Leveraging Light Pollution and Streetlight Outage Data for Crime Vulnerability Analysis on Chicago Streets

Vishal Goud Mogili*
University of Illinois at Chicago

Snigdha Ghosh Dastidar†
University of Illinois at Chicago

Reezwan Ul Haq Mohammad‡
University of Illinois at Chicago

Project GitHub Repository: https://github.com/vishalgoudmogili/cs524-project

ABSTRACT

This project investigates the influence of light pollution and streetlight outages on crime in Chicago. Using crime data and light pollution data from VIIRS, we calculated the Light Pollution Index (LPI) and mapped crimes with street light outage data from 311 services for individual crimes. Later, we aggregated these metrics into a street-level Light Vulnerability Index (LVI). These indices were integrated into an interactive web-based visualization system using Leaflet and React, featuring a choropleth map and complementary visualizations. The system allows users to analyze spatial and temporal crime patterns influenced by lighting conditions and explore how varying weights of LPI and streetlight outages affect the LVI. The results demonstrate actionable insights for urban safety planning, while future work aims to improve data resolution and scalability.

1 INTRODUCTION

There is a general convention that lighting reduces criminal activities by increasing visibility, but research indicates that additional lighting can also create opportunities for certain crimes. For example, improved lighting may facilitate surveillance. Still, it also enables a few crimes like theft or vandalism as it increases activity and visibility, which makes the place more attractive for an offense to occur, or improved lighting on the street decreases the side alleys' visibility. The Light Vulnerability Index (LVI) project seeks to quantify and visualize street-level vulnerabilities by integrating satellite-based light pollution data, crime records, and streetlight outage information. Our work combines geospatial analytics and interactive visualization to offer actionable insights for urban planning and crime prevention.

2 RELATED WORK

The relationship between lighting and crime has been studied, with mixed findings on its effectiveness in crime prevention. A study from 2000, the Chicago Alley Lighting Project, evaluated the impact of increased lighting in urban alleys on crime rates. This study also revealed that while improved lighting did not significantly reduce violent crimes, it increased non-index crimes such as vandalism and trespassing. This increase was attributed to additional visibility, which created opportunities for specific activities to occur and be reported. It also highlighted the complex phenomenon of crime displacement, where enhanced lighting in one area shifted criminal activities to nearby poorly lit locations, decreasing the benefits of lighting. These lighting improvements have become a cause of crime in adjacent areas. These findings emphasize that lighting improvements alone are not a universal solution to crime prevention and must be paired with other measures, such as community engagement and urban planning. Building on these insights, our study explores the interplay of light pollution, streetlight outages, and crime on a street level. Unlike the static analysis of alley lighting, we leverage dynamic, satellite-derived light pollution data and integrate the street light outage dataset to create a comprehensive Light Vulnerability Index (LVI). This approach provides a nuanced understanding of how lighting conditions influence crime patterns, which gives insights into targeted urban interventions.

3 PROBLEM STATEMENT

In urban environments, lighting plays a crucial role in public safety, especially during nighttime hours. Traditional thinking often associates well-lit areas with reduced crime rates, while poorly lit streets are perceived as vulnerable to criminal activities. However, emerging evidence challenges this binary notion, suggesting that both excessive lighting (light pollution) and insufficient lighting (due to streetlight outages) may influence crime patterns in complex ways. For instance, excessive lighting can create glare and shadows that obscure visibility, while streetlight outages can leave entire areas in darkness, increasing their susceptibility to crime.

Chicago, like many other metropolitan cities, experiences significant nighttime crime, making it an ideal case study to investigate the relationship between lighting and criminal activity. Over the years, there have been reports and studies—such as the Chicago Alley Lighting Project—which reveal that changes in urban lighting have nuanced effects on crime rates. This project aims to answer critical questions: Do changes in light pollution significantly impact crime? How do streetlight outages worsen safety concerns? And can we develop a metric to identify streets most vulnerable to lighting-related crimes?

