Indian Journal of Spatial Science
Spring Issue, 11 (1) 2020 pp. 69 - 75

Indian Journal of Spatial Science
Cosmos Impact Factor 2018 : 6.521 IP Index 2019 : 2.080 Advanced Science Index 2019 : 1.320
Peer Reviewed and UGC Approved (Sl No. 7617)
EISSN: 2249 - 4316 Homepage: www.indiansss.org ISSN: 2249 - 3921

Estimation of Land Surface Temperature of Cooch Behar Municipality to study Urban Heat Island using Landsat 8 Image

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Article Info

Article History

Received on:
14 January 2020
Accepted in *Revised Form* on:
14 February, 2020
Available *Online* on and from:
21 March, 2020

Keywords
Land Surface Temperature
SUHI
NDBI
NDVI
Landsat8 Data.

Abstract

Global warming has obtained more and more attention because the global mean surface temperature has increased since the late 19th century. As more than 50% of the human population lives in cities, urbanization has become an important contributor to global warming. The changes in land use/cover include loss of agricultural lands, loss of forest lands, increase of barren area, increase of impermeable surface of the area because of the built-up area, etc. The development of land use land cover is very much useful to the city planner and policymakers. For the sustainable urban ecosystems, the amount of land required for growing the vegetation can be estimated from these studies. One of the major implications of urbanization is an increase in surface temperature and development of Urban Heat Island. Surface temperature is increased by anthropogenic heat discharges due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decrease in vegetation and water pervious surfaces which reduce the surface temperature through evapotranspiration. Landsat8 images are widely used to observe the land surface temperature. In addition to the development of land use/cover maps band, 6 of the Landsat8 imagery is useful for deriving the surface temperature. Several researchers used Landsat8 imagery to develop land use/cover images as well as temperature images

Introduction

Urban growth and sprawl have severely altered the biophysical environment (Zhang et.al2011). Rapid urbanization has a significant influence on different aspects of the quality of life and the research in determining the patterns of urbanization and quantifying their impacts is crucial for us (Debbage N and Shephered JM, 2015). Unplanned urbanization and urban sprawl will directly affect the land use and land cover of the area (B. Chun and JM. Guldman, 2014). The changes in land use/cover include loss of agricultural lands, loss of forest lands, and increase of barren area, an increase of impermeable surface of the area because of urban growth (Rouf M. A. and Jahan S. (2013). The Development of land use land cover is very much useful to the city planner and policymakers (BBS, 2003). For the sustainable urban ecosystems, the amount of land required for growing the vegetation can be estimated from these studies (B Bhatta, 2009). One of the major implications of urbanization is an increase in surface temperature and development of Urban Heat Island (Moreno, 1994). Surface temperature is increased by anthropogenic heat discharges due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decrease in vegetation and water pervious surfaces which reduce the surface temperature through evapotranspiration (Robitu. M et al.2006). Landsat8 images are widely used to observe and model the biophysical characteristics of the land surface (M. Javed et al 2008). In addition to the development of land use/cover maps band, 6 of the Landsat8 imagery is useful. For deriving the surface temperature several researchers used the Landsat8 imagery (M. Turker and O. Asik 2005).

The Study area

Cooch Behar is a historical city of West Bengal state in India on the banks of Torsa River with latitude 26° 19' N and longitude 89°27′E. The climate is tropical, with hot summers and moderate winters. The peak temperature reaches 29 °C in May-June, while the winter temperature is 24-27° C. The average humidity is 78% and the average annual rainfall is250 mm. Cooch Behar gets its rainfall from the south-west monsoon. The topography of Cooch Behar is plain. It is also a minor railway junction connecting more or less all states in the country. The city's population is expected to increase to 1.79 lakhs by 2011. With the ever-increasing population and growth of the urban area, the city's landscape is undergoing unwanted changes. Urban Heat Island is one of the upcoming urban climatological problems developing in the city. Build up of such excess heat in the urban area due to reduced vegetative cover and increased built-up surfaces with concrete, asphalt, etc. Because of these phenomena, certain parts of the urban area of the city are becoming extremely hot during day time and particularly during summer seasons, causing a lot of discomfort to the citizens. The present study attempts to find the relation between the land use/cover and land surface temperature of Cooch Behar City (Fig.1).

