

# Mapping Urban Heat: Neighborhood-Level Analysis of Urban Developments in King County, 2014–2024

## ABSTRACT

This study looks at how the Urban Heat Island (UHI) effect has evolved in King County, Washington, over the past decade, from 2014 to 2024. It specifically focuses on how urbanization and new infrastructure developments have affected land surface temperatures (LST). By using high-resolution remote sensing data and spatial analysis tools from Google Earth Engine, the research tracks changes in urban heat across neighborhoods that are undergoing rapid growth. The key areas of focus are expanding residential areas, transportation infrastructure, and the development of satellite cities. The study explores how the increase in impervious surfaces and the loss of vegetation have contributed to rising temperatures, providing concrete evidence of UHI effects in fast-developing areas like Bellevue, West Seattle, and Lynnwood. The findings show that urban sprawl and large-scale infrastructure projects have played a major role in raising local temperatures, with significant consequences for public health and the environment. The study suggests that by incorporating green infrastructure and sustainable design practices, urban planners can take practical steps to reduce UHI impacts and improve climate resilience as cities continue to grow.

## Introduction

Urban heat island (UHI) effects, a growing concern due to rapid urbanization, have become a significant environmental issue in expanding metropolitan areas. King County, Washington, located on the western edge of the United States along the Pacific coast, has seen notable growth and urbanization, particularly in cities like Seattle, Bellevue, and Lynnwood. As one of the region's key economic and technological hubs—home to global companies such as Microsoft and Amazon—King County is experiencing the challenges that come with rapid growth. With a growing population and expanding infrastructure, the rising land surface temperatures (LST) in the area present serious challenges, such as higher energy consumption, reduced comfort for residents, and increased climate-related risks. As the urban areas spread, natural landscapes are often replaced by impervious surfaces, further intensifying the UHI effect. Understanding these dynamics is crucial for addressing both the environmental and societal impacts. This study delves into how urbanization has affected LST changes in King County over the past decade, specifically from 2014 to 2024. By leveraging high-resolution remote sensing data and advanced spatial analysis tools through Google Earth Engine (GEE), the research tracks shifts in urban heat over time and examines how transformations in the built environment contribute to these changes. Key areas of focus include new residential developments, major transportation projects, and the growth of satellite towns evolving from suburban to urban areas.

The study is guided by three main hypotheses. First, the expansion of residential developments, particularly in fast-growing areas like Bellevue and North Bend, has led to a higher density of impervious surfaces, driving localized increases in LST. Second, transportation projects, such as the light rail extension and the reconstruction of the West Seattle Bridge, have altered the thermal landscape by increasing population density and reducing green spaces. Third, the transformation of satellite cities like Issaquah and Lynnwood into urban hubs has significantly changed their thermal profiles, highlighting the regional spread of UHI effects across King County. These hypotheses provide a framework for understanding the environmental impacts of urban growth on different spatial and temporal scales. This research adds to the broader understanding of UHI effects by combining remote sensing, urban geography, and spatial analysis to examine how urban expansion interacts with regional heat patterns. By harnessing the computational power of Google Earth Engine (GEE), the study delivers high-resolution, time-consistent assessments of urban heat, offering fresh perspectives on how changes in infrastructure and land use contribute to UHI effects. The findings underscore the importance of linking infrastructure developments, such as new residential and transportation projects, with increases in LST, providing a clearer understanding of what drives urban heat.

The rest of this paper is structured to follow the logical flow of our research process. We begin with the Literature Review, where we discuss the existing research on UHI effects, their impacts on health and the environment, and previous efforts to mitigate these effects. Building on this foundation, the Data and Methodology section explains the data sources, analytical tools, and methods used to assess urban heat in King County. Following that, the Empirical Results section presents our study's key findings, highlighting the temperature changes and urban development patterns observed in the selected regions. The Discussion section then analyzes these results, considering their implications for urban planning and policy. Finally, the paper concludes with the Concluding Remarks, which summarize the study's contributions and suggest directions for future research and mitigation strategies.

## Literature Review

To set the stage, this review explores four key areas: (1) the health and socioeconomic impacts of UHI, (2) the mechanisms behind its formation, (3) challenges and advancements in measuring UHI, and (4) strategies for reducing its effects. These themes collectively provide a foundation for answering the research question: How has the rapid urbanization in King County influenced urban heat dynamics, and what are the consequences for local communities?

First, the health and socioeconomic impacts of UHI highlight the urgency of addressing this issue. Extreme heat events made worse by the UHI effect, present serious risks to vulnerable populations. Kearn and Vogel (2023) show that low-income communities and outdoor workers in Washington State are disproportionately affected due to limited access to cooling resources and protective infrastructure. Additionally, a 2021 study on crowdsourced air temperature data demonstrates that localized, ground-level monitoring offers a more accurate understanding of heat exposure than satellite data, which often overestimates urban heat. These findings emphasize the need for targeted interventions to protect at-risk groups, such as improving public access to cooling centers and strengthening urban resilience to climate change.

Next, we dive into the mechanisms behind the UHI effect, which explain how urbanization amplifies heat accumulation. Foundational studies, such as Oke (1982), point to key contributors like increased solar radiation absorption by impervious surfaces, slower heat dissipation, and heat generated by human activities. Myrup (1969) builds on this by introducing an atmospheric energy budget model, showing how urban design—like the layout of buildings and streets—affects heat retention. More recently, Li Yang et al. (2021) introduced the two-resistance mechanism (TRM) attribution model, which refines our understanding by showing how soil moisture and evaporative cooling vary based on land use and surface characteristics. Together, these studies highlight the complex relationship between urban design, land surface features, and weather conditions, offering a framework to study UHI effects in rapidly urbanizing areas like King County.

