

Incorporating Social Vulnerability Variables in Flood Susceptibility Mapping

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ABSTRACT

Flood susceptibility mapping (FSM) is a proven approach that relies on reported flood locations and physical characteristics for mapping regional susceptibility to flood hazard. The Chicago Metropolitan Agency for Planning's (CMAP) Flood Susceptibility Index (FSI) is calculated for the City of Chicago and its neighboring counties. Regional vulnerability to the negative effects of flooding varies according to the socioeconomic characteristics of a population. The CDC's Social Vulnerability Index (SVI) is a dataset that describes vulnerability to natural and man-made hazards

How can spatial datasets be used to identify regions disproportionately vulnerable to flooding and its negative effects? What are the implications for enacting equitable stormwater management policy and interventions?

FLOOD SUSCEPTIBILITY INDEX (FSI)

The Regional FSIs are developed by CMAP utilizing the **Frequency Ratio (FR)** method. The indices describe urban and riverine flooding susceptibility as it relates to several flooding-related factors:

- Topographic Wetness Index (TWI)
- Combined Sewer Service Areas
- Elevation Differential Between Property and Nearest Base Flood Elevation (BFE)
- Impervious Cover of Watershed Catchment
- Age of First Development
- Precipitation Variation



Frequency ratio approach

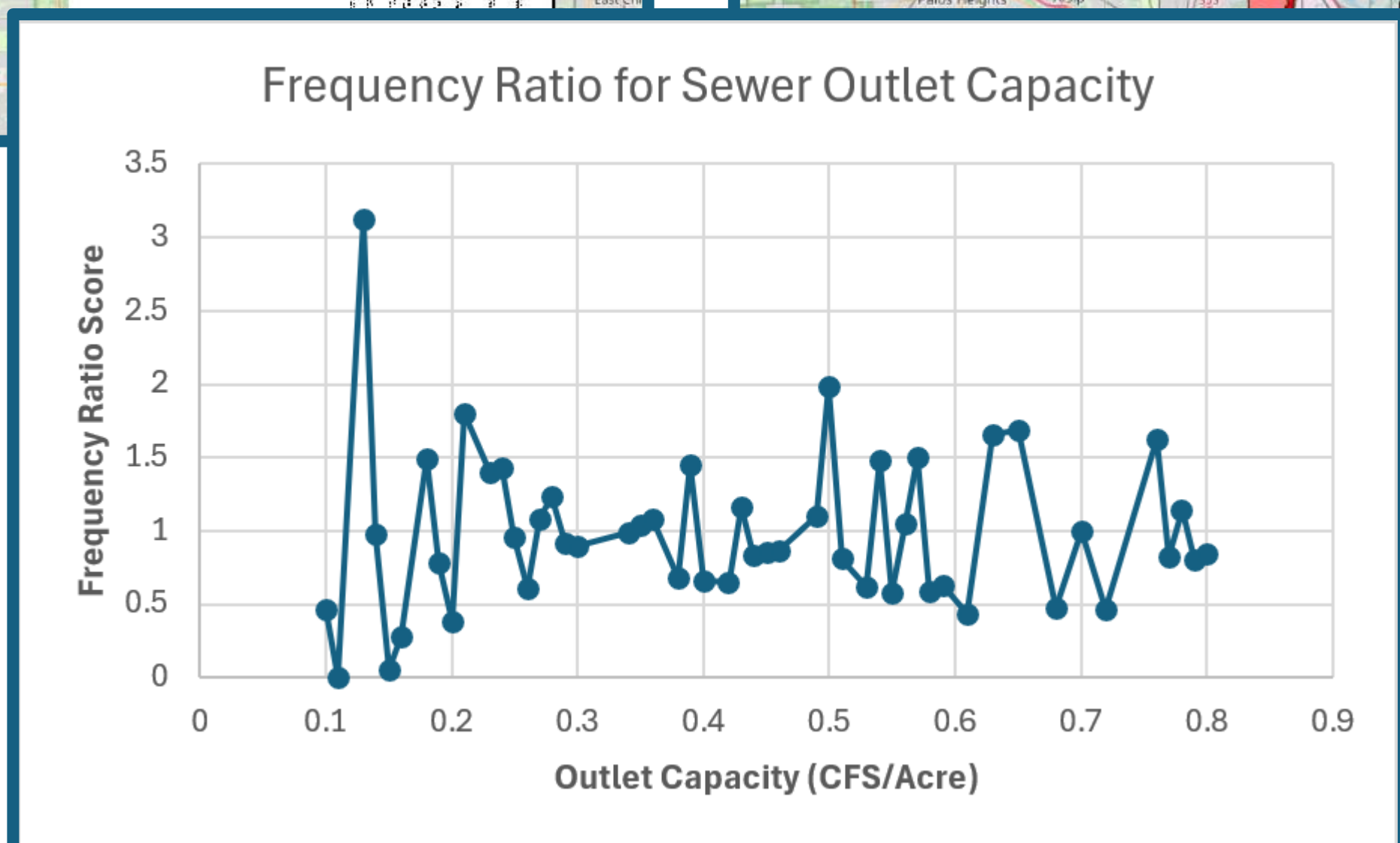
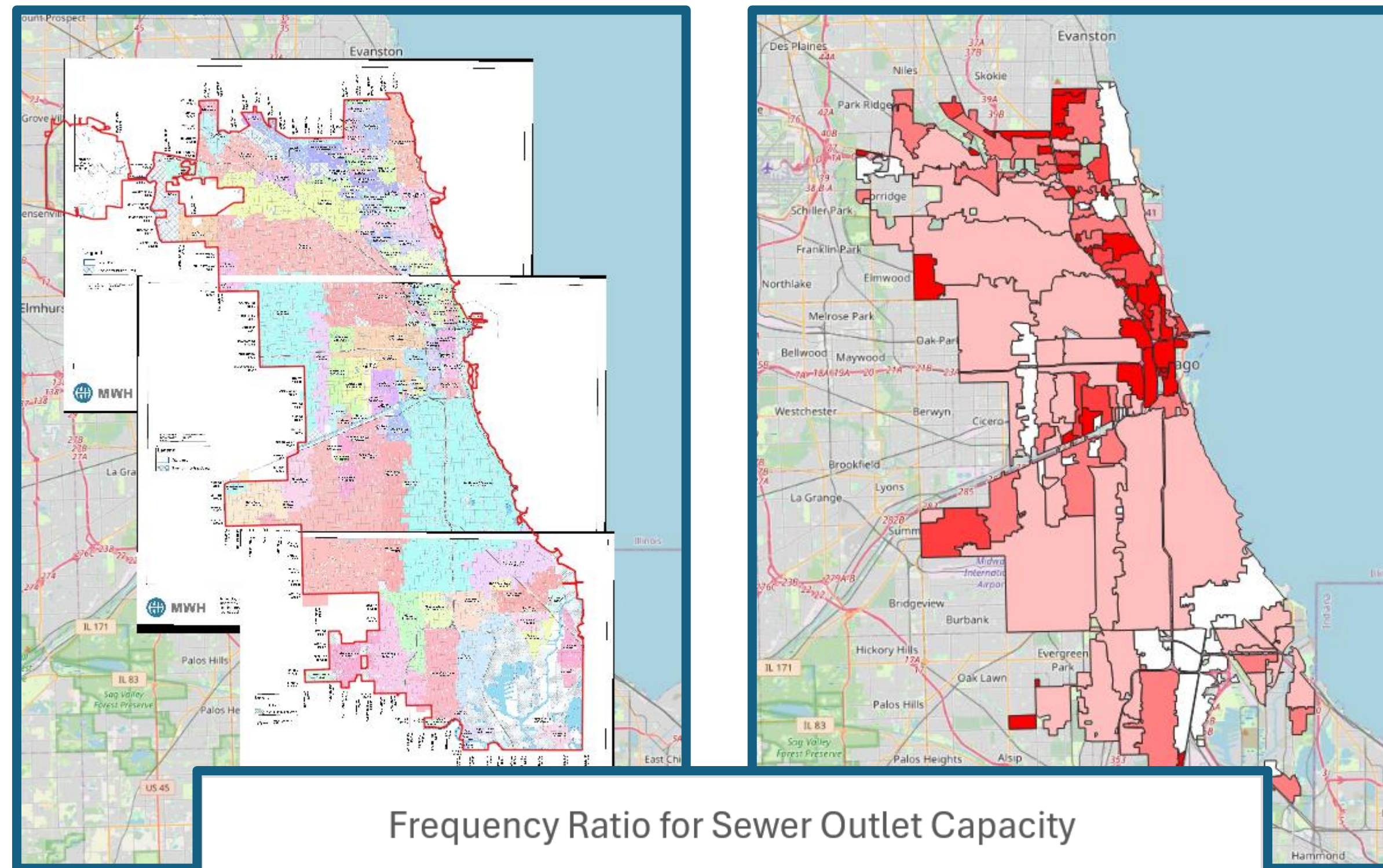
Combined Sewer Service Areas for the Urban Index

