Urban Heat Island Intensity Assessment through Comparative Study on Land Surface Temperature and Normalized Difference Vegetation Index: A Case Study of Chittagong, Bangladesh

Tausif A. Ishtiaque, Zarrin T. Tasin, Kazi S. Akter

***Abstract*—**Current trend of urban expansion, especially in the developing countries has caused significant changes in land cover, which is generating great concern due to its widespread environmental degradation. Energy consumption of the cities is also increasing with the aggravated heat island effect. Distribution of land surface temperature (LST) is one of the most significant climatic parameters affected by urban land cover change. Recent increasing trend of LST is causing elevated temperature profile of the built up area with less vegetative cover. Gradual change in land cover, especially decrease in vegetative cover is enhancing the Urban Heat Island (UHI) effect in the developing cities around the world. Increase in the amount of urban vegetation cover can be a useful solution for the reduction of UHI intensity. LST and Normalized Difference Vegetation Index (NDVI) have widely been accepted as reliable indicators of UHI and vegetation abundance respectively. Chittagong, the second largest city of Bangladesh, has been a growth center due to rapid urbanization over the last several decades. This study assesses the intensity of UHI in Chittagong city by analyzing the relationship between LST and NDVI based on the type of land use/land cover (LULC) in the study area applying an integrated approach of Geographic Information System (GIS), remote sensing (RS), and regression analysis. Land cover map is prepared through an interactive supervised classification using remotely sensed data from Landsat ETM+ image along with NDVI differencing using ArcGIS. LST and NDVI values are extracted from the same image. The regression analysis between LST and NDVI indicates that within the study area, UHI is directly correlated with LST while negatively correlated with NDVI. It interprets that surface temperature reduces with increase in vegetation cover along with reduction in UHI intensity. Moreover, there are noticeable differences in the relationship between LST and NDVI based on the type of LULC. In other words, depending on the type of land usage, increase in vegetation cover has a varying impact on the UHI intensity. This analysis will contribute to the formulation of sustainable urban land use planning decisions as well as suggesting suitable actions for mitigation of UHI intensity within the study area.

***Keywords*—**Land cover change, land surface temperature, normalized difference vegetation index, urban heat island.

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I. Introduction

RAPID urbanization has become a common phenomenon particularly in developing countries complying with the increasing trend of development [1]. More than 50% of the total population of the world is estimated to live in the urban areas and this ratio is predicted to reach 69.6% by 2050 [1]. Urbanization has immense impact on LULC pattern since ecosystems in urban areas are strongly affected by human activities [2]. Currently, land cover change is considered as one of the major driving forces of global environment change. UHI is the most familiar climatic phenomenon used to depict the relationship between urbanization and global climate change.

UHI phenomenon indicates that the heat discrepancy between the urban environment and its surrounding rural areas is due to their variation in relative surface cooling rates. Urban environment has higher atmospheric temperature compared to its peripheries due to recent large-scale replacement of urban vegetation cover with non-evaporating surface having high heat capacity and low solar reflectivity triggering instability of urban atmosphere. Urban thermal environment is strongly influenced by LULC characteristics and vegetation abundance contributing to cooler microclimates. LST is a widely recognized index for demonstrating UHI intensity, as typically there is a high correlation between atmospheric temperatures and surface temperatures in the canopy layer due to emission of thermal energy from surface to atmosphere. Moreover, NDVI is one of the most commonly used vegetation indices for estimation of vegetation abundance.

This study aims to assess the UHI intensity of the study area by portraying a relationship between satellite-derived LST and NDVI values through regression analysis. The findings of this study will assist in the mitigation of UHI impact within the study area and formulating corresponding adaptation to the challenges of climate change.

II. Objective

This study will chiefly address the following objectives:

1. To establish the general relationship between LST and NDVI within the study area based on LULC type through regression analysis.

2. To detect the LULC types that will be most conducive for reduction of urban temperatures through increased vegetation cover leading to UHI mitigation.
3. To contribute in the formulation of sustainable urban planning and sound environmental management policies towards UHI mitigation.

III. Study Area

Chittagong city, located in Chittagong district, is comprised of small hills and narrow valleys and surrounded by rivers. The city lies within 21°54′ north to 22°59′ north latitude and 91°17′ east to 92°14′ east longitude. It is bounded by the Karnaphuli River to the south-east, the Bay of Bengal to the west, and Halda River to the north-east. Chittagong city is under the jurisdiction of various authorities, known as Chittagong City Corporation (CCC), Chittagong Metropolitan Area (CMA), Chittagong Statistical Metropolitan Area (CSMA) and Chittagong Development Authority (CDA). The selected study area for this study is CCC (Fig. 1). The city, under the jurisdiction of City Corporation has a population of about 2.5 million with an area approximately of 168 square kilometers [3].

