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Urban Heat Islands and Water Quality: A Remote Sensing-Based Literature Review

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Abstract

Urban Heat Island (UHI) is a phenomenon in which urban areas experience a higher temperature than more rural areas along an urbanization gradient. Streams draining urban land can experience higher temperatures due to factors such as increased input of stormwater runoff that has been warmed by hot pavement and lessening vegetation cover, which can have many negative effects on the health of the riparian ecosystem. Research into the UHI effect has increased exponentially in the last 20 years, particularly using geospatial technology and satellite observations. The objective of this review is to analyze the current literature on the UHI effect and understand its impact on water quality of urban waterways by synthesizing all the published articles emphasizing the use of remote sensing technology. Articles were synthesized and categorized to understand the data and satellite imagery used (sensor types), research methodology, geographical distribution, and primary research questions. Many studies emphasized the role of water bodies as a heat sink in urban environments and how blue infrastructure can be implemented to mitigate harm or discomfort to humans due to the heat island, but literature exploring the impact of this usage on the riparian ecosystem is sparse. This review aims to offer a data-backed view of this knowledge gap and explore opportunities for future research on this topic.

1. Introduction

1.1 The Urban Heat Island

Urbanization level is increasing across the globe, with more people choosing to live in small to mid-sized cities worldwide. According to the 2025 UN World Urbanization Prospects Report, 45% of the world's population now reside in cities, as opposed to 20% in 1950. Additionally, the amount of land covered by impervious surfaces is increasing at a higher rate than the increase in population (Affairs 2025). The Urban Heat Island (UHI) is a phenomenon in which urban and suburban areas experience a higher ambient temperature than more rural areas along the same urbanization gradient (Fig. 1, Fig. 2). Many factors have been shown to contribute to the UHI effect, with the primary driver being the increase in impervious surface cover due to urbanization and the corresponding decrease in vegetative cover (Srivastava 2024).

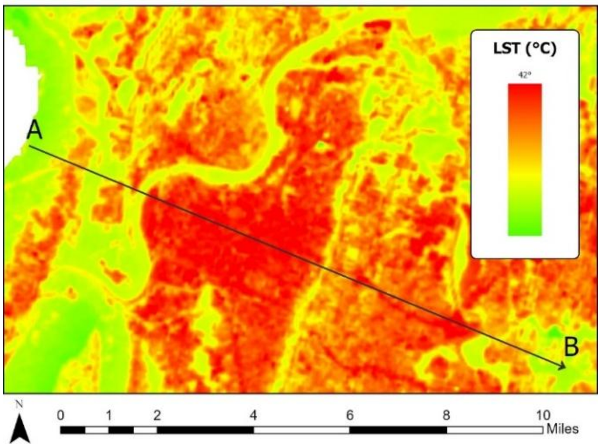

Figure 1: Thermal image of the Chattanooga, TN area displaying Land Surface Temperature (LST) in °C.

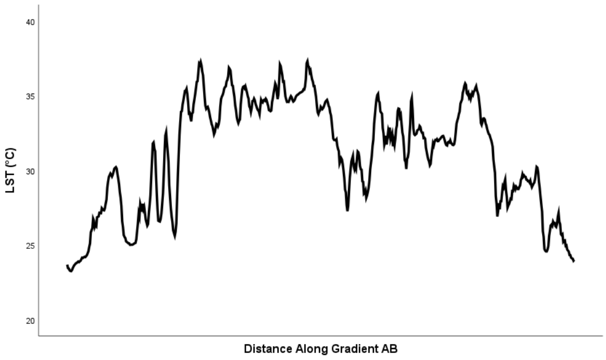

Figure 2: Line graph of the LST (°C) along the urbanization gradient shown in Fig. 1.

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1.2 Urban Stream Syndrome

Urbanization is known to dramatically impact surrounding water bodies. The continued degradation of water bodies draining urban areas has been referred to as “Urban Stream Syndrome” (USS). USS is characterized by negative impacts including increased magnitude of high flow, temperatures, deposition of toxicants and nutrients, and amount of algal biomass, and reduced amounts of sensitive fish, invertebrates, and vegetation (Wayne C. Zipperer, 2020). The degradation of stream health is driven by increased amounts of runoff being introduced into urban waterways. When the amount of impervious surface increases in a watershed, there is less opportunity for both deep and shallow infiltration. Because the increase in impervious surface coverage coincides with a decrease in vegetative cover, there is also less opportunity for water to go towards evapotranspiration. This leads to a sharp increase in the amount of runoff entering streams, lakes, and rivers. Stormwater runoff is often heated when running across impervious surfaces, contributing to increased temperatures in urban water bodies compared to rural water bodies (Paul and Meyer, 2001). In areas experiencing the urban heat island effect, it follows that the temperature increase of impervious surfaces would transfer to an increase in the temperature of heated runoff entering urban water bodies.

