A

Dissertation Report

On

"STUDY OF DIURNAL VARIATION OF LAND SURFACE TEMPERATURE OF INDIAN CITIES AND COMPARISON OF UHI EFFECT USING DIFFERENT SATELLITES DATA"

By

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Submitted in the partial fulfilment for the Award of degree of

Masters of Technology in Water Resource Engineering

To

DEPARTMENT OF CIVIL ENGINEERING
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
JUNE 2016

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

DEPARTMENT OF CIVIL ENGINEERING

Jawahar Lal Nehru Marg, Jaipur- 302017 (Rajasthan)

CERTIFICATE

This is to certify that the dissertation report on **" Study of diurnal variation of land surface temperature of Indian cities and comparison of UHI effect using different satellites data "** prepared by **Shivam Chauhan (ID 2014PCW5166)** in partial fulfilment 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 him under my supervision and guidance during academic session (2015-16). This work is approved for submission.

Place: Jaipur

Date : June 2016

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DECLARATION

I hereby declare that the dissertation which is being presented in this report entitled **" Study of diurnal variation of land surface temperature of Indian cities and comparison of UHI effect using different satellites data "** in fulfilment 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, 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.

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Acknowledgement

The success of any project depends on the efforts of number of wonderful people who always give their valuable advice or helping hand. I sincerely appreciate the inspiration, support and guidance of those people who have been implemental in making this project a success. First of all, I would like to thank the supreme power the Almighty God and my beloved parents for their love and sincere encouragement and motivation for me to work on the right path of life.

I am truly indebted to my advisor, Dr Sumit Khandelwal, whose support and guidance over the years. His supervision has helped me to not only focus on the imminent research questions at hand, but simultaneously keep the bigger picture in perspective. He has been very supportive and patient, which lead to a truly enjoyable post-graduate journey at MNIT. I thank my senior Mr. Aneesh Mathew for his valuable contribution, technical support and willingness to help me. I have developed a sincere respect for his research perspectives and whenever I was stuck in my research, discussion with him was often helpful in trouble-shooting the problem. I owe my sincere gratitude to my two seniors Mr. Rishabh and Miss Neha for their valuable suggestions and help. Gudia, Himanshu and Aparna deserve a special mention for their kind support and affection during this work.

I am highly obliged in taking the opportunity to sincerely thank Prof. I K Bhat, Director MNIT Jaipur for providing research facilities in the Institute.

Last but not the least I express my gratitude towards the Head of The Department Civil Engineering, Prof Gunwant Sharma and Prof Rohit Goyal for their valuable support.

The work is part of research project titled **“Study of Urban Heat Island of Indian Cities and Development of ANN Model for Scientific Planning to Control Urban Heat Island Effect”** by DST.

Place: Jaipur
Date : June 2016

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ABSTRACT

In the modern era of urbanization, the world is facing the transformations of natural surfaces into built-up, anthropogenic areas which result into urban areas encountering high surface temperature. The present study has been carried out to identify the seasonal sprawl of surface temperature for Jaipur and Ahmadabad cities. Remote sensing data from the MODIS sensor (on board on Aqua and Terra platforms) for day and night time have been used. The study has been undertaken for summer, monsoon and winter seasons, prevailing over the study area, by utilizing data of thirteen years from 2003 to 2013. Analysis of 8-day MODIS land surface temperature data for two different time periods i.e. day and night show presence of higher surface temperature and higher UHI intensity during day time in the outskirts of the cities. The temperature gradient follows almost similar pattern over the study area throughout the year.

The present study observes that rural areas of Jaipur are warmer than urban areas during day time and urban areas are warmer than rural areas during night time but in Ahmadabad urban areas are warmer than rural areas both in day and night time. The study includes the correlation analysis between Aqua and Terra derived day-night LSTs which signifies the better results during day-day, night-night and poor results for day-night, night-day for all three seasons for both rural and urban areas for both the cities. Surface temperature characteristics and variations have been observed more uniform during night time compared to day time as there is no interfering passive energy source. To compare 8-day data retrieved LST analysis another study has been done by taking 1-day MODIS data for Jaipur, Ahmadabad and Ludhiana.

This study also involves the comparison of LST correlation values with vegetation indices parameter NDVI for the similar duration. The results for Jaipur and Ahmedabad remain almost similar from 1-day and 8-day. The results for Ludhiana city show better correlation in day-night and night-day LST as compared to day-day and night-night for 2004, 2009, 2012 and 2015. This betterment in correlation is due to the availability of highly dense vegetation outside the city. This vegetation maintains uniformity in temperature variations during day and night.

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Abbreviations

AUHI	:	Atmospheric Urban Heat Island
ADVTD	:	Aqua day LST VS Terra day LST correlation coefficient
ADVTN	:	Aqua day LST VS Terra night LST correlation coefficient
ANVTN	:	Aqua night LST VS Terra night LST correlation coefficient
ANVTD	:	Aqua night LST VS Terra day LST correlation coefficient
ARAD	:	Aqua rural annual day
ARMD	:	Aqua rural monsoon day
ARSD	:	Aqua rural summer day
ARWD	:	Aqua rural winter day
ARAN	:	Aqua rural annual night
ARMN	:	Aqua rural monsoon night
ARSN	:	Aqua rural summer night
ARWN	:	Aqua rural winter night
AUAD	:	Aqua urban annual day
AUMD	:	Aqua urban monsoon day
AUSD	:	Aqua urban summer day
AUWD	:	Aqua urban winter day
AUAN	:	Aqua urban annual night
AUMN	:	Aqua urban monsoon night
AUSN	:	Aqua urban summer night
AUWN	:	Aqua urban winter night
TRAD	:	Terra rural annual day
TRMD	:	Terra rural monsoon day
TRSD	:	Terra rural summer day
TRWD	:	Terra rural winter day
TRAN	:	Terra rural annual night
TRMN	:	Terra rural monsoon night

TRSN	:	Terra rural summer night
TRWN	:	Terra rural winter night
TUAD	:	Terra urban annual day
TUMD	:	Terra urban monsoon day
TUSD	:	Terra urban summer day
TUWD	:	Terra urban winter day
TUAN	:	Terra urban annual night
TUMN	:	Terra urban monsoon night
TUSN	:	Terra urban summer night
TUWN	:	Terra urban winter night
CLUHI	:	Canopy Layer Urban Heat Island
EOSDIS	:	EOS Data Information System
EVI	:	Enhanced Vegetation Index
GHO	:	Global Health Observatory
HDF-EOS	:	Hierarchical Data Format-Earth Observing System
IGBP	:	International Geosphere Biosphere Programme
LPDAAC	:	Land Processes Distributed Active Archive Centre
LST	:	Land Surface Temperature
MODIS	:	Moderate Resolution Imaging Spectroradiometer
MRT	:	Modis Re-projection Tools
NASA	:	National Aeronautics and Space Administration
NDVI	:	Normalized Difference Vegetation Index
NIR	:	Near Infrared
QC	:	Quality Check
SUHI	:	Surface Urban Heat Island
SWIR	:	Shortwave Infrared
UCL	:	Urban Canopy Layer
UHI	:	Urban Heat Island
VI	:	Vegetation Index
WHO	:	World Health Organisation

Chapter 1

Introduction

Today the whole world is facing a continuous increase in temperature which is mainly due to the rapid urbanization. This rapid urbanization leads into the consequent changes in the natural landscape having pervious surface areas like vegetation, forestation ,soil cover into the urban built-up areas including the anthropogenic material based imperious surface like buildings, roads, parking lots and concrete cover which causes changes in the emission, thermal, radiative and moisture interaction between the surface and ambient environment. Land surface temperature is the skin temperature of ground surface (Qin and Karnielli, 1993). It is the governing parameter of physics of land surface processes on local, regional and global scales for combining all the surface-atmosphere interactions and energy fluxes (both sensible and latent) between atmosphere and ground (Mannstein1987). It is also the controlling factor for the physical, chemical and biological processes of earth. Climate studies, climate activities, environmental conditions and management practices of earth surfaces and its surrounding atmosphere involves greater requirement of LST information on an useful scale (Li &Becker 1993). LST significantly changes from point to point on the ground surface and ground measurements are generally point measurements (K. Mao. et a.,). Possible reasons for the increase in land surface temperature is land use which comprises utilization of land for a given human purpose and land cover which comprises biophysical attribute of earth surface.

1.1. Types of Land surface temperature

Here the use of term of type of LST is of significance to scrutinize the temperature of each part of the ground system for pervious surface areas like shaded ground, shade vegetation, sunny ground and sunny vegetation and for impervious surface areas like roads, concrete cover, buildings and built-up (Cassels et al., 1992a, b; Kimes, 1983).

The inherent properties of surface material like thermal conductivity, heat capacity and thermal inertia also put a significant impact over the governing temperature of a body at equilibrium with its surroundings through the thermal processes of conduction, convection and radiation (Campbell, 2002).