However, accurately understanding the UHI effect requires reliable and standardized measurement techniques. Traditional methods often fall short in capturing the subtle differences between urban and rural areas. Stewart (2009) critiques the inconsistent definitions of "urban" and "rural," suggesting the Local Climate Zone (LCZ) framework as a solution. This framework classifies regions based on land cover, building structure, and surface features. Additionally, Gallo et al. (1993) examined how vegetation influences temperature, using the Normalized Difference Vegetation Index (NDVI), which strongly correlates with UHI intensity. Their findings emphasize how vegetation can help cool urban areas. Mirzaei and Haghighat (2010) further this discussion by advocating for a combination of ground-level, satellite, and simulation methods to enhance the precision and comparability of UHI research. These methodological advances are crucial for understanding how urbanization affects heat dynamics at a local level.

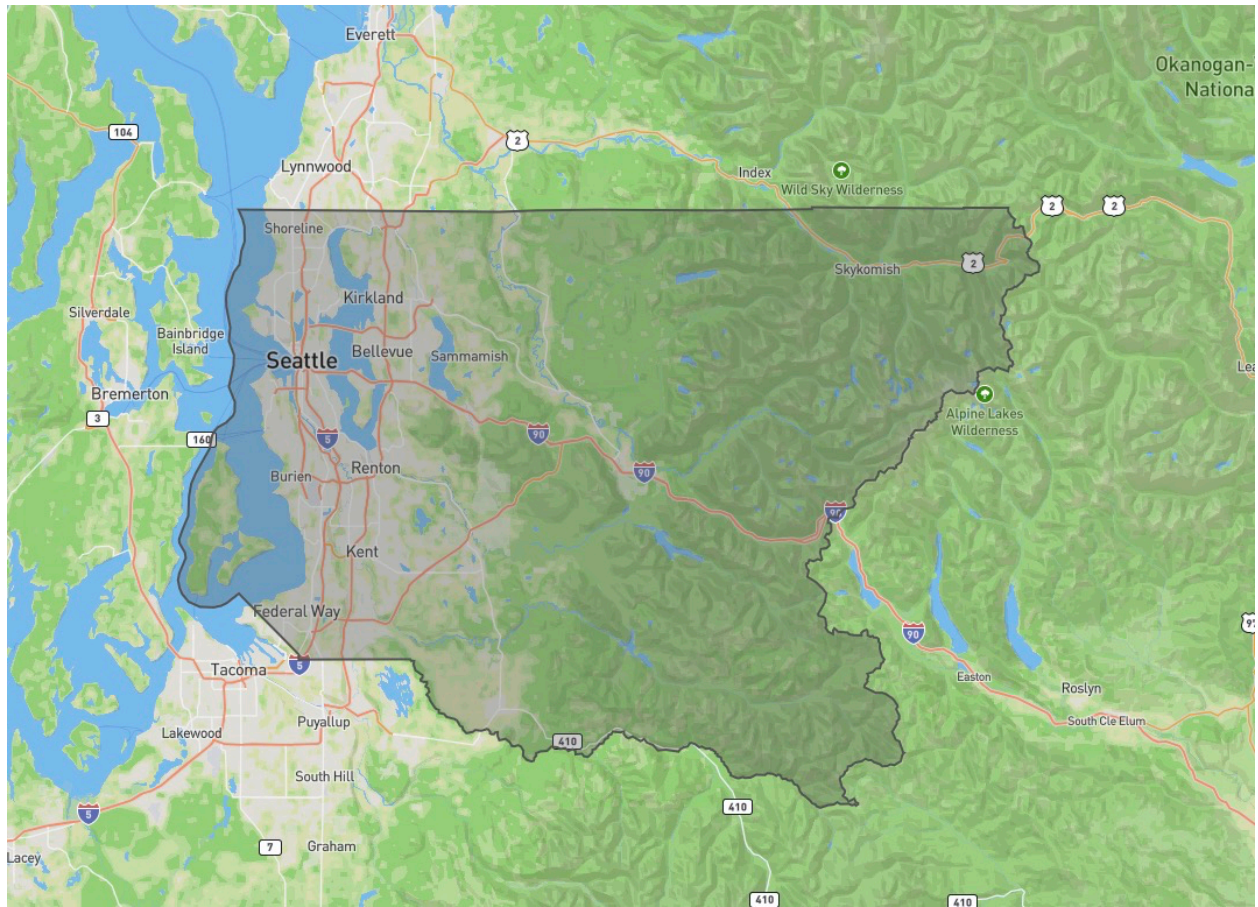
Building on these insights, mitigation strategies emphasize the importance of green infrastructure and sustainable urban design in reducing UHI intensity. Vegetation plays a crucial role in cooling urban areas. Research by Kearn and Vogel (2023) and the study *Urban Heat Island: Aerodynamics or Imperviousness?* highlights how increasing tree canopy coverage and restoring natural landscapes can boost evaporative cooling and lower surface temperatures. For example, Zheng et al. (2023) provide evidence from Shenzhen, where urban renewal projects

focused on increasing vegetation cover have led to significant reductions in urban temperatures. Their findings underscore the potential of transforming impervious surfaces into green spaces, such as parks and green corridors, to counteract UHI. Additionally, Oropeza-Perez (2019) shows that using reflective materials and improving urban ventilation can further alleviate UHI, particularly in densely developed, low-rise areas. Together, these studies underline the importance for urban planners to prioritize green infrastructure and optimize building materials as key strategies for mitigating UHI effects.

Urban renewal projects offer both opportunities and challenges when it comes to mitigating UHI. For example, Zheng et al. (2023) found that changing land use from industrial to commercial or residential, along with improvements in vegetation, can provide significant cooling benefits. However, when industrial areas remain industrial and maintain impervious surfaces, the relief from UHI is minimal. These findings highlight the need to align renewal projects with sustainable urban design principles, such as increasing vegetation cover and using reflective materials. The body of research on UHI offers a thorough understanding of its health impacts, causes, measurement challenges, and strategies for mitigation. While advances in modeling and measurement techniques have improved our knowledge, integrating green infrastructure, urban renewal, and targeted policy interventions is still crucial for addressing the environmental, health, and socioeconomic effects of UHI. This synthesis of research provides a valuable perspective on how rapid urbanization in King County is influencing urban heat dynamics and offers practical strategies for reducing its impact on local communities.