1.3 Benefits of Remote Sensing for Urban Heat Island Studies

While powerful, there are some limitations of field measurements in UHI studies. First, some areas have limited networks of field monitoring stations. This means that the data is not as easily accessible in these locations, and researchers are unable to get consistent, reliable data across a large study site. UHI studies are typically interested in large areas such as a full city, so having enough data across your study site is imperative. Additionally, even in locations with extensive monitoring networks, field measurements are limited to a single point, giving less coverage when exploring large scale impacts. The use of remote sensing technologies can alleviate these issues.

Satellite imagery datasets such as the Landsat collection have global coverage and can help support data availability in locations with limited field monitoring networks. These datasets also have continuous coverage across large areas. In UHI studies, this allows researchers to have continuous raster data of temperature information across the entire study site, providing a more detailed view of how temperature changes between rural, suburban, and urban areas. Popular collections like Landsat, Sentinel, and the Moderate Resolution Imaging Spectroradiometer (MODIS) are accessible to the public and have a long historical record, with images going back to 1972 (Landsat 1). This data is also relatively simple to work with due to platforms like ArcGIS Pro and Google Earth Engine providing robust tools for exploring satellite imagery. Prior water quality studies have found that satellite data is a powerful method for estimating temperature and other water quality parameters and that the estimations from this data show general agreement with field measurements (Pivato et al., 2019; Seo et al., 2022; Li et al., 2024; Naimaee et al., 2024). In-depth reviews also exist exploring the applications of remote sensing on general UHI or water quality study (Quaresma and Oliveira, 2020; Almeida et al., 2021; Batina and Krtalic, 2024; Gholizadeh et al., 2016).

1.4 Objective

The objective of this review is to analyze the current literature on the UHI effect and understand its impact on the water quality of urban waterways. It examines 73 articles selected from Google Scholar, Web of Science, Science Direct, and reference following from selected literature. The papers were chosen and categorized based on geographic region, satellite usage, research methodology, and which aspects of the interaction between the UHI and hydrologic systems the research focused on. The review focuses on studies that used remote sensing for some portion of the research, typically land cover analysis or water temperature extraction, but also examines some pure field studies that have high relevance to the topic and can help evaluate the effectiveness of remote sensing techniques. The work aims to explore all studies that have been conducted on the impacts of thermal pollution in the urban riparian environment and to determine any research gaps in this subject.

2. Summary of Findings

2.1 Studies Over Time

The urban heat island has been the subject of a vast quantity of research over the past decade. Searching Web of Science for papers referring to the urban heat island (“UHI” OR “urban heat island”) returns nearly 11,000 results, with around 1,500 of those publications being released in 2025 alone (Fig. 3). Clearly, the UHI itself is not an understudied phenomenon. However, searching for publications exploring the relation of the UHI and urban water bodies (“water quality” AND “urban heat island” OR “UHI”) delivers a much smaller body of work, totaling 110 results and peaking at 19 publications in 2024. Additionally, many of these works do not provide a quantitative view of the relationship between water and the UHI, only citing water quality decreases as a potential impact of the UHI.

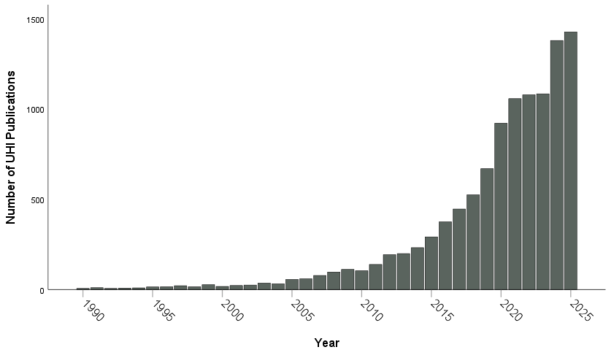

Figure 3: Bar graph showing the frequency of UHI publications from 1990-2025.