Objectives

1) Detection of Built-Up area in Cooch Behar City,
2) Estimation of Land Surface Temperature (LST)
3) Mapping Surface Urban Heat Island (SUHI) By GIS and Remote Sensing.

Database and Methodology

For the present study the following methodology is adopted which involves satellite data collection, classification of the imagery, development of land use/cover maps, preparation of NDVI maps, retrieval of Land Surface Temperature maps and correlation studies. These are briefly outlined here.Cloud Free Landsat8 satellite data of 2018 for the study area has been downloaded from the USGS Earth Explorer website. All the data are pre-processed and projected to the Universal Transverse Mercator (UTM) projection system. The details of the satellite data collected are shown in Table-1.

Preparation of Landuse/ Land Cover Map

Using bands 2 to 7 of the pre-processed images the land use/cover pattern was mapped by supervised classification with the maximum likelihood classification algorithm ARC GIS 10.2.1software. The three classes considered for the study area are Built-up area, Vegetation, and Waterbody. The supervised classification involves pixel categorization by (i) Training, (ii) Classification and (iii) Output. Classification Accuracy assessments were done with field knowledge, visual interpretation and also referring the Google Earth. The classification accuracy was also calculated for the land use/cover map.

Derivation of NDVI image

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigor of vegetation at the surface, as follows:

$$NDVI = (Band4 - Band3)/ (Band4+Band3)$$

Derivation of NDBI image

The Normalized Difference Built-up Index (NDBI) is also a measure of the amount and cover of concrete at the surface as follows:

$$NDBI = (Band5 - Band4)/ (Band5+Band4)$$

Retrieval of LST

The LST retrieval equations are shown in the following steps

1) Conversion to Radiance

$$L\lambda = MLQcal+AL$$

Where,
Lλ= Radiance,
ML=Band-specific multiplicative rescaling factor from the metadata,
AL=Band-specific additive rescaling factor from the metadata,
Qcal=Quantized and calibrated standard product pixel values (DN)

2)Conversion to Satellite Brightness Temperature

$$T = [K2 / \ln(K1 / K2)+1] - 272.15$$

Where,
T= At-satellite brightness temperature (C)
K1 & K2= Band-specific thermal conversion constant from the metadata

3)Conversion of Land Surface Emissivity (LSE)

$$LSE (e) = 0.004PV+0.986$$

Where,
PV = Vegetation (%), 0.004 and 0.986 are onstants

4) Conversion of Land Surface Temperature (LST)

$$LST = BT/1+W*(BT/P)*\ln (e)$$

Where,
BT = At satellite temperature
W = Wavelength of emitted radiance (11.5μm)
P = 14380 (Constant)
e = Land surface emissivity

Results and Discussion

Landuse/ Landcover Map

The landuse/ land cover map of the study area developed for the year 2018 using a supervised classification method is given in the table below The total area of the municipality is 8.29 square kilometers. The details of the land use of the area under study are given in Table-4. The field knowledge and Google Earth were served as the basis for the estimation of classification accuracy. The classification accuracy assessment was performed and the results are shown in Table-2 & 3.

According to the above the tables in Cooch Behar municipality mainly three types of land use land cover are found, such as built-up area, vegetation, water body. The total area of this municipality is 8.29 sq.km and 4.78 sq km belong to Built-up area, 2.78 sq km belong to Vegetation cover, 0.76 sq km belongs to Water body respectively. The overall accuracy of this land use land cover map is 93.33 % that is computed by the author by the above error matrix table. From the above table and figure it observed that the winter temperature ranges from 24.38°C to 27.71°C and the summer temperature ranges from 23.01°C to 29.07°c in the study area. The temperature pattern is changing with the changes in the land use pattern of the municipality. The lower isothermal zone belongs to the dense vegetated and the water body area and the higher isothermal zone belongs to the Built-Up Area.

The NDBI Image

NDBI is one of the most widely used indexes of which applicability in satellite analysis and monitoring of the Built-up area was sufficiently verified in the last two decades. The NDBI value of the pixels varies between -1 and +1. Higher values of NDBI indicate the more Built-up. The Built-up area affects the latent thermal flux of the surface intent to the atmosphere through the reflection. Higher LST (except water bodies) is usually measured in areas with higher NDBI values. The Normalized Difference Built-up Index (NDBI) image developed is shown in Fig.5.