Factor	Categories	Percent (%) of Study Area	Percent (%) of Flood Locations	Frequency Ratio
Combined Sewer Service Area	Present	15.8%	27.4%	2.35
	Absent	84.2%	72.6%	0.75

$\frac{27.4\% \text{ of flood locations in "Present" category}}{15.8\% \text{ of study area is "Present" category}} = FR \text{ of } 2.35$

FREQUENCY RATIO FOR SEWER OUTLET CAPACITY

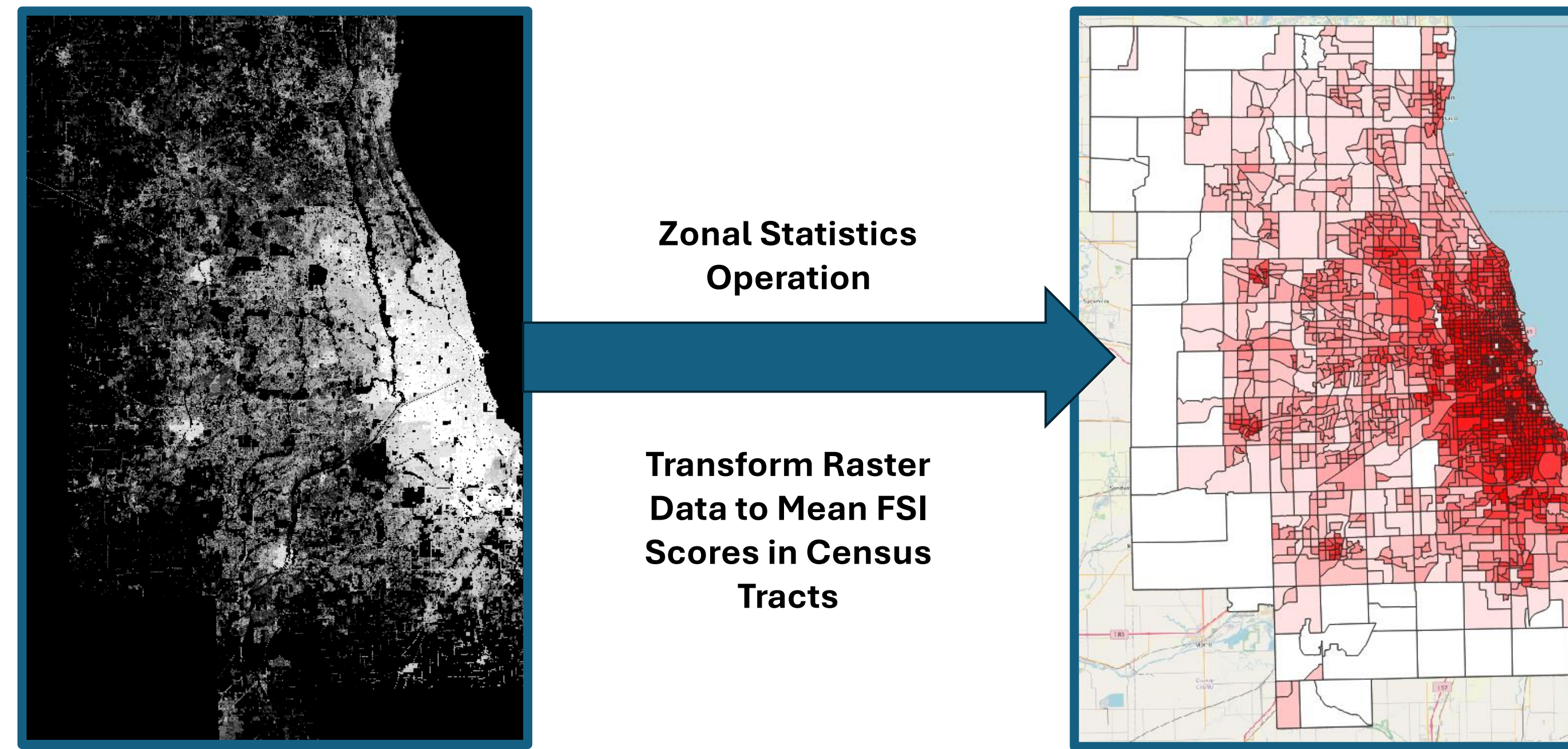
FR scores were calculated based on sewer release rate outlet capacity maps and flood locations identified by City of Chicago's 311 reports for water in the street and water in basements. The figures below show the georeferenced outlet capacity maps (left) and traced polygons (right) utilized for this calculation. The intensity of red in the right figure indicates increased sewer outlet capacity.