## **Data and Methodologies**

This study integrates both vector and raster datasets to assess the impact of rapid urbanization on LST in King County, Washington. The analysis compares two key time periods—2013-2014 and 2023-2024—using a comparative approach to explore how the UHI effect has changed over the past decade and its connection to urban development. The study utilizes satellite imagery, land use data, and infrastructure information to better understand how urbanization drives the intensification of UHI. The datasets used include vector data, which primarily covers transit infrastructure such as light rail expansions and transit hubs, sourced from the King County and Seattle Open Data portals. Urban development data, including new buildings and changes in land use, is obtained from OpenStreetMap (OSM) and Google Maps, and digitized with geojson.io. Raster data comes from the Landsat 8 Collection 2 Level 2 Surface Temperature dataset, accessed via Google Earth Engine (GEE), and is supplemented with orthoimagery and other satellite images to validate urban development patterns. To ensure precise LST measurements, cloud-masking techniques are applied, and thermal data (ST\_B10 band) is converted from Kelvin to Celsius for meaningful comparisons across the two periods, both spatially and temporally.



**Figure 1.** King County, Washington, the study location

The analysis concentrates on four key regions chosen for their rapid urbanization and significant infrastructure changes: Lynnwood, West Seattle, Bellevue, and North Bend. These areas have experienced notable transformations, including the expansion of built-up zones, growth in the tech industry, shifts in population, and ongoing urban construction. The specific changes in each of these regions are outlined as follows:

Lynnwood: located in the northern part of King County, experienced significant urban growth, especially in residential construction between 2014 and 2024. The development of light rail stations spurred both residential and commercial expansion, particularly around the Lynnwood Transit Center. The addition of large shopping malls and new residential areas boosted local commercial and housing development, leading to more buildings and a noticeable reduction in green spaces and vegetation.

West Seattle: situated southwest of downtown Seattle, also underwent major urban changes, particularly in residential and commercial sectors. The reconstruction of the West Seattle Bridge coincided with nearby residential development, driving the creation of new neighborhoods and attracting a growing population.

Bellevue: located just across Lake Washington to the east of Seattle, is a key commercial and residential hub in King County. Over the past decade, Bellevue underwent dramatic transformation, evolving from a suburban commercial center into a high-density urban core. As the population grew, so did the number of commercial buildings and high-rise structures, particularly around Bellevue Square. The rapid growth of the tech industry, with the expansion of offices for Microsoft and other tech companies, led to increased construction density. As a result, green spaces gradually diminished.

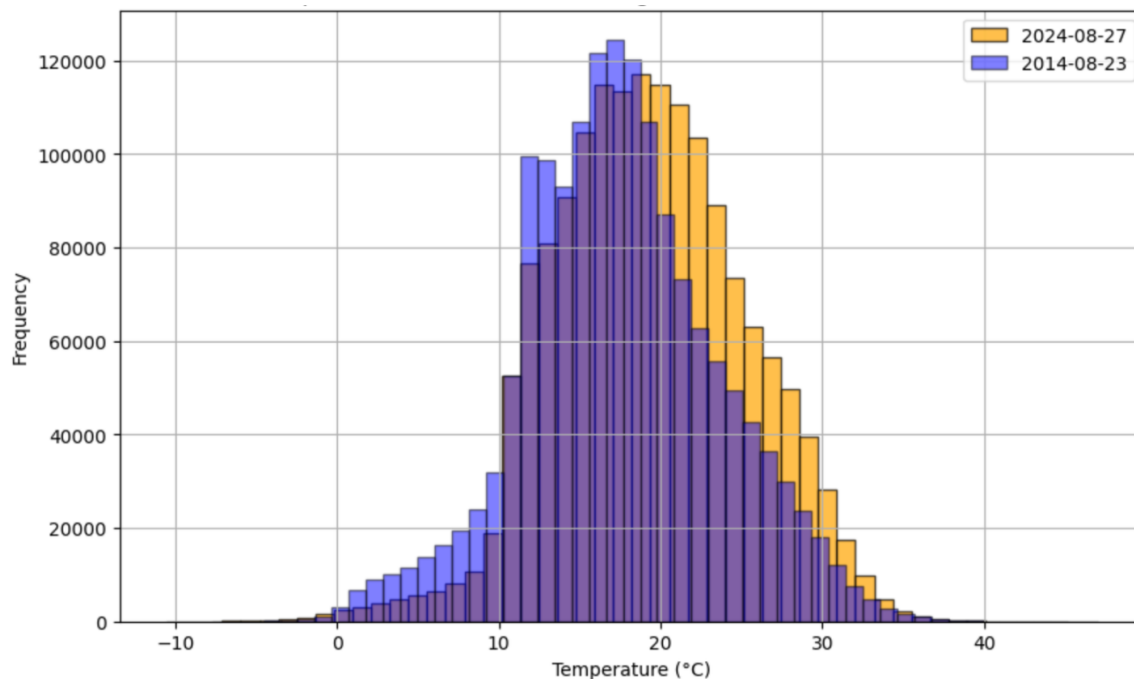
**North Bend:** located to the east of Snoqualmie and near the Cascade foothills, also experienced significant urban expansion between 2014 and 2024, fueled by both residential and commercial growth. As the local population grew—especially due to migration from Seattle—North Bend saw rapid development of low-rise apartments and residential areas. Commercial centers, such as the North Bend Outlets, attracted a large number of shoppers, further driving the area's growth.

Using both spatial and statistical methods, this study examines the impact of urbanization on LST. At the county level, LST maps are created to track temperature changes, focusing on hotspots (areas with significant warming) and cold spots (areas with cooler temperatures). At the neighborhood level, the study investigates how urbanization has localized these impacts, examining temperature shifts and heat distribution. Descriptive statistics—such as the mean, variance, and standard deviation—are used to summarize temperature trends and reveal regional variations in temperature distribution. Histograms help visualize the distribution of LST, illustrating changes across the two time periods.

