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Remote sensing of the urban heat island effect in Srinagar city, India

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ABSTRACT

The acceleration of population growth and the associated economic growth in urban areas leads to multiplier effects on many aspects of development. In India urban population has increased more than four times after independence. It was 62.5 million in 1951, 284.5 million in 2001 and 377 million in 2011. With increase in the population, the demand for residential space has also increased which has unplanned growth of the urban areas. Srinagar city is one such urban area in the hill state of Jammu and Kashmir, India. Being the summer capital of Jammu and Kashmir, population of the city has increased many folds since 1980s. Choked and unmanageable planning and various other anthropogenic interventions in certain areas of this ecologically fragile hill ecosystem have given birth to many climatic issues like Urban Heat Island (UHI) phenomenon. The present study tries to map out the pattern of land use, Land Surface Temperature (LST) using satellite data and field measurements to assess the UHI effect and identify the urban hot spots in Srinagar city. The study used Thermal Infrared data from Landsat 8 TIRS band-10 and field data, collected using IR Gun in various locations pertaining to different materials and land use/cover features of Srinagar city. The results showed that there is a strong relationship between the land use/cover features and the associated differentials in the land surface temperatures during winter and summer season. The study helped to identify urban heat island intensities and hotspots in Srinagar city.

Keywords: Population Growth, Unplanned Growth, Urban Heat Island (UHI), Land Surface Temperature (LST) Landsat 8 TIRS, IR-GUN, Remote Sensing

1. INTRODUCTION

Urbanization has extensively accelerated since World War Second. Presently 50% of the world population (3.4 Billion) is settled in urban areas [1]. Also, it is predicted that inhabitation in cities will reach 60% (5.0 Billion) by 2030 which means around two billion more people will reside inside cities by that year. Increasing population demands more settlements that leads to increased built-up area by removal of vegetation and soil to extract sand, gravel, brick clays, and rock; the replacement of vegetation by planted cover in gardens, parks, sports grounds; the alienation of ground for landfill and waste treatment; wetlands and open space conversion for settlements and the use of land for transportation routes [2]. The simultaneous rapid growth in both population and economic output per capita, and the consequent changes in land use pattern come at a cost to the natural environment [3][4][5]. Indeed, this change is one of the most widely documented climatic effects of man's modification of environmental factors [6] including net primary production [7] biodiversity [8][9][10] and climate and weather at local, regional, and global scales [11]. Urban heating and the formation of the urban heat island (UHI) is one attribute of growing urban density that is of interest across science disciplines because the UHI signal reflects a broad suite of important land surface changes impacting human health, ecosystem function, local weather and possibly climate [12] [13].

The intensity of the UHI tends to vary depending on the size of cities. Generally speaking, the intensity of the UHI increases as the size of a city increases, due to the larger size of the built area [14]. Local meteorological conditions, geography (topography, presence of water bodies such as lakes or rivers, soil types, etc.) also affect the magnitude of an UHI [15]. However, this effect can raise city air temperatures by 2˚C to 10˚C above the surrounding area [16]. The concept of UHI was first studied by Howard in 1818 through field study in city of London. Since then, many monitoring researches have been reported in different cities [17]. With the advancement of sensor technology, thermal remote observation of UHI became possible through the use of satellite, airborne and aircraft platforms. The resultant surface temperature contains the effects of surface radiative and thermodynamic properties, including surface moisture, surface emissivity, surface albedo, the irradiative input at the surface, and the effects of the near surface atmosphere, in addition to the turbulent transfer from the surface [18]. In India, a case study was undertaken to assess and compare UHI and Hotspots based on in-situ measurements and Remote Sensing observations in the megacity of Delhi. Urban heat island effects were found to be more dominant in areas of dense built up infrastructure and at commercial centers. The UHI intensity was observed to be higher in magnitude both during afternoon hours and midnight hours. The three-high ranking UHI locations in the Delhi City were within commercial and densely populated areas [19].

The present study focuses on to study the general pattern of urban land use/cover in Srinagar city. Further it also investigates specifically the relationship between the land use/cover and the urban heat island phenomenon. The study is based on both the field measurements as well as the remotely sensed data.

Study area

The present study has been carried out for Srinagar city, a hill city in the northernmost state of India i.e., Jammu and Kashmir. The city lies between 33º59'14'' N and 34º12'37'' N latitude and 74º41'06¨ E and 74º57'27'' E longitude. The study area spreads between the plains of vale of Kashmir along the river Jhelum. The general relief of the study area is 1580 m above mean sea level. The city is located on both sides of the River Jhelum, locally called *Vyeth* in Kashmir (Figure 1) giving a picturesque look to it. Being the summer capital of the state of Jammu and Kashmir, its population has increased more than 5 times since past 5 decades. Due to the physiographic limitations and lack of proper and suitable planning the city has experienced haphazard urban growth. The city has witnessed urban forces leading to outgrowth of concrete jungle in the fragile hill ecosystem of the city leading to some of the important problems like Urban Heat Island Phenomenon (UHI).

2. METHODOLOGY

The present research is focused to study the urban heat island phenomena for the Srinagar City. The study identifies the factors responsible for increasing this effect by studying the distribution of concrete jungle and the role played by it in capturing the solar heat and increasing the local temperature.

Data used

The study is mainly based on both primary as well as secondary sources of data; the data used for the preparation of land use/land cover of the study area is carried out using IRS-1D LISS III + PAN 2018 merged satellite imagery (Table 1 a and b, Figure 2). For studying the Urban Heat Island phenomena (UHI) Landsat 8TIRS band 10 data pertaining to 19th January-2018 and 27thJune-2018

seasons was analyzed. The Landsat 8TIRS data was downloaded from the USGS website whereas IRS-1D LISS III + PAN 2018 data was procured from the National Remote Sensing Centre, Hyderabad, India. Further for assistance in the process of interpretation SOI topographical sheet was also used.

