S E S 2 0 2 2
Eighteenth International Scientific Conference
SPACE, ECOLOGY, SAFETY
19 – 21 October 2022, Sofia, Bulgaria

ANALYSIS OF URBAN HEAT ISLAND (UHI) THROUGH CLIMATE ENGINE AND ARCGIS PRO IN DIFFERENT CITIES OF BULGARIA

Paraskevi E. Gkatzioura[1], Konstantinos Perakis[2]

[1,2] Laboratory of Informatics in Spatial Planning, Department of Planning and Regional Development, University of Thessaly
e-mail: evitagkatz@gmail.com

Keywords: *Urban Heat Island (UHI), Climate Engine (CE), Land Surface Temperature (LST), NDVI, remote sensing*

Abstract: *The increasing temperature of the atmosphere, combined with the earth's surface temperature, will be the main factor in the global climate crisis. Since the second half of the 20th century, the rapid urbanisation of cities, combined with technological development, human wellbeing, and general population growth, has been directly linked to cities' economic development and sustainability.*

This research aims to analyse the correlation between the Normalised Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) using Climate Engine (CE) tool and ArcGIS Pro GIS software. In addition, Landsat 5/7/8/9 Top of Atmosphere Reflectance Data was used over the period 2012 – 2017 for five cities in Bulgaria. Climate Engine is an online platform to process observation data for getting economic and environmental sustainability directions. The correlation from the above spatial research of Bulgarian cities indicates how to manage the UHI (Urban Heat Island).

Introduction

Air temperature increase in combination with Land Surface Temperature (LST) increase is two of the main factors of environmental crisis (Mustafa et al., 2020). Furthermore, the intensification of urbanisation combined with technological development and human well-being has been the most defining global challenge of the 21st century to ensure population needs and urban economic development (Rimal et al., 2018).

As urban areas develop, heatwaves are trapped among tall and narrowly placed buildings, carbon emissions rise from anthropogenic and productive activities within cities (Ahmed Memon et al., 2008) and urban vegetation decreases. Water demand becomes more intense in order to cover human needs, facing stressful thermal conditions and water urban plants (Takebayashi & Moriyama, 2012). As a result, regional temperatures are increased (Guha et al., 2018), and urban areas behave as Urban Heat Islands (UHI) (Sheng et al., 2017).

UHI refers to the difference in air temperature between a city and its surrounding rural areas especially at night. When the sun goes down, surfaces stop receiving solar energy as long as they continue to radiate the heat stored during the day. Howard firstly observed the phenomenon of UHI in 1833 (Oke, 1982) for the city of London (Mills, 2008) and after a large number of studies being made for different cities around the world (Aflaki et al., 2017; García, 2022; Papamanolis et al., 2015; Sarkar & de Ridder, 2011; Wang et al., 2019) in different time periods. Studying the urban head islands for mitigation, and its effects means more urban green spaces (Ouali et al., 2018), retrofitting buildings and urban spots such as squares, sidewalks with cool pavements (Battista et al., 2020), alerting communities when and where heatwaves are coming.

Analytical studies have been carried for urban hot spots include analysis of remote sensing data from different sensors, data analysis from located temperature measurement stations or analysis by in situ measurements. In addition, in many studies, one way to approach the intensity of the phenomenon is to study the correlation LST with some land use/land cover (LU – LC) spectral indices (Espinoza-Molina et al., 2022; Galodha & Gupta, 2021; García, 2022; Laosuwan & Sangpradit, 2012; Macarof & Statescu, 2017).

Bulgarian urban areas, especially those in Sofia city, were distinguished for green spaces. Urban vegetation in the capital of Bulgaria covered 48,6% of the land cover with the Vitosha mountain in the southwest of the city center (Kopecka & Oťaheľ, 2016). Research for Sofia city has proved that there exists an essential heterogeneity because of different types of land cover. Temperature measurements showed a different profile in the West-East and South-North directions. Sofia city is warmer than its neighboring rural areas by 8º C and the higher land surface temperatures are near the city center (Yanev & Filchev, 2017).

Another interesting attempt was made in Sofia using data from Unmanned Aerial Systems (UAS) data in combination with local climate zones (LCZs). It has been confirmed that as urban vegetation increased, surface temperatures decreased and as built-up areas increased, surface temperatures increased (Dimitrov et al., 2021). As a result, UHI intensity is related to land cover, green, water and built-up areas ((Nuruzzaman, 2015). Vegetation indices e.g. Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), Enhanced Vegetation Index (EVI) (Xue & Su, 2017) studies, evaluate plant growth and measure vegetation cover.

NDVI is one of the most popular vegetation indices. It is an indicator of vegetation health based on how plants reflect the electromagnetic spectrum (Schinasi et al., 2018). In order to calculate NDVI values, we use vegetation absorption and reflection in the range of red and near – infrared (NIR) wavelengths.

$$\text{NDVI} = {(NIR - Red)}\Big/{(NIR + Red)}$$

Values between -1 and 0 indicate dead plants or inorganic objects such as built-up areas and values for live plants range between 0 to 1 – with one being the healthiest (Sileos, Alexandridis, et al., 2013).
In the present study, the spatial distribution of LST and the correlation between LST and NDVI have been analyzed in inland and coastal cities.

Study Area and Data

LST and NDVI values were extracted, corresponding to the five most prominent cities of Bulgaria (Sofia, Plovdiv, Varna, Burgas, Ruse) according to the population distribution. Sofia is the capital city of Bulgaria and Plovdid is the second-largest city which stands out for its historical and geophysical character. Varna city is located in the north part of Bulgarian Black Sea Coast, and Burgas city is in the south.Finally, Ruse city is in northern Bulgaria on the South bank of the Danube.

In the present study, the annual median of the LST through Climate Engine (CE) from the Landsat 5/7/8/9 Top of Atmosphere Reflectance Data at 30m for every year between 2012 and 2017 over the Regions of Interest (ROI) were used. In addition, the annual median values of NDVI were calculated for the same ROIs and during comparable periods.

