A

Dissertation Report

On

“Study of Land Surface Temperature with Surface index, a Parameters Combining Normalized Differential Vegetation Index and Impervious Surface Area”

By

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Submitted in the partial fulfillment for the Award of degree of

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To

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Jawahar Lal Nehru Marg, Jaipur- 302017(Rajasthan)

CERTIFICATE

This is to certify that the dissertation report on **"Study of Land Surface Temperature with Surface Index, a Parameters Combining of Normalized Differential Vegetation Index and Impervious Surface Area"** prepared by **Tanu Sharma (ID 2014PCW5036)** in partial fulfillment for the award of degree of Master of Technology in **Water Resources Engineering** to the Malaviya National Institute of Technology Jaipur, is a record of student's own work carried out by her under my supervision and guidance during academic session (2015-2016). This work is approved for submission.

Place: Jaipur

Date: 30 June 2016

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DECLARATION

I hereby declare that the dissertation which is being presented in this report entitled **"Study of Land Surface Temperature with Surface Index a Parameters Combining Normalized Differential Vegetation Index and Impervious Surface Area"** in fulfillment of the requirement of degree of Master of Technology and submitted to Department of Civil Engineering, Malaviya National Institute of Technology Jaipur is an authentic record of my own work carried out during a period from December 2015 to June 2016 under the supervision of Dr Sumit Khandelwal, Assistant Professor, Department of Civil Engineering, Malaviya National Institute of Technology Jaipur.

The results contained in this thesis have not been submitted, in parts or full, to any other university or institute for the award of any degree or diploma.

Date: 30 June, 2016

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Place: Jaipur　　　　　　　　　　Tanu Sharma

Date : 30 June 2016　　　　　　　　(2013PCW5036)

ABSTRACT

As the years passes urbanization continuously increasing. Because of this urbanization population is also increasing. Urbanization is generating many environmental problems as Urban Heat Island effect. The first phenomena were observed by an English chemist Luke Howard almost since two centuries earlier. The present work is studying LST pattern on surface parameter, which is combination of ISA and NDVI. This work has been done for Jaipur city for years 2009, 2011 and 2013 for summer winter seasons.

In the present work remote sensing data are obtained from MODIS to retrieve LST, NDVI, ISA and SMI. The study shows of Surface Index (SI), firstly, calculated correlation of NDVI and ISA with LST and then by combining of these parameters SI has been evaluated. This SI shows rising temperature pattern as SI value increases in both season summer and winter.

The SMI index is the soil moisture index, which is calculated from LST and NDVI. It is used to find soil condition or surface condition. SMI shows decreasing pattern of LST as SMI increases. This will help in agriculture, flood or drought conditions and in way to reduce the effect of UHI.

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ABBREVIATIONS

AUHI	:	Atmospheric Urban Heat Island
EOSDIS	:	EOS Data Information System
HDF-EOS	:	Hierarchical Data Format-Earth Observing System
IGBP	:	International Geosphere Biosphere Programme
ISA	:	Impervious Surface Area
ISODATA	:	Interactive Self-Organizing Data Analysis Technique Algorithm
LPDAAC	:	Land Processes Distributed Active Archive Centre
LSE	:	Land Surface Emissivity
LST	:	Land Surface Temperature
LULC	:	Land Use and Land Cover
MODIS	:	Moderate Resolution Imaging Spectroradiometer
MRT	:	Modis Re-projection Tools
MSL	:	Mean Sea Level
NASA	:	National Aeronautics and Space Administration
NDVI	:	Normalized Difference Vegetation Index
NIR	:	Near Infrared
OLI	:	Operational Land Imager
QC	:	Quality Check
SDS	:	Science Data Sets
SI	:	Surface Index
SMI	:	Soil Moisture Index
TIR	:	Thermal Infrared
UHI	:	Urban Heat Island

CHAPTER 1
INTRODUCTION

The urban heat island (UHI) is the phenomenon of higher atmospheric and surface temperatures occurs in urban areas than in the surrounding rural areas due to urbanization. Surface covers by non-evaporating impervious materials, soil and some part of the vegetation. The higher temperatures in urban heat islands increase air conditioning demands, raise pollution levels, and may modify precipitation patterns. As a result, the magnitude and pattern of LST regarding the surface materials are major concerns of urban climatology studies.

The surface UHI is typically characterized as land surface temperature (LST) through the use of airborne or satellite thermal infrared remote sensing, which provides a synoptic and uniform means of studying SUHI effects at regional scales. Satellite-measured LST has been used in heat-balance, climate modeling, and global change studies since it is determined by the effective radiating temperature of the Earth's surface. Other than the study of urban climates, relations can be stabilizing between spatial structure of urban thermal patterns and urban surface characteristics with the help of thermal remote sensing.

Land surface temperature (LST) is a required input data for modelling in climatological, hydrological, agricultural, and change detection studies LST can be easily derived from remotely sensed data. It can be used to determine the spatial relationship between LST and different LULC in urban areas. In urban areas, LULC is represented with LST. As LST is sensitive to the vegetation and the content of moisture in the soil, it can be used to find the LULC changes.

1.1 Parameters that affects LST

Over the last decade, studies, experiments are being exercised in several cities in all over the world to find that parameter which affect the LST. The main parameters are:

- **Surface materials**

  Impervious materials which commonly used for pavement and roofs, like concrete and asphalt, having different thermal phenomenon including heat capacity and thermal conductivity and surface irradiative properties, such as albedo and emissivity. These types of impervious materials show big change in heat balance of urban areas. While the materials in rural areas, not having that much change in LST pattern. The urban area is leading to higher temperatures than surrounding rural areas. “Albedo is the ratio of the amount of light reflected from a material to the amount of light shown on the material” (Heat Island Group). Light and dry surfaces (natural ground and forest) have a lower temperature than (Voogt, 2004). They reflect sunlight and therefore, have a cooler surface temperature (Voogt, 2004). The low overall albedo of the urban fabric is a major cause of the heat island effect.

- **Vegetation**

  The lack of vegetation is the major reason for the formation of urban heat islands because it cannot help in cooling via shade and evapotranspiration. Shade cools the air by blocking solar radiation from low albedo surfaces (The Heat Island Group, 2005) i.e. reducing the thermal energy and prevent the surface and ambient temperature from increasing (The Urban Heat Island Phenomenon and Potential Mitigation Strategies, 1999).

- **Geometric effects**

  Urban morphology related to the three-dimensional arrangement, orientation and spacing of buildings in a city, also plays a role in the formation of urban heat islands (USEPA, 2008). Wind flow patterns, heat energy absorption and emittance ability of the surface are influenced by the geometry of an urban city. The tall buildings within the urban areas provide multiple reflection surfaces causing absorption of sunlight, thereby increasing the efficiency with which the urban areas get heated creating "urban canyon effect". Vehicular movement additionally causes its impacts on urban morphology by advancing warmth and air contamination from this mode of transportation (Oke, 1988).

- **Soil Moisture**

  In the remote sensing, soil moisture has been a challenging variable. Microwave brightness temperature is sensitive to soil moisture because water in soils has a large impact on soil dielectric constant. Lower the microwave frequency, the higher the relative sensitivity of brightness temperature to soil moisture.

1.2 Need of Present Study

The increase in urban development gives increasing phenomenon of the Urban Heat Island due to increasing the buildings; roads etc. and reduce the vegetation cover and water bodies. These changes have a major impact on energy use, health, and economics. Hence it can become a cause for national concern. UHI is a commonly observed feature in many parts of the world. This study has not been done before regarding UHI and especially for Jaipur city. So this study has been done for Jaipur city as required. The climate of Jaipur city is semi-arid, and it remains hot for the most part of the year. The high growth rate will cause a lot of burden on the city infrastructure, and large-scale development will be required for the increased population. Hence, a better understanding of the heat island effect and its relationship with the surface parameters is required.

1.3 Objectives of the present study

Global Warming is increasing due to Changes in land use and land cover (LULC), increasing population, pollution and infrastructure pressures, urban heat islands (UHI) etc. Variations in the LST (LST dynamics) and its relationship with one or more of the land surface characteristics or parameter (such as NDVI, %ISA, SMI etc.) measuring the extent of urbanization have been discussed in this studies. The study will help in the quantification of the effect of these factors on UHI. The proposed research will also help in providing a basic idea for optimal planning and development of a city in a manner such that the effect of UHI is minimized, also resulting in a reduction of the energy demand. The objectives of the proposed work have been framed as under:-

- To study the 3D correlation between UHI parameters like NDVI, %ISA and LST for Jaipur city.
- To study the relation between %ISA and NDVI and stabilize a new parameter named as SI (Surface Index).
- To study the relationship of SI and LST for summer and winter.
- To determine another parameter that is Soil Moisture Index (SMI) using LST and NDVI.

1.4 Organization of the Thesis

The organization of the thesis in form of different chapters is as follows:-

Chapter 1 contains the Introduction, which describes the UHI and factors responsible. The need and objectives of the present study and various objectives are presented in this chapter.

Chapter 2 this section presents a literature review of the relevant study to fill the gap to the present study.

Chapter 3 describes the data and methodology used including the study of procuring, pre-processing and studying various parameters and their variation and correlations.

Chapter 4 discusses the results and various relationships developed for LST in three parts. The *first* part contains the descriptions of the contribution of different parameters to find out relationships and correlations with LST. While the *second* part describes the new patterns of LST and last part describe the soil moisture index.

Chapter 5 highlights that finding of the research. It also discusses the future scope of that research.

CHAPTER 2

LITERATURE REVIEW

As natural land cover are replaced by impervious surface materials increasingly because of urbanization and urban areas experience higher surface temperatures compared to rural areas, this effect is known as the urban heat island effect. It is characterized by a large expanse of non-evaporating impervious materials covering a majority of urban areas with a consequent increase in sensible heat flux at the expense of latent heat flux (Oke, 1982;Owen et al., 1998). LST is used to predict the energy and water exchanges between land surface and atmosphere, which plays an important role in human–environment interactions and helps urban planners and greening designers make appropriate decisions on urban planning and thermal management. As a result, the magnitude and pattern of UHI effects have been major concerns of many urban climatology studies.

2.1 Overview of Urban Heat Island (UHI)

The zone of UHI is for the shape of the urban area, surrounded by cooler area. The air temperature has a sharp rise at the urbanized area and slow increase towards the rural area. (Voogt, 2004).The UHI phenomenon is a result of several factors, like humidity, wind, temperature, precipitation and sunlight, Size of urban areal extent and building height, Level of pollution in the city, Effect of vegetation, Thermal properties of the fabric, Anthropogenic heat, Land uses.

Zhang et.al (2001) studied the relationship of UHI distribution with land cover Categories for the Beijing city. The LST difference observed is approximately 8-10oC between urban and suburban area. Vegetation shows a negative correlation with daytime LST during March and May and poor correlation during November. The study also shows that built-up and LST have a strong positive correlation in the three months (Pandey, A. K. et. al. 2014).

2.2 Observational Review study of NDVI

Earlier thermal remote sensing studies mostly used the normalized difference vegetation index (NDVI) as the major indicator of urban climate. As vegetation has high reflectance in the near-infrared wavelength and absorbs radiations in red wavelength. Calculation of NDVI is done by using the expression:

NDVI = (NIR –RED)/ (NIR+RED)

Where, NIR and RED stand for the spectral reflectance measurement acquired in near infrared and red band regions, respectively.

Gallo et al. (1993) analysed urban–rural differences in NDVI and surface temperatures. Lo et al. (1997) studied changes in the thermal responses of urban land cover types between day and night and analysed the relation between land cover radiance and vegetation amount. Gallo and Owen (1999) estimated seasonal trends in temperature and NDVI and concluded that differences in NDVI and surface temperature accounted for 40% of the variation in urban–rural temperature differences. The NDVI–temperature relationship has also been utilized in various studies to derive or evaluate two variables — fractional vegetation cover and surface soil water content for climate modeling (Carlson et al., 1995a; Gillies & Carlson, 1995; Gillies et al., 1997; Goward et al., 2002). NDVI index varies in between -1 to 1 where higher value range represents vegetation, lower range represents soil, and rock surfaces while negative value represents water body. The variability and nonlinearity suggest that NDVI alone may not be a sufficient metric to study SUHI quantitatively. To reduce the problem, Weng et al. (2004) proposed new indicator as spectral mixture model instead of NDVI. He found that the vegetation fraction has a slightly stronger negative correlation with LST (Carlson & Ripley, 1997; Gutman & Ignatov, 1998). This indicator shows same limitations of variability and nonlinearity as NDVI.

4.3 Observational Review study of %ISA

SUHI is analysed the relationship between the LST and urbanization (Arthur et al., 2000; Carlson & Arthur, 2000; Oke, 1976; Weng, 2001). In remote sensing, classifications of the impervious surface area are done by the degree of urbanization and extent of urban land use (Bauer et al., 2004; Civco et al., 2002; Yang et al.,2003). Those surfaces which cannot penetrate water are called impervious surfaces. Examples are streets, highways, parking lots, sidewalks, building rooftops, etc. A lot of impervious surfaces are due to population growth and urbanization (Stankowski, 1972). So it is an important indicator of LST. Therefore, analysing the relationship between the LST and percent impervious surface area (%ISA) in an urban area provides the surface UHI phenomena. Previous studies have shown that the higher the urban intensity or imperviousness, usually the higher the land surface temperature

(Oke, 1976; Weng, 2001). In Comparison to the NDVI, the %ISA has fewer changes in different seasons. Comparative studies of NDVI and %ISA as indicators of surface UHI are very limited. For built up areas, Ridd (1995) found a strong negative correlation between %ISA and fractional vegetation cover. Choudhury et al. (1994) and Carlson and Ripley (1997) then quantified the relationship between the percent ISA and fractional vegetation cover based on NDVI value by following equation,

$$ISA = 1 - \left(\frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \right)^2$$

where: $NDVI_{soil}$ and $NDVI_{veg}$ are the NDVI values of the pixels covered by soil or non-vegetation and full vegetation.

(Cui, Y.Y, et. al., May 2012). Yuan, F. & Bauer, E.M (2006) zonally analysis was utilized to evaluate the mean LST at each 1% increment of %ISA from 0% to 100%, and at each 0.01 increment of the NDVI from −1 to 1. Avery strong linear relationship (r2 N0.97) has found between the mean LST and percent imperviousness for the Twin Cities Metropolitan area of Minnesota, and the study also observed not such a strong relationship of LST with NDVI, R2 value approximately 0.11.

4.4 Observational Review study of SMI

Soil moisture is a parameter that plays an important role in in the global energy, water cycle, many natural and agricultural processes (K. Mallick, B.K. Bhattacharya and N. K. Patel, 2009). *In situ* measurements are not feasible that's why Soil moisture derived from satellite data. Two methodologies of soil moisture observation have been identified. The first one is based on measurements in the microwave part of the electromagnetic spectrum, while the second is based on thermal, visible and infrared observations (S. M. Vicente – Serrano, X. Pons-Fernandez and J. M., 2004). NASA initiated SMAP project formulation in 2008 and gave SMAP design formulation.

Temperature statistics are calculated and a linear relationship between the land surface temperature and soil moisture is determined based on the assumption that for equal vegetation classes the soil surface temperature is primarily dependent on the soil moisture content. The linear relationship is determined between the LST and soil moisture index (SMI) value, using:

$$SMI = \left(\frac{LST_{min} - LST}{LST_{max} - LST_{min}}\right) + 1$$

Where LST is the MODIS based land surface temperature, LST_{min} is the minimum temperature in the particular vegetation fraction class, and LST_{max} is the maximum temperature.

Two types of microwave instruments are used in soil moisture measurements. The first are passive radiometers that measure the changes in emissivity. The second are active radiometers. Microwaves have a longer wavelength between 1 mm and 1 meter.

Many microwave-based soil moisture products have been used in various fields of Earth sciences in the past decades (Brocca et al., 2010; Bruckler &Witono, 1989; Chen, Crow, Starks, & Moriasi, 2011; Crow & Ryu, 2009; Engman, 1991; Jackson, Schmugge, & Engman, 1996; Schmugge et al., 2002;Wagner et al., 2007; Zhu et al., 2014). The advantage of microwave-based observations is that they are available under cloudy weather and night time, are less sensitive to roughness conditions of the surface (Wigneron, Schmugge, Chanzy, Calvet, & Kerr, 1998) and can provide information on water content of the top soil layer, rather than the land surface only, even under vegetation coverage (Njoku & Entekhabi, 1996).

The Advanced Microwave Scanning Radiometer 2 (AMSR2) is a passive microwave sensor on board the Global Change Observation Mission 1 — Water (GCOM-W1) satellite that was launched by the Japan Aerospace Exploration Agency (JAXA) in May 2012. AMSR2 is the successor of the successful Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E, May 2002–October 2011) which was the first passive microwave sensor that was widely used for the retrieval of soil moisture (Koike et al., 2004; Njoku et al., 2003; Paloscia, Macelloni, & Santi, 2006).

CHAPTER 3

DATA AND METHODOLOGY

The main objective of the present work is to find new parameters that affect the UHI of Jaipur city. The relationship of LST with that new parameter SI and soil moisture index have also been studied. The LST, %ISA, SMI and NDVI have been derived using remote sensing data. That Remote Sensing data has been downloaded from the United States National Aeronautics and Space Administration (NASA) website, using the internet. This section describes the data used, its property and pre-processing.

3.1 Remote sensing data

In this study, data obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) has been used. MODIS is a sensor onboard Terra and Aqua platform that provides information about the Earth's surface in 36 wavebands, consisting of visible, NIR, shortwave infrared (SWIR) and thermal ranges. It provides the data for entire Earth, and it covers the earth in every one to two days. It is having a swath width of 2330 km. The MODIS sensor acquires data in three spatial resolutions. First, two bands are of 250m, from band 3 to 7; it is of 500m and 1000m for remaining bands. The MODIS products are available with a different temporal resolution of 1-day, 8-day, 16-day, and 1-month, quarterly and yearly (LPDAAC, 2014). The temporal resolution of LST and VI data used in the present study are 8-days and 16-days respectively. The spatial resolution of LST data is 1km and that of VI and 250m and 1 km. The LST data has been retrieved from the11 Aqua MODIS 8-day composite product with the spatial resolution of 1 km x 1km. The VI though retrieved from the same platform but on temporal and spatial resolution of 16 days and 250m respectively. The Table 3.1 tabulates the various MODIS products used in the current study.

