Spatiotemporal Changes of Urban Land Surface Albedo Impact on Thermal Environment in Bucharest Metropolitan City

MARIA A. ZORAN[1*], ROXANA SAVASTRU[1], DAN SAVASTRU[1], MARINA N. TAUTAN[1], ADRIAN C. PENACHE[2]

[1]National Institute of R&D for Optoelectronics,
Bucharest- Magurele,
ROMANIA

[2]University of Bonn, Geography Department,
Bonn,
GERMANY

*Corresponding Author

Abstract: - This study aims to identify the impact of increasing urbanization in the Bucharest metropolitan area in Romania on the regional climate by analyzing spatiotemporal changes in MODIS Terra/Aqua geospatial and in-situ time series of land surface albedo and climate parameters during the 2002- 2022 period. Additionally, this paper quantifies the effect of urban spatiotemporal land surface albedo changes in urban thermal environment. Our analysis combined multiple long-term satellite products (e.g., land surface temperature-LST, normalized vegetation index/Enhanced Vegetation Index –NDVI/EVI, land surface albedo -LSA, leaf area index-LAI, evapotranspiration-ET) with high-resolution land cover datasets in a complex statistical and spatial regression analysis. During summer hot periods, the findings of this study reveal a strong inverse correlation between LSA and LST ($r= -0.80$; $p<0.01$) in all city sectors associated with a high negative impact on the urban thermal environment. As a measure of urban surface thermal properties, broadband albedo depends also on the atmospheric conditions. As a key parameter in urban climate research, LST interannual variations in relationship with air temperature –AT is very important in urban climate studies. The rank correlation analyses revealed that, at the pixel-scale, during the summer season (June-August) air temperature at 2m height AT and LST presents a strong positive correlation ($r= 0.87\%$, $p<0.01$). During summer periods (June – August), LST-NDVI shows an inverse correlation (for central city areal $r= -0.24$, $p< 0.05$; and for metropolis areal $r= -0.69$, $p<0.01$). However, urban/periurban vegetation land covers may have major feedback to the anticipated urban climate change modeling scenarios through albedo changes due to the fact that the urban physical climate system is extremely sensitive to land surface albedo.

Key-Words: - urban thermal environment, land surface albedo, biogeophysical parameters, time series MODIS Terra/Aqua satellite data, Bucharest city, Romania.

Received: May 19, 2023. Revised: August 2, 2023. Accepted: September 27, 2023. Published: October 12, 2023.

