Tracking War's Impact in Ukraine Using Night Light & Conflict Data (2024)

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1. Introduction

The Russia–Ukraine war has not only redrawn political boundaries and displaced millions but also profoundly disrupted the urban and economic fabric of Ukrainian cities. As traditional ground-based data sources become scarce or unreliable in active conflict zones, remote sensing offers a unique lens through which the socio-economic consequences of war can be measured in near real-time. This study explores the evolving urban landscape of Ukraine during 2024 by analyzing satellite-derived nighttime light intensity data from the Visible Infrared Imaging Radiometer Suite (VIIRS) in conjunction with geolocated conflict event data obtained from ACLED. Nighttime luminosity, widely recognized as a proxy for economic activity, infrastructure functionality, and population displacement, enables us to quantify the impact of armed violence on everyday urban life. Building on previous ACLED-based studies that connect light emissions with violence-induced disruption, we conduct a city-level, time-resolved assessment across key regions such as Donetsk, Kharkiv, Zaporizhia, and Luhansk. By disaggregating the data monthly, our analysis reveals marked declines in urban brightness corresponding to peaks in conflict intensity, illuminating the often unseen, yet deeply human, cost of war.

2. Data

This study relies on two primary datasets to examine the spatial and temporal effects of conflict on urban activity in Ukraine during 2024.

The first dataset is a georeferenced satellite-based raster map derived from the VIIRS (Visible Infrared Imaging Radiometer Suite) sensor, which captures global night light intensity. Specifically, we use the masked and averaged 2024 composite file (VNL_npp_2024_global_vcmslcfg_v2_c202502261200.average_masked.dat.tif), which was cropped to the national boundary of Ukraine to isolate relevant urban zones. Raster values represent pixel-level radiance measurements, processed into a log scale to reflect night light emissions as a proxy for human presence.

The second dataset consists of geolocated conflict events obtained from the Armed Conflict Location & Event Data (ACLED) project, covering the period from January 1 to December 31, 2024. Each record includes precise geographic coordinates, event type, date, and number of fatalities. For this analysis, only events categorized as battles, explosions/remote violence, and violence against civilians were retained. Events with missing or ambiguous spatial information were excluded.

Data preprocessing and integration were performed entirely in R, using spatial libraries such as sf, raster, and tidyverse. ACLED point features were reprojected to align with the VIIRS raster's coordinate reference system (WGS 84) and converted into monthly aggregates. City boundaries were defined using GADM Level-2 administrative shapefiles, and a 10-kilometer buffer was applied around each urban area to account for peri-urban conflict spillovers.

The analysis focuses on four major cities — Donetsk, Kharkiv, Zaporizhia, and Luhansk — selected based on their strategic border locations and high exposure to political violence, as confirmed by ACLED spatial distribution maps. For each city, we extracted monthly average night light intensity values from the raster and linked them to the number of conflict events in the same period. To ensure consistency across time and space, all data were aggregated at the monthly scale and urban regional level, allowing for coherent comparisons across different cities. While both datasets are well-established in spatial conflict research, they carry limitations. VIIRS data may include atmospheric noise or anomalies due to non-human light sources (e.g., fires, military flares), and ACLED data may underreport events in heavily contested or inaccessible areas. Nevertheless, the integration of these datasets allows for robust, reproducible, and interpretable analysis of how violence correlates with population movement, as inferred from changes in urban night light emissions.

