Ethiopia

Mapping the urban overheating hazard and its driving factors in Addis Ababa

Case study prepared by:

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Focus

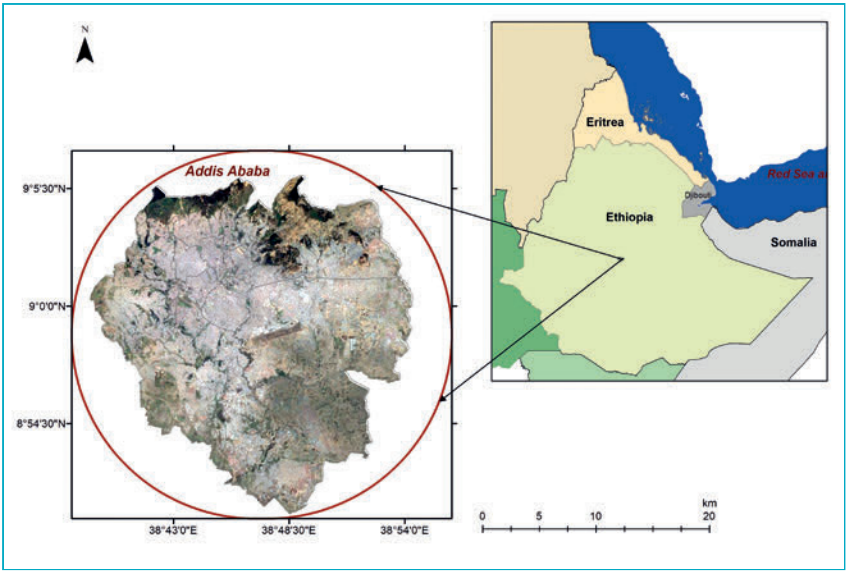
Global warming and the growth of cities are causing dramatic rises in surface temperatures in urban landscapes. The consequence is urban overheating, a global phenomenon in which urban areas exhibit significantly higher temperatures than surrounding rural areas.

The primary health risks of urban overheating are heat stress, which in turn causes increased heart rate and blood pressure, as well as cardiovascular events such as heart attacks and strokes (Mittal and Gupta, 1986). Urban overheating also endangers mental well-being, causing anxiety and sleep disturbances. Vulnerable populations are particularly at risk, such as the elderly, those with pre-existing cardiovascular conditions and children (Diniz *et al.*, 2020). Outdoor workers and individuals with lower socioeconomic status often endure heightened exposure to urban overheating due to limited access to cooling infrastructure and green spaces. This unequal distribution exacerbates health risks and further widens health inequalities (Gouveia *et al.*, 2022).

Project overview

Located in the central Ethiopian highlands, Addis Ababa is the country's capital and largest city (Figure 1). It is divided into ten sub-cities, each with its own administration (Table 1).

Figure 1: Map of Addis Ababa city



It has a subtropical highland climate with two main rainy seasons: from June to September and February to April. Rainfall during the rainy season is generally moderate with occasional downpours, while the rest of the year there is little to no rainfall. However, like many cities in the developing world, Addis Ababa faces numerous challenges related to urbanization, including the urban heat island effect (Degefu *et al.*, 2021).

The city's population has grown significantly since 1950, with a current growth rate of around 4.4%. Table 1 shows each sub-city's population growth between 2007 and 2022. Most areas of the city are vulnerable to overheating and the increasing impacts of heat exposure on the population include the spread of vector-borne diseases, respiratory illnesses and heat-related ailments.

Sub-cities of Addis Ababa	2007 population	2022 population
Addis Ketema	255,372	359,735
Akaki Kaliti	181,270	255,348
Arada	211,501	298,044
Bole	308,995	435,421
Gulele	267,624	377,032
Kirkos	221,234	311,765
Kolfe Keraniyo	428,895	604,226
Lideta	201,713	284,208
Nefas Silk	316,283	445,683
Yeka	346,664	488,537
Total Population	2,739,551	3,859,999

Table 1: Addis Ababa city population by sub-city, 2007 and 2022 (Source: https://www.citypopulation.de/en/ethiopia/admin)

Mapping the urban overheating hazard and understanding its driving factors are essential to protecting and improving human health. By leveraging advanced mapping techniques and analysing the spatial distribution of land surface temperature, policy makers and urban planners can identify the worst-affected areas and implement targeted strategies to mitigate risks (Wyrwa and Chen, 2017).

The research objectives in this study, therefore, are to:

1. Map the spatial distribution of urban overheating in Addis Ababa;
2. Identify and analyse the driving factors contributing to urban overheating;
3. Develop recommendations for urban planning and public health interventions to mitigate the urban overheating hazard.