Table 3.1.1 MODIS data used for study

Remote Sensing Product	Short Name	Sensor	Platform	Temporal Resolution	Spatial Resolution
Land Cover Type	MCD12Q1	MODIS	Combined Aqua & Terra	Yearly	463.3 m
Land Surface Temperature and Emissivity	MYD11A2	MODIS	Aqua	8 Day	926.6m
Vegetation Indices	MYD13Q1 MYD13A2	MODIS	Aqua	16 Day	231.7 m 926.6m

3.2.1 MODIS Product- Land Surface Temperature

MYD11A2 LST is a level 3 MODIS Land Surface Temperature data product having 8- day and 1km temporal resolution and spatial resolution, respectively.it is calculated by averaging the view-time LST of two to eight days for clear-sky conditions (Wan, 2007). The data product comprises of 12 Science Data Sets (SDS) layers which constitute day and night images of LST and information such as view angle, view time and clear sky conditions during observation for LST, both for day time and night time LST. The product also contains bands 31 and 32, which have been used to derive LST. Both day and night time LST data layers have been used in the present study. The time of acquiring daytime LST is 1:30 PM noon whereas the acquiring time during night is 1:30 AM.

3.2.2 MODIS Products- Vegetation Indices

Global MODIS vegetation indices are designed to provide consistent spatial and temporal comparisons of vegetation conditions. MODIS data set includes two vegetation indices normalised difference vegetation index (NDVI) and the enhanced vegetation index (EVI) used to characterize land surface biophysical properties and processes, including primary production and land cover conversion. There exists a complete, global time series record of 6 VI products from each of the Terra and Aqua MODIS sensors, at varying spatial (250m, 1km, 0.05 degree) and temporal (16-day, monthly) resolutions to meet the needs of the research and application communities. MODIS vegetation indices produced on 16-day intervals and at multiple spatial resolutions, provide consistent spatial and temporal comparisons of vegetation canopy greenness, chlorophyll, and canopy structure and a composite property of leaf area. The present study uses data retrieved from MYD13Q1 which provides data at a spatial and temporal resolution of 250m and 16 days respectively. Another data has been used as MYD13A2 having same temporal resolution and 926.6 m spatial resolution.

3.2 Methodology

The methodology contains two parts to fill the objective of this thesis. The first part describes the data collection in which what data has used and from where that collected; has been described. In second part processing and method of analysis of these data have been described.

- **Data collection**:

  Data is acquired for Jaipur city for summer rainy and winter season. The summer season extends from March to June, whereas winter extends from November to February. SI has been found out for three years like 2009, 2011 and 2013. Soil moisture index has been calculated for three years 2011, 2013 and 2015. The LST Product has been used as MYD11A2 which having 8-day temporal resolution and 1 km spatial resolution and NDVI product has been used as MYD13Q1 with 16 day temporal and 250m spatial resolution. While for SMI calculation NDVI product has been used as MYD13A2 with 16 days temporal and 1000m spatial resolution and LST product has been used same as above because resolution of both of them need to be Same in SMI calculation. Various data products have been freely downloaded from the LPDAAC website using NASA Warehouse Inventory Search Tool (WIST). Data should be downloaded according to their stream like atmosphere, land, ocean, etc., a sensor as MODIS, ASTER, AVHRR, etc., location through latitude/longitude, orthographic, equatorial search, etc. and time duration from start date/time to end date/time.

- **Data Analysis:**

  The remote sensing work has been done using ArcGIS software. The various data layers have been extracted using a simple tool known as ‘extract by mask’ via feature mask. After that LST and NDVI are obtained with the help of spatial analysis tool as ‘Raster Calculator’. The corresponding scale multiplication factors of LST and NDVI are as 0.02 and 0.0001 respectively for MODIS data products. LST obtained from 8 days MODIS MYD11A2 product with 926.6m resolution While NDVI obtained from 16 days MODIS MYD13Q1 product of 231.6m resolution. For analysing the relationship, the spatial resolution should be same. Hence the NDVI has been aggregated to the LST resolution by 'Nearest neighbourhood' algorithm of the resampling technique using 'Aggregate-Generalization of spatial analyst tool'. %ISA has been calculated using NDVI raster image in ArcGIS.

To find out the correlation between LST, NDVI, and %ISA; SPSS software has been used and 3D correlation has been stabilized using 3D scatter graph tool. For analysis of these variable and to stabilize new parameter as SI by giving weights to NDVI and %ISA and add both of them in excel.

Other parameter soil moisture index is also determined by using LST and NDVI. Firstly, NDVI image classified into five classes via unsupervised classification in ArcGIS. Then Extract the corresponding LST for each class and combined all classes using mosaicking tool in ArcGIS.

3.3 Software used in the study

Two following software's were used for this project

1. IBM SPSS Statistics 20: This software has been used for statistics like 3D correlation.

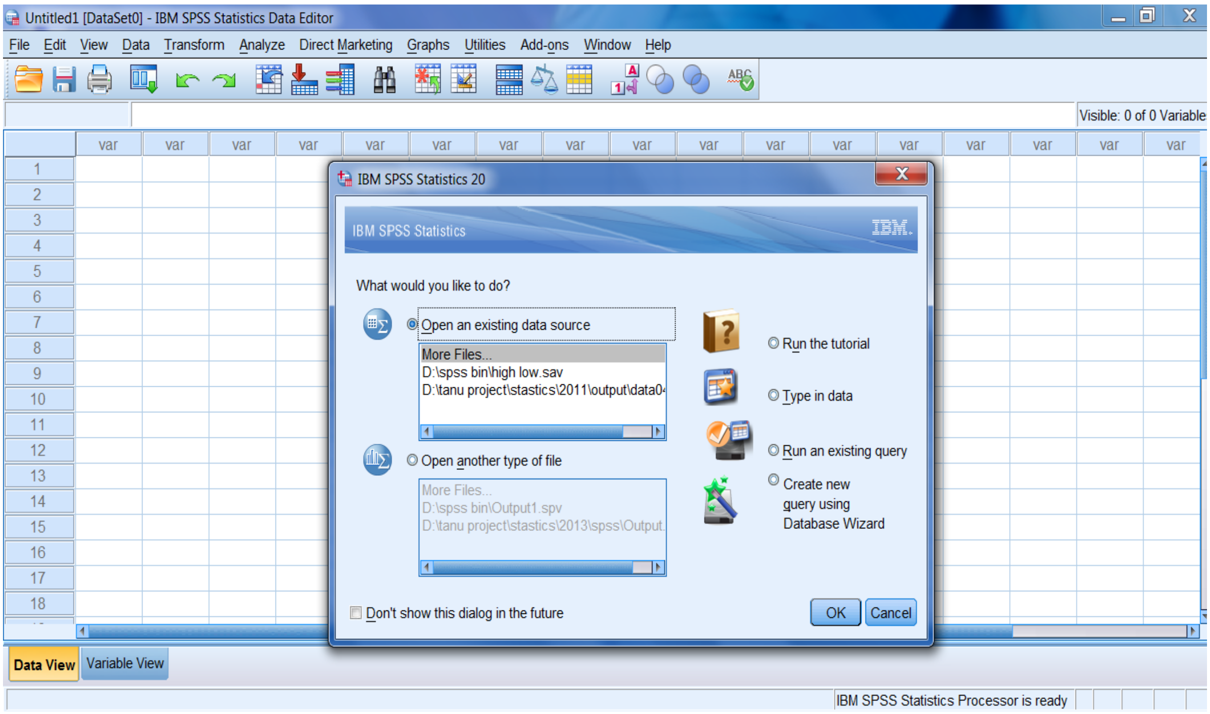


Figure 3.3.1: SPSS 20 software image

2. ArcGIS: This was also used to compliment the display and processing of the data like LST, NDVI, %ISA and SMI.

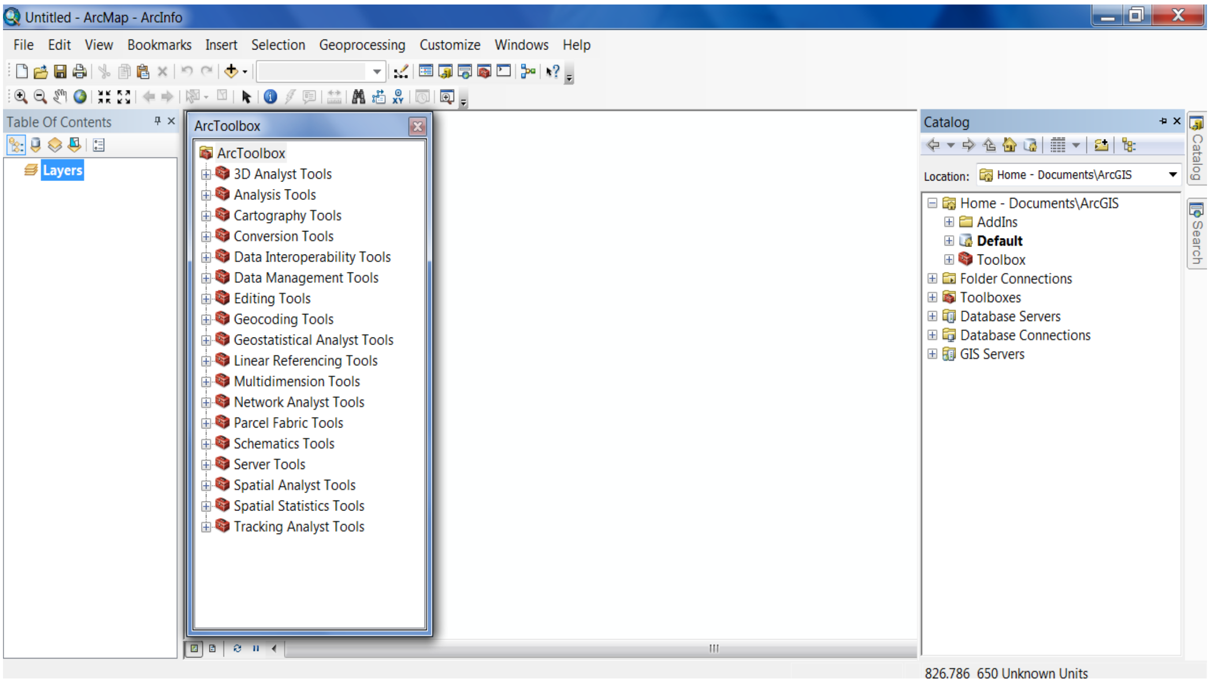


Figure 3.3.2: ArcGIS software image

3. MRT (MODIS Re-projection Tools): MRT is used for re-projecting the data from Sinusoidal projection to UTM Zone 43N projection system with WGS84 datum and has been reformatted from HDFEOS (Hierarchical Data Format-Earth Observing System) to GeoTIFF format.

4. EXCEL: this has been used for calculation and analysis via graphs.

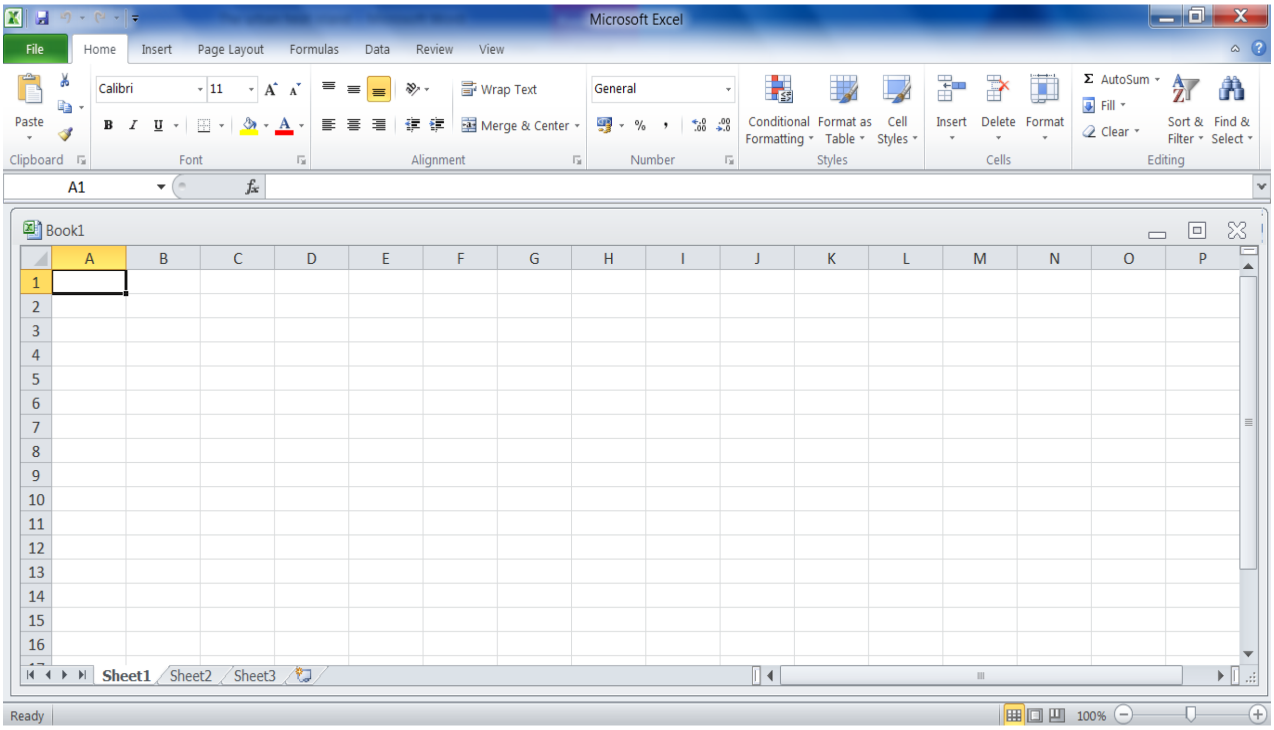


Figure 3.3.3: EXCEL image

3.4 Study are - Jaipur City

Jaipur is the capital of Rajasthan also known as the Pink City. Jaipur is India's 10th largest city and having the total population of 33 lakh. It is located in Northern India, and its geographical location is 26^{o} 25' to 27^{o} 51' north latitude and 74^{0} 55'to 76^{0} 10' east longitude. The altitude of the city is 431 m above MSL. The city is located predominately on plain terrain and is surrounded by Aravalli hill range on the north, northeast and east side. The semi-arid climate of Jaipur causes extreme diurnal and annual temperature as temperature range between 5oC to 22oC in winter season while in winter season temperature rising up to 45oC and low rainfall as 650mm of annual rainfall. So the study area which is an 8km buffer around the urban polygon retrieved from MODIS yearly land cover type image (MCD12Q1) covers the rural area.

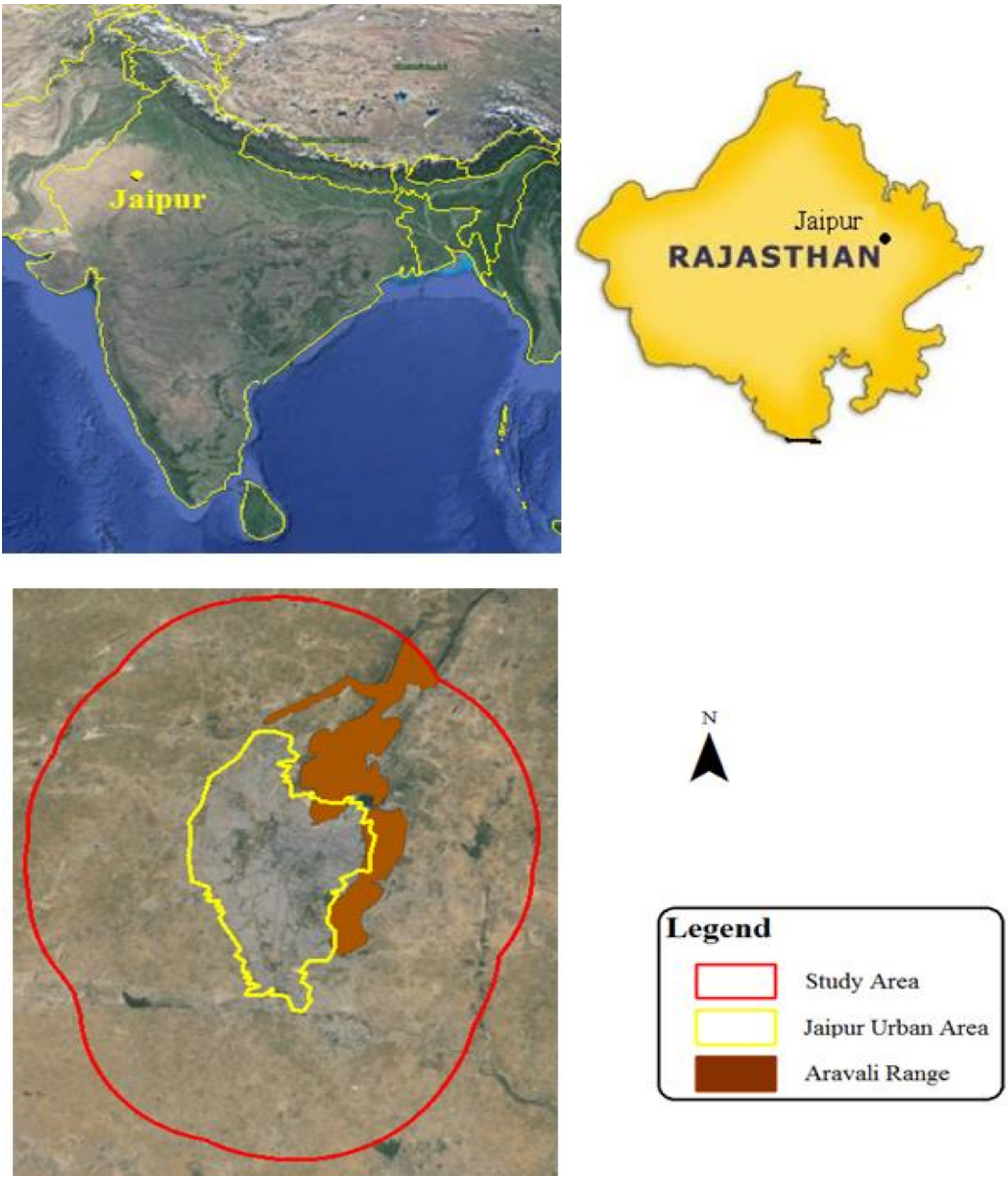


Figure 3.4.1: Google Earth © image of the Jaipur study area

CHAPTER 4

RESULTS AND DISCUSSION

This chapter describes the new parameter which shows the relationship with LST for Jaipur city. One another parameter, soil moisture index is also described in this document. Soil moisture index has calculated for three years like 2011, 2013 and 2015 for summer, winter and rainy seasons. Nomenclature for that new parameter is Surface Index (SI) which is basically a combination of NDVI and %ISA. SI has calculated for three years like 2009, 2011 and 2013 for summer-winter for Jaipur city.