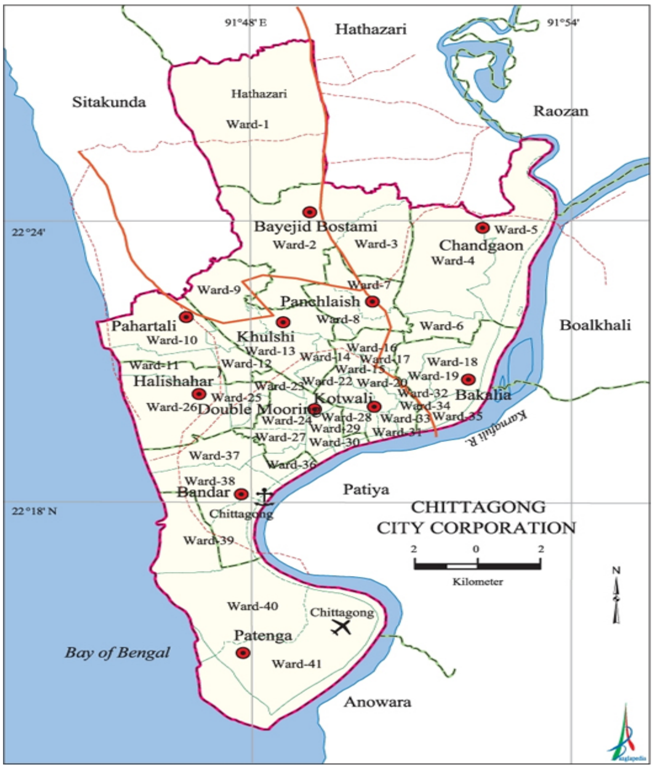


Fig. 1 Location map of Chittagong City Corporation [4]

IV. Methodology

We have derived both LST and NDVI maps of CCC from the same Landsat 7 ETM+ imagery dated 16th April, 2014. The image was acquired at 4:16 p.m. local time under clear weather conditions (0% cloud coverage). The temperature at the time of capture was 34°C and the humidity was 35%.

Previous studies have revealed that SUHI intensities are at their greatest during the afternoon and hence Landsat images were duly selected to represent the UHI anomaly through contrast between LST [5]. Therefore, the selection of the image, which was the best image available given that it was captured in the afternoon, is suitable.

A. Satellite Imagery Pre-Processing

Atmospheric condition was considered to be uniform in the image without application of atmospheric correction as the image was taken at 0% cloud coverage condition.

The USGS geometrically corrected and georeferenced the satellite image to the WGS1984 datum and Universal Transverse Mercator (UTM) zone 46N coordinate system. This correction process employs both digital elevation models and ground control points for obtaining a product devoid of distortions corresponding to the rotation, curvature etc. of the earth, view angle effects of sensor and attitude deviations from nominal for satellite.

B. Data Processing

1. Derivation of NDVI

For calculating NDVI values of the study area, the reflectance values from the red (ρred) and near- infrared (ρnir) channels were used (1) [6]:

$$NDVI = (\rho_{nir} - \rho_{red}) / (\rho_{nir} + \rho_{red}) \quad (1)$$

2. Derivation of LST

The images in the thermal band of Landsat 7 ETM+ sensor are captured twice: once in low gain mode (band 6L) for surfaces with high brightness and once in high gain mode (band 6H) for surfaces with low brightness [7]. As the image acquired on 16th April, 2014 had relatively high brightness, Band 6L was used in this study.

3. Conversion to Radiance

Pixel values are converted to units of absolute radiance using 32 bit floating-point calculations. These values are then scaled to byte values prior to media output. In order to convert DN to radiance units the following equation is used:

$$L\lambda = Grescale * QCAL + Brescale \quad (2)$$

which can also be expressed as [7]:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN\lambda \quad (3)$$

where: Lλ=spectral radiance at the sensor's aperture; QCAL = digital number (DN) of the band 6; QCALMIN = minimum quantized calibrated pixel value = 1; QCALMAX = maximum quantized calibrated pixel value = 255; LMAXλ = spectral radiance scaled to QCALMAX; LMINλ = spectral radiance scaled to QCALMIN.