Team

The research project was initiated and designed by Seyoum Melese Eshetie of the Space Science and Geospatial Institute of Ethiopia. The Land Development Bureau and Addis Ababa City Health provided heat hazard data and information.

Method

Urban overheating hazard maps are powerful tools for identifying areas at higher risk of heat-related health impacts. By integrating geographical information systems (GIS) and remote sensing technologies, these maps provide detailed spatial data on the distribution of heat within urban areas. This information is crucial for identifying vulnerable populations and implementing targeted interventions to protect public health during heatwaves.

Satellite-derived urban overheating data can also be used in combination with other environmental and socioeconomic data to develop heat vulnerability maps. These maps identify areas and populations most at risk from heat hazards based on factors such as land cover, population density and socioeconomic indicators.

Understanding the driving factors behind urban overheating is equally crucial, and analysing these factors can identify areas at risk and enable targeted interventions that reduce urban overheating effects (Huang *et al.*, 2019).

Data sources

Landsat data from the NASA Earth Data portal (https://lpdaac.usgs.gov) were used to derive urban overheating, normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), normalized difference water index (NDWI) and elevation. Additionally, climate data (air temperature and rainfall) were obtained from WorldClim (https://www.worldclim.org) while population density data has been acquired from WorldPop (https://www.worldpop.org).

Workflow

1. Landsat imagery of the study area was calibrated to correct for atmospheric effects and distortions. These correction procedures were implemented to ensure consistency and accuracy in the calculations and to extract relevant information such as land cover classification and vegetation indices.
2. Using established algorithms, thermal band data and spatial analysis techniques were used to identify areas at risk of urban overheating and generate thematic maps to visualize the spatial distribution of the phenomenon and its drivers.
3. Regression analysis (Koenker Statistic and Geographically Weighted Regression (GWR)) was then applied to model the relationship between urban overheating and the identified drivers (taking spatial and temporal variations into account).
4. Findings from the analysis were interpreted to understand the drivers of land surface temperature and their implications for urban overheating.
5. Finally, the findings from the study were communicated to public health officials, policy makers and urban planners to inform decision making processes and develop effective mitigation strategies.

Results

Hotspot identification

The urban overheating pattern and spatial distribution information extracted from the NASA Landsat data is shown in Figure 2. The analysis reveals hotspot zones in many parts of the city. The sub-cities of Addis Kalema, Arada and Lideta exhibit the highest vulnerability to urban overheating, with significant populations at risk. Gulelie, Nifas Silk and Akaki Kality follow closely as the next most vulnerable areas. Bole and Yeka are identified as the sub-cities with the third most vulnerable populations.

Driving factors

Examination of relationships between urban overheating and explanatory variables reveal significant relationships with regards to air temperature, rainfall, built-up areas (NDBI), elevation, vegetation (NDVI) and population density. The NDWI (water) coefficient has a negative value of -1.51, indicating that areas with higher water content tend to have lower land surface temperatures. This finding aligns with previous research that has highlighted the cooling effect of water on land surface