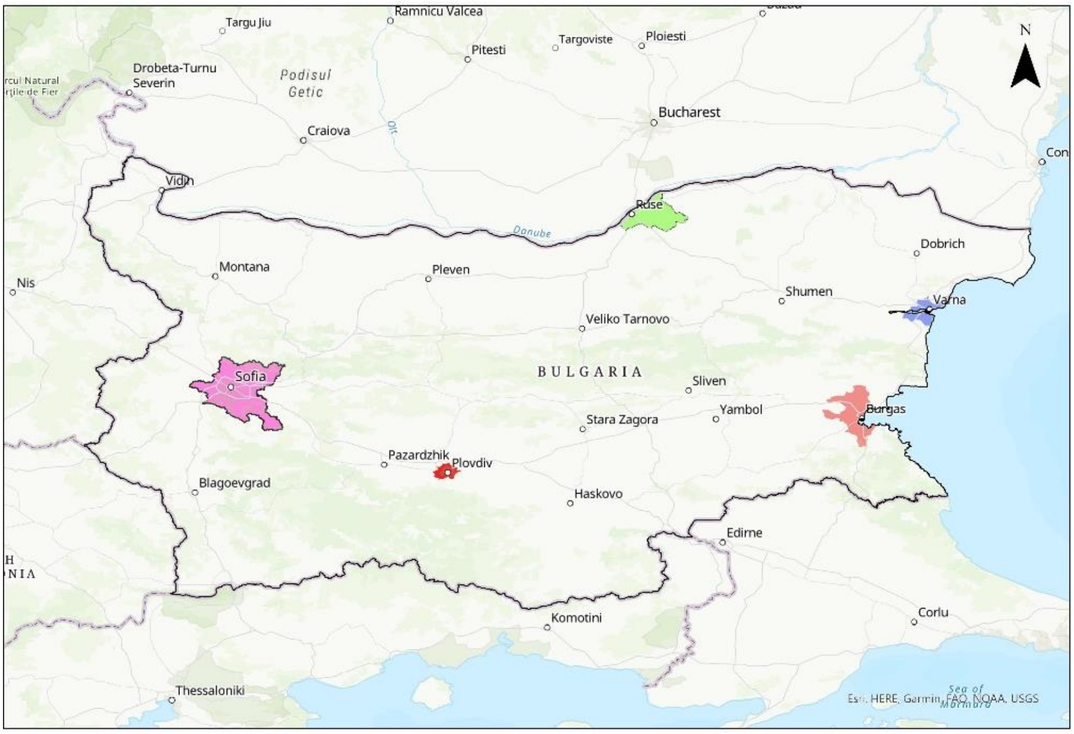

Fig. 1. Study Area with selected ROIs

Methodology & Results

The following methodology carries out a correlation analysis between the Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) through Climate Engine (CE) and ArcGIS Pro. *Climate Engine* is a web application, based on cloud computing technology that provides ready-to-use remote sensing data for analysis, visualization and monitoring of environmental and climate change without storage and cost limitations (Huntington et al., 2017). ArcGIS Pro 3.0 was used to study the correlation between LST and NDVI values.

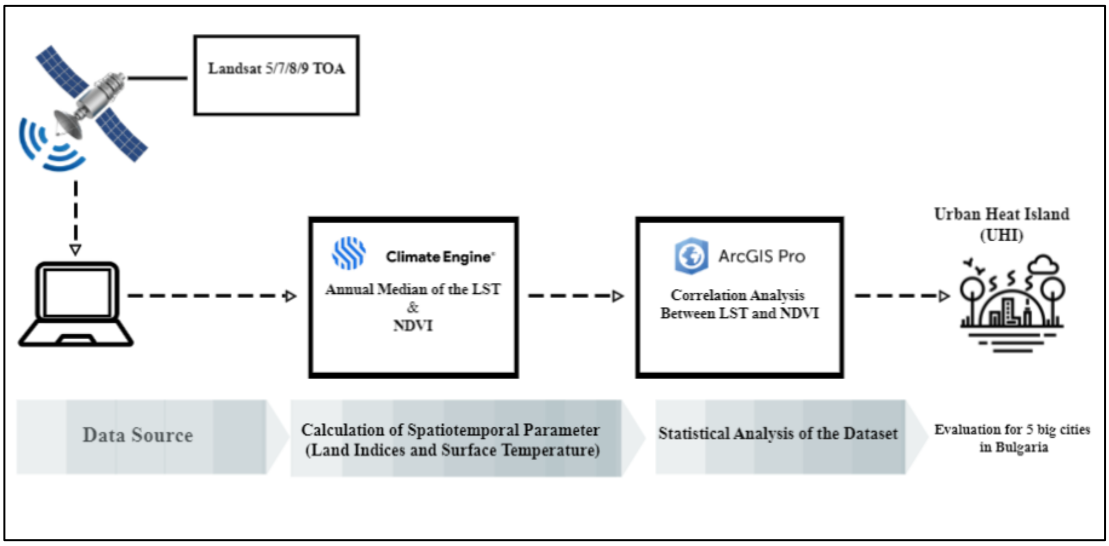

Fig. 2. Methodology flow chart for the study

According to NDVI temporal series shown in Fig. 3, a periodicity in NDVI values appears obvious. Comparing the Figure of NDVI values below with the Figure 4 of Land Surface Temperature (LST), we observe that the minimum and maximum values appeared at the same period as the corresponding NDVI minima and maxima. Figures 3 and 4 show the results corresponding to Burgas city. The conclusion is that a correlation between temperature and NDVI exists. Additionally considering the existing correlation of NDVI and LST we can distinguish that the minimum LST values correspond, more or less, to the minimum NDVI values.

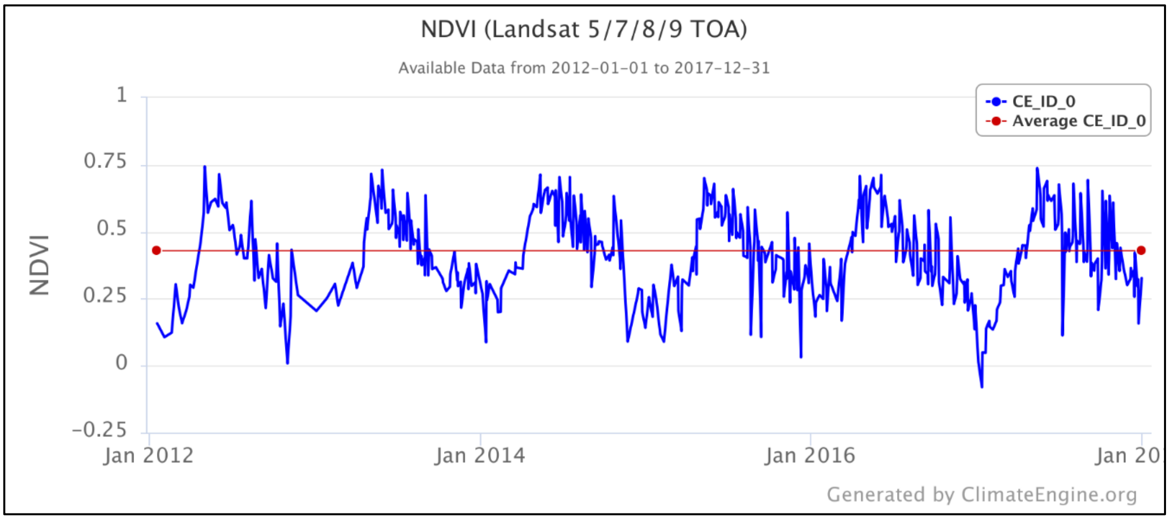

Fig. 3. Normalized Difference Vegetation Index (NDVI) time series for Burgas city over the five year period 2012-2017

