Identifying temperature 'hotspots' for increasing urban resilience to heat stress in Kolkata, West Bengal, India

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Abstract

Climate change and rapid urbanization have led to increased temperatures in cities, particularly during summer. With projections indicating that over two-thirds of the global population will be urban by 2050, the disruption of biophysical processes and rising intra-urban temperatures pose serious health and environmental concerns. To monitor urban temperature distribution, researchers use ground-based meteorological stations for air temperature and satellite data for land surface temperature (LST). LST maps are especially valuable for identifying temperature "hotspots"—areas with significantly higher temperatures—which can guide targeted adaptation and mitigation strategies. This study focuses on identifying such hotspots in Kolkata district, West Bengal, using Landsat-8 satellite data. Key hotspots include Dhapa (a landfill site), Kidderpore, Chitpur, and Cossipore. Residents in slums near these hotspots face severe challenges during summer, including lack of clean drinking water and extreme heat. Women are disproportionately affected due to domestic responsibilities and social restrictions that prevent them from sleeping outdoors, unlike men.

The analysis reveals that northeastern and mid-western parts of Kolkata are warmer, while central and eastern areas are relatively cooler. This correlates with the presence of blue-green infrastructure, as indicated by NDVI (Normalized Difference Vegetation Index) calculations. To enhance urban resilience, the study recommends afforestation and development of green infrastructure in hotspot areas. Techniques like Miyawaki plantations can rapidly establish urban forests, contributing to climate adaptation and fulfilling Sustainable Development Goals (SDGs) 5 (gender equality) and 11 (sustainable cities and communities).

1. Introduction

In recent decades, the twin forces of climate change and rapid urbanization have significantly reshaped the thermal dynamics of cities across the globe. Urban areas, particularly in developing regions, are experiencing intensified temperature increases during summer months—a phenomenon widely recognized as the Urban Heat Island (UHI) effect. This effect arises from the replacement of natural landscapes with impervious surfaces such as concrete and asphalt, which absorb and retain heat more efficiently than vegetation (Aboulnaga et al., 2024). With projections indicating that over two-thirds of the global population will reside in urban areas by 2050 (Ramachandra et al., 2025), the need to understand and mitigate intra-urban temperature variations has become a pressing concern for sustainable urban development and public health.

The implications of rising urban temperatures are profound, ranging from increased energy consumption and deteriorating air quality to heightened risks of heat-related illnesses, particularly among vulnerable populations. Monitoring and analyzing urban temperature distribution is therefore essential. While ground-based meteorological stations provide localized air temperature data, satellite-derived Land Surface Temperature (LST) offers a broader and more spatially detailed perspective. LST maps are particularly valuable for identifying temperature "hotspots"—localized zones with significantly elevated surface temperatures—which can inform targeted adaptation and mitigation strategies (Ramachandra et al., 2025; Tyagi et al., 2021).

This study centers on the Kolkata district in West Bengal, a densely populated urban region grappling with acute heat stress challenges. Using Landsat-8 satellite data, the research identifies key temperature hotspots which are also home to informal settlements where residents endure extreme summer conditions with limited access to clean drinking water and cooling infrastructure. We have also highlighted the gendered dimensions of heat vulnerability, noting that women face compounded challenges due to domestic responsibilities and social norms that restrict their ability to seek relief from the heat.

The primary objectives of this paper are threefold: (1) to map and analyze the spatial distribution of urban heat hotspots in Kolkata using satellite-derived LST data; (2) to examine the socio-environmental impacts of these hotspots, with a focus on vulnerable populations; and (3) to propose actionable strategies for enhancing urban resilience through afforestation and green infrastructure development. The study advocates for the adoption of techniques such as Miyawaki plantations to rapidly establish urban forests, which can play a pivotal role in climate adaptation. Furthermore, the research aligns with Sustainable

Development Goals (SDGs) 5 and 11, promoting gender equality and sustainable urban communities.