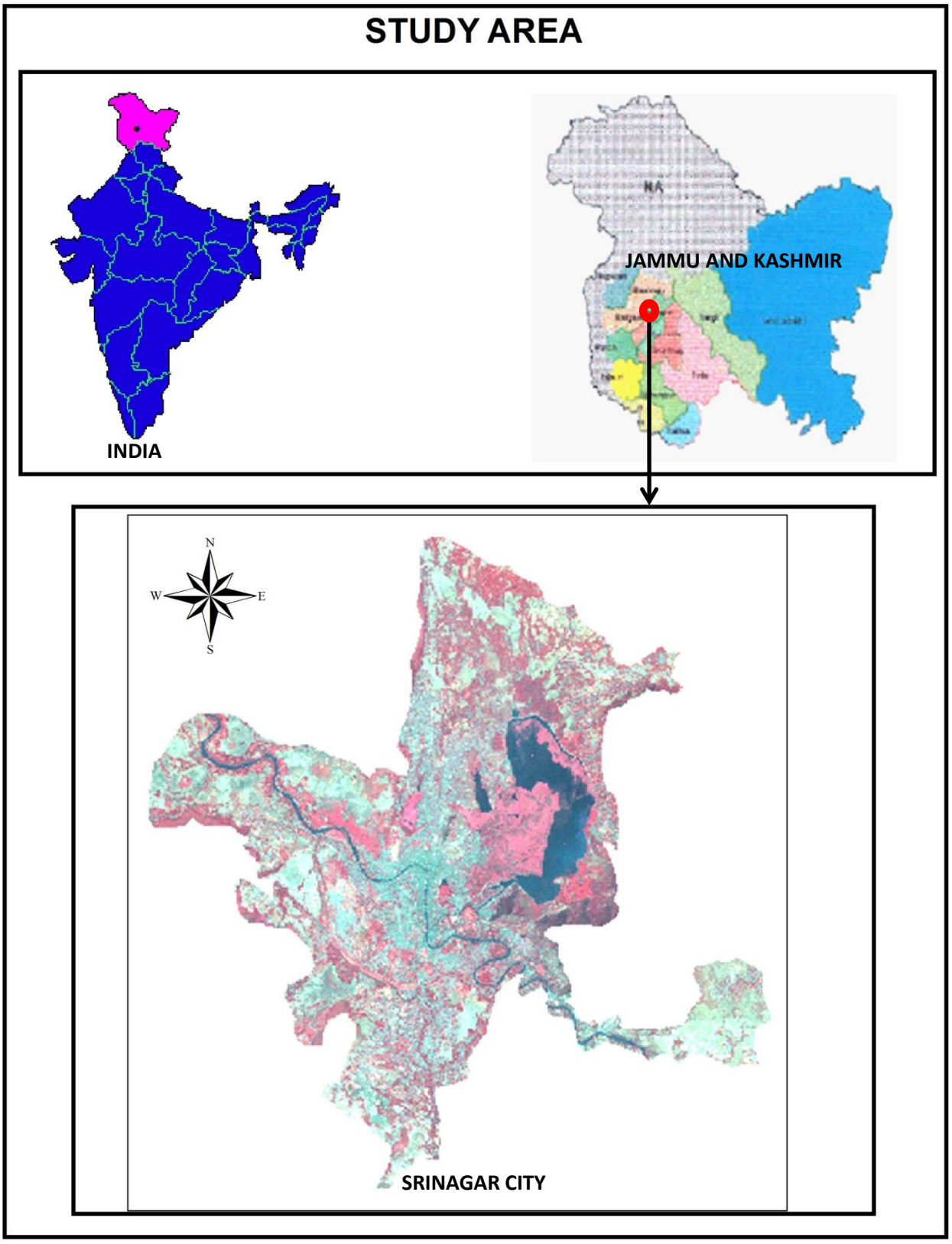

Figure 1 Location Map of Study Area

Table 1(a) Details of satellite data used in the study

S. No.	Data used	Path/ Row	Date of Pass	Wave length width in µm/Band	Spatial resolution (meters)	Swath (km)	Purpose
1	IRS-1D LISS-III	92/46	10-10-2018	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	23.5	142	Land use and Land cover mapping
2	IRS-1D PAN	92/46	10-10-2018	0.5-0.75	5.8	70	Land use and Land cover mapping
4	Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales	--	--	--	--	--	To Generate boundary and Base layer maps
5	Field visit data captured using IR Gun and GPS	--	--	--	--		For collection of In-situ temperature data and geo-correcting and generating validation dataset

Table 1 (b) Details of Landsat data used in the study

S. No.	Data used	Path/ Row	Date and time of Pass	Wave length width in µm/Band	Spatial resolution (meters)	Swath (km)	Sun Elevation	Earth - Sun Distance	Sun Azimuth	Purpose
1	Landsat 8 TIRS Band 10	149/36	05:35:53.1931517Z 19-01-2018	10.60 – 11.19	30	185	30.46	0.98	153	Generation of Land Surface Temperature (LST) and Heat maps
2	Landsat 8 TIRS Band 10	149/36	05:35:36.5767330Z 27-06-2018	10.60 – 11.19	30	185	76.72	1.016	114.65	Generation of Land Surface Temperature (LST) and Heat maps