Type of land surface	**Associated temperature**
1.Bare soil	Soil surface temperature(SST)
2.Sparse vegetation ground	Vegetation canopy + vegetation body + soil temperature
3.Dense vegetation ground	Canopy surface temperature of vegetation
4.Impervious surface	Top of Surface temperature

Economic growth of any nation puts an emphasis over the open agriculture reduction, urban expansion and temperature variations. LST is good change indicator to express all these alterations altogether. LST represents high spatial heterogeneity. Basically, LST is an accurate energy exchange indicator between Earth and its ambient atmosphere (Zhengming et al., 1989).LST variations are subjected to land use, wind speed , humidity ,seasonality, surface air temperature and time of day(Wang et al.,2008; Keramitsoglou et al,.2011).

1.2.Impacts of LST

- LST increase results into increase temperature during summer makes human life discomfort able and comfortable during winter season (Voogt, 2004).
- LST puts a negative impact over energy consumption during summers and enhanced pressure results over the power supplies. A study in London city between increased temperature, energy consumption and CO_2 emissions suggests about the decrease in heating load along with increase in cooling load and overheating hours as

location changes from rural to urban sites. Increased energy supplies results into the heat emissions into atmosphere as well as increased green house gas emission which further cause environmental pollution.

- Aquatic ecosystem is damaged due to intermingling of warm water flowing over hot pavements, rooftops into the river, lakes, pond and sea-sides as heat transfer between the surface and flowing water occurs. (EPA, 2013)
- Contributions of hotter air results into the accelerated smog production concerning to health and environment (Gray and Finister, 2000).
- Excessive heat events, or abrupt and dramatic temperature increases, are particularly dangerous and can result in above-average rates of mortality (EPA, 2013).

1.3.Necessity of the present study

Urban population is increasing very fast as it was 10% in 1990 and 60% in 2015 and it will rise up-to 75% by 2050. Highest urban growth is reported into the India, China and Nigeria (source-World Urbanization Prospects by UN DESA report). Among these three countries India is accounting 38% of total urban growth, which is highest. This will result into the increased LST and adverse impacts on the human life. Hence it is the necessity of the present study for human comfort and adaptability. Previously reported studies mainly focus over the cold cities and there is very less information about warm Indian cities i.e. lesser references are available for hot-semi and arid climate. The present study includes the seasonal variation, diurnal variation of day-night temperature and existing correlation of two hot semi-arid cities (Ahmadabad & Jaipur) and one humid subtropical climate city (Ludhiana) and comparative analysis of these cities with 8-day as well as 1-day data with vegetation indices.

1.4. General Objective of the present study

The aim of the study is to replicate the diurnal variation of LST and existing correlation of the Indian cities from 2003 to 2015 by satellite data with the help of GIS and remote sensing techniques.

1.5 Specific Objectives

- To evaluate the temporal variation of MODIS day and night time land surface temperature by Aqua 8-day data.
- To evaluate the temporal variation of MODIS day and night time land surface temperature by Terra 8-day data.
- To evaluate the seasonal variation of LST for summer, monsoon, winter and annually.
- To evaluate the temporal and seasonal behavior of Aqua and Terra retrieved LST of the urban and rural area separately.
- To evaluate the correlation between Aqua & Terra 8-day average LST for day-night, seasonally and annually.
- To evaluate the correlation between Aqua & Terra 8-day average LST for urban and rural area separately.
- To evaluate the correlation between Aqua & Terra 1-day average LST for day-night to cross validate the 8-day data results.
- To compare the 1-day correlation coefficients with the corresponding dated NDVI values and establish a relation.

1.6 Organization of the thesis

The organization of the thesis work as follows:-

Chapter 1 contains Introduction, describing the LST and its socio-environmental impacts. It also discusses the necessity of the study and various specific objectives behind this study.

Chapter 2 discusses about the comprehensive review of literature, previous studies and those gapes which result into this study.

Chapter 3 describes the data and methodology used in the study.

Chapter 4 discusses the results and various relationships developed for LST for study area.

Chapter 5 outlines the findings of the research. It also discusses the future scope of research in this direction.

Chapter 2

Literature review

Land surface temperature (LST) effects climate and weather at a wide range of temporal scale as it is a key factor in determining heat fluxes into the boundary layer and surface energy balance (Atlas et al., 1993; Segal et al., 1989). Land surface temperature is an integrating factor which resembles the cumulative effects of the shortwave and longwave radiation on land surface, near surface meteorology, soil moisture, vegetation amount; antecedent precipitation and land cover type (Dai et al., 1999). LST differs from surface to surface as behavior of natural surface is far different from the behavioral pattern of manmade anthropogenic material composed urban surface in terms of blockage of prevailing winds due to high rise buildings in cities, man-made released heat, changes in the rainfall pattern, evaporation and absorption of longwave shortwave radiation (Mirzaei and Haghighat,2010). To solve many problems associated with climate change in the urban areas and interaction between human and environment, Land surface temperature plays a vital role (Ramchandra and Uttam, 2009). Recent developments in the field of remote sensing by launching satellites having sensors equipped with thermal infrared bands made possible in obtaining high resolution images at the large spectral range with repetitive cover age of Earth's land surface and monitoring of land surface temperature(Mallick, Kant and Bharat,2008). Thermal imaging and mapping of temporal and spatial distribution of LST can be used as an alternative in the absence of regular network of ground weather stations (Feizizadeh, Blaschke, Nazmfar, Akbari and Kohabanani, 2013)

2.1. Land Surface Temperature and Characteristics

LST is radiative skin temperature of the ground surface. Land surface temperature of an element of earth surface is calculated from measured radiance (Norman & Becker, 1995). Skin temperature refers to the temperature of the top surface in bare soil conditions and to the effective emitting temperature of vegetation canopies as determined from a view of the top of a canopy. Radiative skin temperature is an instantaneous phenomenon which forms the interface between the atmosphere and soil (land). Basically it is the temperature of plantery surface at radiative equilibrium. At radiative equilibrium it is assumed that incoming radiative energy coming from sun is equal to outgoing radiation emitted by the planet.

2.2. Physics of Radiative Energy

It involves the incoming & outgoing energy.

1. Incoming energy is based on surface reflectivity (Albedo). Total incoming energy is calculated by the product of day side planetary area and absorbed solar radiation by planet. The absorbed solar radiation by planet is the difference of total solar flux and reflected back to space. This incoming energy is obtained by inverse square law.
2. Outgoing energy (energy flux per unit area emitted by planet) is based on Stefan Boltzmann law.

If Radiative equilibrium is not followed then temperature of the surface must rise or fall and Diurnal variations, seasonal variation in LST occur. LST mainly depends on the surface Albedo, vegetation cover and soil moisture.

2.3. Factors responsible for LST rise

The various possible responsible factors for LST increment are listed as below

1. Location (Latitude, Altitude and Sun angle variation) - Surface temperature is observed higher at near the equator and as the distance is increased from equator (nearer to the poles), the temperature is lower. Due to curve surface of earth the solar vertical radiation strikes the earth surface at different angles (at equator the angle of incidence is 90*). Altitude is the height of surface from the mean sea level. At higher altitudes (mountains) the temperature is lower as compared to lower altitudes (land) due to less availability of water vapor in air in the atmosphere so less heat absorption takes place.

2. Climate (Humidity, Weather, Wind and Cloud cover) – Humidity is the amount of water vapor in the atmosphere which influences the cloud cover. Hence, higher amount of humidity, higher clouds (near the equator), the more will be the surface temperature. The wind speed controls the surface temperature as the lower wind speed makes possible for the amount of solar radiation to reach the earth surface by reducing the amount of heat convection.

3. Anthropogenic Heat: - It refers to heat produced by human activities. It is generated from variety of sources and is estimated by summing up all the energy used for operating appliances, for heating and cooling, industrial and transportation.

4. Material characteristics (composition, texture and density of land components): The urban surfaces comprises mainly of heat absorbing materials which also have greater capacity to release heat during night absorbed during day sun light.

5. Urban Geometry: - Urban geometry is influencing parameter for surface temperature increment, urban geometry is referred as dimensions and spacing of buildings in the city. It influences the wind flow, energy absorption and surface ability to emit long wave radiations back to atmosphere.

6. Land surface type: - The natural obstruction to the solar radiation is vegetation which reduces the solar heat to interact with ground surface by maintaining humidity by evapotranspiration and lowers the surface temperature. Rural areas are dominated by this vegetal cover and soil but urban area is comprised of roads, buildings and built-up which makes rural area colder than the urban one.

2.4. Related previous observational studies on LST

The first study on the diurnal cycle of land surface temperature (LST) was reported by Trenberth in1984 which comprises of three basic elements: noise, diurnal climatic mean temperature cycle and instantaneous variations. The noise element signifies random measurement errors along with very small fluctuations (Jin and Treadon 2003, Jin and Dickinson 1999). The instantaneous variations are made of atmospheric state, surface properties along with wind, humidity and soil moisture. The diurnal climatic mean temperature cycle is dominated by the latitude, vegetal cover, Albedo, surface roughness, sunset, sunrise and surface insolation. However it may vary by the amplitude of the surface but it does not show any significant rapid changes day to day (Jin and Treadon 2003). Previous studies based on modeling it can be assumed that noise component can be ignored when the diurnal cycle of LST is derived from daily twice satellite measurements (Jin and Treadon 2003).