2.2 Geographical Distribution

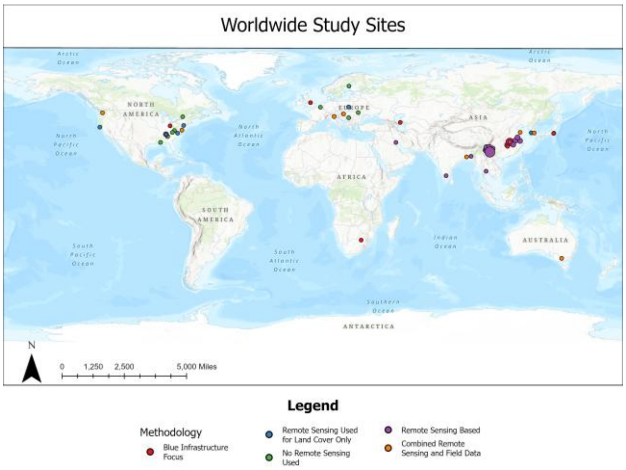

Figure 4: World map showing the global distribution of study sites, coded with color and size to indicate methods and quantity of studies.

Of the 51 non-review papers analyzed, 23 of the studies were conducted in Asia (45%), 15 in North America (29%), 8 in Europe (16%), and 1 each in Australia, Africa, and Eurasia (2% each). 2 of the studies utilized global datasets rather than investigating a specific site (4%) (Fig. 4).

The largest portion of studies took place in China, in part due to multiple studies that have been carried out by a group at Yunnan Normal University, specifically looking at factors impacting lake temperature in the Yunnan-Guizhou Plateau region (Duan et al., 2024; Peng et al., 2022; Tang et al., 2022; Zhao et al., 2022; Yang et al., 2020). Additionally, many cities in China appear prone to experiencing the UHI effect. Although specific population numbers vary between sources, China is home to 4 of 33 recognized worldwide megacities, or cities with a population greater than 10 million people (Appendix A). Additionally, China has 5 cities that are on the fringe of becoming megacities with populations greater than 7 million people. Many of the publications analyzed in this review occurred around Shanghai, Wuhan, and Changsha, which are all large urban hubs with populations of 29.56, 7.36, and 5.13 million respectively. This heightened level of region-wide urbanization could explain why researchers are focusing on the human and environmental impacts of urbanization.

2.3 Research Focus

Publications were categorized into three groups based on research focus. First, we pulled any articles that presented a review of theory or previous literature. These were categorized as “synthesis papers” and used for background or to guide further exploration of literature. We collected 21 synthesis papers (14% of total).

The second category is “blue infrastructure”. These papers emphasized the role of water bodies in mitigating the urban heat island effect and contained 11 publications (17%). Many of these studies took place in megacities, emphasizing the importance of methods to alleviate human discomfort from the UHI effect. (Gidey and Mhangara, 2025; Zhou et al., 2021; Lin et al., 2020; Nakayama and Hashimoto, 2011; Yang et al., 2015; Wu et al., 2019). Some of these studies found that water bodies exhibited a variable cooling effect. Hathaway and Sharples (2012) found that ambient air temperature above the river was reduced by around 1.5°C during the spring, and that the effect varied seasonally between Spring and Summer months (Hathway and Sharples, 2012). Wang et al. (2019) similarly found that there was a negative correlation between water coverage and LST in Wuhan, China, though the impact may vary based on water body distribution and land use types (Wang et al., 2019). Conversely, Zhang et al (2025) found that increases in MNDWI (Modified Normalized Difference Water Index) increased the apparent temperature in the Chang-Zhu-Tan region, attributing this effect to the extreme humidity in the summer and relative warming effect of water in the winter (Zhang et al., 2025). The results of these studies highlight the complexity of the relationship between urban water bodies and UHI effects, specifically how the magnitude of heating or cooling effects can vary in different climates.

The final category consists of all papers that investigated the specific impacts of the urban heat island on water quality. This was the largest category, containing 40 publications (62%). We performed further analysis on this category of papers to determine the overall level of remote sensing usage (Figure 3) as well as which products were most prevalent for those studies that relied on remote sensing technology for their analysis (Table 1).

Of the 40 publications analyzing the impact of urban heat on water quality, 10 studies (25%) used no remote sensing data, and 7 studies (17.5%) used remote sensing data for land cover information exclusively. These studies agreed that urbanized streams experienced higher temperatures than their rural counterparts, citing differences of 1-3.5°C (Somers et al., 2013; Ciupa and Suligowski, 2024; Brans et al., 2018). Grzywna et al. (2024) showed a very strong correlation between air temperature and water temperature, estimating that every increase in air temperature of 1°C would result in a 0.86°C increase in water temperature (Grzywna et al., 2024). Multiple field measurement-based publications focused on the impacts of urbanization on stream flow patterns (Somers et al., 2013; Adamowski and Prokoph, 2013; Roland et al., 2023). These studies indicated that urban streams showed a higher sensitivity to temperature increase than forested streams. For example, Somers et.al. cites a sharp increase of up to 4°C in urban streams during summer storms, while forested streams showed a much more gradual increase (Somers et al., 2013).