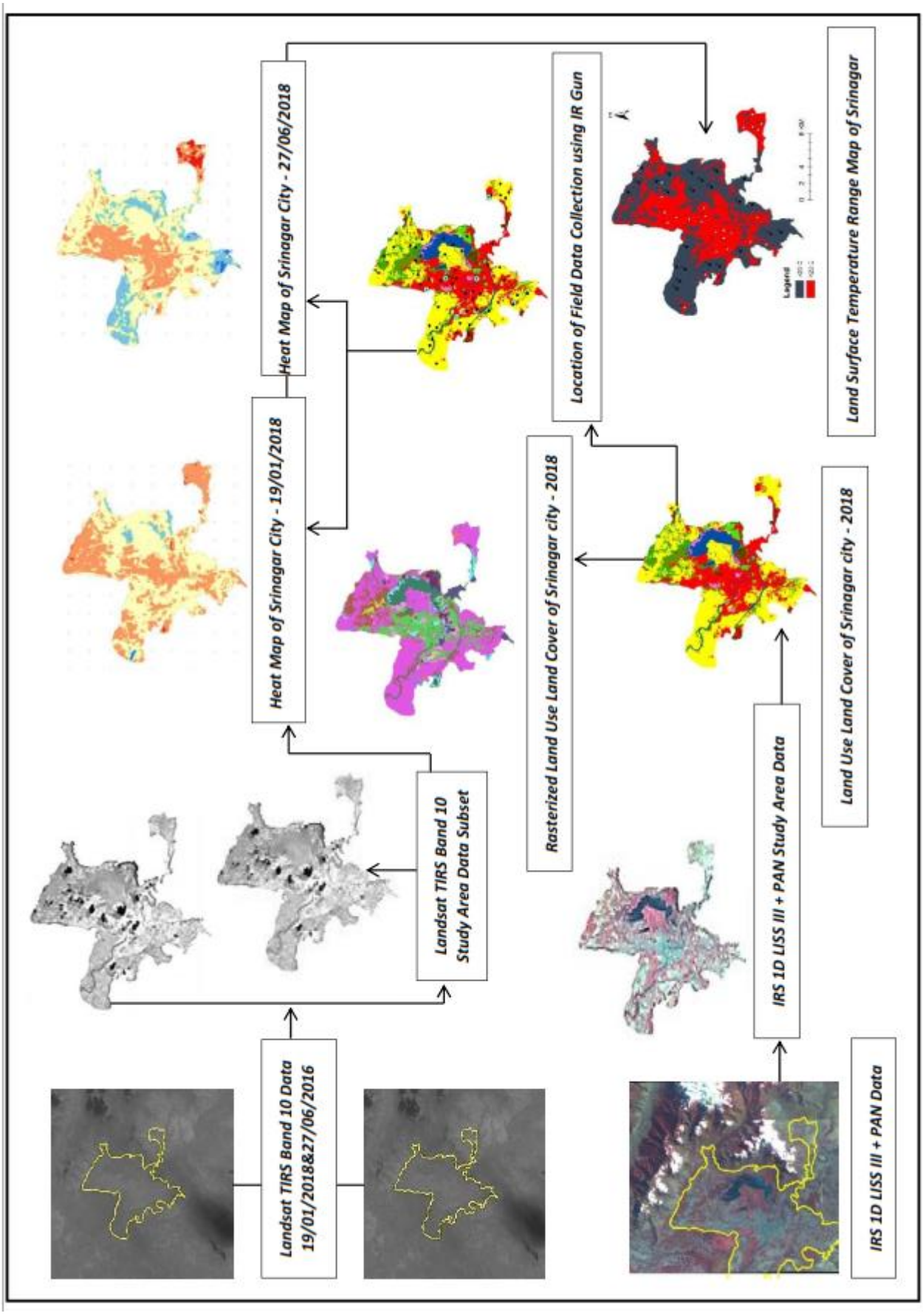

Figure 2 Methodology for Assessing UHI Effect

Data Collection from the Field

For the collection of field data Srinagar City was arbitrarily divided into five zones i.e., east, west, north, south and central. Data was collected for the thermal analysis from 70 selected points evenly distributed throughout the five zones and was averaged for seven selected stations.

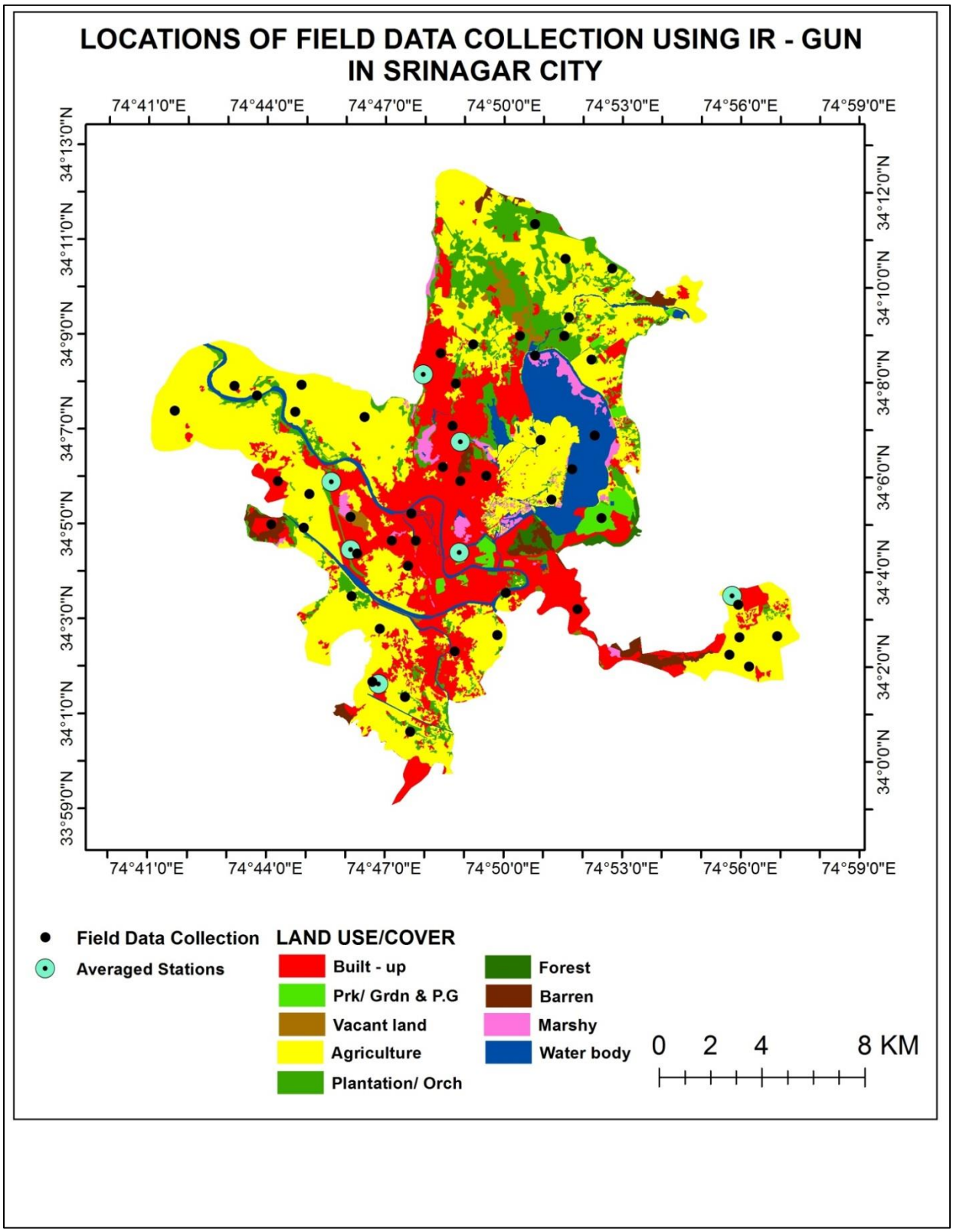

Figure 3 Location of Field Data Collection in Srinagar City – 19/01/2018& 27/06/2018

The data was collected using the Infrared Gun for different time periods from morning till evening i.e., morning (9:30 to 10:30 am), afternoon (2:00 to 3:00 pm) and evening (6:00 to 7:00 pm). The data was collected from 19th - 21st January (during *Chillai Kalaan* – coldest part of winter in Kashmir) 2018 and 27th - 29thJune2018. On an average five various built-up surfaces were selected depending on building orientation, surface heat gain capacity. The surface temperature of each selected building was measured using the IR-Gun. On the basis of various parameters like urban development, presence of open and green spaces in the area temperature data was collected randomly from all the zones of the City.

The temperature data collected for different zones during different time periods of the day in the month of January and June 2018 are given in table 2 & 3 and figure 3. The different time period temperature data was then averaged for every day.