For a more detailed analysis, the effects of urbanization and infrastructure development are mapped using satellite imagery. Areas such as Bellevue, West Seattle, Lynnwood, and Issaquah are analyzed in greater depth. These newly developed urban areas are digitized into polygons and overlaid on LST maps to examine the relationship between urban development and temperature changes. Spatial interpolation techniques, including kernel density estimation (KDE), are applied to visualize the concentration of heat across King County, offering a clearer view of how urbanization is shaping the thermal landscape.

## Empirical results

Based on the methodology described, the following results were obtained. We will now present the findings related to temperature shifts, the impact of urbanization on LST in key regions, and the specific changes in land use and infrastructure. Each section focuses on a particular aspect of the data, including general temperature changes over time and detailed regional analyses for Lynnwood, West Seattle, Bellevue, and North Bend.

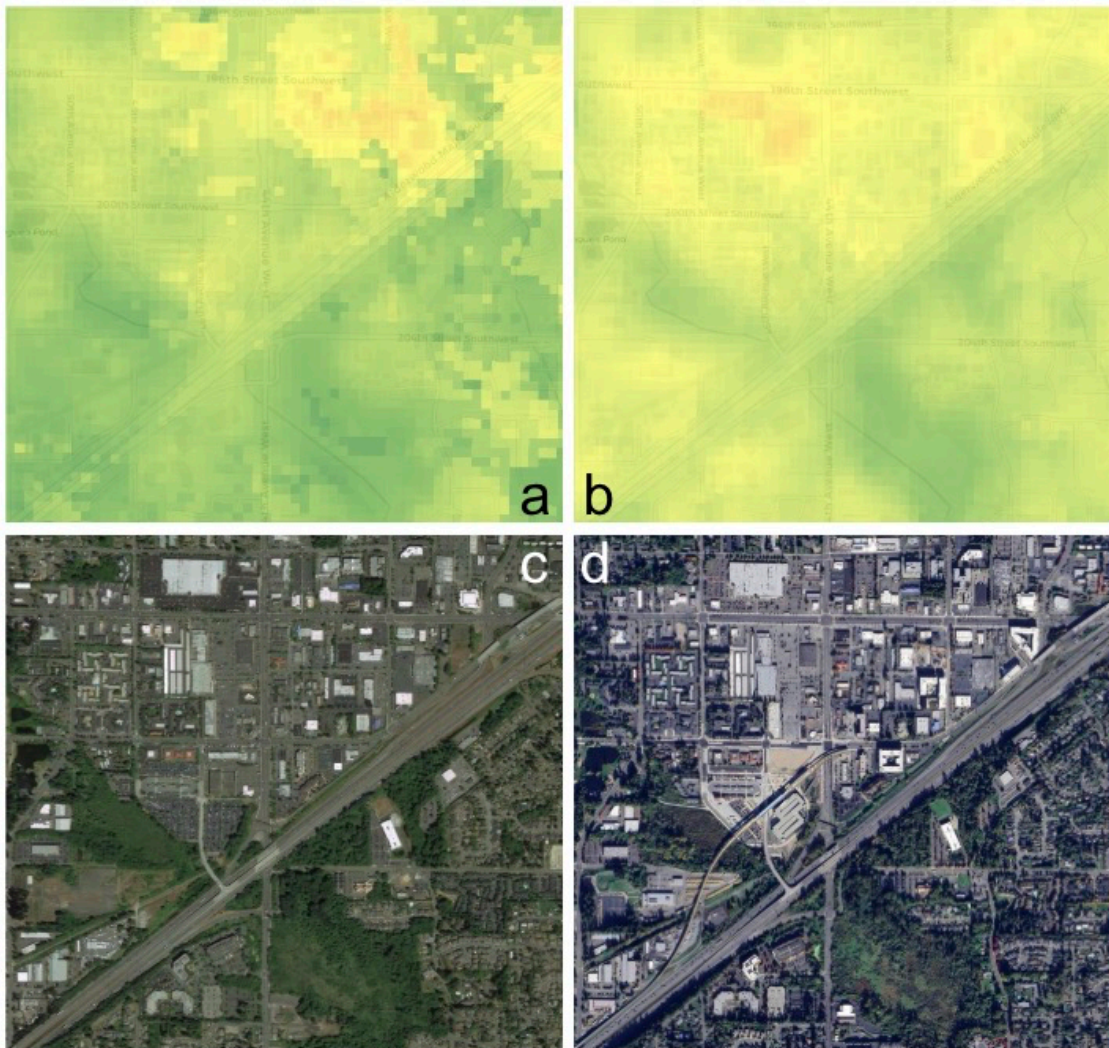


**Figure 2.** The comparison of Landsat 8 LST Histogram 2014 vs. 2024

The histogram compares LST distributions from Landsat 8 for two dates: August 23, 2014 (represented by purple bars) and August 27, 2024 (represented by yellow bars). A key observation from this comparison is the shift in temperature distribution. The 2024 data (yellow) shows a slight rightward shift compared to the 2014 data (purple), indicating an overall increase in LST over the decade. This suggests that the average temperature in the area has risen, likely due to urbanization and the increase in impervious surfaces. Both distributions display a similar bell curve, with a peak frequency around 15–20°C, although the peak in 2024 is slightly broader. Additionally, the 2024 distribution shows a longer tail at higher temperatures, reflecting more extreme heat events. This higher frequency of temperatures in the 20–30°C range further supports the idea that urban development has intensified localized warming effects, reinforcing the hypothesis that urbanization and reduced vegetation cover contribute to rising LST in King County.

