Urban Lakeshore Microclimate Regulation in Jakarta: Land Surface Temperature Insights from Landsat 8

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Abstract *Air temperature in urban areas tends to be higher compared to suburban areas. To address this issue, local governments utilize blue open spaces, such as lakes, which can increase humidity and lower air temperature. In addition, the availability of green open space along lakeshore also offers potential for reducing air temperature. This study aims to measure the microclimate regulation services of three lakeshores in Jakarta (Setu Babakan, Srengseng Urban Forest Lake, and South Sunter Lake) using Landsat 8 imagery and land surface temperature (LST) approach. The results show that Srengseng Urban Forest Lake has the lowest mean LST at 18.81 °C, followed by South Sunter Lake (19.67 °C) and Setu Babakan (20.07 °C). The LST result falls within the comfortable level for humans. The variation of LST indicates that it can be influenced by various factors beyond land cover, such as slope and terrain gradient. These factors can serve as important considerations for stakeholders in designing thermally comfortable public open spaces for visitors.*

Keywords: Blue open space, Lake, Temperature, Thermal comfort, Urban landscape

Introduction

Urban areas tend to have higher air temperatures compared to suburban areas, a phenomenon known as the urban heat island (UHI) (Teurlincx et al., 2019). Intensive development, along with heat-emitting surfaces and limited green open spaces, worsens the city’s thermal conditions. On the other hand, urban residents still need to engage in outdoor activities, both for work and recreation (Fongar et al., 2019; Yin et al., 2025). This situation leads to discomfort among the community, especially during midday when solar radiation reaches its peak. If not properly addressed, the rise in temperature can decrease productivity, reduce quality of life, and in extreme conditions, potentially cause serious health problems such as heat stroke (Mabon et al., 2019). The UHI phenomenon worldwide has affected the physical and mental health of urban populations, while also increasing heat-related morbidity and mortality (Li et al., 2020). In many countries with extreme heat conditions, this phenomenon has led to decreased labor productivity, resulting in significant economic losses.

In addition to affecting humans, high air temperatures in urban areas can threaten the sustainability of atmospheric balance. Various organisms living in urban environments have different adaptive capacities to climate change. Elevated air temperatures pose extinction risks to several sensitive species inhabiting urban areas, such as insects (McGlynn et al., 2019). The loss of certain insect species can reduce the ecosystem service of pollination essential for food provision. Species extinction may also alter the food chain. Several aquatic ecosystems are also affected by UHI due to their high sensitivity to rising temperatures and the increased presence of water pollutants during the dry season (Egwumah et al., 2022). Overall, UHI contributes to biodiversity loss, habitat fragmentation, and ecosystem service decline, underscoring the importance of integrating ecological considerations into urban climate adaptation strategies.

Freshwater ecosystems have the ability to regulate the microclimate by cooling the surrounding area, a phenomenon known as the urban cooling island (Cheval et al., 2020). Microclimate regulation in urban areas is closely related to SDG 11 (sustainable cities and communities) and SDG 13 (climate action). The presence of green open spaces (GOS) within a sufficient distance can have a significant effect on lake ecosystems in reducing surrounding air temperatures (Lin et al., 2020; Wang & Ouyang, 2021; X. Zhou & Chen, 2018). The interconnection between blue open spaces (BOS) and GOS in regulating the urban microclimate indicates that the management of GOS in lake/reservoir ecosystems is inseparable. Green infrastructure has the potential to contribute to ecosystem services in a sustainable manner (Lebrasseur, 2022). Moreover, the provision of urban GOS along lake buffer zones can deliver social, health, economic sustainability, climate, and environmental benefits (Hansen et al., 2019).

To assess the ecosystem service of microclimate regulation in a given area, several approaches can be applied. Conventional methods of measuring temperature and humidity can be carried out using wet- and dry-bulb thermometers. However, geographic information system (GIS) analysis utilizing imagery data with Thermal Infrared Sensors (TIRS) offers several advantages over conventional methods (Cheval et al., 2020). This analysis enables simultaneous measurements at multiple locations, allows for the assessment of surface temperature in past periods, and facilitates the acquisition of multi-temporal surface temperature data.