Table 2 Temperature Data Collected on Field from 19th- 21st January 2018

S.No	Station*	Morning (9:30 to 10:30)	Afternoon (2:00 to 3:00)	Evening (6:00 to 7:00)	Latitude	Longitude
1	Parimpora	5.1	11.5	3.1	34°5'53.436"N	74°45'38.778"E
2	Bemina	5.9	13.3	4.6	34°4'29.831"N	74°46'8.482.1"E
3	Soura	6.1	12.9	3.9	34°8'10.711"N	74°47'53.698"E
4	Bagh-i-Ali Mardan	4.9	13.8	5.6	34°6'45.711"N	74°48'52.863"E
5	LalChowk	6.9	14.7	7.6	34°4'24.339"N	74°48'53.171"E
6	Barzulla	4.5	12.6	6.2	34°1'35.363"N	74°46'47.069"E
7	Khanmoah	5.1	12.8	4.5	34°3'29.895"N	74°55'45.675"E

Table 3 Temperature Data Collected on Field from 27th – 29th June 2018

S.No	Station*	Morning (9:30 to 10:30)	Afternoon (2:00 to 3:00)	Evening (6:00 to 7:00)	Latitude	Longitude
1	Parimpora	18.9	32.5	17.1	34°5'53.436"N	74°45'38.778"E
2	Bemina	19.1	33.3	18.6	34°4'29.831"N	74°46'8.482.1"E
3	Soura	17.1	34.9	17.9	34°8'10.711"N	74°47'53.698"E
4	Bagh-i-Ali Mardan	20.9	35.8	21.6	34°6'45.711"N	74°48'52.863"E
5	LalChowk	21.9	36.7	22.6	34°4'24.339"N	74°48'53.171"E
6	Barzulla	19.5	34.6	20.2	34°1'35.363"N	74°46'47.069"E
7	Khanmoah	20.02	35.2	21.3	34°3'29.895"N	74°55'45.675"E

*Average of 10 points

Processing of Raster Data

Remotely sensed data was geo-referenced, geo-corrected, rectified and cropped pertaining to the study area (Municipal limits of Srinagar city) in Earth Resource Data Analysis System (ERDAS) Imagine 2015 software. Geo-registration of remote sensing data (LANDSAT 8 TIRS bands 10 and IRS-1D LISS III + PAN 2018) was done using ground control points collected from the field with the help of pre-calibrated GPS (Global Positioning System) and known points from geo-referenced topographic maps published by the Survey of India. Image-to-image registration has been performed to bring the entire image in the same geometry using Universal Transverse Mercator (UTM) as its projection and WGS 84 as its datum with sub-pixel accuracy. Satellite imagery was stacked into different bands to produce a false color composite. The IRS-1D LISS III + PAN 2018data pertained to the month of March.

Processing of Vector Data

IRS-1D LISS III + PAN 2018 image was digitized in GIS environment using ArcMap 10.2 software in the form of polygons representing different land use land cover categories. Reference to legacy data and other ancillary information has been used for precise interpretation of land use classes and delineation of the same. Land use/cover classification was based on National Remote Sensing Center (NRSC) classification (Level 1). The maps were put to further processing like area estimation, map composition and output generation.

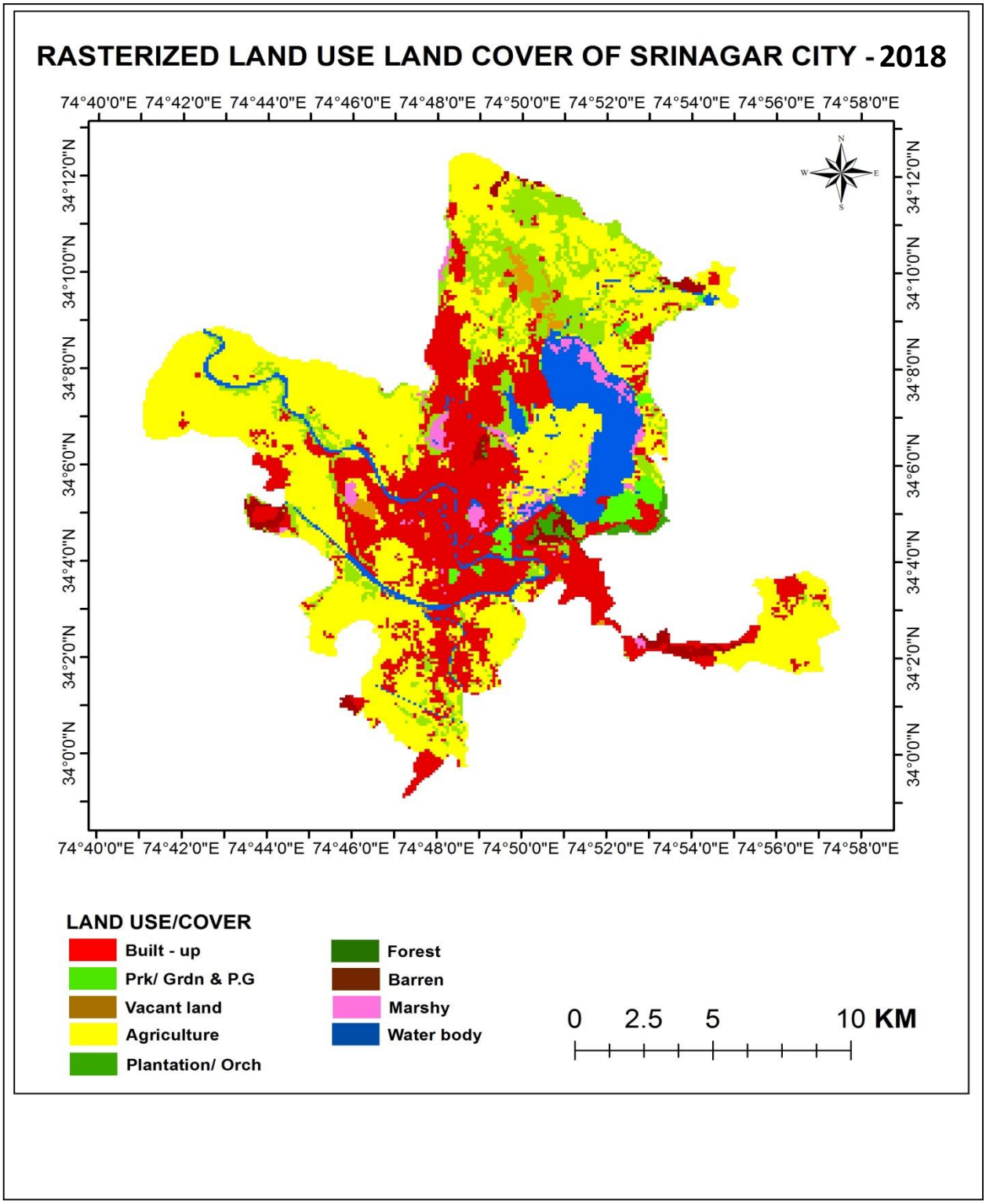

Figure 4 Rasterized Land Use Land Cover of Srinagar City – 2018

Thematic Accuracy

Accuracy assessment was done for entire study area. All the Land Use Land Cover categories were numbered map-wise and sample chosen for field verification using the following

Equation (Jensen 1986):

Sample Size

N= 4 pq' / E2

Where p is the expected percent accuracy (90 %), q' = difference between 100 and p. E is the allowable error, and N the number of points to be sampled.

Rasterization of Vector Data

The land use/cover vector map was rasterized for deriving the class wise land surface temperatures (Figure 4).