4.1 Correlation between %ISA NDVI and LST

The 3D correlation between %ISA, NDVI and LST has been used in retrieving LST data for summer and winter of the Jaipur city for three years duration. The study has been done with the help of SPSS 20 software via 3D scattered graphs for three the year 2009, 2011 and 2013, for studying the relation between them for Jaipur city. The data and graphs are as follow;

Table4.1.1 : Data of various parameters as %ISA, NDVI winter, NDVI summer, Mean LST summer and Mean LST winter for 2009

Year 2009				
%ISA	NDVI WINTER	NDVI SUMMER	MEAN LST SUMMER	MEAN LST WINTER
0	0.425214	0.287575	304.9515	280.4081
0.01	0.44929	0.294543	304.64	281.0914
0.02	0.47632	0.29422	305.1587	280.0307
0.03	0.317375	0.286093	305.0471	281.0628
0.04	0.377663	0.283312	305.18	280.0153
0.05	0.440162	0.295545	305.2473	280.1055
0.06	0.421083	0.290525	304.7883	280.3583
0.07	0.4191	0.297669	304.7275	280.935
0.08	0.389145	0.294056	305.3778	280.7267
0.09	0.39119	0.281767	304.8555	280.8767
0.1	0.402662	0.283935	304.929	281.163
0.11	0.361295	0.284321	304.961	280.9358
0.12	0.431507	0.287962	304.8846	281.2369
0.13	0.394465	0.269561	305.1689	280.44
0.14	0.3805	0.278023	305.0745	280.6582

0.15	0.401004	0.277246	305.1615	280.9585
0.16	0.388652	0.27505	304.8773	281.1991
0.17	0.348004	0.259123	304.8936	281.3773
0.18	0.409396	0.283676	304.3419	282.2219
0.19	0.382944	0.26156	304.5773	282.012
0.2	0.394095	0.279853	304.4671	281.9988
0.21	0.380909	0.286827	304.7413	281.428
0.22	0.404713	0.260571	305.2562	280.9333
0.23	0.370945	0.272479	304.5926	282.0947
0.24	0.403657	0.273778	304.6965	281.9713
0.25	0.350675	0.298065	304.7235	281.3741
0.26	0.328924	0.293919	304.5275	281.9512
0.27	0.378476	0.284942	304.5854	281.9346
0.28	0.3805	0.263512	304.9908	282.2054
0.29	0.352047	0.274321	304.5042	281.6505
0.3	0.362448	0.265441	304.4765	282.2082
0.31	0.334392	0.258789	304.3455	282.4033
0.32	0.382167	0.281769	304.5723	281.8369
0.33	0.31445	0.267236	304.54	282.6273
0.34	0.367521	0.271686	304.3286	283.0257
0.35	0.37112	0.259944	304.7322	282.0067
0.36	0.33918	0.291667	303.9511	282.6444
0.37	0.35214	0.279563	304.5425	282.1625
0.38	0.443589	0.288627	303.8382	282.86
0.39	0.38091	0.227467	304.74	281.6567
0.4	0.331847	0.263044	304.2955	282.1289
0.41	0.304345	0.234943	304.3743	282.9486
0.42	0.349789	0.267244	304.0733	282.8622
0.43	0.4547	0.259133	303.8933	283.9
0.44	0.40335	0.250638	304.455	282.62
0.45	0.427275	0.255408	303.7567	283.59
0.46	0.39876	0.27382	304.602	282.682
0.47	0.432867	0.29824	303.292	283.8
0.48	0.356838	0.250086	304.4486	282.6428
0.49	0.435344	0.251425	304.1525	282.9225
0.5	0.30165	0.261355	303.4473	284.1964
0.51	0.326375	0.277457	304.0029	283.6257
0.52	0.26346	0.244589	304.4022	282.6555
0.53	0.4196	0.231838	303.9	283.16
0.54	0.420925	0.330767	303.28	283.2267
0.55	0.3778	0.22828	303.416	283.76
0.56	0.43514	0.243725	304.2225	283.275
0.57	0.399067	0.282682	303.6291	283.64
0.58	0.355767	0.22692	303.976	283.652
0.59	0.32844	0.247771	303.5086	283.6171

0.6	0.318	0.2566	303.7222	283.3
0.61	0.322375	0.219	303.71	283.2
0.62	0.36625	0.230925	303.575	283.975
0.63	0.406225	0.24235	303.86	283.5767
0.64	0.33116	0.247417	303.8967	283.05
0.65	0.47225	0.18985	303.28	284.96
0.66	0.493975	0.2405	302.94	283.58
0.67	0.3022	0.2799	302.54	285.46
0.68	0.3707	0.235375	303.915	283.175
0.69	0.36125	0.242133	303.42	284.1667
0.7	0.309667	0.21898	303.152	284.728
0.71	0.439467	0.269	303.355	284.49
0.72	0.48995	0.215333	303.4067	283.6267
0.73	0.392533	0.230429	303.3571	283.82
0.74	0.3706	0.2192	303.32	284.36
0.75	0.39255	0.22576	303.596	284.512
0.76	0.3325	0.228117	303.13	284.9867
0.77	0.34015	0.202	303.05	286.1
0.78	0.338294	0.2024	302.92	283.2
0.79	0.425214	0.220875	303.515	283.655
0.8	0.44929	0.1993	302.815	284.865
0.81	0.47632	0.240667	303.3133	284.4933
0.83	0.317375	0.214833	303.1533	285.12
0.84	0.377663	0.2194	302.41	285.66
0.85	0.440162	0.20452	303.16	284.716
0.86	0.421083	0.193071	303.1343	285.1143
0.87	0.4191	0.20675	302.83	284.15
0.88	0.389145	0.24365	302.56	285.17
0.89	0.39119	0.1853	304.64	284.42
0.91	0.402662	0.1885	302.44	287.01
0.93	0.361295	0.19425	303.78	284.84
0.95	0.431507	0.2535	302.32	284.7
0.96	0.394465	0.2202	303	284.58
0.98	0.3805	0.2096	302.66	285.69
1	0.401004	0.20985	302.63	284.6

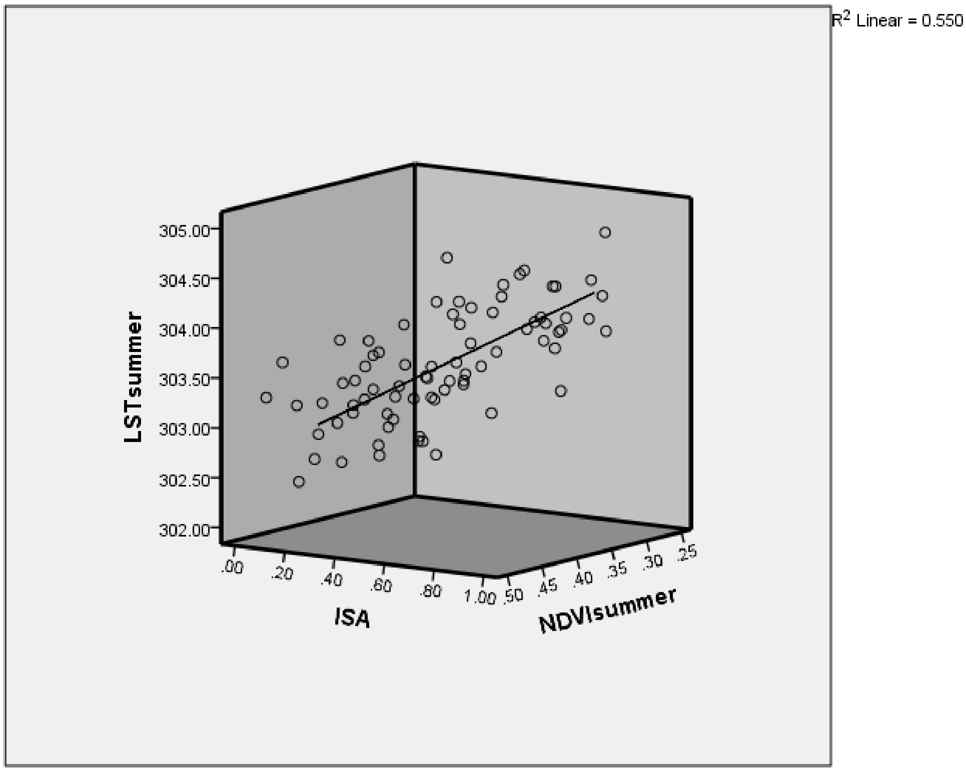


Figure 4.1.1: 3D Correlation between %ISA, NDVI and LST for summer 2009

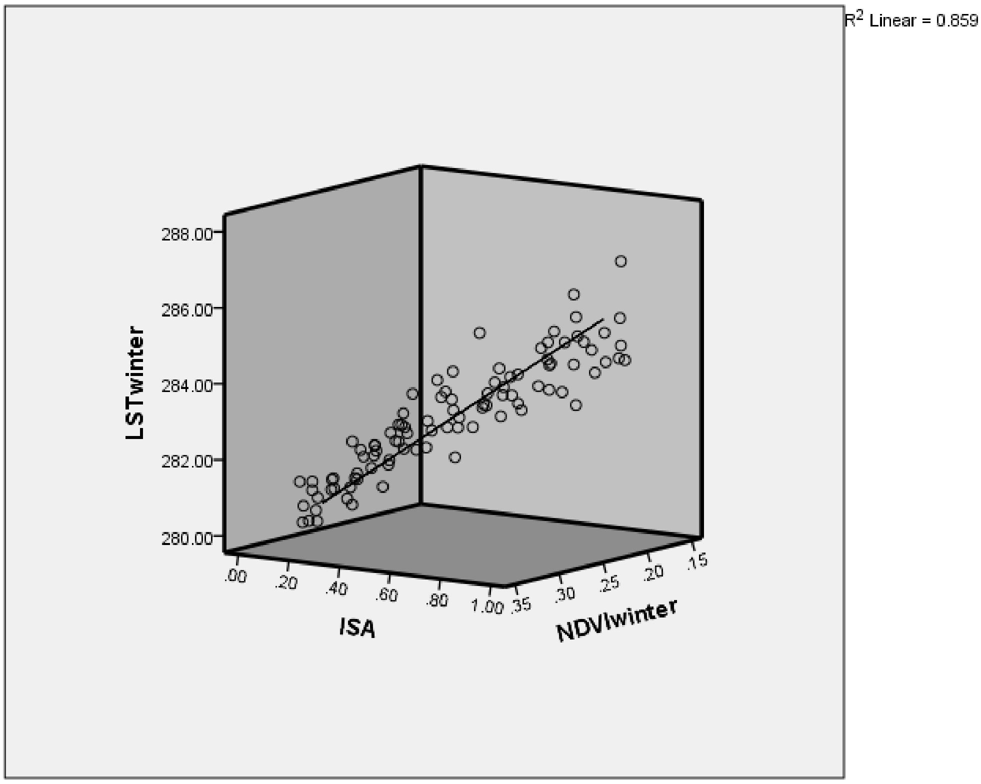


Figure 4.1.2: 3D Correlation between %ISA, NDVI and LST for winter 2009

Figure 4.1.2: Data of various parameters as %ISA, NDVI winter, NDVI summer, Mean LST summer and Mean LST winter for 2011

Year 2011				
%ISA	NDVI WINTER	NDVI SUMMER	MEAN LST SUMMER	MEAN LST WINTER
0.01	0.425214	0.231957	293.0933	283.4395
0.02	0.44929	0.23025	293.4417	283.706
0.03	0.47632	0.22076	294.216	282.316
0.04	0.317375	0.234481	294.1609	283.545
0.05	0.377663	0.224176	293.7624	284.0075
0.06	0.440162	0.232557	294.6583	282.9338
0.07	0.421083	0.225418	293.4109	284.55
0.08	0.4191	0.231719	294.1037	283.4783
0.09	0.389145	0.211188	294.7671	283.8855
0.1	0.39119	0.225193	293.7533	283.0181
0.11	0.402662	0.2298	294.7754	283.8138
0.12	0.361295	0.230083	294.7911	283.7842
0.14	0.431507	0.238143	294.6504	283.5671
0.15	0.394465	0.232423	294.6154	283.6648
0.16	0.3805	0.214582	293.7764	283.5469
0.17	0.401004	0.23659	295.248	283.8892
0.18	0.388652	0.229031	293.9138	284.2208
0.19	0.348004	0.24285	294.1025	283.7904
0.2	0.409396	0.220011	294.7267	283.5911
0.21	0.382944	0.2382	295.74	283.5592
0.22	0.394095	0.2362	294.6575	283.9967
0.23	0.380909	0.230027	294.7255	284.4567
0.25	0.404713	0.228489	294.9133	283.9918
0.26	0.370945	0.202229	295.3657	283.5421
0.27	0.403657	0.217175	294.75	283.5617
0.28	0.350675	0.2112	295.4625	283.53
0.29	0.328924	0.2144	296.82	284.113
0.3	0.378476	0.227717	296.1367	284.4724
0.31	0.3805	0.2157	296.06	284.1758
0.32	0.352047	0.228129	296.3971	284.1576
0.33	0.362448	0.210029	295.1943	283.9971
0.34	0.334392	0.2251	295.4571	284.841
0.35	0.382167	0.234557	294.8914	283.9421
0.36	0.31445	0.243271	295.8571	284.4076
0.37	0.367521	0.24142	296.116	284.0108
0.39	0.37112	0.2502	296.2833	284.195
0.4	0.33918	0.219417	296.55	284.549
0.41	0.35214	0.228933	295.5133	284.3725
0.42	0.443589	0.237333	295.7067	283.7129

0.44	0.38091	0.24795	295.46	284.5853
0.45	0.331847	0.229567	297.0333	284.876
0.46	0.304345	0.257133	295.18	283.838
0.47	0.349789	0.2428	296.9067	284.4844
0.48	0.4547	0.23415	297.17	285.518
0.49	0.40335	0.21475	295.478	285.7373
0.5	0.427275	0.2262	296.1	286.0582
0.51	0.39876	0.240914	296.94	285.1378
0.52	0.432867	0.1862	296.64	284.73
0.53	0.356838	0.23036	296.788	285.34
0.54	0.435344	0.1971	297.14	286.175
0.55	0.30165	0.2316	295	285.295
0.56	0.326375	0.21946	295.68	285.465
0.57	0.26346	0.2332	297.5	285.6086
0.58	0.4196	0.23425	294.94	285.436
0.59	0.420925	0.237	296.88	285.4644
0.62	0.3778	0.227414	296.7371	285.345
0.63	0.43514	0.23795	297.71	286.1971
0.64	0.399067	0.244075	297.16	286.74
0.65	0.355767	0.2209	296.785	285.4067
0.66	0.32844	0.2153	296.94	286.8867
0.67	0.318	0.24685	296.655	286.965
0.68	0.322375	0.2128	297.86	287.555
0.69	0.36625	0.22614	296.488	286.984
0.7	0.406225	0.26285	298.03	285.7
0.71	0.33116	0.25744	297.496	286.1
0.72	0.47225	0.24675	297.37	286.21
0.73	0.493975	0.24485	297.48	285.265
0.74	0.3022	0.2205	297.53	287.272
0.75	0.3707	0.2499	296.675	285.4933
0.77	0.36125	0.25725	297.485	286.9
0.78	0.309667	0.22878	296.996	286.7
0.79	0.439467	0.2767	295.85	285.5133
0.8	0.48995	0.25625	297.82	286.48
0.81	0.392533	0.23588	296.608	286.6867
0.83	0.3706	0.245	297.34	287.305
0.84	0.39255	0.2253	297.84	287.155
0.85	0.3325	0.2196	295.89	286.705
0.86	0.34015	0.2511	297.2667	286.8867
0.87	0.338294	0.2134	295.91	285.704
0.88	0.425214	0.241325	298.42	286.364
0.89	0.44929	0.23695	297.09	286.96
0.9	0.47632	0.2542	297.515	287.27
0.91	0.317375	0.22676	297.5067	287.2933
0.92	0.377663	0.2133	297.38	287.448

0.94	0.440162	0.265367	297.94	287
0.95	0.421083	0.249667	298.14	287.68
0.98	0.4191	0.242	298.8333	286.9467
0.99	0.389145	0.2164	298.24	287.32
1	0.39119	0.233129	298.94	286.9667

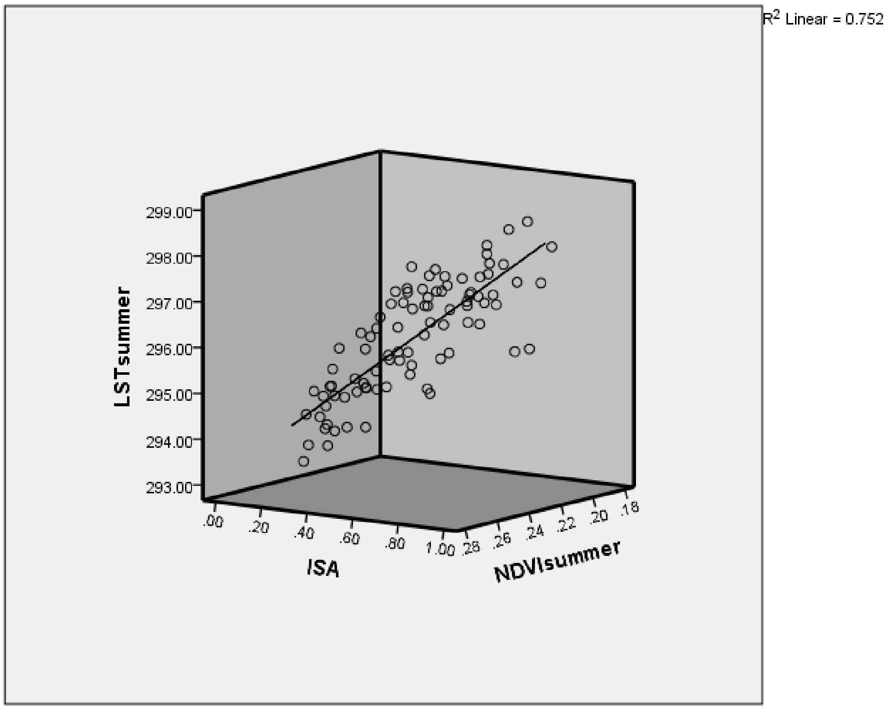


Figure 4.1.3: 3D Correlation between %ISA, NDVI and LST for summer 2011

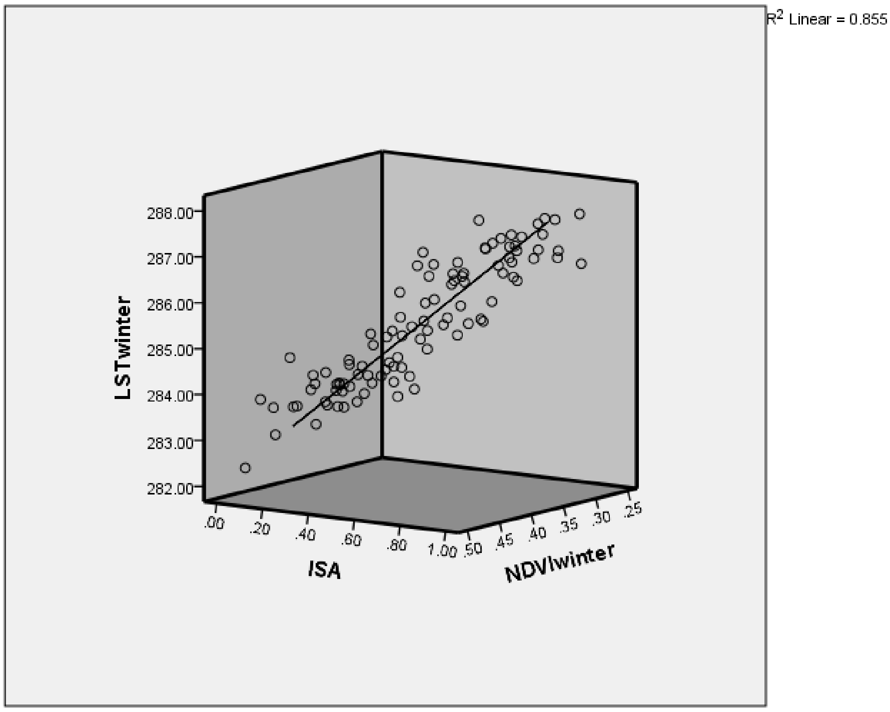


Figure 4.1.4: 3D Correlation between %ISA, NDVI and LST for winter 2011

Figure 4.1.3: Data of various parameters as %ISA, NDVI winter, NDVI summer, Mean LST summer and Mean LST winter for 2013

