İSTANBUL UNIVERSITY PRESS

Coğrafya Dergisi
Journal of Geography

Coğrafya Dergisi–Journal of Geography
JGEOGRAPHY 2025, (50): 15–26

https://doi.org/10.26650/JGEOG2025-1558275

Submitted: 30.09.2024
Revision Requested: 10.12.2024
Last Revision Received: 20.03.2025
Accepted: 25.03.2025

Research Article

Open Access

Urban Heat Islands in Bulgaria during the Heatwave of July 2024

Eugenia Sarafova [1], Kliment Naydenov [1], Dimitar Zhelev [1], Antonina Atanasova [1] & Metodi Ivanov [1]

[1] Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Sofia, Bulgaria,

Abstract This research paper investigates the Urban Heat Island (UHI) phenomenon in Bulgaria during the extreme heatwave event in July 2024, using high-resolution ECOSTRESS satellite data from the International Space Station. The analysis focuses on mapping and visualising temperature variations across major urban centres in the country. The data cover 26 of 27 capitals of regions, highlighting the pronounced UHI effect in densely populated and industrial areas. The findings reveal that urban regions consistently exhibit higher surface temperatures, particularly during nighttime, compared to surrounding rural and mountainous areas, which benefit from natural cooling effects. Cities like Sofia, Plovdiv, and Stara Zagora show substantial heat retention, whereas cooler profiles are observed in areas like Smolyan, due to higher altitudes and forest cover. The study also relates these results to demographic data from the latest population census. It identifies a concerning trend of population decline in rural regions, while urban areas face environmental stresses from heat accumulation. Recommendations include enhancing green infrastructure, promoting sustainable urban development, and focusing on rural revitalisation to mitigate the dual challenges of population loss and heat-related environmental risks. These insights are critical for improving resilience to future heatwaves in Bulgaria.

Keywords Urban Heat Island · heatwave · mapping

Citation: Sarafova, E., Naydenov, K., Zhelev, D., Atanasova, A. & Ivanov, M. (2025). Urban heat islands in Bulgaria during the heatwave of July 2024. *Coğrafya Dergisi–Journal of Geography*, (50), 15-26. https://doi.org/10.26650/JGEOG2025-1558275

Corresponding author: Eugenia Sarafova evgenia@gea.uni-sofia.bg

Introduction

Climate change is one of the most discussed topics in society, e.g., in recent decades, the climate of the planet has significantly changed. According to research conducted by the Joint Research Centre of the European Commission (JRC), heat waves in Europe are expected to be more frequent and intense (Feyen et al., 2020). If no action is taken, by the end of the XXI century, the number of deaths in Europe caused by heat waves is expected to increase 30 times. In a scenario with a temperature increase of 3° C by 2100, this would lead to 90 000 deaths per year. As the average temperature increases by 1.5° C, the data shows that there will be 30 000 deaths per year. To a greater extent, people living in the southern part of the continent are most in danger. According to the JRC report, there are two additional factors —the health status and age of people and whether they are living in cities experiencing the urban heat island effect. Bulgaria is particularly vulnerable to the effects of climate change, as air temperature rises and intense rainfall occur more often in the region. The interconnected nature of the climate system suggests that the observed increase in average temperature will lead to changes in various meteorological factors, including precipitation patterns, wind dynamics, and atmospheric pressure. These changes are poised to have far-reaching implications for several sectors, such as the economy, water resources, biodiversity, infrastructure, and public health.

Heatwaves and their impacts on the population have been studied for just several decades. Currently, there are many studies on this topic, because of new data sources that became available for free use in recent years, such as Landsat, Sentinel-3, and EOSTRESS. In the last 5 years, such analysis has been performed for different parts of the world (Fernandes, Ferreira, Nascimento, Freitas & Ometto, 2024), (Raufu, 2024), (Garcia, 2022), (Nasir, Ul, Rashid, Coluzzi & Lanfredi, 2022), and in the region (Cetin et al., 2024) (Nojarov & Nikolova, 2022), showing the significant effect of heat on urban areas.

Heat waves and their effects on the health of Bulgaria's population have not yet been sufficiently studied. A study performed 10 years ago (Ivanov & Evtimov, 2014) assesses heat stress in the country for the period 2003–2012. After that, (Dimitrov & Spasova, 2020) considered the heat waves in Sofia and their impact on heart attack and stroke cases in the summer, establishing that for the warm half-year between 2007 and 2011, 24 heat waves were registered in Sofia city, which in total made 148 days or 19.3% of all time during the warm half-year. In the same year, (Dimitrov, Popov, & Iliev 2020) use an Unmanned Aerial Vehicle, equipped with a thermal camera, which clearly demonstrated the differences in surface temperature in the urban area of the capital city. On the other hand, more studies dedicated to population structure, urban ecology, and extreme events in Bulgaria have been published in the last 5 years, and some of them relate to the problems of climate change in urban areas (Stoycheva & Geneletti, 2023), (Nojarov, Vlaskov & Vatova 2023), (Todorov & Kirilov, 2022), (Sarafova, 2021), (Sarafova, 2021), (Burdarov & Petrova-Hristova, 2020), (Atanasova & Naydenov, 2020).

According to the National Statistical Institute, Bulgaria's demographic trends indicate a relatively high average age, with the elderly population being especially vulnerable to extreme temperatures. The life expectancy data for the 2021-2023 period across Bulgarian regions show significant regional and gender disparities. On average, women have a higher life expectancy than men, with most regions showing a gap of about 4 to 6 years. For instance, in Sofia (the capital), the average life expectancy is 75.4 years, with men at 71.9 years and women at 78.9 years. The regions with the lowest life expectancy are Vidin and Vratsa, where life expectancy is notably lower for both men and women, with Vidin's male life expectancy at just 66.5 years. These trends highlight the continued health and social inequalities between regions and genders. All these factors present significant challenges, particularly in light of substantial regional disparities that, when combined with an ageing demographic, threaten to impact the economy through labour shortages, as well as strain social and healthcare systems. Therefore, investigating the health impacts of heatwaves on this demographic is critical for developing effective public health strategies and climate adaptation measures.

Data from the Barcelona Institute for Global Health and a recent publication (Gallo et al, 2024) show that urban heat islands (UHI) are responsible for over 4% of deaths in European cities during the summer of 2023. The Global Health Institute report indicates that over the past year, countries in Southern Europe, such as Greece, with 393 deaths per million people, and Bulgaria, with 229 deaths per million people, have experienced the highest mortality rates. The report also highlights that women and the elderly are particularly vulnerable to heat-related deaths, with individuals aged 80 and over facing up to 78% higher risk compared to those aged 65-79. Given the concerning data on mortality due to heat waves and climate change, especially in Bulgaria, which has one of the highest mortality rates in Europe and an ageing population, it raises crucial questions about the impact of climate change on the health of the population in the coming years.