This study evaluates surface temperature (LST) at three typologically different lake buffer zones in Jakarta including Setu Babakan Lake (residential), Srengseng Urban Forest Lake (urban forest), and South Sunter Lake (commercial). The objectives are to (1) produce multi-site LST estimates under similar atmospheric conditions, (2) examine relation between LST patterns, surrounding land cover, and built-up intensity, and (3) discuss implications for urban heat mitigation strategies. In doing so, the study addresses gaps in comparative, site-specific evidence for blue–green synergy in tropical urban contexts.

Literature Review

a. Urban Heat Island and impacts

The Urban Heat Island (UHI) phenomenon is where urban zones exhibit higher air and surface temperatures than surrounding rural or suburban areas. UHI has been widely documented as a critical consequence of urbanization (e.g., impervious surfaces, high building density, and reduced vegetation cover). Elevated urban temperatures negatively affect human thermal comfort, health (increasing heat-related morbidity and mortality), and labor productivity, and may exacerbate atmospheric imbalances (Y. Li et al., 2020). The human and ecological consequences of UHI include increased risk of heat stroke during extreme events and threats to thermally sensitive species (e.g., certain insect taxa), which can in turn disrupt ecosystem services such as pollination (McGlynn et al., 2019).

b. Blue–Green Infrastructure as Urban Cooling Agents

A growing body of literature highlights that urban cooling is not solely attributable to green open spaces (GOS), but water bodies (blue open spaces, BOS) also exert a strong microclimatic regulating influence. Freshwater systems can produce an "urban cooling island" effect by moderating the microclimate of surrounding areas (Cheval et al., 2020). Several studies suggest that the cooling potential of water bodies may exceed that of vegetation alone because of water's biophysical properties and thermal inertia (Lin et al., 2020; Y. Zhou et al., 2021). The synergistic combination of blue and green infrastructure (e.g., lakes with vegetated buffer strips) produces stronger cooling benefits than green infrastructure alone, and selection of evergreen vegetation in buffer zones can help maintain year-round cooling performance (Egwumah et al., 2022; Wang & Ouyang, 2021; Y. Zhou et al., 2021). Provisioning of green open space along lake buffers additionally yields a broad set of co-benefits including social, health, economic, climatic, and environmental (Hansen et al., 2019; Lebrasseur, 2022). It will support sustainable urban development goals.

c. Spatial Configuration, Land Cover, and Cooling Effectiveness

The effectiveness of blue–green features depends strongly on landscape context and spatial configuration. Proximity and clustering of water bodies can amplify cooling impacts across the urban fabric (Y. Zhou et al., 2021). Conversely, extensive built-up land (industrial complexes, paved surfaces) elevates land surface temperature (LST) through high heat storage and poor cooling capacity, and anthropogenic drivers such as population density and regional economic growth are correlated with increased built-up area and higher LST (Wen et al., 2021; Yuan et al., 2021). Green corridors and vegetated buffers around water bodies act as transition zones that reduce abrupt temperature gradients between water surfaces and adjacent urbanized land (Nikolaus et al., 2022).

d. Remote Sensing Methods for Microclimate and LST Assessment

Remote sensing offers spatially continuous, synoptic measurements that are particularly suited to urban microclimate studies. Thermal infrared sensors (TIRS), such as those on Landsat-8, enable the estimation of land surface temperature (LST) over wide areas and multiple time periods. These are advantages over point-based conventional measurements (e.g., wet/dry bulb thermometers), which are spatially limited (Cheval et al., 2020). Standard processing workflows include radiometric calibration, geometric correction, atmospheric correction (when applied), emissivity estimation, and conversion of radiance to temperature. LST derived from TIRS is widely used to assess spatial patterns of surface heating and to infer potential urban cooling effects, although LST and near-surface air temperature are distinct variables and may differ in absolute value due to energy transfer processes and measurement contexts (Do Nascimento et al., 2022; Peng et al., 2018).

