lack of recreation space was calculated using the formula: 100 – percent recreation space

Lack of tree canopy

Description: The percent of a census tract that lacks tree canopy cover.

Indicator Measurement Units: Estimated percent of tract with lack of tree canopy

Rationale: Communities with more trees have been found to have reductions in childhood obesity rates, decreased cognitive fatigue, improvement in worker attitudes on the job, and reduced stress, anger, depression, and anxiety. Tree cover is also associated with improved aesthetics, noise reduction, and stronger social cohesion and community empowerment.[68] These benefits are especially relevant in urbanized areas, and prior studies have found less tree canopy in communities with lower incomes or with larger communities of color. [69] The urban heat island effect is also significantly impacted by tree cover. Tree cover keeps cities cooler. Studies have found people who are Black, African American, Hispanic or Latino are disproportionately more likely to live in areas experiencing the largest increase in heat illness or missed work hours from extreme heat.[70] Extreme heat also makes existing medical conditions like respiratory and heart disease worse.[71]

Stressor Value Calculation Method:

- Obtained tree canopy cover of the conterminous United States (CONUS) raster data produced by the U.S. Department of Agriculture (USDA) Forest Service. Tree canopy cover is derived from multi-spectral satellite imagery (30-meter resolution) and other available ground and ancillary information.
- Clipped the CONUS raster to Minnesota state boundaries
- Used zonal statistics to calculate the average pixel value (tree canopy) within each census tract which is equivalent to the average tree canopy cover percentage for a census tract
- To get lack of tree canopy per a census tract, we then subtracted 100 minus census tract tree canopy percentage to get a value of the percent of a census tract that lacks tree canopy cover

[68] "Neighborhood Greenness and 2-Year Changes in Body Mass Index of Children and Youth" by Janice F. Bell, PhD, MPH, Jeffrey S. Wilson, PhD, and Gilbert C. Liu, MD, MS. The commentary is "Decrease in Activity From Childhood to Adolescence: Potential Causes and Consequences" by Nicholas J. Wareham, MBBS, PhD, Kirsten Corder, PhD, and Esther M. F. van Sluijs, PhD. Both appear in the American Journal of Preventive Medicine, Volume 35, Issue 6 (December 2008).

[69] Drescher M. (2019). Urban heating and canopy cover need to be considered as matters of environmental justice. Proceedings of the National Academy of Sciences of the United States of America, 116(52), 26153–26154. Advance online publication. https://doi.org/10.1073/pnas.1917213116.

[70] Nowak, D.J., Hirabayashi, S, Doyle, M, McGovern, M, Pasher, J. 2018. Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban Forestry & Urban Greening. 29: 40-48.

[71]U.S. EPA (U.S. Environmental Protection Agency). 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. EPA 430-R-21-003. Accessed September 6, 2022: https://www.epa.gov/cira/social-vulnerability-report.

Permitted sites and other agency interests

Description: MPCA regulated activities, sites, and permits per square mile unique from other stressors.

Indicator Measurement Units: MPCA regulated activities, sites, and permits per square mile

Rationale: A single facility or activity causing pollution will most likely not harm public health outcomes. But having a concentration of many sources of pollution in an area can contribute to these negative conditions and add stress to communities. Several studies have found that living near hazardous wastes sites, industrial sites, cropland with pesticide applications, highly trafficked roads, nuclear power plants, gas stations or repair shops is related to an increased risk of adverse health outcomes.[72] The facilities identified above can contribute to increased truck traffic, dust, odor, and noise. Research has found significant relationships between living near environmental hazards and harmful public health outcomes. This includes adverse pregnancy outcomes, childhood cancers, asthma hospitalizations, chronic respiratory symptoms, death from stroke, PCB toxicity, end-stage renal disease, and diabetes.[73]

Stressor Value Calculation Method:

- A list of regulated sites and activities overseen by the MPCA and active in the past five years was obtained, including permits, licenses, certifications, and registrations. Air, land, and water MPCA programs that were addressed under other environmental stressors were excluded from this effort. The MPCA regulatory programs included in this indicator were Aboveground Storage Tanks, Construction Stormwater, Feedlots, Hazardous Waste, Municipal Separate Storm Sewer Systems (MS4), Petroleum Remediation, Subsurface Sewage Treatment Systems (SSTS), Underground Storage Tanks, and Wastewater.
- Locations of MPCA-regulated sites and activities were spatially intersected with census tracts.
- The total number of regulated sites and activities within each census tract was calculated by summing unique agency interest and program combinations, allowing only one instance of each combination per census tract.
- Regulated site and activity density was calculated as activities per square mile by dividing the total number of MPCA-regulated activities in each census tract by the tract's land area (square miles).

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[72] Kihal-Talantikite, W., Zmirou-Navier, D., Padilla, C., & Deguen, S. (2017). Systematic literature review of reproductive outcome associated with residential proximity to polluted sites. International journal of health geographics, 16(1), 20.

[73] Jean D. Brender, RN, PhD,corresponding author Juliana A. Maantay, PhD, MUP, and Jayajit Chakraborty, PhD, MS. 2011. "Residential Proximity to Environmental Hazards and Adverse Health Outcomes." National Library of Medicine - National Center for Biotechnology Information. December. Accessed September 16, 2025. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3222489/. Duarte, C. P. F. (2022). *There Is Still Life After Death: Reflections on Overconsumption and Waste* (Master's thesis, Florida Atlantic University).