The impact of climate change on human health in Bulgaria has not yet been sufficiently studied. It is expected that extreme weather events will affect large cities where the population is concentrated due to increased vulnerability. The combination of densely populated urban centres, heavy traffic, limited green space, and numerous sealed areas make these areas particularly susceptible to severe climate impacts. The phenomenon of urban heat islands is receiving increasing scientific attention in Bulgaria, with a focus on understanding their harmful effects on public health and well-being.

ECOSTRESS (Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station) is a valuable tool for measuring land surface temperature (LST) via high-resolution thermal infrared observations. The instrument operates at a spatial resolution of 70 metres, which allows for detailed assessments of temperature variations across urban and natural landscapes. ECOSTRESS is mounted on the International Space Station (ISS) and gathers data globally within latitudes of 52° N to 52° S. ECOSTRESS data has been widely used in urban studies to assess land surface temperature (LST) and urban heat island (UHI) effects. For instance, Hu et al. (2022) evaluated ECOSTRESS LST products and validated their use in urban environments. Similarly, Chang et al. (2022) leveraged ECOSTRESS LST data alongside The Geostationary Operational Environmental Satellite (GOES) – R Series to investigate the diurnal variation of surface urban heat islands, while Zhang et al. (2022) combined ECOSTRESS LST with machine learning techniques to study the urban heat exposure dynamics in the city of Xi'an.

According to the National Institute of Meteorology and Hydrology of Bulgaria (NIMH)'s monthly bulletin and its section "Particularly dangerous phenomena", during the period 06 – 24.07. 2024. Bulgaria is experiencing an intense heatwave. The number of consecutive days with a maximum air temperature above 40 °C in the town of Sandanski (Blagoevgrad region) was 9 (10–18.07.2024), and in both the village of Parvomay and the municipality of Petrich – 6 (13.07. – 18.07.2024). The average monthly temperatures deviated from the monthly norm between +1.4 °C (Gabrovo) and +3.9 °C (Ruse). According to the NIMH, July 2024 was almost as warm as July 2012—the warmest July since 1930 in the country. The monthly maximum temperature was measured in Ruse on 17.07.2024, with an average daily temperature of 33.3°C. The highest maximum temperatures in urban areas were between 32°C and 42 °C and were measured from 14 to 18.07.2024.

According to the report, as a result of the high temperatures and lack of precipitation, as well as human negligence, from 12.07.2024 to at the end of the month dozens of fires raged in the country. Strong wind gusts contributed to the growth of fire fronts and made extinguishing difficult. In some municipalities, a partial state of emergency was declared, and residents of several villages were evacuated. On July 16, 2024, a large fire in Sakar Mountain consumed over 100,000 hectares, including 24,000 hectares of forest, resulting in the injury of a 19-year-old volunteer. These fires not only caused significant ecological damage but also forced the evacuation of multiple villages. The intense heatwave and the ensuing fires highlight the growing risk of extreme weather events in Bulgaria, particularly under the influence of climate change.

The aim of this study was to map and analyse urban heat islands in the capitals of the Bulgarian regions during the July 2024 heatwave using the ISS instrument ECOSTRESS. By analysing and visualising the thermal data for these urban areas, this study seeks to provide insights into the occurrence and spatial distribution of UHIs, with a focus on understanding their intensity, to help the process of urban planning and disaster risk reduction in the context of extreme heat events. The findings contribute to the development of effective mitigation strategies for managing heat-related risks in Bulgarian regions and municipalities.

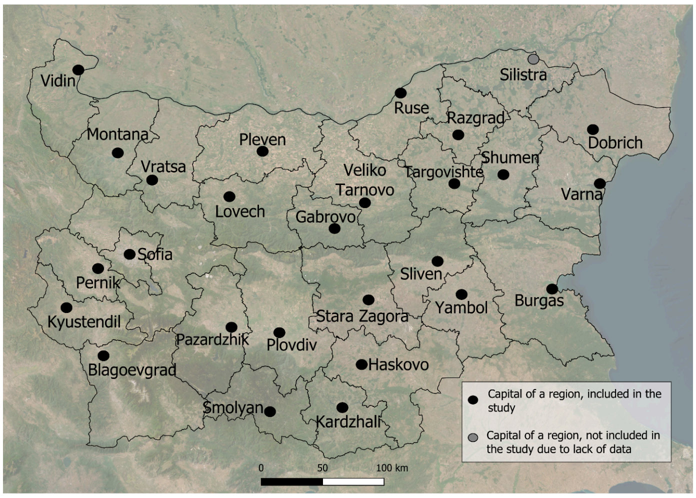
Data and Methods

Remote Sensing Data

The research methodology involved a systematic approach to analysing and mapping urban heat islands in Bulgaria using ECOSTRESS Land Surface Temperature (LST) data. First, LST data were sourced from the ECOSTRESS product available on the LP DAAC (Land Processes Distributed Active Archive Centre) website, focusing on the relevant datasets for the July 2024 heatwave. The start and end dates for the search were selected from the information for the heatwave of NIMH's report, i.e. from 06 to 24.07.2024. The acquired LST data underwent a projection change to ensure compatibility with the study area, and temperature values were recalculated from Kelvin to Celsius using the Raster Calculator in QGIS, allowing for more interpretable results. A preliminary data quality check was conducted to identify and reject any rasters that could be unreliable due to issues such as cloud cover and minimal coverage within the country, ensuring that only high-quality data were retained for further analysis. Finally, the cleaned and processed LST data, together with cloud mask layers for each specific date selected was analysed to identify and map urban heat islands across the capitals of the Bulgarian regions. This involved employing spatial analysis techniques in QGIS to visualise temperature variations and assess the intensity and distribution of urban heat islands. Through this comprehensive methodology, the research aimed to enhance understanding of urban heat islands in the context of the extreme heat conditions experienced in July 2024, ultimately contributing valuable insights for urban planning and disaster risk management.

Figure 1

Capital of the regions (NUTS 3) in Bulgaria



The results were datasets covering 26 of 27 capitals of the regions in Bulgaria (the regions are 28 in total, but Sofia is the capital of two of them, Figure 1).

Population data

The data from the National Statistical Institute (NSI) of Bulgaria reveal a general trend of population decline across most regions in the country. This trend is consistent with broader demographic patterns observed in Eastern European countries, where factors such as ageing populations, declining birth rates, and emigration contribute to shrinking populations. For instance, the total population of Bulgaria has decreased steadily from approximately 7.85 million in 2002 to approximately 6.45 million by 2022.

From a regional perspective, there is considerable variation in population changes across administrative levels. Larger urban areas, particularly municipalities and cities like Sofia, Plovdiv, and Varna, may have experienced slower rates of population decline compared to rural municipalities and smaller towns, which tend to show sharper decreases. For example, regions such as Vidin show significant declines, with populations halving over the studied period, highlighting the impact of rural depopulation and migration to urban centres or abroad.

Table 1 presents the future population scenario data developed by the NSI. The most likely scenario indicates a significant and steady population decline across all regions. For instance, in the Blagoevgrad region, the total population is expected to decrease from 306 370 in 2020 to 184 242 by 2070, representing a 39.9% decrease. Similar trends are observed in other regions, such as Burgas, where the population is projected to shrink by approximately 23.7% over the same period.