### Lynnwood: Urbanization, Light Rail Expansion and LST Changes

Lynnwood experienced substantial urban expansion between 2014 and 2024, particularly in residential construction. The development of light rail stations sparked a notable increase in both residential and commercial building projects, especially around the Lynnwood Transit Center. In the 2024 satellite image, this area clearly shows a shift from open spaces and low-density buildings to more densely packed residential and commercial structures. The addition of large shopping malls and residential developments has driven local commercial and housing growth, significantly increasing the built-up area. As seen in the 2024 image, these developments have led to a dramatic reduction in green spaces and vegetation, which were more prevalent in 2014.

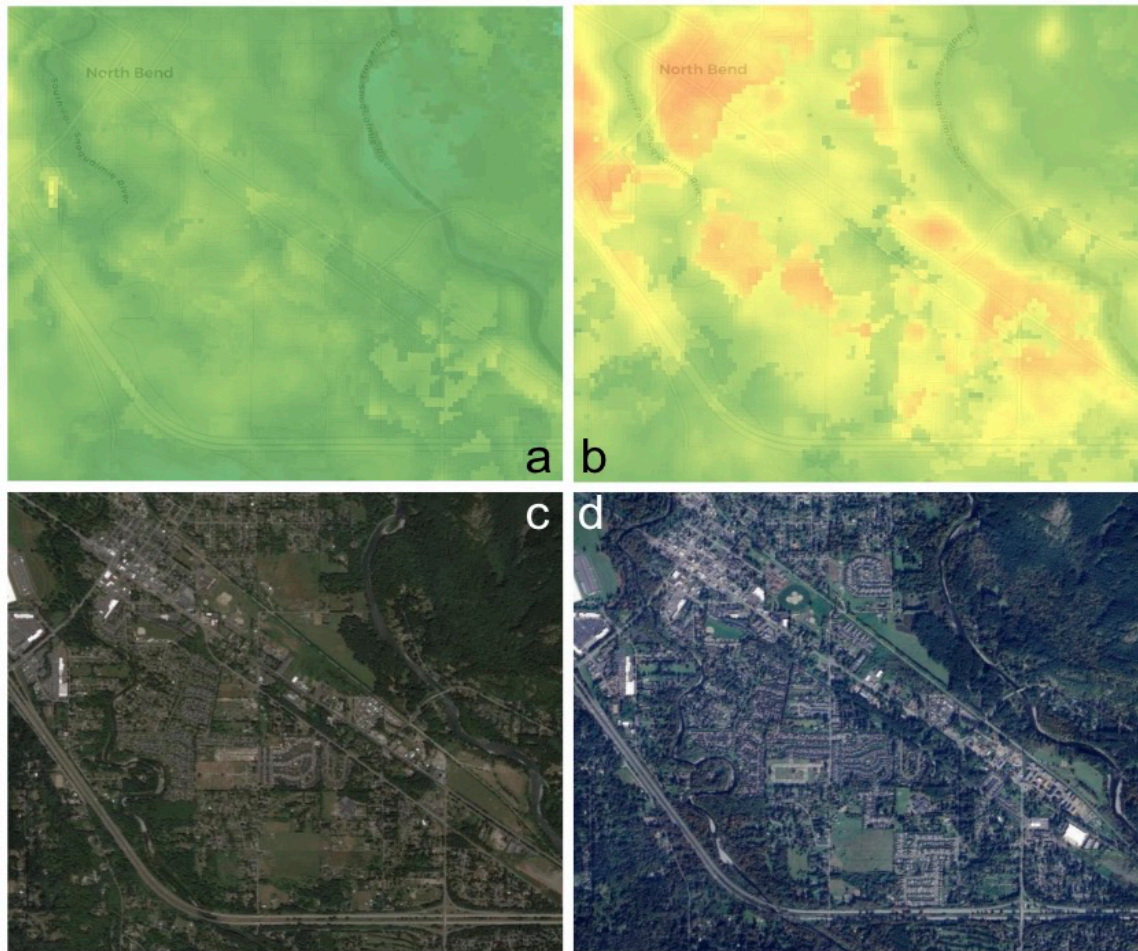


**Figure 3.** Lynnwood Light Rail Station: Satellite Imagery of (a) 2014 and (b) 2024, LST of (c) 2014 and (d) 2024.

These changes have contributed to a significant rise in local LST, as shown in the temperature maps. The increase in impervious surfaces and the loss of natural landscapes around the transit center have resulted in localized warming. The area along 196th St SW, in particular, has become much hotter due to the loss of greenery and trees following the closure of a nearby mall. The shift from scattered hotspots to more uniformly warm areas in the 2024 image highlights how suburban sprawl and infrastructure expansion have intensified the UHI effect in Lynnwood.

### Snoqualmie/North Bend: Urban Expansion and Hotspot Formation

Snoqualmie and North Bend have also seen significant increases in temperature, especially in residential areas and commercial hubs like the North Bend Outlets. A comparison of the 2014 and 2024 satellite images reveals the transformation of the area from open spaces with sparse development in 2014 to substantial urban sprawl in 2024. The earlier image shows large expanses of undeveloped land and green spaces, while the 2024 image highlights the growth of low-rise condos, apartments, and suburban housing near the region's center, along with newly built shopping malls and parking lots.