1 Introduction

The increased and rapid urbanization contributes to global climate change through increasing carbon emissions due to enhanced population, consumption, and activation, and also through affecting radiative forcing due to the changes of the geometry and the composition of surface elements, and induced changes of Earth's radiative variables. Land surface albedo (LSA) defined as the fraction of radiative flux reflected by a surface to the atmosphere, is one of the key geophysical variables controlling the land surface radiation budget, that plays a crucial role in climate changes. Its spatiotemporal variability is due to solar illumination changes, rapid changes in atmospheric conditions, vegetation land cover and growth, soil moisture, and different human activities like as agricultural practices. Anthropogenic and natural activities will have a serious impact on local and regional climate due to alteration of the effective surface albedo, which leads to local phenomena such as urban heat islands (UHIs) and the increased effects of summer heat waves (HWs), [1], [2]. For this reason, urban LSA is regarded as an important indicator for mitigating the UHI phenomenon. However, in the physical climate system, land surface cover determines the radiation balance of the surface and also, affects the land and air surface temperature and boundary-layer structure of the atmosphere, [3], [4]. Also, the urban overheating during summer heat waves needs the implementation of mitigation actions. For reliable forecasts of future climate change across large metropolitan areas, an understanding of fluctuations in urban land surface albedo is required. Higher ambient temperatures are evidence of the urban heat island phenomenon, which has an adverse impact on human health and occurs in highly populated regions of cities. The urban heat island phenomenon, which has a serious impact on human health, is characterized by higher ambient temperatures in the dense parts of the cities compared to their surrounding environment. It is generated by the positive thermal balance in the urban built environment attributed to the excessive absorption of solar radiation by the impervious surfaces, the release of anthropogenic heat, the reduced evapotranspiration and surface permeability, and the lack of urban ventilation. Previous studies have reported the important role of high albedo materials and vegetation land cover in mitigating urban thermal stress, but local and regional atmospheric circulation and air quality are essential parameters in the surface energy balance, land surface albedo is identified as a primary essential climate variable (ECV) is an essential tool of climate change at local urban scale. The albedo quantity, most relevant to the energy budget comprises the shortwave domain (0.4 μm- 4 μm), which includes the visible (0.4μm- 0.7μm) and near-infrared (0.7 μm- 4 μm) spectral wavelengths, where the solar downwelling radiation is more relevant. Land surface albedo is related to several biogeophysical, biogeochemical, and hydrological cycles as the absorbed radiant flux (e.g. absorbed photosynthetically active radiation), which drives the processes of plant photosynthesis, evapotranspiration, and vegetation growth, [5], [6]. Urban land cover spatiotemporal changes attributed to natural and anthropogenic factors have a direct impact on land surface albedo variability, [7], [8]. Both urban microclimates and outdoor thermal environments depend not only on the regional climate at a large scale but at a local scale and are also linked to the features of the urban built environment (its form and fabrics). The urban thermal environment is under the influence of city spatial structure characteristics, land use/land cover, and landscape patterns. Due to the increased urban heat island phenomenon, the urban thermal environment will gradually deteriorate, which affects the quality of urban human health, being related to urban energy consumption, ecosystem operation, vegetation phenology, and sustainable city economy. For urban thermal environment characterization, this study uses land surface temperature (LST), which is an important parameter used to characterize the land surface changes and the spatiotemporal pattern and influencing factors of the urban thermal environment. Green space was measured with a satellite-derived vegetation index normalized vegetation index (NDVI), which captures the combined availability of gardens, street trees, parks, and forests. The variability in urban vegetation land cover cooling impacts on city thermal environment as a function of sunlight and vegetation moisture content, with surface solar irradiance and the cooling variability of vegetation characteristics described by Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR across the metropolis' selected sectors. In urban thermal environment studies, the short-wave broadband albedo is considered to be one of the most important physical parameters for climate models, because it provides crucial information on the exchange of solar radiation between the land surface and the atmosphere. The MODIS broadband albedo product used in this study has both high spatial and high temporal resolutions. However, using satellite remote sensing data of various spatial, spectral, angular, and temporal resolutions, albedo can be derived at the pixel scale over an entire analyzed urban area. In-situ observational monitoring data can be used for the validation of satellite data. This brings a more accurate estimation of climate models. Time series satellite data provide information on the urban growth associated with derived biogeophysical land surface parameters, (vegetation fraction cover, built-up indices, land surface temperatures, land surface albedo), which are good indicators of urban thermal environment changes, [9], [10], [11]. Synergy's use of time series-derived satellite biophysical parameters and in-situ monitoring data can provide useful information for urban land cover spatiotemporal dynamics. Extreme summer heatwave events driven by a persistent high-pressure system coupled with low soil moisture on the land surface can exacerbate people's vulnerability to increased air temperature (AT) and land surface temperature (LST) in the Bucharest metropolitan area. Urban green and reflective urban surfaces can improve the urban thermal environment by reducing urban heat. Although several studies have described the spatial pattern and influencing factors of the urban thermal environment, the relationship between the land surface albedo and the urban thermal environment in Bucharest has not yet been established. Based on a time series of MODIS Terra/Aqua data during the 2000-2022 period, this study conducted a spatiotemporal analysis of urban biogeophysical parameters spatiotemporal changes in their interaction with climate variability and extreme events to detect urban footprints on Land Surface Albedo, and Land Surface Temperature in the Bucharest metropolis, in Romania. Also, urban growth and climate change impact the thermal environment in relationship with several biogeophysical variables. The information provided by this study may be useful for urban planning, building design, and energy efficiency initiatives in large metropolitan areas of Bucharest aimed at mitigating the summer UHI phenomenon, especially associated with HWs. By better knowledge and predicting urban albedo, decision-makers can implement targeted interventions and adopt strategies to reduce UHI effects, enhance urban thermal comfort, and optimize energy consumption in the city.

2 Study Test Area and Data used

2.1 Bucharest Test Area

The capital of Romania, Bucharest, is located in both the South-East of Romania and the South-East of Europe. Is described by a star-shaped pattern (Fig.1), being bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E.