Year 2013				
%ISA	**NDVI WINTER**	**NDVI SUMMER**	**MEAN LST SUMMER**	**MEAN LST WINTER**
0.01	0.335915	0.23281	299.0044	284.21
0.02	0.299825	0.230676	299.8971	283.67
0.03	0.2821	0.23404	299.1486	283.18
0.04	0.30502	0.213	299.9827	282.70
0.05	0.322033	0.227787	299.4533	283.22
0.07	0.30614	0.226	299.4661	284.54
0.08	0.336467	0.231617	300.376	284.04
0.09	0.343257	0.241525	300.2271	283.89
0.1	0.307767	0.223606	300.7889	283.28
0.11	0.355256	0.2045	299.595	284.72
0.12	0.348857	0.233368	300.4235	284.21
0.15	0.308967	0.2158	300.0108	283.63
0.16	0.282729	0.219957	300.5095	283.04
0.17	0.301925	0.230657	300.2307	283.19
0.18	0.32342	0.218667	300.6694	284.18
0.19	0.329271	0.24205	300.7819	283.74
0.2	0.283344	0.251582	301.1886	283.12
0.21	0.30228	0.210578	301.14	284.40
0.22	0.2885	0.1989	300.3862	284.16
0.23	0.334663	0.219067	301.2654	284.62
0.24	0.326633	0.224443	300.54	284.01
0.26	0.3268	0.2343	300.7486	283.49
0.27	0.347507	0.21308	299.89	283.80
0.28	0.3324	0.230686	299.676	284.89
0.29	0.3274	0.2171	301.552	283.76
0.3	0.315821	0.2183	300.7343	283.32
0.31	0.3396	0.2229	301.7133	285.08
0.32	0.3428	0.21478	300.4286	283.82
0.33	0.297169	0.2113	300.8889	283.73
0.34	0.339292	0.239625	300.916	285.32
0.35	0.347647	0.191567	300.71	284.41
0.36	0.305747	0.220233	301.51	284.01
0.37	0.326854	0.2064	300.7533	284.00
0.38	0.337588	0.233188	301.02	284.19
0.39	0.332437	0.2011	300.875	283.48
0.4	0.33418	0.223225	301.504	284.02
0.41	0.32684	0.230783	301.545	284.23
0.42	0.320127	0.209414	301.92	284.13
0.43	0.345783	0.237317	300.6333	284.91

0.45	0.339317	0.220067	302.2533	284.48
0.47	0.33066	0.1872	301.75	284.31
0.48	0.35143	0.20522	301.204	284.74
0.49	0.376181	0.204067	301.9533	284.23
0.5	0.354142	0.20442	301.4067	284.54
0.51	0.331008	0.2268	302.34	284.46
0.52	0.35601	0.179033	301.05	285.15
0.55	0.3274	0.207117	301.185	285.20
0.57	0.344521	0.18815	300.94	284.39
0.58	0.295092	0.1886	300.5067	284.24
0.59	0.32828	0.206825	300.6867	284.68
0.61	0.319159	0.2326	301.4943	284.25
0.62	0.322467	0.177233	301.97	284.09
0.63	0.31435	0.188567	301.72	285.16
0.64	0.316562	0.206929	301.03	284.16
0.65	0.362775	0.2438	302.16	284.03
0.67	0.338678	0.2054	301.8133	285.10
0.71	0.316783	0.203267	301.44	285.96
0.74	0.361117	0.2171	302.46	285.17
0.75	0.283111	0.192267	301.55	285.82
0.77	0.319273	0.22255	301.8466	284.53
0.79	0.29815	0.1893	302.075	285.59
0.8	0.27285	0.210533	301.22	286.26
0.81	0.271678	0.2021	301.9233	284.50
0.82	0.306671	0.172143	301.5733	285.18
0.84	0.299817	0.183933	301.936	286.22
0.85	0.284875	0.16185	302.4733	284.65
0.86	0.2678	0.1769	302.36	285.42
0.87	0.276643	0.1867	302.22	285.37
0.88	0.2736	0.1543	302.6	284.29
0.89	0.335217	0.1813	302.16	285.33
0.9	0.264233	0.15655	302.56	286.42
0.91	0.2818	0.19655	301.94	286.93
0.92	0.316683	0.1853	302.11	286.38
0.93	0.28505	0.2233	302.204	285.20
0.94	0.274533	0.16332	302.24	286.56
0.95	0.277433	0.1664	302.04	284.75
0.97	0.303488	0.1479	302.51	285.04
1	0.275422	0.190713	301.972	285.04

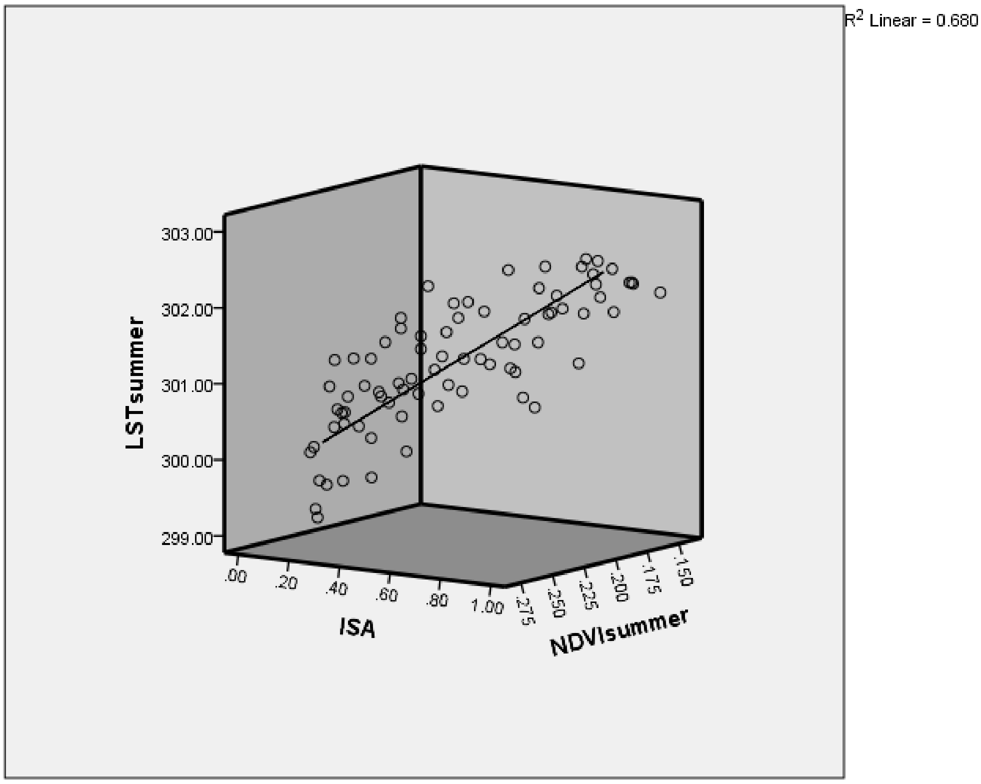


Figure 4.1.5: 3D Correlation between %ISA, NDVI and LST for summer 2013

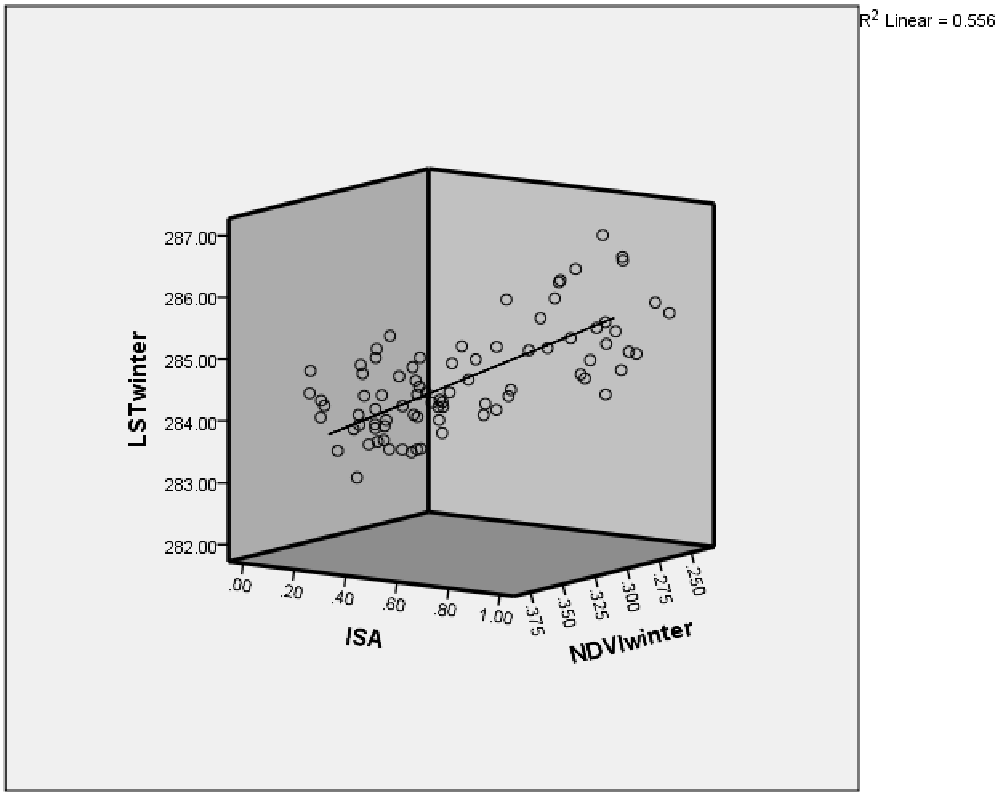


Figure 4.1.6: 3D Correlation between %ISA, NDVI and LST for winter 2013

A good positive correlation between %ISA, NDVI and LST, which vary from 0.6 to 0.8 .Above results shows a better correlation in winter than summer and it decreases as years going on. In summer there is variation in correlation and not gives a certain pattern. These correlations are above the 0.5 as given in table 4.1.4, so these parameters have definitely a good relation. Hence, from a combination of these parameters %ISA and NDVI, a new parameter can be established. That parameter has been tried to find out in further section in 4.2.

Table 4.1.4: 3D Correlation values for SUMMER and WINTER for years 2009, 2011 and 2013

YEAR	SUMMER	WINTER
2009	.55	.859
2011	.75	.855
2013	.68	.56

4.2 Relation of New parameter as SI with LST

Surface includes two type of material permeable and impermeable. Impermeable surface value can get from Impermeable Surface Index (%ISA) and permeable surface value can be concluded by NDVI. So we can say that Surface Index is the combination of %ISA and NDVI. Hence, after giving weight for %ISA and NDVI, added both of parameter to get a new parameter which has been called surface index.

The LST pattern for SI for winter and summer shows increasing pattern. The Jaipur city has buffered of 8 km. The parameter SI is the combination of NDVI and %ISA, so SI pattern is somewhat similar to %ISA but the range of that parameter has been decreased because of NDVI. This relationship got the positive liner co-relation and got the value of R^2 about 0.9 as given in table 4.2.16.

The pattern of given weightage is such as the %ISA value increases as well as weightage for %ISA also increases because higher %ISA value gives the higher LST value, that means more impermeable surface gives more reflectance value. So it can say that the pixel that having higher %ISA value which also having more impermeable surface than permeable surface. As a result that same pixel has lower weightage for NDVI. On the other hand which pixels have lower %ISA weightage that having higher NDVI weightage. So weightage pattern for NDVI is increasing as NDVI shows decreasing pattern for LST because as the vegetation increases temperature decreases. As a result, the pixels showing lower LST at corresponding NDVI, that pixels having more vegetation so these pixels having higher weightage.

The weightage tables, correlation graphs and data for SI vs LST for different season and different years are as follows;

Table 4.2.1: NDVI weightage values for summer 2009

NDVI value range for summer 2009	**Weightage (%)**
<0.11	0
>=0.11 to <0.16	50
>=0.16 to <0.25	80
>=0.25 to <0.31	100

Table 4.2.2: %ISA weightage values for summer 2009

%ISA value range for summer 2009	**Weightage (%)**
<=0.1	10
>0.1 to <=0.2	20
>0.2 to <=0.3	30
>0.3 to <=0.5	50
>0.5 to <=0.6	60
>0.6 to <=0.8	80
>0.8 to <=0.9	90
>0.9	100

Table 4.2.3: NDVI weightage values for winter 2009

NDVI value range for winter 2009	**Weightage (%)**
>=0.1 to <0.2	30
>=0.2 to <0.3	70
>=0.3 to <0.4	100

Table 4.2.4: %ISA weightage values for summer 2009

%ISA value range for winter 2009	Weightage (%)
>=0 to <0.2	10
>=0.2 to <0.4	30
>=0.4 to <0.6	70
>=0.6 to <0.8	90
>=0.8	100

Table 4.2.5: NDVI weightage values for summer 2011

NDVI value range for summer 2011	Weightage (%)
<0.17	10
>=0.17 to <0.19	30
>=0.19 to <0.34	80
>=0.34 to <=0.37	100

Table 4.2.6: %ISA weightage values for summer 2011

%ISA value range for summer 2011	Weightage (%)
<=0.1	10
>0.1 to <=0.2	20
>0.2 to <=0.3	30
>0.3 to <=0.5	40
>0.5 to <=0.7	55
>0.85 to <=0.96	95
>0.96	100

Table 4.2.7: NDVI weightage values for winter 2011

NDVI value range for winter 2011	Weightage (%)
<0.12	10
>=0.12 to <0.2	20
>=0.2 to <0.4	40
>=0.4 to <0.5	60
>=0.5 to <=0.6	70
>0.6 to <=0.7	80
>=0.7	100

Table 4.2.8: %ISA weightage values for winter 2011

%ISA value range for winter 2011	Weightage (%)
<=0.1	10

>0.1 to <=0.2	20
>0.2 to <=0.3	30
>0.3 to <=0.5	40
>0.5 to <=0.7	55
>0.85 to <=0.96	95
>0.96	100

Table 4.2.9: NDVI weightage values for summer 2013

NDVI value range for summer 2013	Weightage (%)
<0.12	10
>=0.12 to <0.15	50
>=0.15	100

Table 4.2.10: %ISA weightage values for summer 2013

%ISA value range for summer 2013	Weightage (%)
<=0.1	10
>0.1 to <=0.2	20
>0.2 to <=0.3	30
>0.3 to <=0.5	40
>0.5 to <=0.7	55
>0.85 to <=0.96	95
>0.96	100

Table 4.2.11: NDVI weightage values for winter 2013

NDVI value range for winter 2013	Weightage (%)
<=0.15	20
>0.15 to <=0.2	50
>0.2	100

Table 4.2.12: %ISA weightage values for winter 2013

%ISA value range for winter 2013	Weightage (%)
<=0.1	10
>0.1 to <=0.2	20
>0.2 to <=0.3	30
>0.3 to <=0.5	50
>0.5 to <=0.6	60
>0.6 to <=0.8	80
>0.8 to <=0.9	90

Table 4.2.13: Data of SI and Mean LST for summer-winter 2009

2009		
SI	**MEAN LST WINTER**	**MEAN LST SUMMER**
0.12	280.44	295.62
0.13	280.9188	292.552
0.14	280.7269	293.75
0.15	280.2809	293.0672
0.16	280.9418	292.6427
0.17	280.299	292.0837
0.18	281.2516	292.7319
0.19	280.884	294.2427
0.2	280.958	292.5244
0.21	280.6796	291.9879
0.22	281.0894	292.7265
0.23	280.6195	294.7354
0.24	281.128	293.9689
0.25	281.6271	295.252
0.26	281.5845	294.7945
0.27	281.6551	295.3222
0.28	281.8642	294.8867
0.29	281.92	294.51
0.3	282.2738	294.402
0.31	282.3443	294.548
0.32	282.6517	295.1724
0.33	282.3127	296.2457
0.34	282.48	295.2478
0.35	282.1167	295.8835
0.36	282.62	294.474
0.37	283.2147	295.8525
0.38	282.512	295.5084
0.39	282.6733	295.7293
0.4	283.3169	295.3316
0.41	283.2143	296.6033
0.42	283.1325	296.5183
0.43	283.1057	294.4543
0.44	283.81	295.1267
0.45	283.2518	295.125
0.46	283.6978	295.0733
0.47	282.9892	294.3867
0.48	283.8508	296.12
0.49	283.8	295.1467
0.5	283.7083	295.3911
0.51	283.92	295.0029
0.52	282.7333	294.94
0.53	283.2509	293.24

0.54	284.28	294.52
0.55	283.076	295.525
0.56	283.7629	296.01
0.57	284.4333	295.7267
0.58	283.58	296.4
0.59	285.2628	296.58
0.6	284.835	296.22
0.61	284.8933	297.68
0.62	284.2075	296.41
0.63	284.3911	295.8333
0.64	284.7633	296.22
0.65	285.29	295.8
0.66	284.72	293.7329
0.72	285.22	294.0233
0.73	284.7133	293.2941
0.74	285.36	294.1448
0.75	284.09	294.5013
0.76	284.235	294.9332
0.77	285.42	294.9436
0.78	284.92	294.6423
0.83	284.7	294.4815
0.84	284.58	294.9631
0.85	285.44	295.3764
0.87	284.6	295.3764