By integrating remote sensing technology with socio-environmental analysis, this paper contributes to the growing body of knowledge on urban climate resilience and offers practical insights for policymakers, urban planners, and community stakeholders.

Study Area:

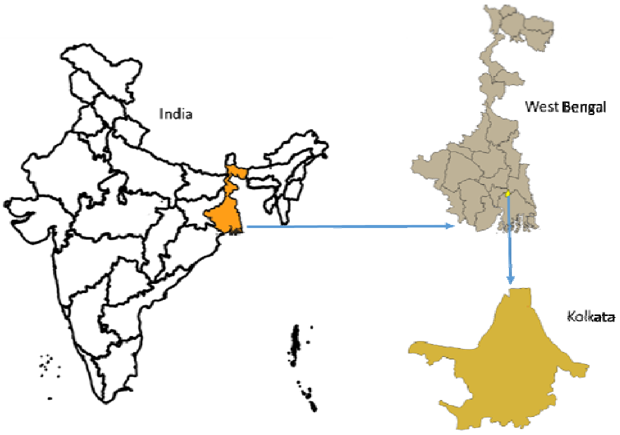

Figure 1: Study Area

Kolkata, the capital of West Bengal, is one of India's oldest metropolitan cities, historically known as Calcutta. Founded in 1690 by Job Charnock, the city emerged from three villages—Sutanuti, Gobindapur, and Kolikata—on the banks of the Hooghly River (Basu et al., 2025). Over centuries, Kolkata evolved into a major trade and cultural hub, serving as the capital of British India until 1911.Kolkata experiences a tropical savanna climate (Köppen classification Aw), characterized by hot, humid summers and mild winters. The annual mean temperature is approximately 26.8°C, with summer highs often exceeding 40°C in May and June (Climate of Kolkata, Wikipedia). Winters are brief, lasting about two and a half months, with lows dipping to around 9–11°C. The city receives an average annual rainfall of 1,836.5 mm, primarily during the South-West monsoon from June to September (Climate of Kolkata, Wikipedia).. Thunderstorms known locally as KalBaisakhi (Nor'westers) occur in early summer, bringing relief from the heat.Kolkata's socio-economic landscape is marked by stark contrasts. While it remains a center for education, culture, and commerce, the city grapples with urban poverty and inequality. Approximately 31.35% of residents live in informal settlements or *bastis*, often lacking access to basic amenities like clean water, sanitation, and solid waste management (Haque et al., 2019).The city has undergone unplanned urban expansion, especially in peripheral areas, leading to encroachment on agricultural land and consequently straining the infrastructure. Migrants from neighboring states such as Bihar, Odisha, and Uttar Pradesh continue to flock to Kolkata in search of employment, often settling in low-income neighborhoods (Haque et al., 2019). Despite efforts to decentralize development to secondary cities like Asansol and Siliguri, Kolkata remains the primary economic magnet in Eastern India. Kolkata's population dynamics have shifted over time. While the city core (the area under Kolkata Municipal Corporation) has seen a negative growth rate of -0.18%, the Kolkata Urban Agglomeration (KUA) continues to grow rapidly due to migration and suburban expansion (Haque et al., 2019). The city's population exceeds 14 million, with a dense concentration in the central districts. Historically, Kolkata has been a melting pot of cultures, with diverse communities coexisting, though segregation by socio-economic class remains prevalent (Basu et al., 2025). The demographic structure reflects a transition from agrarian roots to an urban-industrial society. The division of labor and occupational diversification has fostered economic interdependence, but also exacerbated social inequalities. Urban restructuring has led to a mosaic of residential zones, often delineated by income and caste, reinforcing patterns of exclusion (Basu et al., 2025).

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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Data and Methodology

We used Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal InfraRed Sensor). The datasets were of May month, which is the peak summer month in Kolkata, and of 2014-2019-2024 period. Thus we got the data for 08 May 2014, 06 May 2019 and 03 May 2024. The details of the data used has been given in Table 1.