To address these questions, we introduce the Light Vulnerability Index (LVI), a metric that combines the impact of light pollution and streetlight outages to assess a street's vulnerability to crime. By leveraging spatial and temporal analysis of crime records, VIIRS Nighttime Light Pollution data, and streetlight outage logs, this project provides actionable insights for urban planners and policymakers. These insights aim to enhance nighttime safety, optimize resource allocation for streetlight maintenance, and create adaptive urban lighting strategies that balance security and energy efficiency.

This research aims to improve urban safety by analyzing how lighting affects crime, using detailed data instead of simple assumptions to show the complex relationship between light and crime.

4 DATA AND METHODOLOGY

4.1 Data Sources

We used three different datasets to analyze the relationship between light conditions and crime in Chicago from 2013-2023.

- The first dataset, sourced from the Chicago Data Portal, has detailed records of crimes, including attributes such as the type of crime, the date and time of occurrence, geographic coordinates, and associated street names.

*e-mail: vmogil2@uic.edu
†e-mail: sdasti2@uic.edu
‡e-mail: rmoham27@uic.edu

- The second dataset used in the analysis was the VIIRS Nighttime Light Pollution data from NOAA, providing monthly average radiance values across Chicago. These satellite-derived measurements offered high-resolution insights into light intensity's spatial and temporal distribution.
- The third dataset involved streetlight outages, also sourced from the Chicago Data Portal, which recorded instances of streetlight failures with their respective locations and statuses.

4.2 Data Preprocessing

Several preprocessing steps were performed to prepare the data for analysis to clean, transform, and integrate the datasets.

- **Crime Data Cleaning:** The crime dataset was filtered to focus on nighttime crimes between 6 PM and 6 AM. This subset of data was deemed most relevant for analyzing lighting conditions. Records with missing or invalid latitude, longitude, or date fields were removed to ensure spatial and temporal integrity. The street names were extracted and standardized from the `block` column to allow a consistent mapping with other datasets.
- **Assigning Light Pollution Values:** Each crime record was geospatially mapped to light pollution data from the VIIRS dataset. Three radiance values(previous, current, and next month) are fetched for each crime. These values are used to calculate the Light Pollution Index (LPI) for each crime using the formula:

  $$\text{LPI} = \frac{\text{Light Poll (Prev Month)} + \text{Light Poll (Next Month)}}{2 \times \text{Light Poll (Curr Month)}}$$

  This index quantified the relative change in light pollution surrounding the crime's occurrence.
- **Integrating Streetlight Outage Data:** Streetlight outages were spatially joined to crime locations. For each crime, a binary indicator was added to denote whether a streetlight outage was active at the time and location of the incident (`1` for an outage, `0` for no outage). This allowed for a combined analysis of dynamic light pollution and infrastructure reliability.
- **Aggregating Data at the Street Level:** Crimes were grouped by their corresponding streets to calculate aggregated metrics:
  - **Mean LPI:** The average Light Pollution Index across all crimes on the street.
  - **Mean Streetlight Outage:** The average frequency of outages impacting the street.
  - **Crime Statistics:** Metrics such as the most frequent crime type, peak crime hours, and monthly crime distributions were computed for each street.

4.3 Methodology

The aggregated metrics were combined to calculate the Light Vulnerability Index (LVI) for each street using the formula:

$$\text{LVI (Street)} = \alpha \times \text{Mean (LPI)} + \beta \times \text{Mean (Streetlight Outage)}$$

Where α and β are user-defined weights that allow dynamic adjustment based on the relative importance of light pollution and streetlight outages. The default values were set to $\alpha = 0.7$ and $\beta = 0.3$. The interactive visualization interface enables users to modify these values to explore different weighting configurations and their influence on the Light Vulnerability Index (LVI). For instance, if an urban planning team aims to prioritize streets for maintenance during streetlight outages, they can increase the weight of the streetlight outage parameter (β) while reducing the emphasis on the Light Pollution Index (α). This adjustment would make the LVI more sensitive to streetlight outage data, identifying streets that require immediate attention. Conversely, suppose the focus is on understanding which streets are more prone to crimes influenced by light pollution conditions. In that case, the team can assign a higher weight to the LPI and a lower weight to the streetlight outage parameter.