Higher sewer outlet capacity corresponded with lower FR scores, with fewer flood locations occurring in areas with higher sewer outlet capacity.

ZONAL STATISTICS

A **zonal statistics operation** utilizes spatial analytics to calculate statistics on cell values of a raster within the zones defined by another dataset. The zonal statistic geoprocessing tool was utilized to calculate mean FSI scores for the 1983 census tracts within CMAP's 7-county service area. The figures below show the input raster of FSI scores (left) and mean FSI scores (right). The intensity of red in the right figure indicates higher mean FSI scores for a census tract.



SOCIAL VULNERABILITY INDEX (SVI)

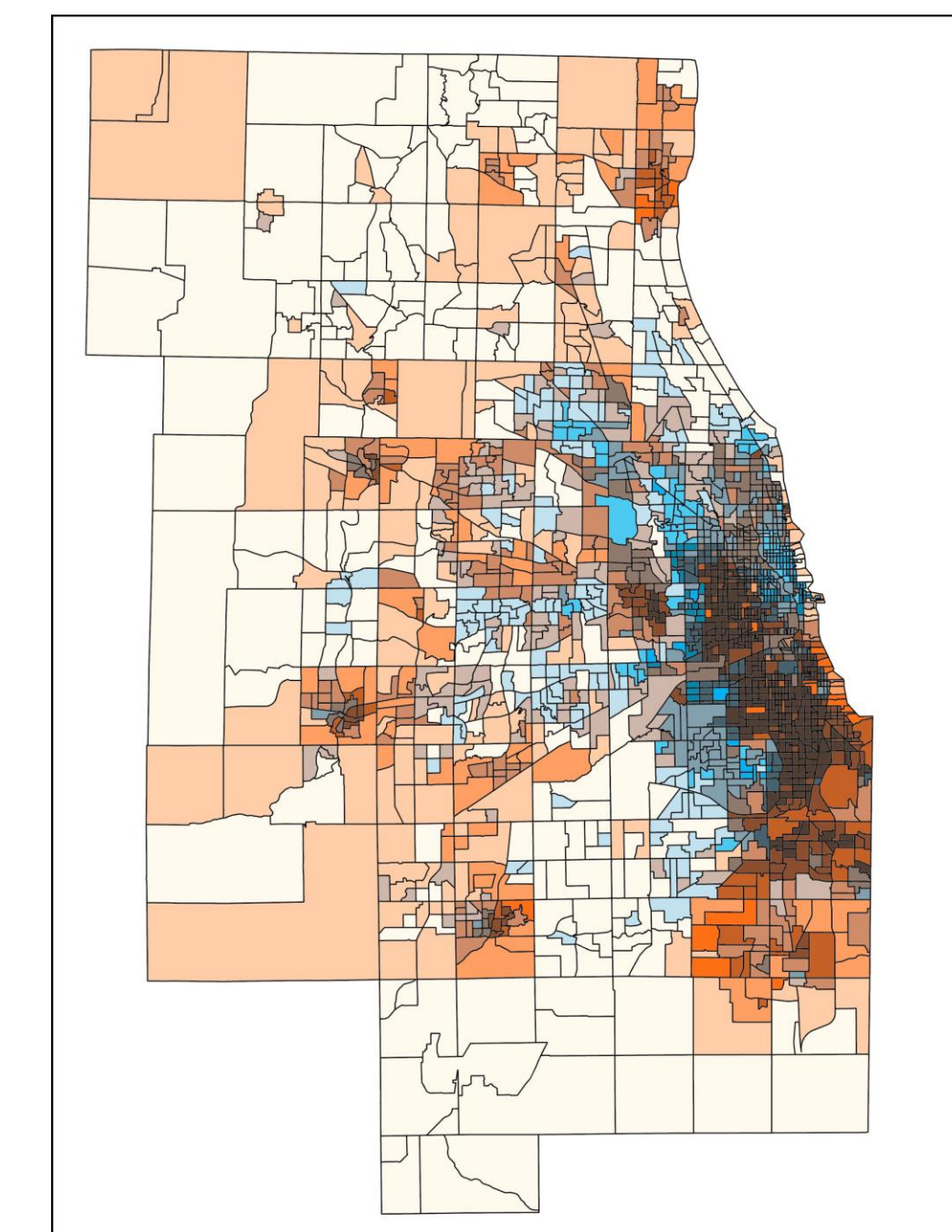
Social vulnerability refers to the potential negative effects on communities caused by external hazards. The CDC's SVI uses 16 census variables to help identify vulnerable communities. SVI data was merged with FSI data to better understand regional susceptibility to flooding and its relationship to increased vulnerability to flooding's negative effects. Census tracts in the top 10%, i.e., at the 90th percentile of values, are assigned a **flag** to indicate high vulnerability.

