S E S 2 0 2 4
Twentieth Anniversary International Scientific Conference
SPACE, ECOLOGY, SAFETY
22 – 25 October 2024, Sofia, Bulgaria

MAPPING URBAN HEAT ISLAND INTENSITY IN GREEK REGIONAL UNITS: A REMOTE SENSING APPROACH USING THE UTFVI INDEX ON GOOGLE EARTH ENGINE

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Keywords: *Urban Heat Island; Google Earth Engine; Land Surface Temperature; Landsat; Sustainable Development Goals;*

Abstract: *The Urban Heat Island (UHI) phenomenon is a significant environmental issue, due to rapid urbanization and affecting many Greek regional units, where the replacement of natural areas with urban structures leads to increased land surface temperatures. This rise in various temperature impacts like the microclimate, quality of life, and public health.*

In this study, the intensity and extent of the UHI phenomenon, were analyzed in selected Greek regional units for the period 2019-2023. The analysis conducted in the present research, utilizing the Google Earth Engine platform and Landsat 8 satellite data, combined with the Urban Thermal Field Variance Index (UTFVI), generated multitemporal assessment of UHI trends. The results revealed an increased land surface temperature in urban areas compared to surrounding rural regions, according to UHI intensity classification levels.

The present research, highlights the importance of using cloud-based geospatial tools like Google Earth Engine, in order to monitor urban temperature, increase over time and underscores the need for sustainable development strategies to mitigate heat stress to improve living conditions in urban areas.

Introduction

The increase in atmospheric temperature, combined with the Land Surface Temperature (LST), plays a decisive role in the climate crisis (Mustafa et al., 2020). Since the second half of the 20^{th} century, the rapid urbanization of cities, together with technological advancement, human activities, and the general increase in population, has been directly linked to the economic development and urban sustainability of cities (Filho et al., 2017).

The intensification of this phenomenon has become the most critical challenge of the 21st century globally, as dramatic changes in land cover were made to address issues related to urban economic growth and residents' needs (Rimal et al., 2018).

The Urban Heat Island (UHI) phenomenon is inextricably linked to both human activity within cities and productive activities, and it has been extensively studied across a wide geographic range (Kim and Brown, 2021). The existence of the phenomenon became noticeable in the 19th century when major urban centers in northern Europe began to take shape. The intensity of the phenomenon is influenced and co-shaped by a set of factors (economic, social, topographical) (Nuruzzaman, 2015), making its long-term study crucial for mitigating its impacts across various sectors and achieving environmental restoration.

The thermal effects have a direct economic impact on each society, highlighting the necessity of quantitatively assessing the UHI phenomenon in order to adopt the best practices for mitigating and addressing it.

In this paper, we have developed a Google Earth Engine (GEE) algorithm for determining Land Surface Temperature and analyzing the Urban Heat Island effect at 30 m spatial resolution using Landsat 8 images. Our analysis also incorporates the Urban Thermal Field Variance Index (UTFVI), which provides insight into the thermal stress experienced by urban areas.

All processes are developed within the cloud computing platform of Google Earth Engine (GEE), which facilitates large-scale geospatial data analysis (Gorelick et al., 2017). GEE allows users to access vast repositories of satellite imagery and other spatial datasets, while taking advantage of the platform's computational infrastructure to perform complex spatial and temporal analyses efficiently (Kumar & Mutanga, 2018).

This cloud-based architecture eliminates the need for extensive local computing resources, enabling the processing of global-scale datasets in near real-time. The scalability of GEE supports a wide range of applications, including environmental monitoring, land use and land cover analysis, climate change assessment, disaster management, and urban planning (Amani et al., 2020).

Study Area and Data

UHI and UTFVI estimation was carried out for three Regional Units in the center part of Greece. Specifically, this study concerns the Regional Units of Magnesia, Larissa, and Phiotis. The first two administratively belong to the Region of Thessaly, while the Regional Unit of Phiotis belongs to the Region of Central Greece.

Table 1. GDP and Population Data for Selected Regional Units of Greece (2020-2021)

Regional Unit	GDP (2020)	Population (2021)
Larissa	3,864.93	305,979.00
Heraklion	3,782.01	305,017.00
Achaïa	3,661.82	268,963.00
Boeotia	3,005.32	210,778.00
Euboea	2,853.49	206,831.00
Magnesia	2,354.66	177,448.00
Aetolia-Acarnania	2,223.00	156,706.00
Chania	2,026.39	151,317.00
Phiotis	2,017.77	149,896.00
Korinthia	1,942.16	146,080.00

The aforementioned regional units are among the ten urban areas with the highest population density and economic activity, based on Gross Domestic Product (GDP) and data from the 2021 Census[1] regarding population distribution. In determining these areas, spatial parameters were also considered, such as the identity of the regions and their degree of polycentricity. The regions of Attica and Thessaloniki were excluded from the analysis due to their polycentric nature, which significantly affects Urban Heat Island phenomenon, as well as most island regions, with the exception of Crete and Euboea, due to their high population concentration (Papadam, 2015).