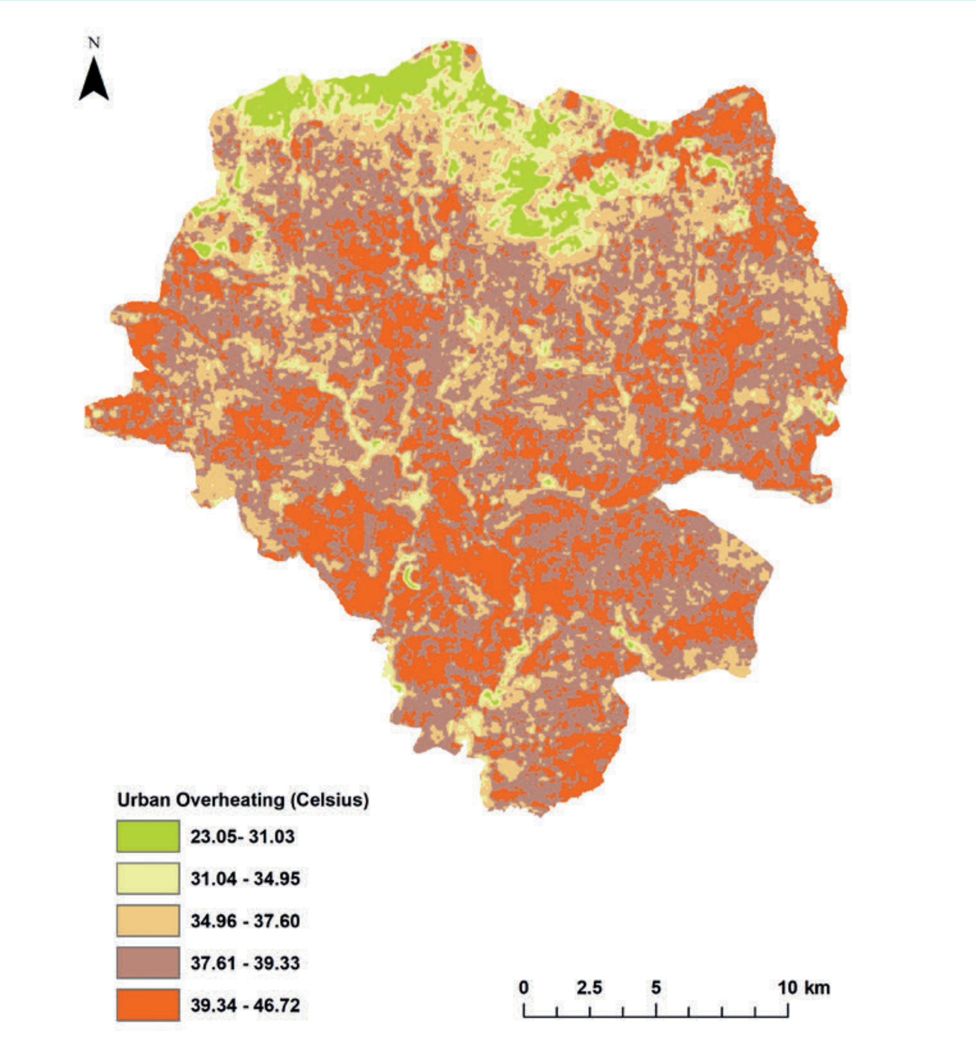


Figure 2: Map of the urban overheating pattern across Addis Ababa

temperature. Results are visually depicted in Figures 3a-c, which show that whereas there is a positive correlation between urban overheating and air temperature, urban overheating generally declines as either NDVI (vegetation cover) or elevation increase. The findings have important implications for land and urban planning and can inform efforts to mitigate the impact of urbanization and climate change on land surface temperature using adaptations such as tree planting.

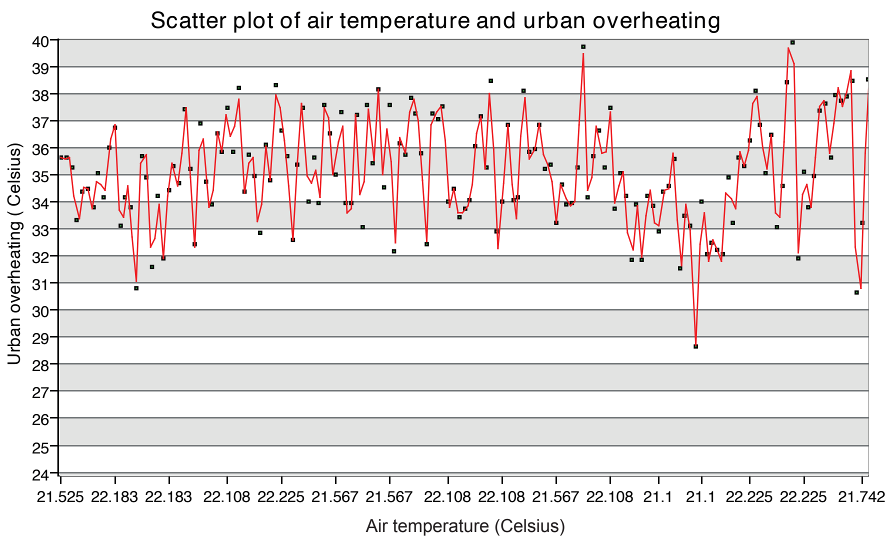


Figure 3a: Scatter plot graph showing positive correlation between air temperature and urban overheating

