QUANTIFYING THE COOLING FUNCTION OF URBAN VEGETATION BASED ON IMAGE DATA ANALYSIS

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Abstract
Important regulatory ecosystem functions of vegetation include cooling functions. CICES (ver. 5.1) classifies this function as Regulation of temperature and humidity, including ventilation and transpiration cices (code 2.2.6.2). In urban environments, this is one of the most important biocultural functions of the landscape, which has been highly valued by humans in recent times.
However, for the expected benefit, it is not enough to know only its area but also the spatial distribution and the degree of undulations of a given function throughout the year. This paper presents an analysis of this function in Olomouc and its immediate surroundings. The results for the relative and absolute quantification of a) surface temperature change and b) Cooling Capacity Index are presented. Land surface temperature is the emitted thermal radiation from the ground surface or from the surface of tree canopies in vegetated areas. The urban cooling model (included in InVEST model) calculates a heat mitigation index based on shade, evapotranspiration and albedo, as well as distance from cooling islands. The results are related to the amount, type and distribution of vegetation as well as the population in each urban area.

Keywords: cooling function, satellite images, urban vegetation, Olomouc, spatio-temporal analysis

Introduction

Vegetation is an important factor in mitigation of UHI (Urban Heat Island), a phonomenon of significantly higher temperatures in urban areas (Mirzaei, 2015). Understanding vegetation and its ability to cool its surroundings through evapotranspiration (process of releasing water vapour into atmosphere) is an essential step in general heat mitigation (Stanhill, 2019). Quantifying cooling function is important for understaning urban climate and development of environmental and political strategies. This can be done through calulation of relevant characteristics such as Land Surface Temperature (LST) and Cooling Capaciy Index (CCI). LST refers to radiative temperature (temeprature based on amount of emitted solar radiation by an object) and is often different from air temperature (which refers to kinetic energy of air partciles (Meshesha et al., 2024). LST can be retrieved using thermal satellite imagery. Difference in land surface temperature values for objects (especially between vegetation and impervious surfaces) can reach up to several tens of degrees Celsius (Naserikia et al., 2023). CCI then refers to a ratio of actual cooling ability of an object compared to their potential (maximal) cooling ability in ideal conditions. This index was developed by Stanford University through Natural Capital Project which includes Urban Cooling Model (Sharp et al., 2018) (one of the charactericts calculated by this model is CCI). This study was done for city of Olomouc, one of the regional capitals of the Czech Republic with focus on urban greenery (parks).

Materials and methods

We calculated LST and CCI using Landsat 8 and Landsat 9 data with additional meteorological data from Czech Hydrometeorological Institute (CHMU) and meteorological data acquired by sensor under the supervision of the department (maximum and minimum air temperature, relative air humidity, wind speed, atmospheric pressure, incoming solar radiation). The satellite sensing days were scattered from March 2023 to the end of March 2024 (see Figure 5). Sensing days were based on amount of clouds which were checked visually. Small clouds or cloud shadows were filtered using Landsat Level 1 Quality Assesment Band. LST was calculated based on Avdan and Jovanovska (Avdan & Jovanovska, 2016), where BT stands for at-sensor temperature (˚C), λ is constant of 10.895, ρ is a constant of 1.438 and ε stands for LSE (Land Surface Emissivity).

$$LST = \frac{BT}{1 + \frac{(\lambda \times BT)}{1.438} \times \log(\varepsilon)} \quad (1)$$

CCI was then calulated with proportion of shade in the satellite pixel (S), albedo (α) and ETI (Evapotranspiration Index). All values were normalized to fit the scale from 0 to 1 compared to its maximal potential; e.g. 0.72 means the pixel shows 72 % of its maximal cooling capacity. Therefore the higher value of CCI the better cooling effect the pixel shows.

$$CCI = 0.6 \times S + 0.2 \times \alpha + 0.2 \times ETI \quad (2)$$

Results

Accoring to the graph (Figure 5) classes Vegetation and Meadows have the highest impact on the CCI with values differing frim 0.45 to 0.63 over the twelve months period. Both classes keep a steady trend after they peaked at the start of May 2023, with another smaller uprise in the Meadows classes in September. CCI values for agricultiral lands keep dropping in June due to (presumably) periodic works in the fiels. Artificial parts of the city keep, for the most part, significanlty lower CCI trend compared to all classes.

This changes during late autumn (October), when the values for agricultural classes also go down. A big drop can be seen between October and January for all classes, due to larger data gap which was caused by clouds covering the area of interest. The maps (Figure 6) show that lower values of CCI are located mostly on the water bodies and in places with high volume of built-up areas (mainly the inner city and areas around main railway as they are part of industrial development). Agricultural fields differ depending on individual crops and their growth phase.