e. Factors Influencing LST Estimates and Interpretation

Interpreting LST requires careful consideration of multiple controlling factors. Surface emissivity varies by land cover and must be accounted for to avoid bias in LST retrievals (Bera et al., 2021). Topography (slope/aspect) alters solar incidence and reflectance, while shadows and local geometry (buildings, trees) can produce localized reductions in apparent LST in thermal imagery due to low emitted radiance from shaded surfaces (Cao et al., 2021). Temporal considerations (season and time of observation) further complicate comparisons between LST and air temperature; for example, in some subtropical contexts LST can be lower than air temperature during spring–summer but higher in autumn–winter, with differences on the order of ~3°C reported (Cao et al., 2021).

f. Empirical Evidence: Lakes, Reservoirs, and Urban Cooling

Empirical studies across different settings show that lakes and reservoirs can reduce local surface temperatures substantially—reported reductions vary but can be on the order of several degrees Celsius (e.g., 5–7°C in some comparative analyses). Case studies demonstrate that urban forests containing water bodies often exhibit the lowest LST averages compared to residential, commercial, or industrial surroundings (Do Nascimento et al., 2022; Lin et al., 2020). Such findings underscore the potential of managed blue–green infrastructure to mitigate UHI effects in cities.

g. Gaps in the Literature

While numerous studies document the cooling effects of blue and green spaces, notable gaps remain. First, many studies evaluate either blue or green infrastructure in isolation; fewer examine the comparative or combined effects of specific lake buffer typologies across contrasting urban landscapes within the same metropolitan area. Second, discrepancies between LST and in-situ air temperature are well recognized, yet standardized protocols for integrating LST results with human thermal comfort metrics in urban planning contexts are still developing. Finally, research focusing on tropical megacities, where seasonal drying and vegetation phenology differ from temperate zones, is comparatively limited. Site-specific analyses are therefore needed to inform local planning (e.g., species selection, buffer widths, and spatial arrangement) that maximize cooling and co-benefits.

Methodology

The study was conducted on three lakes/reservoirs in Jakarta: Setu Babakan Lake (SBL), Srengseng Urban Forest Lake (SUFL), and South Sunter Lake (SSL). These three lakes were selected because they are surrounded by different types of landscapes. SBL is surrounded by residential areas, SUFL is surrounded by urban forest, and SSL is surrounded by commercial buildings. In this way, the potential urban cooling effects of the three lakes can be identified. The map of study location can be seen on Figure 1.