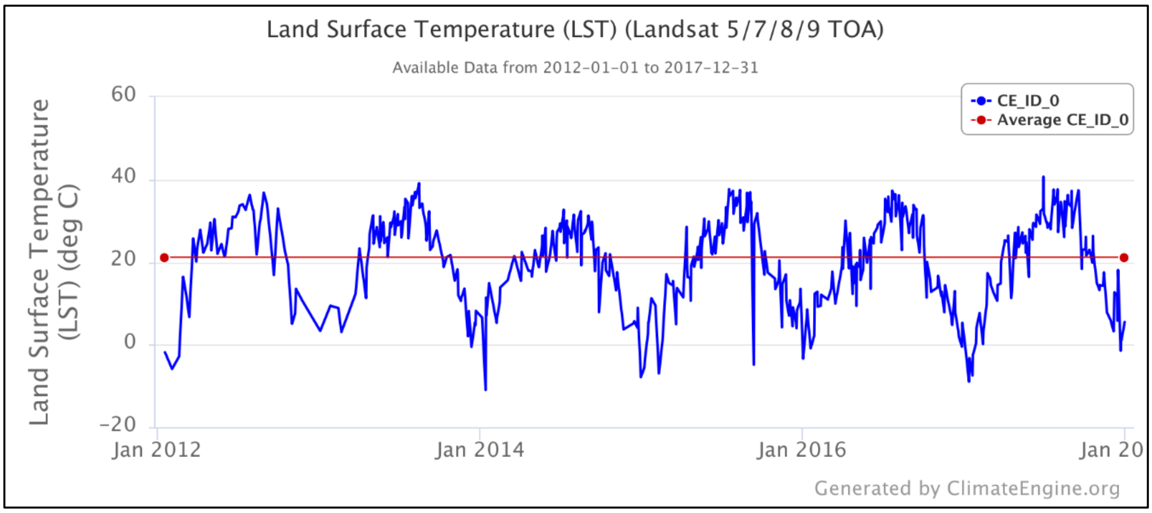

Fig. 4. Land Surface Temperature (LST) time series for Burgas city over the five year period 2012-2017

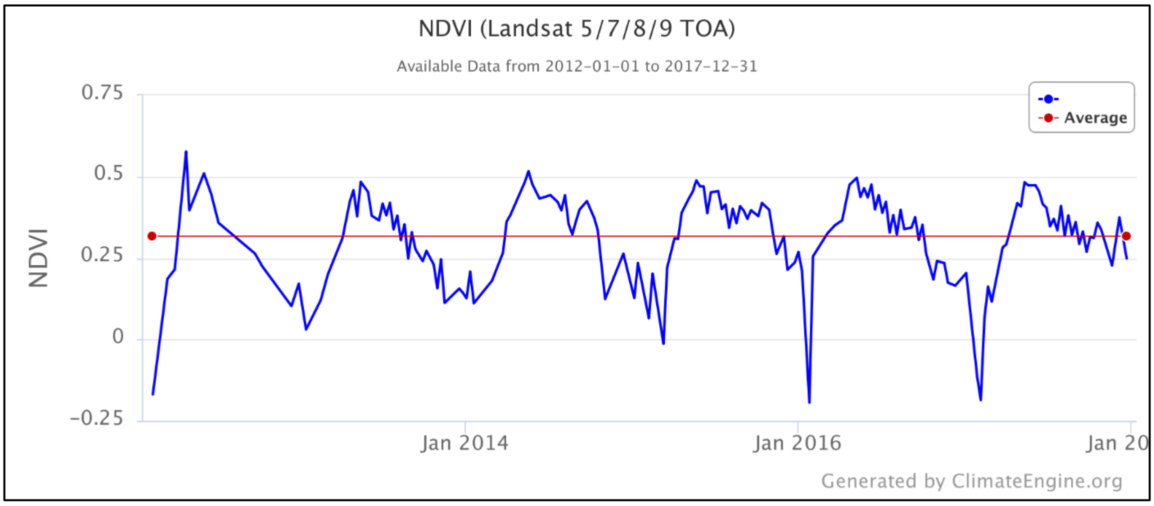

Fig. 5. Normalized Difference Vegetation Index (NDVI) time series for Plovdiv city over the five year period 2012-2017

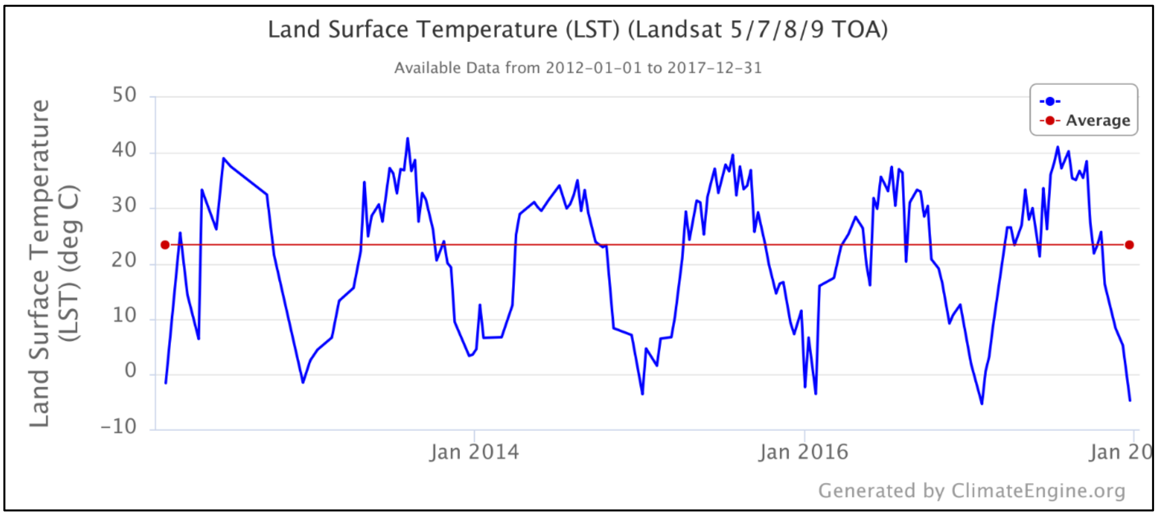

Fig. 6. Land Surface Temperature (LST) time series for Plovdiv city over the five year period 2012-2017