Thermal analysis of TIRS band 10 of Landsat 8 Data for 19th January and 27th June 2018

Land Surface Temperature (LST) is related to surface energy and water balance, at the local as well as global scale. It is one of the most important variables measured by satellite remote sensing. The present study used TIRS (Thermal Infrared Sensor) band 10 of Landsat 8 data of two time periods i.e., 19th January and 27thJune, 2018. This data is collected at 100 meters but re sampled to 30 meters to match OLI multispectral bands. The thermal analysis of the Landsat data was carried out using ENVI 5 Image Processing software in the form of following steps

1. Calculation of land surface temperature:

a) Conversion of DN to TOA (Top of Atmosphere) Radiance

$L\underline{\lambda}$ = MLQcal + AL

Where:

$L\underline{\lambda}$ = TOA spectral radiance (Watts/(m2*srad*µm)

ML = Band-specific multiplicative rescaling factor (band 10)

Qcal = Quantized and calibrated standard product pixel value (DN)

AL = Band-specific additive rescaling factor

In ENVI 5 basic tools the formula was put as [(0.0003342*b1) + 0.10] where, 0.0003342 represents ML, b1 represents Band 10, and 0.10 represents AL for Scene ID.

b) Conversion of Radiance to Temperature

K2/*ln*(K1/Lλ + 1) where *ln* = natural log

Where:

T = At-satellite brightness temperature (K)

Lλ = TOA spectral radiance (Watts/(m2*srad*µm)

K1 = Calibration constant 1 (Landsat 8 band 10 value 774.8853)

K2 = Calibration constant 2 (Landsat 8 band 10 value 1321.0789)

In ENVI 5 basic tools the formula was put in two parts

a. [ALOG (774.8853/b1+1)]

b. [(1321.0789/b1)]

c) Conversion of Kelvin to Celsius

[(b1-273.15)]

2) Superimposing of the field data using GPS location on Landsat data for validation.

Generation of heat maps of the Srinagar city was done using ArcMap 10.2. The temperature data collected on field from 19th – 21st January and 27th – 29th June 2018at 9:30 to 10:30 am was averaged and randomly matched with the temperature values generated from the thermal analysis of satellite data for January and June 2018 respectively.

3. FINDINGS FROM THERMAL ANALYSIS OF LANDSAT TIRS DATA

The field data collected from the different locations (table 2 and 3; figure 3) and the thermal analysis of Landsat TIRS data of the city for January and June enabled to generate the heat map in ArcMap 10.2 software (Figure 5 and 6). The generated heat maps were classified into different ranges of temperature by the software. The different classes for January are 1) Class-1: -3.704 - 0˚C, 2) Class-2: 0.0001 – 3.171˚C, 3) Class-3: 3.171 – 6.607˚C, 4) Class-4 6.608 – 10.04˚C, 5) Class-5 10.05 – 13.48˚C. Similarly, the heap map for June was classified into five different classes i.e., 1) Class-1: 13.93 – 18.50˚C, 2) Class-2: 18.51 – 23.07˚C, 3) Class-3: 23.08 – 27.64˚C, 4)

Class-4 27.65 – 32.21˚C, 5) Class-5 32.22 – 36.78˚C. These classified maps helped in identifying the urban hotspots in the Srinagar city both in the winter as well as in the summer season.