4. Conversion to Temperature

ETM+ imagery can be modified from spectral radiance to the effective at-satellite temperatures of the viewed Earth-atmosphere system assuming unity emissivity and applying pre-launch calibration constants. The modification formula [8] is:

$$T = \frac{K2}{\ln(\frac{k1}{L_\lambda}+1)} \quad (4)$$

where T is the effective at-satellite temperature with unit Kelvin, K2 is the calibration constant 2, K1 is the calibration constant 1 and L is the spectral radiance with unit watts/(meter squared * ster * µm).

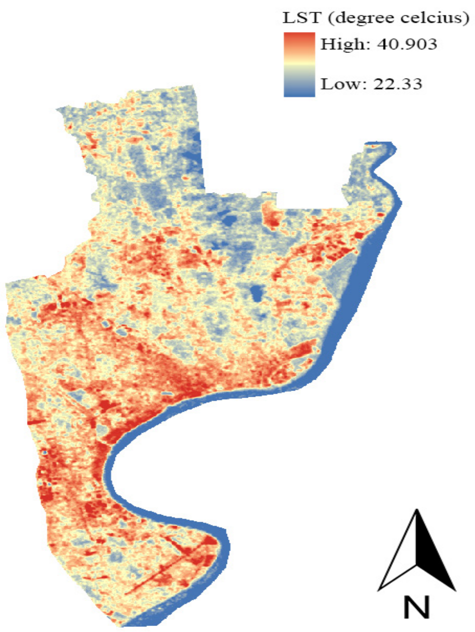
TABLE I
ETM+ AND TM THERMAL BAND CALIBRATION CONSTANTS

	Constant 1- K1 watts (meter squared * ster * µm)	Constant 2-K2 Kelvin
Landsat 7	666.09	1282.71
Landsat 5	607.76	1260.56

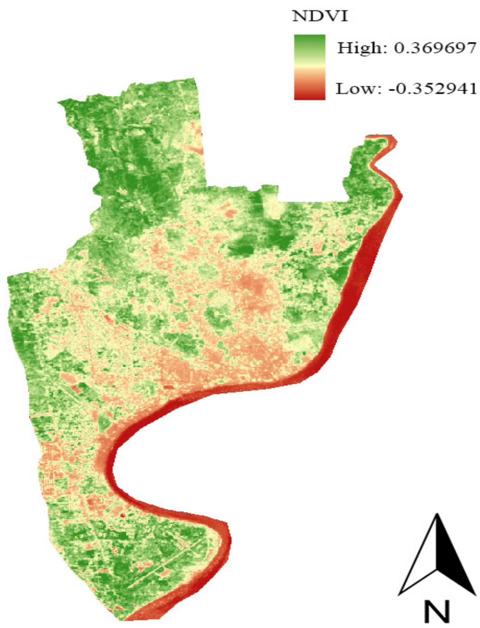
V. RESULT

A. Visual Interpretation of LST and NDVI Imagery

Figs. 2 (a) and (b) show the spatial distribution of LST and NDVI amidst the study area. Visual pattern indicates that highest vegetation cover is concentrated primarily in the northern part of the study area with maximum NDVI value. Some pockets of high NDVI values are also observed in the central and outer regions of the area. Low vegetation cover appears in the central portion of the study area as well as along the river boundary. LST distribution pattern is found opposite to that of NDVI. UHI hotspots are observed in the central part where as low LST values are obtained in the northern part of the study area.



(a)

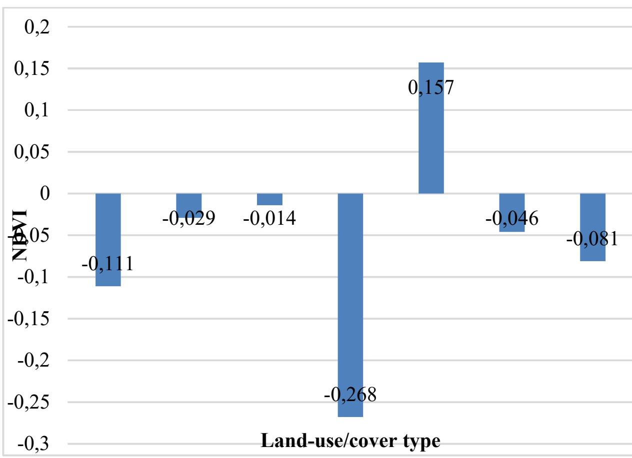


(b)

