Abstract

In recent decades, population growth and industrialization has prompted a global increase in proportion of population living in urban areas. Currently, 55% of the world population and 83% of the US population are urban. Consequently, the resulting land transformations have caused significant ecological, including flash flooding, stormwater erosion, water quality impairments, and urban heat island (UHI) effect and globally in the form of increased greenhouse gas emissions and climate change. The UHI effect is exacerbated by urban sprawl, increased impervious surfaces, and poor land development policies. Developing any mitigation measures requires a better understanding of the spatial patterns of UHI and the socioeconomic makeup of the area that are most impacted by this phenomenon. In order to tailor mitigation measures, identifying which socioeconomic groups are most vulnerable to urban heat island phenomenon is crucial. The present study focuses on calculating temperature values across the City of Greenville, South Carolina using Landsat Satellite data, and comparing it with demographic makeup of the area based on US Census data. Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) were calculated and analyzed using GIS. Results show that 37% of all census tract numbers within the study area experience surface temperatures ranging from 27°C to 5°C above the average temperature of the city. Of these neighborhoods, 72% of them have a median household income below $40,000 a year. Included in these neighborhoods are historically disadvantaged populations that are also most vulnerable to the effects of UHI. Results from this study can help local government mitigate measures, such as increasing tree plantation, reducing impervious surfaces, and promoting local innovation in green roofing practices.

Introduction and Background

In recent decades, the global expansion of urban development has prompted the world’s population to shift away from living in rural areas. Currently, 55% of the global population and 83% of the US population live in urban areas. However, the coupled impacts of climate change and rapid urbanization is likely to have negative health impacts on human and environmental well-being. These factors can be contributed to or exacerbated by the phenomenon of urban heat island (UHI) effect which is expected to worsen as climate change and rapid urbanization continue to increase (Heaviside et al., 2017). Urban heat island effect (UHI) is defined by higher air and land surface temperature (LST) in urban areas in comparison to surrounding rural areas, generated by high levels of near-surface energy emission, solar radiation absorption ground objects or materials, and low evapotranspiration (Guha et al., 2018). The significance of conducting research within this study area is that the city of Greenville has experienced rapid urban growth in the last 10 years and there has yet to be formal research conducted for this area concerning urban heat island effect and associated social implications. Studying UHI has become increasingly important, not only in terms of understanding urban development impacts the natural environment, but also as a tool for mitigating UHI and improving the adaptive capacity and heat equity of communities. Information regarding how previous urban development may have an impact to local citizens in both environmental and social aspects is critical for creating comprehensive future urban planning for pro-longed urban well-being.

In this study, LANDSAT 8 OLI/TIRS C1 Level-1 satellite data from 2016 to 2020 was retrieved to calculate land surface temperature (LST) from the thermal infrared sensor (TIRS) band 10. Bands 4 and 5 were used to calculate the normalized difference vegetation index (NDVI) and bands 5 and 6 were used to calculate the normalized difference built-up index (NDBI). U.S. Census block level data was used to understand local demography within the study area in order to identify vulnerable socioeconomic groups to urban heat island effect. All calculations and analysis was done through use of GIS.

We would like to thank Furman University’s Office of Undergraduate Research for funding this research and many opportunities to expand my skills and understanding of GIS as it applies to urban sciences and sustainability. We also would like to acknowledge the faculty at the Department of Earth, Environmental, and Sustainability Sciences for their support, enthusiasm, and dedication to their students for them to be able to complete their research successfully. A special thanks to many student peers who have helped review this research at various stages to make it better.

Results

The highest mean surface temperatures were commonly distributed in the western region of the city, with an average temperature range of ≥ 27.49°C to ≤ 31.52°C Celsius. Whereas the lowest mean surface temperatures were commonly distributed in the eastern region of the city, with an average temperature range of ≤ 23.03°C to ≤ 27.49°C Celsius across the central region of the city, with an average temperature range of ≤ 27.49°C to ≤ 31.52°C Celsius. Results show that land surface temperatures above 26.94°C defined in this study as, Urban Heat Island (UHI) effect. Areas where NDVI is 0 to 1, NDBI is 0 to 1 which correlates to these areas having a higher land surface temperature on average, specifically in the West and West-central regions of Greenville. This is indicative of how increased impervious surfaces without sufficient vegetation for cooling which can contribute to higher land surface temperatures and UHI effect (Macarof et al., 2017; Guha et al., 2018). Results indicate UHI effect is experienced across all racial demographics, those that have a median household income below $40,000 correlates with higher land surface temperatures on average. In addition, this socio-economic group correlated with lack of sufficient presence of vegetation, which could contribute to higher LST (Macarof et al., 2017). This could be indicative of underlying socio-economic inequalities which exist in the city of Greenville, SC (Voelkel et al., 2018).

Despite several trends found between land use and land change indices and land surface temperatures, this study did not find as strong of a relationship between land surface temperature and demographic data as expected. This could be due to the scale of the study, as the census data is aggregated to represent such a large area that it is not quite reflecting the ground reality and disparities as well. Further exploring the demographic data at block level might reveal more realistic patterns and relationships.