The NDVI Image

NDVI is one of the most widely used indexes of which applicability in satellite analysis and monitoring of vegetation cover was sufficiently verified in the last two decades. The NDVI value of the pixels varies between -1 and +1. Higher values of NDVI indicate richer and healthier vegetation. Vegetation affects the latent thermal flux of the surface intent to the atmosphere through evapotranspiration. Lower LST (except water bodies) is usually measured in areas with higher NDVI values. The Normalized Difference Vegetation Index (NDVI) image developed is shown in Fig.5

The LST Image:

From brightness temperature (TB) and Emissivity images the final Land Surface Temperature image was obtained by developing a model in ARC GIS10.2.1. The Final LST image is shown in the Fig.6. From the LST image, it is observed that the LST in winter ranges from 24.38°C to 27.70°C and the mean temperature is 25.50°C. On the other hand, the LST in summer ranges from 23.06°C to 29.07°C and the mean temperature is 26.51°C. The highest temperatures of about 29°C in urban-built up areas and other impervious areas and lowest temperatures of about 23°c exist in vegetative areas.

The Relation between Built-up area and LST

From the above calculation, it is reflected that the Correlation coefficient of this correlation is 0.99820 which means the more built-up area the higher LST reflectance. The relationship of the built-up index and LST is shown in the simulated graph. The graph in fig.7 indicates that the LST is increasing with the increasing value of the Built-up Index (BI). Positive value of BI represents the Built-up area, bare soil, and earth-fill or sand.

The Relation between vegetation coverage and LST

Fig.8 shows the relation between The Vegetation index and LST of the extracted municipality area. From the above calculation, it is reflected that the Correlation coefficient of this correlation is -0.911532 which means the less vegetation coverage the higher LST reflectance. The relationship of the NDVI and LST is shown in the simulated graph. The graph in this figure indicates that the LST is increasing with the decreasing value of NDVI. Negative value of NDVI represents less vegetation coverage.

The Impact of Built-up Area on LST

The digital remote sensing method provides not only a measure of the magnitude of surface temperatures of the entire town area but also the spatial distribution of the surface heat on urban land use. In this study, we have selected a double-time data of winter and summer season, 2018 and the built-up area of the Cooch Behar municipality was detected by using various indices and algorithms.

The Google Earth Image shows the actual urban built-up area over Cooch Behar municipality. It can be seen that a star like the urban morphological extension is occurring from the middle part of this municipality town except for the SW part. Settlements are mainly extended along with roads and railway lines. The middle and NE part where the main bus stands are located acts as the central point of settlement extension. Settlements can be seen along with Cooch Behar- Dinhata road towards south, Cooch Behar-Siliguri road towards north-east and Cooch Behar-Guwahati roads towards the eastern direction from the central part of the Cooch Behar municipality respectively. Within the urban central area, numerous sub-centers of LST with higher surface radiant temperature were mainly located in the old and recently congested built-up features. It can be identified that the heat island concentrated over the CBD (Harishpal more, Bus terminus) of Cooch Behar municipality town. Here the temperature varies from 24.38°C to 27.71°C in winter and 23.01°C to 29.07°C in summer. From the analysis of the data, three Urban Heat Island is found in this municipality are shown in fig.9. Two of them are common in both summer and winter season, one is located near airport area (Winter temperature 27°C & summer temperature 29°C) and another is located near Gandhi Colony, Bangchatra road (Winter temperature 27.5°C & summer temperature 29.05°C). Least one is only formed in the summer season which is located in Mini Bus stand (summer temperature 29.07°C) of the municipality area.

Surface Heat Island Intensity

The existence of a Surface Urban Heat Island (SUHI) is determined by calculating the SUHI by the following formula:

$$SUHI = (LSTu - LSTr)$$

Where,

LSTu = Land Surface Temperature of Urban Area

LST r = Land Surface Temperature of Rural Area

A positive value indicates the existence of a SUHI, i.e. the Land surface Temperature of the urban area is higher than the rural. A negative SUHI means that the Land Surface Temperature is lower than the rural temperature and so indicates Surface urban Cool Island. For the SUHI effect being specifically identified by using LST based on the above formula.