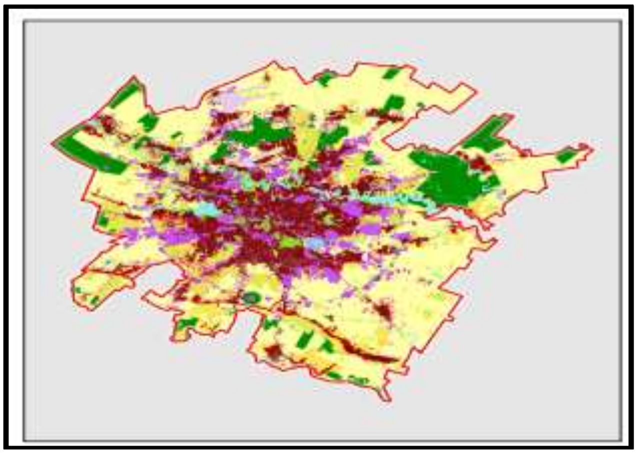

Fig. 1: Bucharest test site

The main central coordinates are latitude 44°25′N, longitude 26°06′E. The urban metropolitan area of Bucharest includes the city of Bucharest (228 km^2) and the surrounding areas belonging to Ilfov County (329 km$^{2)}$, covering a total surface of 557 km^2. The city is crossed by the Dambovița and Colentina rivers. While the Dambovița River crosses Bucharest from northeast to southwest through its center, the Colentina River has meanders and marsh areas. It forms a succession of lakes in the Northern part of Bucharest. At the local scale, its climate is continental, with four seasons (spring – March, April, May, summer – June, July, August, autumn –September, October, November, winter – December, January, February). During last year July and August months have been the warmest months of the year, with average maximum air temperatures higher than 30°C. August month recorded the lowest number of rainy days in the year and the smallest amount of rainfall in the summer.

2.2 Data Used

The time series analysis of derived biogeophysical parameters for the Bucharest metropolitan area is based on satellite remote sensing MODIS Terra/Aqua, Landsat TM/ETM+, and Sentinel 2 data acquired during the 2000-2022 period. Land cover dynamics were assessed using time series Landsat TM/ETM+ (Landsat TM: 23/07/2002, 12/06/2007, 16/07/2012, 06/07/2016, and Landsat ETM+ 17/07/2022) and time-series MODIS Terra data for 2002-2022 period. The analyzed period registered several heat wave periods, of which summers 2003, 2007 2010, 2012, 2017, and 2022 have been the highest. We used time series MODIS Terra products: 8-Day L3 Global 1km SIN Grid land surface temperature (LST)/emissivity MOD11A2/LST_Day_1km, 16-day MODIS 13Q1/250m_16_days_NDVI/EVI composites with a 250 m spatial resolution, MCD43A/VIS and NIR surface albedo, mainly for their capacity to detect anthropogenic and climate impacts on urban thermal environment and land cover changes, [12], [13], [14], [15]. Missing values were replaced by linear interpolation considering neighboring values within the LST, NDVI/EVI, LAI, and FPAR time series. Landsat ETM+ 17/07/2022 image was used for validation and training. Have been selected 5 periurban and 5 urban test areas as well as a central Bucharest test area and an entire metropolis test area. Additional in situ monitoring spectroradiometrical data, and meteorological monitoring data at air quality and meteorological networks have been used.

2.3 Statistical Analysis

In this study air (AT), and land surface temperature (LST), as well as vegetation-indicating parameters (NDVI, LAI, vegetation land cover, etc.) and land surface albedo (LSA) were clustered according to the methods, scope, and thermal environment. The findings were expressed by the statistical correlation between vegetation parameters and thermal parameters like AT, LST, and LSA. For similarity between two-time series data of the averaged daily air temperature (TA), and derived satellite biogeophysical parameters (LST, VIS, and NIR surface albedo, NDVI) in Bucharest this study used Spearman cross-correlation analysis and non-parametric test coefficients as well as linear regression analysis. For assessment of the normality of the averaged daily time-series data sets, Kolmogorov-Smirnov Tests of Normality. ORIGIN 10.0 software version 2021 for Microsoft Windows was used for data processing. For satellite data, ENVI 5.7 version, and IDL 7.0 software have been used.