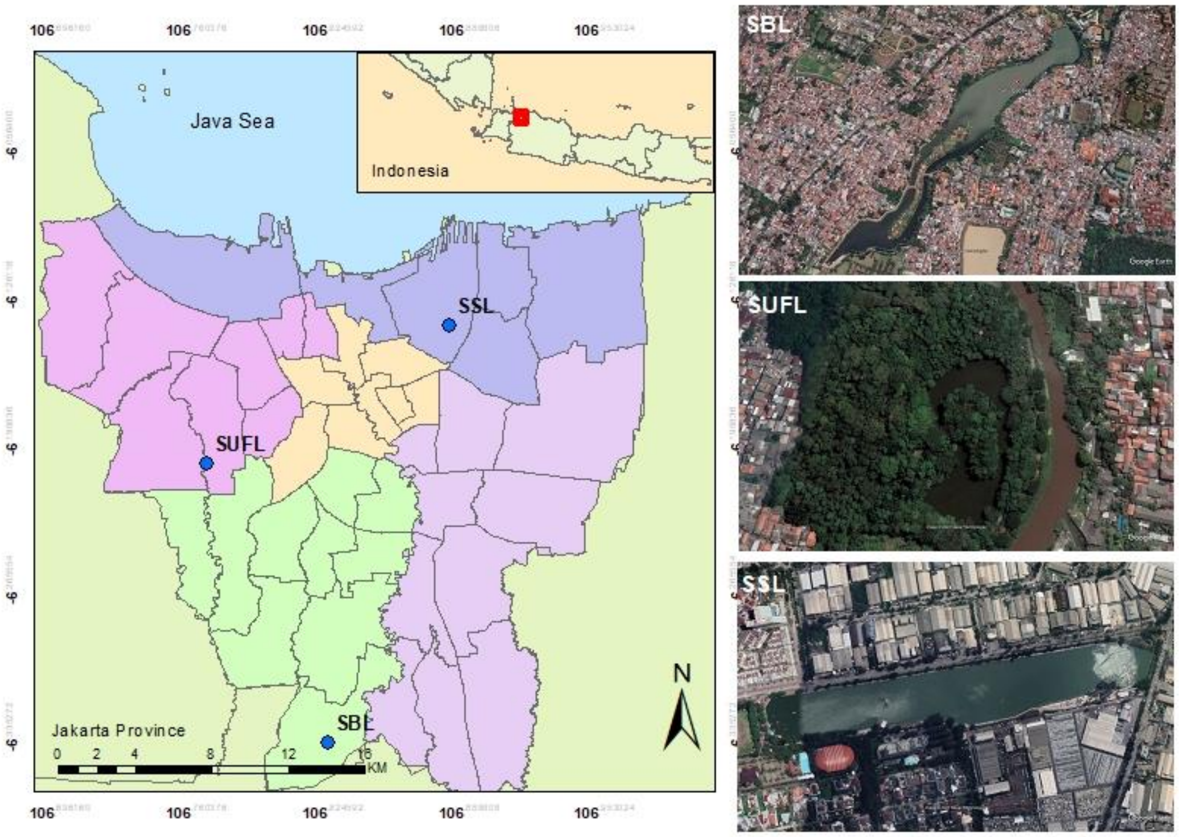

Figure 1: Study locations

Data collection was carried out through satellite image interpretation. Landsat-8 satellite imagery (Path 122 Row 64), band 10, with cloud-free or minimally cloudy conditions in the study area, was obtained from USGS (https://earthexplorer.usgs.gov/). The selected satellite imagery period was during the dry season (July) of 2022. The year 2022 was chosen as the data collection period because of the prolonged dry season, allowing the highest potential surface temperature to be identified, and because satellite imagery during the dry season tends to be relatively free from cloud cover.

In this study, the assessment of microclimate regulation ecosystem services used only one component, namely surface temperature. Before processing, Landsat-8 OLI/TIRS imagery was radiometrically calibrated and geometrically corrected. Visual interpretation methods were applied to obtain lake information from Landsat-8 OLI imagery. Data processing of the lake/reservoir buffer zones was carried out through land surface temperature (LST) analysis of the buffer area using GIS software (ArcGIS 10.8). The surface temperature data processing workflow is shown in Figure 2. Subsequently, the data were analyzed in relation to thermal comfort.