Table 1: Details of satellite data used (Source: https://landsat.gsfc.nasa.gov/satellites/landsat-8/)

Satellite	Sensor	Spectral Bands	Spatial Resolution	Temporal Resolution
Landsat 8	OLI	Coastal/Aerosol, Blue, Green, Red, NIR, SWIR-1, SWIR-2, PAN, Cirrus	30 m	16 days, equatorial crossing time around 10 AM
Landsat 8	TIRS	TIR-1, TIR-2	100 m	16 days, equatorial crossing time around 10 AM

The Landsat 8 satellite carries two sensors, viz., the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). These two sensors provide seasonal coverage of the global landmass at a spatial resolution of 30 meters (visible, NIR, SWIR); 100 meters (thermal); and 15 meters (panchromatic) for various spectral regions of electromagnetic spectrum.Though the data in thermal bands are collected at 100 m resolution, it is resampled to 30 m by the United States Geological Survey (USGS) before distributing to users. These datasets are downloaded from the earthexplorer website ((https://earthexplorer.usgs.gov/).

LST retrieval from TIR data requires parameters related to atmospheric effects, sensor (like spectral range and viewing angle), and the target surface (such as emissivity and geometry) (Sekertekin and Bonafoni, 2020). Different researchers have proposed different methods of LST retrieval from satellite data depending on these parameters. A raw satellite image provides information in the form of digital numbers (DN). The basic process involves conversion of DN to spectral radiance, which in turn then is converted to brightness temperature (BT)using thermal conversion constants (Rajeshwari and Mani, 2014). BT is then converted to LST employing Land Surface Emissivity (LSE) and Normalized Difference Vegetation Index (NDVI) (Figure 2).LSE providesa measure to know how efficiently a land surface emits thermal infrared radiation compared to a blackbody at the same temperature.It's a value ranges from 0 to 1, where 1 represents a perfect emitter (a blackbody) and 0 represents a perfect reflector.LSE is influenced by factors like surface composition, roughness, and water content. NDVI is a ratio calculated using reflectance captured in red and NIR (Near Infrared) region of electromagnetic spectrum. It provides a quantitative measures of how 'green' an area is.Healthy, green vegetation absorbs most of the visible red light and reflects a large portion of near-infrared light. This difference is used to calculate the NDVI. NDVI values varies from -1 to +1. Values close to +1 indicate presence of dense, healthy vegetation whereas those near -1 are a representation of water bodies.

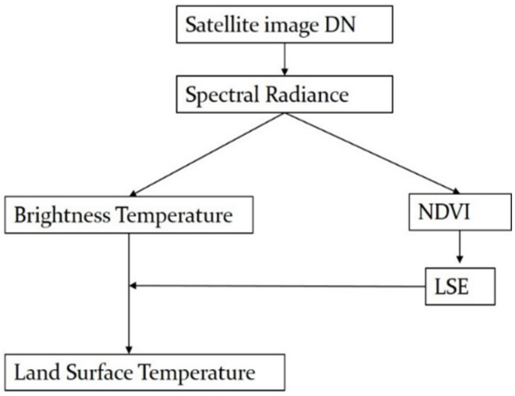

Figure 2: Methodology to compute LST from satellite data

The thermal bands, band 10 and band 11, are mostly employed for the purpose of LST retrieval; however, it has been observed that band 11 has more uncertainty than band 10 (Yu et al., 2014). Therefore, band 10 of Landsat 8 data was used for retrieval of LST.The value of Top of Atmosphere (TOA) spectral radiance (Lλ) was determined by multiplying multiplicative rescaling factor (0.000342) of TIR (Thermal Infrared) bands with its corresponding TIR band and adding additive rescaling factor (0.1) with it.

$$L\lambda = ML*Qcal + AL \quad \text{(Equation 1)}$$

Where, Lλ = Top of Atmospheric Radiance in watts/ (m2*srad*μm)
ML = Band specific multiplicative rescaling factor
Qcal = band 10 image
AL = Band specific additive rescaling factor

The spectral radiance thus computed is converted to Brightness Temperature (BT) through the following equation (Rajeshwari and Mani, 2014):

$$BT=K2/L\lambda\ [(K1/L\lambda) + 1] \quad \text{(Equation 2)}$$

Where K1 and K2- thermal conversion constant and Lλ represents Top of Atmospheric spectral radiance.