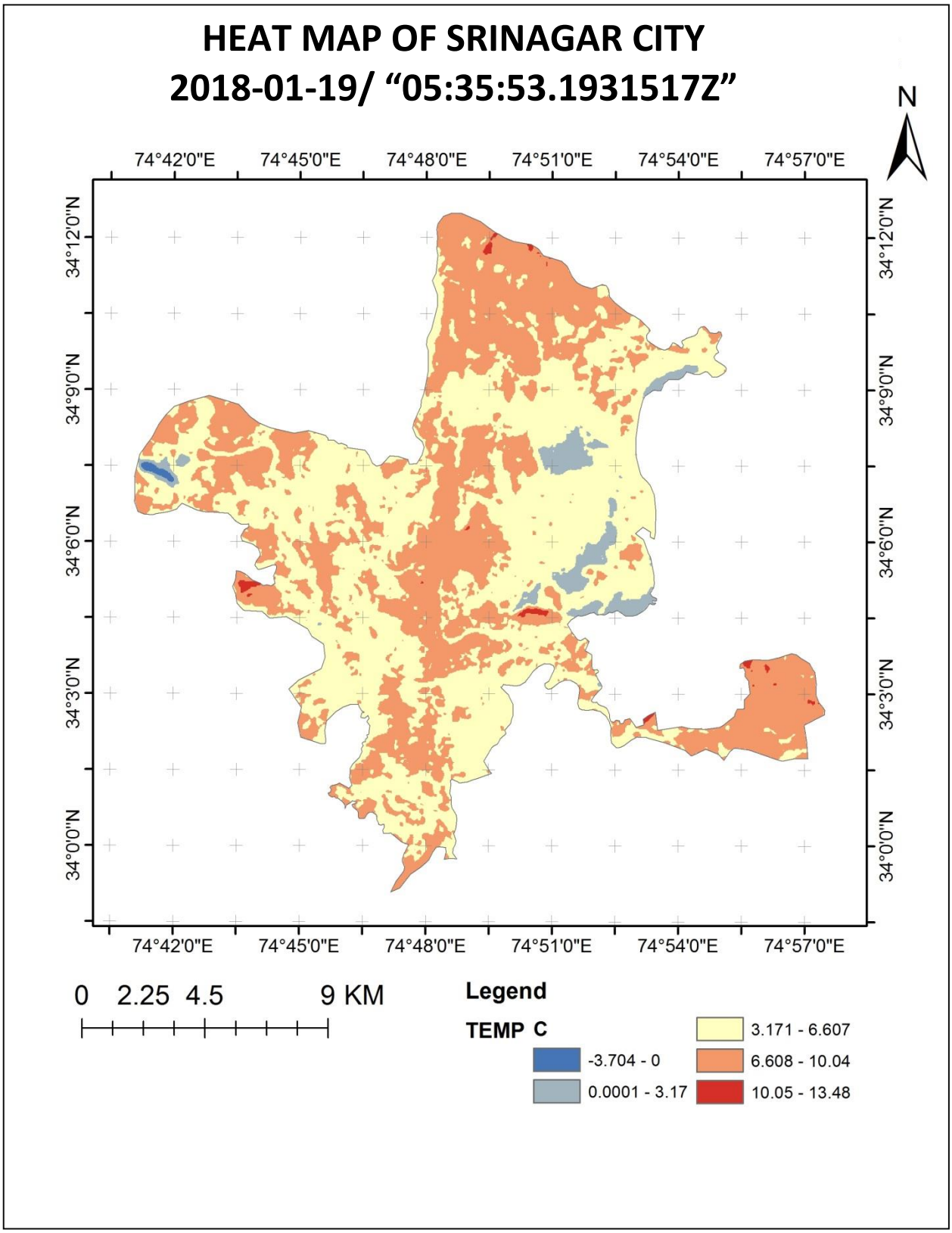

Figure 5 Heat Map of Srinagar City – 19/01/2018

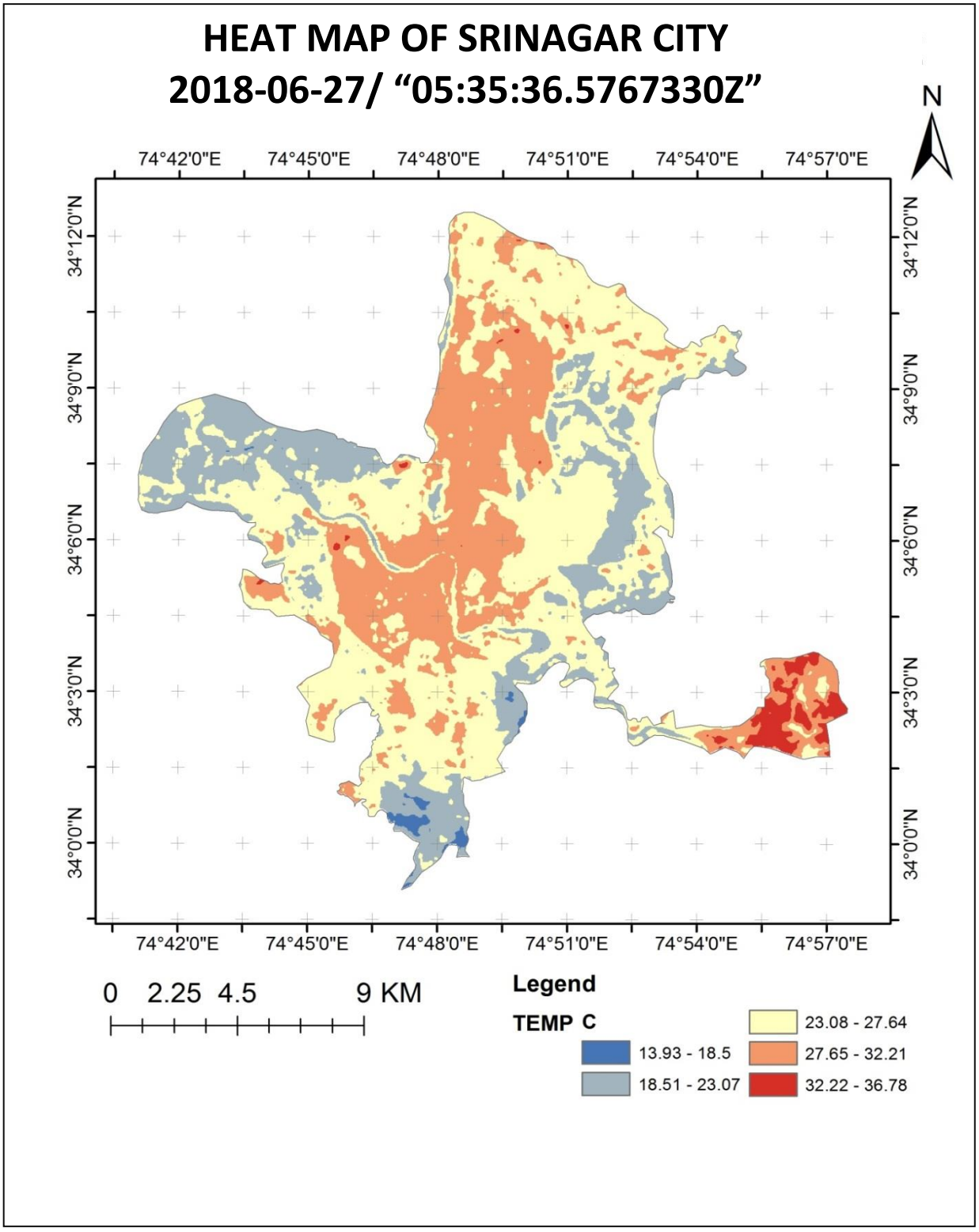

Figure 6 Heat Map of Srinagar City – 27/06/2018

The statistics derived from the classified heat maps is given in table 4 and 5. The figures show 127.70 Sq. Km i.e., 55% of the total land area of the city during severe winter is having the temperatures ranging from 3.16 – 6.60 ˚C and 0.37 Sq. Km i.e., only 0.15% of the total land use is having the lowest temperature varying from -3.7 – 0˚C. Whereas, 114.70 Sq. Km i.e., 48% of the total area experienced temperatures ranging from 23.06 - 27.63˚C. The important hotspots identified cover the total area of more than 6.8 Sq. Km where the temperature varies from 27.63 – 36.78˚C.