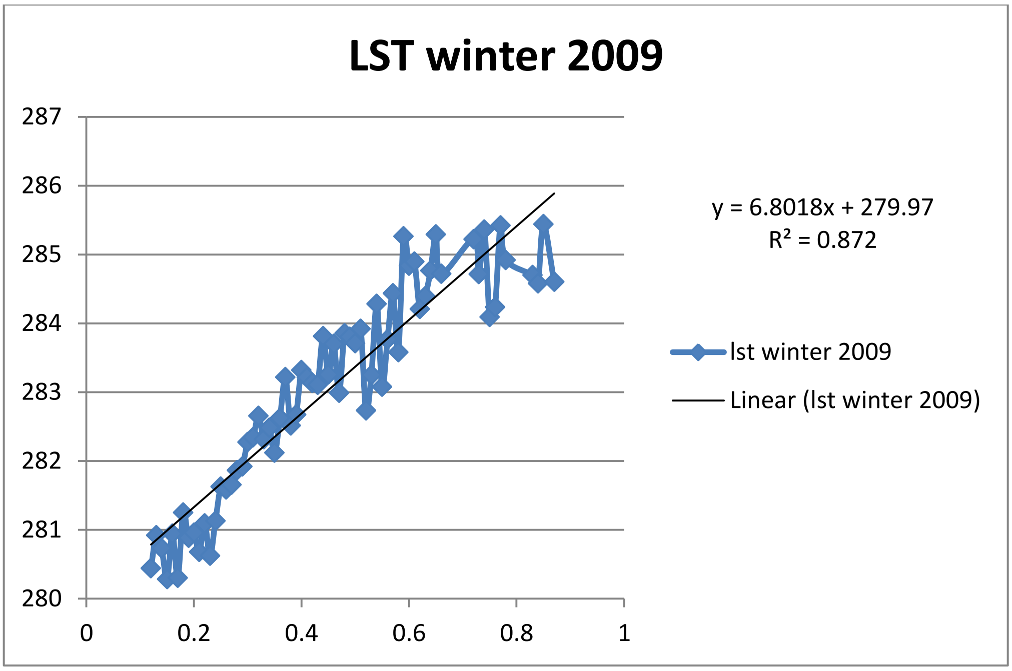


Figure 4.2.1: Graph between Mean LST vs SI for winter 2009

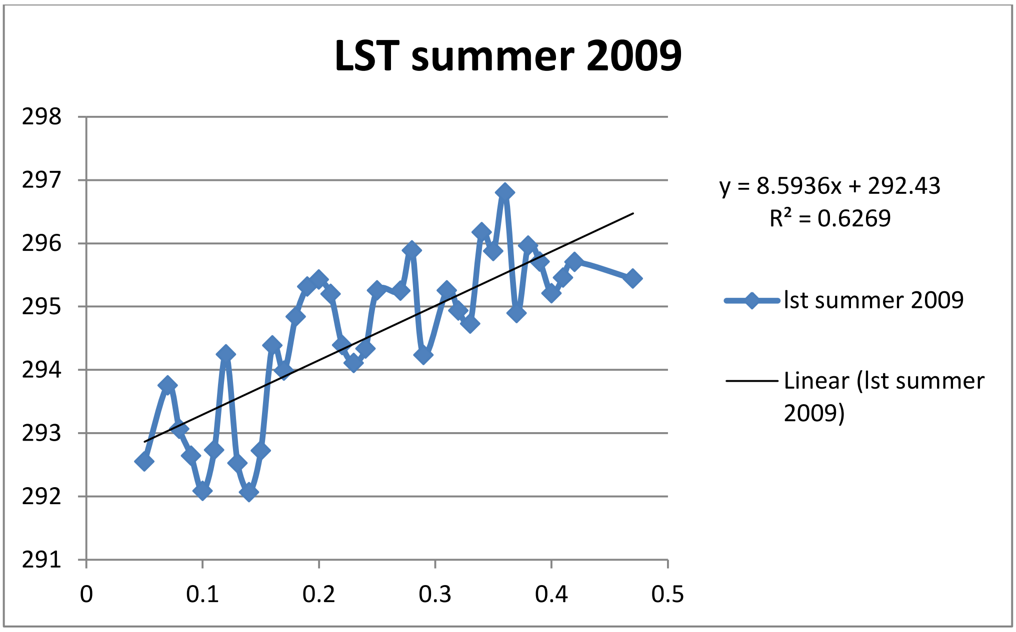


Figure 4.2.2: Graph between Mean LST vs SI for summer 2009

Table 4.2.14: Data of SI and Mean LST for summer-winter 2011

2011		
SI	**MEAN LST SUMMER**	**MEAN LST WINTER**
0.09	293.4323	284.2894
0.1	293.4256	283.9173
0.11	293.1785	284.2462
0.12	293.1981	283.672
0.13	293.3504	284.1343
0.14	293.5661	283.7642
0.15	293.5821	283.715
0.16	294.7352	283.8642
0.17	294.6474	283.713
0.18	294.1963	283.7143
0.19	294.845	284.3793
0.2	293.9626	284.1861
0.21	294.6025	284.4566
0.22	295.2374	283.9751
0.23	295.2477	284.128
0.24	295.3686	284.0606
0.25	294.9417	284.2812
0.26	295.9305	284.1454
0.27	296.0048	284.6303
0.28	296.3086	284.7503
0.29	295.9818	284.2345
0.3	296.6096	284.9483
0.31	296.7829	285.1867
0.32	296.6269	284.5862
0.33	296.7762	284.9412
0.34	296.0764	285.361
0.35	297.5491	284.4376
0.36	296.4309	285.1538
0.37	297.1775	285.0089
0.38	296.145	285.3552
0.39	297.62	284.9527
0.41	298.12	285.5915
0.42	298.06	286.06

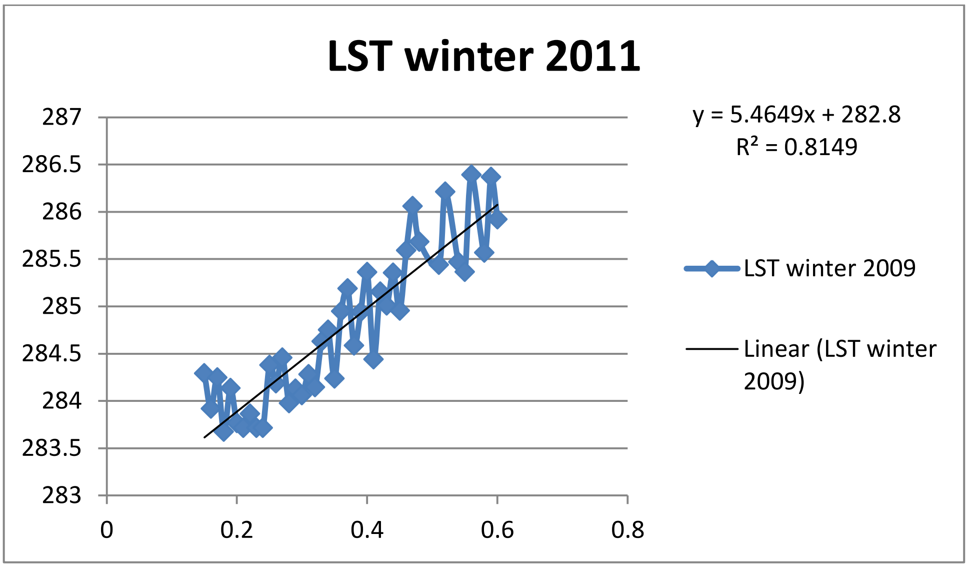


Figure 4.2.3: Graph between Mean LST vs SI for winter 2011

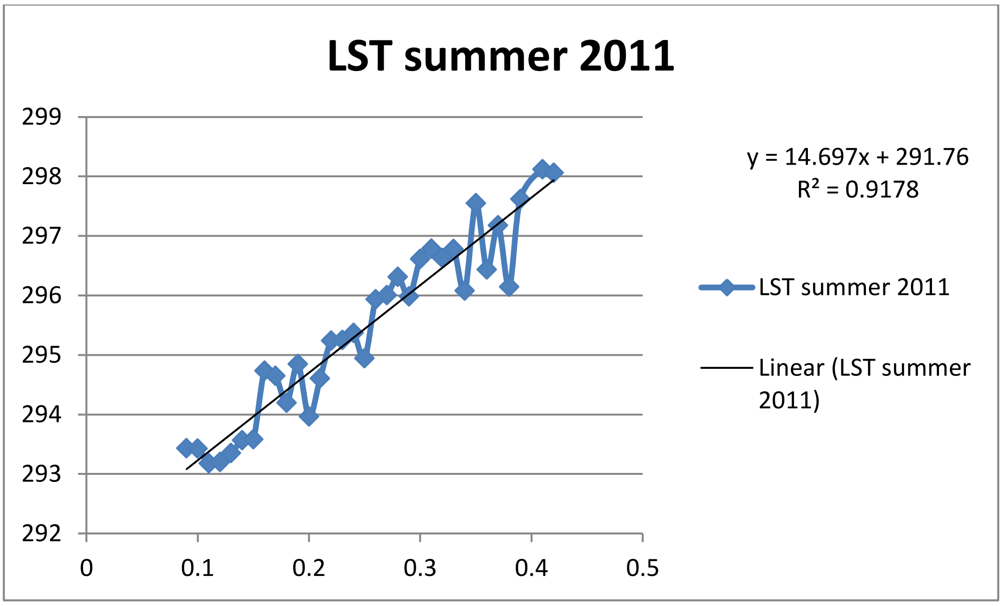


Figure 4.2.4: Graph between Mean LST vs SI for summer 2011

Table 4.2.15: Data of SI and Mean LST for summer-winter 2013

2013		
SI	**MEAN LST SUMMER**	**MEAN LST WINTER**
0.07	298.775	282.74
0.1	299.1702	284
0.11	298.9088	284.5129
0.12	298.9156	283.045
0.13	299.6758	284.946
0.14	300.3351	283.1431
0.15	299.9015	283.3691
0.16	300.1247	283.4971
0.17	300.7079	284.5631
0.18	300.2376	283.1257
0.19	300.4353	284.4171
0.2	301.0557	284.081
0.21	301.16	284.4655
0.22	301.3303	284.75
0.23	301.1822	284.2644
0.24	300.792	284.825
0.25	300.7885	284.0046
0.26	301.1543	284.4178
0.27	301.3671	284.2898
0.28	301.1157	284.4534
0.29	301.1488	284.022
0.3	300.8817	283.9885
0.31	300.93	284.1232
0.32	300.958	283.7658
0.33	300.856	283.6828
0.37	301.54	283.7615
0.38	301.72	284.5107
0.39	302.06	284.0244
0.4	302.1	284.3993
0.42	302.96	284.3785

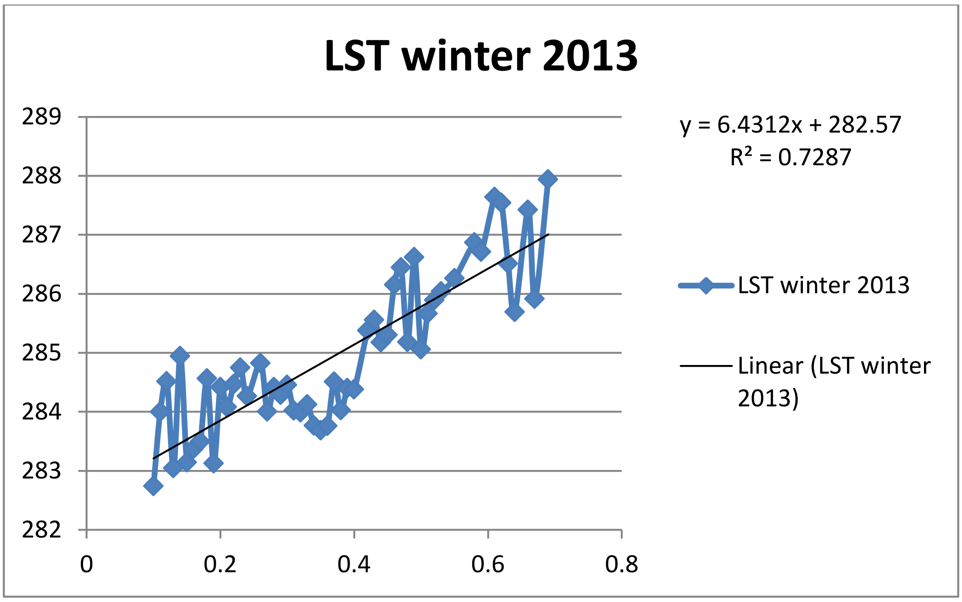


Figure 4.2.5: Graph between Mean LST vs SI for winter 2013

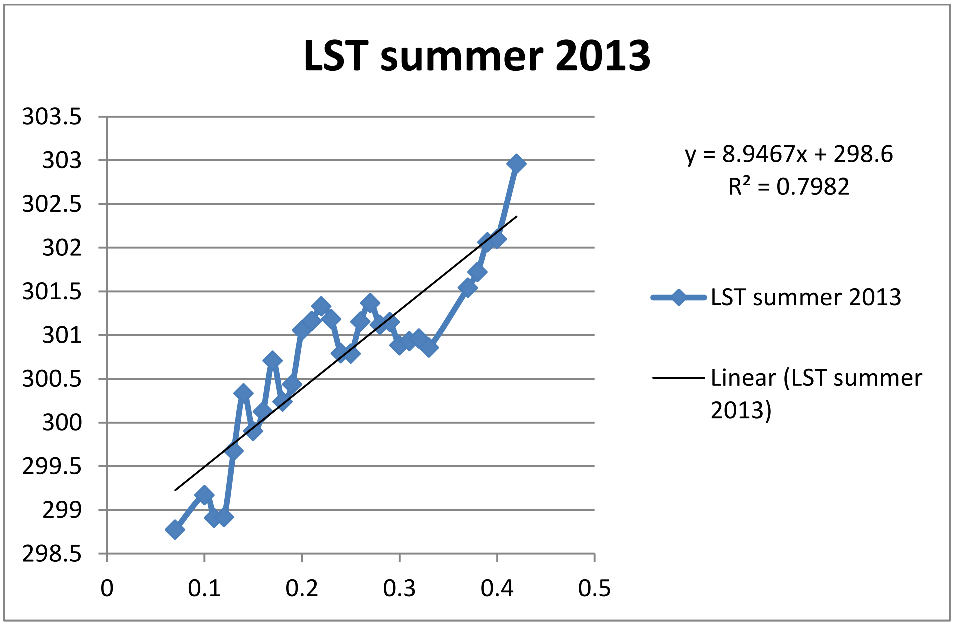


Figure 4.2.6: Graph between Mean LST vs SI for summer 2013

As shown in results, SI has a good positive correlation with LST. It shows better correlation and higher slope in summer than winter as given in the following table. The value of R^2 for years 2009, 2011 and 2013 are decreasing in order as 0.9, 0.8 and 0.7 respectively in winter and in summer, values are as 0.6, 0.9 and 0.8 respectively. The slope value for the year 2009, 2011 and 2013 are as 6.8, 5.5 and 6.4 respectively in winter and in summer the slope values are as 8.6, 14.7 and 8.9 respectively. It means SI value for summer has better significance than winter.

As previous studies %ISA shows a positive correlation with LST and NDVI shows a negative correlation with LST. In this study, the correlation of SI is positive linear and higher slope value than %ISA but the range of SI data value is less than %ISA. It varies up to on an average 0.6 as NDVI range varies. It means as SI increases; LST also increases and higher values of SI shows impermeable surface and lower values of SI shows permeable surface or vegetation, moist soil, water, etc. Higher slope significance that changes in surface type shows a large change in temperature.

Table 4.2.16: Correlation values of SI with LST for study duration

YEAR		SUMMER	WINTER
2009	**R^2**	0.6	0.9
	SLOPE	8.6	6.8
2011	**R^2**	0.9	0.8
	SLOPE	14.7	5.5
2013	**R^2**	0.8	0.7
	SLOPE	8.9	6.4

Now this report contain raster image of that Surface Index (SI) for summer and winter for years 2009, 2011 and 2013 respectively. These images show higher SI value in urban areas than suburban areas as well as higher SI values in summer season than winter season. The maximum, minimum and mean values have listed in table 4.21. These raster images and result table are as follows;

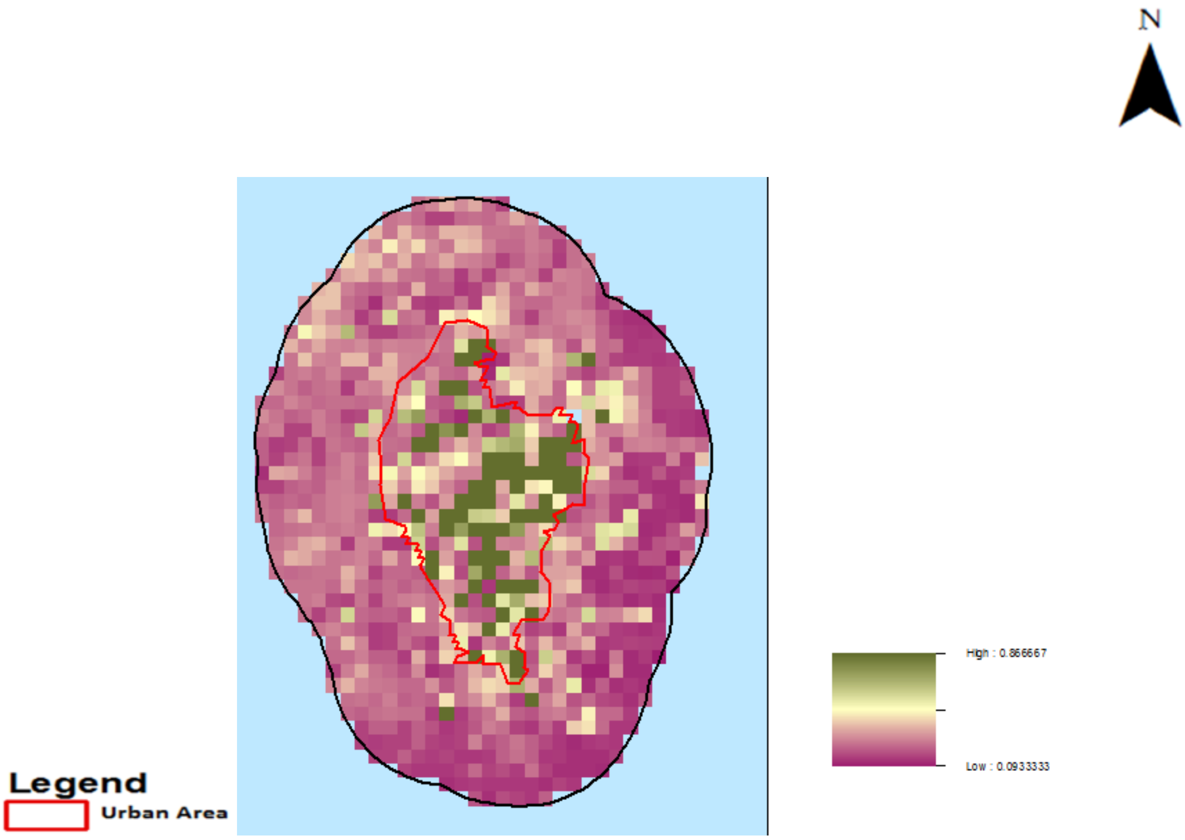


Figure 4.2.7: Surface Index (SI) for summer 2009

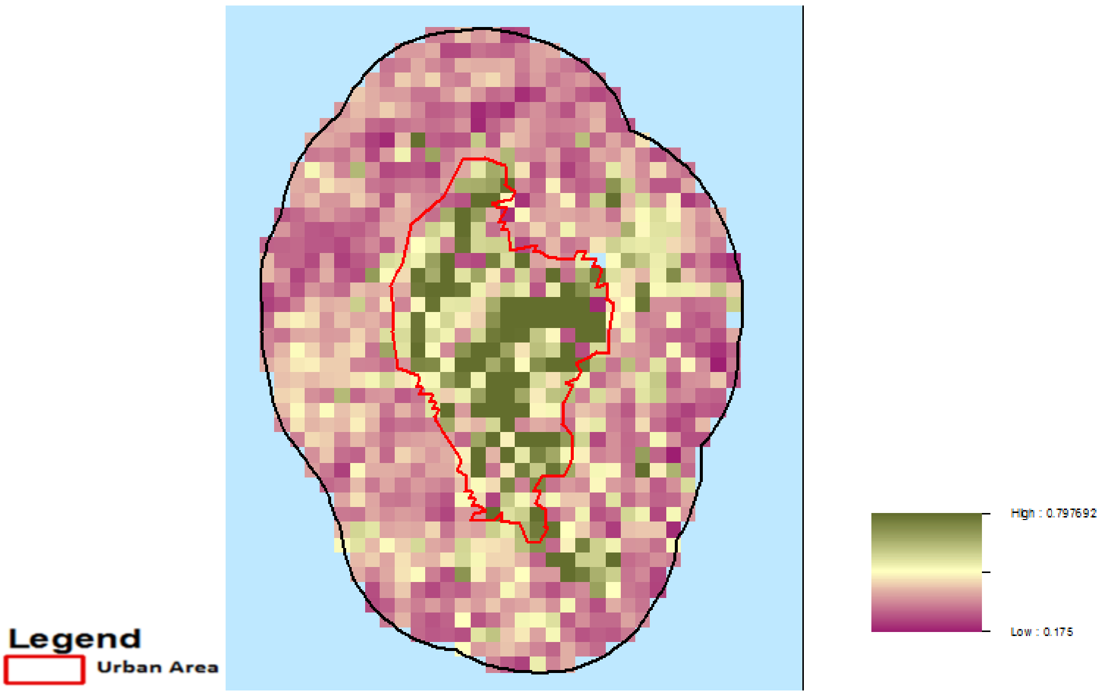
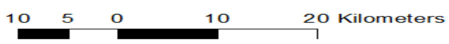


