Spatial Distribution of Gun Violence in Philadelphia: A Census-Based Analysis

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Abstract: **Gun violence in Philadelphia is characterized by a strong geographic variation that aligns with underlying socioeconomic disparities. This project analyzes the spatial distribution of shooting victims using incident-level data sourced from the city's data portal (OpenDataPhilly) and demographic indicators from the 2022 ACS at the census-tract level. Shooting incidents were aggregated to tracts and normalized as shooting rates per 1,000 residents. A series of univariate choropleth maps, hot spot analysis, Moran's I (both global and local), and bivariate maps were used to examine spatial patterns and their socioeconomic correlates. The results after these analyses show that there are statistically significant clusters of shooting rates, with high-risk hot spots concentrated in central Philadelphia. The Bivariate mapping and scatterplot analysis reveal strong correlations between high shooting rates and high poverty, and high housing vacancy and low median income. Also, it was discovered that places with high average incomes exhibited low shooting rates. These findings demonstrate a clear spatial link between concentrated socioeconomic inequality and exposure to gun violence, highlighting the importance of neighborhood-level disparities in shaping risk.**

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I. INTRODUCTION

When it comes to public safety across major cities in the United States, gun violence is one of the most persistent public safety challenges. Philadelphia is, therefore, no exception. These geographic concentrations indicate that structural and socioeconomic conditions play a critical role in shaping risk (Sampson, 2012). Understanding where shootings occur and which neighborhood characteristics align with elevated violence is essential for targeted policy intervention, equitable resource allocation, and evidence-based planning (Cook & Ludwig, 2020).

Census data provide a standardized and spatially consistent framework for examining social inequality at the neighborhood scale (U.S. Census Bureau, 2023). Meanwhile, incident-level shooting datasets allow researchers to analyze violence with precise geographic accuracy, supporting fine-grained spatial analysis (Andresen & Malleson, 2014). Integrating these datasets within a GIS environment enables the measurement of spatial patterns, detection of statistically significant clusters, and exploration of how demographic and housing conditions relate to gun violence (Chainey & Ratcliffe, 2013).

This project will analyze shooting victims and their geographical and socioeconomic characteristics across the Philadelphia census tracts. It will evaluate spatial joins, population-normalized rate calculations, exploratory mapping, hotspot detection, spatial autocorrelation, and bivariate visualization to determine whether gun violence is spatially clustered and the relationship between such clusters and indicators of poverty, income, and housing vacancy. The findings support increased awareness and location-based intervention strategies by offering a spatially explicit understanding of inequality and gun violence risk within the city.

II. STUDY AREA

Philadelphia covers approximately 135 square miles and is subdivided into 384 census tracts, providing a detailed spatial framework for neighborhood-level analysis. The city has a population of about 1.6 million residents, reflecting its status as one of the largest and most densely populated urban centers in the United States (U.S. Census Bureau, 2023). For spatial socioeconomic studies, its diverse urban landscape—which includes residential, commercial, and industrial zones—creates significant neighborhood contrasts. Census tracts serve as the analytical unit because they offer consistent geographic boundaries and capture demographic and housing characteristics at an appropriate neighborhood scale. The city boundaries and tract divisions used in the spatial analysis are shown on the study area map below.

Fig 1 Study Area Map

III. DATA & METHODS

This study integrates incident-level shooting data with census-based socioeconomic variables to analyze spatial patterns of gun violence across Philadelphia census tracts. All processing and analysis were conducted in ArcGIS Pro using the NAD 1983 StatePlane Pennsylvania South FIPS 3702 projected coordinate system to ensure accurate distance-based computations, which is in line with spatial crime-analysis standards. Using local projection minimizes distortion across Philadelphia's urban extent and ensures correct interpretation of Euclidean distances in spatial statistics (Hot Spot Analysis, Moran's I).

➢ *Data Sources*

Three primary datasets were used:

- *Shooting Victims Data (2022–2024)*

✓ Source: OpenDataPhilly
✓ Format: CSV (with WGS 1984)
✓ Description: Incident-level shooting victims, including both criminal and police-involved shootings. Each record contains latitude/longitude, the time and year of occurrence, and victim attributes such as age, race, and wound.

- *Census Tract Boundaries*

✓ Source: U.S. Census Bureau TIGER/Line
✓ Format: Polygon feature class
✓ Description: 2020 census tract boundaries for Philadelphia.

- *Socioeconomic Data (American Community Survey 2022 5-Year Estimates)*

✓ Source: American Community Survey
✓ Attributes Used: Total population, median household income, poverty rate, housing vacancy rate (U.S. Census Bureau, 2023).

➢ *Data Cleaning, Integration, and Preprocessing*

- *Conversion & Standardization*

✓ ACS socioeconomic tables were joined to census tracts using the GEOID field.
✓ Attribute fields were checked for missing values, range errors, and inconsistencies.

- *Spatial Join (Aggregation)*

Spatial Join (Intersect) aggregated shooting incidents into their corresponding census tracts, producing a Join_Count field. This converted point events into tract-level totals, enabling neighborhood-scale analysis.

- *Rate Normalization*

To compare tracts of different population sizes, a standardized shooting rate was calculated:

$$ShootRate_{1000} = \left(\frac{Join\_Count}{TotalPopulation}\right) \times 1000$$

Normalization prevents large tracts from appearing disproportionately high simply because of population size and enables meaningful comparisons across neighborhoods (Weisburd, 2015).