Flag	Description	Median FSI Score		Difference	Mann-Whitney p-Value
		Without Flag	With Flag		
F_POV	Beneath Federal Poverty Level	65.883	93.174	27.291	2.735e-32
F_UNEMP	Unemployed	63.633	93.996	30.363	3.157e-51
F_PCI	Per Capita Income	64.234	94.055	29.821	1.839e-47
F_NOHSDP	No High School Diploma	64.470	90.964	26.494	1.412e-29
F_AGE65	Aged 65 and Older	74.790	45.511	-29.279	7.682e-07
F_AGE17	Aged 17 and Younger	71.314	80.462	9.148	0.00133
F_DISABL	Persons with Disability	70.300	93.181	22.881	1.125e-11
F_SNGPNT	Single Parent Households	66.007	92.997	26.99	2.176e-29
F_MINRTY	Minority	61.111	94.715	33.604	1.208e-82
F_LIMENG	Limited English Speaking	63.367	89.291	25.924	3.089e-30
F_MUNUIT	Multi-Unit Housing	70.581	78.935	8.354	0.278
F_MOBILE	Mobile Homes	73.324	45.206	-28.118	6.596e-05
F_CROWD	Crowded Households	67.065	85.173	18.108	6.015e-13
F_NOVEH	No Vehicle	63.687	91.929	28.242	8.445e-32
F_GROUPQ	Institutionalized Group Quarters	72.205	76.345	4.14	0.714

