Assessing spatiotemporal distribution of the effectiveness of Blue-Green Infrastructure in mitigating the Urban Heat Island phenomenon in Wroclaw, Poland under the Digital Twin concept for spatial policy optimization

Grzegorz Budzik [1], Tomasz Kowalczyk [1], Piotr Krajewski [2], Monika Lebiedzińska [2], Agnieszka Soszyńska [3]

[1] Wroclaw University of Environmental and Life Sciences, Department of Environmental Protection and Development, Poland
[2] Wroclaw University of Environmental and Life Sciences, Institute of Spatial Management, Poland
[3] University of Leicester, Department of Physics and Astronomy, National Centre for Earth Observation, United Kingdom

Wrocław University of Environmental and Life Sciences

Ministry of Science and Higher Education
Republic of Poland

INTRODUCTION

Background:
Urban areas frequently experience higher temperatures than rural areas due to the urban heat island effect (UHI), which poses challenges during heat waves, particularly for vulnerable populations. Blue-green infrastructure (BGI) has been proposed as a solution to mitigate UHI effects, but its implementation faces financial and operational challenges. Optimizing the development of BGI, while considering both internal BGI factors and external factors related to urban morphology, is crucial for cost-effective implementation. The cooling properties of BGI, known as Urban Cool Island (UCI), generate lower temperatures than impervious surfaces, allowing for the extension of cooling zones beyond BGI boundaries through advection currents that affect nearby buildings. The characteristics of this extent, known as the high-cooling distance (HCD) and intensity (HCI) are critical for measuring cooling potential and creating urban design guidelines.

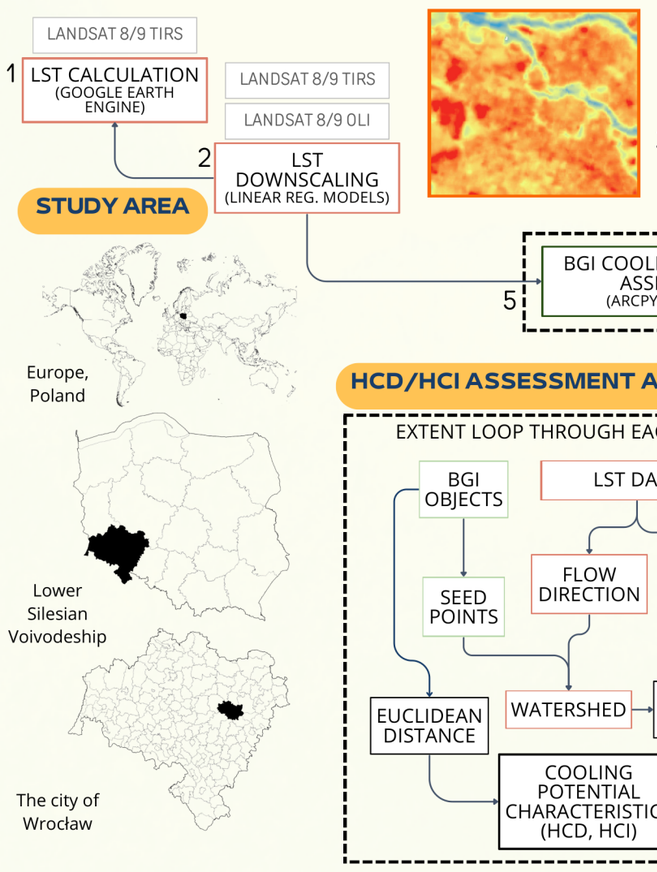
Research gaps:

- limited exploration of variability in cooling potential across different urban morphological features
- lack of consideration for additional characteristics such as Leaf Area Index (LAI) and BGI quality in remote sensing-related UCI extent studies
- scarcity of research on BGI's cooling potential in European contexts, including Poland, hindering practical planning activities
- lack of robust guidelines for BGI planning in the context of minimizing heat-related deaths
- variability in the methods used to delineate BGI objects in literature, with many studies relying on manual determination

AIM

Identification and assessment of factors that influence the specificity of BGI cooling potential concerning various local climate zones

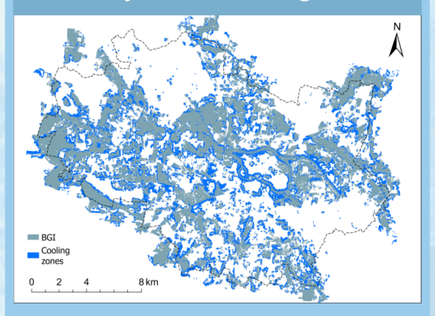
METHODS AND STUDY AREA



RESULTS

1. Assessment of BGI objects characteristics:

BGI objects and cooling zones



BGI CHARACTERISTICS

- Log area (AR)
- Log perimiter (PER)
- Log Landscape Shape Index (LSI)
- Log perimiter density (PD)
- Log BGI objects spatial density (BGID)
- Mean Leaf Area Index (LAI)
- Mean NDVI (NDVI)
- Canopy height 95 percentile (CH)
- Canopy cover (CC)