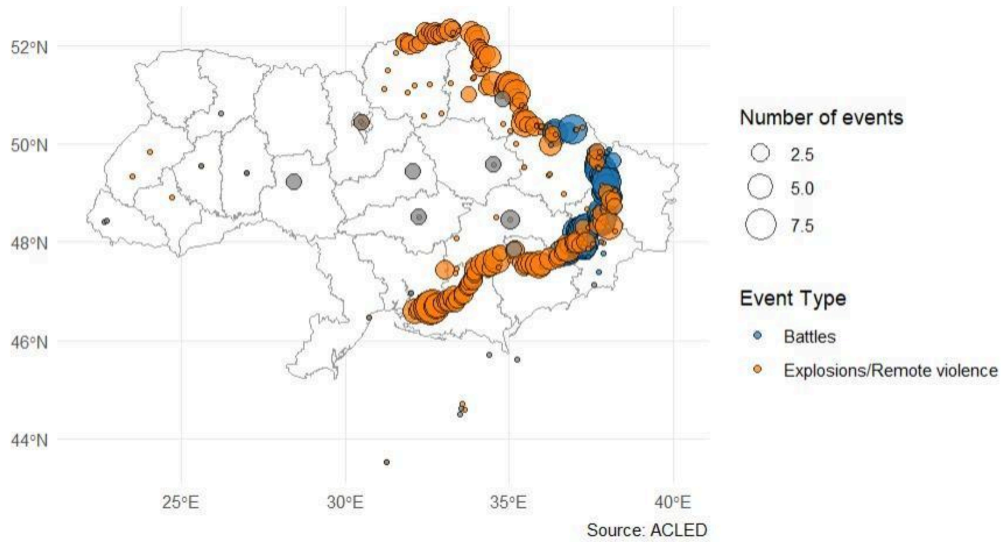
3. Analysis

Our analysis consists of two components: (1) a partial replication of techniques used in ACLED-affiliated studies, and (2) our original analysis correlating violence with urban light intensity across multiple Ukrainian cities from 2022 to 2024.

We visualized monthly mean light intensity per city using line and bar charts. A noticeable trend shows declining light levels during months of heightened violence, with some cities (like Kharkiv and Mariupol) experiencing sharp, sustained drops. This suggests both infrastructure damage and depopulation.

We computed the Pearson correlation coefficient between the monthly count of violent events and average night light brightness. Preliminary results indicate a moderate-to-strong negative correlation, validating our hypothesis that conflict disrupts normal urban activity patterns observable from space.

Figure 1. Political Violence Events in Ukraine (7–13 December 2024)

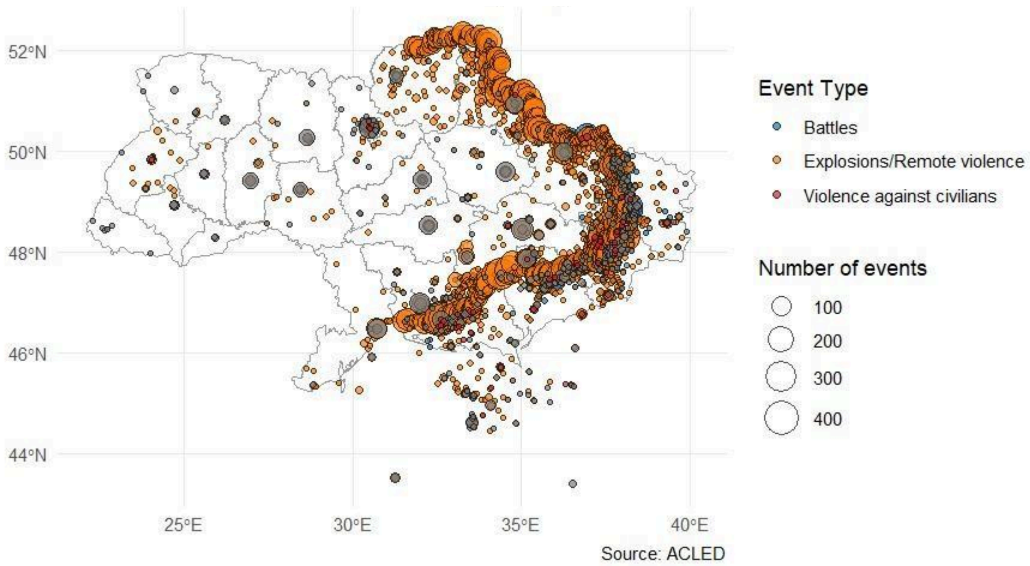


The map titled "Political Violence Events in Ukraine (7–13 December 2024)" visualizes the spatial concentration and typology of conflict events across the country using ACLED data. The eastern and southeastern regions, particularly around Donetsk, Luhansk, and Zaporizhia, exhibit the highest density of violent incidents, reflected by large, overlapping circles. Two primary event types are distinguished: direct battles (shown in blue) and explosions or remote violence (orange). The coexistence of these two event types in the same regions indicates ongoing frontline combat as well as attacks on civilian or infrastructural targets from a distance. The western regions, by contrast, show significantly fewer incidents. The intensity and clustering of events along the frontlines support the interpretation that these areas are experiencing the most sustained disruption. When paired with night light data, this spatial pattern suggests that these zones are also likely to suffer from decreased brightness due to infrastructure damage and population displacement.