Nicholas C. Coops et.al (2003) studied estimation of afternoon MODIS Land Surface Temperature (LST) based on the morning MODIS overpass, elevation information and location. They elaborated the differences between the Aqua LST and Terra LST over wide range of dates and climates and they made an adjustment and applied over the Terra LST to approximate a synthetic Aqua LST. They reported the difference between the two LST as 0.3° to 3.2°.

Menglin Jin and Robert E. Dickinson in 1999 reported the necessity of diurnal cycle of skin temperature for land surface studies and ambient climate change detection. They used polar satellite LST data over geostationary data. They put an algorithm for the use of satellite based temperature data to provide the diurnal information under cloudy and uncloudy conditions by ignoring the noise.

"The surface of the earth has experienced various changes because of anthropogenic activities over the past half century, including mostly deforestation and urbanization" (Ownes, 1998). The urbanization and changes in land uses have consequent effect in environmental impacts related to microclimate. The natural areas are replaced by hard landscape materials, such as concrete, glass and metal. Natural features, including vegetation, water bodies and soil, increase the retention of thermal energy by a natural mechanism called evapotranspiration (Rodgers et al., 2001), which decreases the thermal energy percentage achieving by surface and heat percentage that is re-emitted into the atmosphere. However, human activities have resulted in changes in surface energy balances, with a rise in sensible heat flux and a fall of latent heat flux (Stull, 1988).

Qiao et al. (2013) has observed diurnal and seasonal impacts of urbanization and increase LST on the urban thermal environment. They proposed a contribution index for Beijing city to explore the impact of urbanization over LST using MODIS data. They have suggested about the notable cooling effect of Vegetation (NDVI) during summer and shifting of nighttime LST in other season and suggested modern urban designs based on vegetation.

Ayansina Ayanlade., (2016) has studied the effect of UHI phenomenon as an adverse impact of urban land surface temperature surrounding rural areas along with urbanization in both developed and developing countries. Two indexes, contribution (CI) and landscape (LI) were used to estimate the LST contributions from urban and rural area and to access the relationship between NDVI and LST. The correlation analysis between LST and NDVI has done for day and night time and highest R^2 values for day time during wet (monsoon season) were obtained and lowest values were recorded for night time in summers.

Jasper Van Doninck (2011) has reported potential of multitemporal Aqua and Terra MODIS LST data to obtain diurnal surface temperature amplitudes by a large numbers of land surface temperature measurements to combine it with surface Albedo to develop a new parameter Apparent Thermal Inertial (ATI). The temporal behavior of apparent thermal inertia, derived using MODIS data only, showed a strong correspondence to that of AMSR-E soil moisture, especially in arid and semi-arid environments.

Parida et al., (2008) has reported land surface temperature variation in relation to vegetation type using MODIS data in Gujarat state of India. They studied the temporal variation of LST based on MODIS data from 2000 to 2004 during reproductive phase of crops in desert, rainfed agriculture, irrigated agriculture and forest areas. They resulted highest surface temperature in the desert-based agriculture followed by rain fed agriculture, irrigated agriculture, and forest. They found a correlation range (0.50-0.98) in MODIS LST and air temperature.

Mathew, A. et al., (2015), studied the relationship of LST with various parameters like NDVI for Ahmedabad city. The LST has been extracted using MODIS data while NDVI by Landsat TM. The study showed a negative correlation with LST, suggesting that green cover reduces the effect of UHI.

Yunfei Bao et al., (2011) observed LST and emissivity retrieval by integrating the MODIS Aqua and Terra data by taking solar zenith angle, view zenith angle and atmospheric water vapor as an independent variable to analyze their sensitivities to the same infrared channel measurements of MODIS. They found a root mean square error as 0.66K for one of the site area and this error is less than 0.7K rms error when the results are compared with EOS MODIS LST data product using physics based on day/night algorithm.

C. O. Mito et al., reported LST retrieval from MODIS data using split window algorithm using a line-by-line radiative transfer program me (Fast Atmospheric Signature Code-FASCODE) at wavelengths 11.03 and 12.02mm. The Uivieri algorithm which was applied to Advanced Very High Resolution Radiometer (AVHRR) channels 4 and 5, is extended by simulations to account the atmospheric effects in particular water vapor column amount. These simulations helped to determine new coefficients of this algorithm appropriate to MODIS bands 31 and 32 using different atmospheric conditions.

Charlie J. Tomlinson et al., (2012) have studied the comparison of night time land surface temperature from MODIS and ground based air temperature by a customize network of data loggers. The result showed that the night time LST is lower than night time air temperature. This result has an important application for health-heat studies and heat-wave warning system and MODIS LST may be used as proxy data for air temperature.

Zehngming Wan, (2006) has discussed the MODIS LST & emissivity products in the current (V4) and previous versions with eight new refinements (surface elevation) for V5 product with real Terra and Aqua MODIS data. These refinements used for removal of temporal averaging in the 1km daily level-3 LST product, removal of cloud-contaminated LSTs in level-3 LST products.

These refinements significantly improved the spatial coverage of LSTs in highland regions and the accuracy (1K) as well as stability (0.5K<root mean square values<0.7K with heavy aerosol loading) of MODIS LST products. LST products depend on clear-sky conditions because of the inherent limitation of the thermal infrared remote sensing.

William L. Crosson et al., (2011) has concluded the results of Aqua and Terra LST merged data to fill in the spatial gaps of Aqua satellite data. The closer temporal proximity of Aqua and Terra data allowed to combine information from the two data sources that can reduce the data loss (cloud data).An approach 'Merging of data' supplemented existing Aqua and Terra day and night time LST products. The study involved using independent offsets for each grid cell and accounting for factors such as land cover, elevation, terrain slope and aspect, latitude, season and snow cover, which control the diurnal cycle of LST. For the six-year period, the merged data set increases data coverage by 24% and 30% for daytime and nighttime overpasses, respectively, relative to the Aqua LST product alone.

Nina Schwarz et al.,(2012) has found the relationship of LST and air temperature to quantify the UHI phenomenon which includes the alteration of urban temperature surrounded by rural areas and its impacts over human health. The main conclusion for future studies on UHIs is to use several UHI indicators in parallel to acknowledge the uncertainty of measuring the UHI using a single indicator and either ground measurements or remote sensing.

J.A.Sobrino et al., (2010) has reported the impact of spatial resolution and satellite overpass time on evolution of the surface urban heat island effects. They showed that spatial resolution greater than 50m are needed to properly estimate the SUHI (LST) and satellite overpass time is immediately before sunrise.

Fan Huang et al., (2014) has developed a generic framework for modeling diurnal land surface temperatures with remotely sensed thermal observations under clear sky. DULST modeling has an importance in detection of surface property (thermal inertia) and soil properties (evapotranspiration and heat fluxes) for climate change studies which is helpful in modeling temperature dynamics under modeling accuracy. This study includes the modeling of conversion of ground-surface heat flux into temperature using surface energy balance and heat conduction equation.

Xiaoxiao Li et al., (2015) has studied remote sensing of the surface urban heat island and land architecture in Phoenix, Arizona with combined effects of land composition and configuration and cadastral–demographic–economic factors to determine role and effect of land composition over LST and SUHI effect. The results showed a distinct thing that is effect of land configuration over LST and SUHI is more than land composition. This result showed that the rearrangement in the composition and configuration of the land-cover can be used to ameliorate the UHI effect.

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Chapter 3

Data and Methodology

The present work is having the primary objective of analyzing the intensity and characteristics of LST over study areas around Jaipur, Ahmedabad and Ludhiana cities in India respectively. The study also includes the seasonal variation of LST and effect of land surface characteristics over LST. To carry out this study huge amount of remote sensing data has been downloaded for the study areas from the center piece of United Space National Aeronautics and Space Administration (NASA) i.e. Earth Observing System (EOS). Various details regarding the remote sensing data including its characteristics and pre-processing have been listed below.

3.1. Remote sensing Data used for the present study

Remote sensing data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor has been used. NASA is the centerpiece of Earth Observing System. MODIS is an EOS instrument cum sensor having new spectroradiometer which enables it to scan $\pm 55^{\circ}$ from Nadir. MODIS provides information about earth surface in 36 wavebands covering Band1-19 in visible range, Band 26 in Near Infrared (NIR) and remaining bands in the Shortwave Infrared (SWIR) and Thermal Infrared (TIR). It has a viewing swath width of 2330 km and views the earth surface in every one to two days. It has global coverage, dynamic range of radiometric resolution and accurate calibration in multiple T.I.R. bands. It acquires images at three spatial resolutions of 250m for the first two bands, 500m for the band 3 to band 7 and 1000m for the remaining bands as well as temporal resolutions of 1-day, 8-day, 16-day 1-month, quarterly and yearly (Land Processes Distributed Action Archive Centre ,2010). The Land Processes Distributed Active Archive Center (LP DAAC) is one of several discipline-specific data centers within the NASA Earth Observing System Data and Information System (EOSDIS). The LP DAAC is located at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South

Dakota. MODIS is a sensor or one of the instruments which are carried out by two sun-synchronous polar orbiting satellites. The details is listed below.