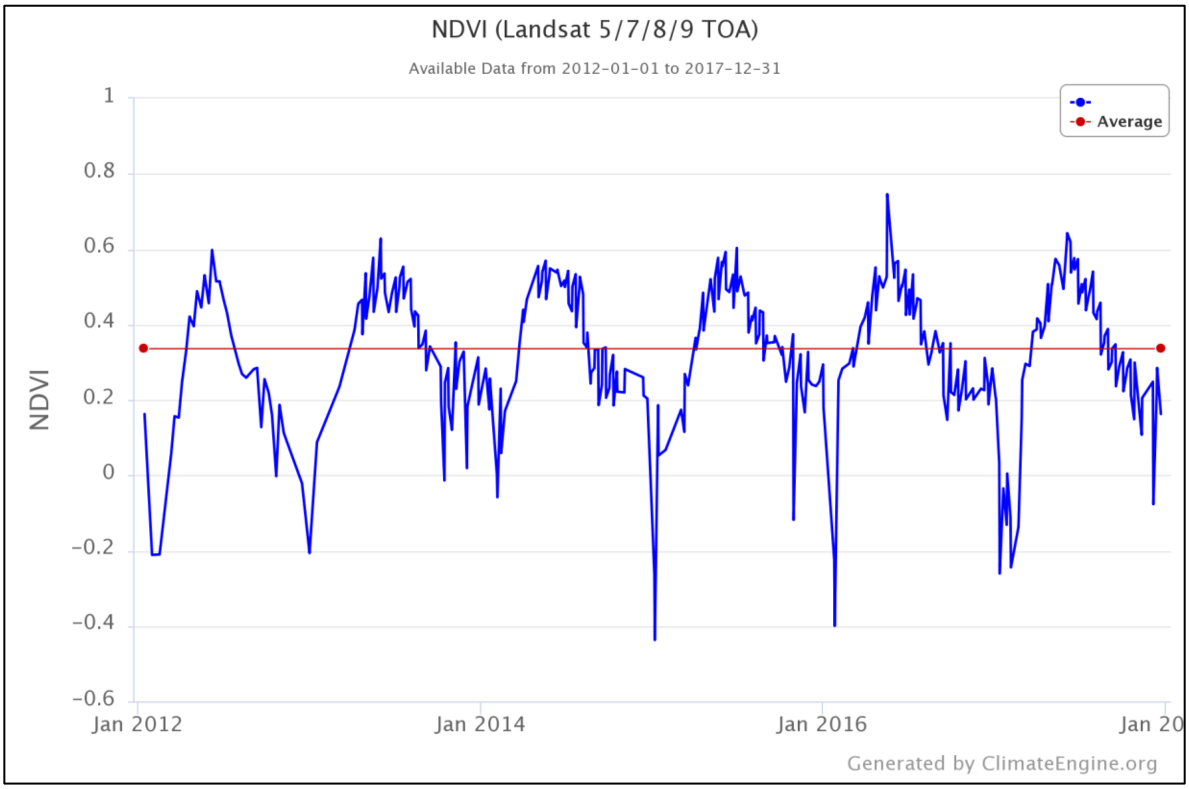

Fig. 7. Normalized Difference Vegetation Index (NDVI) time series for Ruse city over the five year period 2012-2017

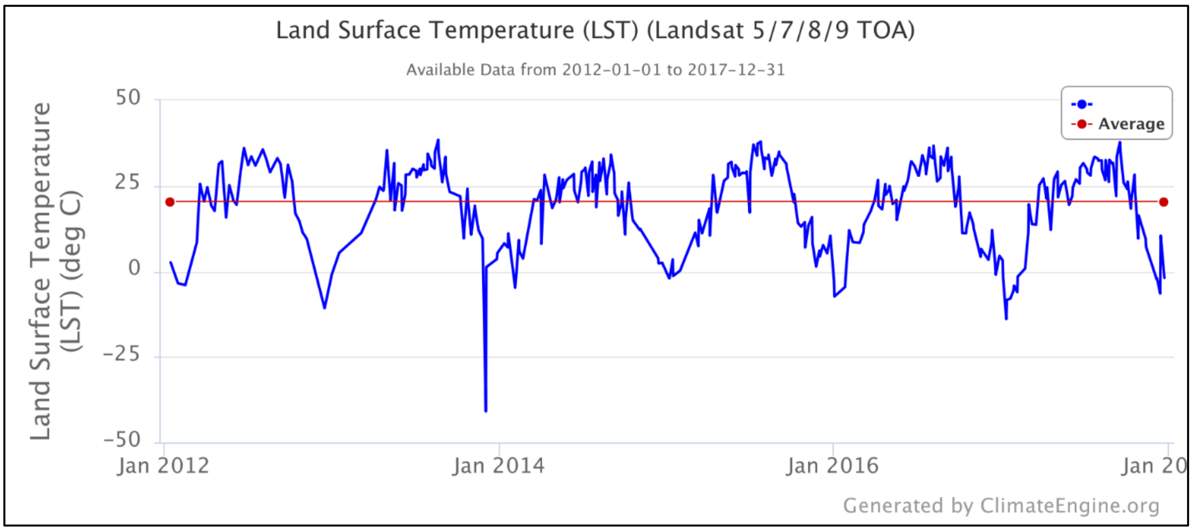

Fig. 8. Land Surface Temperature (LST) time series for Ruse city over the five year period 2012-2017

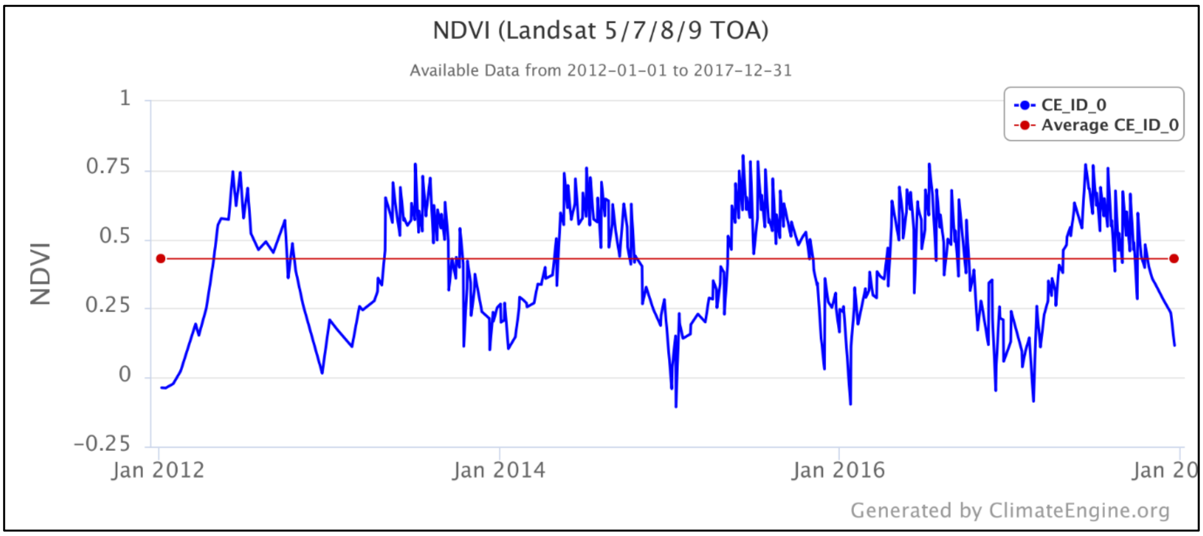

Fig. 9. Normalized Difference Vegetation Index (NDVI) time series for Sofia city over the five year period 2012-2017

