Relationship between extreme heat and violent crime in San Diego County: analysis and recommendations for crime prevention and climate change mitigation.

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Abstract

This study examines the relationship between extreme heat events and violent crime in San Diego County, providing a climate action analysis that focuses on climate mitigation and crime prevention. Through a comprehensive analysis utilizing space-time hot spot analysis in ArcGIS Pro, the study explores the underlying mechanisms connecting extreme heat to violent crime. While the analysis did not reveal a significant correlation between high temperature days and increased incidence of violent crimes, it did identify areas for targeted interventions to reduce both extreme heat events and violent crime incidents. The analysis of the current City of San Diego 2022 Climate Action Plan suggests that actions promoting the creation of inviting and safe public spaces and increasing tree canopy coverage can have dual benefits in addressing climate change and crime prevention.

1. Introduction

Climate change is no longer seen as just an environmental issue, but a complex societal issue with far-reaching implications. As the Earth's climate continues to undergo significant changes, understanding the various effects of climate change becomes critical to understanding its impact on all aspects of human society. One area that has attracted increasing attention is the relationship between temperature extremes and violent crime. Exploring this link not only reveals the broader societal impacts of climate change but also provides an opportunity to develop strategies to address environmental and social challenges.

To examine this relationship in depth for San Diego County, my research questions are:

1. Is there any spatial and temporal relationship between climate change and the occurrence of violent crime events?
2. What are the sustainable development strategies that can help reduce the warming effects of climate change and prevent crime?

Based on the result of exploring the relationship between extreme temperatures and violent crime, this study aims to contribute to the recommendation of investigating sustainable development strategies. The findings have the potential to inform policymakers, urban planners, and community stakeholders to develop proactive measures to enhance community safety, well-being, and the environment.

2. Literature Review

2.1 Climate Change

Climate change is the result of rising levels of greenhouse gasses in the atmosphere, including carbon dioxide (CO_2) released primarily through human activities such as the burning of fossil fuels and deforestation. These emissions are causing the Earth's temperature to rise and leading to serious consequences such as rising sea levels, more frequent and intense heat waves, droughts, floods, and other extreme weather events (EPA, 2023). Like many other areas of the world, San Diego is experiencing the heating effects of climate change. According to the San Diego County Department of Health and Human Services (HHSA) 2021 Annual Excess Heat Report, San Diego County experienced eight heat events in 2021, ranging from two to eight days, with the longest occurring in September. And over the past 15 years, average temperatures in San Diego County have trended upward, even in coastal areas, as evidenced by the increased number of overheating alerts (HHSA, 2022).

Climate change is causing an increase in extreme heat events for several reasons. Firstly, as greenhouse gasses trap more heat in the atmosphere, global temperatures are rising, which leads to more frequent and intense heat waves (Nymoen, 2022). Secondly, climate change is altering weather patterns, leading to changes in the distribution of heat and cold across the globe. This can lead to prolonged periods of extreme heat in some regions. Thirdly, climate change is causing changes in the natural systems that help regulate temperatures, such as changes in ocean currents and atmospheric circulation patterns. These changes can lead to more extreme and unpredictable weather patterns, including heat waves (United Nations Thailand, 2022).

2.2 Urban Heat island effect

The urban heat island effect occurs with the implementation of urban areas, where concentrated artificial buildings gradually replace natural vegetation. The absorption and re-release of solar heat from buildings to natural landscapes and water bodies result in higher temperatures in urban areas than in surrounding rural areas, which can be referred to as the urban "heat island" effect (EPA, n.d.). Typically, heat islands form throughout the day and become more pronounced after sunset due to the slow release of heat from urban materials (EPA, n.d.). According to the City of San Diego's Climate Equity Index (CEI), the urban heat island index layer shows an upward trend in heating effects as one moves inland to more densely populated and less green areas (City of San Diego, n.d.; Smith, 2022).

2.3 Temperature vs. Crime

The literature on temperature and crime suggests that there is a positive correlation between hot temperatures and certain types of crime, although the relationship is complex and varies across different types of crime, locations, and socioeconomic groups. In detail, Schinasi & Hamra in their article, "A Time Series Analysis of Associations between Daily Temperature and Crime Events in Philadelphia, Pennsylvania," state that there is an inverted, U-shaped relationship between temperature and crime, specifically "rates of crime, especially disorderly conduct and violent crimes, were highest when temperatures in the range of 22.6-28 °C. In particular, rates of violent crime and disorderly conduct were highest when temperatures were anomalously warm during cold months" (Schinasi & Hamra, 2017). However, because of the differences in climate and weather situations, Heilmann & Kahn in their research hold a different perspective. Based on their analysis of results of Los Angeles' spatially disaggregated daily crime data, they considered that on days when the daily maximum temperature exceeded 85 degrees Fahrenheit, on average, there was a 2.2% increase in overall crime and a 5.7% increase in violent crime (Heilmann & Kahn, 2019). Similar results were shown in a study by Ransom (2014), which considered the effects of model-based temperature increases and suggested that murders are expected to increase by 2.2% and aggravated assaults by 2.3% over the 90-year period from 2000-2009 to 2090-2099. Another study holds the identical view. The relationship between ambient temperature and violent crime by Tiihonen et al. (2017) gives the conclusion that a 2°C increase in average temperature will increase violent crime rates in non-tropical and non-subtropical regions by more than 3% if other factors remain constant.

2.4 Mechanism

According to studies, warmer temperatures are more likely to facilitate crimes because of the combination of the routine activity hypothesis and the temperature aggression hypothesis. Specifically, the routine activities theory states that three factors - motivated offenders, suitable targets, and the absence of capable guardianship - are necessary for a crime to occur (Cohen & Felson, 1979). In terms of seasonality, the theory highlights the importance of movements and congregations of populations. During the summer, the increase in public activities and large crowds create more opportunities for motivated offenders to find suitable targets who are vulnerable or distracted (Pinkerton, 2021).

The second theory is the temperature aggression hypothesis, which explains from the mental health perspective. It suggests that higher temperatures make people more irritated and aggressive (Anderson et al., 2000). This theory posits that uncomfortable temperatures can cause a significant increase in aggressive motivation. This is supported by studies that have found that aggression increases significantly when temperatures rise above certain thresholds (Baron & Lawton, 1972). In other words, as the temperature increases, so does the likelihood of aggressive behavior. This mechanism is particularly relevant in areas where temperatures are extreme, such as in cities with urban heat island effects.

The local economic condition and labor market can play a role in the relationship between climate events and crime. In particular, climate events that cause economic productivity to decline may create conditions that increase the value of engaging in conflict relative to the value of engaging in normal economic activity (Dell et al., 2012; Miguel et al., 2004). In other words, when people are struggling to make ends meet due to economic downturns caused by climate events, they may be more likely to engage in criminal activity as a means of obtaining resources.

State capacity is another potential mechanism linking climate events and crime (Hsiang et al., 2013). A competing hypothesis argues that a decline in economic productivity reduces the strength of government institutions, weakens their ability to suppress crime and insurgency, or encourages competitors to initiate conflict during these periods of relative vulnerability (Burke & Leigh, 2010; Buckley et al., 2010). In other words, when economic conditions decline due to climate events, governments may become less effective at maintaining social order and preventing criminal activity.

"Grievances" of inequity are also thought to play a role in the relationship between high temperature and crime. When climate events increase actual or perceived social and economic inequalities in a society, this could motivate attempts to redistribute assets, potentially leading to conflicts over resources (Hsiang et al., 2013).

Climate-induced migration and urbanization is another potential mechanism linking high temperature and crime (Hsiang et al., 2013). If a climate event causes large population movements or rapid urbanization, this could lead to conflicts over geographically fixed resources that are not climate-related but become relatively scarce where populations are concentrated (Jensen & Gleditsch, 2009). For example, if a large number of people are forced to move to a new area due to a climate event, this could lead to competition over resources like food, water, and housing, potentially resulting in increased criminal activity.