Table3.1: Details of Aqua and Terra satellite

Satellite	Launching date	Equator pass time	Main application
Terra (EOS-AM-1)	Dec12,1999	10:30AM 10:30PM	Focuses on land based application
Aqua (EOS-PM-1)	May4,2002	01:30PM 01:30AM	Focuses on water based application

The temporal resolution of LST is 1-Day and 8-day respectively and spatial resolution is 1km in the present study work. The LST data has been retrieved from Aqua as well as Terra for temporal resolution of both 1-Day and 8-Day composite and spatial resolution of 1km x 1km. The Vegetation Indices (VI) product is retrieved from the above mentioned platform of spatial resolution of 1km x1km and temporal resolution of 16-Day composite. Remote sensing data used for the present study with necessary characteristics is tabulated below;

Table3.2: Details of MODIS data used for the present study

S. No.	Remote sensing data product	Sensor	Short name	Resolution		Platform
				Temporal	Spatial	
1.	Surface temperature and emissivity (LST)	MODIS	MYD11A1	1-Day	926.6m	Aqua
		MODIS	MOD11A1	1-Day	926.6m	Terra
		MODIS	MYD11A2	8-Day	926.6m	Aqua
		MODIS	MOD11A2	8-Day	926.6m	Terra

S. No.	Remote sensing data product	Sensor	Short name	Resolution		Platform
				Temporal	Spatial	
2	Vegetation indices(VI)	MODIS	MYD13Q1	16-Day	926.6m	Aqua
3	Land Cover type	MODIS	MCD12Q1	Yearly	463.3m	Aqua

The illustration of the above mentioned remote sensing MODIS data products as follows:

3.1.1. MODIS data products-Vegetation Indices (VI)

Vegetation indices is empirical representation of vegetation activity in the form of dimensionless parameter. It shows on a pixel the extent of condition or amount of vegetation activity. Vegetation Indices derived from satellite data are used in climate modelling, land applications and natural resource monitoring and management. It is calculated in two spectral response bands mainly in the red and NIR. The spectral response contrast between the red and NIR regions brings a sensitive measurement of Vis including low or minimal contrast over no vegetation and maximum contrast over healthy vegetation. In case of medium vegetation the contribution from red and NIR bands but in case of high dense vegetation chief contributor is NIR band as red band is totally saturated or absorbed by the presence of chlorophyll in the vegetation. After radiometric calibration, spatially-temporally gridding, cloud-atmospherically correction the NIR and red spectral responses are used to generate the VI maps for the desired region (Huete et al., 1999). MODIS vegetation indices produced on 16-day intervals and at multiple spatial resolutions, provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure(). There are mainly two MODIS Vegetation Indices available one is Normalized Difference Vegetation Index (NDVI) that incorporates transformation between two spectral bands i.e. red and NIR, having values between -1 to 1 and it provides continuity with NOAA, AVHRR NDVI time series record for historical and climatic applications. It is adapted for global processing as it is very extensively used in local, regional and global monitoring of vegetation studies. Though it has a drawback that the atmosphere retards the contrast of red and NIR signals and it becomes saturated for the dense vegetation (Huete et al., 1999). . It is commonly expressed as:

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3}$$

Where ρ_3 is the reflectance of red wave bands and ρ_4 is the reflectance corresponds to the near infrared wave bands (Rouse et al. 1974). There is a global time series record of 6 VI products from Aqua and Terra MODIS sensors at spatial (250m,500m,1km, 0.05 degree) and temporal (16-day, monthly) resolutions. 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. Beside the atmospheric effects over the NDVI values, it is also affected by the aerosol contamination at coarser resolutions and at finer resolutions it is affected by the smoke, dust particles, particulate matter and cirrus clouds.

The second MODIS VI is the Enhanced Vegetation Index (EVI) which is soil based and instant. It minimizes variations of canopy-soil and enhances sensitivity over dense vegetation conditions. It is also termed as modified NDVI as it demarcates atmospheric and soil effects from the vegetation signal (Solano et al, 2010) The EVI formula are written as:

$$EVI = 2 \circ \frac{\rho_{NIR} - \rho_{Red}}{(L + \rho_{NIR} + C_1 \rho_{Red} + c_2 \rho_{blue})}$$

Where ρ is apparent (top-of-the-atmosphere) or surface directional reflectance, L is a canopy background adjustment term, and C1 and C2 weigh the use of the blue channel in aerosol correction of the red channel (Huete and Liu, 1994). These two MODIS vegetation products characterize vegetation processes and ranges globally and effectively. The gridded VIs of MODIS is MYD13Q1 provides gridded global land coverage in form of 12 SDS layers, gives reflectance values for red, blue, NIR and MIR bands along with NDVI and EVI values at 16 days temporal interval and 232m spatial resolution for the study areas. This data includes the Quality Assurance (QA) flags that show the quality of

VI product which enable the user to eliminate those pixels on the basis of detection of clouds and hence include only good quality pixel in the present study.

3.1.1.1. Data set characteristics

The typical data set characteristics of MODIS NDVI product used for the present study work is tabulated below

Table3.3: Details of data set characteristics of MODIS NDVI product

S.No.	Data Set Characteristics	
1.	Temporal Coverage	February 24, 2000 -
2.	Area	~10 x 10 lat/long
3.	File Size	~1–22 MB
4.	Projection	Sinusoidal
5.	Data Format	HDF-EOS
6.	Dimensions	1200 x 1200 rows/columns
7.	Resolution	1 kilometer

3.1.1.2. Data Access Tools

Data Pool : The Data Pool (On-line Archive) provides access to all MODIS products, and a rolling archive of ASTER level-1B products that cover the U.S. and its Territories.

Reverb : This tool provides access to a complete data record of all MODIS and ASTER products available from the LP DAAC.

GloVis : The Global Visualization interface provides access to tiled MODIS products that have an associated browse image, and all ASTER level-1B products.

MRTWeb : The MODIS re-projection Tool Web interface provides access to all MRT services offered by the stand-alone MRT.

3.1.2. MODIS data products-Land Cover Type

The identification and classification of land surface into different classes such as urban or built-up class, wetlands, sparsely vegetated/ barren, closed and open shrub lands, water/ice/snow, savannas/ woody savannas and mixed forests can be done by this product. Additional details can be found on the Land Processes Distributed Action Archive Centre website, 2011. This product discuss in detail about the land cover properties by using supervised decision classification tree method in classifying the five different Land Cover schemes which is incorporated by the above product, which is tabulated as follows. The primary land cover classification scheme comprises 17 classes illustrated by IGBP scheme, which contains 3 non vegetated class, 3 human altered class and 11natural vegetation classes. The results of all stated schemes are quite similar. The classification by MODIS derived Net Primary Production (NPP) scheme found better for the region and hence this scheme has been employed for the present study.

Table3.4: Details of various classification schemes with their land cover type

S.NO.	Land cover type	Classification Scheme
1.	Type-1	International Geosphere Biosphere Program me(IGBP) global vegetation classification scheme
2.	Type-2	University of Maryland(UMD) classifation scheme
3.	Type-3	MODIS derived LAR/fPAR scheme
4.	Type-4	MODIS derived Net Primary Production (NPP) scheme
5.	Type-5	Plant Functional Type (PFT) scheme

3.1.3. MODIS data products-Surface Temperature and emissivity (LST)

Moderate Imaging Spectroradiometer (MODIS) is one of the sensors on board Aqua and Terra satellites; MODIS sensor has 36 spectral bands. For the present work MODIS TIR (Thermal Infrared) bands (Band31 having band width 10.780-11.280μm and band 32 having band width 11.770-12.270μm) are used. MODIS LST data products are composite of MOD11A1, MOD11A2, MOD11B1, MOD11C1, MOD11C2, MOD11C3 and MOD11L2. Each LST product in the sequence is built from the previous LST products. The first LST product, MOD11L2, is the LST at 1km spatial resolution for a swath. MOD11_L2 LST is constructed using the MODIS sensor radiance data product (MOD021KM), the geolocation product (MOD03), the atmospheric temperature and water profile product (MOD07L2), the cloud mask product (MOD35L2), the quarterly land cover (MOD12Q1), and snow product (MOD10L2) (Wan, 2007). The next MODIS LST product is MOD11A1 LST which is generated from MOD11_L2 products results of a day. For preparing the MOD11A1 LST product the scientific data sets of all pixels in MOD11_L2 are mapped onto grids in the sinusoidal projection and the LST values of overlapping pixels in each grid are averaged with overlapping areas as weight (Wan, 2007). After MOD11B1, V5 MOD11A2 product is the fourth LST product which is used in this study. Production of MOD11A2 is done by using a simple average method in the current algorithm for the MOD11A2 product for each 8 days (from two to eight days). The MOD11A2 MODIS LST products are archived in Hierarchical Data Format - Earth Observing System (HDF-EOS) format files, including global metadata and scientific data sets (SDSs) with local attributes. The SDSs in the MOD11A1 product include LST_Day_1km, QC_Day, Day_view_time, Day_view_angl, LST_Night_1km, QC_Night, Night_view_time, Night_view_angl, Emis_31, Emis_32, Clear_ sky_ days, Clear_ sky_ nights, as shown in Table. MOD11A2 product local Attributes included the coefficients of the calibration which converts the SDS value to real LST value in kelvin. For example the valid range of LST in MODIS LST maps is between 7500 and 65535. Converting to kelvin, these values should be multiplied to the scale factor of 0.02 which is available in local attributes (Wan, 2007).