The equation to compute LSE is (Rajeshwari and Mani, 2014):

$$LSE\ (\varepsilon) = \varepsilon s\ (1\text{-}FVC) + \varepsilon v * FVC \quad \text{(Equation 3)}$$

Where εs andεv are soil and vegetative emissivity values of the corresponding bands, and FVC is Fractional Vegetation Cover. FVC for an image was calculated by :

$$FVC = NDVI - NDVIs/ NDVIv - NDVIs \quad \text{(Equation 4)}$$

Where NDVIs is NDVI reclassified for soil
NDVIv = NDVI reclassified for vegetation

NDVI is computed from red and near-infrared bands of Landsat 8 OLI data as follows:

$$NDVI = (NIR - Red)/ (NIR + Red) \quad \text{(Equation 5)}$$

The LST is now retrieved using the equation (Yu et al., 2014):

$$LST = \gamma\ [\varepsilon\ \text{-}1\ (\Psi1\ BT + \Psi2)+\Psi3] + \delta \quad \text{(Equation 6)}$$

The symbols γ, Ψ and δ, are coefficients and the equations used to compute these coefficients can be found in Yu et al., 2014.

In addition, we also computed NDBI (Normalized Difference Built-up Index) for the three dates pertaining to 2014, 2019 and 2024.NDBI helps differentiate between areas with human-made structures (like buildings and roads) and natural landscapes (like vegetation and water bodies. This provides an idea of expansion of concrete jungles over the years which essentially are energy trapping and retaining infrastructures leading to a rise in ambient temperatures.Built-up areas tend to reflect more in shortwave infrared (SWIR) region of electromagnetic spectrum and less in NIR, compared to natural vegetation. NDBI utilizes this difference in reflectance to calculate a value that indicates the presence of built-up areas.The NDBI is calculated using the following formula:

NDBI = (SWIR - NIR) / (SWIR + NIR) (Equation 7)

NDBI values typically range from -1 to +1. Negative values generally indicate non-built-up areas (like water and vegetation), while positive values indicate built-up areas.

Results and Discussions

The LST, NDVI and NDBI maps of study area for the duration 2014-2024 are shown in Figure 3, 4 and 5. Spatial analysis reveals that the northeastern and mid-western parts of Kolkata are consistently warmer, while central and eastern regions are relatively cooler. This thermal disparity correlates strongly with the presence of green infrastructure, as indicated by Normalized Difference Vegetation Index (NDVI) calculations. Areas with higher vegetation cover and water bodies tend to exhibit lower surface temperatures, underscoring the importance of ecological planning in urban heat mitigation (Ramachandra et al., 2025; Qian et al., 2022). Compared to 2014, there seems to be a reduction in temperature in 2019. This mostly stems from the impacts of cyclone Fani. This cyclone covered the areas of states like West Bengal and Odisha during 26 April 2019 to 04 May 2019 and brought heavy rainfall in these states which might have resulted in lowering the temperature in otherwise hotter May month. But in 2024, many areas surrounding the central region have also started experiencing temperature in excess of 40°C. Ward numbers 7-29 and 37-47 have showed temperatures exceeding 45°C in 2024. Many of these areas have highly dense slum populations, in which the indoor temperatures can significantly exceed the outdoor temperatures (Mukhopadhyay, et al., 2021). Some areas with high slum populations include Narkeldanga in Ward number 29, Tangra and Tiljala in Ward number 58, and Metiabruz in Ward number 137 (Chakraborty and Bose, 2017). Many areas in these wards have shown the LST> 45°C in all the three study years. Other key hotspots include Dhapa (a landfill site), Kidderpore, Chitpur, and Cossipore. People living in such slums face a variety of problems which are further compounded by extreme heat. Lack of water, sanitation and green cooling areas make the life on slum-dwellers extremely challenging. The situation is all the more severe for women. This is because women are not allowed to sleep outside like men on account of sociological behaviour and norms in the night. This deprives them the chance to cool down even after sunset. As these women work both outside and inside during the day, lack of proper cooling facilities in night does not provide them proper rest. Many slum-dwellers also get-up early to fetch water from public supplies and store them for later consumption. Improper storage of fresh water may also lead to breeding of harmful mosquitoes which may result in outbreak of vector-borne diseases. There is need to prioritize government efforts in such ‘hotspots’ to provide cooling facilities along with other basic amenities to people living in these areas. Government should also consider carrying out plantation drives in such ‘hotspots’ to provide green shelters to local people. Techniques like Miyawaki plantations can be attempted to quickly grow a green belt of local plants in dense, congested areas.