Figure 2. Sample Report Map:

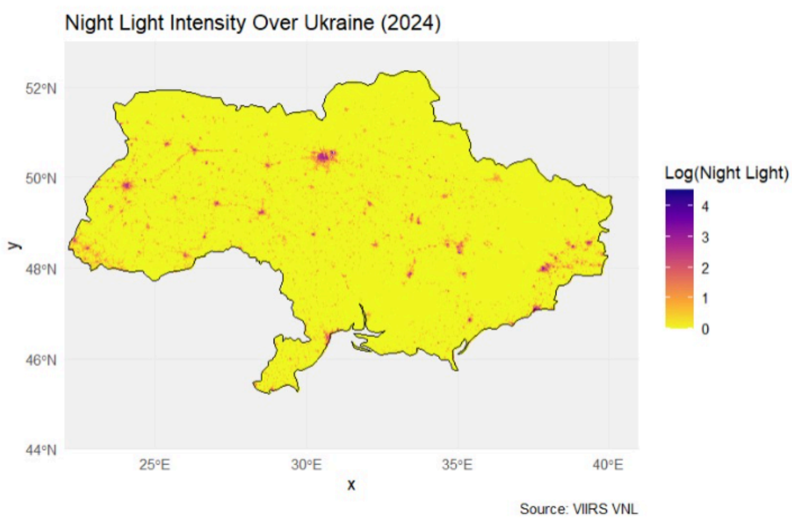
The Sample Report Map titled "Political Violence Events (7–13 December 2024)" provides a district-level overview of conflict activity across Ukraine. Each dot represents a recorded event categorized into one of three types: mob violence (light blue), battles (orange), and explosions or remote violence (dark blue). The spatial distribution highlights a distinct conflict corridor stretching from the northeast (Sumy, Kharkiv) to the southeast (Zaporizhia, Donetsk, Luhansk) and down into Kherson, with significant event clusters along this axis. Western regions such as Lviv, Chernivtsi, and Zakarpattia remain mostly unaffected, showing no or minimal conflict activity.The number of events per district is depicted using graduated circles, reinforcing that eastern and southern districts are the most intensely affected zones. This map not only visualizes the concentration of violence but also allows for comparison across different provinces. It serves as a valuable baseline for evaluating the impact of conflict on local infrastructure and population presence, particularly when cross-referenced with changes in night light intensity. The map supports the conclusion that the geographic scope of conflict is not uniform, but heavily concentrated in strategic frontline regions of eastern Ukraine.

Figure 3. Political Violence Events in Ukraine (2024)