This flexibility makes the LVI a versatile tool, allowing policymakers, urban planners, and safety authorities to adapt the index to specific objectives, such as optimizing streetlight repairs, improving nighttime safety, or targeting areas with significant light pollution issues. The LVI thus acts as a decision support tool for urban infrastructure planning and crime prevention strategies.

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5 Implementation

5.1 Backend Development

The backend was developed using Flask to serve the processed GeoJSON files and enable interactive data retrieval for the frontend. Two key API endpoints were implemented:

- **Street-Level Data Endpoint**: This endpoint served the street-level GeoJSON files containing metrics like LVI, LPI, streetlight outage frequency, and additional crime-related attributes. The GeoJSON format allowed efficient integration with Leaflet.js for mapping visualizations. The endpoint was structured as:

```
GET /api/streets
Response: GeoJSON containing street-level metrics.
```

- **Boundary Data Endpoint**: This endpoint provided the geographic boundaries of Chicago, giving users contextual information about the neighborhoods and wards surrounding the streets. The endpoint was structured as:

```
GET /api/boundaries
Response: GeoJSON containing Chicago boundary data.
```

The backend dynamically responded to user inputs from the frontend, such as changes in the weights of LPI and streetlight outages (α and β). This allowed the system to recompute LVI values on the fly, enabling users to explore how different weight configurations impacted street-level vulnerabilities. This interactive functionality was central to the system's utility for urban planners and policymakers.

5.2 Frontend Development

The frontend for the project was developed using React in combination with Leaflet.js for interactive mapping and D3.js for data-driven visualizations. The integration of these technologies allowed us to create an interactive, user-friendly interface that presents spatial and temporal crime patterns influenced by lighting conditions.

Interactive Choropleth Map: The choropleth map, as shown in Fig. 1, was implemented using Leaflet.js. This visualization provided a spatial overview of the Light Vulnerability Index (LVI) across Chicago streets. Streets were color-coded based on their LVI values, with red indicating higher vulnerability and green representing lower vulnerability. Each street on the map was interactive, featuring popups displaying detailed metrics such as the most frequent crime type, total crime count, peak crime hours, and monthly crime distributions. Users could dynamically adjust the weights of LPI and streetlight outages using a control panel, and the changes were instantly reflected on the map. This allowed real-time exploration of how different weight configurations influenced the LVI, making it a valuable tool for urban planners and policymakers.

Scatter Plot Visualization: The scatter plot, depicted in Fig. 2, was developed using D3.js to enable comparative analysis of streets across different metrics such as LVI, LPI, and streetlight outage frequency. A dropdown menu allowed users to toggle between these metrics, providing flexibility in data analysis. The scatter plot effectively highlighted outliers, such as streets with disproportionately high LPI or frequent outages, offering insights into areas requiring targeted interventions. The plot was styled to be responsive and visually engaging, ensuring ease of interpretation.

Heatmap Visualization: To analyze temporal crime patterns, a heatmap was created using D3.js, as illustrated in Fig. 3. The x-axis represented hours of the day, while the y-axis listed streets. The intensity of each cell indicated the frequency of crimes at a specific time on a specific street. This visualization highlighted critical periods for crime on various streets, enabling data-driven decisions like deploying police patrols during high-risk hours or identifying times for increased streetlight monitoring.

Line Chart Visualization: The line chart, shown in Fig. 4, was also implemented using D3.js to visualize monthly crime trends for selected streets. This chart provided a historical perspective, helping users identify seasonal crime variations or months with significant spikes in crime rates. The line chart added a temporal dimension to the analysis, complementing the spatial insights provided by the map and heatmap. It was particularly useful for evaluating the long-term impact of lighting conditions on crime patterns and planning future interventions.

Responsiveness and Interactivity: The frontend was designed to be responsive, ensuring compatibility across various devices and screen sizes. Users could interact with multiple visualizations simultaneously, enabling a comprehensive exploration of the data. For instance, selecting a high-LVI street on the map would display additional details in a popup while simultaneously highlighting corresponding data points in the scatter plot and updating trends in the line chart. This level of interactivity made the interface intuitive and accessible for users with varying technical expertise.