Conclusion

The analysis of Landsat-8 satellite data in this study reveals a significant and growing urban heat island effect in Kolkata, with specific hotspots reaching temperatures over 45°C. The study confirms a strong inverse correlation between land surface temperature (LST) and the presence of green infrastructure, with cooler temperatures consistently observed in areas with higher vegetation cover and water bodies. This highlights the critical role of ecological planning in mitigating urban heat. Notably, the northeastern and mid-western parts of the city are experiencing the most severe heat, and these areas often coincide with dense slum populations, exacerbating the risks for vulnerable communities. The findings underscore the urgent need for targeted, data-driven interventions. While the temperature drop observed in 2019 due to Cyclone Fani demonstrates the temporary cooling effect of natural events, the steady temperature rise observed since then, especially in 2024, indicates that proactive, long-term strategies are essential.

Recommendations and Future Directions

Based on these results, we recommend a focused and multi-faceted approach to enhance urban resilience and protect vulnerable populations. The key recommendations are highlighted as follows:

Prioritize Hotspot Interventions: The efforts of Government and municipal corporations should be concentrated on identified hotspots like Narkeldanga, Tangra, Tiljala, Metiabruz, Dhapa, Kidderpore, Chitpur, and Cossipore. These areas, particularly those with dense slum populations, require immediate action to provide cooling facilities and other essential amenities.

Expand Green Infrastructure: A key strategy for long-term heat mitigation is the rapid expansion of green cover. We propose implementing Miyawaki plantations in dense, congested areas to quickly establish urban forests. This technique can create localized green belts that provide shade, improve air quality, and contribute to a significant reduction in LST.

Address Socio-Economic Disparities: The women in slums are disproportionately affected by extreme heat due to social restrictions. Future strategies must be designed with a gender-sensitive lens, ensuring that cooling facilities and public spaces are accessible to all residents.

Integrate Data-Driven Planning: There is a need of integrated data-driven urban planning combining data from multiple sources like remote sensing, socio-economic, demographic studies. Further, there is a need of continuous monitoring of temperature trends and the evaluation of intervention effectiveness, so as to help the city achieve Sustainable Development Goals (SDGs) 5 and 11.

Further research should focus on a more granular analysis of indoor temperatures in these hotspots and the specific health impacts on residents, particularly women and children. This will provide a more comprehensive understanding of the challenges and guide the development of more effective and equitable solutions.