Table 1

Population statistics for the regions in Bulgaria. The percentage change in the total population in Bulgaria from 2020 to 2070, according to the National Statistical Institute data, is the most likely scenario.

Region	Total Population (2023)	Population < 19 y (2023)	Population > 65 years of age (2023)	% Change from 2020 to 2070
Blagoevgrad	287077	55843	63609	–39.9
Burgas	384446	78099	86611	–23.7
Varna	434191	86027	56458	–20.5
Veliko Tarnovo	202232	34555	55467	–40.4
Vidin	71773	11556	22431	–60.0
Vratsa	147619	28034	36890	–45.9
Gabrovo	94862	15311	28716	–56.7
Dobrich	146635	25924	39233	–41.3
Kardzhali	146562	24517	38715	–41.9
Kyustendil	107673	17891	30649	–50.6
Lovech	112225	20710	31347	–45.5
Montana	114526	14724	32269	–38.5
Pazardzhik	225261	43161	54652	–37.6
Pernik	111032	19264	29026	–46.5
Pleven	217881	39183	61512	–38.2
Plovdiv	633586	93774	142393	–16.2
Razgrad	100696	17848	25203	–40.1
Ruse	187830	23253	50574	–35.1
Silistra*	94739	16564	26263	–43.6
Sliven	170051	42903	38019	–11.3
Smolyan	92107	13548	26616	–65.0
Sofia	226420	32320	54413	–37.0
Sofia (capital)	1286965	250866	247474	6.5
Stara Zagora	290350	57379	71343	–29.9
Targovishte	95609	17601	24324	–33.8
Haskovo	207114	39459	53381	–36.0
Shumen	149699	27018	37766	–42.9
Yambol	106320	16134	28483	–32.2

* Silistra was not included in this research because of a lack of sensor data.

There are no specific data regarding future age structure within these scenarios, although it is evident that if the current birth rate remains the same, the population will become significantly older. This trend poses substantial challenges in addressing urban heat island (UHI) effects, as an ageing population may be more vulnerable to extreme heat events and less able to adapt to increasing temperatures in urban environments. The combination of an older, shrinking population and the intensifying UHI effect could further strain public health resources and urban planning efforts, making it imperative to consider age dynamics in future climate adaptation strategies.

The expected depopulation implies a continued ageing of the population, with models showing that fewer and fewer young people will remain in Bulgaria due to factors such as low birth rates, emigration, and lower birth rates. The long-term implications indicate the likelihood of major challenges in sustaining economic growth, maintaining workforce, and addressing regional imbalances, particularly in rural areas. These trends are consistent with current demographic trajectories and highlight the need for policy interventions to mitigate the social and economic impacts of such significant population losses.

Geographical perspectives and predispositions

The diverse physical geography of Bulgaria predetermines the appearance of the UHI. Altitude, topography, land cover, and atmospheric circulation are natural predispositions of landscapes that affect the appearance of the UHI phenomenon in urban areas. The size of an urban area, the density of buildings, and the city's morphology are additional society-determined factors determining spatial diversity.

The altitude of the examined cities in Bulgaria varies between 0 and 30 m (Burgas) and 1002 m (Smolyan). Several cities are located in lowlands near 100 m of altitude or even below: Burgas (0-120), Vidin (34-45m), Ruse (22-150 m), and Varna (0-150 m). Most of the examined cities were located between 100 and 500 m altitudes: Plovdiv, Pazardzhik, Pleven, Stara Zagora, etc. They all display intense features of urban heat islands like the outlined shape of downtown, industrial zones, extensive roads, and other manmade facilities.

There are only three examined cities above 500-m altitude. The capital city Sofia (550-700 m), the largest in the country, Kyustendil (530-600 m), and Smolyan (900-1002 m), one of the smallest examined cities. The altitude has a cooling effect in all three cases based on the vertical temperature gradient. The cooling effect is visible in Sofia, even the most prominent city with the most significant heat island. The heat island is observed, but the temperature values are lower than those in lower cities like Plovdiv, Ruse, and Stara Zagora.

In terms of topography, most of the examined cities are located in plains and lowlands. Most of the land in these areas is arable and is actively used for agriculture. These areas have no abundance of natural vegetation, and the black soil types dominate (Vertisols in the Upper Thracian Plain, South Bulgaria, and Chernozems in the Danubian Plain, North Bulgaria). Dark soil albedo causes heating of the surface, and in periods after harvest, it may stimulate a vaster heating screen on the surface of agricultural lands.

Few cities (Smolyan, Kardzhali, Gabrovo, Veliko Tarnovo, and Lovech) are not placed in such landforms as plains or landforms. They are located in river valleys formed by mountainous topography. The limited space for building in valleys determines the extreme density of concrete infrastructures and asphalt roads. In the case of heat waves, these territories explicitly heat up among the hilly surroundings, which are pretty visible phenomena in the thermal maps described in the next section.

Several Bulgarian cities are located in transitional zones between mountains and lowlands (plains): Stara Zagora, Sliven, Kyustendil, and Haskovo. These cities experience the phenomenon of urban heat islands even more distinctively because the forested hilly landscapes are cooled in contrast to warmed urban infrastructure.

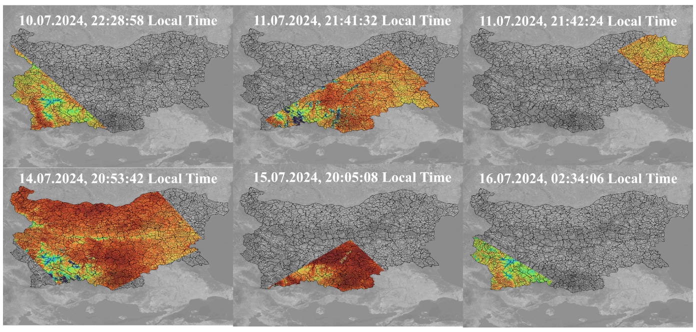
Diurnal sea breezes are another natural predisposition that partially affects the appearance of the urban heat island in the cities of Varna and Burgas. The local winds across the rivers exert a similar cooling effect. The riverbank areas of Vidin and Ruse demonstrate atmospheric influence. Most of these areas are well-forested and are part of riverside gardens and parks. As a result, they appear as a narrow strip next to an urban heat island.

Results

After the first round of data availability analysis and quality control procedures, the data mapped on Figure 2 was selected for further analysis. The largest area coverage was captured on 14.07.2024, the date on which most of the Bulgarian regional capitals were covered. The city of Silistra, located in the northeastern part of the country, is not covered during the heatwave.

Figure 2

Data availability from ECOSTRESS during July 2024 heatwave in Bulgaria



The minimum temperatures recorded in the raster layers varied widely, with some instances reporting negative values, likely due to cloud cover or sensor anomalies. For example, on July 11, 2024, the minimum recorded temperature was −41.39°C, indicating potential interference from clouds, which can obstruct accurate readings (Table 2). The maximum temperatures reached high levels, especially on July 14 and 15, when values approached or exceeded 42°C. The extreme temperature of 47.89°C was identified near a fire spot near the city of Stara Zagora on July 14, highlighting the influence of local events on the temperature readings. In these two raster layers, there were also pixels with much higher values, due to fires. They were excluded from the analysis of this research as they are not related to UHI.