MODIS HDF files are shown by a rather long name, the breakdown of MODIS filenames is (MODIS overview, USGS, 2011):

MOD11A2.A2008321.h27v05.005. 202354788467.HDF

MOD11A2 : MODIS product group and processing level

A2008321 : year and Julian day of granule capture

H27v05 : number of tile in MODIS tiling system

005 : version of processing code

202354788467: time stamp of processing

Table3.5: Details of SDS of MODIS LST product (MOD11A2)

S.NO.	SDS NAME	LONG NAME	UNIT	VALID RANGE	FILL VALUE	SCALE FACTOR	ADD OFFSET
0	LST_Day_1km	Daily daytime 1km grid Land-surface Temperature	Kelvin	7500-65535	0	0.02	0
1	QC_Day	Quality control for daytime LST and emissivity	none	0-255	0	NA	NA
2	Day_view_time	(local solar) Time of daytime Land-surface Temperature observation	hrs	0-240	255	0.1	0
3	Day_view_angle	View zenith angle of daytime Land-surface Temperature	deg	0-130	255	1	-65
4	LST_Night_1km	Daily nighttime 1km grid Land-surface Temperature	Kelvin	7500-65535	0	0.02	0
5	QC_Night	Quality control for nighttime LST and emissivity	none	0-255	0	NA	NA
6	Night_view_time	(local solar) Time of nighttime Land-surface Temperature observation	hrs	0-240	255	0.1	0
7	Night_view_angle	View zenith angle of nighttime Land-surface Temperature	deg	0-130	255	1	-65
8	Emis_31	Band 31 emissivity	none	1-255	0	0.002	0.49
9	Emis_32	Band 32 emissivity	none	1-255	0	0.002	0.49
10	Clear_sky_days	the days in clear-sky conditions and with validate LSTs	none	0-255	0	NA	NA
11	Clear_sky_nights	the nights in clear-sky conditions and with validate LSTs	none	0-255	0	NA	NA

3.1.3.1. MYD11A1 & MOD11A1

MYD11A1 is1-Day LST data for MODIS sensor on board Aqua satellite and MOD11A1 stands for Terra satellite. The above data is available for day (10.30AM for Terra satellite, 01.30PM for Aqua Satellite) and night time (10.30PM for Aqua satellite, 01.30AM Terra for Satellite). The data incorporates 12 separate Science Data Sets (SDS) involving day-night LST images, day-night view time, day-night view angle, day-night quality check, day-night clear sky coverage and emissivities for band 31-32. Version-5 MODIS/Terra Land Surface Temperature/Emissivity products are validated to Stage 2, which means that their accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts MODIS sensor uses the reflected surface radiation in order to obtain the TIR signature. Also MODIS TIR signature values are stored in a database from accurate atmospheric transfer simulations for various boundary and atmospheric conditions.

3.1.3.2. Data Set Characteristics

Table3.6: Details of data set characteristics of MODIS LST product (MOD11A1)

S.No.	Data Set Characteristics	
1.	Temporal Coverage	March 5, 2000 – till date
2.	Area	~1100 km x 1100 km (Latitude/Longitude)
3.	File Size	2.1 MB
4.	Data Format	HDF-EOS
5.	Projection	Sinusoidal
6.	Dimensions	1200 x 1200 (Rows/Columns)
7.	Resolution	1kilometer (0.93-km)

3.1.3.3. MYD11A2 & MOD11A2

The MODIS Aqua/Terra Land Surface Temperature and Emissivity (LST/E) products provide per-pixel temperature and emissivity values in a sequence of swath-based to grid-based global products. The MODIS Aqua/Terra LST/E Daily L3 Global 1 km Grid product (MOD11A2/MYD11A2), is tile-based and gridded in the Sinusoidal projection, and produced daily at 1 kilometer spatial resolution. The main difference between the above data and this data is for temporal resolution i.e. this data has averaged LST values of two to eight days under clear sky conditions (Wan, 2007). It also has 12 SDS. It has a quality flag also, QC_Day and QC_Night for day and night respectively in form of a SDS. This QC flag provides essential information to analyze the results of an algorithm in spatial context of pixel (LPDACC, 2010). The QC information can be extracted by reading the flags 8-bit unsigned integer which establish the quality of LST results and make user to use only the required data. The QC information has been utilized to find and use the best quality pixel (having zero value for the bit numbers 0, 2 and 6 indicating an error of <2K in calculation of LST) for the present study.

3.1.3.3. Data Set Characteristics

Table3.7: Details of data set characteristics of MODIS LST product (MOD11A2)

S.No.	Data Set Characteristics	
1.	Temporal Coverage	March 5, 2000 – till date
2.	Area	~1100 km x 1100 km (Latitude/Longitude)
3.	File Size	2.1 MB
4.	Data Format	HDF-EOS
5.	Projection	Sinusoidal
6.	Dimensions	1200 x 1200 (Rows/Columns)
7.	Resolution	1kilometer (0.93-km)

A quality assurance tutorial was published in 2012 by USGS EROS Center that all MODIS land products have HDF data sets having different Science Data Sets (SDS) along with one QA data layer. QA layer includes file-level metadata (summary of a file data quality), pixel-level metadata and Land Data Operational Product Evaluation (LDOPE) web information. They help users to be sure about data consistency as per table 3.8. By using this QA layer table, low quality pixels can be filtered out (Neteler, 2010).

3.2. Methodology

LST is retrieved from MODIS TIR data only in clear-sky conditions. Cloudy pixels must be skipped in the LST processing, because the thermal infrared signals cannot pass through clouds besides the fact that the probability of cloudy conditions is usually more than 50% at the regional and global scales (WAN et al., 2004). MODIS LST data is retrieved from two online sources. The first is the website of university of Oklahoma, available at http://www.eomf.ou.edu/visualization/gmap/, in earth observation and modeling part, MODIS data is available for each MODIS pixel.

Table3.8: Bit field legend of QC flag for LST (LPDAAC, 2014)

Bit No.	Long Name	Bit Comb.	Indication
0–1	Mandatory QA Flags	0	LST produced, good quality, not necessary to examine more detailed QA
		1	LST produced, other quality, recommend examination of more detailed QA
		10	LST not produced due to cloud effects
		11	LST not produced primarily due to reasons other than cloud
2–3	Data Quality Flag	0	Good data quality of L1B in 7 TIR bands
		1	Other quality data
		10	TBD
		11	TBD
4–5	Emissivity Error Flag	0	Average emissivity error <= 0.01
		1	Average emissivity error <= 0.02
		10	Average emissivity error <= 0.04
		11	Average emissivity error > 0.04
6–7	LST Error Flag	0	Average LST error <= 1K
		1	Average LST error <= 2K
		10	Average LST error <= 3K
		11	Average LST error > 3K

From this website data can be downloaded as ASCII Table, CSV Table, and series of graphs, including data on selected tile (place name) and pixel. The second source is http://reverb.echo.nasa.gov/reverb/datasets, this website provides temporal and spatial criteria for searching needed LST images, and so 8-day HDF LST images are downloaded from this source. For the present study work second method is adopted.

To retrieve LST values, MODIS pixel locations were entered based either on the geographic coordinates (Latitude and Longitude) or directly the place name on reverb echo. LST values were retrieved from 2003 to 2015 with 1 & 8-day interval .The raw LST values were multiplied by the scale factor of 0.02 which was defined in the LST product user manual (Zheng Ming, 2007).

3.3. Preprocessing of remote sensing data

The standard archive format for EOS Data Information System (EOSDIS) products which are in Sinusoidal Projection System, is Hierarchical Data Format-Earth Observing System (HDF-EOS) format. The Earth gridded tile area of each MODIS image covers approximately 1100 km x 1100 km. Pre-processing of downloaded MODIS images has been done using MODIS Re-projection Tools (MRT). MRT is used for sub setting of the data to smaller area. The data has also simultaneously been re-projected from Sinusoidal projection to UTM Zone 43N projection system with WGS84 datum and has been reformatted from HDF-EOS to GeoTIFF format.

3.4. Study area and its climate

Jaipur, Ahmedabad and Ludhiana are three cities which are used as study area in the present study of Land Surface Temperature.