Dynamic Data Loading: All visualizations dynamically fetched data from the Flask-based backend via API endpoints. This ensured that the frontend reflected the latest data and user-configured parameters, such as adjusted weights for LPI and streetlight outages. By using GeoJSON for the map data and JSON for other visualizations, the system maintained efficient data communication between the backend and frontend.

As illustrated through these visualizations (Figs. 1, 2, 3, 4), the frontend development successfully transformed complex geospatial and temporal crime data into an interactive tool for analysis and decision-making. This comprehensive approach ensures that the system is not only informative but also actionable for improving urban safety.

6 Figures and Results

Choropleth Map (Fig. 1): The choropleth map provided a spatial overview of street-level vulnerabilities. By displaying streets in a color-coded format based on LVI, it allowed users to quickly identify high-risk areas. Clicking on a street revealed detailed information, including the most frequent crime type, peak crime hours, and monthly crime trends.

Scatter Plot (Fig. 2): The scatter plot enabled comparative analysis of streets across different metrics. Users could toggle between LVI, LPI, and streetlight outages, revealing insights into how various factors contributed to street vulnerability. This visualization highlighted outliers, such as streets with disproportionately high LPI or outage values.

Heatmap (Fig. 3): The heatmap illustrated temporal crime patterns for each street. It revealed trends like streets with frequent crimes during late-night hours, providing actionable insights for

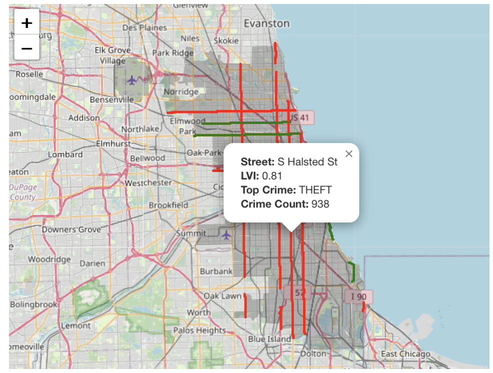

Figure 1: Choropleth map visualizing street-level Light Vulnerability Index (LVI) in Chicago. High LVI streets are shown in red, while low LVI streets are shown in green.

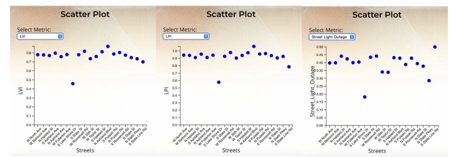

Figure 2: Scatter plot comparing streets based on LVI, LPI, and streetlight outage frequency.

targeted interventions. For example, streets with consistently high crime rates during specific hours could be prioritized for enhanced lighting or patrols.

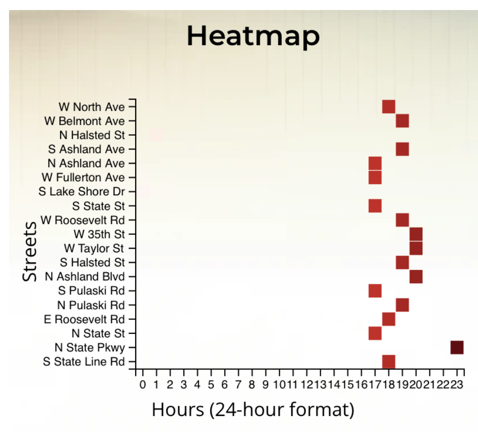

Figure 3: Heatmap showing the temporal distribution of crimes on streets by hour of the day.

Line Chart (Fig. 4): The line chart showed how crime trends evolved over time for selected streets. By visualizing monthly crime counts, it helped users understand the long-term impact of lighting conditions on crime patterns. This visualization was particularly useful for identifying seasonal trends or evaluating the effectiveness of interventions.