- *Data Consistency Checks*

✓ All layers were stored as feature classes in one geodatabase.
✓ Census tract boundaries confirmed to match Philadelphia's administrative extent.
✓ All datasets were verified to have the same projections.
✓ GEOID-based joins were checked and confirmed for attribute alignment.

- *Final Analysis-Ready Layers*

✓ Tracts with Shooting Rate, that is, (all socioeconomic variables + shooting rate)
✓ Projected Shooting Points
✓ Cleaned Census Tracts

These layers served as inputs for hotspot detection, spatial autocorrelation, bivariate mapping, and correlation analysis.

➢ *Exploratory Univariate Mapping*
Univariate choropleth maps were created for:

- Shooting rate per 1,000 residents
- Poverty rate
- Median household income
- Housing vacancy

Each variable was classified using Natural Breaks (Jenks) to capture meaningful variation in skewed social and crime datasets (Chainey & Ratcliffe, 2013).

➢ *Hot Spot Analysis (Getis–Ord Gi*)*
Hot Spot Analysis was applied to the field with normalized shootings per 1000, conceptualized as Fixed Distance Bands and a Distance Threshold of 4,000 meters, ensuring tracts have enough nearby neighbors for meaningful hotspot detection.

The distance threshold reflects neighborhood-scale proximity patterns common in dense urban environments (Andresen & Malleson, 2014).

The hotspot statistic identified high–high clusters (hot spots), low–low clusters (cold spots), and nonsignificant areas at 90%, 95%, and 99% confidence levels.

➢ *Global Spatial Autocorrelation (Moran's I)*
Global Moran's I tested whether shooting rates displayed an overall clustered, dispersed, or random pattern.

Moran's I statistically confirms whether observed clustering exceeds what would occur by chance (Anselin, 1995).

➢ *Local Spatial Autocorrelation (LISA)*
Local Moran's I identified micro-scale patterns not captured by global measures. Output categories included:

- High–High clusters (violence concentration)
- Low–Low clusters (stable low-violence areas)
- High–Low / Low–High outliers (transitional areas)

This refined cluster detection strengthens the spatial interpretation of neighborhood-level violence.

➢ *Bivariate Mapping & Correlation Analysis*
Three bivariate maps assessed the spatial association between violence and socioeconomic conditions:

- Shooting Rate vs Poverty Rate
- Shooting Rate vs Housing Vacancy
- Shooting Rate vs Median Household Income

Bivariate color matrices allowed simultaneous visualization of two variables, revealing where social disadvantage coincides with elevated violence.

Scatter plots further quantified relationship strength and direction, linking spatial patterns to socioeconomic inequality (Sampson, 2012).

IV. RESULTS

The results of the analysis describe the spatial distribution of shootings in Philadelphia, the behavior of the underlying socioeconomic variables, and the statistical relationships identified between them. Each subsection references the specific maps and graphics that should accompany the narrative.

➢ *Shooting Rates per 1,000 Residents*

The tract-level shooting rate map revealed substantial spatial variation across Philadelphia. Several tracts exhibited extremely high per-capita shooting rates while others reported almost none. A clear concentration of elevated shooting rates appeared in the central and upper-north corridor of the city, with surrounding areas showing moderately elevated values and outlying tracts displaying lower or negligible rates. This pattern established the baseline understanding upon which all further statistical analysis was conducted.
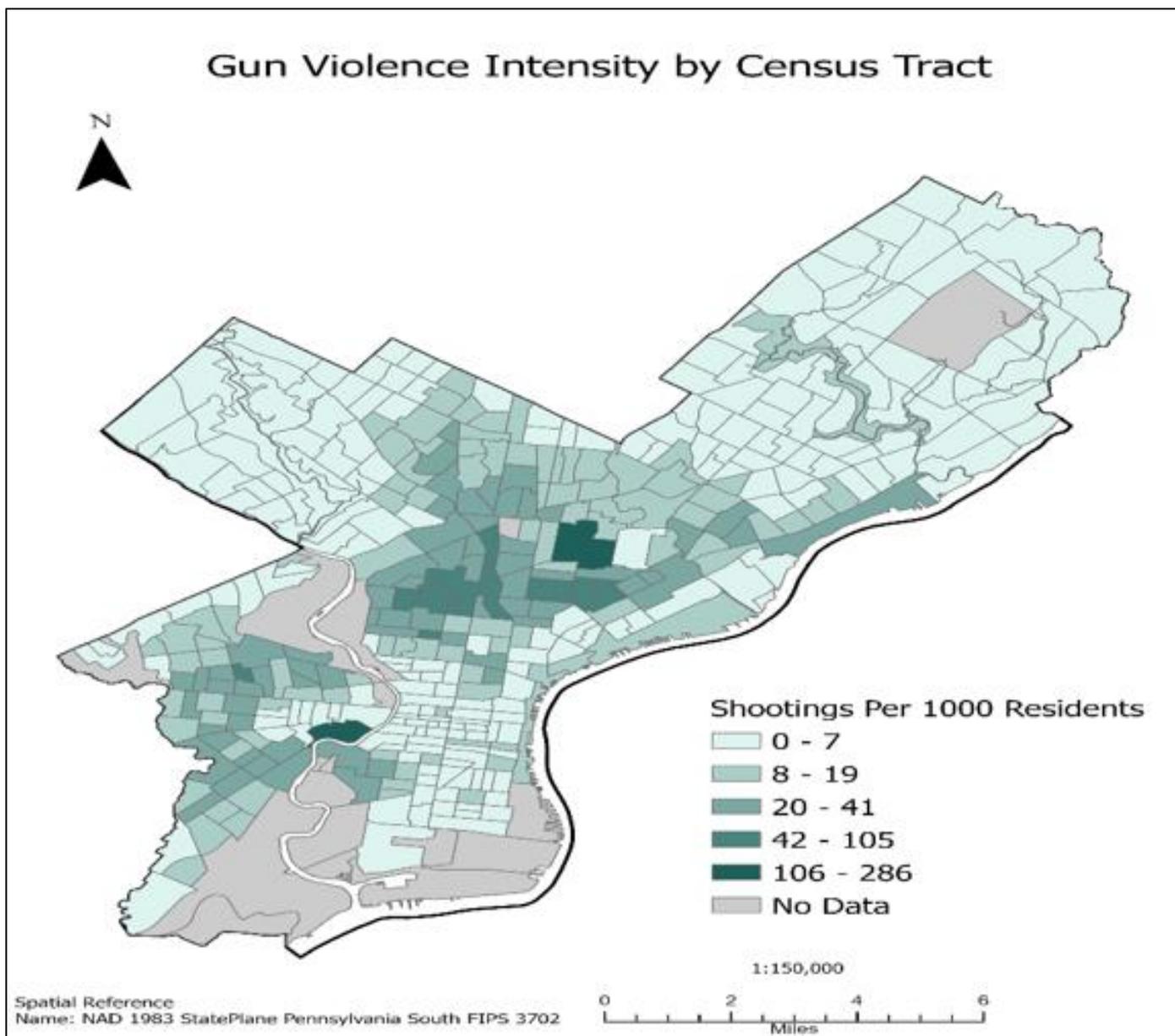

