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Geoinformation modeling of the urban heat island in Kharkiv under wartime conditions

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SUMMARY

An analysis of the literature sources (Rees, Hebryn-Baidy, Belenok, 2024) identified a list of factors that may contribute to changes in urban heat islands during military conflicts: destruction of green spaces; fires; disruption of natural water regimes due to the destruction of dams and obstruction of watercourses; changes in energy use patterns (use of generators); disruption of urban cooling systems (reduced intensity of air conditioning operation in the summer due to temporary population relocation and power outages); changes in traffic flows (increased frequency of traffic jams due to air raid alerts); forced changes in the operational modes of enterprises (due to shelling and power outages).

An experimental analysis of the changes in urban heat islands in Kharkiv during the winter and spring of 2022, in the early days and weeks of the full-scale invasion, recorded shifts in the location of urban heat islands, which are most likely related to the damage or shutdown of industrial facilities, a reduction in electricity consumption due to emergency power cuts, and population displacement to safer areas outside the city.

The application of the methodology for studying urban heat islands, using Kharkiv as a case study during the period of full-scale military aggression, with the use of GEE and Landsat data, demonstrated its effectiveness and the potential for its application in analyzing changes in other areas.

Introduction

Under the conditions of Russia's full-scale armed aggression against Ukraine, large-scale landscape transformations are occurring in areas adjacent to the front line due to active hostilities. These changes affect terrain modifications *(Orlenko et al., 2024)* as well as the distribution of heat and moisture, which are influenced by military activities, including the destruction of buildings and infrastructure, and fires caused by shelling. Urban and rural areas, forests, agricultural lands, and other landscapes are undergoing significant alterations. Satellite technologies provide valuable tools for studying these changes, including the spatial distribution of objects, phenomena, and processes on the Earth's surface. Particularly useful is the analysis of infrared imagery, which enables the detection of thermal anomalies on the surface and their temporal dynamics.

Method and Theory

The Urban Heat Island (UHI) effect is a phenomenon in which urban areas exhibit significantly higher temperatures than the surrounding rural and wild regions. This temperature difference is primarily caused by the human-modified environment, which includes buildings, roads, and other infrastructure that absorb and retain heat. The effect is driven by urban construction materials such as asphalt and cement, which generally have low albedo and high thermal mass. This meteorological phenomenon contributes to increased greenhouse gas concentrations, air pollution, and reduced nighttime cooling *(What Is an Urban Heat Island?, w. d.).*

Since the early 1970s, the temporal and spatial variations in the contours of SUHI have been a significant topic in the literature on urban remote sensing in the thermal range. These studies have primarily focused on their relationship with land use and land cover (LULC) *(Stewart et al., 2021).*

The authors *(Stewart et al., 2021)* investigate the diurnal variations of surface urban heat islands and conclude that temperature distribution depends on regional climate, urban morphology, vegetation cover, soil moisture, and wind speed.

A study of the city of Pristina (partially recognized Republic of Kosovo) based on Landsat data revealed the highest temperatures in areas dominated by impervious materials, as well as in all locations lacking vegetation *(Berila & Isufi, 2021).*

At night, the UHI effect intensifies due to the higher thermal inertia of construction materials used for urban buildings. Therefore, the authors *(Roshan et al., 2024)* analyzed the nighttime distribution of UHI in 2022 across the cities of Kharkiv, Donetsk, and Mariupol.

In the study by *(Rees, Hebryn-Baidy, and Belenok, 2024),* a comprehensive assessment of multi-temporal LULC changes and their impact on LST in Kharkiv, Ukraine, from 1984 to 2023 was conducted using remote sensing technologies. The results indicated a general increase in the urban heat island effect, particularly during the summer. However, the study did not consider the consequences of military actions.

The analysis of multi-temporal remote sensing data enables the identification of the spatial distribution of thermal indicators in different urban areas, allowing for an assessment of anthropogenic factors influencing UHI formation. For this study, Landsat 8/9 data were used, which offer the best spatial resolution of the thermal band among all available non-commercial satellites—100 m, provided to users with a processed resolution of 30 m.

The methodology included the processing of the thermal band in the Google Earth Engine (GEE) environment and consisted of the following stages.