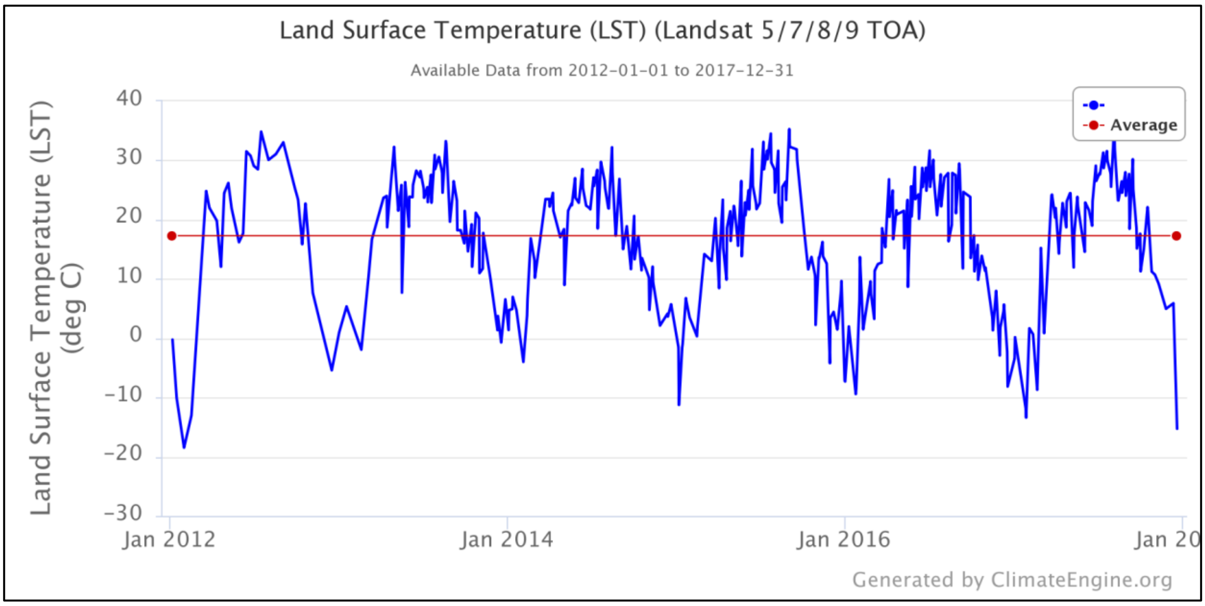

Fig. 10. Land Surface Temperature (LST) time series for Sofia city over the five year period 2012-2017

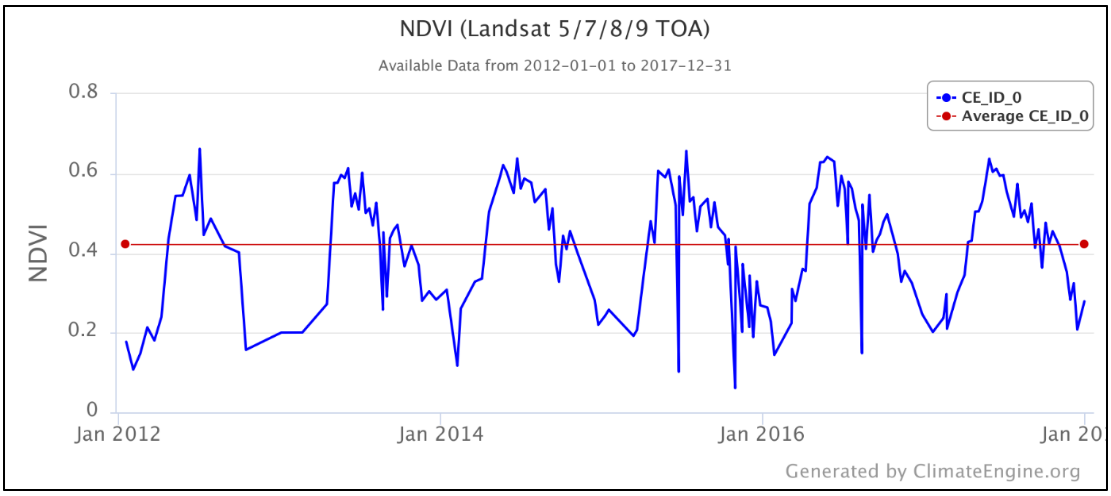

Fig. 11. Normalized Difference Vegetation Index (NDVI) time series for Varna city over the five year period 2012-2017

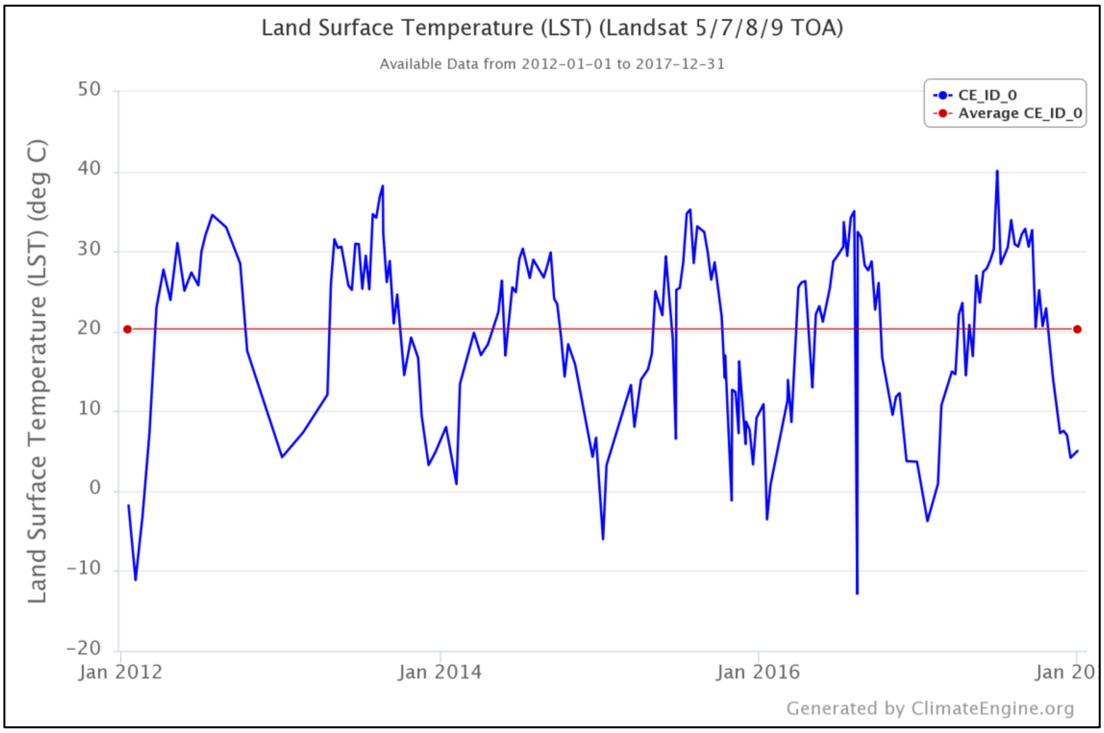

Fig. 12. Land Surface Temperature (LST) time series for Varna city over the five year period 2012-2017

All the above Figures show that the NDVI values present a periodicity over the five years 2012-2017. High NDVI values indicate the presence of green vegetation, especially in Sofia, where NDVI reach the value of 0.8. Conversely, the lowest NDVI values appear during the winter period.

Concerning NASA's Earth Observatory publication (https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php), negative values of NDVI indicate the non-existence of vegetation. Furthermore, Faridatul & Ahmed (2020) found that urban areas presented NDVI values between 0 and 1. It is well known that urban areas contain various landcover, including vegetation. On the other hand, the absence of vegetation, provides NDVI values below 0.

In conclusion, trying to find the correlation between the corresponding actual vegetation NDVI values and LST values in the selected five Areas Of Interest (AOI),and, of course according to the previous remarks, we can exclude all NDVI negative values.

Consequently, the Figures below showing the correlation between NDVI and LST values in our Regions Of Interest indicate more or less an existing correlation between NDVI and LST in all our ROIs.