Finally, the logistics of human conflict may also be affected by climate events. For example, alterations to the physical environment due to climate events, such as changes in road quality, could affect where disputes or violence occur, potentially leading to increased criminal activity (Hsiang et al., 2013).

In conclusion, the mechanisms behind the relationship between high temperature and crime are complex and multifaceted. The routine activity hypothesis and the temperature aggression hypothesis are two theories that have been put forth to explain this relationship. Other potential mechanisms include economic downturns caused by climate events, climate-induced migration and urbanization, and the logistics of human conflict. While the exact nature of this relationship remains the subject of ongoing research, it is clear that high temperature has a significant impact on human behavior and can lead to an increase in criminal activity. As such, addressing climate change is not only important for environmental reasons but also for social and economic reasons.

3. Hypothesis

Numerous studies have indicated that extreme heat has a positive correlation with violent crime, as higher temperatures can lead to increased aggression and discomfort, contributing to elevated crime rates. Based on those studies and findings, I assume that extreme heat can increase the occurrence of violent crime in San Diego County. And the implementation of mitigation strategies for reducing extreme heat events and crime events should put more effort into the community that experienced the most heat waves and highest crime rates.

4. Methodology

In this study, the primary data processing was done in Rstudio to organize data into monthly groups and create shapefiles (Geographic Information System - GIS - layers). Then, the shapefiles were adjusted to the grid level to be analyzed in Esri's ArcGIS Pro. Thus, it was separated into 2 sections to finish the analysis, which was 1) data collection and processing, 2) space-time analysis in ArcGIS Pro

4.1 Data Collection and Processing

This step is a preparation stage for further exploration of extreme temperature and violent crime relationship analysis in ArcGIS Pro. The data collected included total violent crime data (by local agencies), total population data (by ZIP), and extreme temperature data (by ZIP) from 2010 to 2020 for San Diego County. The study period ended in 2020 due to the reason that not all data were currently available. Total violent crime data is monthly data extracted from the Automated Regional Justice Information System (ARJIS); total population is yearly data obtained from American Community Survey (ACS) 5-Year Estimates conducted by U.S. Census Bureau's Population Estimates Program; and extreme temperature data, including daily maximum and minimum temperature, were downloaded from the Climatology Lab's Gridded Surface Meteorological dataset (gridMET).

To facilitate the analysis, the shapefile of the Census Tracts with ZIP codes for San Diego County was downloaded from the SANDAG website as the base layer. Due to the difference in data collection level, a 5km x 5km grid layer was made in ArcGIS Pro based on San Diego's Census Tract for further disaggregation and aggregation.

To define the extreme heat events from extreme daily temperatures, the first thing I did was calculate heat wave definitions specific to each ZIP code to represent the extreme heat events, which was completed in Rstudio. Specifically, I calculated the 95th and 99th percentiles for both maximum and minimum temperatures within each ZIP code in the 2010 to 2020 time range, since using a 10-year range rather than a one-year range to calculate extreme heat events for each ZIP code provides a more comprehensive and reliable analysis of temperature patterns and the occurrence of extreme heat. After that, I accounted for the number of days exceeding the 95th percentile and 99th percentile respectively for both maximum and minimum temperatures each month for each ZIP code, in which I got four different scenarios of heat waves in each month for each ZIP code (Table 1). To take temperature errors into consideration and complete the analysis, the temperature's monthly standard errors were calculated for each ZIP code for both maximum and minimum temperatures.

Heat Waves	Definition	Indicator
Heat Wave 1 (HW1)	Days exceed the 95th percentile of extreme maximum temperature	Daytime warming
Heat Wave 2 (HW2)	Days exceed the 99th percentile of extreme maximum temperature	Daytime warming
Heat Wave 3 (HW3)	Days exceed the 95th percentile of extreme minimum temperature	Night warming
Heat Wave 4 (HW4)	Days exceed the 99th percentile of extreme minimum temperature	Night warming

Table 1: Heat waves with definitions and their representatives.

For the analysis of change in violent crime occurrence, it was transferred to the monthly violent crime rates analysis in grids instead of the total number of violent crime events to ensure the violent crime event comparison under the same population size. Thus, the total violent crime data and the total population data were joined to the grid layer respectively in Rstudio and calculated the crime rate per 1,000 people at the grid level.

After all of the above steps were finished, the calculated variables for extreme heat and violent crime rate were joined to the grid layer and exported as a shapefile for further analysis in ArcGIS Pro.

4.2 Space-time analysis in ArcGIS Pro

Getting the layer with heat waves and violent crime rates under the grid level, the Space-Time Analysis can be done in ArcGIS Pro. To transfer the change information in crime rates and four different heat waves scenarios with time, the tool "Create Space Time Cube by Defined Locations" was used first to convert my layer into a cube which treats the time information as the third dimension to form a temporal grid with field and spatial information in 3D. Specifically, I set the time step interval into 3 months and aligned it from

March 2010 to help better understand the seasonal change. For the field summary method, I calculated the mean of the crime rate and the sum of heat waves, filling the empty bins with the average value of space-time neighbors. After obtaining the space-time cube, the seasonal changes in violent crime rates and heat waves were visualized through “Visualize Space Time Cube in 3D” tool.

Given the 3D map, it might be hard to understand the meaning of standara. To get more information on the significant clustering of the map, the tool, Emerging Hot Spot Analysis, was used to summarize the analyzed fields’ emerging patterns, which is how the hot spots change with time (Esri, n.d.). Another hotspot analysis tool used to analyze the space-time cube is the Local Outlier Analysis. For this tool, it can help better identify the significant cluster and outlier compared to the neighborhood and all other bins in the context of both space and time (Esri, n.d.).

5. Findings and Analysis

This part is the result of the method part, which presented how heat waves and violent crime rates changed over time and how their hotspots intersected within San Diego county.

5.1 Heat waves changed over time

Applying the heat wave data to the "Create Spatial Time Cube by Defined Location" tool and visualizing it in 3D by "Visualize Spatial Time Cube", the cumulative heat waves at 3-month intervals for four different scenarios from March 2010 to December 2020 are presented in Figure 1. To classify the heat waves, I equally assigned the heat wave observations to five classes: no heat wave, short heat wave, moderate heat wave, long heat wave, and very long heat wave. The detailed classification of each heat wave is shown in Table 2 by number of days.

	HW1	HW2	HW3	HW4
No Heat Wave	≤ 0	≤ 0	≤ 0	≤ 0
Short Heat Wave	≤ 4	≤ 2	≤ 1	≤ 1
Moderate Heat Wave	≤ 10	≤ 6	≤ 3	≤ 3
Long Heat Wave	≤ 27	≤ 15	≤ 8	≤ 8
Extremely Long Heat Wave	≤ 300	≤ 125	≤ 225	≤ 175

Table 2: Heat Wave(s) detailed classification.

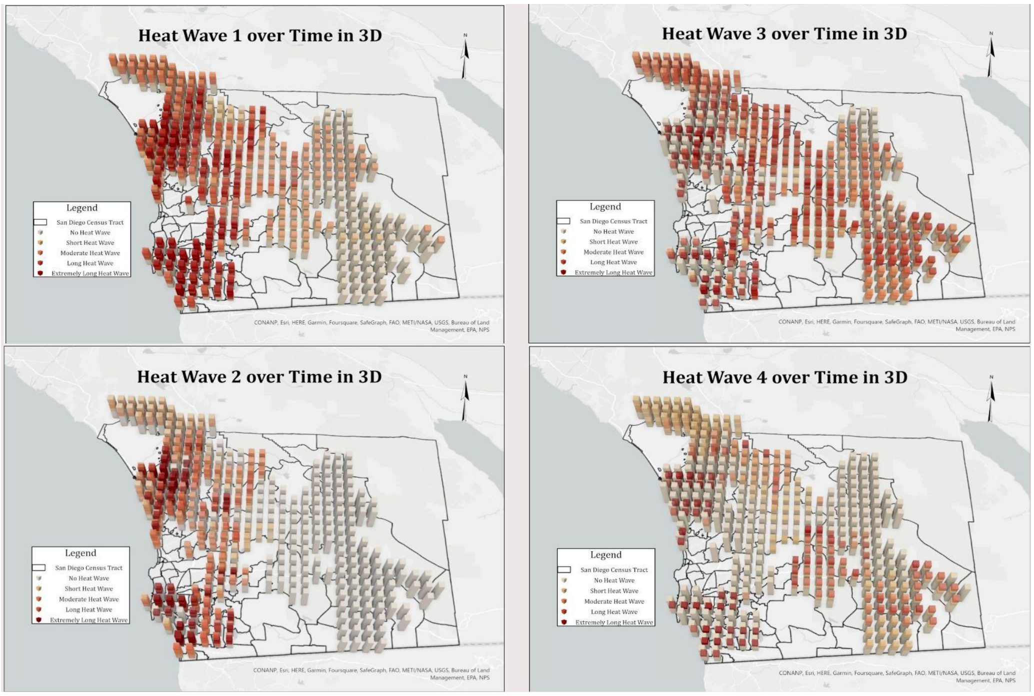

Figure 1: Heat waves 1-4 over time in 3D.