Fig 1 Univariate Choropleth – Shooting Rate per 1,000 Residents

➢ *Socioeconomic Indicators*

The socioeconomic variables displayed strong spatial structure. Poverty rates were highest in central Philadelphia, forming a band of disadvantaged neighborhoods. The distribution of housing vacancies showed that vacant clusters were concentrated mostly in the city's central and towards the south-west parts. Median income, on the other hand, exhibited an inverse pattern compared to poverty rates, with the lowest-income tracts primarily overlapping high-poverty areas. These maps visually indicated a possible correlation between higher rates of gun violence and socioeconomic disadvantage.
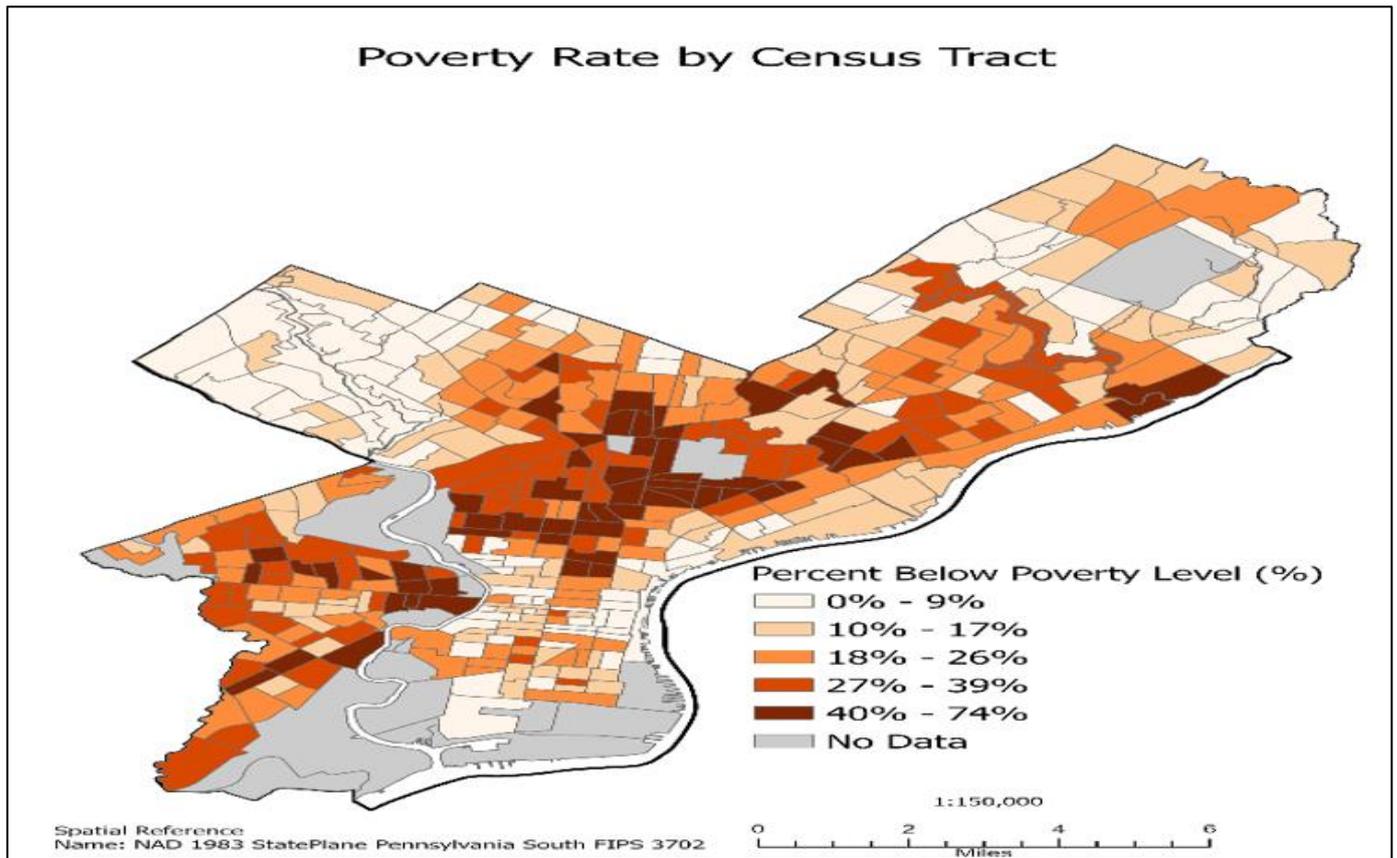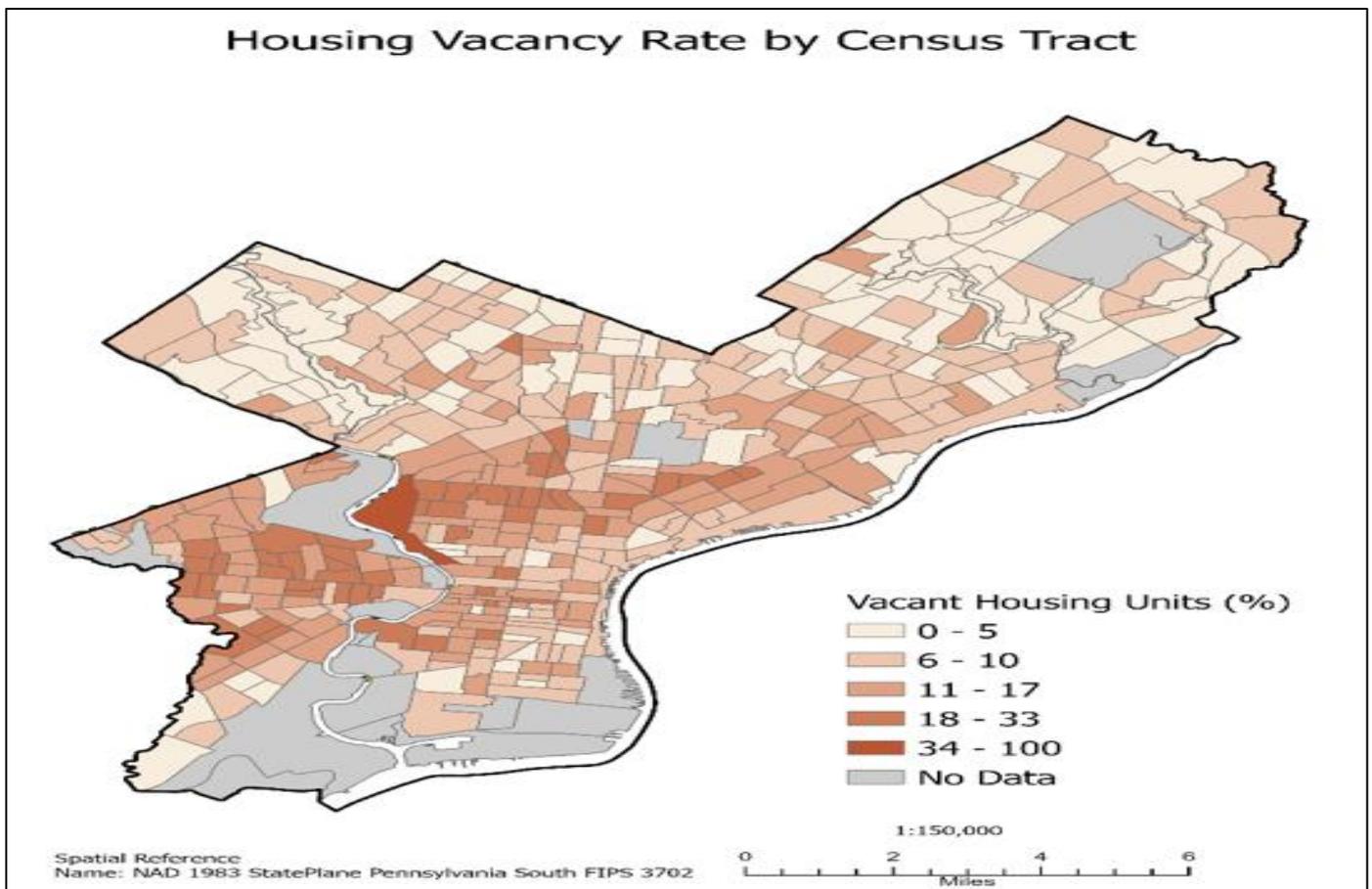
Fig 3 Univariate Choropleths – Poverty Rate

