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URBAN HEAT ISLAND RISK ASSESSMENT AND MAPPING IN THE SWEDISH RESIDENTIAL SECTOR

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Abstract

Although Scandinavian countries, including Sweden, are relatively less vulnerable to climate change, Swedish residential dwellings specifically those constructed before the 1975s are likely to be impacted by current extreme weather events (EWE) such as urban heat islands (UHI). This EWE can worsen air quality, increase heat-related illnesses (particularly among vulnerable populations), and raise maintenance costs and energy demand for cooling in buildings.

This study aimed to map UHI risk in Sweden's residential sector using a scenario-based analysis approach. Moderate Resolution Imaging Spectroradiometer (MODIS) Remote sensing (RS) imagery data (land surface temperature (LST)) and some statistical data (including the number of houses, building typologies, and characteristics) collected from the SCB (Statistics Sweden) and TABULA database are used. The overall UHI risk maps for Sweden are developed following the risk matrix approach, by weighting and aggregating the created maps for UHI hazard, building exposure, and vulnerability. Here, the geographical information system ArcGIS pro 3.1 was used to carry out the different spatial analysis tasks, including pre-processing of spatial data, developing required maps, and performing raster calculations.

The outcomes reveal a range of areas posing risks, with most high-risk zones situated in the southern and southeastern regions. Moreover, there is a discernible impact of the UHI on most of the buildings across Sweden constructed prior to the 1960s. Nevertheless, for structures built between 1961 to 1975, only those in the southern regions display potential susceptibility to the UHI. Furthermore, the western areas exhibit a low UHI risk.

Despite the limitation of data used, the findings of this study have practical implications, as they can help homeowners, renovation companies, and policymakers implement appropriate adaptation strategies. The approach used is comprehensive, easily applicable, scalable, and can be replicated anywhere, assisting in the development of climate-resilient buildings not only in Sweden but also in other regions.

Keywords: climate change, climate risk assessment, urban heat island, land surface temperature, adaptation, mitigation, resilience, sustainability.

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1 Introduction

Population growth and the expansion of the built environment by constructing new buildings and the development of urban infrastructure (transportation, roads, energy, and water…), the extensive use of different materials (including high inertia materials) and systems (air conditioners), have a big impact on the surrounding environment, such as the increase in land surface temperature (LST). Changes in surface properties of the urban environments significantly impact the local microclimate (Rocha and Holzkämper, 2023), and contribute to a temperature difference between urban and rural areas, which commonly referred to as an urban heat island (UHI) effect (Verichev *et al.*, 2023). In Sweden and Scandinavia, the temperature will increase more than the global mean, and the Swedish government has created model scenarios showing that the average temperature in Sweden will rise by 3−5 °C by the 2080s in comparison with the period 1960−1990 (Swedish Government, 2007). Regarding this context, Swedish residential dwellings specifically those constructed before the 1975s are likely to be impacted by extreme weather events (EWE) related to the increase in temperature such as heatwaves and UHI. UHI has adverse effects on human health, energy consumption, and air quality. UHI also influences the precipitation rate which can lead to water-based disasters such as flooding (Steensen *et al.*, 2022). Thus, it is critical to assess the risks associated with potential EWE to make informed renovation decisions.

Extensive research has been conducted to evaluate and map the risk of urban heat island (UHI) occurrence in various regions, encompassing both small and large populated cities. For instance, the work of Ranagalage et al. examined the spatial changes of urban heat island formation in the Colombo district, Sri Lanka (Ranagalage *et al.*, 2018). In the study of Verichev et al., the influence of the UHI effect on the energy performance of residential buildings is investigated in the city of Valdivia, Chile, during the summer period (Verichev *et al.*, 2023). Ibrahim investigated the urban LULC changes and their effect on LST in Dohuk City, Iraq using Landsat RS data and GIS (Ibrahim, 2017). In another study, Kumar et al. discussed the effect of LST on UHI in Varanasi City, India (Kumar *et al.*, 2021). UHI vulnerability and risk mapping in Helsinki, Finland is investigated in (Räsänen et al., (2019). A literature review on heat stress in indoor environments of Scandinavian urban areas is presented in (Kownacki *et al.*, 2019).