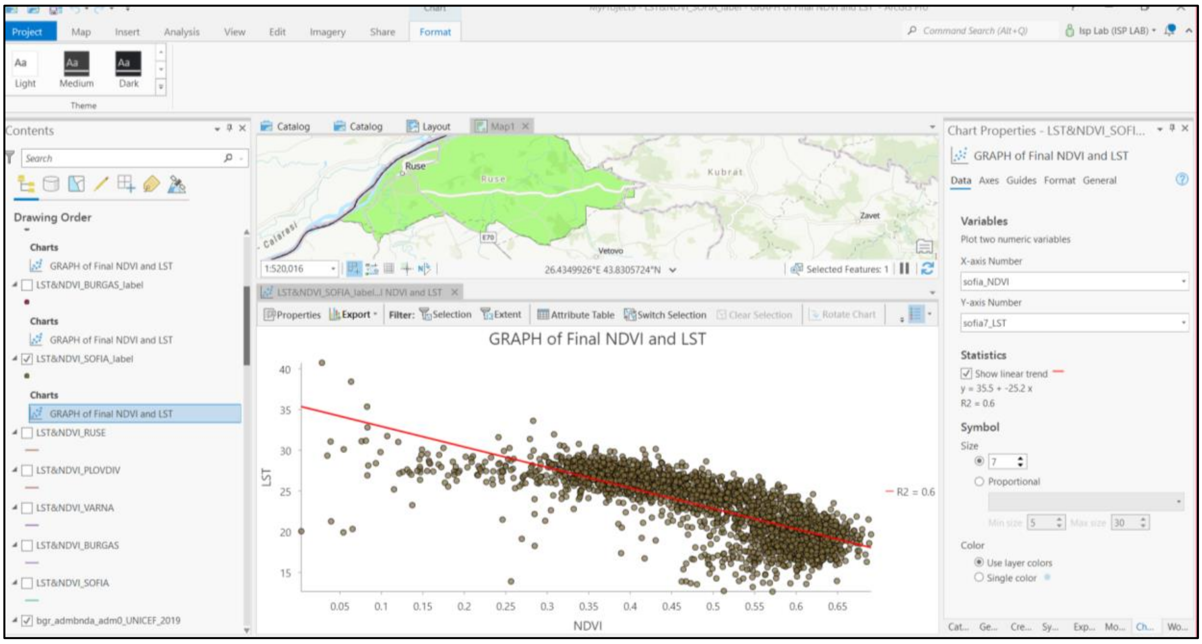

Fig. 13. Interface of ArcGIS Pro for estimate the correlation between NDVI and LST