15 studies relied on solely remote sensing data (37.5%). 8 studies (20%) used a combination of remote sensing and field data, often using field-collected water quality data to validate the remotely sensed temperature (Ding and Elmore, 2015; Mondal et al., 2024; Duan et al., 2024) or weather data to supplement additional parameters (Li et al., 2024; Seo et al., 2022; Ding and Elmore, 2015). These publications generally supported the findings of the non-remote sensing studies. Zahn et al. (2021) corroborated the claim that urban streams experience more extreme temperature surges than streams in more forested watersheds and added the finding that air temperature is a key indicator of surge intensity. This publication also shows a strong link between urbanization and thermal pollution of waterways (Zahn et al., 2021). Additionally, Yang et al. (2020) explained that lakes in the Yunnan-Guizhou Plateau region experienced consistent warming driven by near surface air temperature (NSAT) increases from 2001-2018, and that urban and suburban lakes were more affected by NSAT increases than rural lakes (Yang et al., 2020).

2.3.1 Studies by Satellite Type/Sensor: A notable majority of remote sensing-based studies used Landsat or MODIS imagery for their analysis. Many studies used a combination of products, selecting Landsat imagery for exploring land cover or water boundaries and MODIS products, such as MOD11A2, for collecting LST (Peng et al., 2022; Tang et al., 2022; Zhao et al., 2022; Zhang et al., 2025; Firozjaei et al., 2023). This combination of products is very powerful, taking advantage of the higher spatial resolution of Landsat imagery to get accurate land cover data, while still utilizing the higher temporal resolution of MODIS products.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), MODIS/ASTER Airborne Simulator (MASTER), LiDAR, and aerial photography were underrepresented in the selected studies. ASTER imagery was used for digital elevation model collection in studies that used Landsat or MODIS data for their temperature analysis (Zhao et al., 2022; Dos Santos, 2020). MASTER imagery was used for one study in Washington, USA (Tan and Cherkauer, 2013). The imagery used in this study had a very high spatial resolution (5 and 15m). MASTER imagery has incredible applications in exploring small scale variation in stream temperature due to this high spatial resolution, but it has the drawback of losing some of the availability and ease of access that comes with Landsat or MODIS data. Lastly, one publication used LiDAR data for building a 3D city model of the study site in conjunction with Landsat imagery (Chun and Guldmann, 2014). This is an interesting application that follows with additional literature explaining that the magnitude of cooling effects from water bodies is affected by the geometry of cities, as well as the known impact of city geometry on UHI formation (Phelan et al., 2015). A detailed list of which products were used in each study is provided in Table 1.

Satellite/ Database	Product	Publications
Landsat	Landsat 1/3 MSS	Hossain and Easson, 2021
	Landsat 4/5 TM	Chun and Guldmann, 2014; Yang et al., 2015; Ding and Elmore, 2015; Zhang et al., 2019; Hall and Hossain, 2020; Naim and Kafy, 2021; Hossain and Easson, 2021; Tang et al., 2022; Peng et al., 2022; Hossain et al., 2022; Luo et al., 2023; Naimaee et al., 2024; Gidey and Mhangara, 2025; Puttanapong et al., 2025
	Landsat 7 ETM+	Ding and Elmore, 2015; Wu et al., 2019; Zhang et al., 2019; Pivato et al., 2019; Tan et al., 2020; Naim and Kafy, 2021; Hossain, 2021; Tang et al., 2022; Peng et al., 2022; Luo et al., 2023; Puttanapong et al., 2025
	Landsat 8 OLI/TIRS	Hall and Hossain, 2020; Zhou et al., 2021; Naim and Kafy, 2021; Hossain, 2021; Zhao et al., 2022; Tang et al., 2022; Peng et al., 2022; Hossain et al., 2022; Seo et al., 2022; A and V, 2024; Duan et al., 2024; Mondal et al., 2024; Gidey and Mhangara, 2025; Lin et al., 2020; Naimaee et al., 2024; Wang et al., 2019; Zahn et al., 2021; Firozjaei et al., 2023; Li et al., 2024; Zhang et al., 2025; Puttanapong et al., 2025; Hossain et al., 2025
	Landsat 9 OLI	Puttanapong et al., 2025
MODIS	MOD07	Firozjaei et al., 2023; Zhang et al., 2025
	MOD09GA	Yang et al., 2020