3 Results and Discussion

To identify the urban footprints on land surface temperature and land surface albedo and their changes during the 2000-2022 period in the Bucharest metropolitan area, we used a long time series of MODIS Terra/Aqua land-surface satellite products and reanalysis data to investigate the urban land cover– air and land surface temperature interactions.

3.1 Land Use/ Land Cover, and Changes

In 2018, according to Copernicus Urban Atlas land use land cover (LULC) distribution (km^2) in Bucharest metropolitan region was following: artificial area 33.6%, agricultural area 53%, natural areas 10.7%, wetland 0.2% and water 2.4%, [16]. The registered changes of LULC during the 2012-2018 period for the Bucharest metropolitan area were defined as urban expansion through uptake of agricultural areas (71.9%), uptake of natural areas (1.3%), uptake of wetlands/water (1.3%), loss of artificial area (12.3%) and other changes (13.5%). Is well recognized that urban land cover artificial properties will change the urban surface energy and water balance different from the natural surfaces. Also, the city morphology and urban forms and topography of Bucharest can impact climate at the microscale by creating urban canyons due to changes in wind speed and direction, building walls creating warmer spots, which results in urban thermal discomfort, [17], [18], [19]. Change detection analysis provided by this study for the 2000 -2022 period shows that Bucharest city expanded in all directions inside the 6 sectors, the highest rate of city growth was inside the Northern sectors but also in the periurban areas. The results of this study highlighted a characteristic spatial pattern, gradients, and landscape metrics, which support an understanding of Bucharest's spatial growth and the future modeling of urban development in Romania.

3.2 Land Surface Albedo (LSA)

Fig. 2 presents temporal variations of daily average MODIS/Terra Broadband BRDF albedo MCD43A in band-1 during 2002-2022 for the Bucharest metropolitan area. This study found a strong inverse relationship between LSA and LST (r= -0.80; p<0.01) during summertime in the city areas with a negative impact on the urban thermal environment. Broadband albedo, which measures urban surface properties depends also on the atmospheric conditions, [20], [21], [22], [23], [24], [25], [26]. Assigning albedo values to different urban/periurban land cover types is useful for adapting the level of interventions and their impacts on the urban form that underwent specific evolutions between the 2000 and 2022 time window.

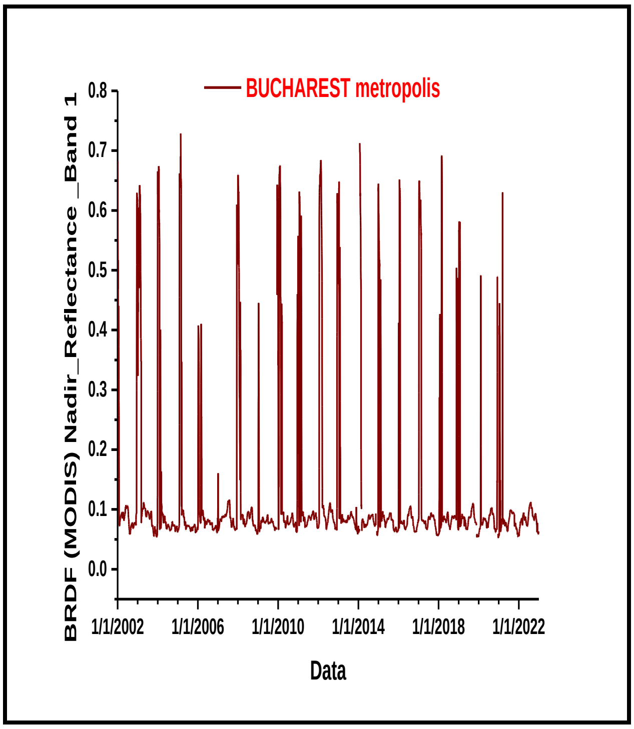

Fig. 2: Temporal variations of daily average MODIS/Terra Broadband BRDF albedo MCD43A in band-1 during 2002-2022.

