GIS-based remote sensing identification method of thermal pollution in cities: case study of Lutsk, Ukraine and Lublin, Poland*

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Abstract
Due to climate change, heat waves are expected to occur more frequently in the future, which might cause adverse health effects for the urban population. The combination of high temperatures and poor air quality significantly impinges on the natural environment and could cause degradation. This accentuates the need to assess residents' health risks regarding air pollutants and anomalously high summer air temperatures. However, comprehensive information on the spatial and temporal distribution of temperature and particulate matter concentration in cities is complex to obtain since only a few measurement sites exist. The text discusses the modern methods for monitoring heat islands in urban areas using remote sensing data. It focuses on the techniques for monitoring both the quantity and quality of temperature indicators using various cloud-based web services. It also introduces an algorithm and provides examples for estimating spatial and temporal surface temperature variations in cities using the EO-Browser service.

Keywords
land surface temperature (LST), GIS-based web services, EO-Browser, Evalscript, Landsat-8,9

1. Introduction

Thermal pollution is a significant environmental issue that impacts the health and comfort of city residents, as well as energy consumption and society's ecological footprint. It is often categorized as direct or indirect. Direct thermal pollution involves the release of heated gases and liquid vapors into the environment, such as emissions from thermal power plants, industrial facilities, and vehicle engines. Indirect thermal pollution occurs when greenhouse gas emissions, like carbon dioxide and methane, contribute to the greenhouse effect.

To reduce the impact of direct thermal pollution, cities are developing a combination of architectural and planning solutions, vertical and horizontal landscaping, changes in traffic flow, and maximizing the use of "green energy". An accurate assessment of the spatial distribution of heat islands and their changes is crucial for developing these solutions. Remote sensing methods, including thermal sensors on satellites, are widely used to gather information about the flow of infrared radiation from different parts of the Earth to estimate Land Surface Temperature (LST). However, the quality and accuracy of this data depend largely on the information technology used for processing.

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2. Related works

During the study, an analysis of the most recent scientific publications on urban heat islands was conducted. The research [1] helps to choose various mitigation solutions required to address urban heat across diverse climatic contexts. The purpose of [2] is to highlight the issue of research on measures involving the use of vegetation has a decisive prevalence over research on other measures. This review [3] shows an exponentially increasing trend in satellite-based SUHI publications since 2005, with large biases in the geographic areas, study time of day, study seasons, and research foci. The goal of the studies [4-6] was to determine surface urban heat islands detected by all-weather satellite land surface temperature and a modeling toolbox designed using a spatial technique. The web application LST products were evaluated to observe and document the behavior of different emissivity products on LST [7-9]. Tool for environmental indices computing using Landsat and remote sensing data/techniques. The research [10,11] uses web service-oriented geoprocessing system for supporting intelligent land cover change detection. The investigations [12, 13] dedicate vegetation indexes in the EO-Browser and EOS LandViewer services and cloudiness dynamics in Lutsk in the context of climate change. In work [14] web GIS was used to promote stakeholder understanding of scientific results in sustainable urban development. In [15] the authors explore some of urban heat research, and highlights positive progress which offers grounds for optimism. The work [16] presents the concept of an information system for predicting the temperature regime of the earth's surface using machine learning. Forecasting is carried out on the basis of historical data for a certain territory. To increase the accuracy of forecasting results, an analysis of the features of climatic zones was carried out to identify patterns. A comparison of the dependencies of the average monthly temperatures of the earth's surface in countries, depending on their location in climatic zones, is carried out.

Currently, there are several satellites equipped with a thermal infrared channel that can monitor temperature differences on the Earth's surface. These satellites include MODIS (Terra/Aqua), Sentinel-3, NOAA 20 (VIIRS), Landsat-8, Landsat-9, and others. However, most of these satellites have a low spatial resolution, ranging from 375 meters to 1 kilometer per pixel, which limits their effectiveness for detailed research [4]. Among open-access civilian satellites, the highest thermal sensor resolution is 100 meters, found on Landsat-8 (operational since 2013) and Landsat-9 (operational since 2021) operated by the US Geological Survey. Although this resolution is lower than other multispectral satellite channels, it still allows for detecting and analyzing Land Surface Temperature (LST) differences at the city level (Figure 1).