These findings are based on tabular data (Table 1) and Landsat 8/9 imagery. We can conclude that the highest impact on CCI values is by the classes Vegetation and Meadows. Both classes peak in first half of May (likely due to plant and crop growth during spring) and are followed by a steady trend until September.

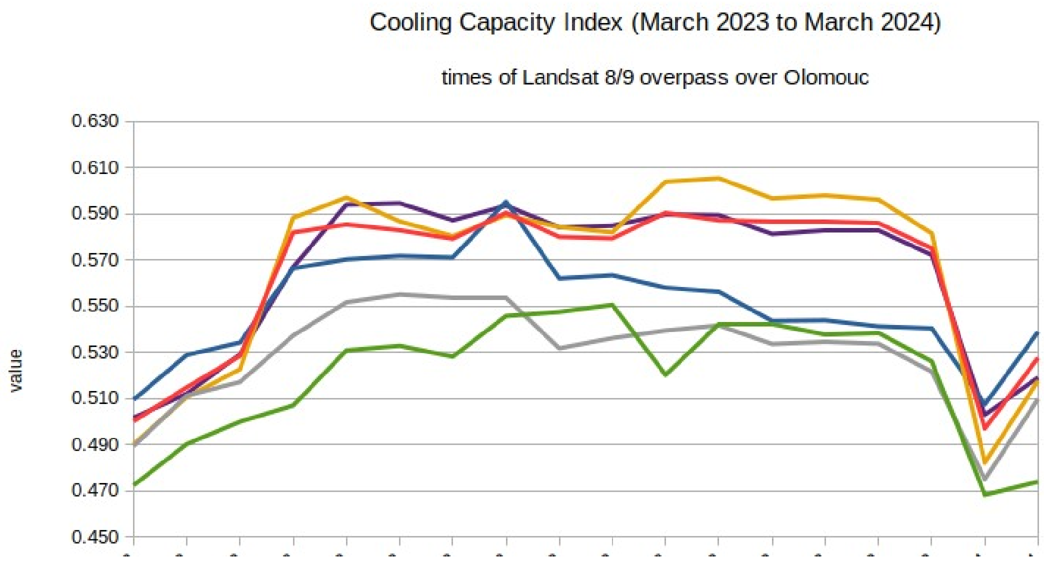

Fig. 5: CCI values through March 2023 to 2024 for biotope groups.

Discussion

The most significant habitat contributing to cooling capacity were proved to be classes vegetation and meadows with values ranging from 0.45 to 0.63. Both of the classes peak during May and mainintain a steady trend. The lowest CCI values, as presumed, were in class of aritifical areas (Ronchi et al., 2020). A significant gap in data was discovered in time period between October and January causing irregularities in the data due to presence of heavy clouds over the area of interest. The apparently relatively small between the CCI values is caused by averaging primary values. „Average“ is given due to thermal band spatial resolution. Although we have detailed terrestrial vegetation data (visible and infrared spectrum), which more accurately captured the landscape heterogeneity and allowed us to analyze homogeneous parts of the surface, it was necessary to use a coarser spatial resolution (100 m/pixel, scalable to 30 m (Lu et al., 2020)) to create heterogeneous segments (mix of habitat types) where values of surface types are averaged. However, for smaller areas (rural villages) this still can be a challenging spatial resolution to work with as the biotopes are smaller in size compared to the size of pixel. There are no non-commercial satellites with more precise resolution. Sentinel-2 data can be used, however the problem with this data is missing thermal bands. Thermal bands can be found in Sentinel-3 although its pixel is 1 km (Guzinski & Nieto, 2019), which makes it harder to work with on smaller areas. Understanding such dynamics is vital for several reasons. Heat stress caused by long periods of higher temepratures reflects poorly on life forms. As plants get heat stressed they are unable to photosysntetise and enrich the atmosphere with water vapour used to cool down the air. Heat mitigation is also important for human life, as long time heat exposure can have fatal consequences on health (Stanhill, 2019). These metrics can be used as part of local policy-making in environmental fields.