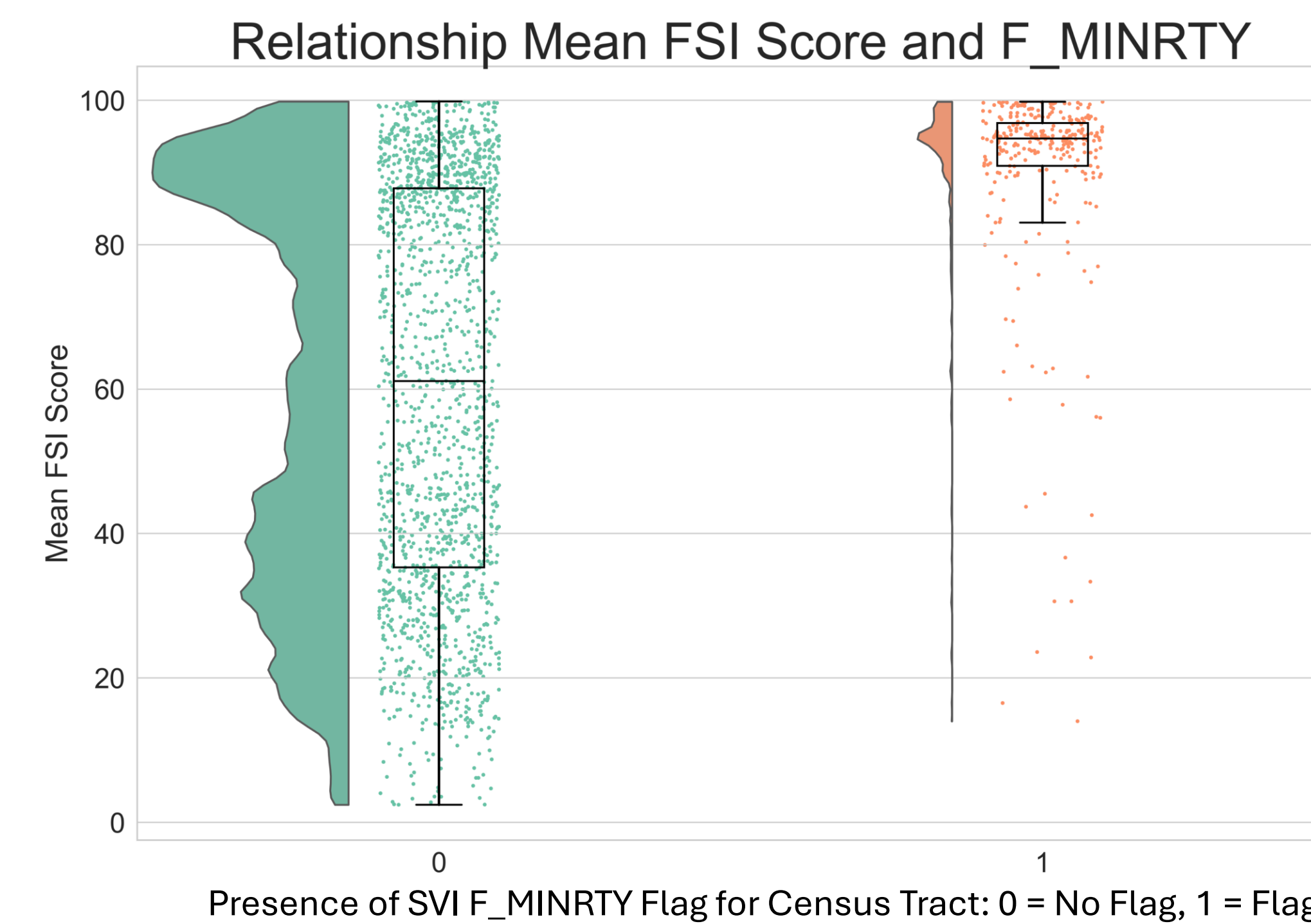
- Socioeconomic Status
- Household Composition & Disability
- Minority Status & Language
- Housing Type & Transportation
- Lower Median FSI Score w/ Flag
- Higher Median FSI Score w/ Flag

VISUALIZING FSI & SVI

Bivariate choropleth maps (left) are useful for visualizing two datasets across space. **Raincloud plots** (right) illustrate data distribution and key summary statistics, e.g. median and confidence intervals.