As mentioned in Table 1, the heat waves were categorized as HW1, HW2, HW3, and HW4. HW1 and HW2 represent the daytime warming that is mainly associated with the urban heat island effect, while HW3 and HW4 are indicative of the night warming effect, as they are derived from extreme minimum temperatures. The maps provided in this study depict the spatial and temporal distribution of heat waves, highlighting regions where and when temperatures have reached exceptionally high levels. Specifically, these temperature extremes are identified at the 95th and 99th percentiles for both daily maximum and daily minimum conditions.

Analysis of these maps, depicted in Figure 1, highlights distinct patterns associated with heat waves. The HW1 map shows that the incidence of heat waves decreases as one moves inland from the coast, suggesting that urban heat island effects are more prevalent in coastal areas. However, this map also shows a clear temporal pattern, with heat waves always occurring near the coast during the study period, and more recently heat waves occurring slightly inland. The HW2 map reinforces the prominence of heat waves along the coast, emphasizing their intensity and spatial concentration, but does not provide significant insight into temporal patterns. In contrast, the HW3 map shows a relatively uniform distribution of heat waves across San Diego County, lacking a clear pattern of extreme temperature events. It also shows that more nocturnal warming has been observed inland in recent years, while nocturnal warming in coastal areas occurred in the middle of the study period. Finally, the HW4 map is a more obvious representation of HW3, highlighting the concentration of extremely high temperatures in specific inland areas, which have recently been more prone to extremely high temperatures compared to coastal areas.

By integrating the information presented in Table 1 and the maps in Figure 1, a comprehensive understanding of the spatial characteristics and trends of heat waves emerges. The analysis suggests that daytime warming caused by the urban heat island effect is primarily concentrated along coastal areas. While night heat waves are more evenly distributed across the county as a whole, with certain inland regions experience more pronounced and localized episodes of extreme heat.

Emerging Hot Spot Analysis for Heat Waves

To examine the temporal dynamics of heat wave occurrences, an emerging hotspot analysis was employed to discern patterns of extreme heat, as visually represented in Figure 2. The Emerging Hot Spot Analysis tool assesses the z-scores, p-values, and classifications of each bin from space-time hot spot analysis, applies the Mann-Kendall trend test, and then leverage the assessment of how the hotspots of each column varied over time (Esri, n.d.). Figure 2 displays three distinct patterns that were identified: consecutive hotspots, sporadic hotspots, and no pattern detected. Consecutive hotspots pertain to locations exhibiting a single uninterrupted run of at least two statistically significant hotspots during the final time-step intervals. Sporadic hotspots indicate statistically significant hotspots in the final time-step interval, accompanied by intermittent occurrences in previous intervals. Conversely, the designation "no pattern detected" denotes columns that do not conform to the defined hot or cold spot patterns.

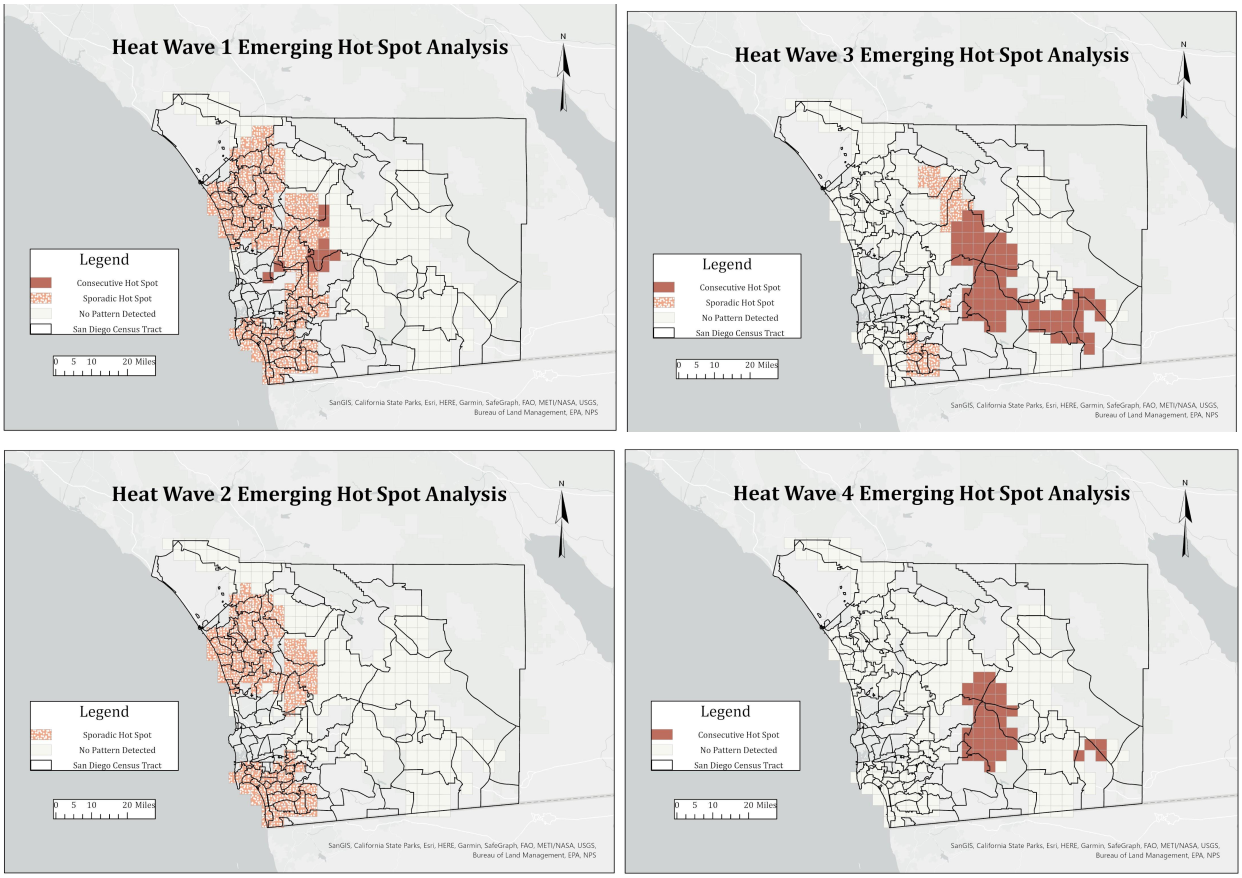

Figure 2: Heat Wave 1-4 Emerging Hot Spot Analysis in San Diego County.

The analysis of the HW1 map reveals intermittent occurrences of extreme heat events along the coastal area, extending approximately 20 miles inland. Additionally, several localized spots within the central region of San Diego County exhibit uninterrupted heat waves. This suggests that these areas experienced sustained periods of elevated temperatures. Similarly, the HW2 map displays a comparable heat wave pattern along the coastal region, albeit without the presence of consecutive hotspots. This suggests that the central area of San Diego also encountered extreme heat waves, although the intensity of these events may be lower compared to those observed in the coastal areas.