7 Conclusion

This project underscores the critical influence of lighting conditions on nighttime crime patterns in urban environments. By introducing the Light Pollution Index (LPI) and the Street Light Vulnerability Index (LVI), we provide robust analytical tools for quantifying

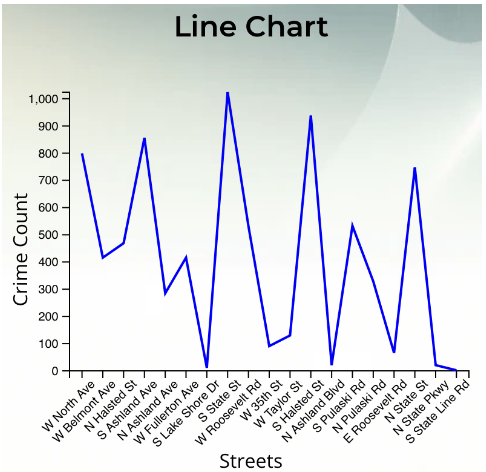

Figure 4: Line chart visualizing monthly crime trends on selected streets.

lighting-related vulnerabilities at a granular level. These indices enable a comprehensive assessment of the interplay between lighting conditions and crime, particularly at the street level.

Our project reveals that streets experiencing frequent streetlight outages and significant fluctuations in light pollution are disproportionately prone to criminal activity. This highlights the importance of consistent and optimal lighting conditions in enhancing urban safety. Furthermore, the integration of diverse datasets, including crime records, lighting conditions, and urban infrastructure, enables a multidimensional analysis that yields actionable insights for urban planning and public safety strategies.

- Streetlight Outages and Crime: Streets with frequent streetlight outages are consistently linked to elevated crime rates. These outages create localized dark zones, reducing visibility and fostering conditions that are conducive to criminal activity.
- Light Pollution and Vulnerability: Contrary to the intuitive assumption that more light ensures safety, our analysis reveals that excessive fluctuations in light pollution are also correlated with higher crime rates. Variability in artificial light levels, particularly in areas transitioning between dark and over-illuminated states, can create confusion in visibility and potentially disrupt natural behaviors, contributing to crime susceptibility.
- Integrated Analysis for Actionable Insights: Through the integration of diverse datasets—crime records, streetlight outage reports, satellite-based light pollution metrics, and urban infrastructure data—this research highlights the spatial and temporal correlations between lighting conditions and criminal activity. Streets experiencing both high LPI values and frequent outages exhibit compounded vulnerabilities.

The insights derived from this project can inform city planners and policymakers in prioritizing streetlight repairs, optimizing lighting infrastructure, and addressing vulnerabilities in high-risk areas. By leveraging these findings, urban safety measures can be effectively targeted, ultimately contributing to safer, more resilient communities.

8 Future Work

This project sets the foundation for a deeper understanding of how lighting conditions influence nighttime crime patterns, but there are several avenues for future exploration to enhance the applicability and scope of the findings:

- **Granular Analysis:** Currently, the analysis focuses on 12 major streets, providing a limited but impactful overview. Future work aims to expand this scope to include a greater number of streets across the city. By incorporating more granular data, the methodology can provide highly localized and targeted recommendations for improving lighting infrastructure and public safety.

  Additionally, we plan to introduce advanced filtering options, such as crime type and severity, allowing users to customize their analysis and gain nuanced insights into specific crime patterns.
- **Incorporate Additional Variables:** Expanding the dataset to include other influential variables will enable a more comprehensive analysis of lighting conditions and crime:
  - Building Density and Height: Understanding how urban structures influence lighting diffusion and shadow patterns will offer deeper insights into lighting vulnerabilities in high-density urban areas.
  - Traffic Flow and Pedestrian Activity: Factoring in natural surveillance through vehicle and foot traffic data will help account for the role of human presence in deterring crime.
- **Time-Series Analysis:** Future research will include longitudinal studies to track lighting infrastructure changes and their impact on crime over extended periods. This will help identify persistent trends and evaluate the sustainability of lighting interventions.
- **Intervention Simulations:** Simulating the impact of potential interventions, such as faster streetlight repairs or optimized lighting designs to reduce light pollution, will allow policymakers to test scenarios virtually before implementation. These simulations can provide data-driven recommendations to allocate resources effectively.
- **Broader Applications:** To validate the effectiveness of the Light Vulnerability Index (LVI) framework, we aim to apply it in other cities with diverse urban layouts and socio-economic contexts. By testing in varied environments, we can refine the indices and ensure their robustness and scalability.

By pursuing these directions, future work will not only enhance the precision and relevance of the current findings but also establish the LVI framework as a versatile tool for urban safety planning on a global scale.

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