Table 2

Raster statistics for the examined dates

Raster	Min Value ℃	Max Value ℃	Mean Value ℃	Std Dev ℃
10.07.2024, 22:28:58 local time	3.39	30.09	19.26	3.52
11.07.2024, 21:41:32 local time	−41.39 (clouds)	32.95	21.06	5.90
11.07.2024, 21:42:24 local time	12.95	28.09	20.5	1.99
14.07.2024, 20:53:42 local time	−76.81 (clouds)	47.89 (near fire spot)	23.91	4.74
15.07.2024, 20:05:08 local time	−7.61	42.05 (near fire spot)	27.10	3.70
15.07.2024, 02:34:06, and 16.07.2024 local time	3.13	26.05	17.16	3.54

The mean temperature across the recorded dates showed a consistent upward trend, with an average of around 19.26°C on July 10 and escalating to 27.10°C by July 15. This increase indicates significant heat accumulation likely influenced by urbanisation and the ongoing heatwave. The standard deviation values (ranging from 1.99°C to 5.90°C) show varying degrees of temperature consistency. A higher standard deviation indicates greater variability in temperature, particularly on July 11, when conditions likely fluctuated significantly due to environmental factors, such as cloud cover and urban heat effects. The temperatures recorded late in the evening (around 21:41) still reflect high values, underscoring the persistent heat characteristics of urban heat islands.

The data captured on July 10, 2024, at 22:28 local time (Figure 3), illustrates the distribution of surface temperatures within the urban and surrounding areas of Sofia, Blagoevgrad, Pernik, and Kyustendil. In all the maps, the central urban regions exhibit significantly higher temperatures, indicated by red and orange hues, than the cooler peripheral and green zones, such as the mountains and less densely populated areas. Sofia Airport can be seen from the eastern part of the capital. This region is a place in the country where records are being recorded during the summer heatwaves. As seen on the maps, this area experiences a combination of climatic and geographical factors that contribute to elevated temperatures, especially in lowland and valley areas where heat accumulation is more pronounced.

The data captured on 11 July 2024, at 21:41 highlights the urban heat island (UHI) effect across several cities, as mapped in

Figure 3

UHI mapping in Sofia, Blagoevgrad, Pernik, and Kyustendil on 10.07.2024

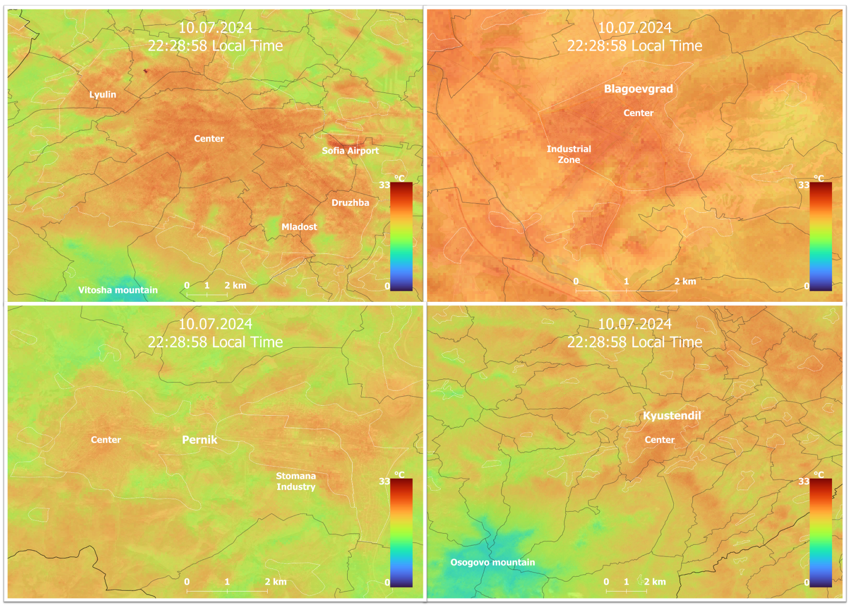


Figure 4 - Plovdiv, Stara Zagora, Sliven, Yambol, Burgas, Varna, and Dobrich. As with the previous data, urban centres and industrial zones appear in red and orange, indicating elevated surface temperatures near 33°C, while surrounding rural and natural areas are cooler, which are depicted in green and blue.

Plovdiv, for example, shows significant heat accumulation in the city centre and industrial zones, with cooler areas around the Maritsa River and regions to the west, potentially due to cloud cover or water bodies helping to moderate temperatures. Stara Zagora and Sliven also exhibit high-temperature zones, particularly in industrial regions, while areas of cloud cover may affect the temperature readings in some parts of the cities.

In coastal regions like Burgas and Varna, the UHI effect is more pronounced around the urban centres and airports, whereas the proximity to bodies of water like Lake Burgas and Lake Varna introduces localised cooling effects. The presence of water bodies contributes to temperature moderation, as reflected in the cooler patches surrounding these lakes. Dobrich, in contrast, shows more green and blue tones, indicating cooler surface temperatures compared to the other cities in this set, which leads to lower urbanisation or the presence of more vegetation.

Figure 4

UHI mapping in Plovdiv, Stara Zagora, Sliven, Yambol, Burgas, Varna, and Dobrich on 11.07.2024