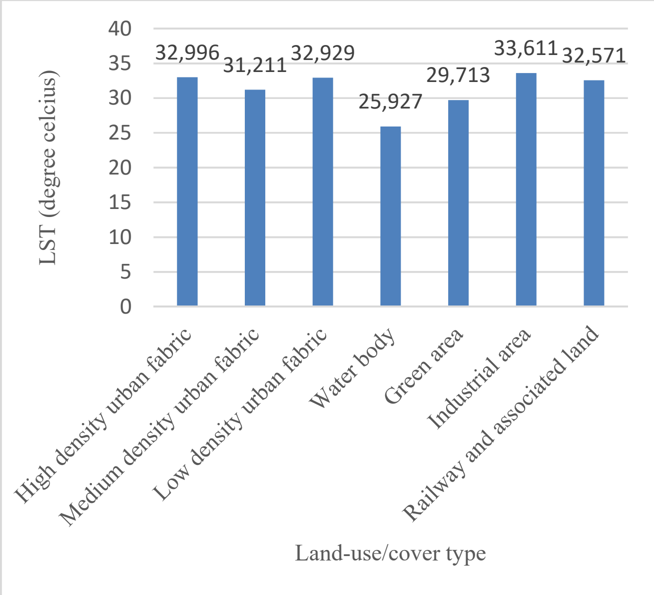
Fig. 2 (a) LST image of the study area, (b) NDVI image of the study area

B. Differences in Mean LST and Mean NDVI by LULC Type

Figs. 3 (a) and (b) demonstrate the statistical analysis of LST and NDVI values respectively based on selected LULC types. Highest mean NDVI value (0.1567) is exhibited by the LULC type "green areas" due to predominance of vegetation cover within this area corresponding to the lowest mean LST value (29.7125) following "water bodies" (25.9271). This phenomenon results from relatively higher rate of evapotranspiration in this zone. Lowest mean NDVI value (-0.1114) is exhibited by the LULC type "high density urban fabric" following "water bodies" (-0.2677) due to shortage of vegetation cover within this area corresponding to the second highest mean LST value (32.9959). The LULC types "railways and associated land" and "industrial areas" also exhibited very low mean NDVI values (-0.0810 and -0.0461 respectively).



(a)



(b)

Fig. 3 (a) Mean values of NDVI associated with each LULC type, (b) Mean values of LST associated with each LULC type

The LULC type “water bodies” illustrates the lowest mean NDVI reading due to unavailability of vegetation cover within this area. Mean LST value of “water bodies” is also lowest as surface temperature of water increases very slowly. This phenomenon interprets that water bodies do not portray an inverse correlation between LST and NDVI like other land cover types.

C. Relationship between LST and NDVI for all LULC Polygons

Fig. 4 demonstrates a regression analysis between mean LST and mean NDVI values for all LULC polygons within the study area. The result depicts significant inverse relationship between LST and NDVI values of the study area. This indicates that LULC polygons with high NDVI readings generally register low LST readings and vice versa.

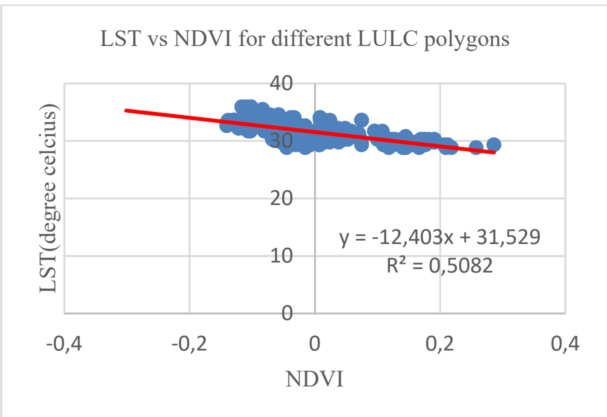


Fig. 4 Linear regression scatter plot of mean LST and mean NDVI associated with every LULC polygon (excluding polygons defined as “water bodies”).

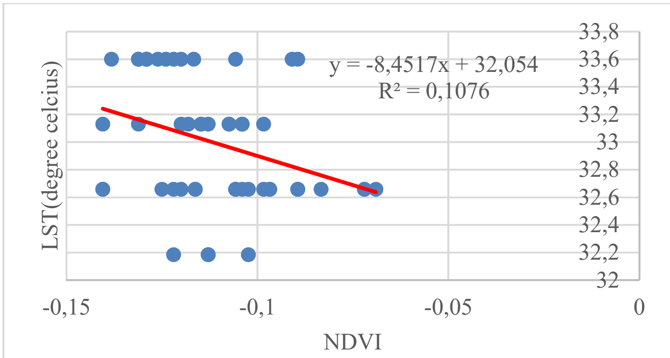
D. Relationship between LST and NDVI by LULC Type

Table II demonstrates the relationship between LST and NDVI for each LULC type by presenting the regression functions and correlation co-efficient (R^2) that measures the strength of linear regression.