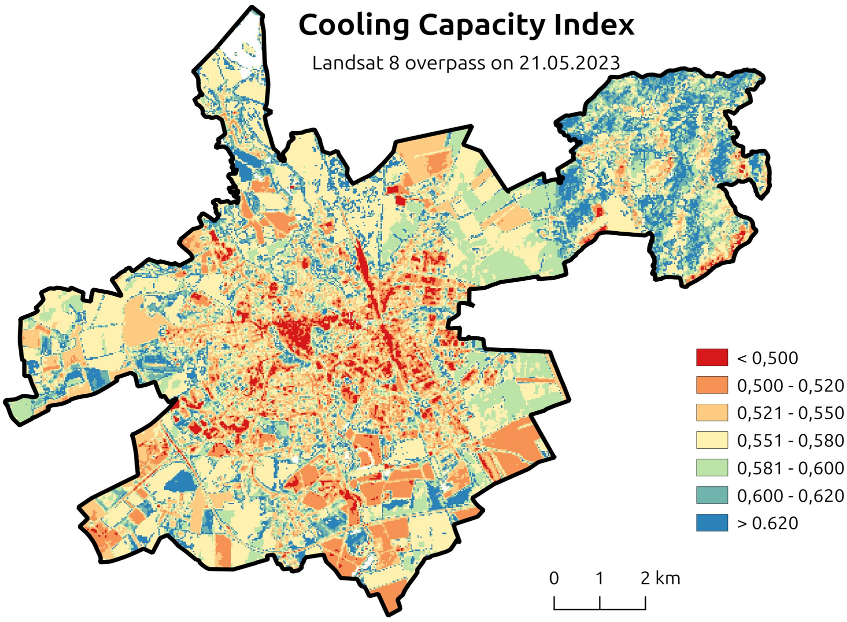

Fig. 6: An example map of chosen CCI values through March 2023 to March 2024 for Olomouc on 21st May 2023.

Conclusions

This study demonstrates vegetation and meadow habitat classes playing critical role in city cooling. These classes show highest CCI values. Agricultural seasonal work is shown to reduce vegetation cover and shading, influencing the cooling capacity. There are limitations for this type of studies due to coarse satellite resolution and clouds during autumn and winter. Using strategies and metrics such as CCI or LST can help to develop strategies which can be then used by local government to mitigate effect of Urban Heat Islands and to promote green spaces and create healthy and comfortable environment.

Tab. 1: Progress of CCI values through March 2023 to March 2024.

	HABITAT GROUPS					
	Meadows	**Water related**	**Vegetation**	**Other**	**Agricultural**	**Artificial**
20.03.2024	0.518	0.474	0.519	0.528	0.539	0.510
09.01.2024	0.482	0.468	0.503	0.497	0.507	0.475
21.10.2023	0.582	0.526	0.572	0.575	0.540	0.522
05.10.2023	0.596	0.538	0.583	0.586	0.541	0.534
27.09.2023	0.598	0.538	0.583	0.587	0.544	0.535
26.09.2023	0.597	0.542	0.581	0.586	0.544	0.534
11.09.2023	0.605	0.542	0.589	0.587	0.556	0.542
10.09.2023	0.604	0.520	0.590	0.590	0.558	0.539
09.07.2023	0.582	0.551	0.585	0.579	0.563	0.536
08.07.2023	0.584	0.548	0.584	0.580	0.562	0.532
22.06.2023	0.589	0.546	0.594	0.590	0.595	0.554
02.06.2023	0.580	0.528	0.587	0.579	0.571	0.554
29.05.2023	0.587	0.533	0.595	0.583	0.572	0.555
21.05.2023	0.597	0.531	0.594	0.585	0.570	0.552
05.05.2023	0.588	0.507	0.567	0.582	0.566	0.537
12.04.2023	0.523	0.500	0.529	0.529	0.534	0.517
19.03.2023	0.511	0.490	0.512	0.515	0.529	0.511
03.03.2023	0.490	0.472	0.502	0.500	0.509	0.489

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Souhrn

Tato studie zkoumala vliv vegetace na ochlazovací efekt ve městě Olomouc pomocí dat z družic Landsat 8 a Landsat 9 za období od března 2023 do března 2024. Výsledky ukazují, že luční porosty a ostatní vegetace mají nejvýznamnější vliv (CCI v hodnotách 0.45-0.63), zatímco zemědělská půda vykazuje kolísavou chladící kapacitu kvůli sezónním pracím. Jak bylo předpokládáno, umělé a zastavěné povrchy mají nejnižší schopnost ochlazovat. Studie potvrzuje zásadní roli vegetace pro snížení efektu tepelného ostrova a zdůrazňuje potřebu zachování zdravých vegetačních ploch a jejich případného rozšiřování v rámci urbanistických strategií pro zajištění tepelného komfortu obyvatel a příjemnějšího městského prostředí.

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