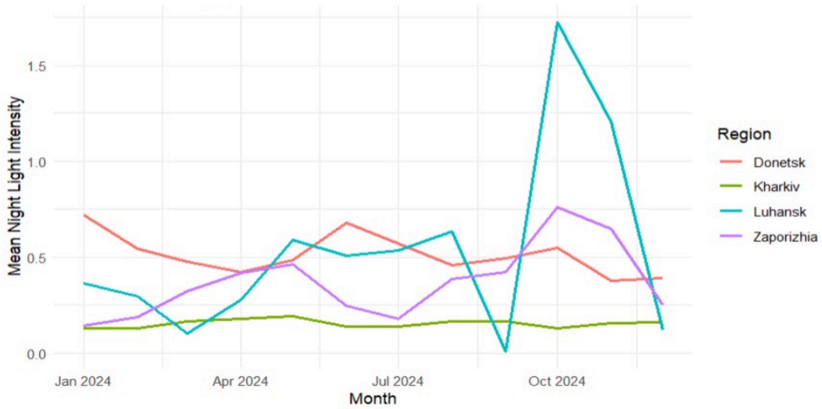
The map titled "Political Violence Events in Ukraine (2024)" offers a year-long spatial overview of armed conflict events across the country, based on ACLED data. Each event is classified as one of three types: battles (blue), explosions or remote violence (orange), and violence against civilians (red). The density and scale of these events are visualized through graduated circles, with the largest ones representing over 400 events in a single location.The eastern and southeastern regions, particularly areas near Donetsk, Luhansk, Zaporizhia, and Kherson, show extreme clustering of conflict activity. Notably, there is a high prevalence of violence against civilians (marked in red), indicating targeted attacks beyond military objectives. Western and northern Ukraine remain relatively calm in contrast.This map supports the narrative that political violence in Ukraine is heavily concentrated along a broad east-to-south corridor, reflecting the ongoing frontline dynamics. The visualization also emphasizes the humanitarian toll of the conflict, with many civilian-targeted incidents recorded throughout 2024.

Figure 4. National Light Map:



The “National Night Light Map” is a satellite-based raster map that visualizes night light intensity across Ukraine for the year 2024, using data collected from the VIIRS (Visible Infrared Imaging Radiometer Suite) sensor. The map employs a logarithmic color scale from 0 (dark) to 4+ (very bright), providing a visual proxy for human activity and population distribution. In cities such as Kyiv, Odesa, Dnipro,and Kharkiv, where conflict has been minimal or limited to outer administrative boundaries, night light intensity is relatively high. In contrast, cities like Donetsk and Zaporizhia, which have experienced sustained conflict throughout the year, show notably lower brightness levels. This decline strongly suggests that urban population density in these areas has decreased, likely due to displacement during periods of intense political violence. Because this is a raster map derived from satellite imagery, it enables large-scale, non-intrusive monitoring of population presence across time and space. When paired with conflict event data, it becomes evident that cities exposed to repeated violence consistently exhibit diminished night light signals, reinforcing the idea that night light loss can indicate depopulation in conflict zones.

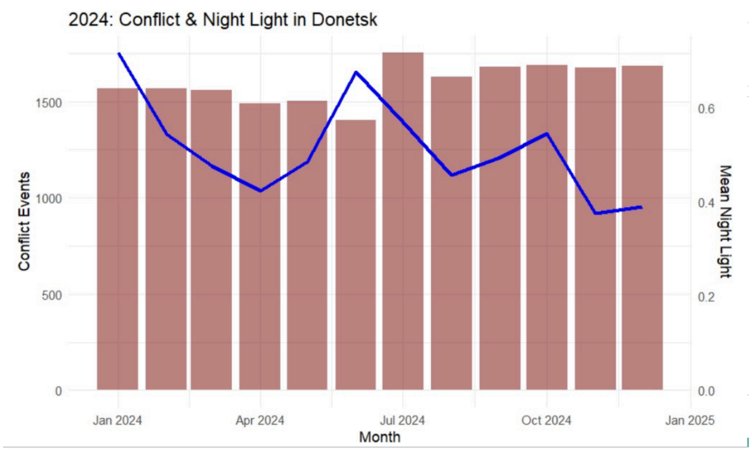
Figure 5. Night Light Intensity Over Time (2024) - Donetsk, Kharkiv, Zaporizhia, Luhansk