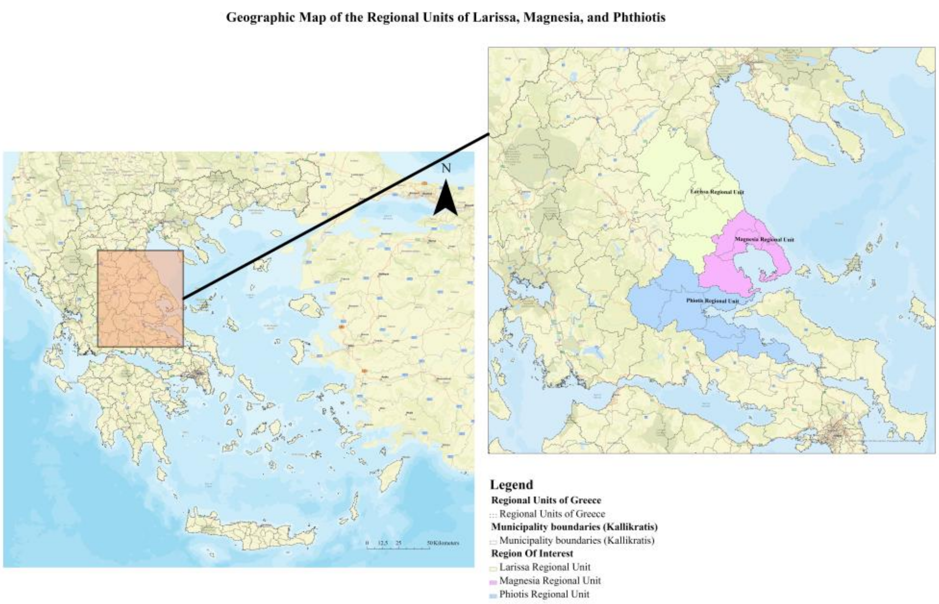

Fig. 1. Location map of the Regions of Interest

Methodology

The methodology section will describe the stages of image processing, retrieval LST, estimation of SUHI magnitude and UTFVI, and the relationship between SUHI and UTFVI.

[1]Hellenic Statistical Authority: https://elstat-outsourcers.statistics.gr/census_results_2022_en.pdf

Specifically:

- The annual median Land Surface Temperature (LST) was computed using Google Earth Engine (GEE), processing data from the Landsat 8 Collection 2 Level 2 for the years 2019 to 2023. This approach allows for precise temporal analysis of thermal changes across the regions of interest, utilizing the computational power of GEE to efficiently manage and analyze large-scale datasets
- The annual mean LST for our ROI in order to compute the UHI and UTFVI

UHI effect during the daytime was derived based on daily average temperatures. The UHI phenomenon occurs when the temperature in an urban center exceeds that of its surrounding areas. In order to compare UHI variations across different years, normalization was carried out using (1) as described by (Naim & Kafy, 2021):

(1)

$$SUHI = \frac{LST - LSTmean}{STD}$$

Where LST is the land surface temperature, LSTmean is the mean land surface temperature, and STD is the standard deviation.

Urban Thermal Field Variance Index (UTFVI) is applied in this study using (2) given by (Liu & Zhang, 2011).

(2)

$$UTFVI = \frac{Ts - Tm}{Tm}$$

Where Ts is the land surface temperature, Tm is the mean LST of the area.

Urban Thermal Field Variance Index is used to quantify the thermal homogeneity in urban areas, contributing to the assessment of prevailing environmental conditions. Depending on the intensity of the UHI phenomenon, it is classified into six levels for evaluating thermal differences and environmental stress (Renard et al., 2019).

Table 2. Threshold values of Urban Thermal Field Variance Index (UTFVI) and ecological evaluation index

Urban Thermal Field Variation Index	**Urban Heat Island Phenomenon**	**Ecological Evaluation Index**
<0	None	Excellent
0-0,0005	Weak	Good
0,0005-0,010	Middle	Normal
0,010-0,015	Strong	Bad
0,015-0,020	Stronger	Worse
>0,020	Strongest	Worst

UTFVI values reflect different levels of environmental quality, determined by thermal dispersion and temperature distribution within an area. These metrics provide critical insights into the region's thermal dynamics and potential ecological impacts, enabling the evaluation of environmental stress and sustainability challenges in urban ecosystems.

Results

Figure 2 illustrates the trends of mean temperature, UHI, and UTFVI across the studied regions, providing a clear comparison of thermal conditions and Urban Heat Island intensity. Specifically, analyzing the results we noticed that the Regional Unit of Larissa, due to its inland location and lack of proximity to the sea, experiences more intense Urban Heat Island effects, driven by high population density, lack of green spaces, and extensive urbanization.

In contrast, coastal areas such as Magnesia and Phiotis have milder thermal conditions due to the influence of sea breezes and the cooling effect of water bodies. The recent reduction in UHI and UTFVI indices in Volos, linked to heavy rainfall, highlights the temporary cooling effect of water on the local climate and emphasizes the importance of proper environmental management in urban planning.