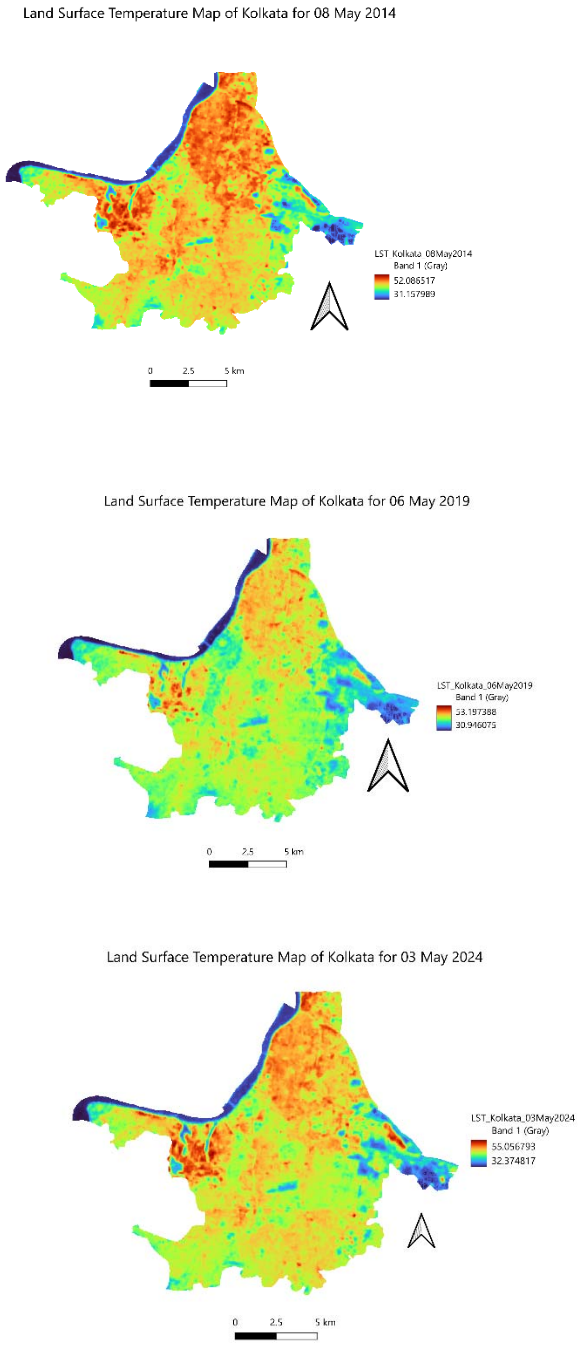

Figure 3: LST maps of Kolkata for May 2014, 2019 and 2024

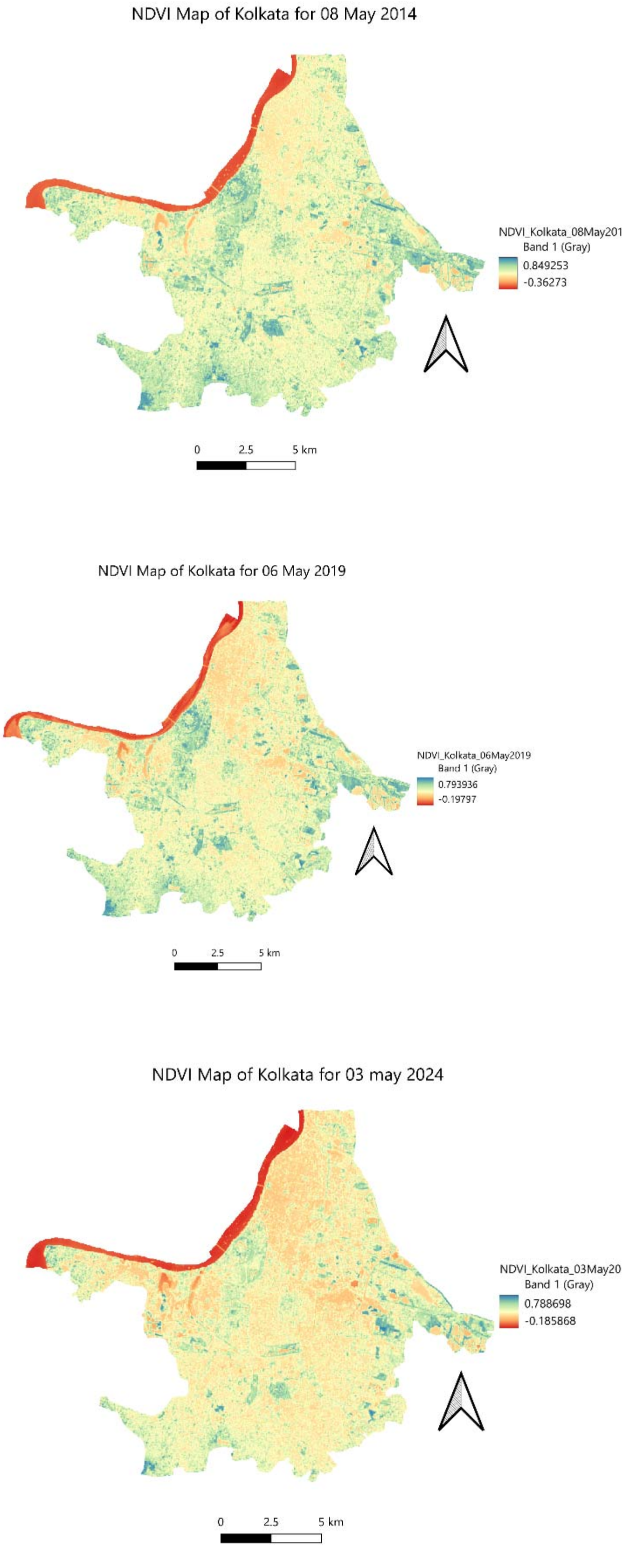

Figure 4: NDVI Maps of Kolkata for May 2014, 2019 and 2024

