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Integrating Albedo and Remote Sensing Indices to Assess the Urban Heat and Greening Priorities in Trincomalee, Sri Lanka

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I. INTRODUCTION

Rapid urbanisation causes a dramatic increase in built-up areas, while natural vegetation is significantly diminished. Although this supports economic and social development, it has negative impacts on the environment and biodiversity. One of the challenges is the Urban Heat Island (UHI) effect, where built-up surfaces absorb and retain heat, raising urban temperatures compared to surrounding rural areas. The reduction of vegetation, expansion of impervious surfaces, and decline in surface reflectivity (albedo) collectively contribute to thermal stress and reduced urban livability. Assessing these interactions is crucial for climate-sensitive urban planning, especially in rapidly developing coastal cities such as Trincomalee, Sri Lanka. By analysing and correlating key remote sensing indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), Land Surface Temperature (LST), Urban Heat Island (UHI), Urban Thermal Field Variance Index (UTFVI), Greening Priority Index (GPI), and Albedo, this study aims to identify the spatio-temporal variations in green cover and heat patterns between 2015 and 2025 in Trincomalee Town and Gravets DS Division.

II. LITERATURE REVIEW

Urbanisation is one of the main drivers of environmental change, and it has an impact on climatic and land-use mechanisms. It is estimated that in 2018, 55% of people in the world were living in urban cities, and it will increase upto 68% by 2050 [1]. The notable impact of this trend is the Urban Heat Island (UHI) effect, i. e. the fact that urban environments have higher temperatures compared to rural environments, which is explained by the replacement of native vegetation with heat-absorbing surfaces, like concrete and asphalt [2]. In addition, population growth, industrialization, and the development of infrastructure also contribute to this further. In Sri Lanka, studies in Galle have shown a surface temperature rise of about 2.74°C over the past two decades [1]. Research worldwide highlights the link between green space reduction and stronger UHI effects, especially in rapidly urbanising Asian regions [3]. Green spaces help to moderate the surface temperatures via evapotranspiration, increase biodiversity, and capture carbon, but urban development has caused a reduction in the tree cover in Sri Lanka to 61.4% in 2000 to about 52.8% in 2020 [1]. Surface albedo, calculated by the Liang (2001, 2002) equations, provides an idea of the proportion of solar radiation reflected by surface materials. Recognising the connections between vegetation cover, surface reflectivity, and urban heat is vital for designing sustainable mitigation measures and advancing climate-resilient urban planning.

III. MATERIALS AND METHODS

A. Study Area

The study area, shown in Fig. 1 is Trincomalee Town & Gravets Divisional Secretariat Division (DSD). While it serves as the economic and administrative centre of the Trincomalee District, It covers 129.695 km² with 42 Grama Niladhari Divisions (GNDs). The population was 113,994 in 2022, an increase from 97,487 recorded in 2012. Due to its rapid urbanisation, dense coastal settlements, and growing socio-economic and tourism activities, this area is significant for studying urban heat and green space dynamics.

B. Derivation of Key Remote Sensing Indices

The Landsat 8 (OLI/ TIRS - level 2) images were used with the acquisition date of 30 July 2025 (0.10% cloud cover) and 3 July 2015 (10.9% cloud cover) from Path 151, Row 054. After applying proper cloud masking, key remote sensing indices were generated using B1-B10. Those are NDVI for vegetation cover, NDWI for surface water, NDBI for built-up areas, and UTFVI for ecological stress. LST and UHI intensity

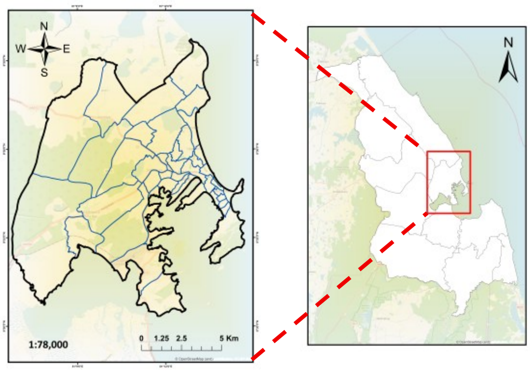

Fig. 1. Study Area - Trincomalee Town & Gravets DS division.

TABLE I. TEMPORAL VARIATION OF LAND USE CLASSES BETWEEN 2015 AND 2025 DERIVED THROUGH KEY REMOTE SENSING INDICES.

Index with Criteria	Feature	Area 2015 (km^2)	Area 2025 (km^2)
NDVI > 0.35	Vegetation	122.68	121.70
NDWI > -0.15	Water bodies	1.44	1.70
NDBI > -0.2	Built-up area	53.95	56.74
UTFVI > 0.1	Ecological stress	29.48	18.88
UHI > 3 °C	Temperature risk zone	23.91	24.97

were calculated using the Mono-Window Algorithm. Meanwhile, Greening Priority Index (GPI) was developed using normalized NDVI and LST layers.