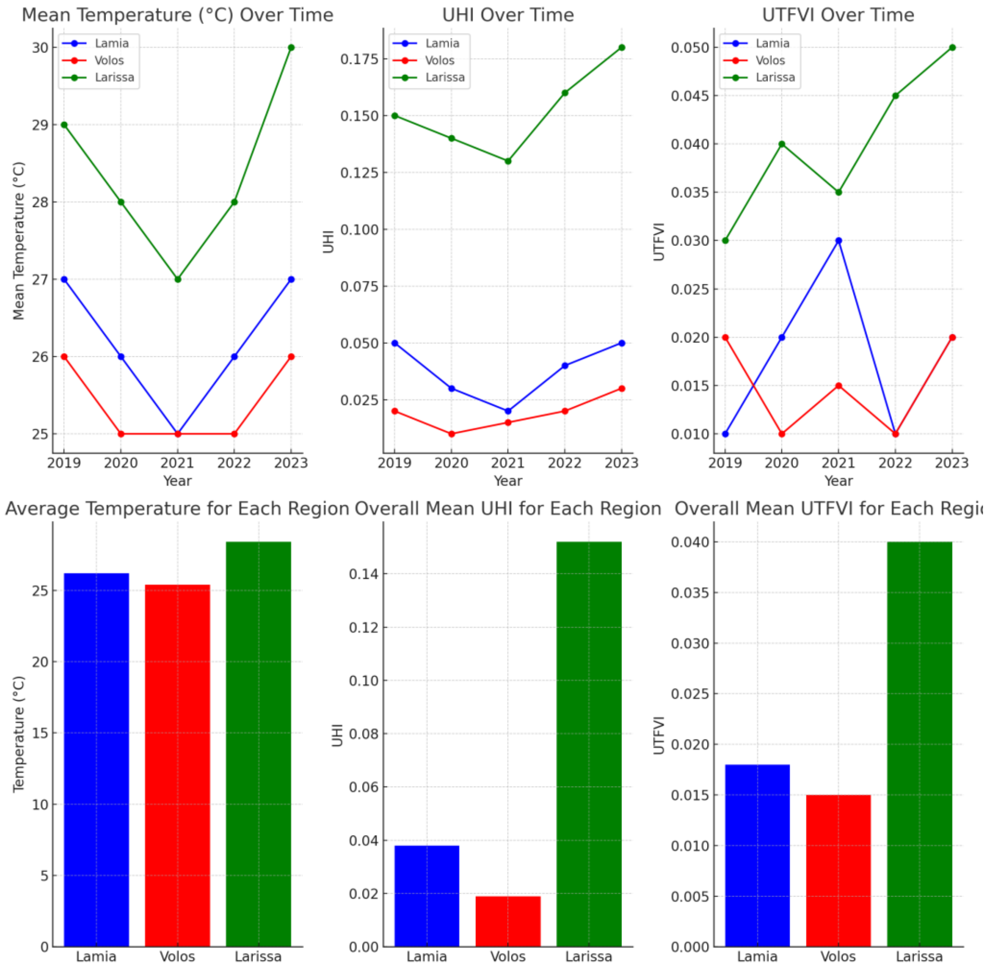

Fig. 2. Mean temperature, UHI, and UTFVI trends (2019–2023)
for Regional Units of Phiotis, Magnesia and Larissa

For each of the three regions of interest, the Pearson correlation coefficient was calculated between Land surface temperature (LST), the Urban Heat Island (UHI) phenomenon, and the Urban Thermal Field Variance Index (UTFVI). The results derived from these correlations are presented in the Table 3.

Table 3. Pearson correlation coefficients between UHI, LST, and UTFVI for the regions of Lamia, Larisa, and Volos

Regional Unit	**UHI vs LST**	**UHI vs UTFVI**	**UTFVI vs LST**
Lamia	-0.30	0.98	-0.40
Larisa	-0.67	0.99	-0.63
Volos	0.12	0.97	-0.05

The results reveal strong positive correlations between the UHI intensity and UTFVI across all regions, indicating that urbanization is directly linked to increased thermal heterogeneity, particularly in inland areas like Regional Unit of Larissa. However, the correlations between LST and UHI are varied: they are negative in Regional Units of Larissa and Phiotis but positive in Regional Unit of Volos, indicating a distinct impact of surface temperature on UHI intensity, influenced by the unique local characteristics of each region.

Conclusions

In this work, a methodology was developed to investigate the behavior of the UHI phenomenon, based on the large-scale analysis capabilities of GEE. Specifically, the promising results regarding the three ROIs were presented: they clearly show how urbanization influenced the UHI magnitude according to the LST changes. The findings reveal a strong correlation between increased urbanization and elevated UHI intensity, highlighting the role of land surface changes in amplifying heat stress in urban areas.

Moreover, these results underscore the importance of incorporating sustainable urban planning practices to mitigate the environmental and social costs associated with UHI effects. As UHI contributes to higher energy consumption, increased cooling costs, and deteriorating public health outcomes, understanding and addressing this phenomenon is crucial for minimizing long-term economic and societal impacts.

The study emphasizes that adopting green infrastructure, such as expanding green spaces and improving urban design, can significantly reduce the economic burden of managing heat-related stress in urban environments, thus contributing to more sustainable and cost-effective urban development strategies.

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