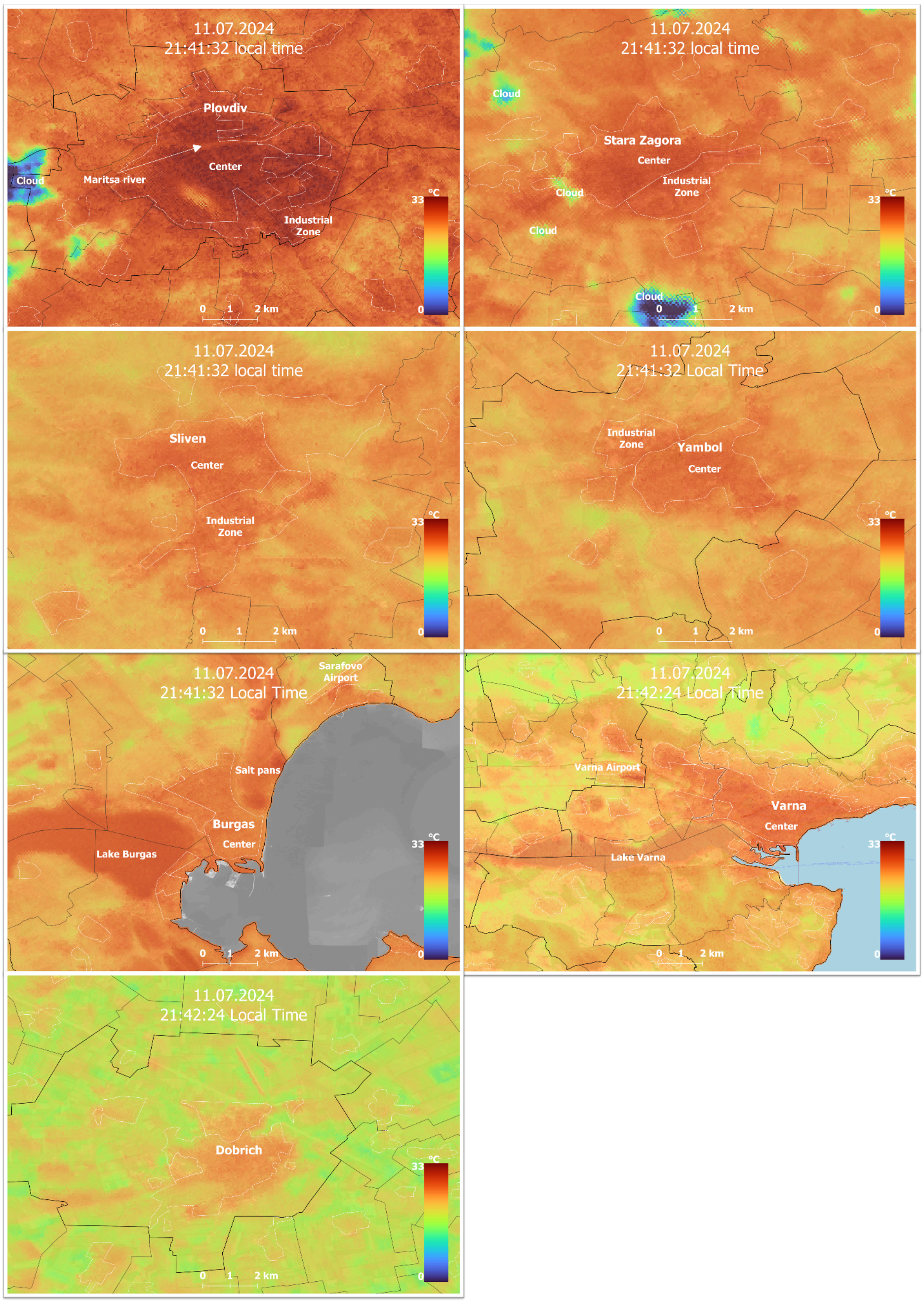


Figure 5 recorded data on 14 July 2024. The urban centres in cities such as Vidin, Montana, Pleven, Veliko Tarnovo, and many others are shown in bright red and orange tones, indicating high surface temperatures of up to 33°C. The distinct colour gradient emphasises the significant temperature differences between urban and rural areas, with the surrounding green and blue regions remaining cooler, likely due to vegetation, open land, or water bodies.

The data that was analysed for 14.07.2024 covered many regional capitals in the country (Figure 5). Particularly noticeable is the recurring UHI effect in cities like Sofia, Burgas, and Ruse. Sofia has significant heat retention, especially around its industrial and densely populated areas, with slightly cooler regions around Vitosha mountain. Burgas, a coastal city, benefits from some cooling near the water and additional heating as it is located near the salt pans, yet its urban and industrial zones remain highly affected by heat buildup. Ruse's proximity to the Danube River also moderates temperatures slightly in certain areas, but still the UHI effect is significant.

Several smaller cities, including Shumen, Yambol, and Kardzhali, also exhibit distinct UHI patterns, with heat concentrated on their centres and industrial areas. The city of Smolyan appears to be one of the coolest cities in the world, with its predominantly green tones indicating much lower temperatures due to its mountainous terrain in Rhodope mountains, and lesser urbanisation.

The results for the surface temperature of the Burgas Lakes are quite interesting. The surface of this shallow water basin was warmer than the surrounding waters during the observed heat wave. The neighbouring territories were cooler, which could be explained by the predominant hydrophilic vegetation. Similar but not outlined thermal contrast was observed in Varna Lake. The outcome of this observation is that these shallow seaside lakes do not provide an external cooling effect on the neighbouring urban areas.

The data taken on July 15, 2024 (Figure 6), captures the urban heat island (UHI) effect in the cities of Plovdiv, Stara Zagora, Haskovo, Kardzhali, and Smolyan. As in the previous maps, urban areas are shown in deep red and orange, indicating high temperatures, while cooler surrounding regions are shown in