Discussion

The highest mean surface temperatures were commonly distributed in the western region of the city, with an average temperature range of ≥ 27.49°C to ≤ 31.52°C Celsius. Whereas the lowest mean surface temperatures were commonly distributed in the eastern region of the city, with an average temperature range of ≤ 23.03°C to ≤ 27.49°C Celsius. Across the central region of the city, with an average temperature range of ≤ 27.49°C to ≤ 31.52°C Celsius. Results show that land surface temperatures above 26.94°C defined in this study as, Urban Heat Island (UHI) effect. Areas where NDVI is 0 to 1, NDBI is 0 to 1 which correlates to these areas having a higher land surface temperature on average, specifically in the West and West-central regions of Greenville. This is indicative of how increased impervious surfaces without sufficient vegetation for cooling which can contribute to higher land surface temperatures and UHI effect (Macarof et al., 2017; Guha et al., 2018). Results indicate UHI effect is experienced across all racial demographics, those that have a median household income below $40,000 correlates with higher land surface temperatures on average. In addition, this socio-economic group correlated with lack of sufficient presence of vegetation, which could contribute to higher LST (Macarof et al., 2017). This could be indicative of underlying socio-economic inequalities which exist in the city of Greenville, SC (Voelkel et al., 2018).

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Literature Cited

• Currently 55% of the global population and 83% of the US population live in urban areas.  
  – the coupled impacts of climate change and rapid urbanization is likely to have negative health impacts on human and environmental well-being.
• These factors can be contributed to or exacerbated by the phenomenon of urban heat island (UHI) effect which is expected to worsen as climate change and rapid urbanization continue to increase (Heaviside et. al., 2017).
  – Urban heat island effect (UHI) is defined by higher air and land surface temperature (LST) in urban areas in comparison to surrounding rural areas, generated by high levels of near-surface energy emission, solar radiation absorption ground objects or materials, and low evapotranspiration (Guha et. al., 2018).
• The significance of conducting research within this study area is that the city of Greenville has experience rapid urban growth in the last 10 years and there has yet to be formal research conducted for this area concerning urban heat island effect and associated social implications.
• Studying UHI has become increasingly important, not only in terms of understanding how urban development impacts the natural environment, but also as a tool for mitigating UHI and improving the adaptive capacity and heat equity of communities.
• Information regarding how previous urban development may have an impact to local citizens in both environmental and social aspects is critical for creating comprehensive future urban planning for pro-longed urban well-being.
• LANDSAT 8 OLI/TIRS C1 Level-1 satellite data from July 18th, 2020 was retrieved to calculate land surface temperature (LST) from the thermal infrared sensor (TIRS) band 10.

• Bands 4 (red) and 5 (NIR) were used to calculate the normalized difference vegetation index (NDVI)

• Bands 5 (NIR) and 6 (SWIR 1) were used to calculate the normalized difference built-up index (NDBI).

• U.S. Census block level data was used to understand local demography within the study area in order to identify vulnerable socio-economic groups to urban heat island effect.
Results

Normalized Difference Vegetation Index (NDVI) for the City Greenville, SC

Normalized Difference Built-up Index (NDBI) for the City of Greenville, SC

Land Surface Temperature (LST) for the City of Greenville, SC. Spectral heat map

Median Household Income for the City of Greenville, SC. Aggregated by census tract block group level

- A strong correlation was found between NDVI and NDBI, areas with a vegetation index of 0 to -1 correlated with a built-up index of 0 to 1.
- This relationship can also be seen between LST and Median household income. Areas with a 0 to -1 NDVI have higher surface temperatures and lower median incomes.
- The highest mean surface temperatures were most commonly distributed in the western region of the city, with an average temperature range of $\geq 27.49^\circ$ to $\leq 31.52^\circ$ Celsius.
- The lowest mean surface temperatures were most commonly distributed in the eastern region of the city, with an average temperature range of $\leq 23.03^\circ$ to $\leq 27.49^\circ$ Celsius.
- Across the central region of the city, the mean surface temperature range is much smaller, $\leq 27.49^\circ$ to $\leq 29.12^\circ$.
The highest mean surface temperatures were commonly distributed in the western region of the city, with an average temperature range of $\geq 27.49^\circ$ to $\leq 31.52^\circ$ Celsius.

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Across the central region of the city, the mean surface temperature range is much smaller, $\leq 27.49^\circ$ to $\leq 29.12^\circ$ Celsius.

Results show that land surface temperatures above 26.94$^\circ$ defined in this study as, Urban Heat island (UHI) effect.

Areas where NDVI is 0 to -1, NDBI is 0 to 1 which correlates to these areas having a higher land surface temperature on average, specifically in the West and West-central regions of Greenville.

This is indicative of how increased impervious surfaces without sufficient vegetation for cooling can contribute to higher land surface temperatures and UHI effect (Macarof et al., 2017; Guha et. al., 2018).

Results indicate UHI effect is experienced across all racial demographics, those that have a median household income below $40,000 correlates with higher land surface temperatures on average.

In addition, this socio-economic group correlated with lack of sufficient presence of vegetation, which could contribute to higher LST (Macarof et al., 2017).

This could be indicative of underlying socio-economic inequalities which exist in the city of Greenville, SC (Voelkel et al., 2018).

Despite several trends found between land use and land change indices and land surface temperatures, this study did not find as strong of a relationship between land surface temperatures and socio-economic or racial demographics as we expected.

This could be due to the scale of the study, as the census data is aggregated to represent such a large area that it is not quite reflecting the ground reality and disparities as well.
We would like to thank Furman University’s Office of Undergraduate Research for funding this research and many opportunities to expand my skills and understanding of GIS as it applies to urban sciences and sustainability. We also would like to acknowledge the faculty at the Department of Earth, Environmental, and Sustainability Sciences for their support, enthusiasm, and dedication to their students for them to be able to complete their research successfully. A special thanks to many student peers who have helped review this research at various stages to make it better.


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