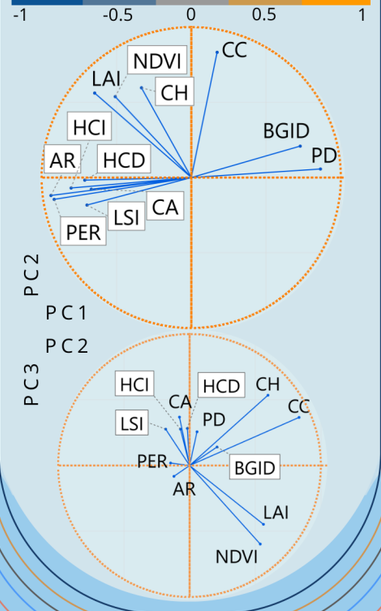
BGI COOLING POTENTIAL

- Max high-cooling distance (HCD)
- Max high-cooling intensity (HCI)
- Cooling area (CA)

2. Data redundancy reduction (PCA)

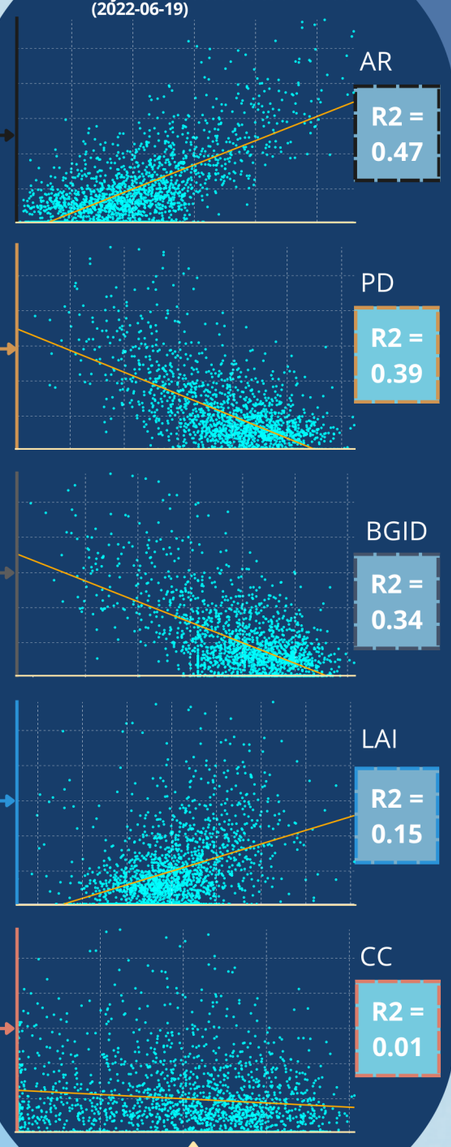
	AR	PER	LSI	PD	LAI	NDVI	CH	CC	BD	HCD	HCI	CA
AR		0,98	0,76	-0,92	0,53	0,30	0,27	-0,26	-0,73	0,57	0,69	0,60
PER	0,98		0,88	-0,81	0,47	0,25	0,29	-0,23	-0,70	0,55	0,68	0,61
LSI	0,76	0,88		-0,44	0,23	0,09	0,28	-0,12	-0,52	0,42	0,53	0,53
PD	-0,92	-0,81	-0,44		-0,60	-0,36	-0,21	0,29	0,70	-0,53	-0,63	-0,50
LAI	0,53	0,47	0,23	-0,60		0,82	0,27	0,16	-0,40	0,36	0,40	0,28
NDVI	0,30	0,25	0,09	-0,36	0,82		0,11	0,17	-0,24	0,14	0,15	0,10
CH	0,27	0,29	0,28	-0,21	0,27	0,11		0,53	-0,13	0,23	0,28	0,26
CC	-0,26	-0,23	-0,12	0,29	0,16	0,17	0,53		0,29	-0,07	-0,13	-0,08
BD	-0,73	-0,70	-0,52	0,70	-0,40	-0,24	-0,13	0,29		-0,46	-0,59	-0,52
HCD	0,57	0,55	0,42	-0,53	0,36	0,14	0,23	-0,07	-0,46		0,82	0,61
HCI	0,69	0,68	0,53	-0,63	0,40	0,15	0,28	-0,13	-0,59	0,82		0,68
CA	0,60	0,61	0,53	-0,50	0,28	0,10	0,26	-0,08	-0,52	0,61	0,68	

Pearson correlation coefficients (p<0.005):



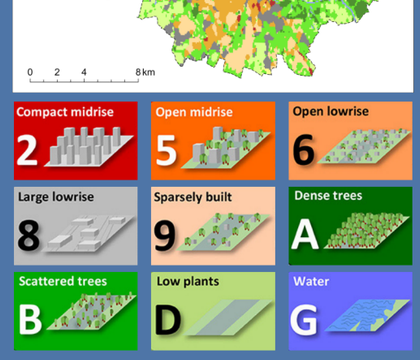
- Log area (AR)
- Log perimiter (PD)
- Log BGI objects spatial density (BGID)
- Mean Leaf Area Index (LAI)
- Canopy cover (CC)
- Max high-cooling intensity (HCI)