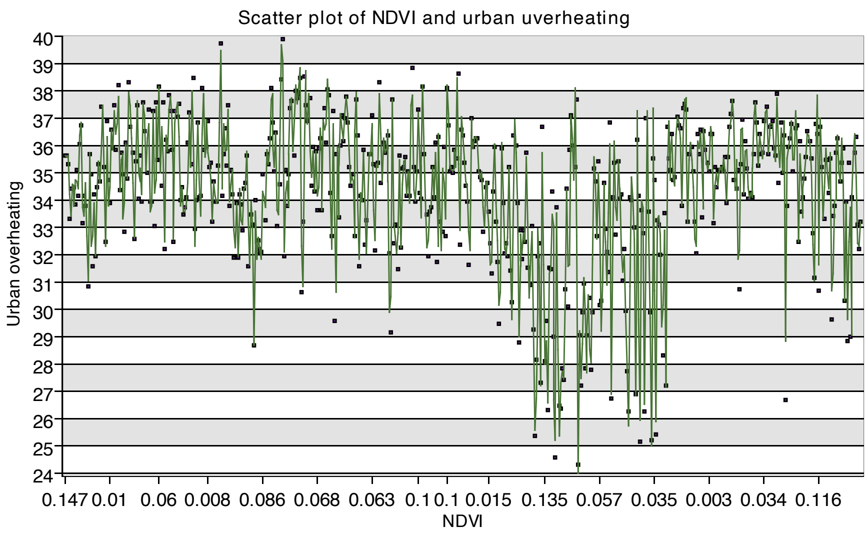


Figure 3b: Scatter plot graph showing that urban overheating declines as NDVI increases

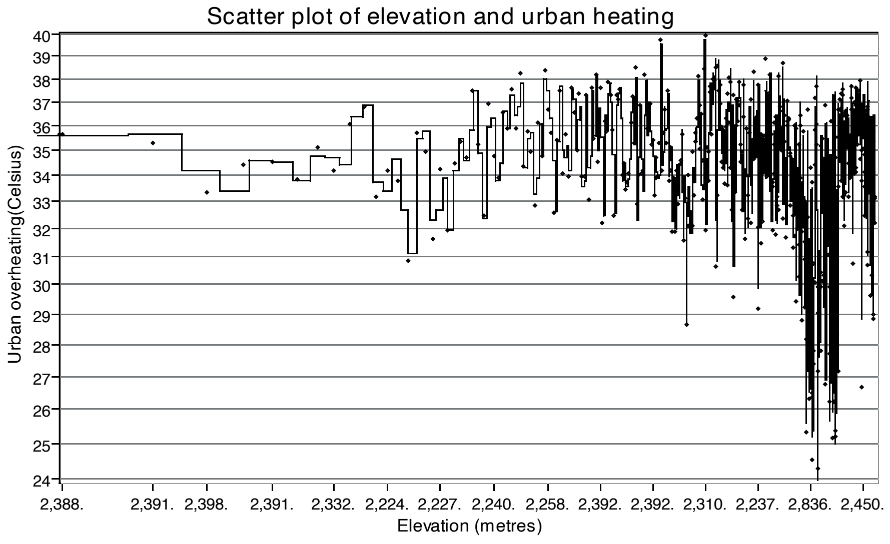


Figure 3c: Scatter plot graph showing that urban overheating declines as elevation increases

Regression models

The Koenker Statistic was employed in regression models to check the strength and reliability of the relationship variables in the study. In this case, non-stationarity was detected. Non-stationarity occurs when statistical properties of a process change over time. To account for this, an alternative model was required, and Geographically Weighted Regression (GWR) was used to rationalize local variations in the data.

GWR is a powerful analysis technique used to model spatially varying relationships between dependent variables and multiple explanatory variables. In this case, the dependent variable is urban overheating, and the multiple explanatory variables are air temperature, rainfall, built-up areas (NDBI), elevation, vegetation cover (NDVI), water (NDWI) and population density. The GWR values in this study indicate a significant spatial variability of relationships (Figure 4), meaning that each of these variables has an impact on urban overheating.

End-users

Health officials, policy makers and urban planners are the primary end-users of this study. Ongoing engagement with end-users provides them with opportunities to