Based on 23 years of time-series analysis of MODIS Terra/Aqua data this study found the following results: (1) TA plays an important role in determining the LSA by controlling snow absence and presence during the winter-to-summer and summer-to-winter transitional periods,; (2) during the winter season urban LSA is greatly influenced by the amount of precipitation or snow; (3) the water and soil moisture conditions during the spring-summer-autumn seasons, can significantly alter the LSA of the urban/periurban vegetation land cover growth; (4) shifts in urban land cover tend to cause persistent changes in LSA. Also, urban surface albedo changes in the Bucharest metropolitan area are highly dependent on local and regional climate variations. However, similar variations of LST can be attributed to factors that are more temporally dynamic like temporal shifts in vegetation phenology (that represents the annual cycles and temporal patterns of plant growth and development), and can significantly alter the seasonal distribution of surface albedo.

3.3 Land Surface Temperature (LST)

Fig. 2 presents a temporal pattern of Land Surface Temperature MOD11A2/LST_Day_1km, for a city central area of 6.5 km x 6.5 km, and a metropolitan area of 40.5km x 40.5 km centred at latitude 44.4355381 ºN and longitude 26.100049 ºE. As was expected, in the central built area of Bucharest with high impervious surfaces LST presents greater temperatures and reflects more heat, while the extended metropolitan area exhibits lower temperatures due to much more vegetated spaces. The significant differences in LST_Day between city central, median, and peripheral zones of the Bucharest metropolitan area have been recorded especially during years with intense heat waves (2003, 2007 and 2010, 2012, 2016, and 2022). Monthly average values of the temperature differences between urban and rural areas range between 1ºC and 8ºC.

Like other studies, [27], [28], [29], [30], this paper reveals a strong positive correlation at the pixel scale, during the summer season (June-August) air temperature at 2m height TA and LST presents ($r= 0.87\%$, $p<0.01$).

3.4 NDVI/EVI

The results of this study show that the disturbances of urban forests and urban green alter land cover biophysical properties, directly impacting local climate and land surface temperature. At the metropolitan scale, urban vegetation loss has high impacts on land surface albedo increase, evapotranspiration (ET) decrease, and reduced values of LAI. In good accordance with previous papers for worldwide cities, the relationships between LST and NDVI/EVI were highly diverse among the various urban/periurban biomes and seasons throughout the entire study period, [31], [32].

Therefore, during the spring season March–May), LST-NDVI shows the dominance of significant positive correlation (Spearman rank correlation coefficient $r=0.90$, $p<0.01$ for city central area; and $r=0.71$; $p<0.01$ for metropolis areal), while during the summer season (June–August), most of the vegetation test areas turned to negative correlation as follow (for central city areal $r= -0.25$, $p< 0.05$; and for metropolis areal $r= -0.69$, $p<0.01$). For autumn and winter seasons, LST correlations with NDVI/EVI were positive in the range of $r= 0.43$ to $r= 0.65$ and $p<0.01$ for central city and metropolis areas. Fig.3 shows the temporal variations of daily average MODIS NDVI and LST_Day during 2002-2022. The contributions of periurban cropland and forest varied distinctly between daytime and nighttime owing to differences in their thermal inertias, [33], [34], [35].

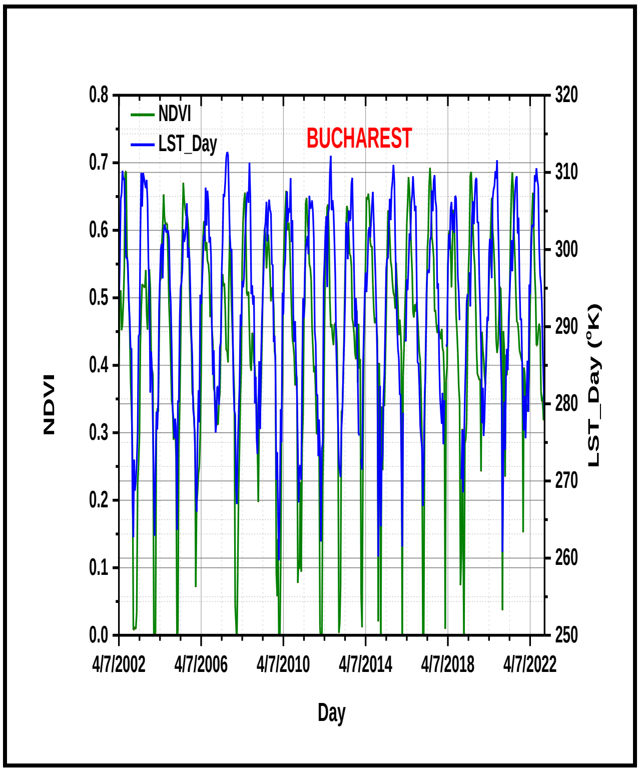

Fig. 3: Temporal variations of daily average MODIS NDVI and LST_Day during 2002-2022