	MOD11A1/A2/A3	Yang et al., 2020; Xu, 2020; Dos Santos, 2020; Zhao et al., 2022; Tang et al., 2022; Peng et al., 2022; Firozjaei et al., 2023; Duan et al., 2024; Li et al., 2024; Saguansap et al., 2024
	MOD13A2/A3	Guo et al., 2019; Dos Santos, 2020
	MCD43A3	Dos Santos, 2020
	MYD1Q31	Xu, 2020
ASTER	GDEM V2	Zhao et al., 2022
	ASTGEM	Dos Santos, 2020
MASTER	5m & 15m	Tan and Cherkauer, 2013
LiDAR	-	Chun and Guldmann, 2014
Land Cover Databases	NLCD	Pagliaro and Knouft, 2020; Zahn et al., 2021; Diem and Orimolade, 2024
	Copernicus CORINE	Li et al., 2024
	MODIS Land Cover	Zhou et al., 2024; Yang et al., 2024

Table 1: Description of analyzed publications based on which remote sensing products were used.

3. Discussion

3.1 Megacities vs. Growing Cities

As of 2025, there are 33 megacities in the world with populations above 10 million (Appendix A). These cities have been extensively shown to exhibit the UHI effect (Hossain, 2021; Saguansap et al., 2024; Puttanapong et al., 2025; Dos Santos, 2020). While these cities have extremely large populations and contribute to a heightened level of global urbanization, there are also many small or mid-sized cites with growing populations. The 2025 UN World Urbanization Prospects Report projects that 81% of the world's 12,000 cities have populations below 250,000 and that this number will only continue to grow up to 2050. This indicates that most people are not living in large megacities and are instead living in small or mid-sized metropolises. Another key point in this report is that the fastest growing cities in the world are in Africa and Asia. Additionally, over two-thirds of these fast-growing cities have populations below 250,000 and typically have less resources to expend on sustainable planning and development (United Nations, 2025).

The urban heat island effect is heavily studied in megacities, but researchers must also study this effect in growing cities. It has been shown that, while less extreme, the UHI effect is also present in smaller cities (Hossain et al., 2022; Hossain et al., 2025). Growing cities provide a phenomenal backdrop for UHI study for many reasons. As these smaller cities are still growing, the extensive record of collections like Landsat allows researchers to easily track the formation of the UHI over a long period, as opposed to a large urban center like New York City which has been heavily urbanized for longer than the Landsat record exists. Growing cities also provide ample opportunity for mitigation and impacts on planning and sustainable development. If we look at New York City again, the structure and sprawl of the city have been determined already. It is very difficult to introduce many practices for developing with UHI prevention in mind because the city is already densely packed with large buildings and other impervious surfaces and the UHI is already intense. Cities like this are instead focused on cooling through practices like urban greening or the implementation of blue infrastructure (Nakayama and Hashimoto, 2011; Chun and Guldmann, 2014; Lin et al., 2020; Saguansap et al., 2024). The smaller scale of growing cities provides a much easier route to prevention. Research can provide actionable insights to policy makers that will help to guide planning and policy decisions that minimize UHI formation in these cities, rather than focusing on modifying existing city structures.

It is important to conduct research in many different locations to get a full view of how the urban heat island impacts cities with varying development patterns or climates. The UHI does not have uniform impacts across every city. Even cities of relatively similar size experience different levels of impact based on development, climate, and size and distribution of vegetation or water bodies (Zhang et al., 2025; Hossain et al., 2025; Wang et al., 2019). It follows that the impact of the UHI on water quality would not be the same for each city. It also would likely differ between different water bodies such as rivers, lakes, and ponds, or rivers and streams with differing morphology. Further research into the effects of the UHI on varying types of water body would be very valuable in exploring the overall UHI effect.

3.2 Technological and Methodological Gaps

Most studies used a combination of Landsat and MODIS imagery, or National Land Cover Database (NLCD) data when unique land cover data was not generated. However, there are some underused technologies that can be powerful when used in conjunction with other data sources.