The first stage involved filtering images based on cloud cover, which was required not to exceed 15%. After this, the dataset of satellite images was further filtered by date range for the study period: the first image was selected from the period before the full-scale invasion, while the others were taken

after its onset. The purpose of this selection was to identify temperature changes specifically associated with military actions.
The next stage was the creation of a mask for the region of interest: (1) cropping the image along the administrative boundaries of the city, and (2) refining the polygon boundaries using a mask of built-up areas derived from the land cover classification provided by Dynamic World (Dynamic World - 10m global land cover dataset in Google Earth Engine, n.d.). This approach enabled the identification of heat island hotspots with the most significant impact on the urban population and highlighted areas where military actions have altered conditions for human activities.
**Next, the calculation of land surface temperature (LST) was performed using the thermal band processing algorithm for the Landsat 8/9 satellites. The 10th band, which contains brightness temperature data, was selected for this purpose. The following steps were carried out: calculation of the Normalized Difference Vegetation Index (NDVI), determination of its minimum and maximum values, computation of the emissivity coefficient, and calculation of LST based on the emissivity coefficient and brightness temperature, following the methodology outlined in *(Cardille et al., 2024, p. 751)*.
For comparison, unit conversion from degrees Celsius to z-score was necessary. Standardized units indicate how much a value deviates from the mean, allowing for an assessment of differences in the spatial distribution of heat islands without requiring strict seasonal filtering.
Next, the calculation of Chebyshev's bounds and the construction of temperature anomaly maps were performed. Mathematician Pafnuty Chebyshev (1821–1894) established a method for estimating the proportion of values within a given number of standard deviations from the mean, even for non-normally distributed data. Thus, it is possible to assess the probability of a random variable deviating from its expected value. By using standardized units and knowing that 1 z-score = 1 σ, the areas corresponding to 93%, 88.8%, and 75% probability thresholds can be determined for any distribution, based on the data presented in Table 1.

***Table 1** Chebyshev's Bounds (Adhikari et al., 2022, p. 14.2.5).*

Range	**Proportion**
average ± 2 SDs	at least 1 - 1/4 (75%)
average ± 3 SDs	at least 1 - 1/9 (88.888…%)
average ± 4 SDs	at least 1 - 1/16 (93.75%)
average ± 5 SDs	at least 1 - 1/25 (96%)

The final step involves calculating the difference between raster values for different periods and visualizing the results on maps.

Example

For this study, the city of Kharkiv was selected due to its immediate exposure to military actions following the onset of full-scale armed aggression. Kharkiv is located in northeastern Ukraine. As of the beginning of Russia's full-scale invasion (February 2022), it was the second-largest city in the country, with a pre-invasion population of approximately 1.4 million people. The climate is moderately continental, with average air temperatures ranging from −6.1°C in January to +20.5°C in July, and an annual average precipitation of 520 mm *(Rees, Hebryn-Baidy, Belenok, 2024).* As an industrial hub, the city's microclimate is warmer than that of the surrounding area due to residential and industrial zones.

The hypothesis of this study is that changes in the urban heat island (UHI) can be detected during and after periods of intense shelling. These changes are attributed to variations in surface albedo caused by the destruction of buildings and infrastructure, vegetation growth on damaged areas, and other contributing factors.
According to open sources (2122 air raid alarms were recorded in Kharkiv region in 2024, n.d.), the periods with the highest frequency of shelling in the city include: a) February–March 2022 (The

onset of the full-scale invasion. Kharkiv experienced massive attacks, particularly in the first weeks of the war); b) August–September 2022 (a period of intense combat, notably during the Ukrainian counteroffensive in Kharkiv Oblast); March 2024 (a total of 277 air raid alarms were recorded in one month, indicating a high intensity of threats); September 2024 (206 air raid alarms recorded in one month); April 2024 (204 air raid alarms recorded). These periods were selected as the most representative for detecting changes in the spatial distribution of urban heat islands (UHI).

Results

As a result of the analysis (Figure 1), significant changes in the distribution of hot and cold spots of the UHI effect were observed between the onset of the full-scale invasion and its active phase in March 2022.