Vegetation had a clear cooling effect as the normalized vegetation difference index (NDVI) increased during summer periods. The results of this study are in good accordance with previous studies, [36], [37], [38], [39], which demonstrated the significant cooling impact of urban green (trees, grass) albedo on cities' thermal environment during hot summers under different climate conditions. Cooling efficiency of vegetation is a function of solar surface irradiance and urban vegetation moisture content, [40]. Urban footprint analysis further revealed changes in green land cover that are highly dependent on land management scenarios. Urban green infrastructure must be an important tool to achieve sustainability and resilience in cities exposed to global warming because of its several benefits, including carbon storage, urban heat islands and summer heat waves mitigation, flooding events, and air quality improvement.

4 Conclusion

During the summer months (June-August) periods, the function of atmospheric conditions, this study reports a strong inversely correlation between LSA and LST in all city sectors of Bucharest associated with a strong negative impact on the urban thermal environment. As a key parameter in urban climate research, LST long-time variations in relationship with air temperature –AT is very important in urban climate studies. The rank correlation analyses revealed that at the pixel scale, during the summer season air temperature at 2m height TA and LST are positively correlated, while LST and NDVI show an inverse correlation, higher for metropolitan areas than for the city center. The quantification of the urban thermal environment and associated heat stress in the context of the urban heat island phenomenon, which has detrimental effects on air quality and human health, is a crucial research need as heat waves are predicted to become more frequent and severe in Romanian urban areas and the South-East of Europe in the coming years due to global climate warming. The findings of this study may offer insights to urban managers and important decision makers for urban planning and management to improve the urban thermal environment and optimize the urban functional structure in the Bucharest metropolitan area. Additionally, the necessity to implement urban heat mitigation technology will take into account the following issues: reducing heat gains; enhancing urban greenery and blue infrastructure; reducing heat losses in the city; involving the use of advanced materials for building the urban surfaces; the urban heat cooling during hot summers through modified urban surface albedo.

Acknowledgments:
This work was supported by the Romanian Ministry of Research, Innovation and Digitalization: through Program 1- Contract no. 18PFE/30.12.2021; National Research Development and Innovation Plan 2022-2027, project no. PN 23 05; Grant CNCS-UEFISCDI, project number PN-III-P4-PCE-2021-0585; Romanian Ministry of European Investment and Projects & Romanian Ministry of Research, Innovation and Digitalization, Contract no.8/1.2.1 PTI ap.2/17.02.2023.

References:

[1] Guo T., He T., Liang S., Roujean J.L., Zhou Y., Huang X, Multi-decadal analysis of high-resolution albedo changes induced by urbanization over contrasted Chinese cities based on Landsat data, *Remote Sensing of Environment*, 269, 2022.

[2] Xiaoping Liu, Shaojian Wang, Peijun Wu, Kuishuang Feng, Klaus Hubacek, Xia Li, and Laixiang Sun, Impacts of urban expansion on terrestrial carbon storage in China, *Environ. Sci. Technol*. 53, 2019, pp, 6834–6844.

[3] Lyu, L., Sun, F., Huang, R., Innovation-based urbanization: evidence from 270 cities at the prefecture level or above in China, *Acta Geograph. Sin*. 73, 2018pp.1910–1922.

[4] Liang, S.L., Wang, D.D., He, T., Yu, Y.Y., Remote sensing of Earth's energy budget: synthesis and review, *Int. J. Digit. Earth* 12, 2019, pp.737–780.

[5] Gueymard C.A., Lara-Fanego V., Sengupta M., Xie Y., Surface albedo and reflectance: review of definitions, angular and spectral effects, and intercomparison of major data sources in support of advanced solar irradiance modeling over the Americas, *Sol. Energy* 182, 2019, pp. 194-212.