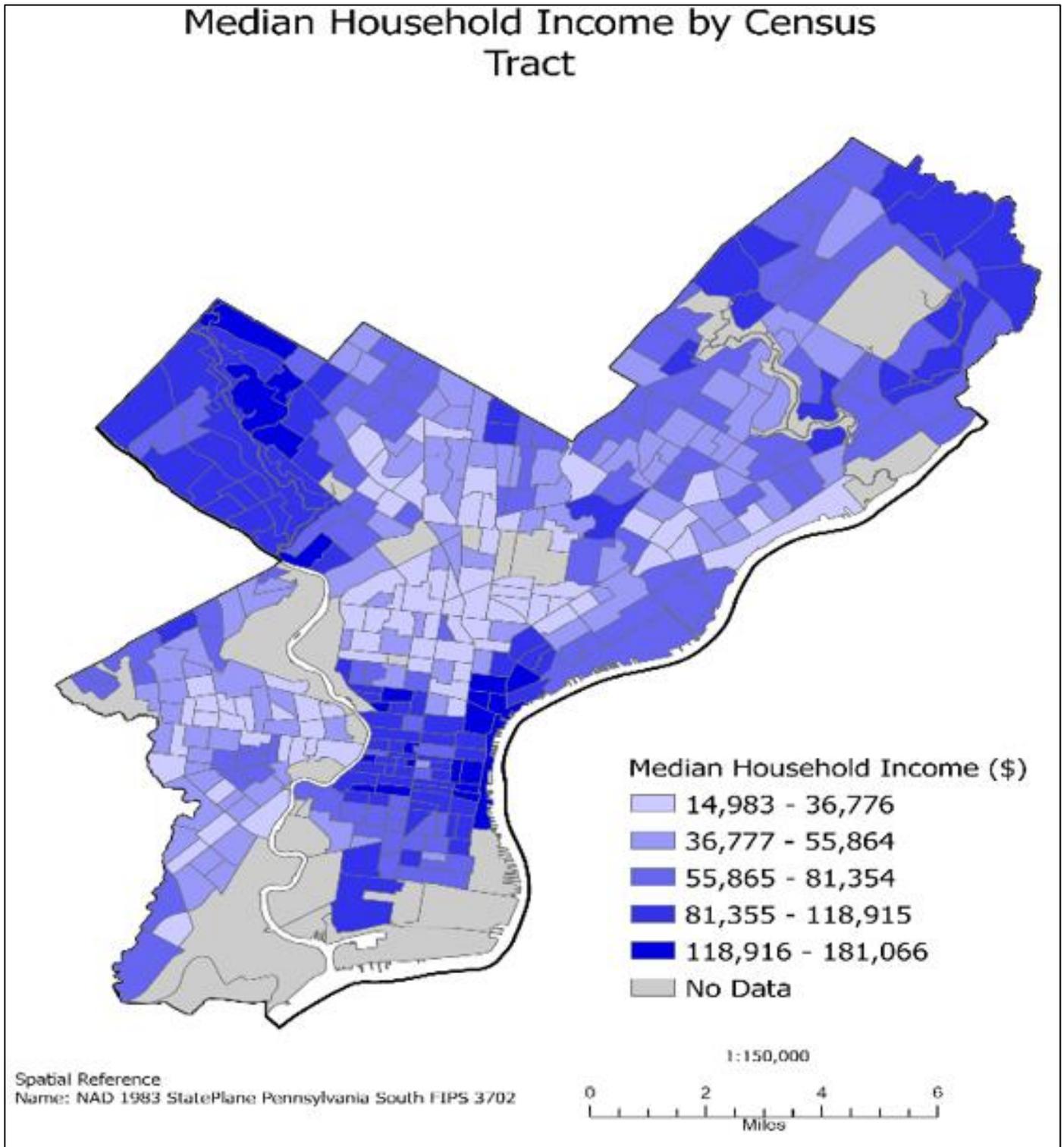Fig 4 Univariate Choropleth – Housing Vacancy

Fig 5 Univariate Choropleths – Median Household Income

➢ *Hot Spot Analysis*

The Hot Spot Analysis identified statistically significant clusters of high per-capita shootings in central Philadelphia. High-high clusters at the 95–99% confidence levels corresponded closely with the areas where the univariate map showed elevated shooting rates. On the other hand, a number of tracts in the western and northeastern parts of the city were identified as statistically significant cold spots, indicating geographical concentrations of low shooting rates.
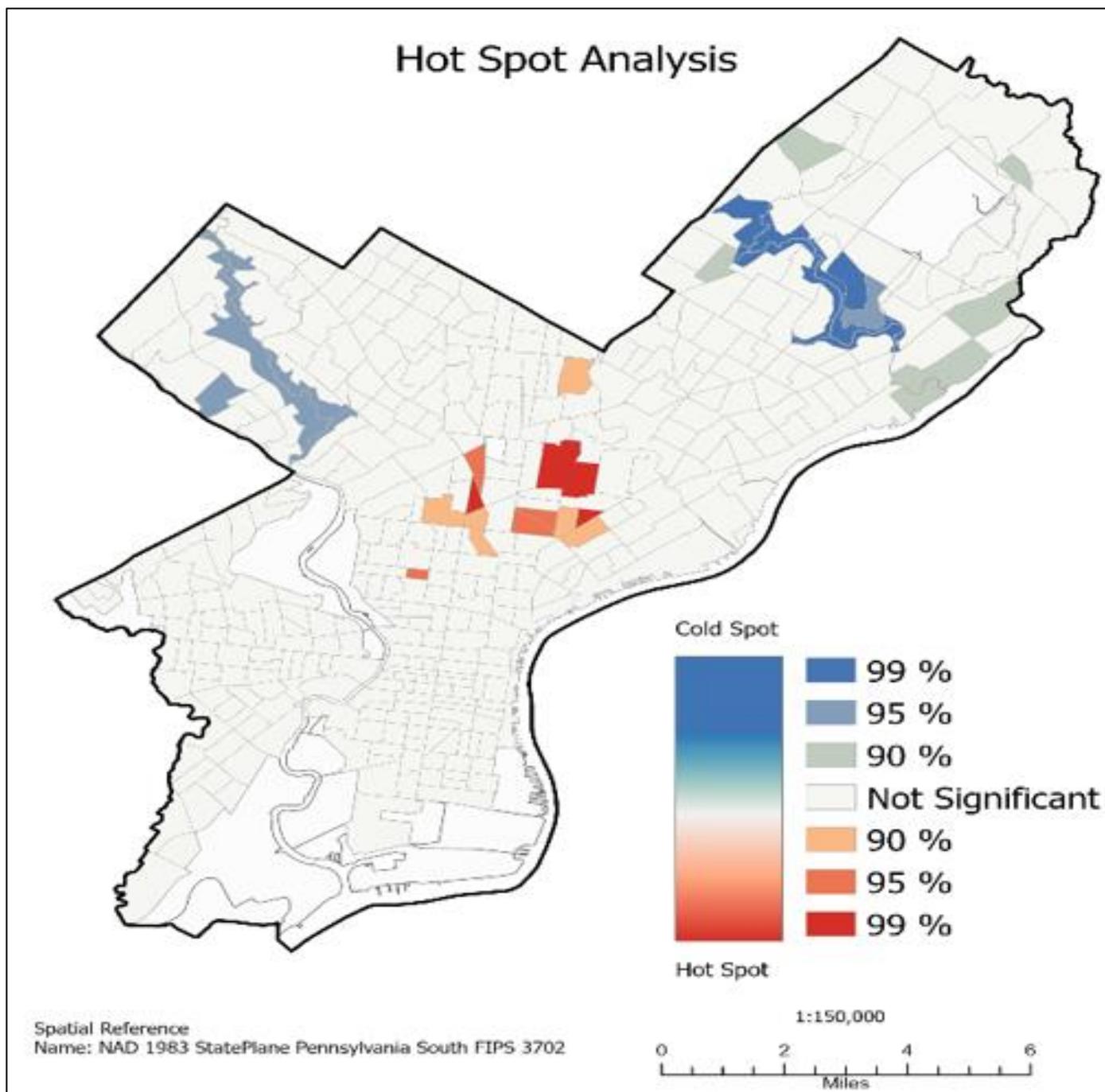
Fig 6 Hot Spot Analysis Result