Highlighting the literature, it is observed that UHI is mostly affected by the change in LST, LULC, and urbanization. In addition, most of these studies used GIS and RS tools to assess and map UHI hazards and risks at the city level and applied to high-temperate areas. Although the stated studies provide useful information, there is still a need for assessing and mapping the UHI risk for multi-cities at the country level, and specifically in northern regions (such as Sweden) to assist policymakers and homeowners in making the appropriate decision in terms of adaptation or relocation or any action to respond to this undesirable phenomenon. It is also crucial to develop a comprehensive assessment method that is based solely on open-source data, and easy to replicate at any location.

This study aimed to map UHI risk in Sweden's residential sector using a scenario-based analysis approach. The main contributions of this work are (i) mapping UHI hazards, and buildings’ exposure across Sweden using remote sensing and statistical data respectively, (ii) assessing building vulnerability through a scenario-based analysis approach, and finally, (iii) Creating UHI risk maps for Sweden by integrating the resulting maps.

2 Materials and Methods

Sweden is in northern Europe and belongs to the Scandinavian region, characterised with four climate zones. The population of Sweden by 2021 was 10.42 million, and its overall surface area is 528,447 km² (SCB: Statistics Sweden (Statistiska centralbyrån)). The single-family houses (SFH) stock in Sweden includes 2 million buildings by 2022 (SCB), which contribute to high portion of energy consumption, and greenhouse gas emissions (GHG).

2.1 Method description and data collection

The geographical information system (GIS) tool ArcGIS pro 3.1 was used to carry out the different spatial analysis tasks, including preprocessing of spatial data, developing required maps, and performing raster calculations and analysis.

2.2 Calculation of LST and UHI Intensity

For the assessment and mapping of Land surface temperature (LST) and UHI hazard, brightness temperatures observed by the MODIS Remote sensing (RS) imagery data (covers the period 01-10 August,2022, and at 1000-m spatial resolution) are used (Pichierri, Bonafoni and Biondi, 2012). LST pattern is regarded as one of the most important indicators of the environmental consequences of land use/land cover change (Sahoo *et al.*, 2022). LST is calculated using Equation (1). Before applying this equation, different preprocessing tasks are performed (grouping images, clipping to Swedish area, and removing no data filled values).

$$LST(°C) = \mathrm{LST}_{MODIS}(°\mathrm{K}) \times \alpha - 273.15 \qquad (1)$$

Where α is a corection factor, its value is 0.02 (as in the MODIS data description by NAZA).

UHI intensity is calculated based on LST using Equation (2) as follows (Rahman *et al.*, 2022).

$$UHI = \frac{LST(°C) - LST_{Min}(°C)}{SD} \qquad (2)$$

Where SD is the standard deviation of LST, and LST_{Min} is the minimum value of LST at the investigated area. The map for UHI hazard is created using Raster calculator tool in ArcGIS Pro.

2.3 Assessing Exposure and building vulnerability

Concerning the exposure map, collected statistical data from the SCB database including the number of single-family houses (SFH) in each Swedish county (21 counties) are used. Here, the number of SFH is categorized into two classes according to the buildings' typologies provided on the TABULA website. Thus, the maps of the exposure for each building typology are developed. For the evaluation of building vulnerability of each typology, a simple assessment method was applied awing to the lack of detailed data about the buildings stock for all of Sweden. As the influence of the UHI effect on the energy performance of residential buildings is demonstrated in several studies as in Verichev et al. (2023), here, the building vulnerability is assessed based on the overall building U value. The U values of SFH in Sweden for the two investigated typologies are presented in Table 1.

TABLE I. *Characteristics of building typologies (from TABULA database)*

Parameter	Building class (built period)	
	Class1 (1920-1960)	*Class2 (1961-1975)*
Roof Uvalue (W/m².°C)	0.29	0.21
External wall Uvalue (W/m².°C)	0.6	0.31
Overal Uvalue (W/m².°C)	0.445	0.26

[a.] *The overall U value for the building is concluded by calculating the average of the U Values of the roofs and external walls.*

2.4 Assessment and mapping of Urban heat island risk

Finally, the overall UHI risk maps for Sweden are developed, by weighting and aggregating the created maps for UHI hazard, exposure, and vulnerability using the raster calculator tool. Before calculating the UHI risk, a reclassification of all the values for the vulnerability, exposure and hazard was performed to values between 1 and 10, with 1 denoting lower associated risk and 10 denoting higher associated risk. Expected values of the risk also lie between 1 and 10 for each region. Equation 3 was used in the raster calculator tool in ArcGIS Pro to find the

$$\boldsymbol{UHI\ risk} = \textbf{UHI hazard} \times \mathbf{0.3} + \textbf{Exposure} \times \mathbf{0.35} + \textbf{Vulnerability} \times \mathbf{0.35} \qquad \textbf{(3)}$$