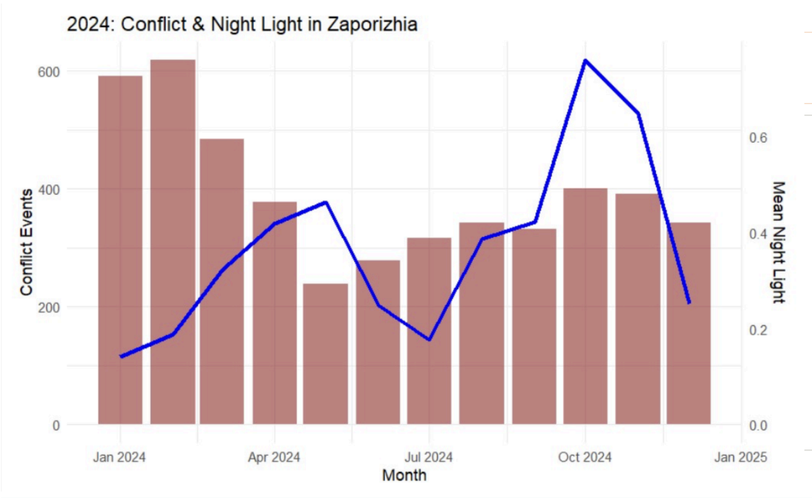
https://www.understandingwar.org/backgrounder/russian-offensive-campaign-assessment-october-27-2024

This line chart presents monthly trends in average night light intensity for four conflict-affected urban areas: Donetsk, Kharkiv, Zaporizhia, and Luhansk. These regions were specifically selected because they are located along the Russian border and, according to spatial data from the ACLED conflict event maps, they represent some of the most heavily impacted areas in Ukraine throughout 2024. The data is drawn from satellite-based VIIRS imagery and serves as a temporal indicator of human presence. Throughout the year, Kharkiv shows a relatively stable but low level of brightness, likely reflecting a consistently diminished population. In contrast, Donetsk and Zaporizhia display fluctuations, with moderate brightness levels that decline toward the end of the year, aligning with reported escalations in political violence. The most striking trend is observed in Luhansk, which experiences a sharp surge in night light intensity around September–October 2024, followed by a steep decline. According to the reference we consulted(ISW), this spike coincides with Russia establishing a new military base in the area, which likely caused a temporary increase in artificial lighting unrelated to civilian return. The subsequent drop suggests renewed displacement or withdrawal of activity. Overall, the chart reinforces the view that night light intensity is closely tied to civilian presence and fluctuates in response to the evolving dynamics of conflict across regions.

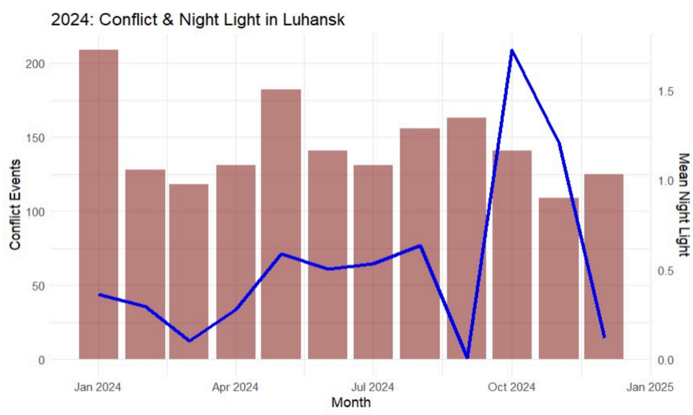
Figure 6,7,8,9. Conflict and Night Light in Donetsk, Zaporizhzhia, Luhansk and Kharkiv



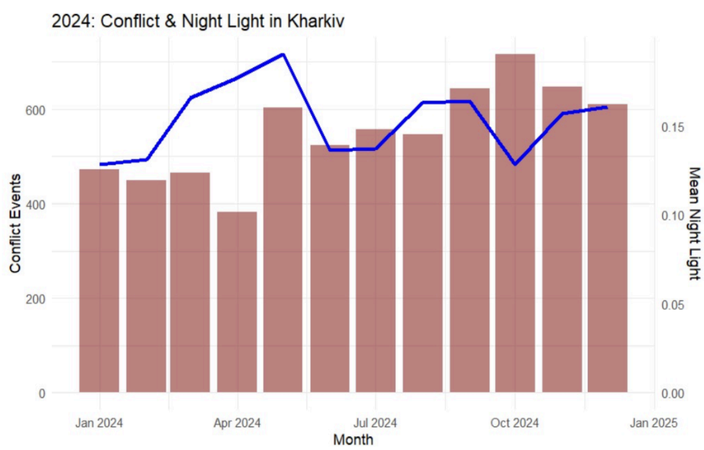
The chart presents conflict events and night light intensity in Donetsk throughout 2024. A key insight is the significant decline in mean night light levels, particularly in March–April and October–November, despite consistently high conflict activity. This trend strongly suggests not only the destruction of energy infrastructure but also a reduction in population density. As a city close to the frontlines, Donetsk has experienced waves of displacement, with civilians fleeing due to intensified bombardments. The decrease in night light serves as a proxy for both infrastructure collapse and demographic shifts. It illustrates how cities near the conflict zone are not only under physical attack but are also becoming increasingly depopulated and darkened. In this context, night light data reveals the broader humanitarian toll of the war and highlights the strategic targeting of border-adjacent urban areas.