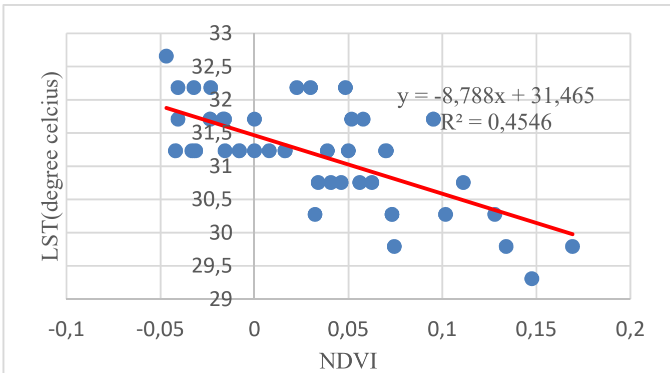
TABLE II
LINEAR REGRESSION RESULTS: MEAN LST AND MEAN NDVI BY LULC TYPE

LULC type	Regression function	R^2
High density urban fabric	y = -8.4517x + 32.054	0.1076
Medium density urban fabric	y = -8.788x + 31.465	0.45459
Low density urban fabric	y = -3.1719x + 29.861	0.06685
Water body	y = 2.3433x + 26.555	0.01285
Green area	y = -6.2575x + 30.694	0.14261
Industrial area	y = -13.771x + 32.975	0.28003
Railway and associated land	y = -7.8552x + 31.934	0.15332

A significant inverse relationship was found between LST and NDVI of all LULC types except water bodies. “Industrial areas” indicated the steepest negative regression slope whereas “urban low density fabric” indicated the shallowest negative regression slope. In other words, with increasing NDVI the LST of “industrial areas” decreases the fastest whereas that of “urban low density fabric” decreases the slowest.



(a)



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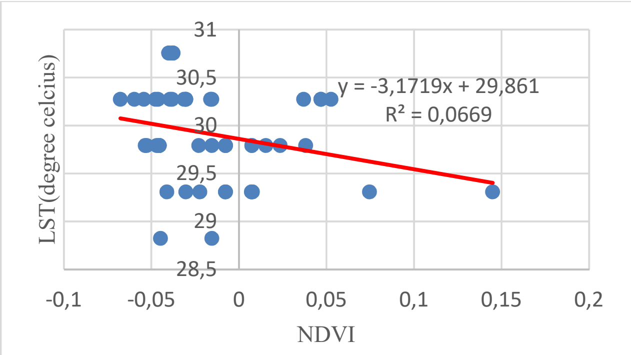

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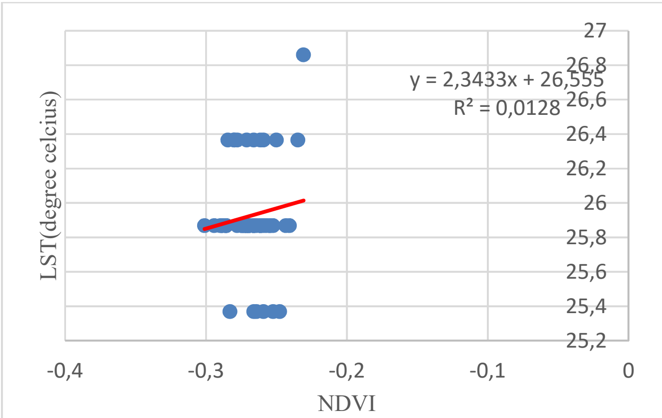

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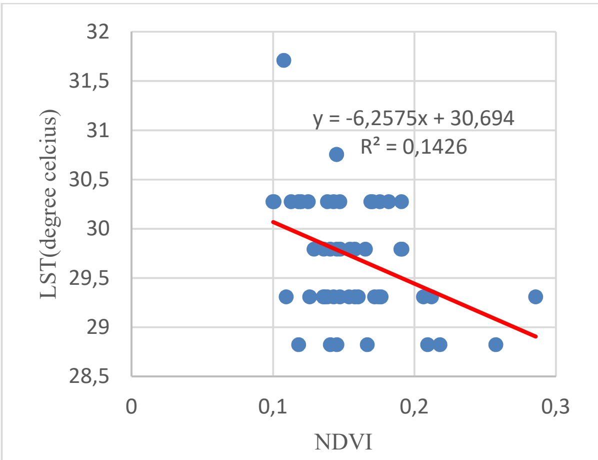