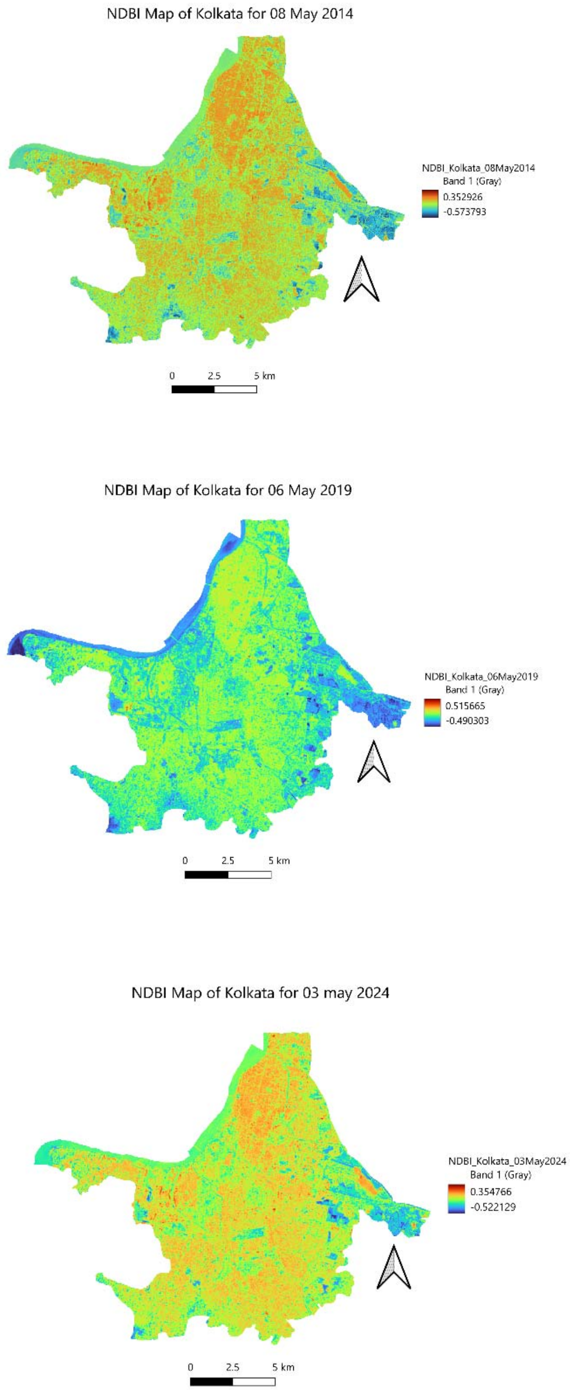

Figure 5: NDBI Maps of Kolkata for May 2014, 2019 and 2024

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