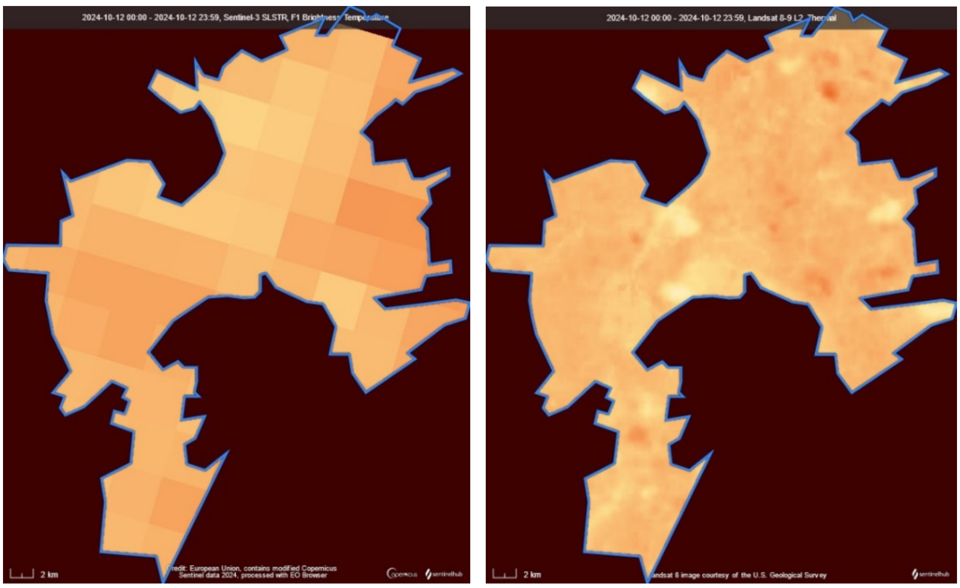

Figure 1: Comparison of thermal images with a 1 km resolution (Sentinel-3, left picture) and 100 m resolution (Landsat-8,9 right picture) for the city of Lutsk on October 12, 2024.

The data from these satellites not only provides a spatial picture of relative LST values, but also offers information on the quantitative parameters of measured brightness values in the long-wave infrared range, which can be converted into absolute temperature values.

Numerous studies have focused on automating LST monitoring using Landsat-8 data. These studies propose implementing these functions using desktop or online GIS, with tools such as ArcGIS, QGIS, and others being commonly used.

Recently, there have been efforts to integrate LST data into cloud-based GIS web services, such as Google Earth Engine, EO-Browser, and EOSDA LandViewer, which have generated considerable interest. Using these services is often more convenient and accessible to more users than working with desktop software products. However, it is important to note that the display of LST from the same satellite data set in these services can differ significantly due to the peculiarities of the applied pre- and post-processing algorithms.

Remember the following text:

For example, the EOSDA LandViewer service (eos.com/products/landviewer) only displays the Landsat-8 thermal channel in shades of gray. However, it provides increased detail and the option to use the pansharpening function. You can also upload your own thermal image to a local device with georeference (kmz file) and create your own overlay with a high-resolution image (Figure 2).

Nevertheless, the LandViewer service does not allow the thermal channel display to be edited or provide the necessary numerical LST parameters. These advanced capabilities are available in the EO-Browser service from Copernicus Sentinel Hub (apps.sentinel-hub.com/eo-browser). In the future, we will describe the main features of thermal pollution assessment based on LST indicators in this service.

3. Methodology and results

We analyzed the human-induced temperature differences in the cities of Lutsk and Lublin using LST data over several years. Based on this analysis, we propose conducting similar studies in the future:

1. Creation of vector files of city contours (KML/KMZ, GPX, JSON) and upload them to the service
2. The general assessment of Landsat-8,9 images over several years to assess spatial differences in the distribution of Land Surface Temperature (LST) across the territory and outline the urban heat island
3. Creation of overlays of thermal and optical images to identify the hottest and coldest areas of the city. Construction of separate vector contours for representative zones selected on this basis (industrial areas, green zones, various residential buildings, etc.)
4. Downloading data on LST numerical parameters for the selected period from EO-Browser (requires authorization on the service). A CSV file is generated with the following data set: thermal-C0/date, thermal-C0/min, thermal-C0/max, thermal-C0/mean, thermal-C0/stDev, thermal-C0/sampleCount, thermal-C0/noDataCount, thermal-C0/median, thermal-C0/p10, thermal-C0/p90, thermal-C0/cloudCoveragePercent.
5. Filtering of the selected numerical data by a percentage of cloud cover (thermal-C0/cloudCoveragePercent), cutting off false data [13]. It should be noted that sometimes there were unrealistic minus values in warm weather, due to obstructions from clouds or fog, even with the declared zero cloudiness of the image. Such data were screened out in the subsequent analysis

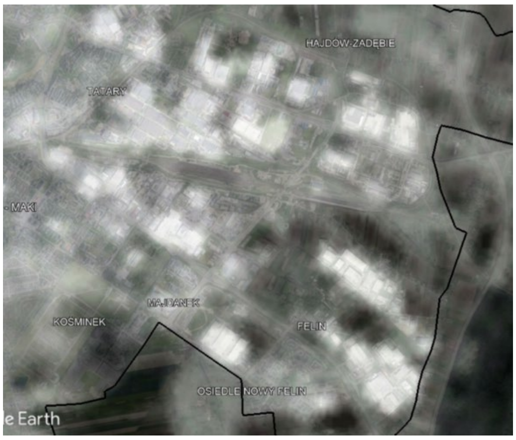

Figure 2: An example of overlaying thermal and optical images in Google Earth (territory of the city of Lublin). The hottest and coldest areas are identified and well-aligned with the city's corresponding industrial or green areas.

Statistical analysis and construction of generalized LST dynamics graphs for each selected area. Comparison of the obtained values with the averages or background. (Table 1)

Table 1
Example comparative results of surface temperature averages determination in different parts of Lutsk and Lublin cities using Landsat-8,9 data in EO-Browser

	t, °C				
	max	min	avg	avg max	avg min
Lublin industrial zone	57,0	-14,7	18,99	23,91	14,5
Lutsk Industrial zone	64,7	-20,3	20,89	32,5	13,9
Green areas Lublin	49,97	-15,59	16,9	21,84	13,88
Green areas Lutsk	41,3	-14,63	14,2	18,7	11,46
Lublin high-rise buildings	50,5	- 15,7	18,82	22,54	13,9
Lutsk high-rise buildings	46,17	-17,59	19,32	23,2	13,8
Manor building in Lublin	48,8	-14,78	18,3	20,1	16,13
Manor building in Lutsk	41,3	-17,75	14,2	18,8	11,47

Improving the visualization of temperature differences by editing the Evalscript display. Since the default temperature scale in EO-Browser is quite unclear in the range of moderate temperatures, it is often necessary to modify it to better represent the detected temperature differences (Figure 3).

There is an option to adjust the color for one or more specific LST values (in Kelvin) and add the colors for the required intermediate values. Also, the script based on the season of the year, the prevailing temperatures in the image and highlighting the range of critical temperatures can be modified.

4. Conclusions

The main reason this study is essential is the impact of climate change and rising temperatures. The use of LST satellite data offers many opportunities for monitoring thermal pollution in urban areas. This data can help identify critical areas that require management solutions to minimize the negative impact. GIS-based web services facilitate access, processing, and visualization of this data [14], including the capability to edit or load custom display scripts. Therefore, it is important to identify the factors contributing to the temperature rise, apart from industrialization, within the climate change phenomenon. Additionally, time-series Landsat-8 satellite images were used to explore temporal shifts across Lutsk (Ukraine) and Lublin (Poland).

Understanding the urban heat island effect in Lutsk, Ukraine, and Lublin, Poland is crucial for designing methods to reduce its harmful effects. This may involve implementing techniques to decrease the use of heat-absorbing materials in the city, such as installing green walls and roofs. Modeling the urban heat island effect in Lutsk can provide valuable guidance to city planners and decision-makers on the most effective methods for controlling the temperature and preventing adverse effects on the local environment and population. Ultimately, this can contribute to the development of a more livable and sustainable city for everyone.