Figure 5

UHI mapping in many regional capitals on 14.07.2024

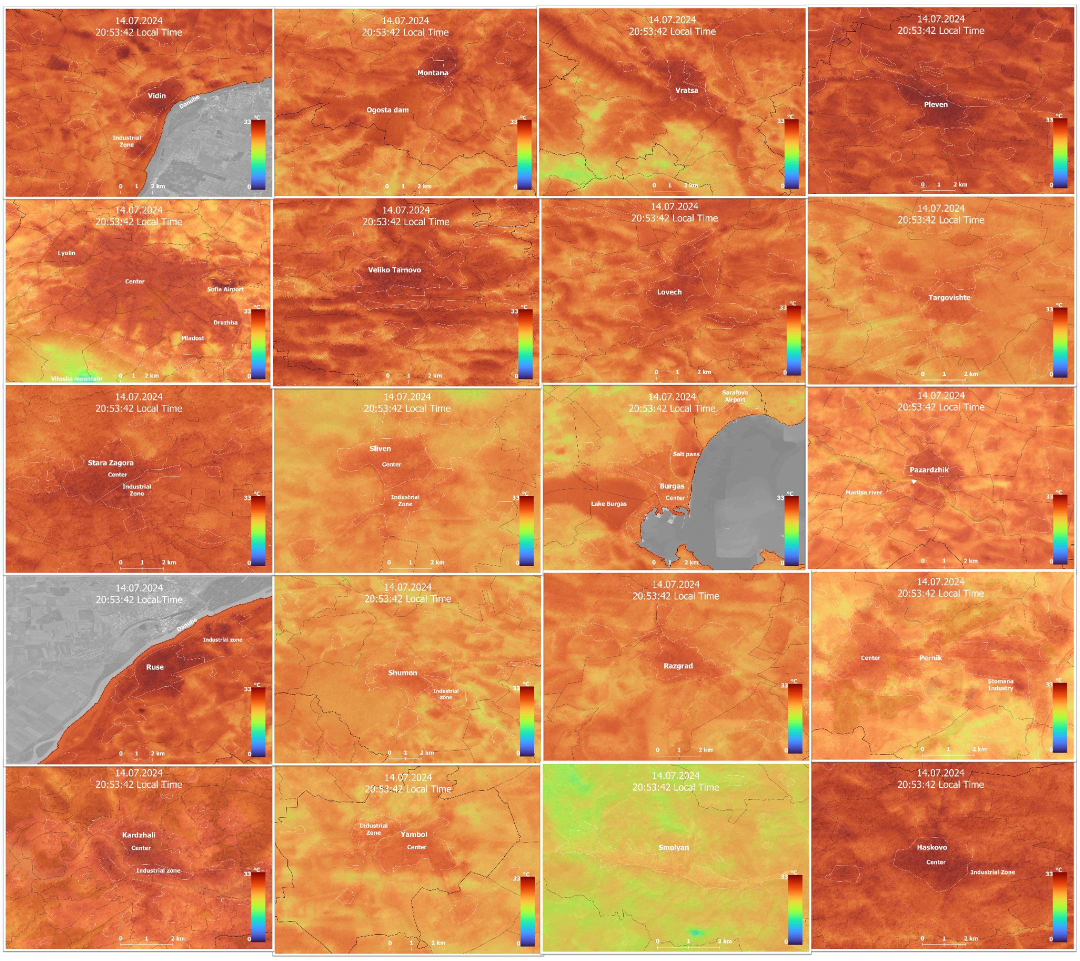
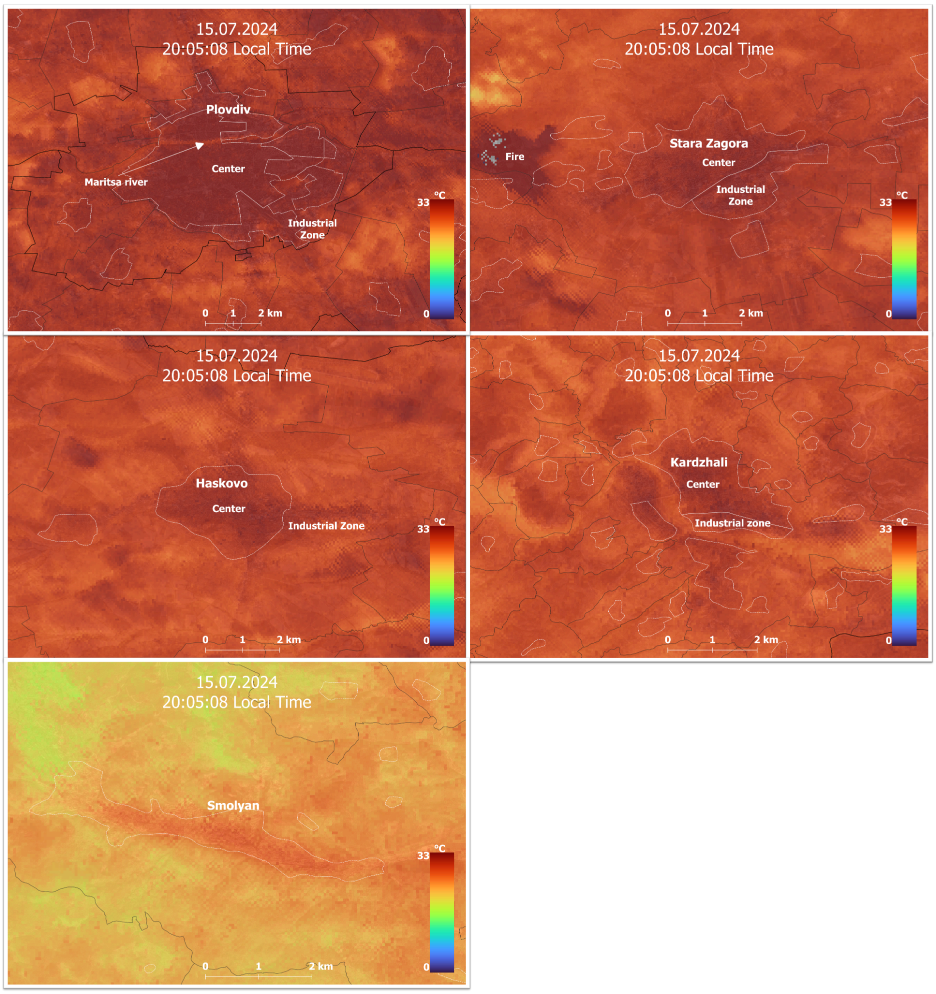


Figure 6

UHI mapping in Plovdiv, Stara Zagora, Haskovo, Kardzhali, and Smolyan on 15.07.2024



green or yellow. Plovdiv stands out for its well-defined heat concentration in its centre and industrial zones, particularly around the Maritsa River. Stara Zagora similarly exhibits elevated temperatures, but what is especially notable in this map is the marking of a fire hotspot, indicating an active or recent fire event (bTV Media Group, 2024) contributing to localised extreme heat. The industrial zones in both cities are significant sources of heat, worsening the UHI effect.

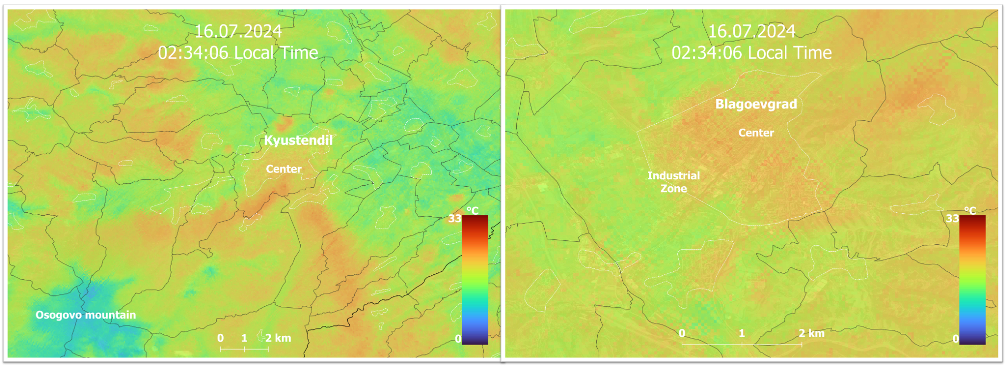
Haskovo and Kardzhali, much like the other cities, show the hottest areas concentrated around their urban centres and industrial zones, demonstrating the typical pattern of higher surface temperatures in developed areas due to the accumulation of heat in buildings, roads, and other infrastructure. Smolyan, by contrast, remains cooler, with more green areas indicative of lower temperatures. As mentioned above, the cooler tones align with Smolyan's location in a more mountainous and vegetated region, suggesting that natural features like forests and terrain continue to mitigate heat buildup, resulting in much lower surface temperatures compared to more urbanised cities.

The visualisation of the heat wave in the urban areas displays the effect of altitude. The best example is the City of Smolyan, where a heat island appears but is not considered a health risk. An additional factor in the mitigation of the heat island effect in Smolyan is the forested land cover that dominates the West Rhodopes Mountain region. The vast coniferous woodlands are a local climate factor. Moreover, the city is located in a narrow downward (diurnal) and upward valley, where local winds prevail and cool down the city's surface.