C. *Albedo Mapping and Correlation Framework*

Surface albedo was calculated using Liang (2001, 2002) equation from Landsat 8 imagery. All layers were preprocessed to a common coordinate system and resolution to ensure the spatial consistency. 1,000 random sample points were generated, and correlation analysis was performed with the aid of Python libraries, and Pearson correlation coefficients (r) and determination values (R^2) were calculated to quantify the strength and direction of these associations. These parameters served as an internal validation step for generated indices.

IV. RESULTS AND DISCUSSION

A. *Temporal Changes in Land Use Classes Derived through Key Remote Sensing Indices (2015-2025)*

Table I summarises the area coverage of land use classes derived from remote sensing indices. While the results highlight a slight increase in built-up areas and UHI, they also indicate a reduction in ecological stress and vegetation cover.

B. *Greening Priority Zones and Surface Reflectance*

Fig. 2 illustrates the spatial distribution of the GPI and Albedo for 2025. The GPI analysis indicates that low-priority (red) zones, representing areas with insufficient vegetation and higher heat accumulation, expanded from 35.78 km^2 (27.56%) in 2015 to 41.77 km^2 (32.17%) in 2025. Conversely, sufficient-green-cover areas increased marginally by 2.47 km^2, showing localised improvement. The Albedo map reveals that highly reflective surfaces, mainly water bodies and dense vegetation, which cover 3.81% of the area, while moderate-albedo zones, dominated by mixed vegetation, occupy 69.11%, and low-albedo urban areas represent 26.98%. These findings highlight the spatial imbalance between vegetated and built-up zones and demonstrate the importance of enhancing urban greening and reflective surfaces to mitigate surface heat accumulation and improve thermal comfort.

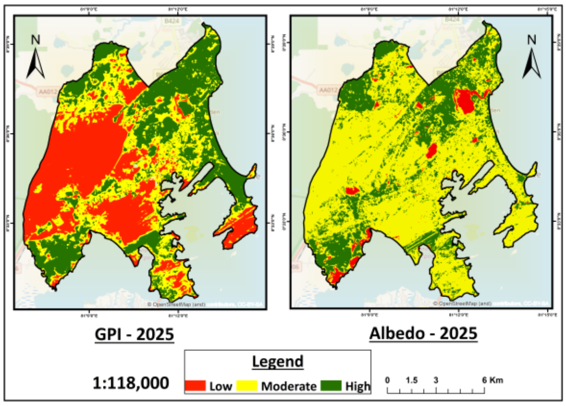

Fig. 2. Greening Priority Index (GPI) Map, and Albedo Map for 2025.

TABLE II. DETERMINATION VALUES (R^2) AMONG KEY REMOTE SENSING INDICES AND THERMAL PARAMETERS.

Indices	LST	UTFVI
NDVI	-0.63	-0.63
NDBI	+0.78	+0.77
NDWI	+0.48	-
GPI	+0.90	-
Albedo	+0.43	-

C. *Correlation between Key Remote Sensing Indices*

Table II shows the results of correlation analysis. The negative correlation between NDVI and LST (r = -0.63) indicates the cooling effect of vegetation, while the strong positive correlation between NDBI and LST (r = 0.78) confirms that impervious surfaces intensify urban heat. Similarly, GPI shows a high positive correlation (r = 0.90) with LST, validating its reliability as an indicator for identifying thermally stressed, low-vegetation zones.

This study is limited by the use of two Landsat acquisition dates, which may not fully capture seasonal variations in vegetation and surface temperature. The 30 m resolution restricts the detection of fine-scale urban features such as narrow streets and small vegetation patches. In addition, the analysis did not include socio-economic factors or on-ground measurements due to data constraints.

V. CONCLUSION

This study demonstrates that integrating NDVI, NDBI, NDWI, LST, UTFVI, GPI, and Albedo offers a clear and effective approach to identifying heat-stressed and low-vegetation zones in Trincomalee. The results highlight how the expansion of built-up areas and the persistence of low-albedo surfaces contribute to elevated surface temperatures, reinforcing the importance of vegetation and reflective surfaces in regulating urban heat. Beyond the local findings, the study emphasizes broader implications for climate-sensitive urban planning in rapidly developing coastal cities. Future work could benefit from the use of multi-season imagery, higher-resolution datasets, and ground-based measurements to improve the precision of thermal analysis. Integrating socio-economic factors and modelling alternative greening or urban-design scenarios would further strengthen planning relevance. The insights produced here support targeted, evidence-based interventions that can help reduce heat exposure, enhance urban resilience, and guide sustainable development in Trincomalee and similar urban environments.

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