Surface temperature is the temperature of a surface adjacent to air space (CIBSE, 2006) and also, it is very difficult to measure. Oke (1978) suggested the true surface temperature is very similar to the surface radiant temperature which can be measured by an infra-red radiation thermometer or by Remote Sensing data using the TIR10/TIR11 band of LANDSAT 8.

Kershaw et al. (2010) suggest the UHI intensity of 2-3°C in summer and 05-1.5°C in winter. In my study, I used the TIR10 band of LANDSAT8 data for assessment of SUHI in the Cooch Behar Municipality and its adjacent surrounding area. In this area by drawing a section line from (26°19′30.29′′N, 89°25′6.53′′E) to (26°20′13.77′′N,89°29′36.92′′E) and is observed that the surface temperature variation 21.45° to 29.78°C. The mean LST of an urban area in summer is 26.04°C and the LST of rural areas in summer is 22.23°C.

The SUHI intensity = (26.04°C- 22.23°C)
= 3.81°C

This agrees with the results shown in the below fig.10

Conclusion

From the above study and investigative work, it can be concluded that Urban Heat Island phenomena are related to the urbanization process. The approach of quantitative remote sensing, digital indexing, and correlation and regression analysis, Web GIS techniques validated that built-up area expansion and urban sprawl have a direct impact on the environmental properties. Surface Urban Heat Island effect has been more prominent in the core of the Cooch Behar (CBD region) town. It's also observed that urban growth introduces SUHI intensity the process of degradation and degeneration of vegetation covers.

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Table-1: Details of Landsat Data (collected)

Date of Image	Satellite/ Sensor	Reference system/Path/ Row
01/04/2018 29/12/2018	Landsat 8 landsat 8	WRS-II/138/42 WRS-II/138/42

Source: USGS Earth Explorer.

Table -2 : The Error Matrix

	Built-Up Area	Vegetation	Water Body	Total(User)
Built-up Area	21	1	0	22
Vegetation	2	18	0	20
Water Body	0	1	17	18
Total (Producer)	23	20	17	60

Source: Computed by the authors

Table-3: Accuracy Table

LULC Category	User Accuracy	Producer Accuracy
Built-Up Area	95.46	91.30
Vegetation	90.00	90.00
Water Body	94.44	100.00

Source: Computed by the Author Overall accuracy=93.33%

Table-4: Detail of Landuse / Land cover of the Municipality

SL.NO.	LULC Category	Area in sq.km
1	Built-up area	4.7846
2	Vegetation	2.7794
3	Water body	0.7260
	Total	8.29

Source: Computed by the Author

Table-5: Temperature Class of Winter and Summer

Temperature	
Winter	Summer
24.38389921 - 25.16621536	23.00637792 - 25.36204473
25.16621537 - 25.51825763	25.36204474 - 26.09967777
25.51825764 - 25.92245431	26.09967778 - 26.69454313
25.92245432 - 26.63957745	26.69454314 - 27.40838155
26.63957746 - 27.70874286	27.40838156 - 29.07400455

Source: Computed By the Author

Table-6: Extracted Ranges of Different Indices

Indices	Minimum	Maximum	Mean
NDBI	0.001004352	0.389823228	0.188650941
NDVI	-0.071635112	0.057953794	-0.030800222

Source: Computed by the Author

Table-7: Range of LST

LST	Minimum	Maximum	Mean
Winter	24.38389921	27.70874286	25.4950586
Summer	23.0637792	29.07400455	26.51287644

Source: Computed by the Author

Table-8: The value of NDBI and LST

SL.NO	NDBI	LST (in°C)	SL.NO	NDBI	LST (in°C)
1	0.066569888	24.24369786	6	0.220572659	26.71833774
2	0.119937185	25.10030397	7	0.251068257	27.07525695
3	0.144333663	25.57619626	8	0.283088635	27.50356001
4	0.167205362	25.9807047	9	0.319683353	28.12221998
5	0.19312662	26.36141853	10	0.389823228	29.07400455