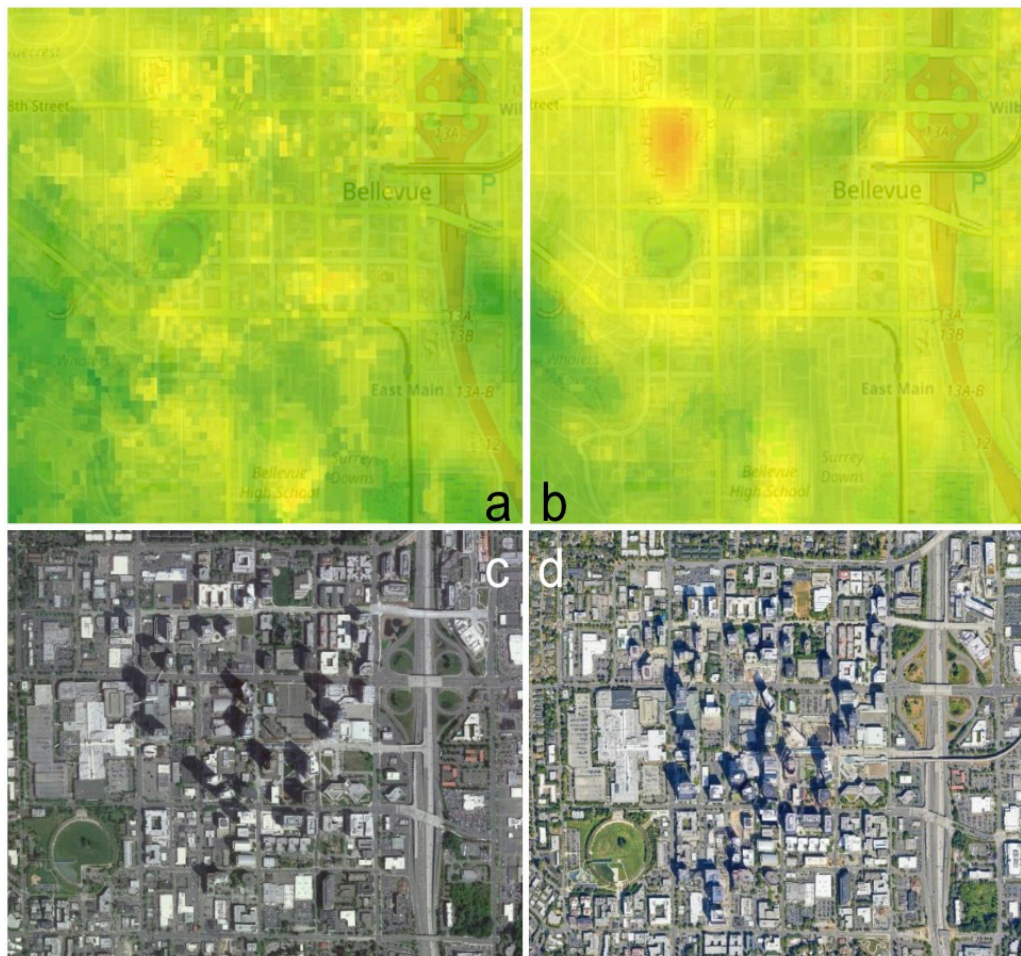


**Figure 4.** North Bend: Satellite Imagery of (a) 2014 and (b) 2024, LST of (c) 2014 and (d) 2024.

These developments have led to a significant increase in impervious surfaces, which has exacerbated the UHI effect. The loss of green spaces, particularly in areas that were once dominated by vegetation, supports the hypothesis that suburban sprawl contributes to intensified UHI effects by altering land use and heat dynamics. The rapid urban expansion shown in the 2024 image, particularly in the northern part of the region along I-90, illustrates a clear pattern of development that has reshaped the area's thermal profile, contributing to more localized warming.

### Bellevue: Transformation into a High-Density Urban Core

Bellevue has undergone significant urban changes over the past decade, with the satellite images showing a clear transformation from 2014 to 2024. The 2024 image reveals a high concentration of tall buildings and new high-rise structures, signaling substantial vertical growth. Green spaces, such as a strategically placed park in the bottom-left corner of the image, help create a more balanced urban environment. In contrast, the 2014 image shows fewer high-rise buildings and more open spaces, reflecting a transitional period before Bellevue evolved into a dense urban core.