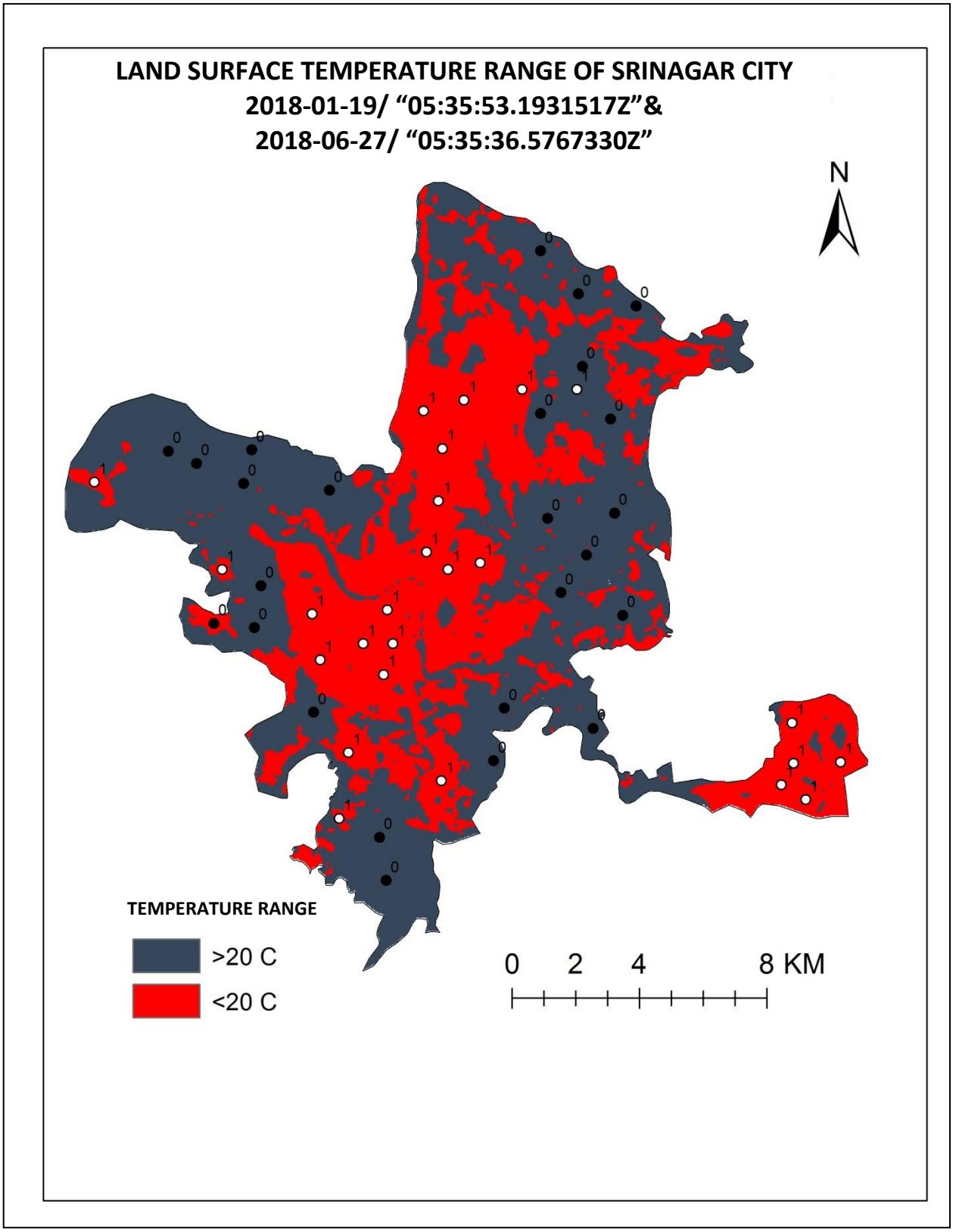

Figure 7 Land Surface Temperature Range Map of Srinagar City – 19/01/2018& 27/06/2018

The higher temperatures were observed at the places having more built-up area e.g., Industrial areas, roads, residential and governmental buildings and offices. These include Lal Chowk city core area, Khanmoah Industrial area and important trade areas in the west of the city.

The analysis of temperature range map (figure 7) showed that the built-up, plantation/orchards, marshy, parks and gardens, some significant agricultural area in and around the core area of the city show the temperature of >20˚C whereas agriculture, forest, water bodies were observed to be having the temperature of <20˚C.

Table 4 Classified Heat map Statistics of Landsat 8 TIRS, Band 10, January-2018

JANUARY 19,2018			
Class	Classes	Cell Nos	Area (Sq. Km)
1	-3.7 – 0	410	0.36
2	0 - 3.16	8797	8.91
3	3.16-6.60	140442	127.70
4	6.60-10.04	107235	96.51
5	10.04-13.480	1017	0.91
	Total	257901	234.46

SOURCE: Based on Landsat TIRS - band 10, January 19, 2018 satellite imagery of Srinagar City

Table 5 Classified Heat map Statistics of Landsat 8 TIRS, Band 10, June-2018

JUNE 27, 2018			
Class	Classes	Cell Nos	Area (Sq. Km)
1	13.92 - 18.49	1653	1.48
2	18.49 - 23.06	53529	48.17
3	23.06 - 27.63	126717	114.70
4	27.632 - 32.20	70444	63.70
5	32.20 - 36.78	5558	5.00
	Total	257901	234.46

SOURCE: Based on Landsat TIRS - band 10, June 27, 2018 satellite imagery of Srinagar City

Land use land cover of Srinagar city

To understand the effect of Urban Heat Island and to validate the thermal analysis of Landsat TIRS data, present date land use/cover patterns of Srinagar city was studied. The analysis of data enabled to map total 9 land use/land cover classes spread over 234.46 $Km^2$of study area. These classes include, Built-up, Parks/Gardens & Playgrounds, Vacant, Agriculture, Plantation/Orchards, Forest, Barren, Marshy and Water body (Figure 8). The statistics derived of different land use/cover classes is given in Table 6 and their detailed explanation is as follows:

Table 6 Land use/Land Cover Distribution in Srinagar city2018

S. No	Land use/ Land cover	2018
1	Built-up area	62.51 *(26.66%)*
2	Parks/Gardens &Playground	3.72 *(1.59%)*
3	Vacant	2.55 *(1.08%)*
4	Agriculture	109.49 *(46.7%)*
5	Plantation/Orchard	26.22 *(11.18%)*
6	Forest	1.53 *(0.65%)*
7	Barren	4.80 *(2.05%)*

8	Marshy	4.68 *(2%)*
9	Water body	18.95 *(8.08%)*
	TOTAL	23446

Note: Area in Sq. Km

SOURCE: Based on IRS-1D LISS III + PAN 2018 merged satellite imagery of Srinagar city