The final data captured on July 16, 2024 (Figure 7) shows the surface temperature distribution in the Kyustendil and Blagoevgrad regions. It indicates lower overall surface temperatures compared to previous images, as suggested by the predominant green and yellow tones, likely due to the earlier time in the morning when the data was collected (02:34 local time). The cooling effect of the night can be clearly seen. In Kyustendil, the UHI effect is still present but more subtle, with the urban centre showing slightly warmer areas in orange hues, while the surrounding natural landscape, including the Osogovo mountain, remains much cooler. The lower

Figure 7

UHI mapping in Kustendil and Blagoevgrad on 16.07.2024



temperatures in the green and blue areas are showing the the mitigation of the influence of natural features such as forests and higher elevations. Blagoevgrad exhibits a similar pattern, where the industrial zone and urban centre are warmer than the surrounding rural areas. However, the overall temperature was lower than that of daytime UHI recordings, emphasizing the nighttime cooling effect. This image provides a clear contrast between urban and natural environments, with cities retaining heat from the day, even at cooler nighttime hours, and rural areas cooling more rapidly.

This comparison highlights the temporal dynamics of the UHI effect, demonstrating that while urban areas continue to emit heat into the night, natural areas, particularly mountainous regions, cool down significantly faster, reducing their thermal footprint during non-peak hours. This observation reinforces the role of natural landscapes in moderating extreme temperatures, particularly during night-time.

The UHI phenomenon reinforces how urban development significantly impacts localised microclimates by retaining heat, particularly in industrial and densely populated areas. The temperature differentials between urban centres and surrounding rural or natural areas highlight the need for urban planning strategies that could mitigate the negative impacts of heat retention, such as increasing green spaces and improving building designs to reduce heat absorption.

There are several places that could be further analysed and require additional data. For example, the Sofia International Airport has an entirely outlined spatial appearance on thermal maps. Asphalt and concrete infrastructures (airstrips, buildings, roads) generate enormous heat accumulators during the day. The lack of trees and the low-mowed grass are a result of the safety standards of the airport complex. This poor green infrastructure determines extreme heating patterns, which result in the heated pole of Bulgaria's capital city. Similar spatial patterns of the heated surfaces were also observed at the international airports in Varna and Burgas.

Discussion

The analysis of population dynamics and surface temperature patterns across Bulgaria provides a comprehensive understanding of demographic trends and the urban heat island (UHI) effect. The population data demonstrate a marked decline in population across most regions, particularly in rural areas, consistent with ongoing trends of urban migration, low birth rates, and emigration. This depopulation intensifies regional disparities as rural municipalities continue to lose residents, while urban centres face challenges of over-concentration. Simultaneously, the ECOSTRESS sensor imagery from the International Space Station highlights the pronounced UHI effect in Bulgarian cities, capitals of regions, with significant heat retention in urban and industrial zones, particularly during nighttime hours. Cities like Sofia, Plovdiv, and Stara Zagora consistently display elevated surface temperatures, whereas mountainous and rural regions, such as Smolyan, exhibit much cooler thermal profiles. These patterns underscore the dual pressures of urbanisation: declining rural populations in many areas on one side and the environmental consequences of heat accumulation in urban centres, on the other.

The examination of Urban Heat Islands (UHI) and their impact on health in this study aligns with prior research that highlighted increased temperatures in urban settings during heatwaves (Fernandes et al., 2024; Garcia, 2022; Nasir et al., 2022). Our analysis adds to this body of knowledge by detailing nighttime heat retention in Bulgarian urban centres, revealing significantly higher temperatures compared to rural and mountainous areas that experience natural cooling. This observation is consistent with earlier findings, such as those by Dimitrov and Spasova (2020), who noted an increase in health incidents like heart attacks and strokes, on hotter days in Sofia. By extending these observations across a broader geographical area and integrating demographic data, the study maps heat distribution and identifies urban populations—especially the elderly—as particularly vulnerable to heat-related health risks. The use of high-resolution ECOSTRESS satellite data has been instrumental in pinpointing critical areas for urban planning and public health initiatives, as well as in developing new ways to enhance heatwave resilience. Thus, this research supports and expands on existing understandings of how UHI effects can influence public health in urban environments.n the other.

The analysis of ECOSTRESS data for the summer heatwave of 2024 addresses a critical gap in surface temperature observations, facilitating a more comprehensive and accurate analysis of urban heat island (UHI) dynamics. The data availability and mapping applications are essential for the continuous monitoring of UHIs, which are known to pose significant health risks, particularly to vulnerable population groups. Considering Bulgaria's ageing demographic profile, the need for systematic, high-resolution monitoring has become increasingly imperative to inform public health strategies and urban adaptation measures.

Conclusion

Bulgaria’s diverse geography, including altitude, topography, and land cover, significantly shapes the intensity and distribution of these heat islands in urban areas. Cities at higher altitudes, like Sofia and Smolyan, experience a cooling effect due to the vertical temperature gradient and forested surroundings, whereas lower-altitude cities, such as Plovdiv and Burgas, experience more intense heat islands. Urban infrastructure, including dense buildings, roads, and industrial zones, further amplifies heat retention, particularly in cities located in plains and valleys. Additionally, natural elements such as sea breezes and river winds offer localised cooling effects, although their scope is limited. These findings highlight the complex interaction between geography and urban development in determining heat dynamics in Bulgarian cities.

In terms of health effects on the population, currently available data indicate a clear link between age and susceptibility to heat waves. The regions with the highest percentage of residents over 65 years old coincide with areas experiencing higher temperatures, as determined by satellite imagery. These regions also exhibit higher mortality rates. This supports the theory that older people are at risk of extreme heat events. When considering regional disparities, noticeable variations exist in the distribution of elderly populations and high temperatures. This leads to the fact that adaptation strategies for climate change must be tailored to the specific characteristics of each region.

Endnotes

The combination of demographic and thermal data underscores the need for integrated urban planning and disaster risk preparedness strategies in Bulgaria. As rural depopulation continues, urban centres are likely to face increasing environmental stresses due to the UHI effect, potentially threatening public health and leading potentially to energy consumption issues. To mitigate these challenges, policy interventions should focus on enhancing green infrastructure, promoting sustainable urban expansion, and incentivizing population retention in rural areas. The cooling effects observed in natural landscapes highlight the importance of preserving green spaces and incorporating nature-based solutions to reduce urban heat stress. Addressing both demographic and environmental concerns is crucial for fostering long-term regional sustainability in Bulgaria.