Google Earth Engine (GEE) is a cloud-based application that provides access to a large catalog of imagery, including Landsat, Sentinel, and MODIS. It also contains "analysis-ready" temperature, climate, atmospheric, and weather data. The GEE code editor allows researchers to easily explore satellite imagery using JavaScript or Python code, providing many opportunities to streamline data analysis. For example, the platform has built-in algorithms for working with Landsat imagery. One such

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algorithm allows you to convert Landsat Digital Number (DN) to top of atmosphere (TOA) reflectance with a single function, simplifying the process of creating land surface temperature (LST) maps. Google Earth Engine also helps to share results with the public in easy-to-understand, impactful ways. This is especially important in research involving the urban heat island as efforts to mitigate the UHI effect are largely based in sustainable development and public policy. Policy makers tend to be especially resistant to environmental concerns, and even more so when those concerns relate to warming or climate change (Ochieng, 2009). Methods of effectively conveying scientific information to policymakers have been extensively researched. These studies stress the importance of illustrative explanations and user-friendly, "visually compelling" methods of delivery (Feldman et al., 2001). One study in this review used GEE and the app functionality to produce an interactive map of lake temperature changes (Li et al., 2024). This is promising work showing that GEE apps can provide a user-friendly interface for sharing results with the public and policy makers in a way that can inspire action.

Another underused technology is NASA's Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). ECOSTRESS is an instrument on the International Space Station (ISS) that is meant to provide high quality temperature data. There are 4 levels of ECOSTRESS data ranging from raw, at-sensor values (L1) to indices incorporating atmospheric data and information from MODIS and Landsat properties (L4) (Fisher et al., 2020). ECOSTRESS imagery is collected very often, with return times between 1 and 4 days, and it has a spatial resolution of 70m (Cite fact sheet). While originally meant for researching plants' resistance to increasing temperature, ECOSTRESS data has very strong applications in UHI study. Much like Google Earth Engine, this imagery can help to streamline analysis because it has ready-to-use LST data, cloud masks, water boundaries, and much more. Members of NASA's Jet Propulsion Laboratory (JPL) have used ECOSTRESS data to create a composite mapping the LST of all streets in Los Angeles, CA by collecting all high-quality imagery from 2018-2023, resampling to 10m resolution, and overlaying the temperature data on a street map of the city.

This method can be replicated for aspects of UHI study such as constructing a map of average temperatures across study sites. The quick return time is extremely useful in this case because it allows researchers to get an average for the specific month that an image was taken with a high resolution. For example, in an ongoing study at the Geological and Environmental Remote Sensing laboratory (GERSLab) at the University of Tennessee at Chattanooga 44 scenes of ECOSTRESS imagery were collected covering Hamilton County, TN in October of 2024. This amount of data allows us to produce a much more accurate map of average temperature across the month, and creating a corresponding LST map from Landsat imagery taken mid-October provides a highly accurate snapshot of deviation from average temperature during that month. Overall, ECOSTRESS imagery can be extremely effective in analyzing temperature changes due to the urban heat island.

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Appendix A: Table of Worldwide Megacity Populations

Region	Country	City	Population (millions)
Asia	China	Shanghai	29.56
		Guangzhou	27.56
		Beijing	17.01
		Shenzhen	13.88
		Suzhou	7.73
		Hangzhou	7.5
		Wuhan	7.36
		Tianjin	7.29
		Chongqing	7.07
	Japan	Tokyo	33.41
		Osaka	12.96
		Nagoya	7.15
	South Korea	Seoul	22.49
	Taiwan	Taipei	9.14
	India	Delhi	30.22
		Kolkata	22.55
		Mumbai	20.2
		Bangalore	13.19
		Chennai	11.15
		Hyderabad	9.19
	Bangladesh	Dhaka	36.59
	Pakistan	Karachi	21.42
		Lahore	15.16
	Indonesia	Jakarta	41.91
	Philippines	Metro Manila	24.74
	Thailand	Bangkok	18.18
	Vietnam	Ho Chi Min City	14.05
	Iran	Tehran	9.18
Africa	Angola	Luanda	11.37
	DR Congo	Kinshasa	10.94
	South Africa	Johannesburg	7.08
	Nigeria	Lagos	12.79
	Egypt	Cairo	25.57
North America	United States	New York	13.92
		Los Angeles	12.74
	Mexico	Mexico City	17.73
South America	Argentina	Buenos Aires	14.02
	Brazil	Sao Paulo	18.95
		Rio de Janeiro	9.5
	Colombia	Bogota	10.62
	Peru	Lima	10.58
Europe	France	Paris	9.38
	Russia	Moscow	14.53
	Turkey	Istanbul	15.02
	United Kingdom	London	10.42