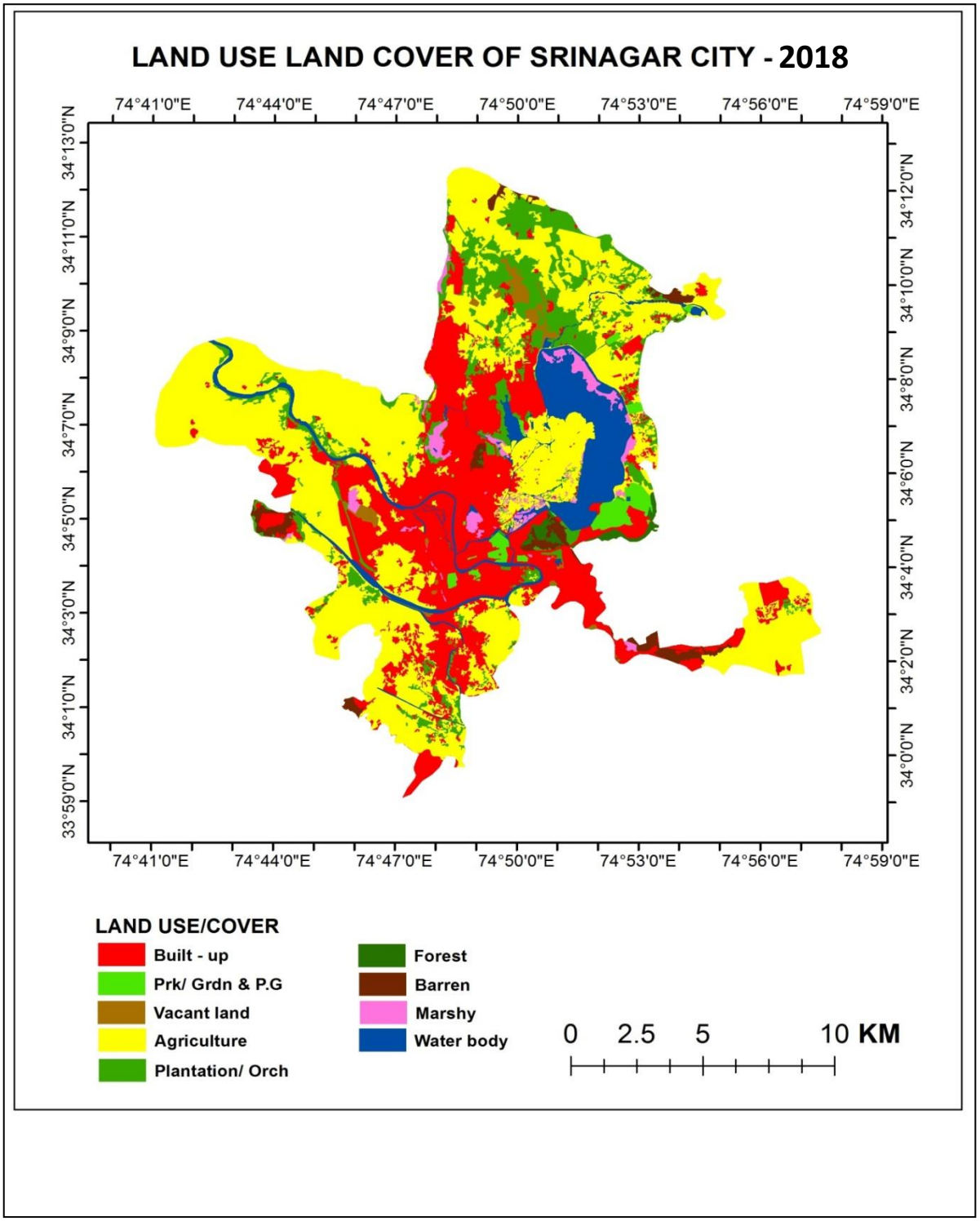

Figure 8 Land Use Land Cover of Srinagar City – 2018

Built-up area

In the present study, built-up class includes residential, scattered settlement, commercial, industrial, restricted, educational, governmental, hospital and religious areas. Built-up area contributes to 62.51 Km^2 (26.66% of the total study area). The general trend of built-up distribution was observed in north, south and west direction only because the area lying to its east is occupied by water body and far western and north-western part is mostly marshy area. The thermal analysis of the Landsat TIRS data for built-up land use class showed that the temperature ranged from 2.90 – 13.51^{0}C on 19th January 2018 where as it was found to be ranging from 22.42 – 36.78^{0}C on 27th June 2018 (Table 7, Figure 5 & 6).

Table 7 Temperature Range of Land Use Land Cover Classes in Srinagar City on 19thJanuary 27th June, 2018

S.No	Land use/cover	January Temp. (^{0}C)	June Temp. (^{0}C)
1	BUILT-UP AREA	2.90 – 13.5	22.42 - 36.78
2	PARKS/GARDENS &PLAYGROUND	2.12 - 9.11	20.20 - 33.53
3	VACANT	3.91 - 8.13	19.76 - 32.53
4	AGRICULTURE	-3.71 - 9.59	13.92 - 32.47
5	PLANTATION/ORCHARD	1.02 - 7.22	16.19 - 31.60
6	FOREST	1.14 - 12.2	20.98 - 30.42
7	BARREN	1.55 - 6.90	19.77 - 31.23
8	MARSHY	2.68 - 7.40	20.34 - 30.79
9	WATER BODY	2.07 - 8.75	18.40 - 29.03

Parks/Gardens & Play grounds

This category includes various parks/gardens and playgrounds which are the areas of recreational activities and they form an important part of the city's culture. This class consists total area of 3.72 Km^2 (1.59% of the total study area). The temperature ranged from 2.12 – 9.11 ^{0}C during the winter season (19th January 2018) whereas it was observed to be varying from 20.20 – 33.53^{0}C during the summer season (27thJune2018).

Vacant

Vacant land includes the land belonging mostly to locals who have left crop cultivation, most of which is speculative land holding. It also includes the abandoned government land covering total area of 2.55 Km^2 (1.08% of the total study area). The temperature observed for this land use varies from 3.19 – 8.13 ^{0}C during winter and 19.76 – 32.53 ^{0}C during summer.

Agriculture

Agricultural class includes mostly Paddy land, Floating/vegetable gardens (*Radh*) and Saffron Karewa fields. The total area mapped under this category includes 109.49 Km^2 (46.7% of the total study area). Agricultural class observed the winter temperature ranging from 3.71 – 9.59 ^{0}C whereas the summer temperature was found to be ranging from 13.92 – 32.47 ^{0}C.

Plantation/Orchard

It includes Willow plantation, Apple, Cherry, Almond, Walnut orchards, distributed all over city except the core area. It contributes the total area of 26.22 hectares (11.18% of the total study area). During winter the temperature varied from 1.02 – 7.22 ^{0}C whereas it was found to be ranging from 16.19 – 31.60 ^{0}C during the summer season.

Forest

Forest class includes the vegetation cover in the hilly areas of the city covering 1.53 Km^2 (0.65% of the total study area). The temperature varied from 1.14 – 12.2 ^0C to 20.98 – 30.42 ^0C from winter to summer season respectively.

Barren

Barren class includes the bare exposed rocks, along with some quarrying sites in the south eastern part of the city. It covers total area of 4.80 Km^2 (2.05% of the total study area). During the winter season the range of temperature was found to be less in this class i.e., 1.55 – 6.90 ^0C whereas it was found to be high during the summer season, 19.77 – 31.23 ^0C.

Marshy

Marshy class includes the wet lands in and around the water bodies of the city. It covers total area of 4.68 Km^2 (2% of the total study area). During winter season the temperature varied from 2.68 – 7.40 ^0C whereas it was found to be ranging from 20.34 – 30.79 ^0C in summer.

Water body

Water body includes the rivers, lakes and water reservoirs of the city. It comprises of 18.95 Km^2 (8.08% of the total study area). The temperatures from winter to summer varied from 2.07 – 8.75 ^0C to 18.40 – 29.03^0C respectively.

4. CONCLUSION

The present work studied the Urban Heat Island effect in Srinagar city. The study carried out the thermal analysis of the Landsat 8 TIRS data downloaded from USGS website. The data pertained to two seasons i.e., 19th January and 27th June 2018. Field data was also collected from different randomly selected locations in the study area using IR-Gun. The satellite thermal data and the surface temperature data collected at various locations were used to generate heat map for the entire Srinagar City. For correlation of the heat maps with the existing land use, the distribution of different land use/land cover classes was carried out.

The UHI effect was found to be higher in the commercial core area of the city i.e., Lal Chowk, also in the dense congested down town built-up area and the important industrial areas i.e., Khrew and Khanmoah and Bagh-i-Mahtab Industrial area in the south-eastern and central part of the city. In the western part i.e., important commercial and trade areas of Bemina and Batamaloo also exhibit the higher temperatures. All these urban hot spots experienced temperatures ranging from27.65 –36.78˚C during the major time of the day.

Finally, it can be concluded that the thermal analysis of LANDSAT-8 TIRS for the month of January and June, 2018 indicated that the urban heat island intensity in Srinagar City was higher during summer Season (June) as compared to the winter season (January). Further the analysis suggested that there is a positive relationship between the distribution of the land use land cover and the temperature differentials in the city thereby testified the effect of UHI.

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