Compared to observations from the HW1 and HW2 maps, the HW3 and HW4 maps show a distinct nocturnal heat wave pattern. The HW3 map shows a continuous distribution of heat waves inland, approximately 20 miles from the coastline, particularly in the central and extreme southeastern portions of San Diego County. In addition, the sporadic hot spots identified on the map indicate intermittent nighttime warming in the southern near-coastal region and in the central inland region to the north. Analysis of the HW4 maps reinforces the observation that nighttime warming occurs primarily in the south-central interior.

Synthesizing the findings from Figure 1, a compelling conclusion can be drawn regarding the distribution of extreme heat events. It becomes evident that extreme heat occurrences consistently transpire in coastal areas, exhibiting an intermittent pattern. Conversely, the inland regions display a pronounced night warming effect, characterized by consecutive heatwave events that have been particularly prevalent in recent years. The observed situation presents an intriguing scenario where coastal areas, typically expected to be cooler due to their proximity to water bodies and water's high heat capacity, exhibit vulnerability to extreme heat. Further investigation and study in these areas are warranted to gain a deeper understanding of the underlying mechanisms and drivers.

5.2 Violent Crime rate changed over time

The application of the Create Space Time Cube by Defined Locations tool also enabled the analysis of violent crime rate data, which was subsequently visualized in a 3D format using the Visualize Space Time Cube tool. Figure 3 showcases the averaged violent crime rate at 3-month intervals, spanning from March 2010 to December 2020. To ensure an equitable representation, the data was classified using a quantile-based approach, resulting in an equal distribution of observations across the five classes.

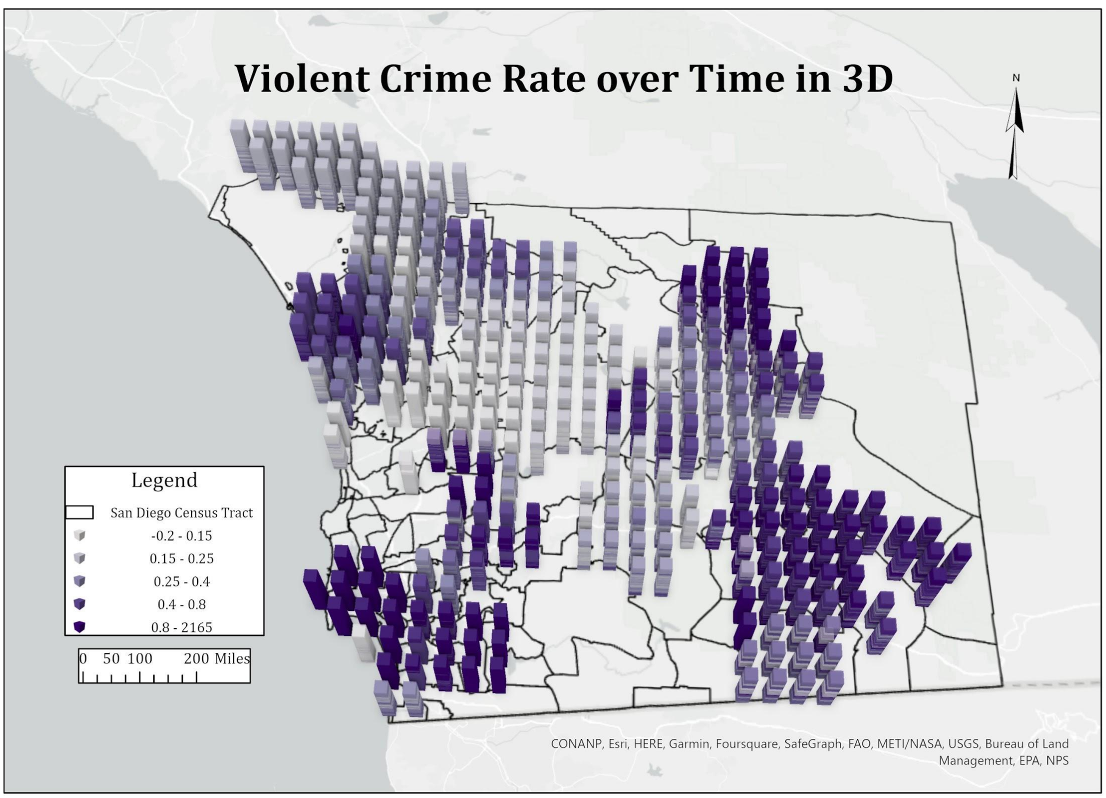

Figure 3: Violent Crime Rate over Time.

Based on the observed map, it is evident that there is a concentration of higher violent crime rates in the inland areas and southern coastal regions. However, it is important to note that the quantile classification employed in the analysis resulted in the last class having a significantly wider numeric range of crime rates compared to the other classes. This wide range of values in the last class may hinder the ability to draw conclusive insights from this particular class alone. Thus, to overcome this limitation and gain more meaningful insights, hot spot analyses were conducted.

Emerging Hot Spot Analysis for Violent Crime Rate

Figure 4 illustrates the results of the emerging hotspot analysis conducted on the map depicting violent crime rates. The analysis yielded an encouraging trend, with hotspots categorized as "decreasing hotspots" in a small area of the southern coastal region and only one grid identified as "sporadic hotspots" next to the cluster's region. This situation suggests that while most of San Diego County does not show a clear pattern, the diminishing hotspots marks a decrease in concentrated high-crime areas. In addition, only one grid was identified as an intermittent hotspot, indicating that high crime rate in that particular area occurs sporadically rather than consistently.

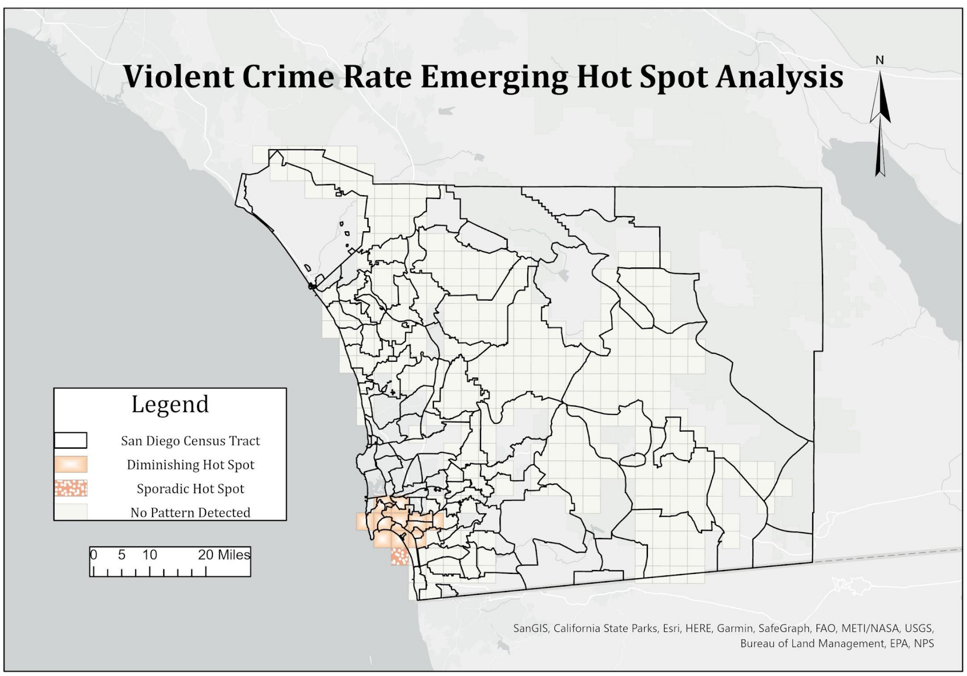

Figure 4: Violent Crime Rate Emerging Hot Spot Analysis.