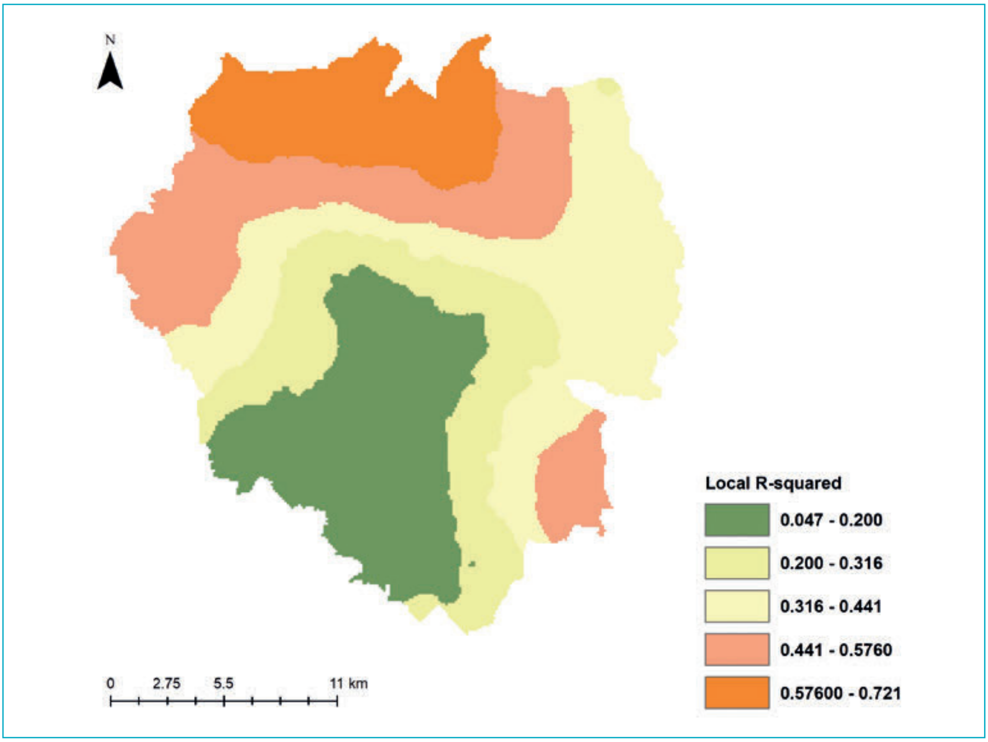


Figure 4: Geographically weighted regression (GWR) result indicated a significant spatial variability of relationships between urban overheating and its driving factors

suggest additional study questions and empowers them to make informed decisions and take appropriate actions based on the study's findings and the following recommendations:

1. *Urban greening initiatives (Addis Kalema, Arada and Lideta)*
   Increase green spaces such as parks, gardens and tree-lined streets. Green areas act as natural coolants, reducing the urban heat island effect and providing shade and cooling.
2. *Cool roof programmes (Addis Kalema, Arada and Lideta)*
   Implement cool roof programmes that promote the use of reflective and heat-reflecting materials for buildings. This will help reduce the amount of heat absorbed by rooftops and subsequently lower indoor temperatures. Additionally, incentivize the use of cool roof technologies through tax breaks or subsidies for building owners.

3. *Heat-resilient infrastructure*
   Incorporate heat-resilient design strategies into infrastructure planning and development. This includes using heat-reflecting materials for roads and pavements, designing buildings with effective ventilation systems and integrating green infrastructure, such as green roofs and vertical gardens, to provide natural cooling.
4. *Urban heat island monitoring and mitigation*
   Establish a comprehensive urban overheating monitoring system to identify hotspots and areas with increased vulnerability to extreme heat. Use the results of this research to prioritize interventions and allocate resources effectively. Implement heat mitigation strategies, such as cool pavements and urban shading structures, in identified high-risk areas.
5. *Public awareness and education*
   Launch public awareness campaigns to educate residents about the health risks associated with urban overheating and the importance of adopting heat mitigation measures. Collaborate with local community organizations and schools to promote sustainable practices, such as water conservation and tree planting.
6. *Collaboration and partnerships*
   Foster collaboration between public health agencies, urban planners, environmental organizations and community stakeholders to develop a holistic and bi-directional approach to address urban overheating. Create interdisciplinary task forces to ensure coordination and synergy between various sectors.

By implementing these recommendations, policy makers can work towards creating a cooler and healthier urban environment in Addis Ababa.

Lessons learned

While the study provided valuable insights into the health impacts of climate change and urban overheating, it is important to acknowledge its limitations. One notable limitation is that there may be other factors in addition to the explanatory variables that contribute to urban heat patterns. For instance, the study primarily examined the vulnerability of sub-cities based on population density and urban characteristics. Additional variables such as socioeconomic factors, infrastructure quality, or access to healthcare may also be relevant. By including them, future studies might provide a more nuanced analysis, allowing for a better assessment of the impacts and potential mitigation strategies.

Furthermore, the study focused on a specific geographical area, and the findings may not be directly applicable to other regions with different climate conditions or urban settings. It would be beneficial for future research to explore the generalizability of the findings across different contexts to ensure a more comprehensive understanding of the health impacts of climate change. Finally, additional analysis using spatial regression models or kernel density estimation, could also be used to uncover the causal factors behind land surface temperature hotspots.

Overall, however, this localized analysis highlights the need for targeted interventions and policies to mitigate the negative effects of urban overheating on human health and promote the development of sustainable and resilient urban environments.

Acknowledgements

Maps and graphs were created by the author except where another source is indicated

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