3.4.1. Jaipur City

Pink city, Jaipur is a 10^{th} largest Indian city which is capital and largest city of largest state, Rajasthan. Jaipur city is having geographical location on north and east hemisphere having the geographic coordinates as 26°25´ to 27°52´ north latitude and 74°55´ to 76°10´ east longitude It is having the total population of 33 lakhs. It is located on plain terrain. The city has a mixed topography of vegetation, barren land, built-up and industries etc. The geography of Jaipur city includes Jhalana (a part of Aravalli mountains) in the east and Nahargarh hills in the north. In west and south-west regions, sanitization is prominent problem while the eastern part is suffering from due to deforestation due to the mining operations. It lies in the semi-arid zone of India having the altitude 431m above sea level. Due to its semi-arid climate the city faces low rainfall and extreme diurnal temperature variations. The annual rainfall of this city is nearly about 650mm. The city experiences brief spell of summer from mid-March to end of June with maximum temperature of 46°c, winter from November to February with minimum of 8° and monsoon from end June to mid-September. The hottest and coldest months are June and December-January respectively.

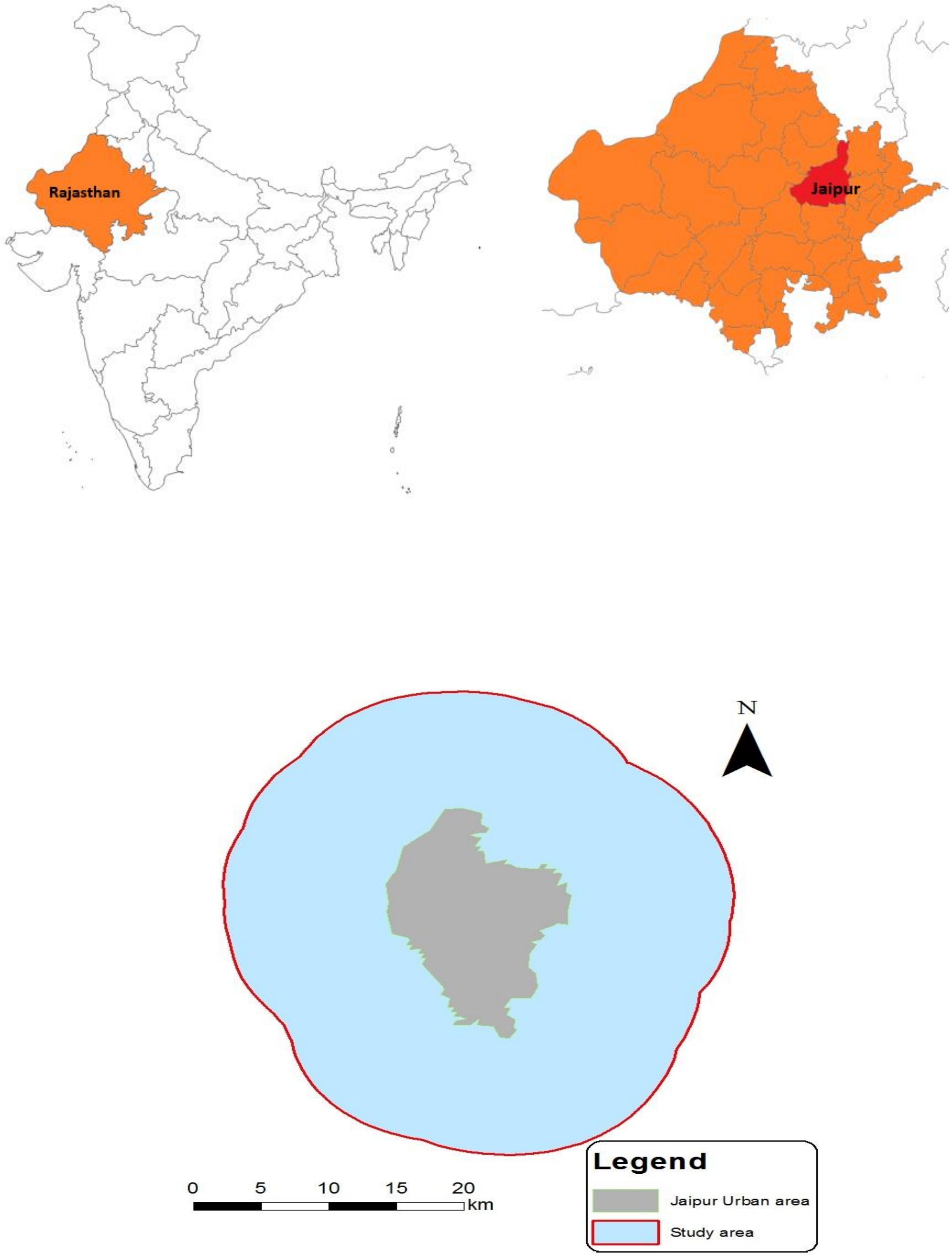


Figure 3.1: Jaipur study area

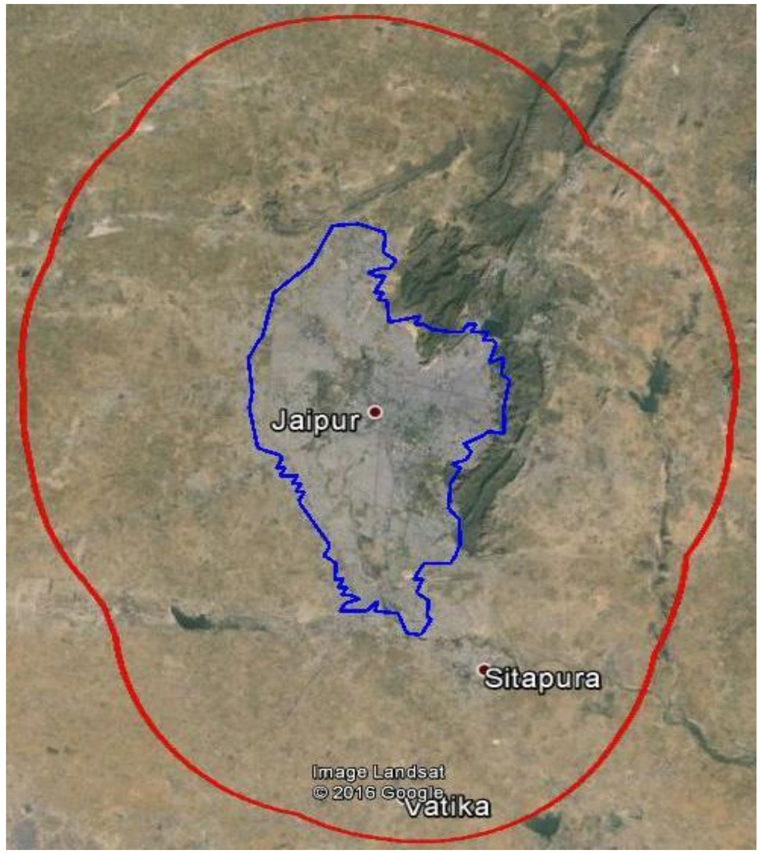


Figure3.2: Google Earth© image of the Jaipur

The outskirts of the city is mainly composed of vegetation hence study area of 12 km buffer outside the city with 1237.8 sq. km is used for the present study. The urban area of the city has been extracted as urban area polygon from MODIS yearly land cover type image (MCD12Q1) of 2011 which is termed as urban boundary having length of 21km in North-South direction and width of 13 km in East-West direction.

3.3.2. Ahmedabad city

Ahmedabad is 7th largest metropolitan in India and it is largest city in Gujrat. It is also the industrial capital of Gujrat having area and population are 464km2 and 56 lakh respectively. It is located on Sabarmati River which demarcates it into two western and eastern regions. The geographic coordinates of the city is 23°02´N to 23°03´N and 72°35´E to 72°58´E. The climate of the city is semi-arid and hot with scanty rainfall.