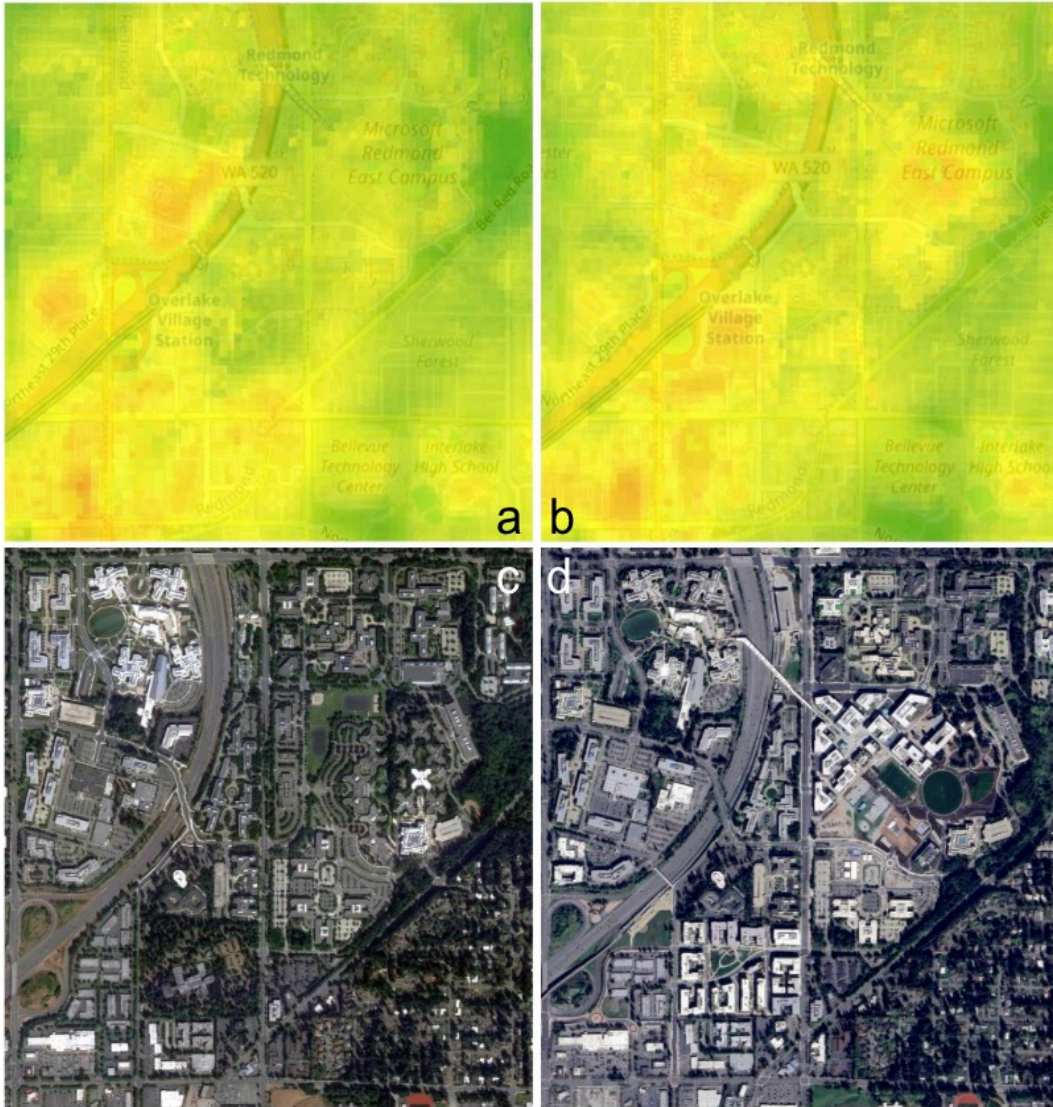


**Figure 4.** Downtown Bellevue: Satellite Imagery of (a) 2014 and (b) 2024, LST of (c) 2014 and (d) 2024.

This transformation in Bellevue supports the hypothesis that rapid urbanization leads to an increase in impervious surfaces, which contributes to the UHI effect. The growing density of infrastructure, as seen in the 2024 image, has been accompanied by a rise in LST. Bellevue Square, in particular, has become a major hotspot due to increased population density and higher traffic volumes, which further intensify localized warming. These observations underscore the importance of incorporating sustainable planning strategies, such as preserving green spaces and utilizing reflective materials, to help mitigate the rise in LST.

#### Crossroads/Microsoft Center Area: Urban Expansion and Green Infrastructure

In the Crossroads/Microsoft Center area, particularly near the Overlake Village Link Station, a comparison of the 2014 and 2024 images shows significant infrastructure changes. The earlier image depicts a blend of business and residential zones, with notable open spaces and green areas, especially in the southern section, which includes parks and recreational fields. In contrast, the 2024 image highlights the development of the new Microsoft center, with additional buildings connected across the highway, signaling expanded infrastructure.



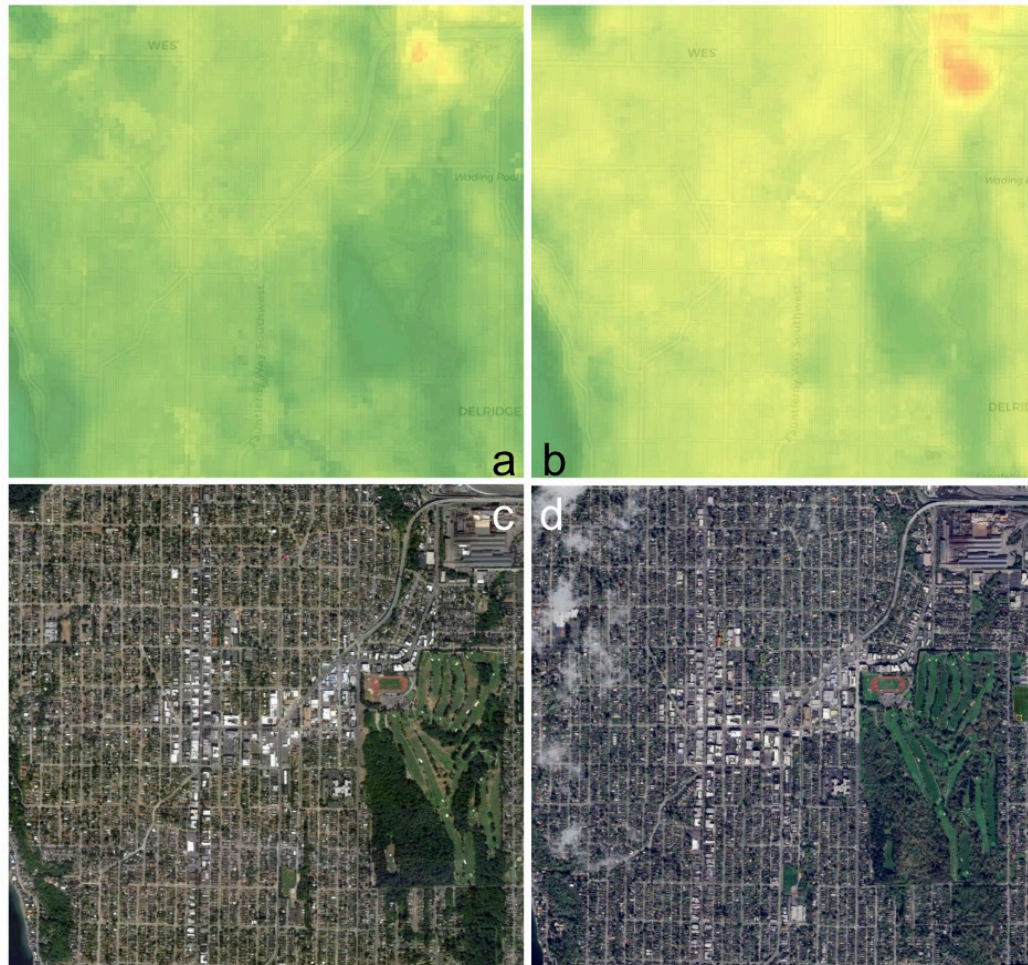
**Figure 5.** Microsoft Campus: Satellite Imagery of (a) 2014 and (b) 2024, LST of (c) 2014 and (d) 2024.