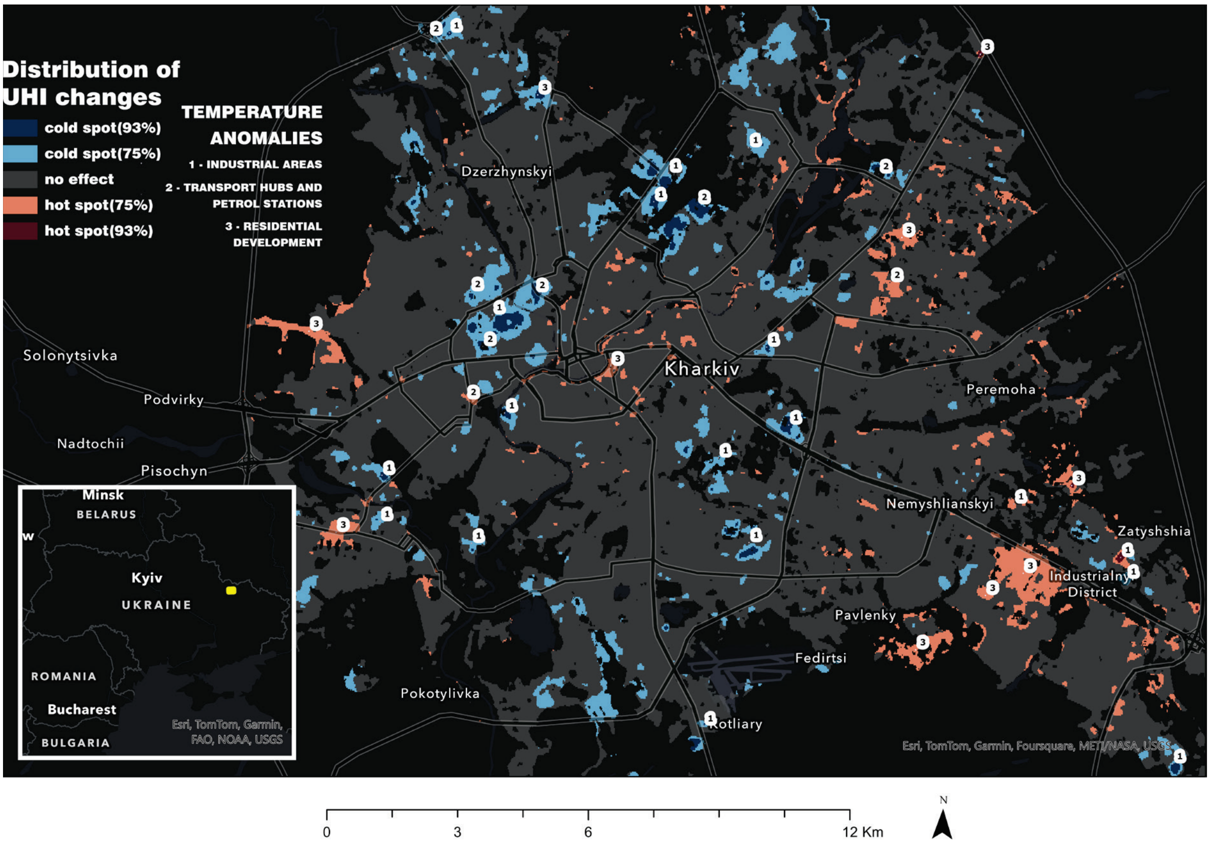

Figure 1 Change in Urban Heat Islands in the City of Kharkiv on March 13, 2022, compared to February 23, 2022.

In the early days of the full-scale invasion, a rapid relocation of heat islands occurred, associated with the damage to industrial facilities, the suspension of enterprise operations, and a decrease in electricity consumption due to curfews, as well as potential population outflows due to migration to safer areas. An analysis of changes in hot and cold spots revealed a swift shift in the spatial distribution of the Urban Heat Island (UHI) effect in the city of Kharkiv. Cold clusters, which correspond to a reduction in Land Surface Temperature (LST), account for a larger portion of thermal anomalies compared to hot clusters. The spatial analysis showed that approximately 65% of the sources of cold spots are industrial enterprises, 30% are transport hubs and gas stations, while the remaining sources consist of residential areas and shopping centers. Hot clusters, which contribute to an increase in LST, cover a smaller area in terms of anomalies. Among the hot cluster sources, residential buildings account for the largest percentage, 64.3%. Thus, the study confirmed the theory of the impact of military actions on changes in the microclimatic environment of the city. The primary sources of CO_2 emissions - industrial enterprises, transport hubs, and trade centers - whose operations were disrupted by military aggression, sharply reduced their contribution to the increase in surface temperature. As a result, the main heat retainers remained certain areas of residential development.

Conclusions

An analysis of the literature sources (Rees, Hebryn-Baidy, Belenok, 2024) identified a list of factors that may contribute to changes in urban heat islands during military conflicts: destruction of green spaces; fires; disruption of natural water regimes due to the destruction of dams and obstruction of watercourses; changes in energy use patterns (use of generators); disruption of urban cooling systems (reduced intensity of air conditioning operation in the summer due to temporary population relocation and power outages); changes in traffic flows (increased frequency of traffic jams due to air raid alerts); forced changes in the operational modes of enterprises (due to shelling and power outages).
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