3. Statistical analysis of the relationships between BGI objects characteristics and HCI: (2022-06-19)



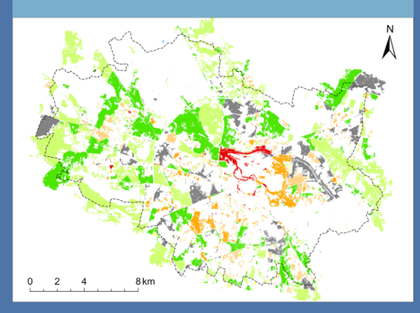
4. Creation of spatial distribution of local climate zones (Demuzere et al., 2021):

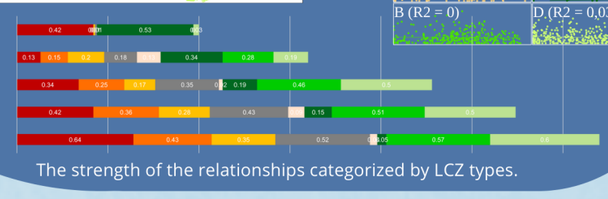
Local climate zones (LCZ)



5. Partitioning BGI objects based on the predominantly cooled LCZ type:

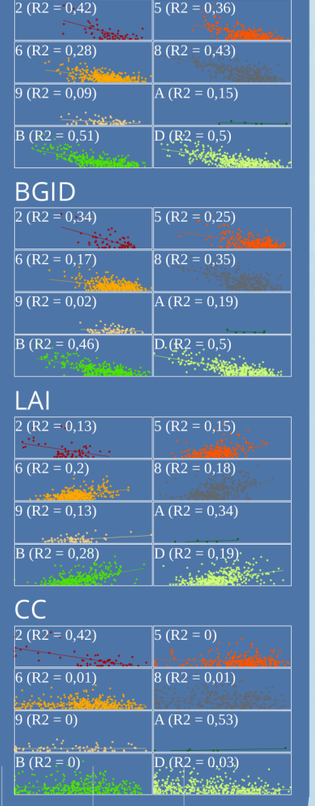
BGI's association with LCZ type



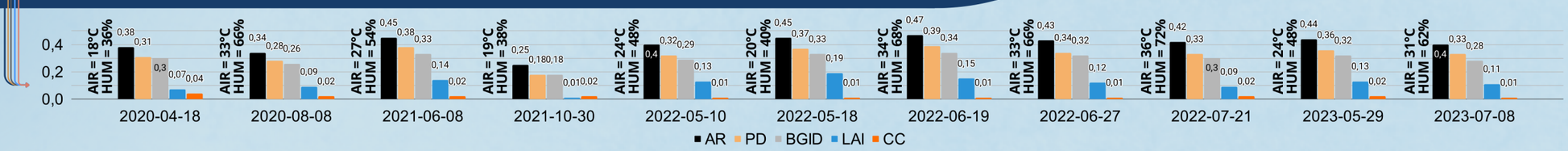


The strength of the relationships categorized by LCZ types.

6. Evaluation of the strength of the relationships according to LCZ types:



7. Time series analysis of R2:



	AIR	PRES	HUM
AR	0,34	0,06	-0,58
PD	0,32	0,10	-0,54
BGID	0,27	0,09	-0,61
LAI	0,17	0,20	-0,44
CC	-0,41	-0,03	-0,11

Pearson correlation coefficients between the characteristics of BGI objects and air temperature (AIR) and humidity (HUM) (p<0.005)

CONCLUSIONS

- In Wroclaw, the HCI is primarily affected by the area of BGI objects, followed by the perimeter density and the spatial density of objects.
- The strongest relationships between BGI characteristics and HCI strength were identified in LCZ 2 (compact midrise).
- The significance structure of individual characteristics in shaping HCI does not depend on external weather conditions and the time of data acquisition.
- The strength of HCI fluctuates over time, yet it remains unclear which weather conditions directly influence it.

DISCUSSION

Advantages:

- The study employs open data, making it transferable to other cities worldwide.
- The HCD/HCI assessment algorithm is universal, capable of processing diverse datasets with various resolutions.
- The method used to generate LCZ (Demuzere et al. 2021) facilitates the standardization of assessing the influence of urban morphology on the cooling potential of BGI objects, thereby enabling comparability with other cities worldwide.

Disadvantages:

- The results obtained are highly dependent on the method of development and downscaling of LST data.
- Due to the LST-SUHI approach, it is unclear whether the demonstrated relationships have a unique impact on the mitigation potential of BGI objects in the context of perceived air temperature levels.

CONTACT US

Grzegorz Budzik

email: grzegorz.budzik@upwr.edu.pl

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