Local Outlier Analysis for Violent Crime Rate

The Local Outlier Analysis was utilized to examine the clustering and presence of outliers within local violent crime hot spots, as demonstrated in Figure 5. Specifically, the Local

Outlier Analysis tool utilizes a space-time NetCDF cube created from data aggregation or defined locations, applying the [Anselin Local Moran's I statistic] to identify significant clusters and outliers in the study area, providing pseudo p-values, type codes, and the statistical significance of the index values based on the number of permutations (Esri, n.d.).The analysis identified five distinct patterns: "Never Significant," "Only High-High Cluster," "Only Low-Higher Outlier," "Only Low-Low Cluster," and "Multiple Types."

The "High-High Cluster" pattern signifies bins with a higher crime rate compared to other bins, and their neighboring bins also exhibit higher rates than the surrounding neighborhoods. Conversely, the "Low-Higher Outlier" pattern indicates bins with a lower crime rate than other bins but with neighboring neighborhoods experiencing higher rates. The "Low-Low Cluster" pattern represents bins with lower crime rates than other bins, and their surrounding neighborhoods exhibit similar lower rates. Finally, the "Multiple Types" pattern refers to a combination of different clustering and outlier patterns present within the analysis.

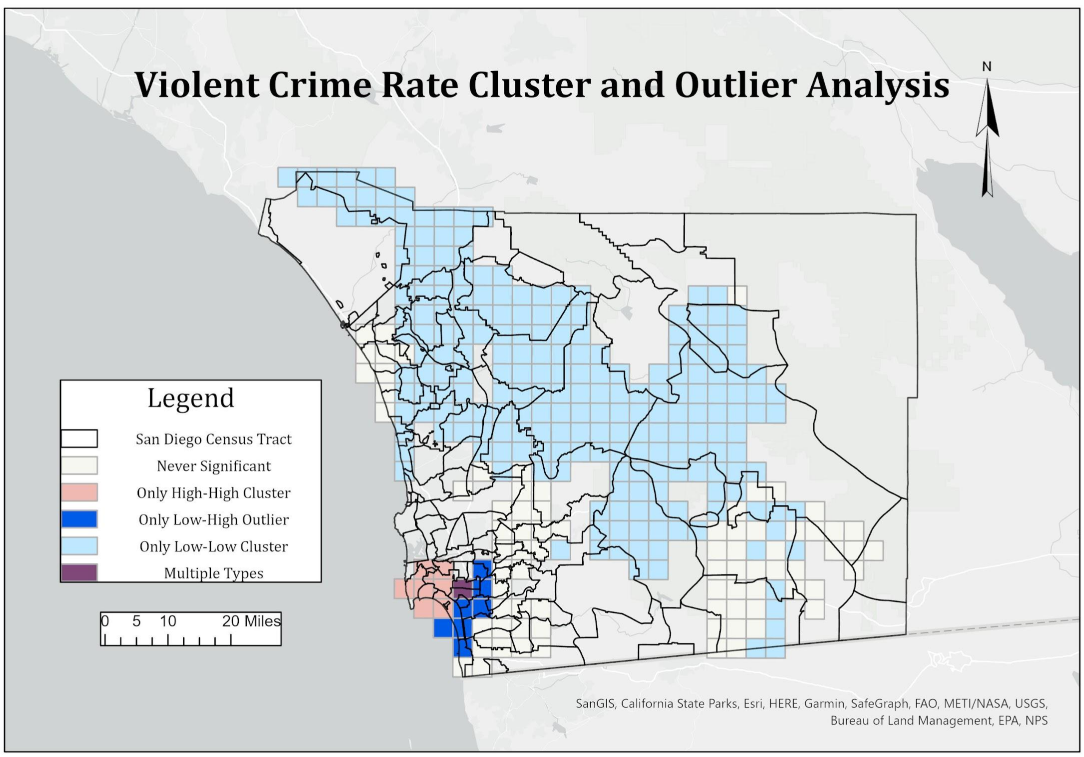

Figure 5: Violent Crime Rate Cluster and Outlier Analysis.

Based on the observed map and the findings from the Local Outlier Analysis (Figure 5), it is evident that the hot spots of violent crime exhibit a similar pattern to the results obtained from the emerging hot spot analysis. These hot spots are primarily concentrated in the southern coastal area of San Diego County. Notably, the most significant crime rate area is located in the southern coastal region, specifically within the class identified as "High-High Cluster." This class represents areas with both a higher crime rate compared to surrounding areas and a higher crime rate within their neighborhood. In addition, the presence of the "Low-High Outlier" class distributed around the "High-High Cluster" class indicates that these areas have a high likelihood of experiencing violent crime events despite having a lower crime rate compared to surrounding areas. This suggests a potential risk or vulnerability in these specific locations.

The combined findings from the emerging hot spot analysis and the Local Outlier Analysis, shown in Figure 6, reveal a significant insight: although there is a declining trend in the overall crime rate, this does not mean that crime events are completely absent, particularly within the identified hot spot areas. This suggests that even in areas where crime rates have declined, they are still high compared to other areas. Thus, it highlights the significance of prioritizing crime prevention and intervention efforts in the southern coastal area, specifically within the "High-High Cluster" and neighboring "Low-High Outlier" regions. Despite the decreasing crime rates, these areas still require targeted attention to address the underlying factors contributing to elevated crime rates and ensure the long-term safety and security of the affected communities.

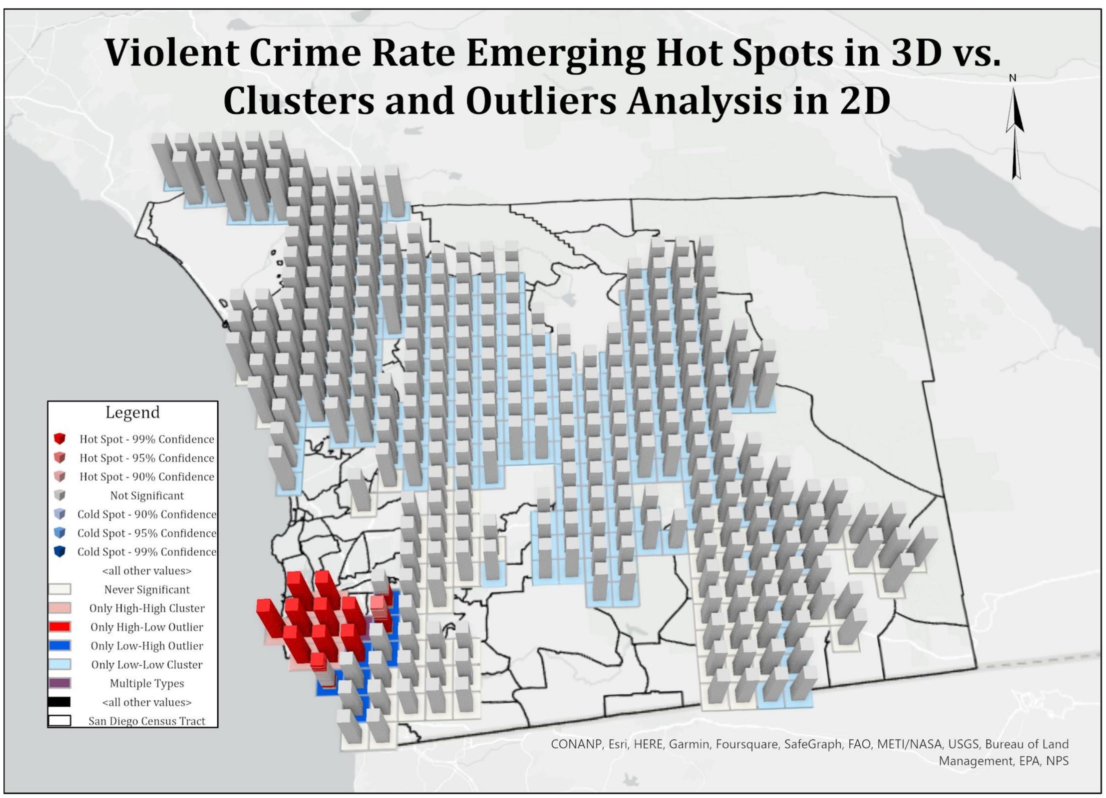

Figure 6: Violent Crime Rate Emerging Hot Spots in 3D vs. Clusters and Outliers Analysis in 2D.