➢ *Moran's I Spatial Autocorrelation*

Global Moran's I confirmed that shootings are not randomly distributed across space. The Moran's I value of 0.1629, with a z-score of 15.49 and a p-value < 0.01, provides strong statistical evidence of clustering behavior. This means that tracts with high shooting rates tend to be located near other high-rate tracts, reinforcing the results identified through the hot spot analysis.

➢ *Local Spatial Autocorrelation (Local Moran's I)*

The Local Moran's I analysis revealed clear neighborhood-scale clustering of shootings in Philadelphia. High–high clusters were concentrated in central and towards the southwest Philadelphia, while low–low clusters appeared in the far northeast and western and southern, reflecting the city's well-known socioeconomic contrasts. Several transitional outliers of low–high and very few high-low were also identified. These results refine the global autocorrelation finding by showing exactly where localized concentrations of violence occur, reinforcing the non-random spatial structure of shootings (Weisburd, 2015).
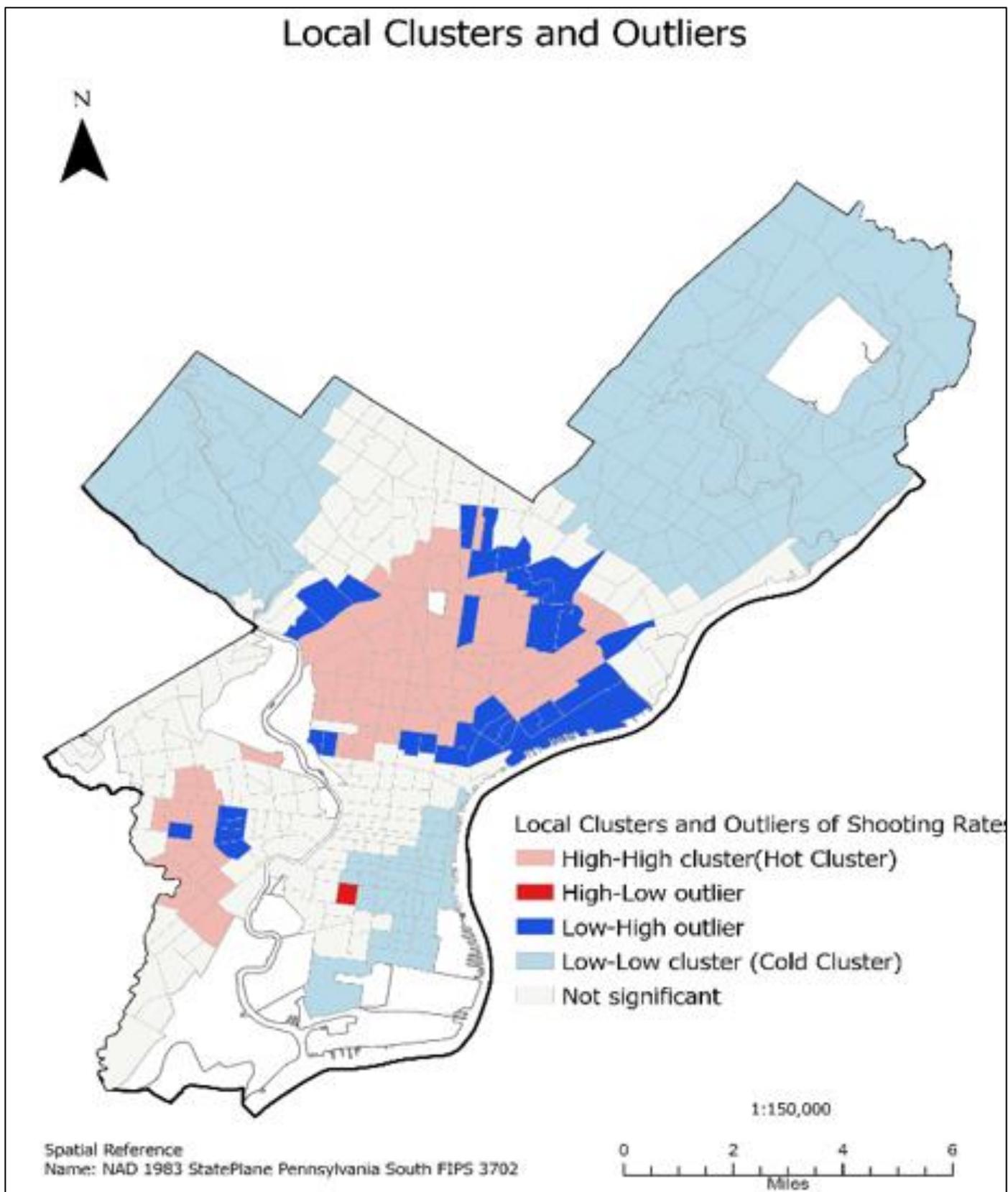
Fig 7 Local Moran's I Result