Figure 4.2.8: Surface Index (SI) for winter 2009



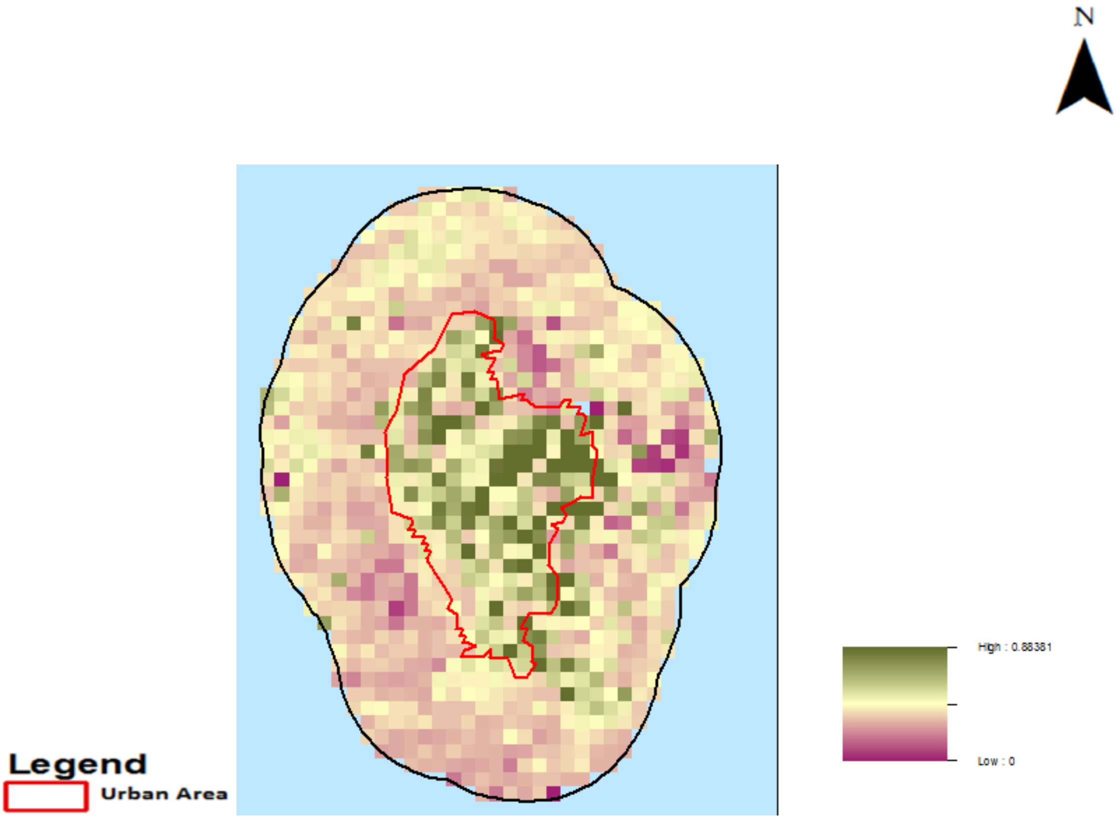


Figure 4.2.9: Surface index (SI) for summer 2011

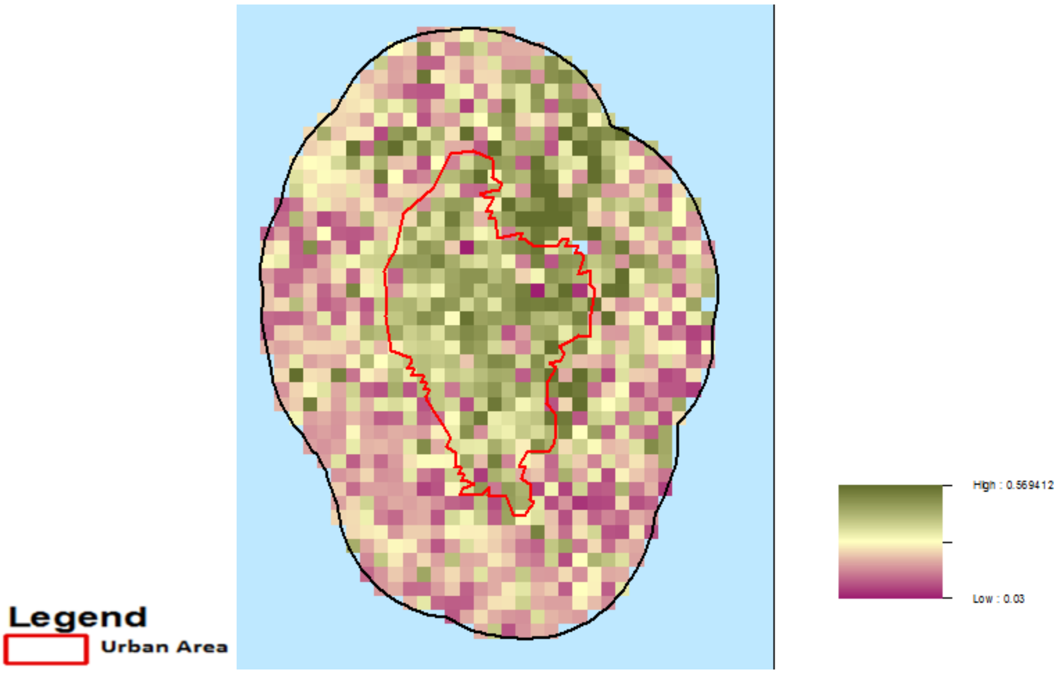
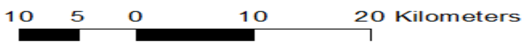


Figure 4.2.10: Surface index (SI) for winter 2011



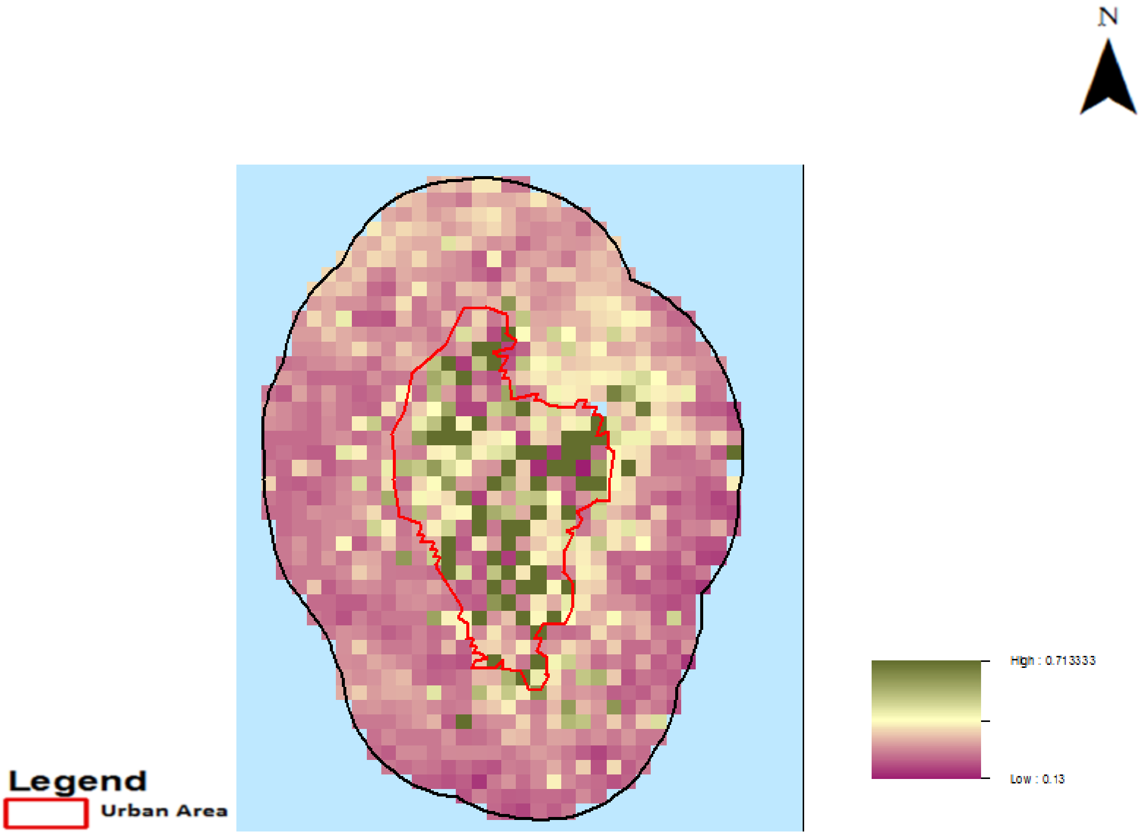


Figure 4.2.11: Surface Index (SI) for winter 2013

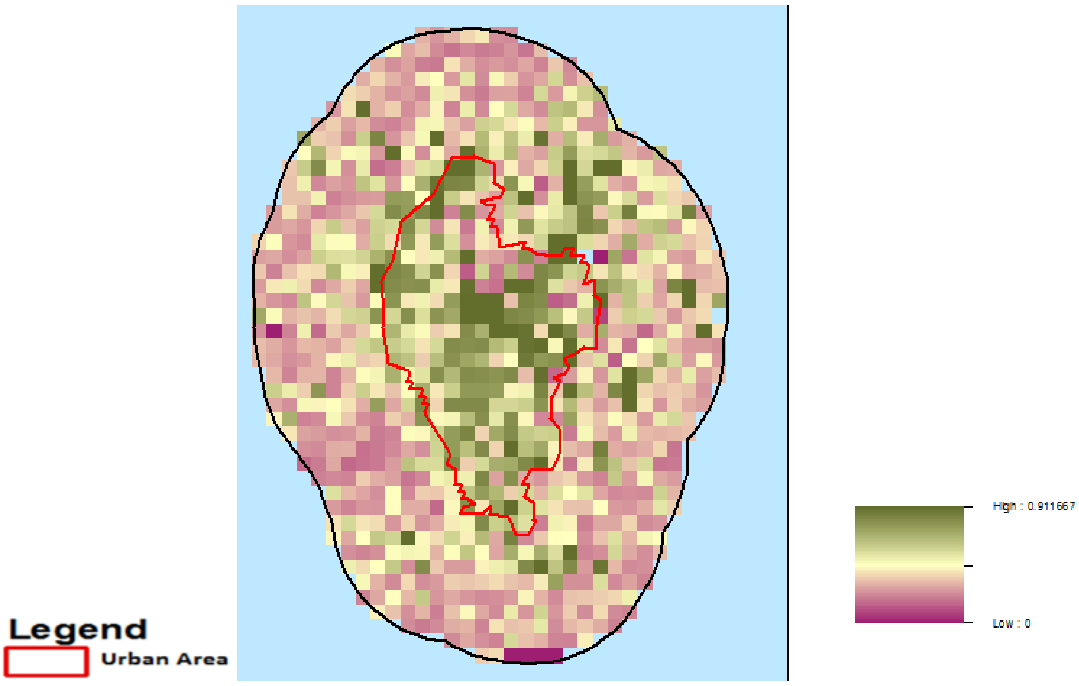


Figure 4.2.12: Surface Index (SI) for summer 2013

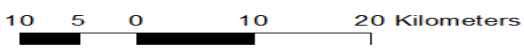


Table 4.2.17: Average Maximum SI, Average Minimum SI, Average SI and Standard Deviation for the study duration of Jaipur

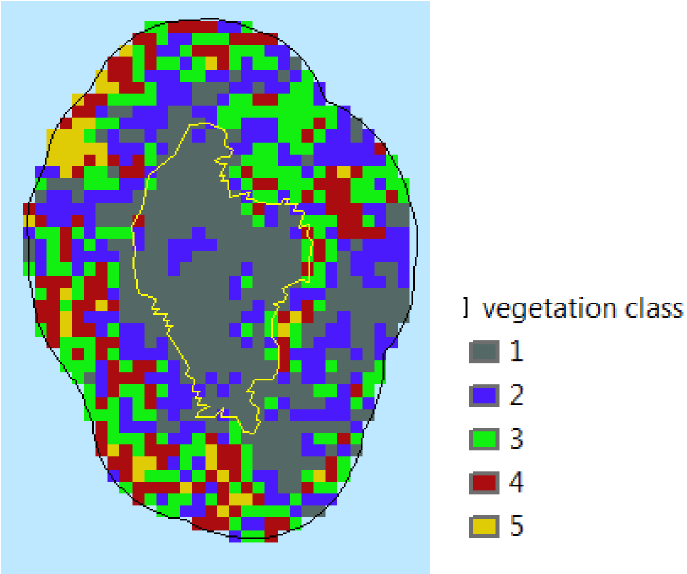
SEASON		WINTER	SUMMER
YEAR			
2009	MINIMUM	0.175	0.0933333333333301
	MAXIMUM	0.79769230769231	0.86666666666667
	MEAN	0.31894406911443	0.2411915000077
	STANDERD DEVIATION	0.10358733101032	0.16759426962321
2011	MINIMUM	0.03	0
	MAXIMUM	0.56941176470588	0.8838095238095201
	MEAN	0.24516808481639	0.24701635236114
	STANDERD DEVIATION	0.1043825363683	0.097700334899524
2013	MINIMUM	0.13	0
	MAXIMUM	0.71333333333333	0.911667
	MEAN	0.23729791866701	0.41053738118332
	STANDERD DEVIATION	0.08852112660285	0.14529279383853

This table presents that the mean value of SI is continuously decreasing in winter as well as in summer as years passing. It is also showing that SI value is higher in summer than winter. In urban areas impermeable surfaces are more than in suburban areas, that's why urban areas are showing the highest value of SI. In the summer season, there is much less moisture than winter season; this is the one of the reasons that the SI value is higher in summer than winter.

One thing has also observed that impermeable surface is continuously increasing as years passing, so SI is shifting toward higher values which show higher temperature in nature. This is not so good for our nature and for human health. Hence, it should be point of consideration.

4.3 Soil Moisture Index (SMI)

The soil moisture index is one of the parameter of surface which is directly or indirectly related to LST. It has been calculated with the help of NDVI and LST satellite images.