Source: Computed by the Author

Table-9: The value of NDVI and LST

Sl. NO.	NDVI	LST	SL. NO.	NDVI	LST
1	0.057953794	24.24369786	6	-0.026914235	26.71833774
2	0.003069081	25.10030397	7	-0.032504345	27.07525695
3	-0.009127522	25.57619626	8	-0.038602646	27.50356001
4	-0.016242207	25.9807047	9	-0.045717331	28.12221998
5	-0.021832317	26.36141853	10	-0.052832016	29.07400455

Source: Computed by the Author

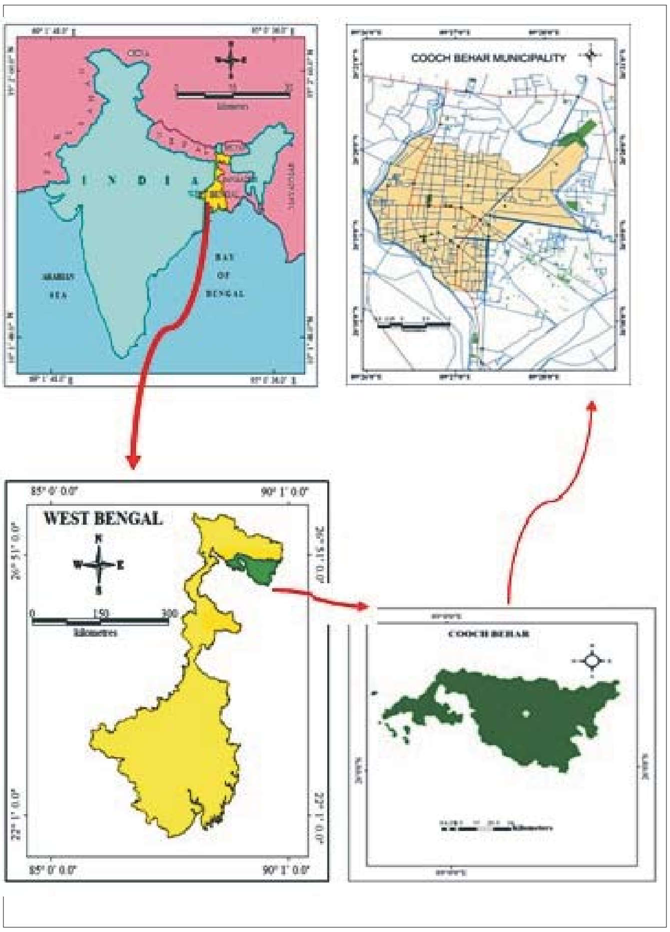