Ethics Committee Approval	Ethics committee approval is not required for the study.
Peer Review	Externally peer-reviewed.
Author Contributions	Conception/Design of Study- E.S., K.N., D.Z., A.A., M.I.; Data Acquisition- E.S., K.N., D.Z., A.A., M.I.; Data Analysis/Interpretation- E.S., K.N., D.Z., A.A., M.I.; Drafting Manuscript- E.S., K.N., D.Z., A.A., M.I.; Critical Revision of Manuscript- E.S., K.N., D.Z., A.A., M.I.; Final Approval and Accountability- E.S., K.N., D.Z., A.A., M.I.
Conflict of Interest	Authors declared no conflict of interest.
Grant Support	This study is financed by the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project No BG-RRP-2.004-0008-C01, “Sofia University Marking Momentum for Innovation and Technological Transfer“

Author Details

Eugenia Sarafova

[1] Sofia University “St. Kliment Ohridski”, Faculty of Geology and Geography, Sofia, Bulgaria,

0000-0002-1164-1204 evgenia@gea.uni-sofia.bg

Kliment Naydenov

[1] Sofia University “St. Kliment Ohridski”, Faculty of Geology and Geography, Sofia, Bulgaria,

0000-0002-5599-5303

Dimitar Zhelev

[1] Sofia University “St. Kliment Ohridski”, Faculty of Geology and Geography, Sofia, Bulgaria,

0000-0001-9652-8042

Antonina Atanasova
[1] Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Sofia, Bulgaria,
0000-0003-0021-4896

Metodi Ivanov
[1] Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Sofia, Bulgaria,
0000-0003-0365-1792

REFERENCES

Atanasova, A., & Naydenov, K. (2020). The innovative approaches for the development of smart cities. S. Nedkov, et al. *Smart Geography: Key Challenges in Geography. Cham, Switzerland: Springer. doi:10.1007/978-3-030-28191-5_19*

Barcelona Institute of Global Health. (2023). Retrieved from https://www.isglobal.org/en/-/el-calor-causo-47.000-muertes-en-europa-en-2023

Burdarov, G., & Petrova-Hristova, K. (2020). Successful practices in the integration of the Roma population in Bulgaria. *6th International Scientific Conference Geobalcanica 2020*. https://doi.org/10.18509/GBP.2020.46

Cetin, M., Ozenen Kavlak, M., Senyel Kurkcuoglu, M. A., et al. (2024). Determination of land surface temperature and urban heat island effects using remote sensing: The case of Kayseri, Türkiye. *Natural Hazards, 120*, 5509-5536. https://doi.org/10.1007/s11069-024-06431-5

Chang, Y., Xiao, J., Li, X., Zhou, D., & Wu, Y. (2022). Combining GOES-R and ECOSTRESS land surface temperature data to investigate diurnal variations in surface urban heat island. *Science of the Total Environment, 823*, 153652. https://doi.org/10.1016/j.scitotenv.2022.153652

Dimitrov, S., Popov, A., & Iliev, M. (2020). Mapping and assessment of urban heat island effects in the city of Sofia, Bulgaria through integrated remote sensing, unmanned aerial systems (UAS), and GIS. *Proceedings of SPIE 11524, Eighth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2020)*. https://doi.org/10.1117/12.2571967

Dimitrov, T., & Spasova, Z. (2019). Heat waves in Sofia and their impact on stroke and heart attack cases in the summer. In *Proceedings of the 12th EFSA Scientific Conference for Bulgaria-Climate change: A global threat to the food chain* (pp. 40–60). Food Chain Risk Assessment Centre of the Ministry of Agriculture of Bulgaria.

Feyen, L., Ciscar, J. C., Gosling, S., Ibarreta, D., & Soria, A. (Eds.). (2020). *Climate change impacts and adaptation in Europe. JRC PESETA IV final report* (EUR 30180EN). Publications Office of the European Union. https://doi.org/10.2760/171121

Fernandes, R., Ferreira, A., Nascimento, V., Freitas, M., & Ometto, J. (2024). Urban heat island assessment in northeastern Brazil using Sentinel-3 SLSTR satellite data. *Sustainability 16*, 4764. https://doi.org/10.3390/su16114764

Gallo, E., Quijal-Zamorano, M., Méndez Turrubiates, R. F., et al. (2024). Heat-related mortality in Europe during 2023 and the role of adaptation in protecting health. *Nature Medicine*. doi: 10.1038/s41591-024-03186-1

García, D. H. (2022). Analysis of urban heat island and heat waves using Sentinel-3 images: A study of Andalusian cities in Spain. *Earth Systems and Environment, 6*, 199-219. https://doi.org/10.1007/s41748-021-00268-9

Hu, T., Mallick, K., Hulley, G. C., Planells, L. P., Göttsche, F. M., Schlerf, M., et al. (2022). Continental-scale evaluation of three ECOSTRESS land surface temperature products over Europe and Africa: Temperature-based validation and cross-satellite comparison. *Remote Sensing of Environment, 282*, 113296. https://doi.org/10.1016/j.rse.2022.113296

Ivanov, V., and Evtimov, S. (2014). Heat risks in Bulgaria during 2003-2012 period. *Bulgarian Geophysical Journal, 40*.

Nasir, F., Ul, M. M. F., Rashid, A. S., Coluzzi, R., and Lanfredi, M. (2022). Monitoring the impact of rapid urbanisation on land surface temperature and assessment of surface urban heat islands using Landsat in a megacity (Lahore) of Pakistan. *Frontiers in Remote Sensing, 3*. https://doi.org/10.3389/frsen.2022.897397

National Statistical Institute. (2021). *Expected average future life of the population during the period 2021–2023*. https://www.nsi.bg/sites/default/files/files/pressreleases/LifeExpectancy_2021-2023_8YLFUQ9.pdf

Nojarov, P., and Nikolova, M. (2022). Heat waves and forest fires in Bulgaria. *Natural Hazards, 114*, 1879-1899. https://doi.org/10.1007/s11069-022-05451-3

Nojarov, P., Vlaskov, V., & Vatova, Y. (2023). Influence of atmospheric circulation on the spatial distribution of precipitation in the area of Sofia city. *Journal of the Bulgarian Geographical Society, 49*, 17-25. https://doi.org/10.3897/jbgs.e108747

Raufu, I. O. (2024). The relationship between remote sensing-based vegetation indices and land surface temperature was explored by quantitative analysis. *Journal of the Bulgarian Geographical Society, 50*, 95-112. https://doi.org/10.3897/jbgs.e124098

Sarafova, E. (2021). How green the urban development units in Sofia are: Earth observation and population time series analysis. *Journal of the Bulgarian Geographical Society, 44*, 25-37. https://doi.org/10.3897/jbgs.e69814

Sarafova, E. (2021). Analysis and visualisation of the core surface temperature of the functional urbanised areas of Sofia, Plovdiv, Varna, and Burgas during the 2021 summer heat wave using Copernicus Sentinel-3 data. *Proceedings of the Scientific Conference "Geography and Regional Development"* - Sozopol, LOPS Foundation. ISSN 1313-4698

Stoycheva, V., and Geneletti, D. (2023). A review of regulating ecosystem services in the context of urban planning. *Journal of the Bulgarian Geographical Society, 48*, 27-42. https://doi.org/10.3897/jbgs.e93499

Todorov, L., and Kirilov, K. (2022). Land use change and monitoring of endangered wetlands using geospatial technologies: A case study of Boyana marsh. *Journal of the Bulgarian Geographical Society, 47*, 3-14. https://doi.org/10.3897/jbgs.e94102

Zhang, Z., Zou, L., Hu, F., & Zhang, Q. (2022). Diurnal dynamics of heat exposure in Xi'an: A perspective from local climate zone. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2022.109400

bTV Media Group. (2024, July 17). The big fire near the city of Stara Zagora is under control. *bTV Media Group*. https://btvnovinite.bg/bulgaria/golemijat-pozhar-kraj-stara-zagora-e-ovladjan.html