A higher weight has been assigned to the vulnerability and exposure than the hazard. This is because currently the UHI hazard's frequency and tensity in Sweden are mostly moderate to low compared to the exposure (large number of elderly people) and building vulnerability (aged buildings without renovation)

3 Results and discussion

After preparing all the required data, and performing the different calculations, we assessed the vulnerability and created the maps for exposure, UHI hazard, and risk. Figure 2 presents the obtained maps for LST and UHI hazard. Figure 4 shows the maps of UHI risk across Sweden for each building class. The created maps for LST and UHI hazard are interesting and brings valuable insights, and the obtained values are acceptable compared to those presented in other studies (which validated our results). The maps show huge difference between the northern and southern locations. The southern regions have high LST and UHI intensity compared to the other regions. This can be demonstrated by the higher temperature in southern regions than in the north. Despite being at the same latitude, a considerable difference is observed between eastern coastal border and western border of Sweden. This can be the result of land cover difference and infrastructure density. It is also the effect of exposure, as the greatest number of SFH are in eastern regions than in the western regions. And as mentioned above, Sweden has a coastline on the eastern side and the Scandinavian Mountain range on the western border with Norway. This landscape variety could have an important impact on both the exposure as well as LST.

The results also show a variety of risk areas and most of the high-risk locations are in the southern and southern east areas of Sweden. It is also found that the buildings built between 1920-1960s are affected by UHI at most of the Swedish regions. However, for the buildings built between 1961-1975s, only those located in the southern regions are potentially affected by UHI phenomenon. It is also seen that the western areas present low risk to UHI. We can conclude that coastal areas in Sweden are the most vulnerable areas to UHI, and other water based extreme events. It is crucial to set urgent adaptation strategies in these regions, as the intensity of EWE are increasing continuously and can lead to even water-based disasters such as flooding (as the effect of UHI on precipitation is demonstrated in some other studies), which will affect the ecosystem, infrastructure, and most vulnerable peoples. We can conclude that coastal areas in Sweden are the most vulnerable areas to UHI, and urgent response should be undertaken to avoid disasters and its potential impacts.