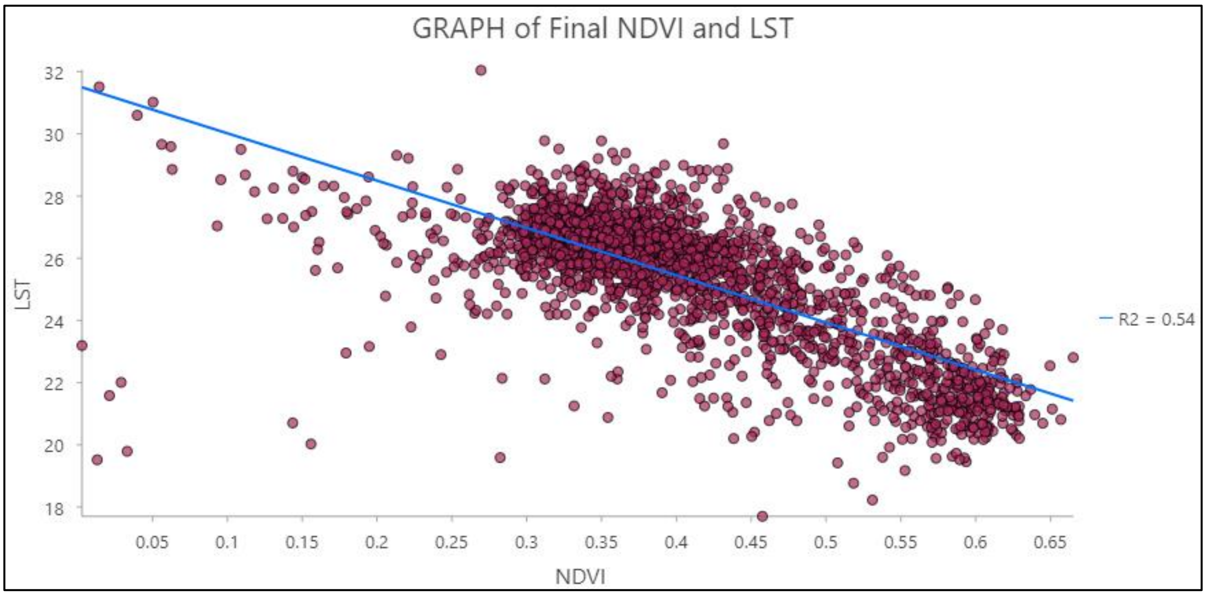

Fig. 14. Bi-plot of LST and NDVI for Burgas city

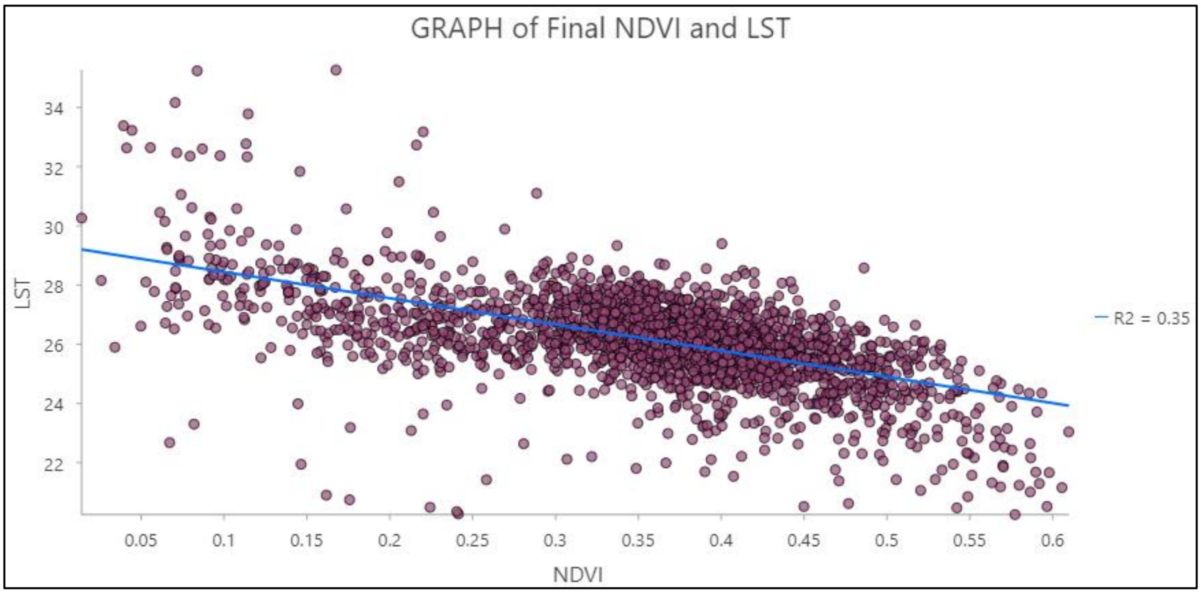

Fig. 15. Bi-plot of LST and NDVI for Plovdiv city

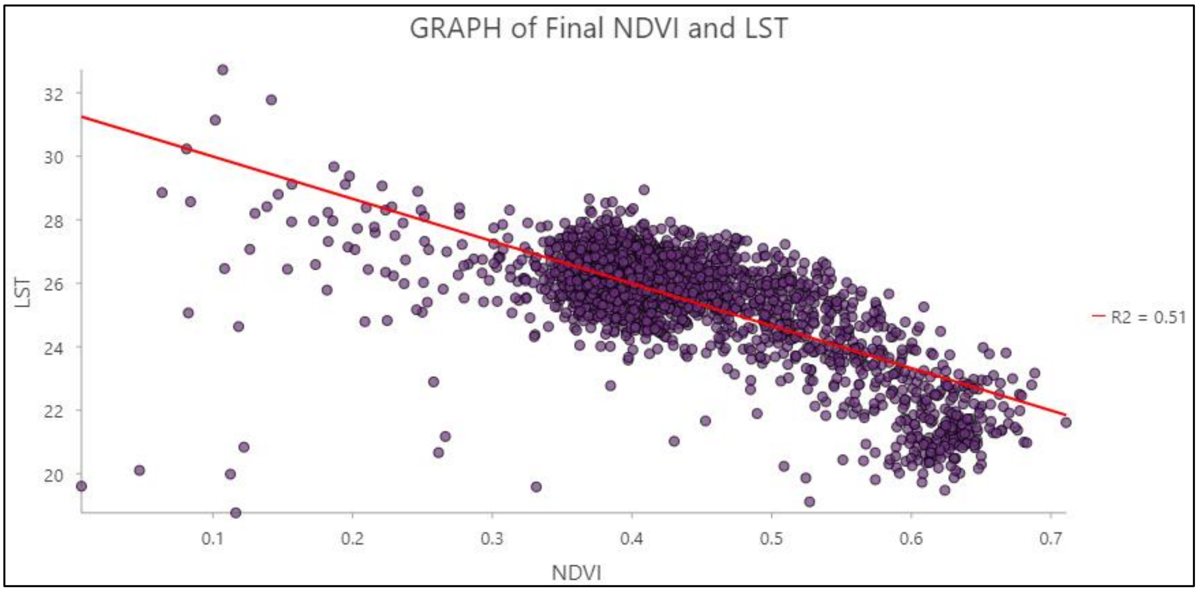

Fig. 16. Bi-plot of LST and NDVI for Ruse city

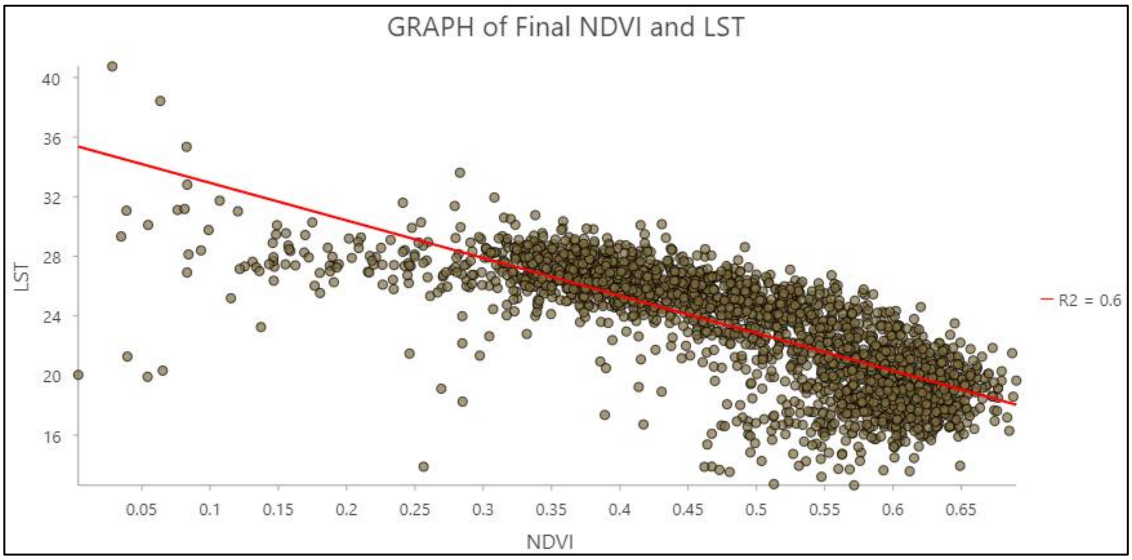

Fig. 17. Bi-plot of LST and NDVI for Sofia city

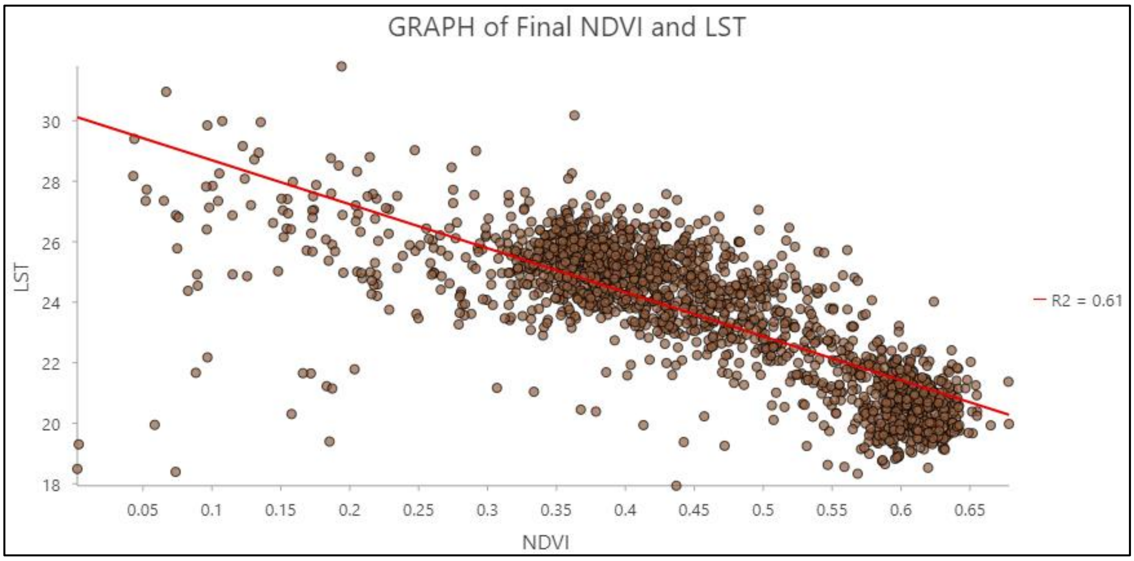

Fig. 18. Bi-plot of LST and NDVI for Varna city

The relationship between LST and NDVI values is linear. All cities' LST measurements negatively correlate with NDVI values (-0.7 and -0.5).

For example, as shown in Figure 17, the bi-plot of NDVI and LST variables for Sofia city indicates an existing negative correlation schematically. Indeed, the determination index's value is equal to 0.6, which corresponds to a negative correlation value equal to - 0,77459.

Conclusion

The present research finds negative correlations between LST values and vegetation index values. Concluding the stronger the NDVI values are, the fewer LST values become. Referring to our ROIs, we can approximately delimit urban green spaces as having the highest NDVI values inside urban areas. On the contrary, it is not probable that Urban Heat Islands contain urban green areas.