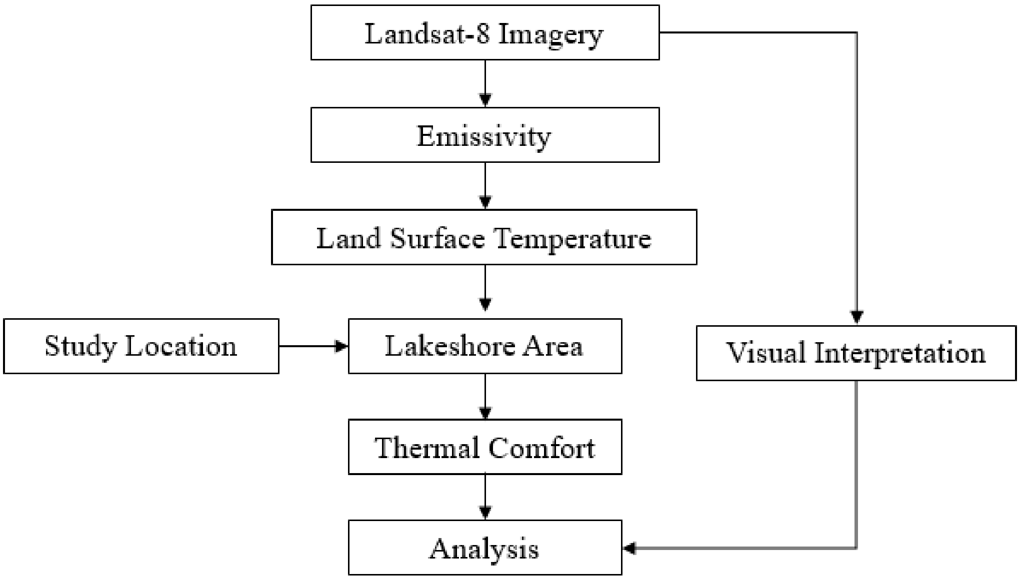

Figure 2: LST Analysis Process

Results and Discussion

The surface temperature values derived from remote sensing analysis are highly influenced by land cover surrounding lakes and reservoirs. Water bodies as a blue open space (BOS) play an important role in lowering surface temperatures. Therefore, lakes located in close proximity to one another can have a positive impact on reducing surface temperatures (Y. Zhou et al., 2021). The potential of water bodies to decrease surface temperature is even considered greater than that of green open spaces (GOS), thus providing a stronger mitigating effect on the urban heat island phenomenon (Lin et al., 2020). The presence of GOS around water bodies also contributes to lowering surface temperatures. GOS such as green belts along the buffer zones of lakes and reservoirs can serve as effective buffer areas between water bodies and surrounding built-up land, preventing a drastic increase in surface temperature from water bodies to adjacent areas.

Compared to GOS alone or BOS alone, the combination of GOS and BOS can provide a greater cooling effect. Water bodies have a more stable cooling capacity due to their strong biophysical characteristics, unlike vegetation, which may shed leaves during the dry season (Y. Zhou et al., 2021). This consideration also highlights the importance of selecting evergreen vegetation around buffer zones so that the cooling effect remains optimal throughout the year. Thus, GOS combined with water bodies (BOS) can provide a stronger cooling effect than GOS without water bodies (BOS).

In contrast to GOS and water bodies, built-up land contributes to increased surface temperatures. Built-up areas have low heat absorption capacity and tend to reflect heat, resulting in poor ability to reduce air temperature (Wen et al., 2021). The positive correlation between the increase in built-up land and surface temperature shows that land surface temperature (LST) is strongly influenced by various anthropogenic factors such as population density and regional GDP growth (Yuan et al., 2021). These two factors significantly contribute to the expansion of built-up areas in urban regions, which in turn leads to an increase in surface temperatures. The LST analysis map can be found on Figure 3, 4, and 5.