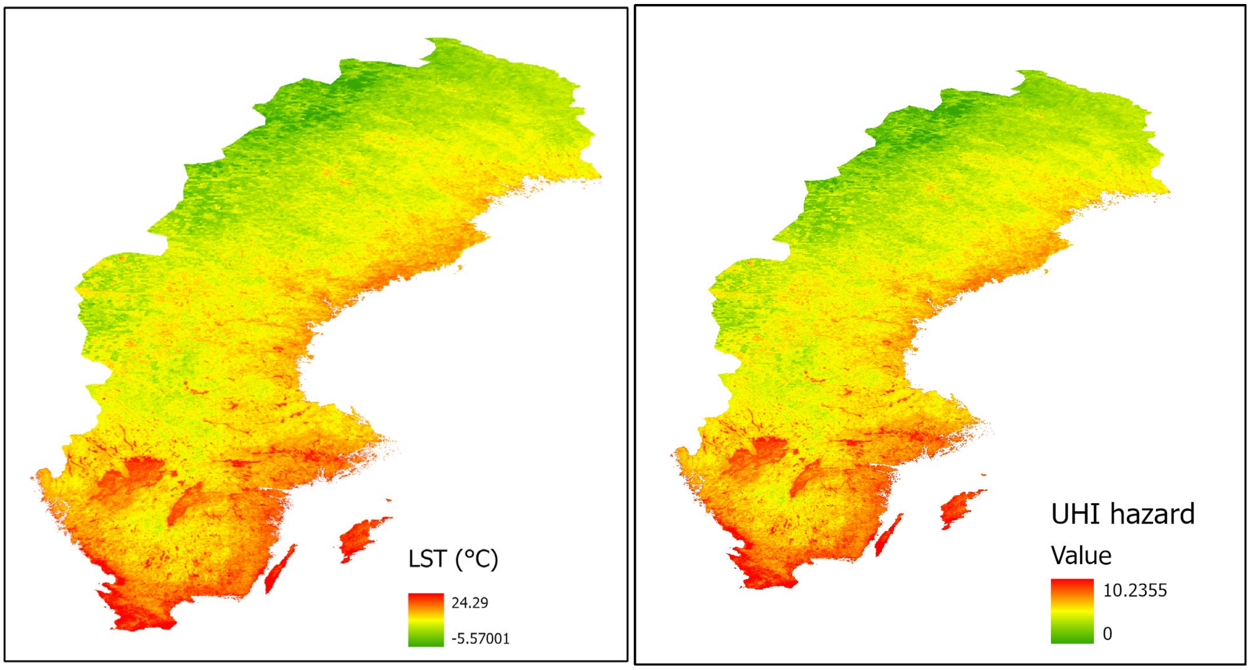

FIGURE 2:

The map of LST and UHI intensity

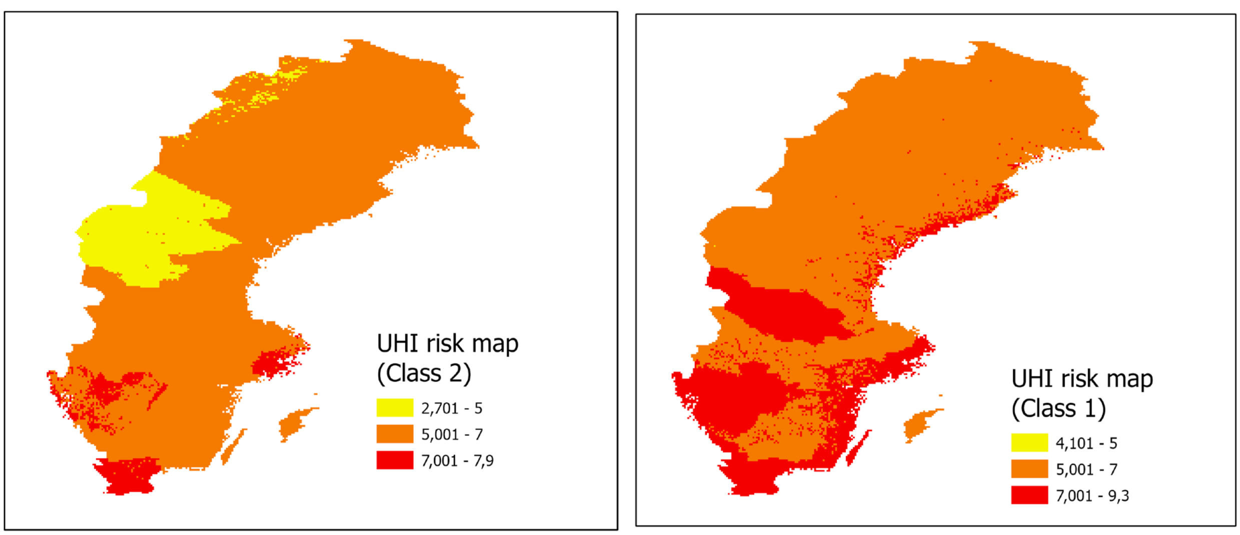

FIGURE 3:

The UHI risk maps for each building class

4 Conclusion

This paper provides a scenario-based method for assessing and mapping UHI risk across the Swedish residential sector. The results show a variety of risk areas and most of the high-risk locations are in the southern and southern east areas of Sweden. It is also seen that the western areas present a low risk to UHI. It is also demonstrated that the buildings built before the 1960s are likely to affected by current extreme events and this will be increased if no adequate adaptation measures are taken specifically with the continues increase in heat intensity globally. We can conclude that coastal areas in Sweden are the most vulnerable areas to UHI, and urgent response should be undertaken to avoid disasters and its potential impacts. Despite the limitation of data used (as we didn't consider other vulnerability factors including social vulnerability and other building information), the findings of this study have practical implications, as they can help homeowners, renovation companies, and policymakers implement appropriate adaptation strategies. The approach used is comprehensive, easily applicable, scalable, and can be replicated anywhere, assisting in the development of climate-resilient buildings not only in Sweden but also in other regions.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Charafeddine M. wrote the first draft, collected the data and created all the maps and figures with input from Brijesh M. and Shashwat S. All authors discussed and reviewed the content of the manuscript.

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