Bivariate Choropleth Map for Flood Susceptibility and Social Vulnerability

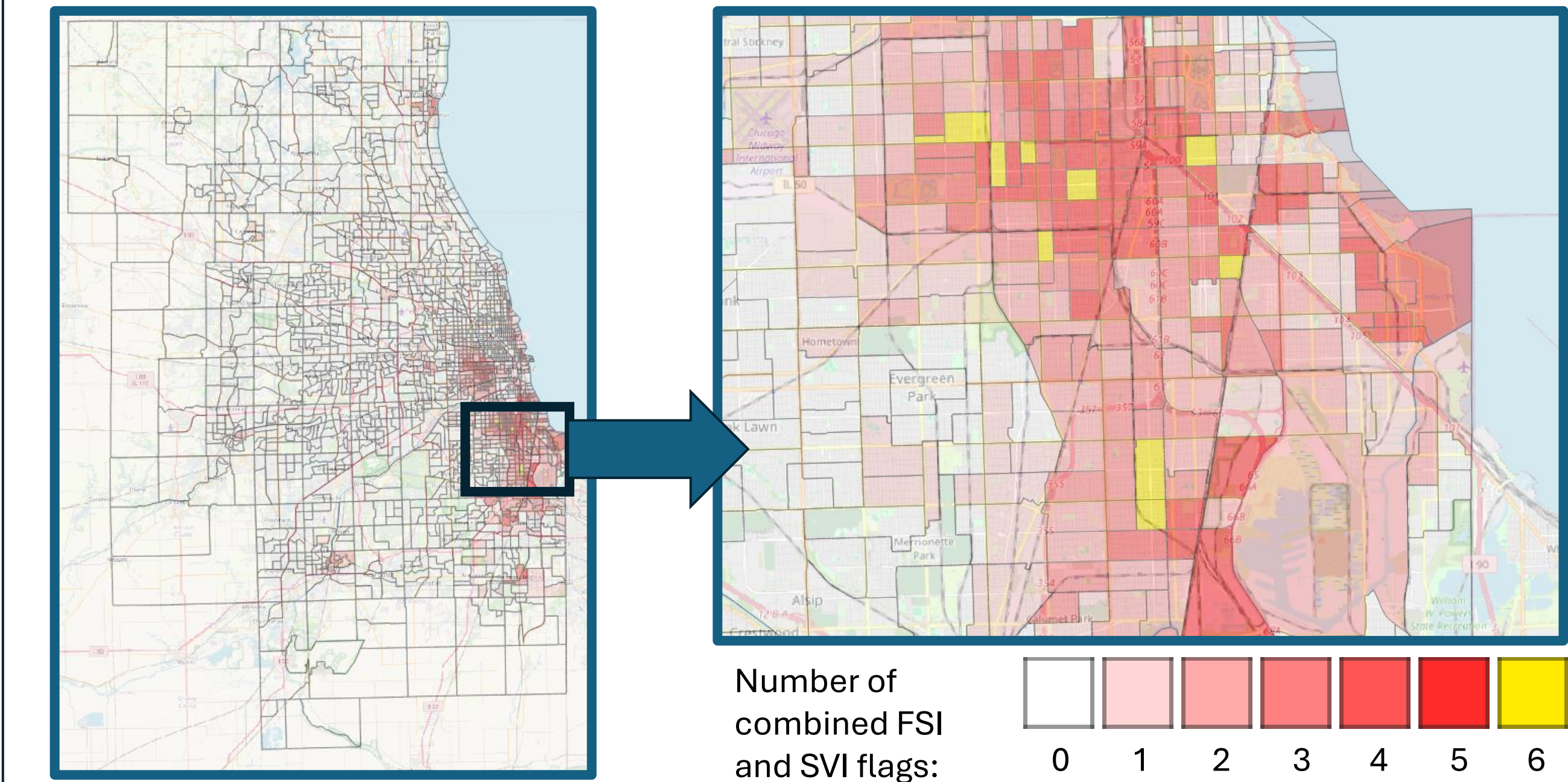


SUMMING FSI & SVI FLAGS

Census tracts in the top 10% of FSI scores were assigned a flag to indicate increased susceptibility to flooding. These FSI flags were summed with the SVI flags from the five variables with the greatest variance in FSI score between flag- and non-flag bearing census tracts, estimate percent population:

- Beneath Federal Poverty Level
- Unemployed
- Per Capita Income
- Minority
- No Vehicle Access

Of the 1983 census tracts subjected to analysis, 11 (~0.5%) census tracts held all six combined FSI and SVI flags. These census tracts were located primarily on the south and near southwest sides of Chicago.



DISCUSSION / IMPLICATIONS

The organizations responsible for the implementation of stormwater management policies require effective methods for the identification of regions that have increased susceptibility to flooding. Flood susceptibility mapping (FSM) is one such reliable method.

Equity and justice considerations must be made a part of stormwater management policies to include those that have been either previously excluded from planning and implementation conversations or have not been thoughtfully considered in terms of their increased socioeconomic vulnerability to the risks and hazards associated with flooding.

The union of flood susceptibility data with demographic data is recommended for the identification of regions both more susceptible to flooding and more vulnerable to suffering as attributed to flooding's negative effects.

SUMMARY / CONCLUSION

The Frequency Ratio (FR) methodology is a widely adopted method for assessing susceptibility to disasters. Limitations of the FR methodology include its lack of description of populations and their socioeconomic characteristics as they relate to potential suffering attributed to natural hazards. Combining the FR methodology with demographic data allows for datasets to work in tandem and help address environmental injustices related to inequitable stormwater management and resultant disparities in water equity.

• Five social vulnerability variables were identified as being uniquely related to increased susceptibility to flooding in the Chicago region.

• In line with the CDC's methodology for attributing "flags" to census tracts in the top 10% of values, census tracts in the top 10% of FSI scores were assigned a flag. The sum of this FSI flag with the flags of the five SVI variables described saw 11 of 1983 (~0.5%) census tracts bearing all six flags.

This approach is recommended for the identification of regions for stormwater management intervention, especially as it relates to environmental justice and the addressing of existing stormwater management inequities.

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