➢ *Bivariate Mapping and Correlation*

The bivariate maps revealed that tracts experiencing high shooting rates frequently coincide with high poverty, higher housing vacancy, and low median household income.

Scatter plots further supported these patterns, showing positive correlation between poverty and shootings, positive association between vacancy and shootings, and negative association between median income and shootings.
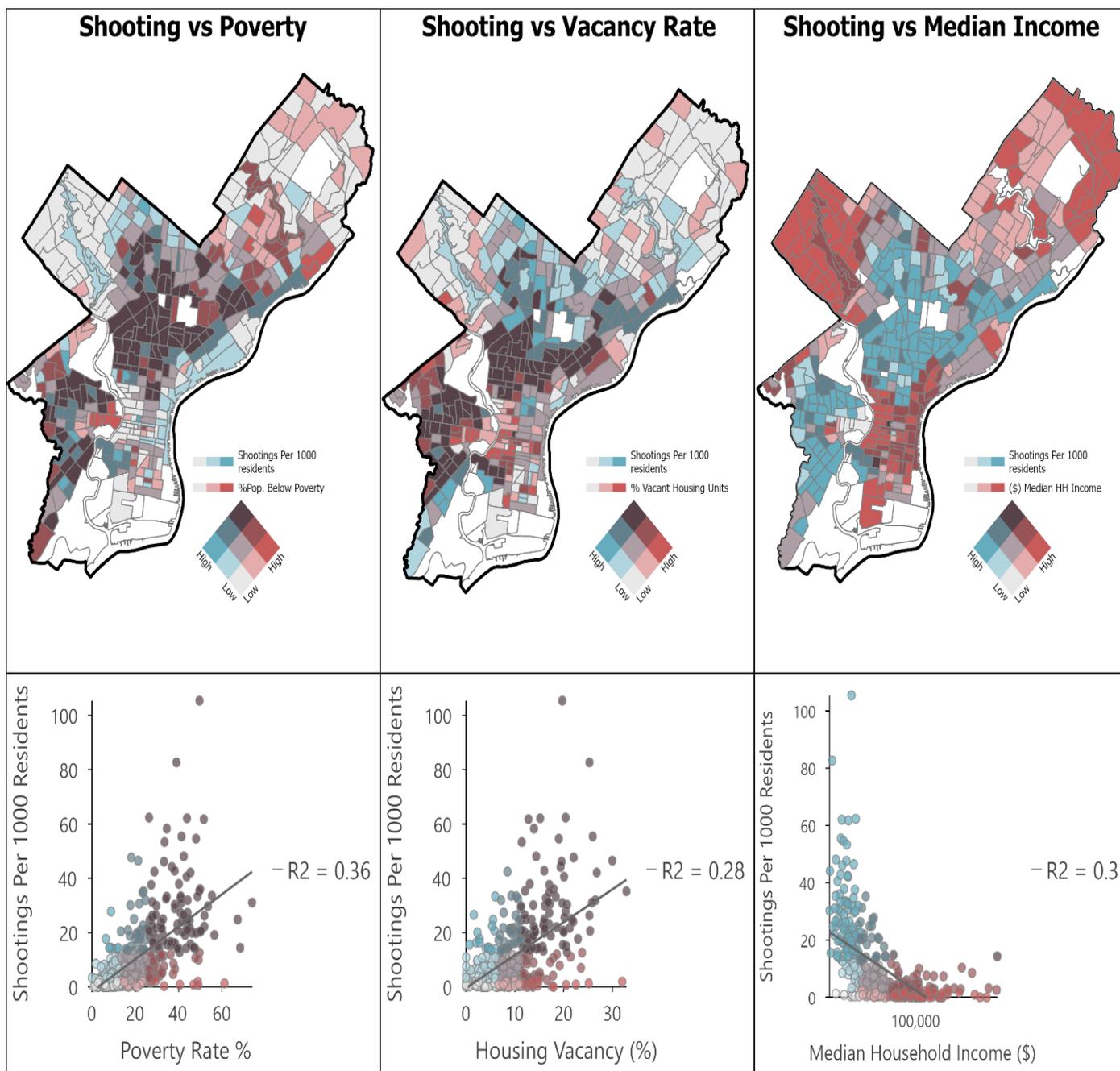
Fig 8 Bivariate Choropleths – Shootings vs Poverty, Shootings vs Housing Vacancy, & Shootings vs median Income

V. DISCUSSION

The spatial analyses demonstrate that gun violence in Philadelphia is significantly concentrated rather than uniformly distributed throughout the city. The hot spot map identifies central Philadelphia as a significant high–high cluster, and the Local Moran's I results confirm this same area as localized clusters of elevated shooting rates. In contrast, the far Northeast and far Western parts of Philadelphia consistently appear as low–low clusters, reflecting safer and more stable neighborhoods.