5.3 Relationship between Extreme Heat and Violent Crime Events

Following the exploration of extreme heat events and the violent crime rate over time, we can now examine the relationship between these two variables. Figure 7 presents a chart depicting the average violent crime rate alongside four distinct scenarios of average heat wave counts, each measured over a three-month interval from March 2010 to December 2020.

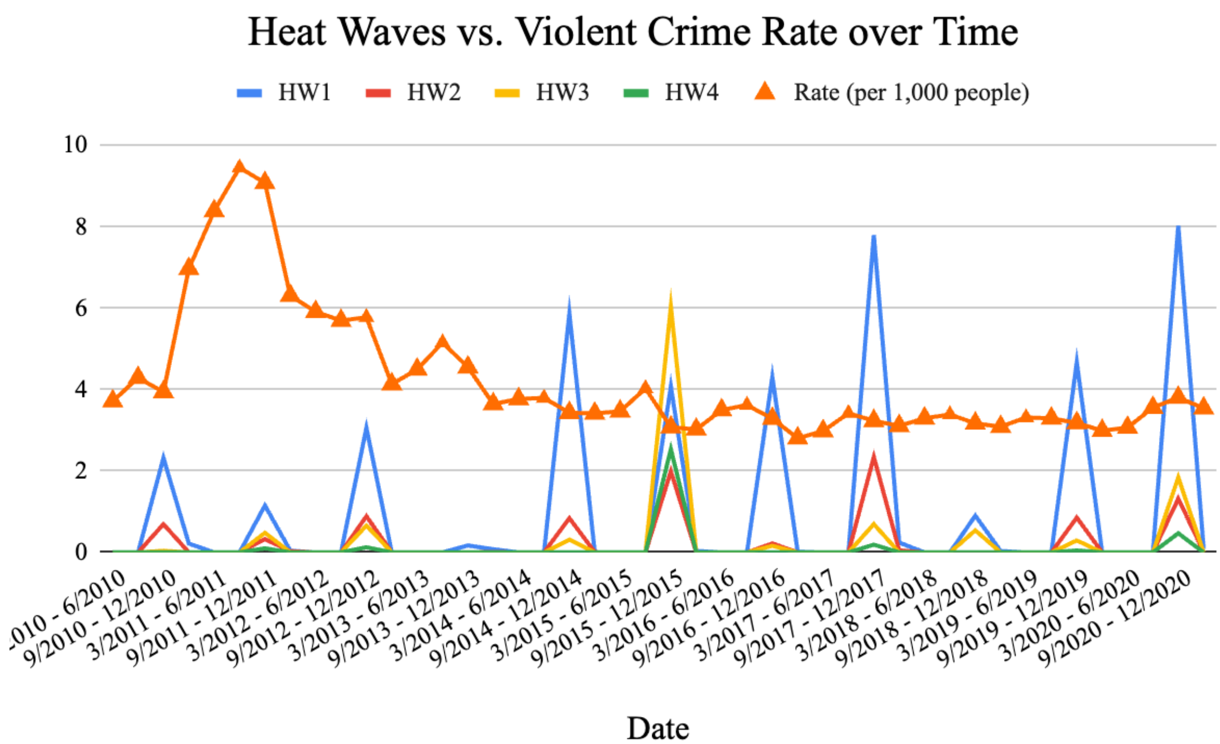

Figure 7: Plot of Heat Waves vs. Violent Crime Rate over Time.

Based on the analysis of the graph, no substantial correlation was observed between the heat wave and violent crime rates. The violent crime rate shows a significant increase in the initial phase of the study period, followed by a gradual decrease with occasional fluctuations. Notably, the crime rate peaks around June of each year but is not apparent. In contrast, the lines representing the number of heat waves show a clear seasonal pattern, peaking around September each year. These observations suggest that while there may be temporal variations in both heat waves and violent crime rates, they do not exhibit a consistent and directly proportional relationship. Thus, further research is warranted to explore potential factors influencing crime rates in relation to heat waves.

Although a direct relationship between extreme heat events and violent crime is not strongly evident in this section, valuable insights can still be gained to inform future mitigation strategies. By identifying hotspots from the emerging hotspot analysis for daytime and nighttime extreme warming (HW2 and HW4), areas requiring heightened attention can be pinpointed. In Figure 8, the intersection of these extreme heat event hotspots and clusters of high violent crime rates (Figure 5) reveals regions of particular concern. Specifically, the southern coastal area exhibits a convergence of HW2 hotspots, high-high crime rate clusters, low-high outliers, and multiple types of crime rates. This region emerges as a priority area for targeted interventions aimed at reducing both extreme heat events and violent crime incidents. Additionally, the region along the middle north coastline, bounded by the red line, experiences the most severe daytime extreme heat events, while the area in the middle of San Diego County, bounded by the purple line, faces significant nighttime warming. These areas also require focused mitigation strategies to alleviate the impact of warming.

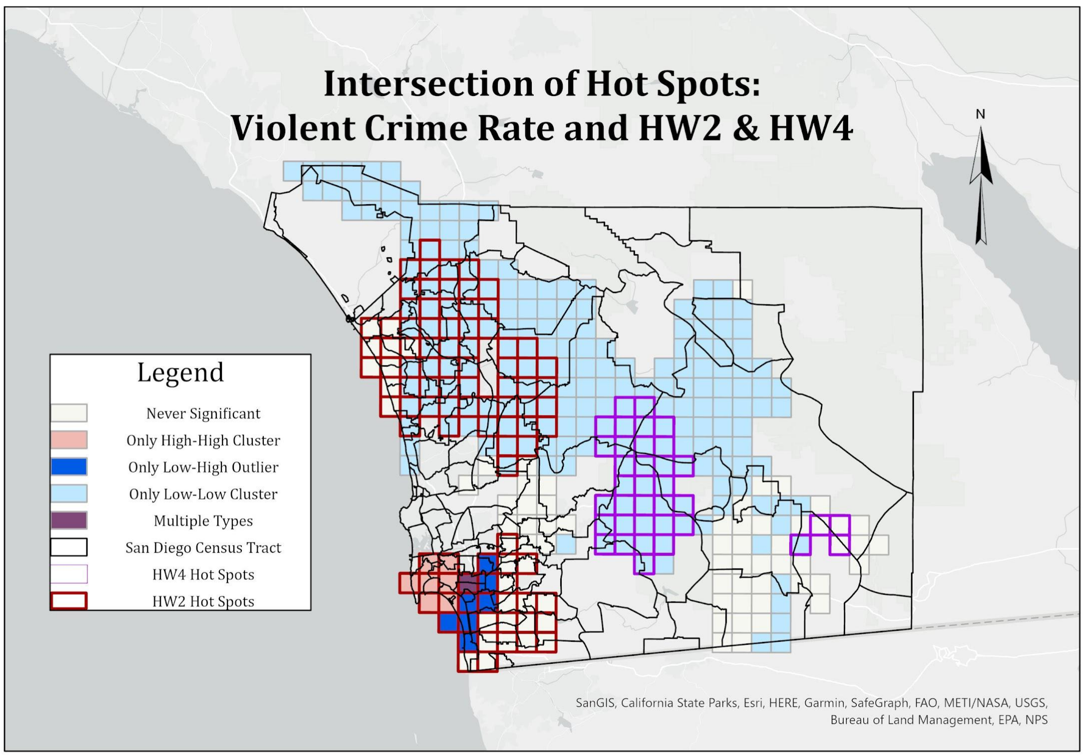

Figure 8: Intersection of Hot Spots: Violent Crime Rate and HW2 & HW4.

5.4 Limitations

This study offers a comprehensive examination of the clustering relationship between extreme heat events and violent crime occurrences. However, it is crucial to recognize the limitations of this research in several key aspects. Firstly, the data collection process was confined by the availability and granularity of San Diego crime data, which were obtained solely at the local agency level. Consequently, the analysis was conducted at a grid level rather than directly at the ZIP code level, potentially introducing inherent inaccuracies and limiting the precision of the findings. Future studies could benefit from accessing more detailed and comprehensive crime data to enhance the spatial resolution and accuracy of the analysis.