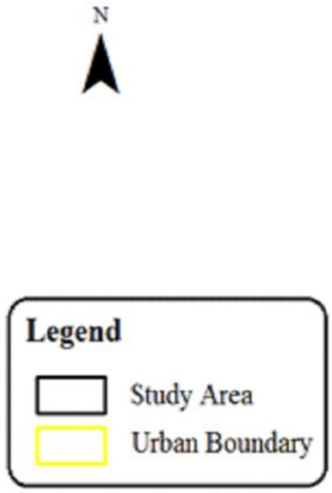


Figure 4.3.1: Classification of NDVI winter 2011

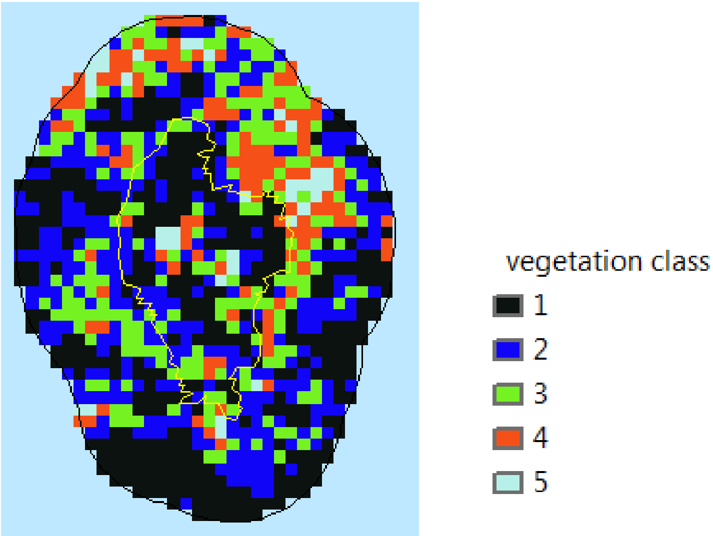
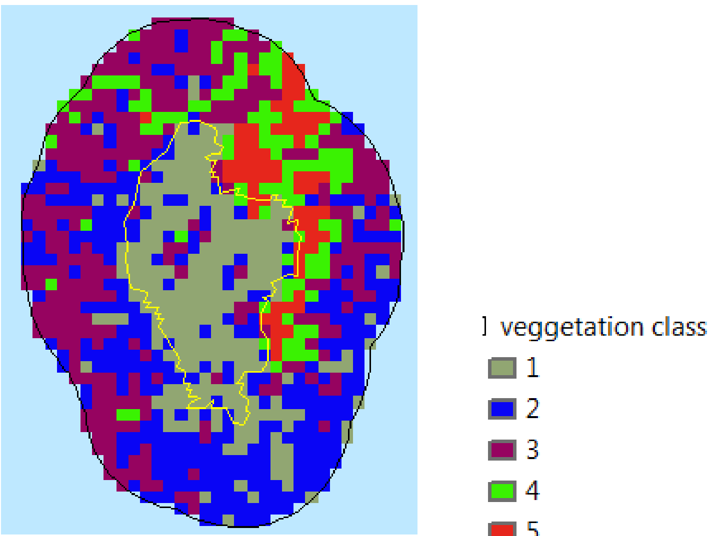


Figure 4.3.2: Classification of NDVI summer 2011



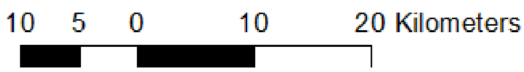


Figure 1.3.3: Classification of NDVI rainy 2011

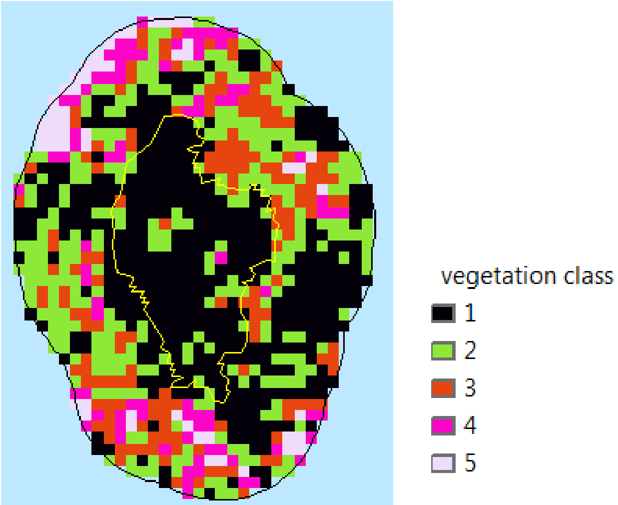
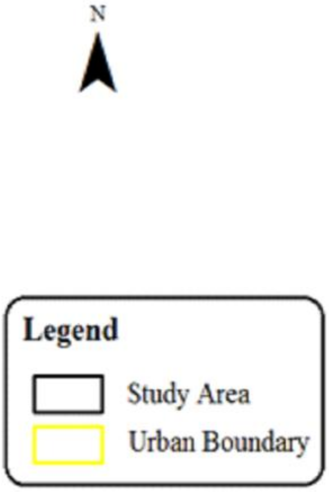


Figure 4.3.4: Classification of NDVI winter 2013



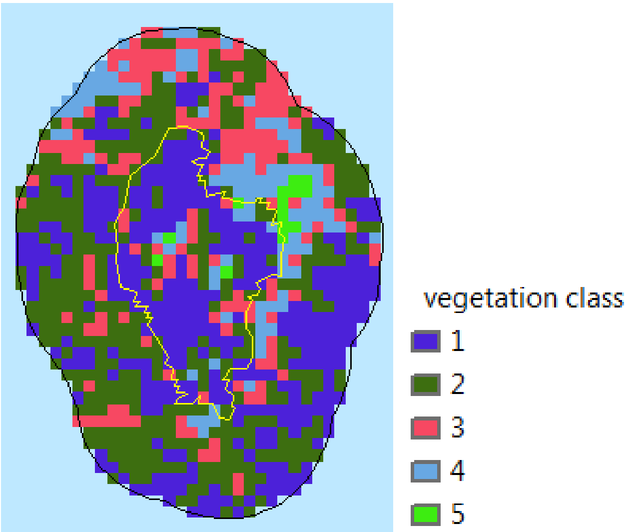
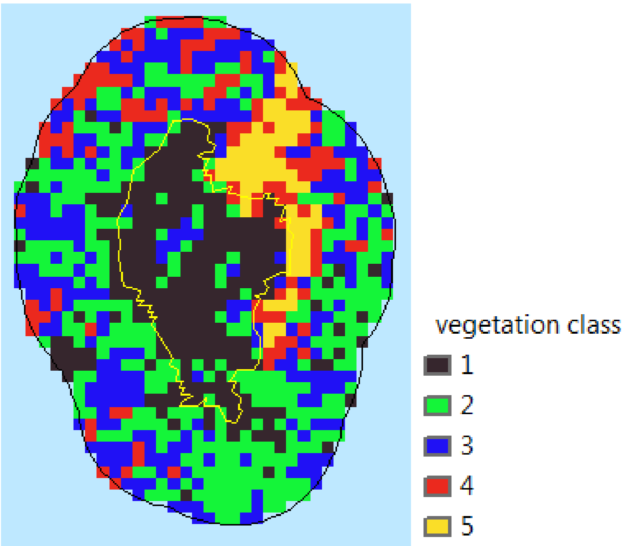


Figure 4.3.5: Classification of NDVI summer 2013



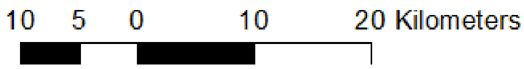
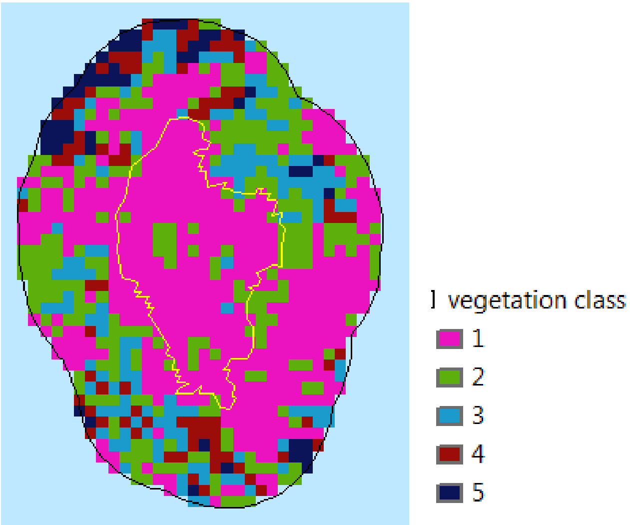


Figure 4.3.6: Classification of NDVI rainy 2013



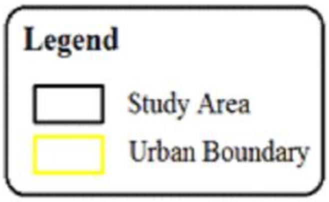


Figure 4.3.7: Classification of NDVI winter 2015

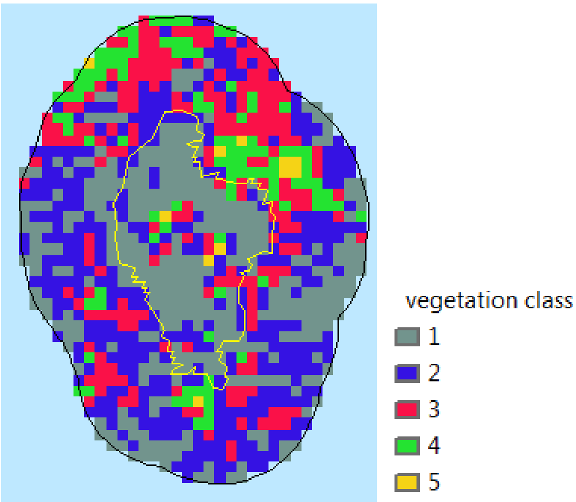
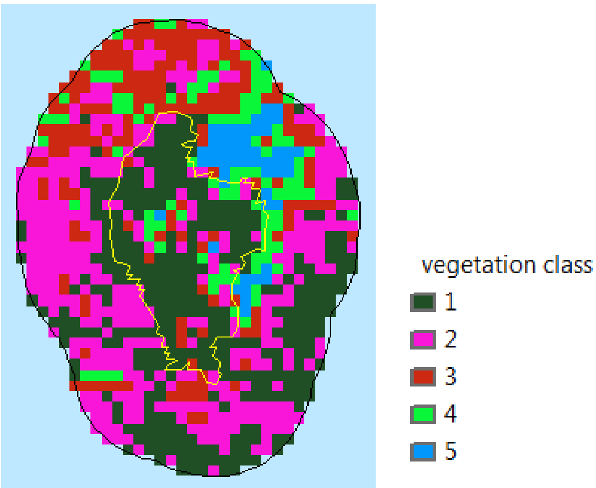


Figure 4.3.8: Classification of NDVI summer 2015



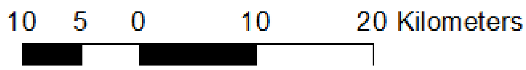


Figure 4.3.9: Classification of NDVI rainy 2015

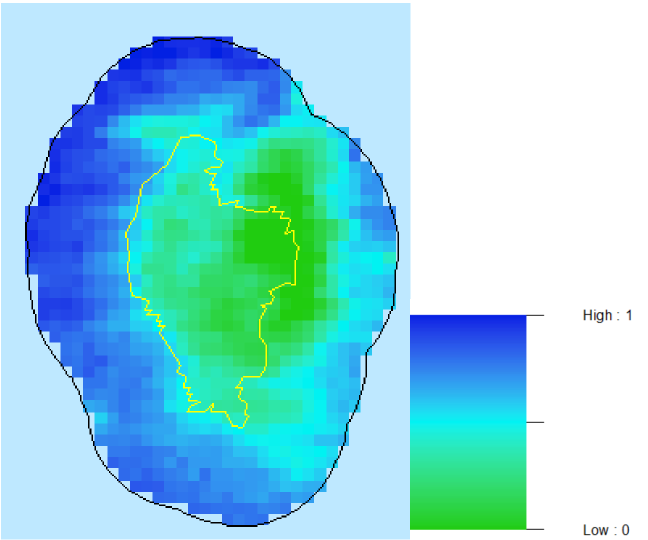
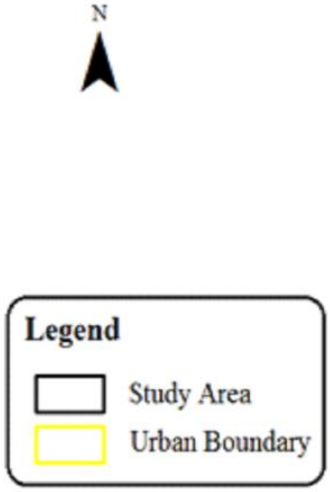


Figure 4.3.10: SMI for winter 2011



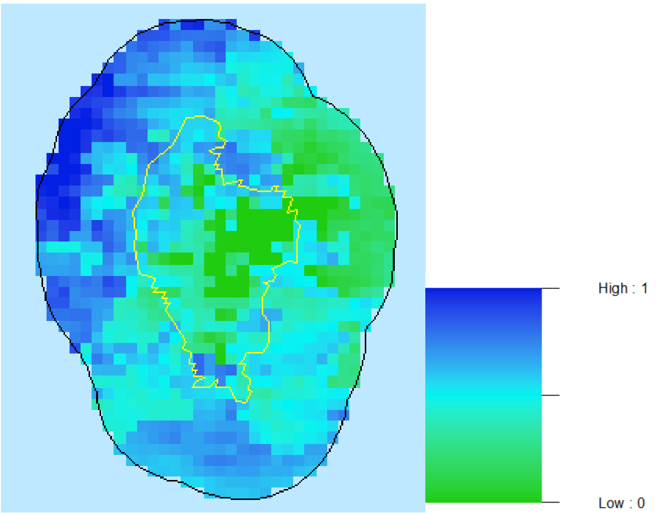


Figure 4.3.11: SMI for summer 2011

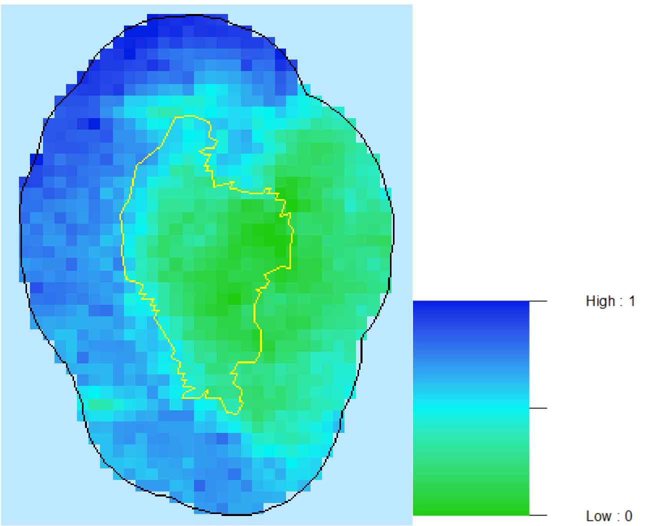
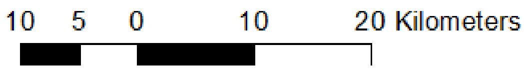


Figure 4.3.12 SMI for rainy 2011



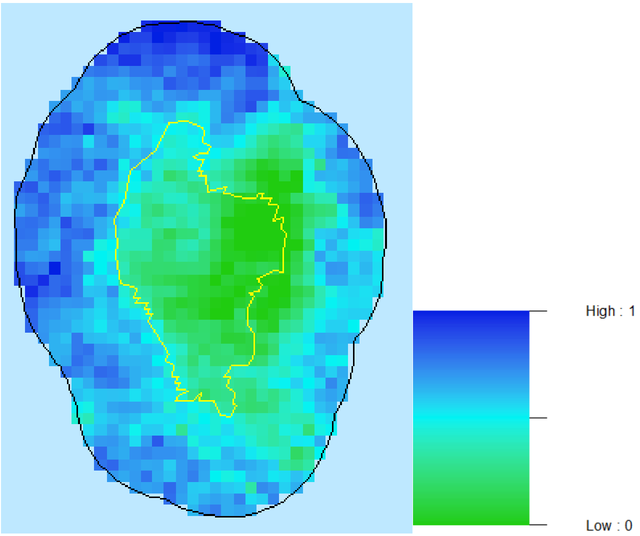


Figure 4.3.13: SMI for winter 2013

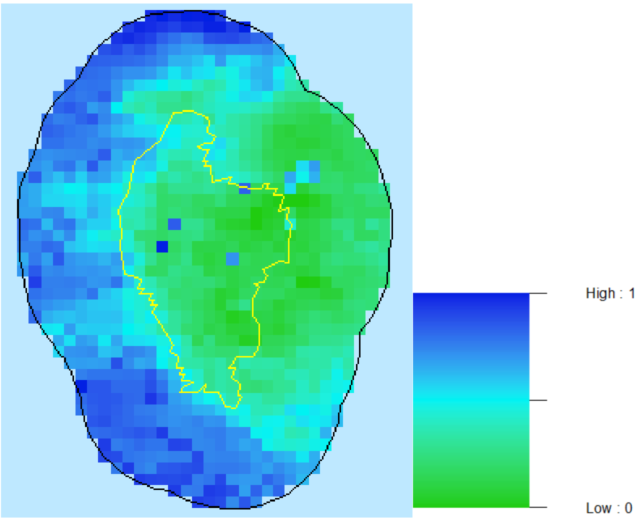


Figure 4.3.14: SMI for summer 2013

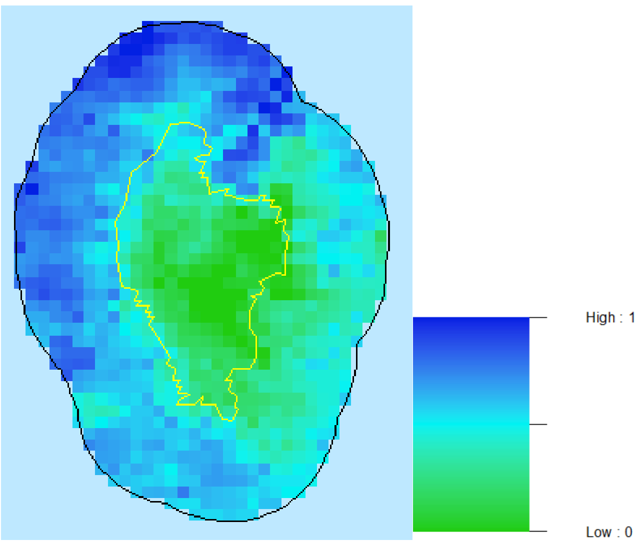
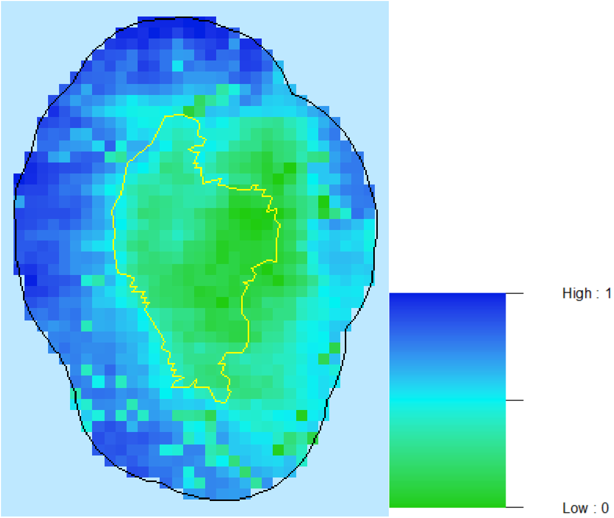


Figure 4.3.15: SMI for rainy 2013



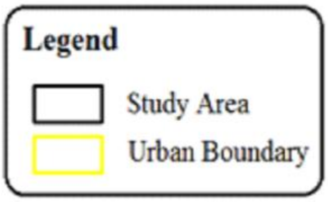


Figure 4.3.16: SMI for winter 2015

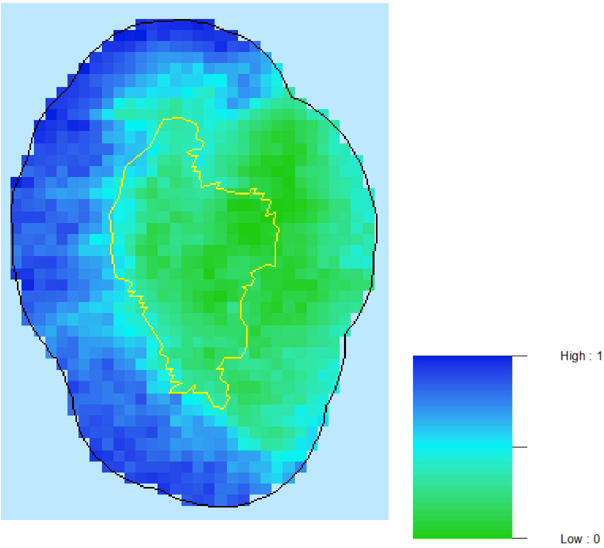
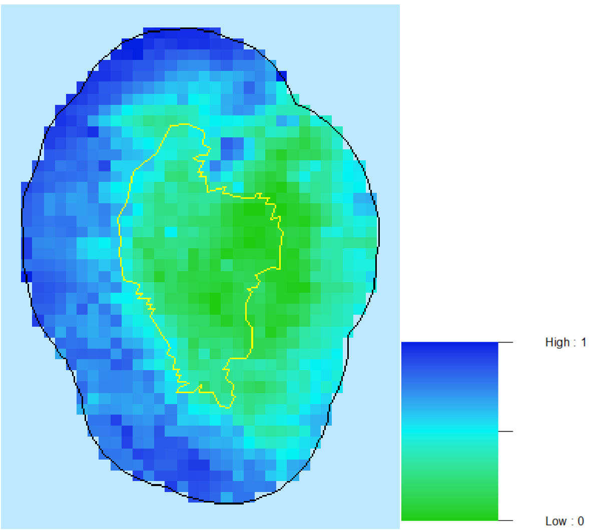


Figure 4.3.17: SMI for summer 2015



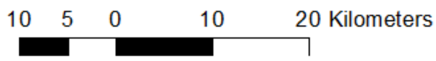


Figure 4.3.18: SMI for rainy 2015

Firstly unsupervised classification has been done on NDVI raster images in ArcGIS software via reclassify tool. NDVI has been classified in 5 classes as 1 to 5 and extracts the LST of same time has been extracted for each class. These vegetation classification images have been shown in figure no. 4.3.1 to 4.3.9. Then combine each class via mosaicking tool in ArcGIS. Finally, SMI has been calculated in raster calculator of ArcGIS. This work has been done for three seasons like winter, summer and rainy for the three years 2011, 2013 and 2015. The range of SMI varies from 0 to 1 as shown in figure 4.3.10 to 4.3.15, as above. Data and graphs of SMI and LST are listed below.