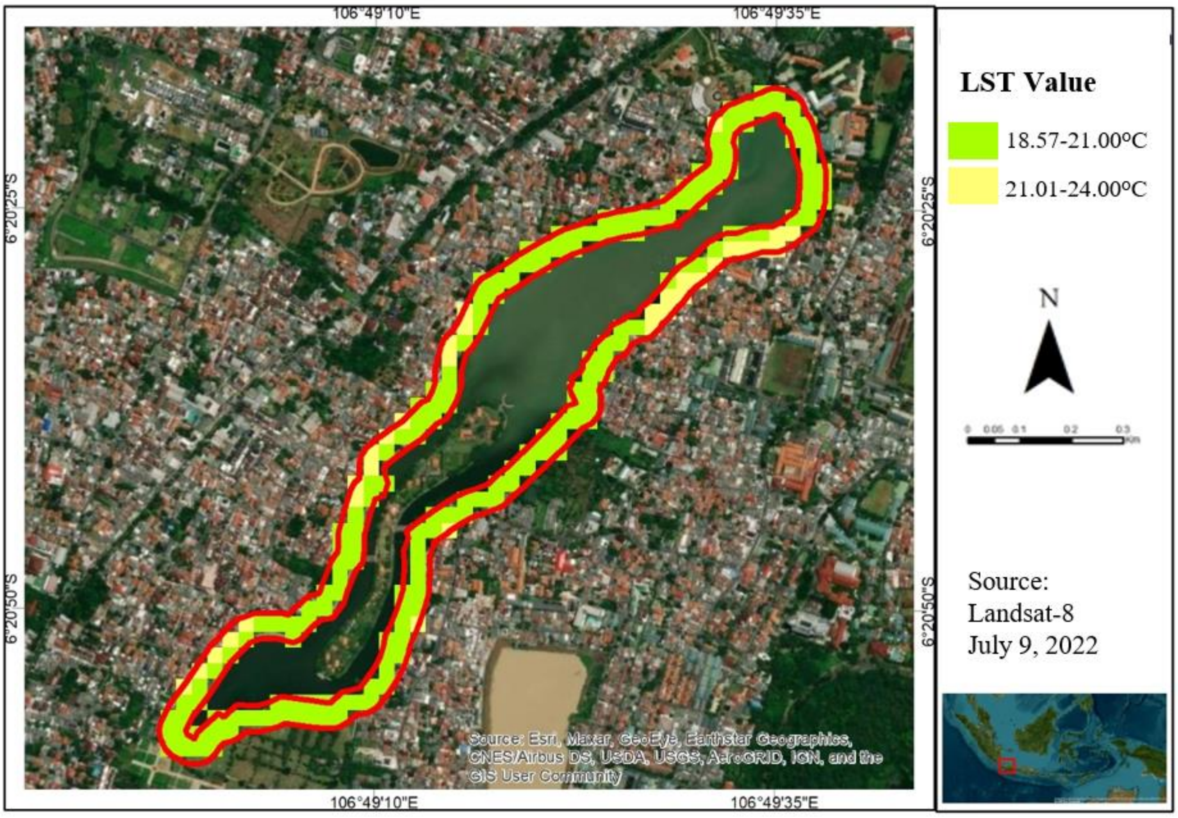

Figure 3: LST Map in Setu Babakan Lake (SBL)

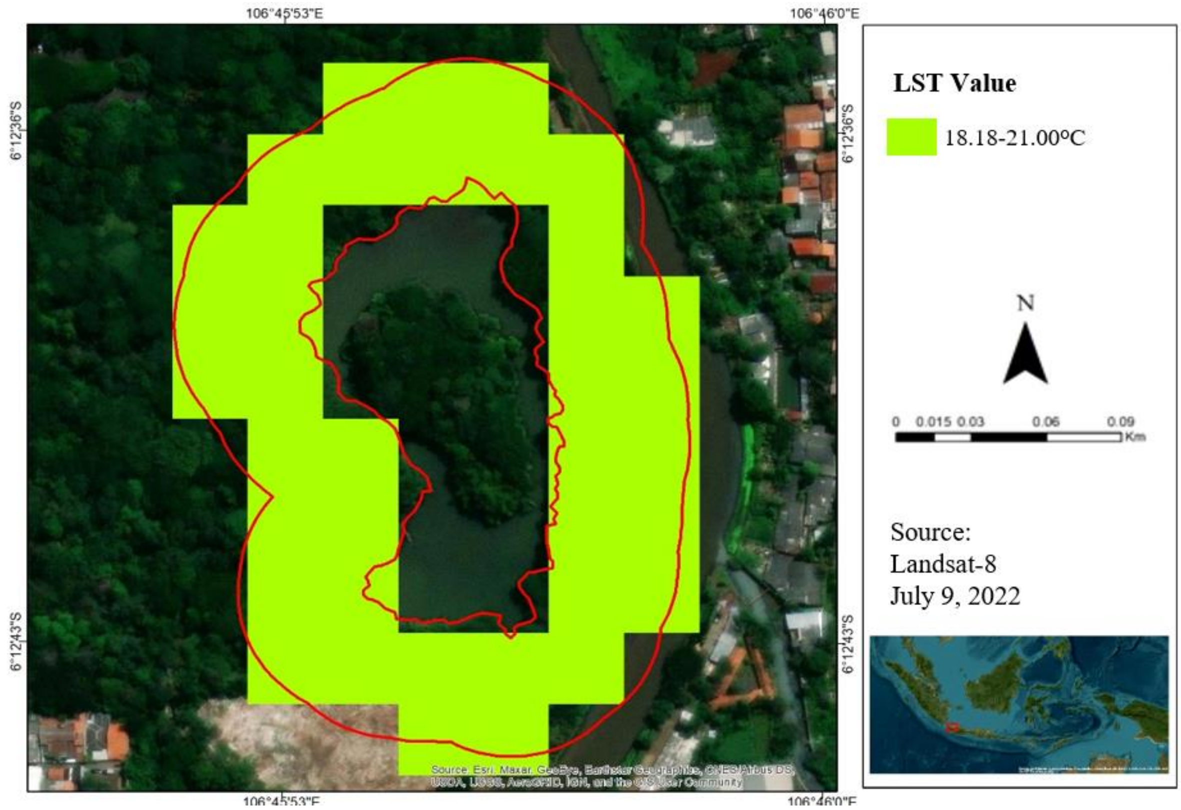

Figure 4: LST Map in Srengseng Urban Forest Lake (SUFL)