Secondly, while this study focused on identifying clustering patterns, it did not quantitatively explore the exact numerical relationship between the rates of violent crime and extreme heat. Employing regression analysis would have allowed for a statistical assessment of the strength and nature of this relationship, enabling a more rigorous understanding of the influence of extreme heat on violent crime incidents. By incorporating additional variables and controlling for potential confounding factors, future research could provide a more nuanced understanding of the complex interplay between extreme heat and violent crime rates.

Moreover, it is important to note that this study primarily examined the clustering relationship between extreme heat events and violent crime occurrences, without explicitly considering other contributing factors such as socio-economic characteristics and local geometry. Exploring the role of socio-economic factors, including income levels, education, and employment rates, as well as analyzing the influence of local geography and urban design, could contribute to a more comprehensive understanding of the contextual dynamics and underlying mechanisms driving the observed clustering patterns. Future research endeavors should strive to integrate these factors into the analysis to better capture the multifaceted nature of the relationship between extreme heat and violent crime.

By acknowledging and addressing these limitations in future research, a more rigorous and comprehensive academic understanding of the aggregated relationship between extreme heat and violent crime can be developed, and contribute to the development of evidence-based strategies and interventions to reduce the occurrence of violent crime and the adverse effects of climate change.

6. Mitigation Strategies

The findings section highlights the interconnectedness of crime events and climate change and emphasizes the need for integrated mitigation strategies. In this part, I will provide an analysis of current mitigation strategies and policies from the perspective of reducing the impact of extreme heat on crime rates.

6.1 Crime Prevention through Environmental Design (CPTED)

Crime Prevention Through Environmental Design (CPTED) is a multi-disciplinary approach that involves utilizing urban and architectural design, as well as managing the built and natural environments, to prevent crime (ICA, n.d.). Jane Jacobs introduced the concept of using the physical environment to reduce crime in 1961, and the term "CPTED" was coined by Professor C. Ray Jeffery in 1971. Architect Oscar Newman further developed the concept in his book "Defensible Space" in 1972 (ICA, n.d.).

CPTED is guided by five key principles: natural access control, natural surveillance, territoriality, activity support, and maintenance (Chandler PD, n.d.). These principles aim to create environments that deter criminal activities, promote a sense of safety, and foster a strong community among residents (ICA, n.d.). By implementing measures such as controlling access points, improving visibility, encouraging community ownership and engagement, and ensuring the upkeep of spaces, CPTED seeks to reduce crime and enhance the overall well-being of communities. The ultimate goal of CPTED is to create environments that not only discourage criminal behavior but also promote a sense of security, social interaction, and community cohesion (Mihinjac & Saville, 2019).

The concept of Crime Prevention Through Environmental Design (CPTED) has evolved over time through different generations. First-Generation CPTED focused on blocking crime opportunities and territorial control through physical design, while Second-Generation CPTED expanded its scope to include neighborhood conditions and social relations, aiming to build community and social cohesion (Mihinjac & Saville, 2019). Third-Generation CPTED is an evolved approach to crime prevention through environmental design that focuses on creating secure and environmentally sustainable urban spaces. It recognizes security as a global issue influenced by geopolitical and sociocultural factors. This approach integrates security measures, physical design elements, and community participation to enhance the quality of life, promote safety, and create user-friendly and ecologically responsible cities (Mihinjac & Saville, 2019; Fennelly & Perry, 2018).

In implementing CPTED, an important consideration is the integration of sustainability to enhance livability and security. In *Sustainability via Security: A New Look* , the authors discuss the need to address security issues within the broader framework of sustainability, which includes environmentally friendly practices and creating safe and resilient communities (Armitage & Gamman, 2009). This involves adopting locally viable and economically productive approaches that foster resilient communities (Mihinjac & Saville, 2019). Green strategies, which prioritize sustainable and environmentally-friendly practices, should be recommended as effective measures for future crime prevention. These strategies entail community-based initiatives that enhance the physical environment and promote social cohesion, resulting in reduced crime rates and improved public safety.

One of the most well-known green strategies in crime prevention is increasing urban green space, such as the creation of public green spaces like parks and gardens. These green spaces facilitate social interaction and physical activity, contributing to a more positive social environment. Studies, including one by Venter et al. (2022), have shown that increasing urban green space can effectively reduce violent and property crimes. However, careful planning and design are essential due to the nuances associated with green spaces. For instance, trees may provide hiding spots for criminals or obstruct visibility, potentially increasing property crime rates. Nevertheless, a study by Conniff (2012) challenges negative stereotypes about trees, emphasizing their positive role in reducing crime. Trees and green spaces can have a calming effect on people, reduce stress, and act as a natural surveillance system. Incorporating trees and green spaces into urban planning and crime prevention strategies not only enhances safety and reduces crime but also offers additional social and environmental benefits like improved air quality and wildlife habitat (Tory et al., 2012).

In conclusion, incorporating green strategies, such as urban greening and the inclusion of trees and green spaces, into Crime Prevention Through Environmental Design (CPTED) can have a positive impact on crime prevention and sustainable development. However, to effectively reduce crime, careful planning and design of green spaces are crucial to consider their specific characteristics and potential influence on crime rates. Despite potential challenges, multiple studies have challenged negative stereotypes about trees and highlighted their ability to reduce crime, enhance community safety, and provide various social and environmental benefits. By integrating green strategies into urban planning and crime prevention efforts, communities can not only improve safety and reduce crime but also facilitate additional advantages such as improved air quality and wildlife habitat.

6.2 Current Mitigation Strategies Recommendation

San Diego has become a leader in addressing climate change and implementing effective mitigation strategies. In December 2015, the San Diego City Council demonstrated its commitment to combating climate change by adopting the Climate Action Plan. The plan aims to achieve a 50% reduction in greenhouse gas emissions by 2035. Building on the 2015 plan, the 2022 Climate Action Plan was developed, setting an even more ambitious goal of reaching net zero emissions by 2035 to help make San Diego a more sustainable place to live, work and play (*2022 Climate Action Plan | Sustainability*, n.d.). Notably, the 2022 Climate Action Plan recognizes the intersection of climate change and public safety, including the impact of climate change on crime and public safety. It emphasizes the importance of investing in critical areas such as education, street lighting, parks, and recreation centers, shelters, permanent housing, and other public gathering areas (Climate Action Plan 2022 | Sustainability, n.d.).

Strategy 3: Mobility & Land Use

Among the various strategies outlined in the 2022 Climate Action Plan, strategies for Mobility & Land Use can be identified as among the most impactful in terms of enhancing public safety. Some of the relevant actions that can be taken to reduce the impacts of climate change and promote crime prevention come from measures for safe and pleasant routes for pedestrians and bicyclists, as follows.

1. *Update street planning and design process with a focus on community input from Communities of Concern to prioritize pedestrians, bicyclists, and transit.*

   This strategy demonstrates a proactive approach to crime prevention and climate change mitigation by prioritizing the needs of pedestrians, bicyclists, and transit users. By involving the Communities of Concern in the planning and design process, this strategy ensures that infrastructure improvements are aligned with the specific safety concerns and mobility requirements of these communities. Thus, this approach can encourage active transportation, help create safer streets, and enhance community connectivity, ultimately reducing crime risks and promoting sustainable modes of travel.

2. *Install pedestrian-oriented street lights for increased safety and comfort in Communities of Concern.*

   By installing pedestrian-oriented streetlights, this strategy addresses both safety concerns and climate change mitigation. Adequate lighting in communities can deter criminal activities and increase the sense of safety, making pedestrians feel more secure when walking or cycling. Additionally, the result of the lighting study from CRIME LAB New York suggests that investments in changing the physical environment, such as new streetlights, can enhance the city's efforts to promote public safety and help reduce citywide inequalities in crime reductions. (Chalfin et al., 2019). Moreover, the use of energy-efficient streetlights contributes to reducing greenhouse gas emissions and energy consumption, aligning with climate change mitigation goals.

