Land-Use and Land-Cover Changes in Kharkiv: Impact on Land Surface Temperature

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SUMMARY

This study explores the relationship between land-use and land-cover changes (LULC) and Land Surface Temperature (LST) in Kharkiv, Ukraine, for 1984 and 2022. Using Landsat 5 and 8 imagery processed through the Google Earth Engine, significant LULC shifts were identified, with 'Built-up' areas and 'Forest' expanses increasing notably. LST readings revealed that 'Forest', 'Vegetation', and 'Water' classes maintained lower temperatures, whereas 'Built-up' and 'Bare land' areas showed elevated temperatures. This analysis underscores the growing urban heat island effects in expanding urban areas like Kharkiv. The findings emphasize the need for sustainable urban planning to mitigate environmental challenges.

Keywords: land surface temperature, land use and land cover, Landsat, Google Earth Engine
Introduction

Land surface temperature (LST) fluctuations are notably influenced by alterations in land use and land cover (LULC). Such changes in LST can profoundly affect urban ecosystems, biodiversity, and the health of its inhabitants. Due to urban development, features such as green spaces, wetlands, aquatic areas, and open lands experience swift changes. Furthermore, unchecked changes in LULC lead to an increase in developed regions at the expense of green spaces, intensifying urban heat island (UHI) impacts. Accelerated urban growth boosts the presence of non-permeable surfaces, such as buildings, roads, and industrial sites, leading to a significant surge in LST. Satellite-based remote sensing provides invaluable data for mapping LST. Instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites offer consistent and high-resolution LST data on a global scale. Additionally, the Thermal Infrared Sensor (TIRS) aboard Landsat 5,8,9 also captures LST data, enabling detailed spatial analysis of surface temperature patterns.

Many research efforts have utilized Landsat data for remote sensing-based LST retrieval. The LST can be derived using methods such as the single-channel approach or the split-window algorithm, especially for sensors with two thermal bands. It should be noted that there is an increasing body of research dedicated to exploring the correlation between LULC changes and the rise in LST, particularly within urban environments (Akomolafe and Rosazlina, 2022). The results of the study (Ashwini and Sil, 2022) highlighted that within the Cachar district of India, anticipated growth in built-up areas by 9.33% by 2040 will cause a 5°C surge in average LST over three decades. The aim of the study (Hussain et al., 2022) is used 30-year Landsat images to show built-up areas in Southern Punjab expanded from 3.63% to 10.8% over three decades, correlating with increasing LST values annually. The study (Mukherjee and Singh, 2020) on LULC changes in Indian cities revealed that over a 20-year span, built-up areas in Surat increased by 85% (Bharuch by 31%), accompanied by a 2.42°C (Bharuch by 2.13°C) rise in temperature per decade. Using Landsat, the study (Rehman et al., 2022) identified that in northern Pakistan, built-up areas and vegetation increased by 2.1% and 11% respectively over 30 years, with associated LST changes. Using a forecasting model with Cellular Automata and Weighted Evidence simulations, the authors project that by 2047, LULC will increase, amplifying temperature variations. The study (Mumtaz et al., 2020) analysed 20-year LULC changes in Lahore and Peshawar, predicting future LULC for 2023 and 2028. Peshawar's vegetation increased by 25.6%, reducing LST, while Lahore's urban expansion of 11.2% and vegetation decrease of 22.6% raised LST. Numerous studies utilizing Landsat data consistently underscore the significant correlation between LULC changes and shifts in LST, with urban expansion often correlating with increased temperatures. These findings illuminate the critical importance of sustainable urban planning and land resource management in mitigating potential environmental challenges and guiding future policy decisions.

The goal of this study is to map the LULC changes and LST over a span from 1984 to 2022. A key aim is to determine specific threshold values of LST for each LULC class. By analyzing the histogram distribution of LST values corresponding to each LULC class, we aim to comprehend the variation in heating for each surface type. The object of this study is the territory of the city of Kharkiv. Located in the northeastern part of Ukraine, within the Slobooda Ukraine region. With a population of 1,421,125, it ranks as the second-largest city in Ukraine, spanning an area of 350 km². Along with its neighboring cities and districts, it forms the Kharkiv agglomeration, boasting a population of over 2 million. Recognized as a major scientific, cultural, industrial, and transportation nucleus of Ukraine, Kharkiv once stood as the third industrial powerhouse in the former USSR. The combination of its vast urban expanse, industrial zones, and diverse infrastructure makes Kharkiv a compelling subject for understanding urban-induced land and temperature changes over time.