[6] Quan Zhang, Mallory Barnes, Michael Benson, Elizabeth Burakowski, A. Christopher Oishi, Andrew Ouimette, Rebecca Sanders-DeMott, Paul C. Stoy, Matt Wenzel, Lihua Xiong, Koong Yi, Kimberly A. Novick, Reforestation and surface cooling in temperate zones: Mechanisms and implications, *Glob. Change Biol.* 26, pp.3384, 2020, 3401.

[7] Chen J.M., Liu J., Evolution of evapotranspiration models using thermal and

shortwave remote sensing data, *Remote Sens. Environ.* 237, 2020, pp. 111594–111614.

[8] Zheng L., Qi Y., Qin Z., Xu X., Dong J., Assessing albedo dynamics and its environmental controls of grasslands over the Tibetan Plateau, *Agric. For. Meteorol.* 307, 2021, pp.108479-108490,

[9] Xingwen Lin, Shengbiao Wu, Bin Chen, Ziyu Lin, Zhengbing Yan, Xiuzhi Chen, Gaofei Yin, Dongqin You, Jianguang Wen, Qiang Liu, Qing Xiao, Qinhuo Liu, Raffaele Lafortezza, Estimating 10-m land surface albedo from Sentinel-2 satellite observations using a direct estimation approach with Google Earth Engine, *ISPRS Journal of Photogrammetry and Remote Sensing* 194, 2022, pp. 1-20.

[10] Shi K., Liu G., Zhou L., Cui Y., Liu S., Wu Y., Satellite remote sensing data reveal increased slope climbing of urban land expansion worldwide, *Landscape and Urban Planning*, 235, 2023, 104755.

[11] Zhengyang Zhang, Lei Lu, Yuhe Zhao, Yuanyuan Wang, Dandan Wei, Xiaodan Wu, Xuanlong Ma, Recent advances in using Chinese Earth observation satellites for remote sensing of vegetation, *ISPRS Journal of Photogrammetry and Remote Sensing*, 195, 2023, pp. 393-407,104755

[12] Schaaf, C. *MCD43A4 MODIS/Terra+Aqua BRDF/Albedo Nadir BRDF Adjusted RefDaily L3 Global - 500m V006*, NASA EOSDIS Land Processes DAAC, 2015.

[13] ORNL DAAC. *MODIS and VIIRS Land Products Global Subsetting and Visualization Tool*, ORNL DAAC, Oak Ridge, Tennessee, USA. 2018. Accessed 10 May 2023.

[14] Wan Z., Hook, S., Hulley, G. *MOD11A2 MODIS/Aqua Land Surface temperature/Emissivity 8-Day L3 Global 1km SIN Grid V061*, NASA EOSDIS Land Processes DAAC, 2021.

[15] Didan K. *MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V06*, NASA EOSDIS Land Processes DAAC, 2021.

[16] Copernicus Urban Atlas. https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018 (Accessed Date: 23 June 2023).

[17] Santamouris, M., & Fiorito, F., On the impact of modified urban albedo on ambient temperature and heat related mortality, *Solar Energy* 216, 2021, pp.493–507.

[18] Santamouris, M., & Yun, G. Y. , Recent development and research priorities on cool and super cool materials to mitigate urban heat island, *Renewable Energy* 161, 2020, pp. 792-807.

[19] Xu, X., AzariJafari, H., Gregory, J., Norford, L., Kirchain, R., An integrated model for quantifying the impacts of pavement albedo and urban morphology on building energy demand, *Energy and Buildings* 211, 2020, pp.109759.

[20] Falasca, S., Ciancio, V., Salata, F., Golasi, I., Rosso, F., & Curci, G., High albedo materials to counteract heat waves in cities: An assessment of meteorology, buildings energy needs and pedestrian thermal comfort, *Building and Environment* 163, 2019, pp.106242.

[21] Zhang Z., Xiong J., Fan M., Tao M., Wang Q., Bai Y. Satellite-observed vegetation responses to aerosols variability. *Agricultural and Forest Meteorology*,329, 2023, 109278.

[22] Chen Y., Yang J., Yang R., Xiao X., XiaJ.C.Contribution of urban functional zones to the spatial distribution of urban thermal environment. *Building and Environment*, 216, 2022, 109000.