Fig. 1: The Study Area

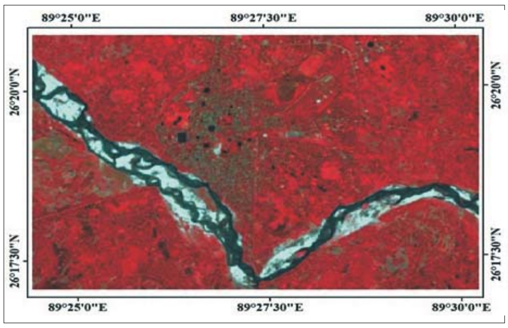

Fig. 2: False Color Composition of the AOI

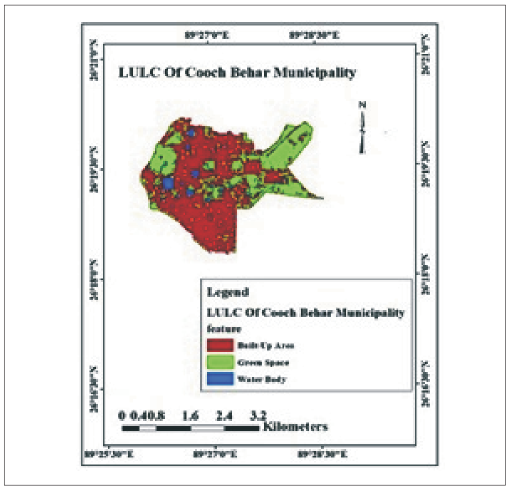

Fig.3: LU/LC Map of Cooch Behar Municipality

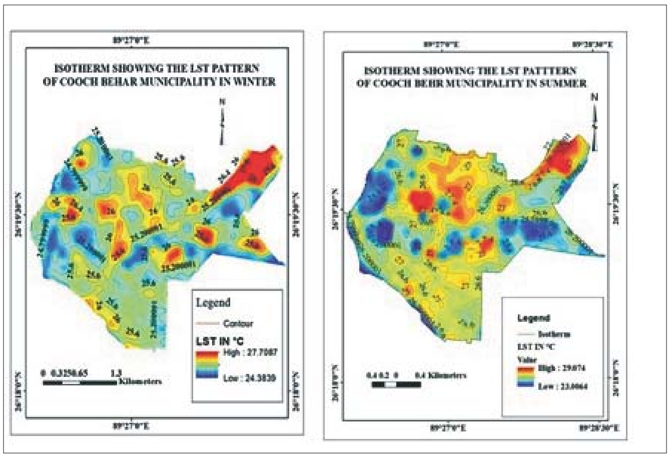

Fig.4: Temperature Distribution in Winter and Summer

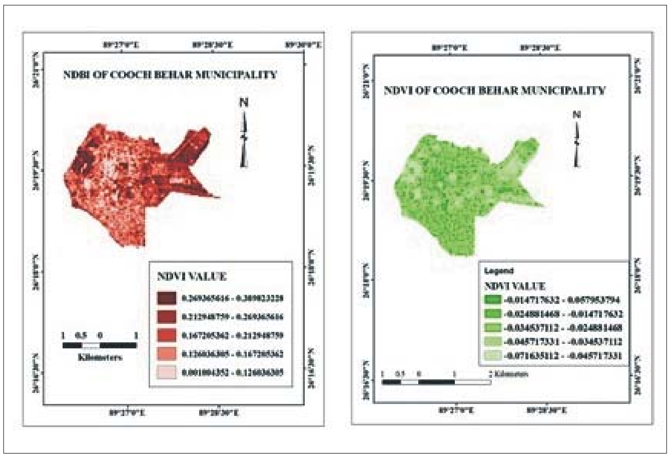

Fig. 5: NDBI & NDVI of Cooch Behar Municipality

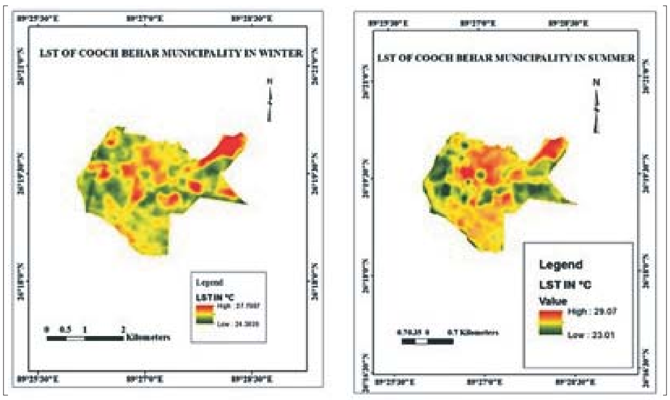