Method

Images from the Landsat 5 (LANDSAT/LT05/C02/T1_L2/LT05_178025_19840716, CLOUD_COVER: 8) and Landsat 8 (LANDSAT/LC08/C02/T1_L2/LC08_177025_20200702, CLOUD_COVER: 0.81) collections were utilized for LULC classification and LST determination. This study utilized the Google
Earth Engine (GEE) cloud computing platform. GEE not only provides access to satellite data for specific time intervals but also boasts robust tools for processing remote sensing data and conducting geospatial analyses (Belenok et al., 2023). The method for determining LST is based on the radiative transfer equation and emissivity corrections using fractional vegetation derived from the NDVI. This method is often referred to as the "Single-Channel Algorithm" ("Monowindow Algorithm"). The approach involves using a single thermal band (in this case, from Landsat imagery) and applying emissivity corrections to derive LST. The calculation involves using the brightness temperature from the thermal band, determining the fractional vegetation using NDVI, computing emissivity based on the fractional vegetation, and finally calculating the LST using the radiative transfer equation. For the LULC classification, the study employed a supervised machine learning approach. Training samples were curated by merging datasets representing distinct land classes: water, bare land, forest, vegetation, and built-up areas. With these samples, a Random Forest classifier, encompassing 100 decision trees, was trained. To evaluate the effectiveness of the classification, validation datasets for the aforementioned land classes were consolidated. The classified outcomes were juxtaposed with this validation set, facilitating the calculation of a confusion matrix, overall accuracy, Kappa coefficient, consumer's accuracy, and producer's accuracy (Belenok, Noszczyk, Hebryn-Baidy and Kryachok, 2021; Belenok et al., 2022). Additionally, to enhance the accuracy of the classification, vegetation indices such as NDVI, NDSI, BAEI, and NDWI were utilized (Belenok et al., 2023). To delineate LST threshold values for each LULC class, distribution histograms were constructed. Data analysis was conducted using the RStudio software environment.

Results

Upon analyzing the classification results of the Kharkiv territory for the periods of 1984 and 2022, we observed significant land-use and land-cover changes. Specifically, 'Built-up' area experienced an increase of 22.08 km² and this change is absolutely justified. Meanwhile 'Forest' area expanded by 48.05 km² and 'Vegetation' territory reduced by 26.63 km². This observed discrepancy can be attributed to both the intricacies of the classification methodology and the ongoing afforestation efforts within the city of Kharkiv. A decrease was noted in the "Bare land" category by 45.06 km². This class undergoes constant fluctuations and depends on the time period. The 'Water' cover enlarged by 1.55 km² (Fig.1.a,b).

The recorded LST values show that the 'Forest', 'Vegetation', and 'Water' categories exhibit lower temperature readings, varying between 26°C and 37°C. Conversely, the 'Built-up' and 'Bare land' classes are marked by elevated LST values, spanning from 38°C to 56°C (Fig.2.a,b). This distinction can be attributed to the differences in surface properties and heat capacities of these land covers. Forested and vegetative areas, due to their ability to transpire, release moisture into the atmosphere, leading to cooling effects. Water bodies similarly have a higher heat capacity, enabling them to absorb and store more heat without significant temperature increase. In contrast, built-up regions and bare lands lack the cooling benefits of transpiration and have lower heat capacities, thus heating up more quickly and retaining heat for longer periods, resulting in higher LST values.
The obtained data depicts the temporal changes in LST for various land cover classes in Kharkiv between July 1984 and July 2022. Over this period, there is a noticeable increase in the minimum and mean LST values across all classes, with the 'Built-up' class experiencing the most significant surge in average temperature (Tab.1). Conversely, the maximum LST values show a slight decrease or stabilization, indicating a narrowing of temperature extremes for these land cover categories.

### Table 1. LST for each LULC classes

<table>
<thead>
<tr>
<th>Class name</th>
<th>16/07/1984</th>
<th>02/07/2022</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min_LST</td>
<td>max_LST</td>
</tr>
<tr>
<td>Water</td>
<td>26.31</td>
<td>50.68</td>
</tr>
<tr>
<td>Bare land</td>
<td>30.05</td>
<td>54.01</td>
</tr>
<tr>
<td>Built-up</td>
<td>27.77</td>
<td>55.88</td>
</tr>
<tr>
<td>Forest</td>
<td>27.80</td>
<td>47.20</td>
</tr>
<tr>
<td>Vegetation</td>
<td>27.71</td>
<td>50.63</td>
</tr>
</tbody>
</table>

During this span, there’s a discernible escalation in the minimum and mean LST values for all classes. Notably, the 'Built-up' class witnessed the most pronounced rise in average temperature, as depicted in Table 1. It's worth noting that the highest density for the 'Built-up' class is observed between 38-43°C (Fig.3). In contrast, the maximum LST values either slightly decreased or remained stable, suggesting a contraction in temperature extremes for these land cover types.

### Conclusions

The research provides a compelling investigation into the nexus between land-use and land-cover changes and LST variations in the urban environment of Kharkiv, a critical city in the
landscape of Ukraine. Positive shifts were observed in the expansion of the 'Forest' area, a potential testament to afforestation initiatives, which can be seen as a proactive approach towards urban sustainability. Concerningly, the growth in 'Built-up' areas, corroborating global urban trends, underscores the looming threat of intensifying urban heat islands, as these areas recorded the highest surge in average temperature. A significant scientific novelty lies in the detailed LST threshold assessment for each LULC class, providing insights into the temperature variations intrinsic to distinct land covers, aiding urban planners and policymakers. While the study's reliance on only two temporal snapshots (July 1984 and July 2022) may appear limiting, future research endeavors are slated to bridge this gap, enriching the temporal spectrum and thus enabling a more comprehensive understanding of LULC and LST dynamics. Future studies by the authors aim to incorporate a broader range of satellite captures to ensure continuity and depth in the temporal evaluation of the urban environment in Kharkiv.

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References