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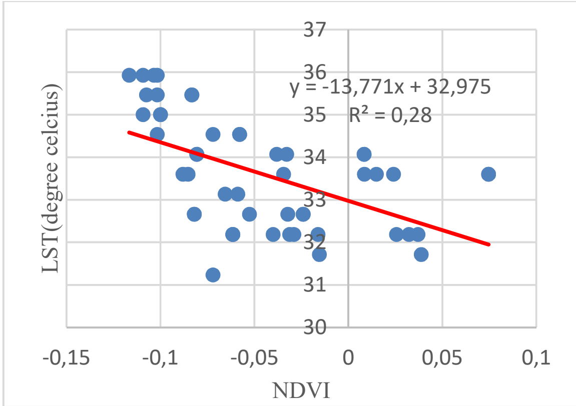

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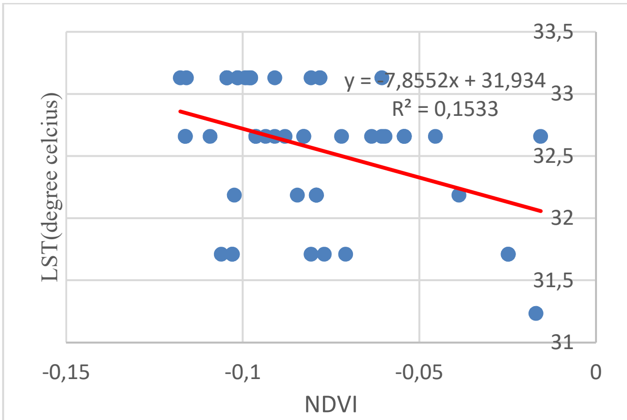

(g)

Fig. 5 (a) LST vs NDVI for "high density urban fabric" (b) LST vs NDVI for "mid density urban fabric" (c) LST vs NDVI for "low density urban fabric" (d) LST vs NDVI for "water body" (e) LST vs NDVI for "green area" (f) LST vs NDVI for "industrial area"(g) LST vs NDVI for "railway and associated land"

VI. Discussion

The general pattern of UHI is related to LST readings whereas LST is associated with the land surface characteristics and LULC types. Inverse correlation is observed between LST and NDVI for all LULC types throughout the study area. The LST of "industrial area" is the highest among all LULC types and it is highly affected by NDVI compared to other areas. This implies that with the increase in vegetation cover in this area, reduction in urban temperature will be most effective. Therefore, increase in vegetation cover in industrial area can be particularly significant in improving urban thermal environment of the study area.

Chittagong city has turned into a growth center in recent years. Residential LULC types cover a major portion of the study area and it is likely to be expanded more in near future. So the thermal characteristics of residential LULC types have a noticeable impact on the thermal environment of the study area. Study results indicate that "urban low density fabric" exhibit the third highest mean LST but produces the mildest negative regression slope among all LULC types. This signifies that with the increase in NDVI value in this zone, decrease in LST will be the slowest compared to other zones. On the other hand, "urban high density fabric" exhibiting the second highest mean LST is comparatively much more effective in reduction of LST through increase in vegetation surface in this area. The result also indicates that the slope of "urban mid density fabric" is steeper than that of "urban high density fabric". This anomaly in result occurred since the correlation between only two basic parameters LST and NDVI is used in this study for simplification of analysis. The influence of other parameters like pressure, altitude etc. is not considered in this study.

VII. Conclusion

This study focuses on the functionality of urban vegetation cover for reducing UHI intensity and consequently diminishing the increased LST values within urban areas that are predicted to occur due to climate change. Awareness regarding this functionality can serve as a means for adaptation to climate change and lessening adverse impacts of urban development through improved urban planning and environmental management policies. This study found that LST and NDVI shared a significant inverse correlation within the study area implying that increasing vegetation cover will generally decrease surface temperatures and thus UHI intensity. These relationships showed different patterns for different LULC types. It interprets that lowering temperature by increasing the amount of vegetation cover is not equally effective for all LULC types. This study specifically points out that increasing vegetation abundance within industrial areas can be particularly effective in reducing urban surface temperatures and thus reducing the intensity of UHI in the study area. The findings presented in this study can be notably useful to those concerned with UHI mitigation and involved in urban and ecological planning.

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