In the future, we plan to conduct further research to improve the accuracy of this method, perform experiments with different urban settlements, and consider various heatwave scenarios.

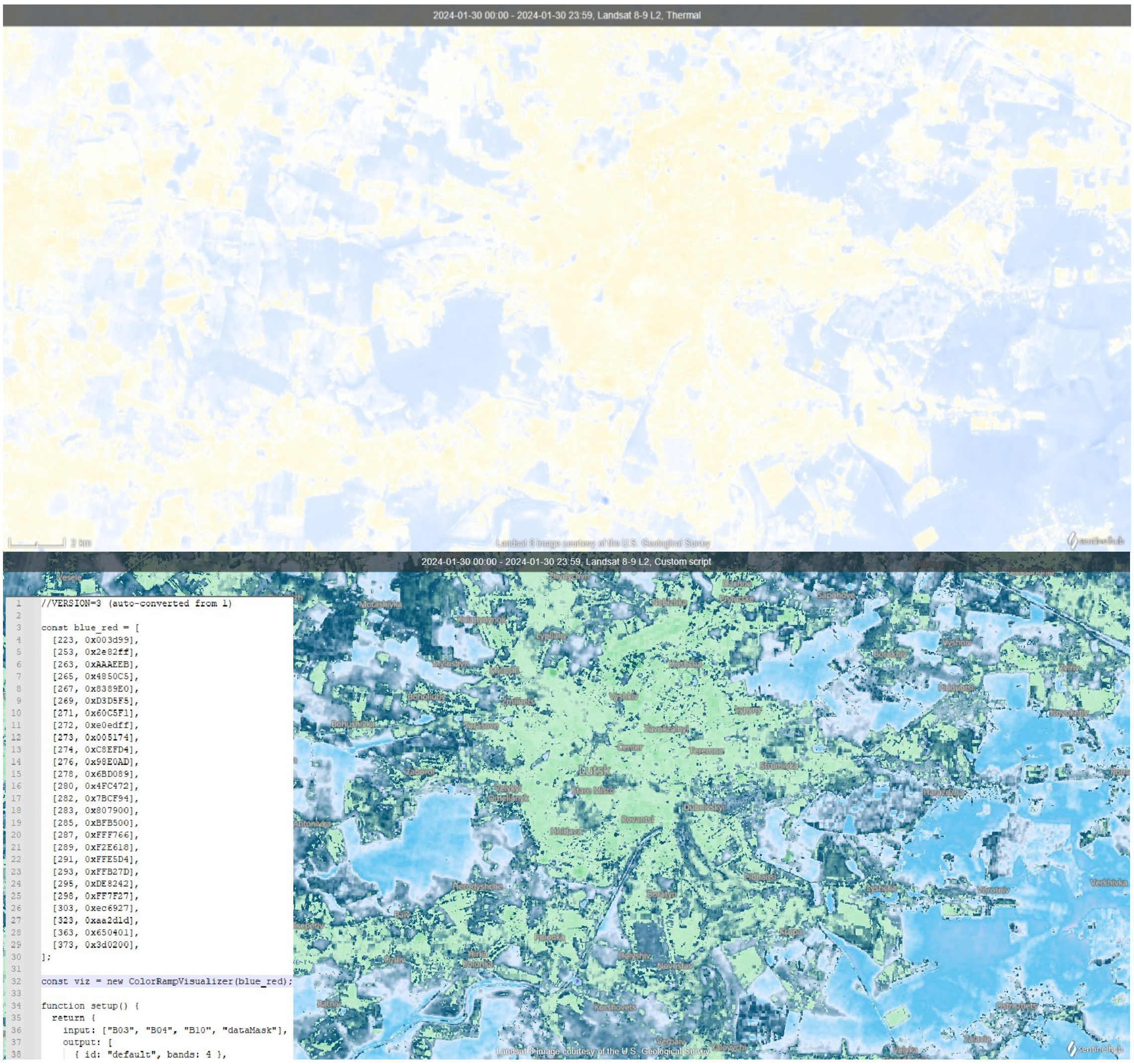

Figure 3: Comparison of the LST display in EO-Browser using the standard temperature scale (top) and with Evalscript's custom modification (Landsat-8,9 image from January 1, 2024).

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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