References:

Aflaki, A., Mirnezhad, M., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Omrany, H., Wang, Z. H., & Akbari, H. (2017). Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. *Cities*, *62*, 131–145. https://doi.org/10.1016/j.cities.2016.09.003

Ahmed Memon, R., Leung, D. Y., & Chunho, L. (2008). A review on the generation, determination and mitigation of Urban Heat Island. In *Journal of Environmental Sciences* (Vol. 20).

Sileos, G., Alexandridis, T., Gitas, I., & Perakis, K. (2013). Vegetation indices: Advances made in biomass estimation and vegetation monitoring in the last 30 years. *Geocarto International*, *21*(4).

Battista, G., Evangelisti, L., Guattari, C., Vollaro, E. D. L., Vollaro, R. D. L., & Asdrubali, F. (2020). Urban heat island mitigation strategies: Experimental and numerical analysis of a university campus in Rome (Italy). *Sustainability (Switzerland)*, *12*(19), 1–18. https://doi.org/10.3390/su12197971

Dimitrov, S., Popov, A., & Iliev, M. (2021). An application of the LCZ approach in surface urban heat island mapping in Sofia, Bulgaria. *Atmosphere*, *12*(11). https://doi.org/10.3390/atmos12111370

Espinoza-Molina, J., Acosta-Caipa, K., Chambe-Vega, E., Huayna, G., Pino-Vargas, E., & Abad, J. (2022). Spatiotemporal Analysis of Urban Heat Islands in Relation to Urban Development, in the Vicinity of the Atacama Desert. *Climate*, *10*(6). https://doi.org/10.3390/cli10060087

Faridatul, M. I., & Ahmed, B. (2020). Assessing agricultural vulnerability to drought in a heterogeneous environment: A remote sensing-based approach. *Remote Sensing*, *12*(20), 1–17. https://doi.org/10.3390/rs12203363

Galodha, A., & Gupta, S. K. (2021). Land surface temperature as an indicator of urban heat island effect: A google earth engine based Web-App. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *44*(M–3), 57–62. https://doi.org/10.5194/isprs-archives-XLIV-M-3-2021-57-2021

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*(1), 199–219. https://doi.org/10.1007/s41748-021-00268-9

Guha, S., Govil, H., Dey, A., & Gill, N. (2018). Analytical study of land surface temperature with NDVI and NDBI using Landsat 8 OLI and TIRS data in Florence and Naples city, Italy. *European Journal of Remote Sensing*, *51*(1), 667–678. https://doi.org/10.1080/22797254.2018.1474494

Huntington, J. L., Hegewisch, K. C., Daudert, B., Morton, C. G., Abatzoglou, J. T., McEvoy, D. J., & Erickson, T. (2017). Climate engine: Cloud computing and visualization of climate and remote sensing data for advanced natural resource monitoring and process understanding. *Bulletin of the American Meteorological Society*, *98*(11), 2397–2409. https://doi.org/10.1175/BAMS-D-15-00324.1

Kopecka, M., & Oťaheľ, J. (2016, June). MAPPING URBAN GREEN SPACES BASED ON REMOTE SENSING DATA: CASE STUDIES IN BULGARIA AND SLOVAKIA. *6th International Conference on Cartography and GIS*. https://scihub.copernicus.eu/dhus/

Laosuwan, T., & Sangpradit, S. (2012). Urban heat island monitoring and analysis by using integration of satellite data and knowledge based method. In *International Journal of Development and Sustainability Online* (Vol. 1, Issue 2). www.isdsnet.com/ijds

Macarof, P., & Statescu, F. (2017). Comparasion of NDBI and NDVI as Indicators of Surface Urban Heat Island Effect in Landsat 8 Imagery: A Case Study of Iasi. *Present Environment and Sustainable Development*, *11*(2), 141–150. https://doi.org/10.1515/pesd-2017-0032

Mills, G. (2008). Luke Howard and The Climate of London. *Weather*, *63*(6), 153–157. https://doi.org/10.1002/wea.195

Mustafa, E. K., Co, Y., Liu, G., Kaloop, M. R., Beshr, A. A., Zarzoura, F., & Sadek, M. (2020). Study for Predicting Land Surface Temperature (LST) Using Landsat Data: A Comparison of Four Algorithms. *Advances in Civil Engineering*, *2020*. https://doi.org/10.1155/2020/7363546

Nuruzzaman, Md. (2015). Urban Heat Island: Causes, Effects and Mitigation Measures - A Review. *International Journal of Environmental Monitoring and Analysis*, *3*(2), 67–73. https://doi.org/10.11648/j.ijema.20150302.15

Oke, T. R. (1982). The energetic basis of the urban heat island. In *Quart. J. R. Met. Soc* (Vol. 108, Issue 455).

Ouali, K., el Harrouni, K., Abidi, M. L., & Diab, Y. (2018). The Urban Heat Island phenomenon modelling and analysis as an adaptation of Maghreb cities to climate change. *MATEC Web of Conferences*, *149*, 02090. https://doi.org/10.1051/matecconf/201814902090

Papamanolis, N., Dimelli, D., & Ragia, L. (2015). *The Urban Heat Island Intensities in Greek cities as a function of the characteristics of the built environment*.

Rimal, B., Zhang, L., Keshtkar, H., Haack, B. N., Rijal, S., & Zhang, P. (2018). Land use/land cover dynamics and modeling of urban land expansion by the integration of cellular automata and markov chain. *ISPRS International Journal of Geo-Information*, *7*(4). https://doi.org/10.3390/ijgi7040154

Sarkar, A., & de Ridder, K. (2011). The Urban Heat Island Intensity of Paris: A Case Study Based on a Simple Urban Surface Parametrization. *Boundary-Layer Meteorology*, *138*(3), 511–520. https://doi.org/10.1007/s10546-010-9568-y

Schinasi, L. H., Benmarhnia, T., & de Roos, A. J. (2018). Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-analysis. *Environmental Research*, *161*, 168–180. https://doi.org/10.1016/j.envres.2017.11.004

Sheng, L., Tang, X., You, H., Gu, Q., & Hu, H. (2017). Comparison of the urban heat island intensity quantified by using air temperature and Landsat land surface temperature in Hangzhou, China. *Ecological Indicators*, *72*, 738–746. https://doi.org/10.1016/j.ecolind.2016.09.009

Takebayashi, H., & Moriyama, M. (2012). Relationships between the properties of an urban street canyon and its radiant environment: Introduction of appropriate urban heat island mitigation technologies. *Solar Energy*, *86*(9), 2255–2262. https://doi.org/10.1016/j.solener.2012.04.019

Wang, W., Liu, K., Tang, R., & Wang, S. (2019). Remote sensing image-based analysis of the urban heat island effect in Shenzhen, China. *Physics and Chemistry of the Earth*, *110*, 168–175. https://doi.org/10.1016/j.pce.2019.01.002

Xue, J., & Su, B. (2017). Significant remote sensing vegetation indices: A review of developments and applications. In *Journal of Sensors* (Vol. 2017). Hindawi Limited. https://doi.org/10.1155/2017/1353691

Yanev, I., & Filchev, L. (2017). *ASSESSMENT OF THE LAND SURFACE TEMPERATURE DYNAMICS IN THE CITY OF SOFIA USING LANDSAT SATELLITE DATA* (Vol. 29). http://landsat.usgs.gov/Landsat_Processing_Details.php