3. *Incorporate trees and additional cooling features such as innovative shade designs, water features, and cooling centers at parks, with a concentration in Communities of Concern.*

   This strategy contributes to both crime prevention and climate change mitigation. From a crime prevention perspective, the presence of well-maintained parks with green spaces and trees has been shown to contribute to a safer and more secure community. A multi-literature study from Shepley et al. highlighted the positive impact of green spaces on crime, including factors such as social interaction, community perception, stress reduction, and the creation of territorial spaces (Shepley et al., 2019). Thus, by creating well-maintained parks with green spaces and trees, communities are provided with inviting and safe spaces that promote social cohesion and community involvement, reduce crime rates and foster a sense of ownership. At the same time, this strategy addresses climate change concerns by helping to mitigate the urban heat island effect and improve air quality. Communities of concern, which often face disproportionate impacts from heat, can benefit from the cooling effects provided by trees and additional cooling features in parks. These efforts contribute to temperature reduction, enhance air quality, and create more comfortable outdoor spaces for residents.

A similar measure under the same strategy that focused on Climate-Focused Land Use also states that "*Support expansion of urban greenspace including park access, open space, and wildlife corridors where appropriate, along streets to encourage outdoor activity, walking, and increase pedestrian access to parks in Communities of Concern*", which can also have a duo effect on increase public safety and also enhance biodiversity and ecosystem resilience.

Strategy 5: Resilient Infrastructure and Healthy Ecosystems

A measure under the Resilient Infrastructure and Healthy Ecosystems section that can help play a big difference is Tree Canopy. Its detailed actions that can help with crime prevention and climate change mitigation are shown below.

1. *Increase tree planting in Communities of Concern starting with the planting of 40K new trees in these communities by 2030.*
2. *Create a Street Tree Master Plan with a target of planting 100,000 trees by 2035. Within the Street Tree Master Plan, identify City lands and spaces that need trees and identify ways to increase permeable areas for new trees, focused in Communities of Concern.*
3. *Conduct a new Urban Tree Canopy assessment utilizing light detection and ranging (LiDAR) technology to identify areas in need of additional tree canopy.*
4. *Increase tree planting in Communities of Concern by identifying city lands/ spaces that need trees.*
5. *Develop a plan to increase permeable areas for new trees and restore spaces that have been paved, focused in Communities of Concern.*
6. *Support expansion of urban tree canopy in parks and along active transportation network. Prioritize implementation in Communities of Concern.*

7. *Develop policies that encourage and incentivize developers, homeowner associations, and other organizations to preserve, maintain and plant trees.*
8. *Reform, streamline, and expand the No Fee Street Tree program to remove barriers that exist which detour or prohibit participation by residents within Communities of Concern.*
9. *Protect and maintain all healthy City trees that have minimal conflicts to existing and future infrastructure, by use of policy, code, public outreach and code enforcement.*
10. *Amend the Land Development Code to increase landscape and parking lot tree planting requirements.*
11. *Streamline permitting for tree planting, dedicate resources to planting in nontraditional street tree locations, and provide reduced fees or fee waivers in Communities of Concern.*
12. *Revise Council Policies and Municipal Codes to strengthen tree protection and enhance tree planting efforts.*
13. *Increase irrigation for trees in Parks and in Street rights-of-way.*
14. *Implement a citywide protocol for tracking planted, removed and maintained street trees.*
15. *Expand volunteer programs and partnerships with community organizations to plant and maintain trees.*
16. *Support the creation of new urban green space along freeways and city right of way.*
17. *Ensure the diversification of tree species, including using native tree and shrub species and/or species that are adapted to higher temperatures and require less water.*
18. *Monitor and report on SDG&E's plans to supplant the City's efforts with direct in-community charitable support for planting up to 2,500 trees in the city over 10 years.*
19. *Perform proper tree maintenance and tree removal to promote a healthy urban forest and safety of trees in public spaces.*
20. *Redesign hardscape infrastructure around existing City trees when possible in order to increase large tree canopy cover.*

The selected actions demonstrate a strategic approach to addressing the intersection of crime prevention and climate change through various policy measures, which mainly come from 5 main perspectives: tree planting in communities of concern, street tree master plan and permeable area, urban tree canopy assessment, preservation and maintenance of trees, collaboration, and community engagement. Specifically, by prioritizing tree planting in communities of concern, these actions recognize the potential of green spaces to enhance community safety, social cohesion, and physical activity, thereby reducing crime rates. The development of a comprehensive street tree master plan and the identification of permeable areas for tree planting further contribute to creating safer and more inviting urban environments. Additionally, the utilization of advanced technologies like LiDAR for urban tree canopy assessment allows for targeted interventions in areas with high crime rates and low tree cover, potentially yielding significant crime reduction outcomes. The preservation and maintenance of existing urban trees serve as a natural surveillance system, deterring criminal activities and fostering a sense of security among residents. Moreover, fostering collaboration and community engagement in these initiatives strengthens community involvement and ownership, fostering sustainable and resilient neighborhoods. From a climate change perspective, the promotion of tree planting initiatives aids in carbon sequestration, improves air quality, and mitigates the impacts of extreme weather events. Overall, these policy actions align crime prevention and climate change agendas, resulting in safer, greener, and more sustainable communities.

7. Conclusion

In conclusion, this study has examined the clustering relationship between extreme heat events and violent crime occurrence in San Diego. In this study, the analysis result suggests that the urban heat island effect is primarily concentrated along coastal areas, while the night warming effect exhibits a tendency to spread inland. Heat waves are more likely to occur in coastal areas due to the urban heat island effect, with the incidence decreasing as moves inland. In recent years, nighttime warming has increased inland compared to coastal areas. Certain inland areas, particularly in the south-central interior, have experienced concentrated extreme night heat events..

The analysis of violent crime rates in San Diego County reveals that hot spots primarily occur in the southern coastal region. Despite an overall declining trend in crime rates, targeted efforts for crime prevention and intervention are still needed in these hot spot areas to address underlying factors contributing to elevated crime rates and ensure long-term safety and security for affected communities.

While a direct relationship between the two variables may not be strongly evident, valuable insights have been gained to inform future mitigation strategies. Even though the study acknowledges the limitations in data collection, analysis, and San Diego local situation consideration, it still gives an insight on future mitigation strategies implementation direction.

In climate action, San Diego has demonstrated leadership in addressing climate change and implementing effective mitigation strategies. The 2015 and 2022 climate action plans reflect the city's commitment to reducing greenhouse gas emissions and achieving net zero emissions by 2035. Importantly, the 2022 Climate Action Plan recognizes the intersection of climate change and public safety, emphasizing investments in key areas such as education, street lighting, and parks and recreation centers.

Based on the CPTED and current mitigation strategies analysis, a number of strategies can be recommended to help San Diego reduce crime incidents and mitigate climate change impacts. Strategies focused on mobility and land use, such as prioritizing pedestrians, bicyclists, and transit users in street planning, installing pedestrian-oriented streetlights, and incorporating trees and cooling features in communities of concern, provide a positive approach to crime prevention and climate change mitigation. In addition, implementing resilient infrastructure and healthy ecosystem measures, including increased tree planting, conducting urban canopy assessments, protecting existing trees, and promoting community engagement, can contribute to crime reduction and climate change resilience.

These recommendations align the crime prevention and climate change agendas and promote safer, greener and more sustainable communities. By prioritizing community input, enhancing safety measures, and creating inviting public spaces, San Diego can address crime risks while mitigating the urban heat island effect, improving air quality, and promoting social cohesion. Collaboration with community organizations, developers, and residents, as well as the use of advanced technology, will increase the effectiveness of these strategies.

In summary, the integration of crime prevention and climate change responses into the San Diego planning and policy framework has great potential to create a safer, sustainable, and resilient city. Strategic implementation measures to integrate crime prevention and climate change response into San Diego's planning and policy framework are recommended to achieve the city's climate goals and enhance public safety to create a safer, sustainable living environment for San Diego residents.

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