The bivariate maps illustrate how these spatial patterns correspond to underlying socioeconomic conditions. High shootings frequently align with high poverty in central Philadelphia, supported by a moderate positive correlation in the scatterplot ($R^2 = 0.36$). Housing vacancy follows a similar but weaker pattern at ($R^2 = 0.28$), with several high-vacancy tracts concentrated in the same corridor. Median income shows the opposite relationship: the lowest-income tracts overlap with the highest shooting rates, while higher-income neighborhoods in the northeast display consistently low numbers of shooting victims.

VI. CONCLUSION

Using GIS, this project analyzed the patterns of gun violence in Philadelphia in relation to the socioeconomic conditions at the neighborhood level. The outcomes of the Hot Spot analysis and Moran's I indicate that shootings are concentrated in certain areas of Philadelphia. Most of these areas are in central Philadelphia and have consistently higher

poverty, lower income, and more vacant housing. However, the northeastern and western areas of Philadelphia are more stable and have lower gun violence.

The bivariate maps and scatterplots emphasize these findings, showing strong positive associations between shootings, poverty, and vacancy, alongside an obvious negative relationship with median income.

Integrating spatial statistics with maps, therefore, clarifies where violence is concentrated and provides a solid foundation for place-based decision-making in Philadelphia.

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APPENDIX
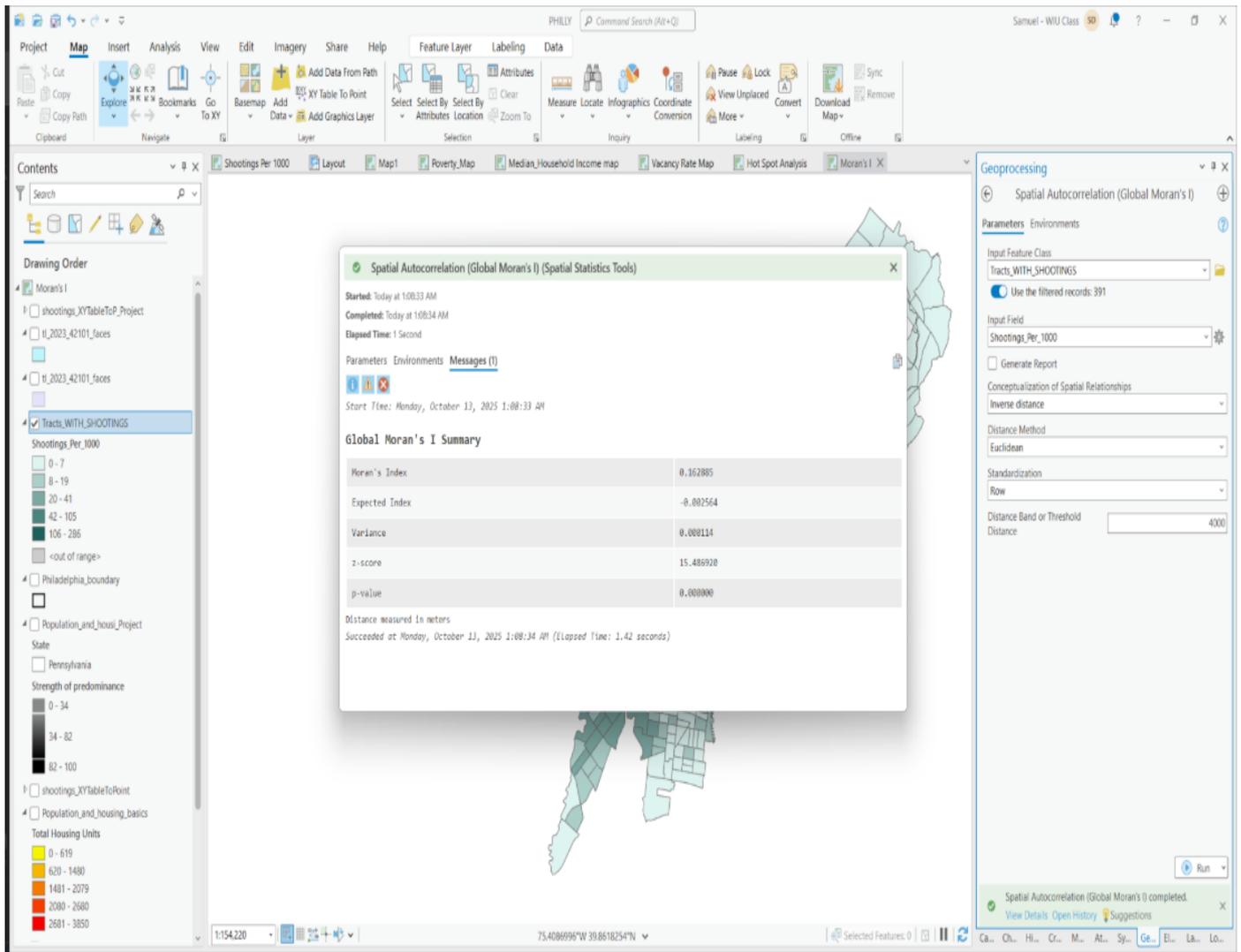
Results: Moran's I = 0.1629, z = 15.49, p < 0.01 → confirms that shooting rates are spatially clustered, not random, supporting the Hot Spot Analysis findings.