Fig. 6: Winter and Summer LST of Cooch Behar Municipality

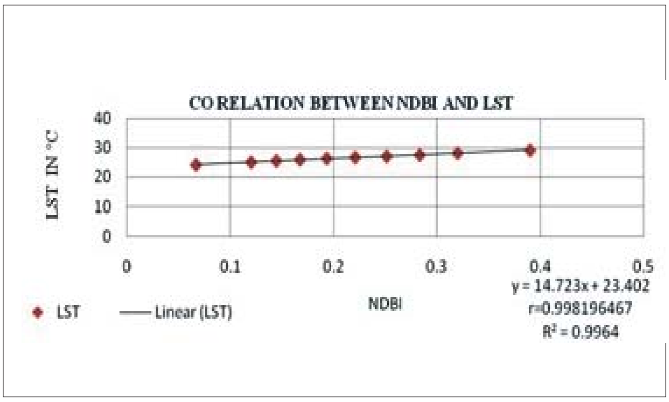

Fig. 7: Relation between Built-Up Index and LST

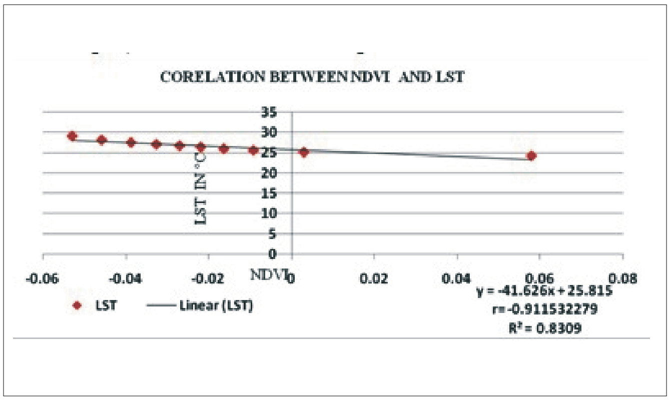

Fig.8: Relation between NDVI and LST

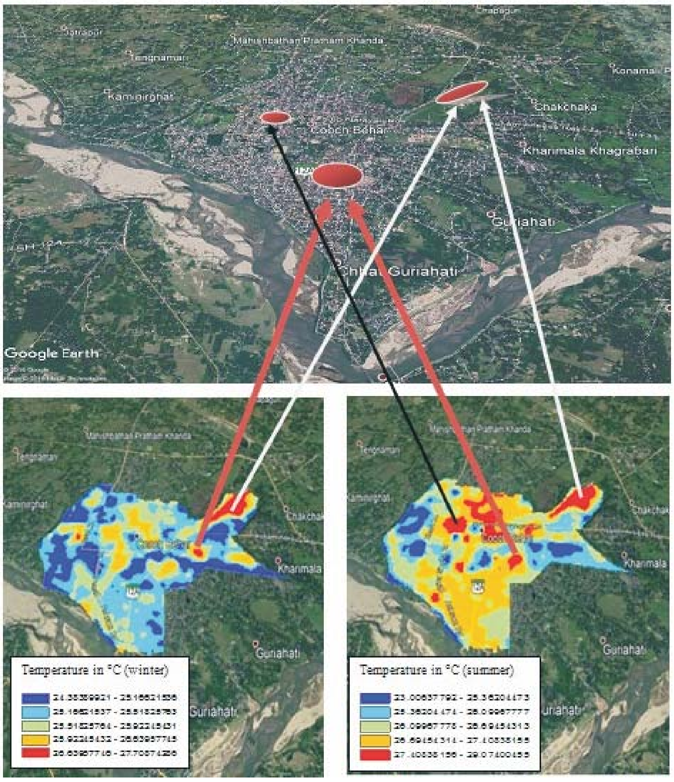

Fig.9: Urban Heat Island in the Municipality

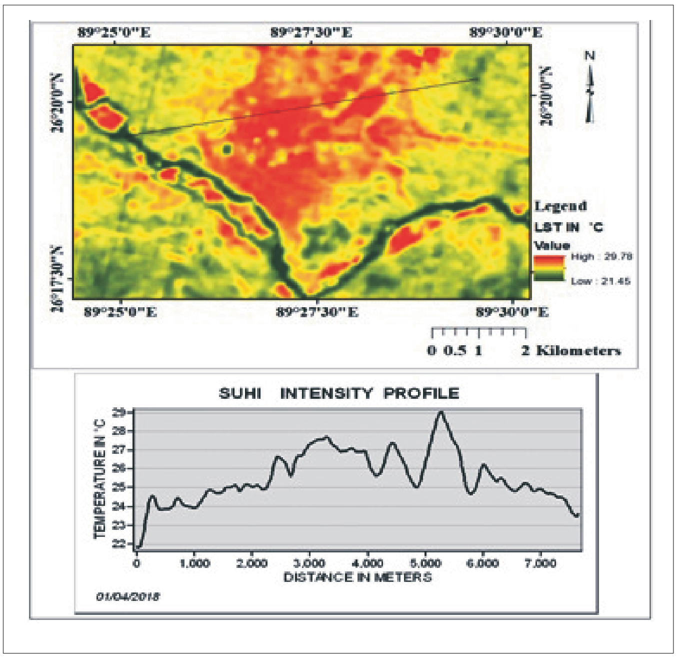

Fig.10: SUHI of Cooch Behar Municipality

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