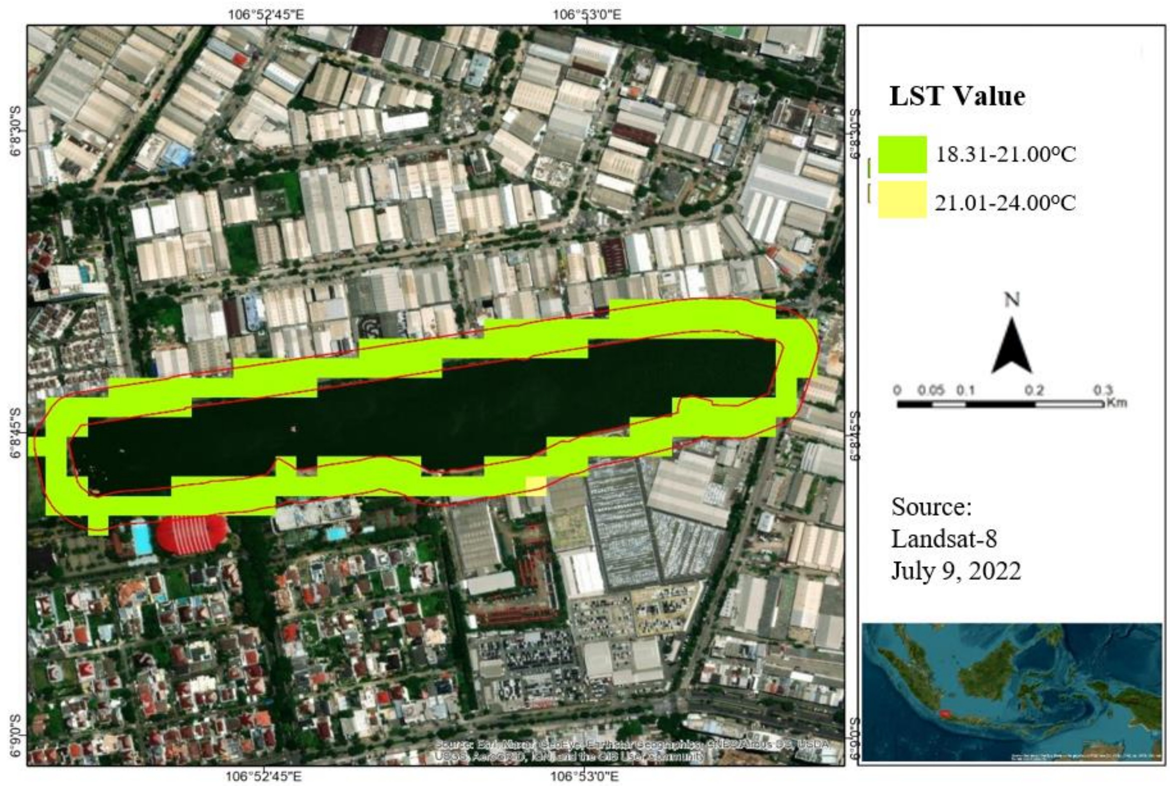

Figure 5: LST Map in South Sunter Lake (SSL)

Table 1: LST Value on Study Location

Location	LST Min (°C)	LST Max (°C)	LST Average (°C)
Setu Babakan Lake (SBL)	18.57	21.57	20.07
Srengseng Urban Forest Lake (SUFL)	18.18	19.45	18.81
South Sunter Lake (SSL)	18.31	21.04	19.67

The LST analysis at the three locations showed relatively low surface temperatures, ranging from 18.18-21.57°C (Table 4.12). This LST range falls within a comfortable level for humans and does not indicate heat stress conditions. The surface temperatures obtained from the LST analysis were lower than the air temperatures recorded on the same date (July 9, 2022) by Kemayoran Meteorological Station in Central Jakarta, which ranged from 25–32°C. This difference indicates that surface temperature values differ from air temperature values. Such differences occur due to energy transfer from the ground surface to the weather station's temperature sensors (Do Nascimento et al., 2022). In several subtropical countries, surface temperatures derived from LST analysis during spring to summer tend to be lower than air temperatures measured by weather stations, while in autumn to winter, surface temperatures are higher than air temperatures, with a difference of about 3°C (Cao et al., 2021).