[23] Zaitunah A., Silitonga, A.F., Syaufina, L. Urban Greening Effect on Land Surface Temperature. *Sensors* 22, 2022, 4168.

[24] Schwarz, N., Schlink, U., Franck, U., Grosmann, K., Relationship of land surface and air temperatures and its implications for quantifying urban heat island indicators—an application for the city of Leipzig (Germany).*Ecological Indicators* 18, 2012, 693–704.

[25] Sun Y., Gao C., Li J., Li W., Ma R, Examining urban thermal environment dynamics and relations to biophysical composition and configuration and socio-economic factors: A case study of the Shanghai metropolitan region, *Sustainable Cities and Society* 40, 2018, 284–295.

[26] Guerreiro S.B., Dawson R.J., Kilsby C., Lewis E., Ford A, Future heat-waves, droughts and floods in 571 European cities, *Environ. Res. Lett.* 13 (3), 2018, 34009.

[27] Zoran M., Dida A. Urban green land cover changes and their relation to climatic variables in an anthropogenically impacted area, *Proc. SPIE* 10431, *Remote Sensing Technologies and Applications in Urban Environments II*, 104310W; doi: 10.1117/12.2278019, 2017.

[32] Zoran M., Savastru R., Savastru D., Zoran L.F. Effect of urban surface albedo on thermal environment characterization. *Proc. SPIE* 11156, *Earth Resources and Environmental Remote Sensing/GIS Applications X*, 111561G, 2019.
[33] Zoran M., Savastru D., Tautan M., Baschir L. Use of satellite data for land surface radiative parameters retrieval of Bucharest metropolitan zone. *Journal of Optoelectronics and Advanced Materials* 21(7-8), 2019, 470-483.
[34] Mohammad Harmay N.S., Kim D., Choi M. Urban Heat Island associated with Land Use / Land Cover and climate variations in Melbourne, Australia. *Sustainable Cities and Society* 69, 2021, 102861.
[35] Klopfer F., The thermal performance of urban form – An analysis on urban structure types in Berlin., *Applied Geography* 152, 2023, 102890.
[36] Smith I.A., Fabian M.P., Hutyra L.R., Urban green space and albedo impacts on surface temperature across seven United States cities. *Science of The Total Environment* 857, 2023, Part 3, 159663. https://doi.org/10.1016/j.scitotenv.2022.159663.
[37] Dong X., Ye Y., Yang Y., Li X., Planning for green infrastructure based on integration of multi-driving factors: A case study in pilot site of sponge city, *Sustainable Cities and Society* 93, 2023, 104549, https://doi.org/10.1016/j.scs.2023.104549.
[38] Chang H-S., Lin Z-H, Hsu, Y-Y. Planning for green infrastructure and mapping synergies and trade-offs: A case study in the Yanshuei River Basin, Taiwan, *Urban Forestry & Urban Greening* 65, 2021, 127325, https://doi.org/10.1016/j.ufug.2021.127325.
[39] Pang G., Chen D., Wang X., Lai H-W., Spatiotemporal variations of land surface albedo and associated influencing factors on the Tibetan Plateau, *Science of The Total Environment* 804, 2022, 150100, https://doi.org/10.1016/j.scitotenv.2021.150100.
[40] Alibakhshi S., Naimi B. Hovi A., Crowther T.W., Rautiainen M. Quantitative analysis of the links between forest structure and land surface albedo on a global scale, *Remote Sensing of Environment* 246, 2020, 111854, https://doi.org/10.1016/j.rse.2020.111854.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Maria Zoran: Conceptualization; Methodology, Supervision, Writing - review & editing.
- Roxana Savastru: Methodology, Validation.
- Dan Savastru: Methodology, Review.
- Marina Tautan: Methodology, Validation.
- Adrian Penache: Data acquisition, Validation.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This work was supported by the Romanian Ministry of Research, Innovation and Digitalization: through Program 1- Contract no. 18PFE/30.12.2021; National Research Development and Innovation Plan 2022-2027, project no. PN 23 05; Grant CNCS-UEFISCDI, project number PN-III-P4-PCE-2021-0585; Romanian Ministry of European Investment and Projects & Romanian Ministry of Research, Innovation and Digitalization, Contract no.8/1.2.1 PTI ap.2/17.02.2023.

Conflict of Interest

The authors have no conflict of interest to declare.