Zaporizhzhia is a strategically critical city in southeastern Ukraine, located near the frontline and home to Europe's largest nuclear power plant. Throughout 2024, the city has been repeatedly targeted by artillery and airstrikes, severely impacting civilian infrastructure and forcing many residents to flee. According to the chart, conflict events are high at the beginning of the year while night light levels remain low—suggesting either widespread displacement or power outages. During spring, conflict activity declines and night light levels rise, indicating a brief period of relative stability. However, in October 2024, there is a sharp spike in both conflict and night light intensity. This may reflect increased military activity or a temporary restoration of electrical infrastructure. Yet, this is immediately followed by a dramatic drop in night light in November and December, likely due to renewed attacks on energy systems.

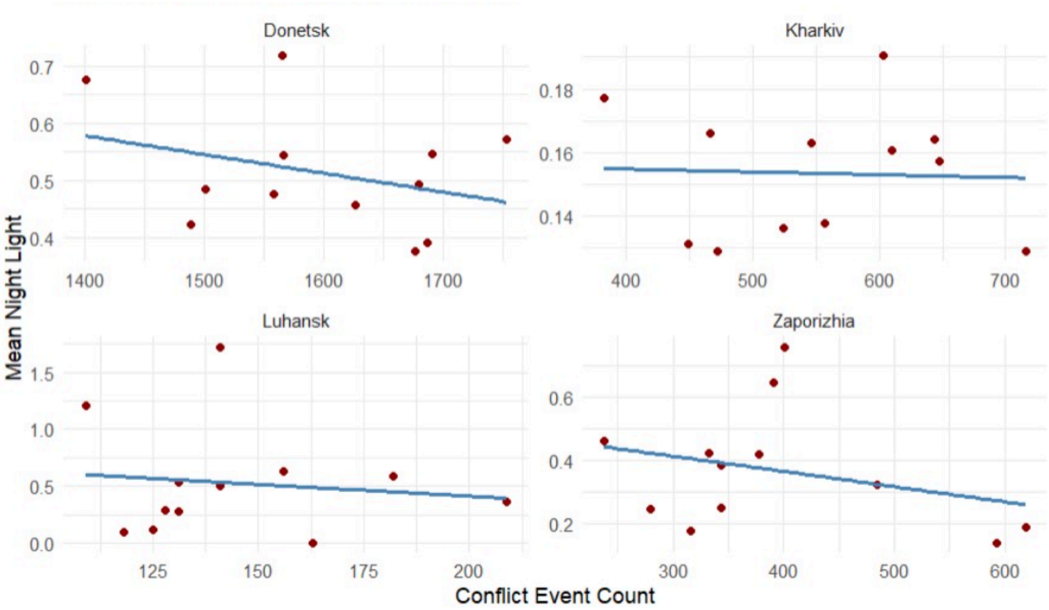


Luhansk is a strategically significant region in eastern Ukraine, under de facto Russian control since 2014 through Russian-backed separatist forces. Following Russia's 2022 full-scale invasion, Moscow formally claimed to annex the territory, although this has not been internationally recognized. Today, Luhansk remains a militarized zone, with persistent conflict and strong Russian military presence. The most striking observation from the chart is the sharp spike in night light intensity in October 2024. This surge likely reflects temporary military or logistical activities, such as troop concentrations or the use of artificial lighting in military installations. Despite moderate conflict levels, the light value rises rapidly, then drops dramatically in the following months. By December, night light is near zero, even as conflict events remain elevated. This suggests a collapse of civilian life, mass displacement, or total blackout due to energy infrastructure failure. Luhansk illustrates that even in Russian-controlled areas, the war severely disrupts daily life. The sharp fluctuations in night light data may not reflect population behavior, but rather shifts in military operations. In either case, the pattern confirms the deep humanitarian and infrastructural toll of the ongoing war.