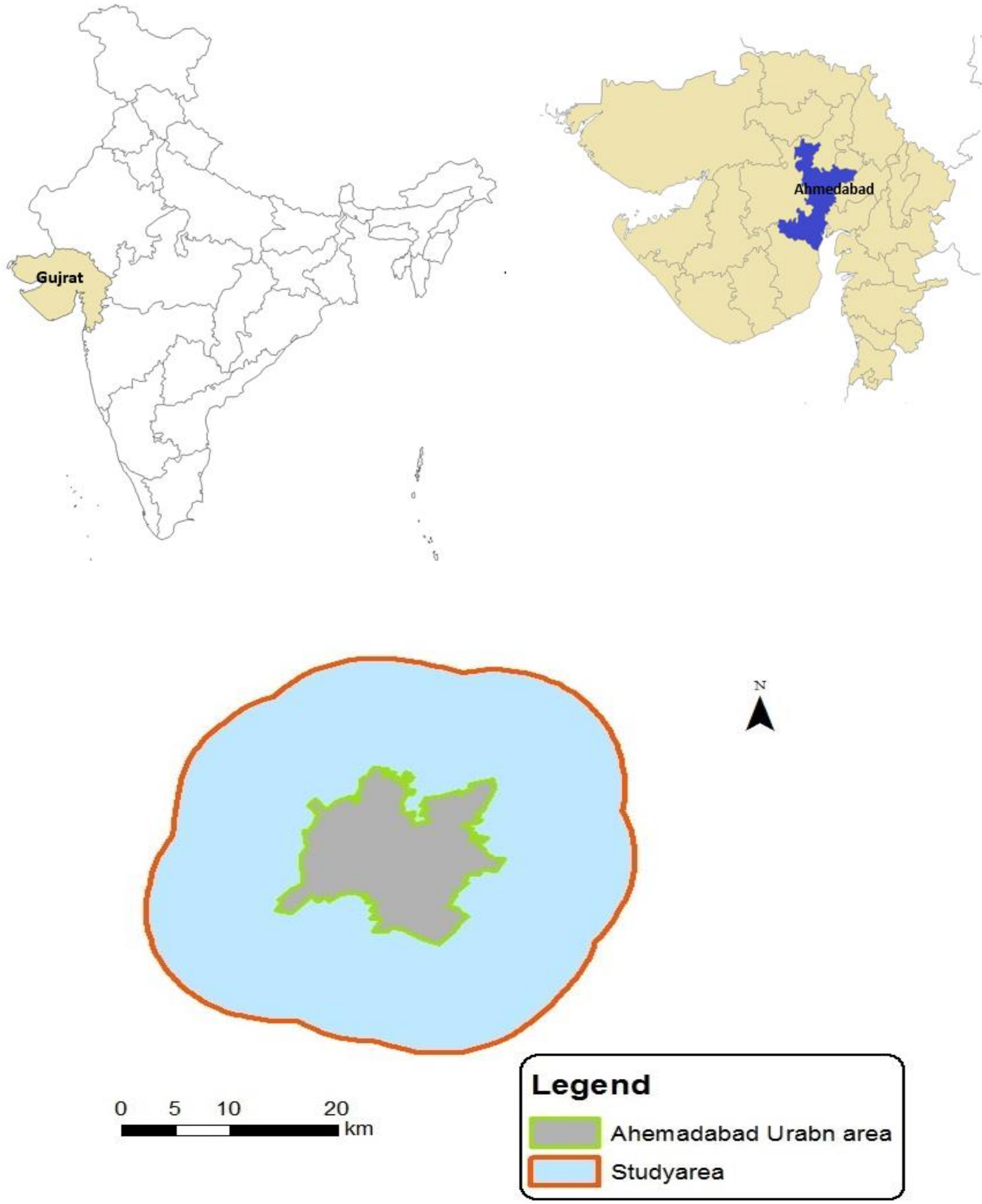


Figure 3.3: Ahmedabad study area

The city experiences summer from mid- March to end-June with maximum temperature of 41°C and winter from early-November to late-February with minimum temperature of 15°C. The city also receives an annual rainfall of 800mm during rainy season in a year. The city is situated over sandy soil which is responsible for extra heating of the city in summer time. The city is composed of river and lakes, one of the lakes is Kankaria Lake which is artificial and 1.5 km in radius, in the southern part of the city. The lake is responsible regulating temperature during hot summers.

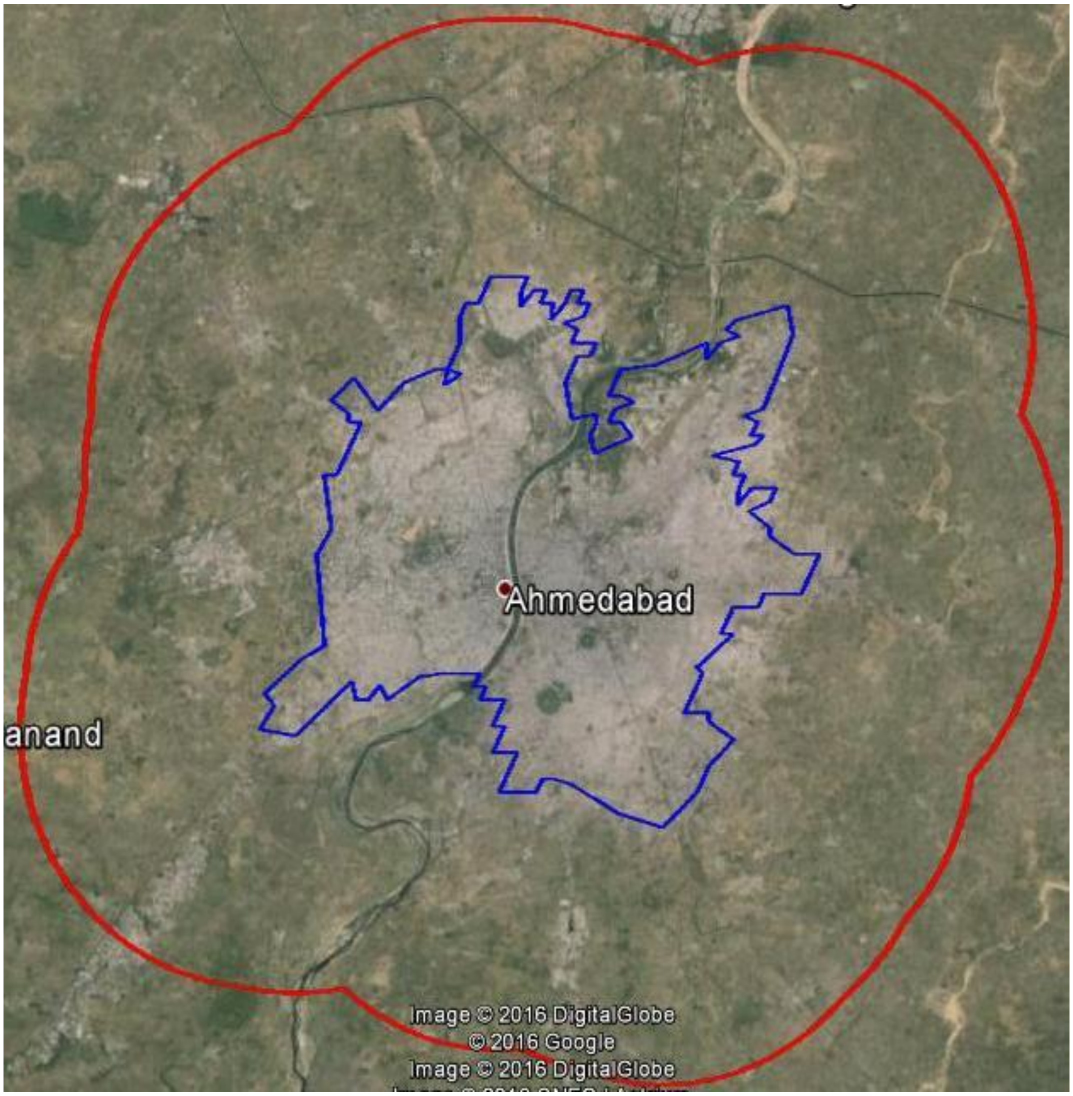
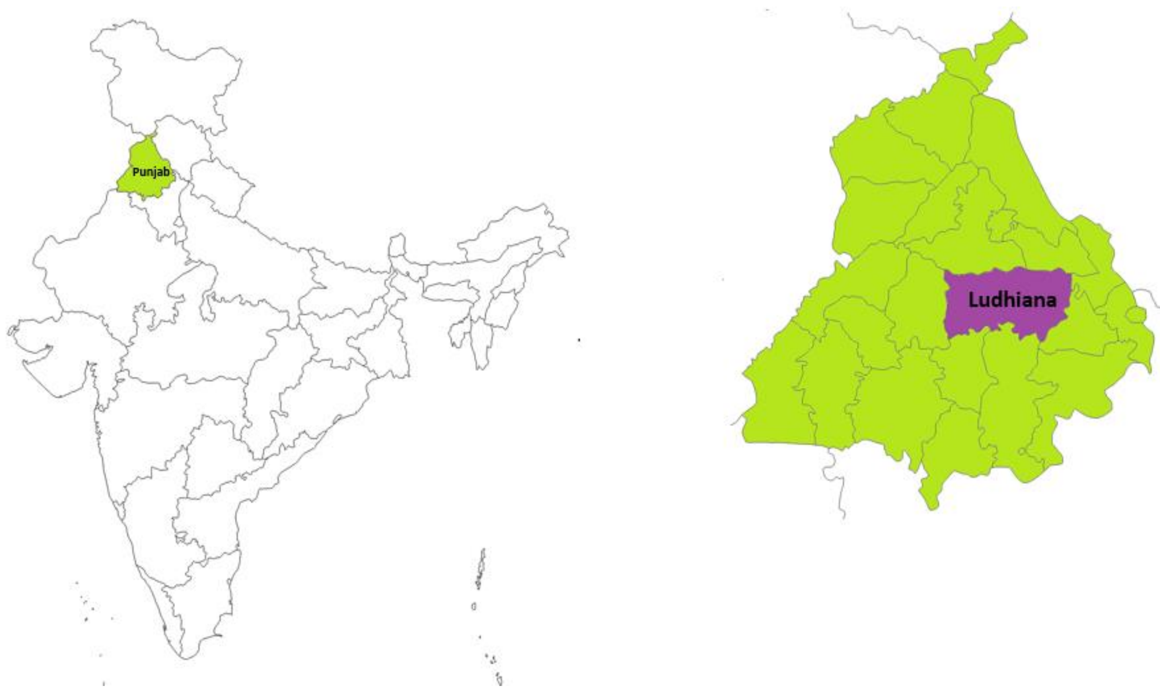


Figure3.4: Google Earth© image of the Ahmedabad

The study area consists of 7 km buffer around the urban area having 903 sq. km area and having length of 12 km in North-South direction and width of 17 km in East-West direction. The urban area boundary is derived by extracting the urban area polygon from MODIS yearly land cover type image (MCD12Q1) of 2010. The sister city of Ahmedabad is Gandhinagar is kept away from the study area.