Apart from being influenced by built-up land, LST is also affected by various other factors. Several studies have shown that slope and inclination affect the angle of incidence and reflectivity of solar radiation. Objects creating shadows around buffer zones may also influence LST values. When direct sunlight is partially or completely blocked and cannot reach the target, shadows form in remote sensing imagery. The presence of shadows in the study area can reduce LST values due to low emissivity. Geographic position and data observation time may also account for differences between air temperature and surface temperature (Cao et al., 2021).

When compared by land cover type, SSL was predicted to have the highest average surface temperature due to the large proportion of built-up land from industrial buildings and paved roads. However, this location recorded slightly lower average surface temperatures than SBL. Based on land cover, areas with the highest potential surface temperatures are those with high population density, followed by areas with low population density and vegetated cover, and finally, areas with vegetation and water bodies (such as rivers, lakes, streams, and dams), which show the lowest temperatures.

Based on the above explanation, building density may be a driving factor behind the lower surface temperature at the buffer zone of SSL compared to the buffer zone of SBL, which has higher building density (Do Nascimento et al., 2022). This also reinforces the potential for lower surface temperatures in urban forests with water body cover, such as SUFL. With an average LST of 18.81°C, this site demonstrated the best microclimate regulation potential among the study locations.

All study sites exhibit considerable potential for microclimate regulation compared to areas dominated by massive built-up land, which are prone to higher surface temperatures. Although LST has a moderate to strong correlation with air temperature, it cannot be directly used as a substitute due to large differences in absolute values. Nevertheless, LST has great potential for detecting elevated air temperature phenomena across various urban locations with ease (Peng et al., 2018). For comparison, the maximum LST at the Pulogadung Industrial Area that is located near the SSL was 26.21°C. This demonstrates that lake and reservoir buffer zones utilized as GOS can reduce surface temperatures by 5–7°C. Similar cooling effects have also been observed elsewhere. Studies in other large cities have shown similar cooling benefits from lakes and vegetation areas. In the Pearl River Delta, China, water bodies were found to act as strong urban heat sinks, reducing the intensity of the surface urban heat island (Lin et al., 2020). In Wuhan, the combination of lakes and surrounding vegetation lowered local temperatures by up to 6 °C, showing the added benefit of blue-green infrastructure (Y. Zhou et al., 2024). Although these studies are from China, the cooling range they reported is in line with what we observed in Jakarta, reinforcing the wider importance of lakes and vegetated buffers as part of urban heat mitigation strategies.

Conclusion and Recommendation

This study demonstrates that lakes and reservoirs in Jakarta play a significant role in regulating urban microclimates, as evidenced by consistently lower land surface temperatures (18.18-21.57 °C) compared to surrounding built-up areas and concurrent air temperatures. The results highlight that microclimatic variations are strongly mediated by landscape composition, with the integration of blue open spaces and vegetated buffers providing synergistic cooling effects that surpass the influence of either element alone. These findings underscore the importance of protecting and enhancing lake buffer zones as critical nature-based solutions for mitigating urban heat islands, while simultaneously delivering co-benefits for human thermal comfort, ecological resilience, and long-term urban sustainability.

Blue-green infrastructure should be integrated into Jakarta's spatial planning to mitigate UHI and support climate adaptation (SDG 11, SDG 13). Evergreen species around lake buffers are recommended around lake buffers to sustain cooling benefits during dry seasons. Municipal regulations should ensure adequate buffer widths for ecological and social co-benefits. Remote sensing and GIS can complement meteorological monitoring, and further research should link LST with thermal comfort indices through multi-seasonal analyses.

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