Kharkiv is located in northeastern Ukraine, close to the Russian border, and has remained under Ukrainian control throughout the war. Although never occupied, the city has suffered relentless artillery and missile strikes, causing severe damage to civilian infrastructure. Kharkiv stands as both a symbolic and strategic stronghold of Ukrainian resistance. The chart shows that conflict activity in 2024 has remained consistently high, peaking in October. Yet, the night light intensity has been relatively stable compared to other frontline cities. This may indicate that the city, despite repeated attacks, managed to maintain a functioning energy infrastructure for most of the year. Both conflict and light levels remain steady from July to September, suggesting that civilians have not completely evacuated and essential services are still operating. However, a noticeable drop in night light during October aligns with peak conflict levels, implying significant damage to the city's electrical grid at that point. Kharkiv demonstrates how, even under heavy fire, cities under Ukrainian control can exhibit greater resilience in terms of civilian presence and infrastructure continuity. It remains one of the few major frontline cities that has not plunged into total darkness despite ongoing assault.

Figure 10. Conflict Events vs Night Light Intensity



The scatter plots titled “Conflict Events vs Night Light Intensity” illustrate the relationship between the number of conflict events and average night light intensity for Donetsk, Kharkiv, Luhansk, and Zaporizhia. Each red dot represents one month of data in 2024, and the blue lines indicate fitted linear regression trends. Across all four cities, the slope of the trend line is negative, meaning that higher levels of conflict are associated with lower night light intensity. This supports the central hypothesis of this study — that political violence leads to depopulation or reduced human presence in urban areas, which is indirectly captured through satellite-based night light data.

While Donetsk and Zaporizhia exhibit a clear negative correlation, indicating that increases in violence coincide with decreased night light intensity, the case of Luhansk stands out due to its greater dispersion and outliers. The wide range in Luhansk’s night light values, even at similar conflict levels, likely reflects irregular spikes in artificial lighting, such as the previously mentioned military base activity. In Kharkiv, the relationship appears nearly flat, suggesting that despite high numbers of conflict events, night light intensity has remained relatively stable. This may point to a more resilient population or infrastructure, or alternatively, that violence was more concentrated in peripheral areas rather than the urban core. Overall, the chart provides quantitative backing for a general trend while also revealing city-specific variations in how conflict influences urban presence.

4. Concluding Remarks

This study demonstrates that satellite-derived nighttime light data can effectively capture the population-level consequences of political violence in urban conflict zones. By correlating VIIRS night light intensity with ACLED conflict event data, we find consistent evidence that urban centers experiencing frequent or intense violence tend to exhibit decreased night light emissions. This pattern is most evident in frontline cities such as Donetsk, Zaporizhia, and Luhansk, where monthly declines in brightness coincide with periods of intensified conflict. While some cities like Kharkiv show greater resilience, the overall trend confirms that night light loss serves as a meaningful proxy for population displacement and disruption of civilian life.

These findings support and extend previous research in the field of spatial conflict analysis by offering city-level, time-resolved insight into how war reshapes the human geography of a nation. For future research, incorporating additional data sources, such as refugee flows, mobile network activity, or infrastructure outage maps, could refine the understanding of war-induced urban change.

From a policy perspective, this approach provides a scalable, cost-effective, and non-intrusive tool for humanitarian actors and crisis response agencies. By integrating night light data into early warning systems or needs assessments, stakeholders can better identify zones of severe displacement, target aid distribution, and allocate resources in near real-time. As conflict monitoring increasingly moves beyond traditional reporting mechanisms, satellite data like VIIRS can play a central role in mapping the invisible costs of war.

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