A new park has been added to the area, likely to mitigate the environmental effects of urbanization and offer both cooling and recreational spaces. Despite the increase in construction density, the strategically placed green areas in the 2024 image demonstrate a deliberate effort toward sustainable development. This mix of urban growth and green infrastructure emphasizes the importance of incorporating green spaces to counteract the UHI effect and improve local cooling, aligning with the mitigation strategies advocated in the literature for rapidly urbanizing regions.

**West Seattle: Gradual Urban Renewal and Localized Warming**

In West Seattle, subtle yet noticeable changes can be seen in the satellite images from 2014 and 2024. While the transformation here is not as dramatic as in other areas, the gradual increase in density and the replacement of older buildings with new constructions have contributed to a rise in impervious surfaces. The 2014 image shows well-established residential neighborhoods with a consistent street layout, surrounded by ample tree cover and open

spaces. In contrast, the 2024 image reveals the replacement of older buildings with newer developments, reflecting ongoing urban renewal, especially in central and commercial areas.



**Figure 6.** West Seattle: Satellite Imagery of (a) 2014 and (b) 2024, LST of (c) 2014 and (d) 2024.

The increase in impervious surfaces, as seen in the 2024 image, has led to localized warming, which further exacerbates the UHI effect. The construction of new buildings and the continued urban renewal process highlight the increasing demand for housing and commercial spaces in this rapidly growing area. Although the changes in West Seattle may seem more gradual compared to other regions, the cumulative impact of these developments has contributed to rising LST over time.

## Discussion

The findings of this study provide clear evidence of rising temperatures driven by the expansion of impervious surfaces, the reduction of vegetation, and increased human activities across key regions such as Bellevue, Lynnwood, North Bend, and West Seattle. These trends are especially noticeable in areas where significant urban transformation has taken place, such as the spread of residential developments, infrastructure projects, and commercial growth. The urban heat patterns observed in King County are not unique but reflect broader trends of urbanization in rapidly growing metropolitan areas. The urbanization of suburban areas like Lynnwood, Bellevue, and North Bend has led to localized increases in temperature, primarily due to the spread of impervious surfaces,

such as roads, buildings, and parking lots. These surfaces absorb and retain heat, exacerbating the UHI effect. Unlike rural areas, where natural vegetation helps cool the environment through evapotranspiration, urban areas replace these cooling mechanisms with heat-retaining structures. This shift, visible in satellite images, underscores how urbanization is directly linked to the rise in LST.

The development of major infrastructure projects, such as the Lynnwood Transit Center and the West Seattle Bridge reconstruction, has exacerbated UHI effects by increasing population density and reducing green spaces. While these infrastructure projects are essential for accommodating population growth and improving connectivity, they also contribute to the loss of vegetation and the spread of heat-retaining surfaces. In areas like Bellevue, where both vertical and horizontal growth have taken place, the transformation into a dense urban core has led to the formation of concentrated hotspots. As shown in the 2024 satellite images, the construction of high-rise buildings, combined with a decrease in open green spaces, has significantly elevated the thermal profile of these regions. These changes reflect a fundamental shift in how urban landscapes in King County are organized, with a clear impact on the local climate.

The integration of high-tech industries, especially in Bellevue, has further intensified urban heat in these areas. The rapid expansion of office spaces for major tech companies, such as Microsoft, has led to a higher concentration of workers and greater energy consumption. As buildings grow taller and denser, the surrounding areas see increased foot traffic, higher demands for ventilation and cooling, and more heat generated by human activities. These localized temperature increases are particularly noticeable in urban centers like Bellevue Square, where the population density has risen significantly in recent years.

Furthermore, suburban areas like North Bend, once known for their open spaces and rural landscapes, have experienced significant urban sprawl over the past decade. The increase in residential and commercial developments has transformed the area, replacing natural landscapes with urbanized spaces and intensifying the UHI effect. The shift from green fields and open areas to built-up environments is clearly visible in the satellite images, where new low-rise apartments and commercial hubs have taken over previously green spaces. As a result, North Bend, like other suburban areas, is seeing notable temperature increases, particularly in regions where large parking lots and commercial developments have been introduced.

## **Concluding Remarks**

This study has examined the relationship between urbanization and the UHI effect in King County, focusing on key regions like Lynnwood, West Seattle, Bellevue, and North Bend. By analyzing LST data, satellite imagery, and urban development patterns from 2014 to 2024, we have identified a clear trend of rising temperatures linked to increased urbanization. The transformation of these areas into denser urban centers has led to a proliferation of impervious surfaces, the loss of green spaces, and intensified localized warming, all of which contribute to the UHI effect. Furthermore, regions with substantial infrastructure development, such as Bellevue and Lynnwood, have experienced significant shifts in their thermal dynamics. While this study provides valuable insights into the spatial and temporal aspects of urban heat, there are some limitations. The use of satellite imagery and remote sensing data, although thorough, may overlook finer environmental details such as microclimates or localized cooling strategies that could also affect the UHI effect. Additionally, the study is focused solely on King County, and future research could expand the analysis to include other metropolitan areas facing similar urbanization challenges.

Future research should focus on refining strategies for mitigating the UHI effect, particularly through the integration of green infrastructure, reflective materials, and urban cooling technologies. Long-term monitoring and more detailed data collection at the neighborhood level could provide deeper insights into the specific factors driving temperature changes, helping to tailor solutions that address both environmental and public health concerns. Additionally, exploring the relationship between UHI and socioeconomic factors could lead to more equitable and effective interventions, particularly for protecting vulnerable populations. The broader impact of this research lies in its potential to inform urban planning and policymaking aimed at creating more sustainable and resilient cities. As urbanization continues to grow, understanding the complex relationship between urban development and heat will be crucial for mitigating climate-related risks. By promoting the integration of green spaces, efficient infrastructure,

and sustainable development practices, cities can reduce the harmful effects of UHI and enhance the quality of life for residents. This study highlights the importance of balancing urban growth with environmental stewardship to create cities that are both livable and resilient in the face of climate change.

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