Table 4.3.1: values of SMI and LST for study years and seasons

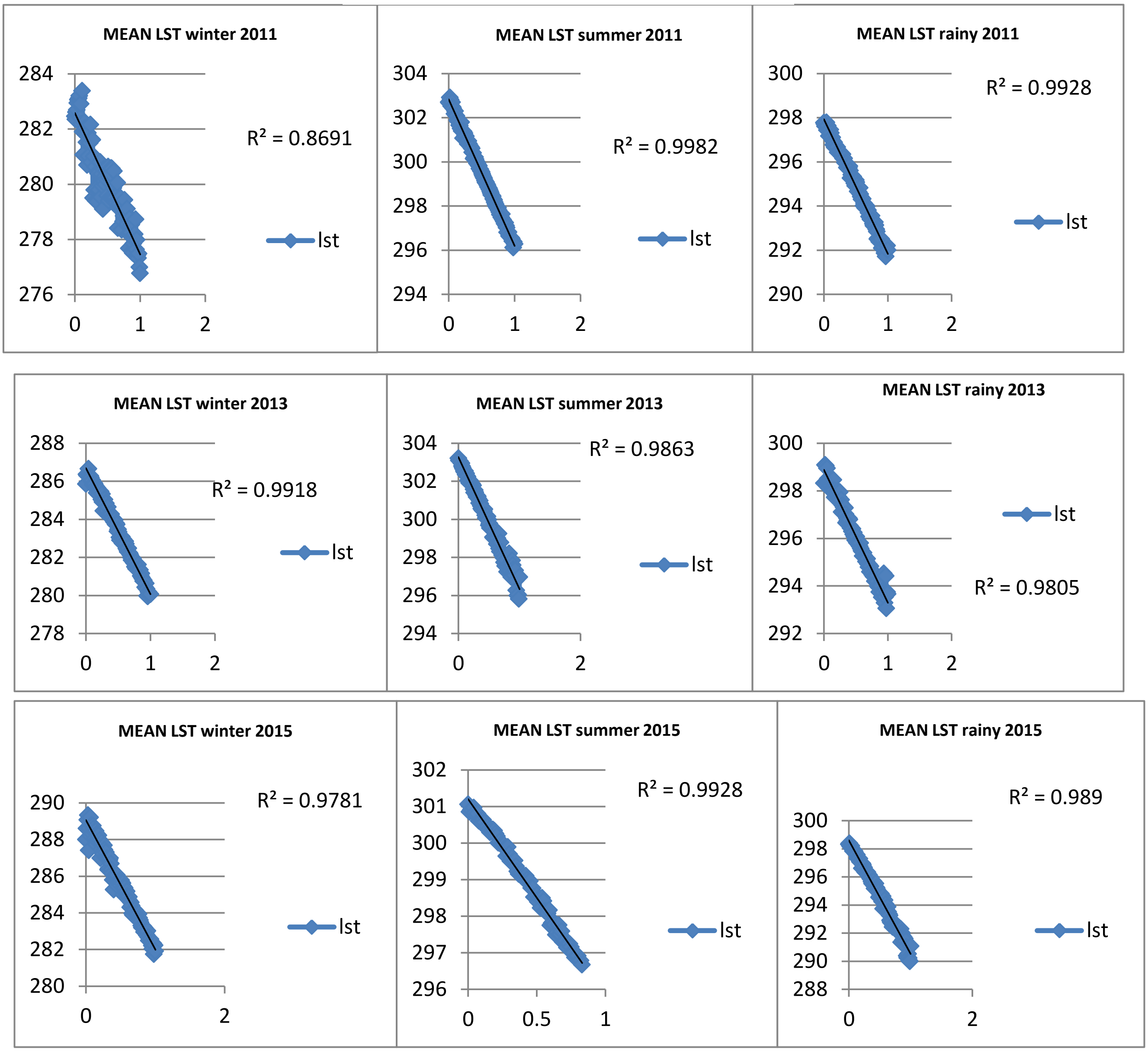
	2011			2013			2015		
Soil Moisture Index (SI)	MEAN LST SUMMER	MEAN LST WINTER	MEAN LST RAINY	MEAN LST SUMMER	MEAN LST WINTER	MEAN LST RAINY	MEAN LST SUMMER	MEAN LST WINTER	MEAN LST RAINY
0	282.456	302.6967	297.7733	285.852	303.208	312.7167	287.996	301.056	298.3143
0.01	282.348	302.66	297.7067	286.3667	303.09	313.26	288.6	300.855	298.3667
0.02	282.6067	302.915	297.61	286.3	303.04	313.3267	289.0733	300.9033	298.2
0.03	282.69	302.81	297.5933	286.2933	302.9371	313.144	289.325	300.89	298.14
0.04	282.94	302.525	297.78	286.65	302.8	313.456	287.41	300.9644	298.1883
0.05	283.0633	302.704	297.435	286.22	302.7267	313.088	288.62	300.8186	298
0.06	283.11	302.4933	297.63	286.28	302.646	313.224	289.21	300.7525	297.9911
0.07	283.204	302.4267	297.4267	286.1867	302.5317	313.0067	288.185	300.8	297.82
0.08	282.4133	302.168	297.17	285.9867	302.4785	313.155	288.7827	300.5983	297.8429
0.09	282.9057	302.305	297.1571	286.0533	302.5337	312.9367	288.3222	300.584	297.8533
0.1	282.18	302.1	297.4636	285.8067	302.3495	312.5425	288.7525	300.55	297.7491
0.11	283.38	302.07	297.3044	285.855	302.4061	312.7817	288.588	300.634	297.6523
0.12	281.8933	301.885	297.1075	285.8943	302.272	312.6943	288.4137	300.5613	297.6025
0.13	281.06	301.84	297.1109	285.8433	302.2312	312.5059	288.0429	300.4255	297.5625
0.14	282.24	301.8267	296.9514	285.6222	302.0489	312.0425	288.46	300.44	297.3089
0.15	281.8333	301.66	296.77	285.7267	302.0185	312.3536	287.7218	300.3575	297.3631
0.16	282.0333	301.635	296.884	285.392	301.9178	312.3643	288.292	300.2953	297.32
0.17	281.85	301.5033	296.6578	285.6325	302.0253	312.3012	288.0143	300.3454	297.2933
0.18	281.52	301.8	296.7671	285.5	301.8729	312.277	288.2275	300.3689	297.0691
0.19	280.688	301.4	296.6506	285.2867	301.8853	312.0453	287.8333	300.3362	297.044
0.2	281.86	301.38	296.6333	285.455	301.8309	312.0467	287.96	300.2514	297.012
0.21	281.015	301.064	296.6723	285.444	301.8453	311.9524	286.9867	300.1853	296.61
0.22	281.57	301.3725	296.4292	285.46	301.78	311.8557	287.4444	300.005	296.9457
0.23	281.495	301.3	296.4292	285.0428	301.5767	311.7409	287.835	300.0329	296.84
0.24	282.1543	301.1914	296.4922	285.324	301.402	311.65	287.2667	299.9612	296.6667
0.25	280.794	301.1533	296.3667	284.912	301.532	311.6925	287.2307	299.948	296.6554
0.26	281.63	300.97	296.435	284.448	301.41	311.4167	287.68	299.9478	296.36

0.27	281.6033	301.0109	296.3373	285.034	301.2657	311.1512	287.4326	299.8625	296.3125
0.28	279.504	300.81	296.2575	285.0325	301.1654	310.6667	287.0437	299.6431	296.366
0.29	281.005	300.94	296.3433	284.8544	301.2382	311.137	287.2967	299.8867	296.395
0.3	279.79	300.8143	296.1491	284.8311	301.2044	311.2867	286.962	299.692	296.3257
0.31	280.6229	300.74	296.175	284.5291	301.0867	310.9756	286.9371	299.5053	296.2083
0.32	279.4	300.688	296.1567	284.44	300.8516	310.715	286.3517	299.5964	296.1267
0.33	279.83	300.6545	295.9727	284.6422	300.98	310.91	286.4267	299.4965	296.1278
0.34	279.3654	300.606	295.94	284.2	300.8133	311.259	286.8829	299.5167	295.96
0.35	280.4333	300.4267	295.928	284.2733	300.7	310.8778	286.99	299.3627	295.8517
0.36	280.38	300.4067	295.745	284.1756	300.5514	310.8609	286.6787	299.2273	295.9311
0.37	279.788	300.1457	295.7214	284.208	300.5022	310.5664	286.3509	299.1475	295.6583
0.38	280.7857	300.1971	295.845	284.268	300.4525	310.3008	286.1371	299.15	295.5186
0.39	280.8044	300.2156	295.7309	284.0975	300.5155	310.5083	285.7844	299.1738	295.4564
0.4	279.5267	300.1152	295.8	284.0082	300.41	310.6625	285.2644	299.1109	295.6775
0.41	280.36	300.015	295.6044	284.07	300.5343	309.9677	285.8345	299.0089	295.3667
0.42	279.9371	299.932	295.264	283.9054	300.206	310.3027	285.93	299.1025	295.1708
0.43	279.094	299.928	295.4123	283.8383	300.0686	310.3287	286.1	299	295.5291
0.44	280.545	299.8537	295.2911	283.9543	300.084	309.6175	285.9233	298.93	295.208
0.45	280.1133	299.81	295.3028	283.7222	300.02	310.2623	286.041	298.9622	295.2255
0.46	280.2733	299.6905	295.325	283.7857	300.1571	310.0677	285.44	298.77	295.1017
0.47	279.992	299.6683	295.2491	283.7236	299.9745	309.8894	285.6575	298.7622	294.9475
0.48	280.1782	299.5937	295.0214	283.3657	299.69	310.152	285.7667	298.52	294.9378
0.49	280.4836	299.537	294.9167	283.4631	299.7778	310.4143	285.76	298.5029	294.5425
0.5	279.58	299.453	295.1743	283.34	299.5375	309.6727	285.4833	298.57	294.5988
0.51	280.6345	299.3775	295.0711	283.044	299.5533	308.9545	285.7733	298.3933	294.7525
0.52	279.3991	299.3	294.9333	282.9044	299.5036	309.832	285.6483	298.4867	294.7875
0.53	280.24	299.2496	294.6617	283.0783	299.58	309.6613	285.6112	298.2244	294.42
0.54	279.5217	299.1543	294.6538	283.0971	299.5675	309.6815	284.992	298.496	294.23
0.55	280.368	299.0621	294.6233	283.0705	299.0662	309.988	285.4122	298.4133	294.6225
0.56	280.5871	299.0714	294.8275	282.7333	299.0143	309.6954	285.3578	298.14	293.725
0.57	280.5637	298.9945	294.5422	282.9529	299.36	309.22	285.09	298.125	293.7615
0.58	279.5233	298.9322	294.4283	282.7323	298.96	308.7693	285.1437	298.0743	294.3367
0.59	279.86	298.8613	294.2975	282.6693	298.9257	309.435	285.1711	298.16	293.9236
0.6	280.4706	298.8161	294.3029	282.84	299.0273	309.36	284.9304	297.7489	294.0345
0.61	279.5343	298.7475	294.32	282.7057	298.69	308.4067	284.7867	297.8067	293.6475
0.62	279.5108	298.6562	294.005	282.465	298.995	308.5167	284.8653	297.852	293.5675
0.63	279.3771	298.5914	294.1188	282.3919	298.7492	309.238	284.6622	297.77	293.872
0.64	279.316	298.4968	294.0583	282.2948	299.2543	308.97	284.2971	297.49	293.5036
0.65	280.05	298.4736	293.9075	282.4758	298.465	309.3	284.57	297.5575	293.3435
0.66	278.4028	298.4413	294.0262	282.243	298.305	307.748	284.3857	297.7514	293.25
0.67	279.1333	298.3256	293.9752	282.2018	298.7812	308.61	283.9657	297.508	292.8971
0.68	279.3769	298.2785	293.8525	282.1304	298.29	309.1133	283.8725	297.59	292.7778
0.69	279.29	298.1738	293.8055	281.9817	298.2612	308.6333	284.1933	297.2907	292.7277
0.7	279.5059	298.088	293.7	281.8526	298.12	309.02	284.1339	297.3215	292.8867
0.71	279.1365	298.0106	293.5241	281.8409	298.1467	307.6657	284.1425	297.3211	292.4345

0.72	278.3429	297.96	293.5382	281.9344	297.9614	308.55	283.9492	297.14	292.5338
0.73	279.1741	297.895	293.398	281.7365	297.73	307.68	283.9938	297.265	292.62
0.74	278.6471	297.918	293.4171	281.6882	297.7476	308.76	283.9574	297.2378	292.5509
0.75	278.8445	297.815	293.554	281.4973	297.5475	308.7	283.8982	297.1575	292.6
0.76	279.4327	297.722	293.3436	281.7243	297.8621	307.46	283.9273	297.0255	292.3933
0.77	278.9908	297.6077	293.195	281.4018	297.5	306.98	283.7259	297.0013	292.528
0.78	278.9547	297.642	293.1053	281.5259	297.2457	306.44	283.595	296.8714	292.3706
0.79	278.7667	297.485	293.0708	281.4345	297.51	307.765	283.48	296.9053	292.4457
0.8	279.1105	297.63	293.275	281.6129	297.2662	307.535	283.3047	296.9117	292.1418
0.81	278.5578	297.3943	293.128	281.3937	298.196	308.72	283.1854	296.7615	292.132
0.82	278.206	297.36	292.94	281.3225	297.6073	307.2	283.188	296.7886	292.362
0.83	277.668	297.2933	292.8433	281.3431	297.6555	308.92	283.2657	296.6733	291.9514
0.84	278.7508	297.19	292.505	281.024	297.28	308.36	282.944	296.6231	292.28
0.85	278.232	297.24	292.5385	281.1533	296.964	306.9333	283.17	296.6015	291.3444
0.86	278.2462	297.1067	292.4867	280.9289	297.8333	308.12	283.0292	296.535	292.0092
0.87	278.5338	297.016	292.38	280.856	297.5829	305.68	282.92	296.5814	291.815
0.88	277.5873	296.8067	292.38	280.748	297.3743	307.98	282.7762	296.5629	291.5267
0.89	277.5	296.7975	292.404	280.785	297.2333	307.94	283.0044	296.3533	291.7127
0.9	277.8422	296.815	292.505	280.4267	297.056	308.54	282.66	296.4617	291.256
0.91	278	296.645	292.0933	280.6314	297.31	305.0933	282.48	296.4267	291.5971
0.92	278.18	296.6086	292.14	280.34	296.78	306.185	282.5633	296.4018	291.42
0.93	278.728	296.58	292.07	279.98	296.26	307.09	282.56	295.7571	291
0.94	277.6327	296.56	292.124	279.94	295.995	308.34	282.38	296.0733	290.3733
0.95	277.9844	296.508	291.86	280.185	296.04	308.24	282.21	296.16	290.244
0.96	277.426	296.4	291.912	280.06	295.8133	307.4	282.0267	295.8514	290.524
0.97	277.32	296.12	291.72	280.0467	296.96	305.2367	282.3267	295.54	290.2133
0.98	277.4867	296.38	292.21	280.06	296.04	308.24	281.7422	296.09	290.04
0.99	276.995	296.2833	292.0033	280.0467	295.8133	307.4	282.22	295.63	289.98
1	276.7657	296.2833	292.0033	280.06	296.96	305.2367	281.904	295.724	291.072

As shown in graphs, as SMI increases LST decreases. The higher value area of SI is more in winter season than summer and winter and lower value of SI lies in urban areas than suburban areas. This SMI parameter is useful for understanding surface or soil condition, which is helpful in cropping, agriculture and this is also useful to estimate flood and drought condition of the city. This will be more useful for that city which having large no. of varieties of vegetation. Last but not the least, this parameter affects the UHI.

Figure 4.3.19: Graphs of SMI vs LST



Chapter 5

Conclusion

The UHI effect is a major point of consideration today. Many previous studies have been done to understand this effect and the factors responsible for it. India is a developing country and facing UHI problem but work has done in this field in comparison to other countries. To study of UHI, it is important to know that what materials land surface contain and how that material affects the LST. Previous studies tell us the LST pattern of the individual land type but not for the combined land types of land surface. The present study tries to fill this gap by analysing the Surface Index (SI) by combining two type of land cover. First land cover is vegetation cover as NDVI and second one is impermeable surface as %ISA. Then LST pattern has been founded for that Surface Index (SI). Eight-day MODIS LST has been used in the present study, for the analysis the correlation of SI with LST for Jaipur city. The study has been done for summer and winter seasons of the year 2009, 2011 and 2013. The mean SI value is higher in summer than winter. It means the range or types of land cover are less in winter than summer. LST shows good correlation with the value above than 0.6 and shows increasing pattern as SI increases means impermeable surfaces increases. The further analysis can be done on this project as combining more parameters of surface and study of UHI effect on this Surface Index.

Another part of this report is the study of another parameter as Soil Moisture Index (SMI). This study has been done for Jaipur city for three seasons as winter, summer and rainy in the year 2011, 2013 and 2015. The Soil Moisture map has been prepared by using NDVI and LST. This map shows as LST increases SMI decreases. The use of Soil Moisture map are in various field as understand processes that link the terrestrial water, energy, and carbon cycles, estimate global water and energy fluxes at the land surface, quantify net carbon flux in boreal landscapes, enhance weather and climate forecast skill and Develop improved flood prediction and drought-monitoring. The future scope of this SMI is that the model can be prepared on this parameter to find all above features and to estimate UHI effect.

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