3.3.3. Ludhiana

Ludhiana is one of the greenest cities of Punjab, situated in the central part of the state in Malwa region. It is also the largest city in north of Delhi having the population around 3.5million. The city is having a length of 96kms and breadth of 39kms with approximately an area of 3767km^2. The geographical location of Ludhiana is on Northern & East hemisphere in UTM Zone-43 with geographical coordinate's 30°34´ N to 31°01´N and 75°18´E to76°20´E.



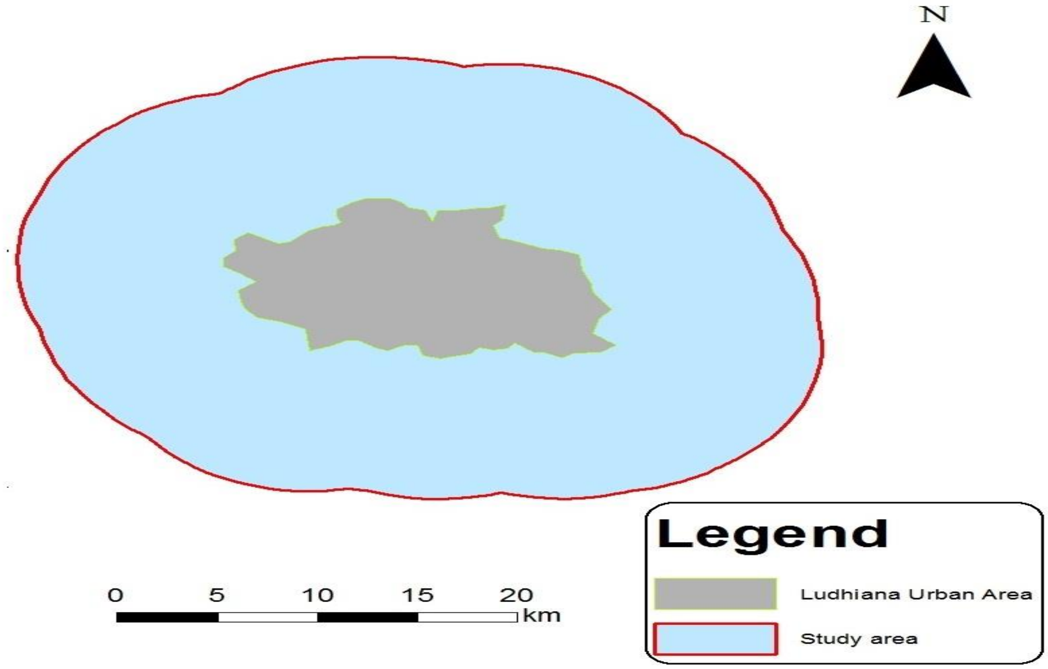


Figure3.5: Ludhiana study area

The city is surrounded by Moga, Ropar and Fatehpur Sahib in West, by Rup agar in East, by Sangrur in South and by Jalandhar in North. The topography of the city is alluvial plain. It is the most advanced agricultural district which provides a growing shape of Punjab agriculture. The geography of Ludhiana assembles the flood plain of Sutlej River. The climate of the city is characterized by dryness except a brief spell of monsoon season in very hot summer and a bracing winter. The cold season is appeared from Middle Nov. to Early March having coldest month Dec, Jan respectively. Similarly the hottest month is June as hot season lasts from Mid-March to End-June. July, August and half of Sept. falls into the monsoon season and post Monsoon occupies the Sept and Mid-Nov months. The 70% of total rainfall occurs in the July-Sept. months while 16% of total is appeared in Dec to March and remaining 14% rainfall occurs in the remaining months.

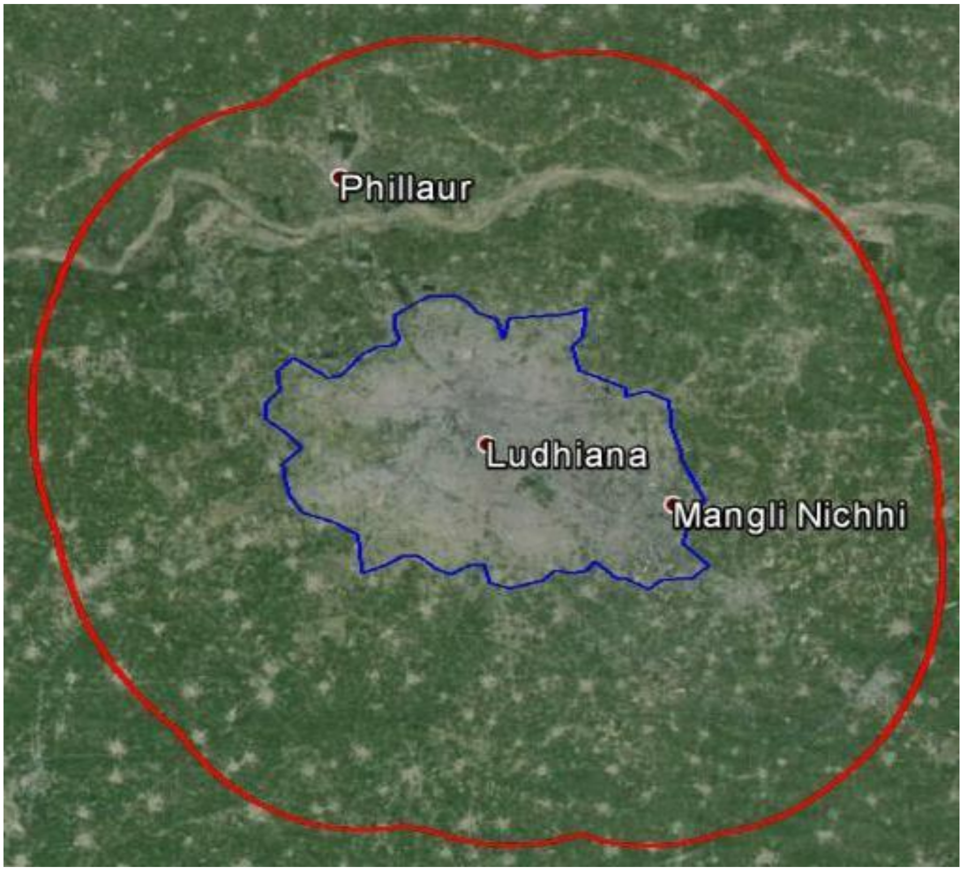


Figure3.6: Google Earth© image of the Ludhiana

3.4. Data Analysis

ArcGIS software is used to analyze the remote sensing data used for present study work. The data analysis by ArcGIS includes the overlaying of vector data layers/feature mask (Shape files of the study area) and raster data layers/input raster layers (LST images, NDVI images), extracting the layers for the corresponding study area by using Spatial analyst tool (Extract By Mask) in tool of ArcGIS. After extraction, the extracted output images have been gone through the Raster Calculator tool of Map algebra of spatial analyst tool. In the raster calculator the output extracted images were multiplied by 0.02 and 0.0001 to obtain the LST and NDVI values respectively. After getting the LST and NDVI values, these images have been gone through by conversion tool (Raster to ASCII) so that these ASCII values can be operational for statistics calculation to find out the correlation in various parameters.

Chapter 4

Result and Discussions

This chapter incorporates about the diurnal surface temperature variations for the study areas. It also includes the seasonal variation of LST during summer, monsoon and winter in day and night respectively. The chapter deals in detail about the LST of required study area in urban and rural classes. This chapter includes the correlation of LST, UHI intensity between MODIS data obtained from AQUA and TERRA satellites. There is also a separate case study regarding the effect of NDVI over the correlations of LST.

4.1. LST Diurnal Patterns

Modern techniques, latest soft wares and thorough research made possible to extract LST information by utilizing remote sensing data of any place. Diurnal patterns of LST has been retrieved for Jaipur and Ahmedabad for day and night time by Aqua and Terra MODIS data for 12 long years from 2003-2015.This includes the thousands of images of the study area. The present document provides detail information of LST daily, seasonally and yearly and establishes a correlation between day and night temperatures.

4.2. Comparison for Jaipur city

The study area for Jaipur city is divided into two zones mainly rural (12 km buffer around Jaipur city) and urban area. The comparison for Jaipur city clearly states the rural temperature during day time is slightly more (1K-3K) than urban temperature during all seasons for all the years from 2003 to 2013 for both aqua and terra. The comparison results for night time depict a just opposite scenario as the urban night time temperature is slightly lesser (3K-4K) than rural temperature for the same season and years. These results show a contradiction to conventional studies and also give clear indications towards the existence of Surface Urban Heat Island Effect in Jaipur. The above phenomenon is cleared by the LST pictures for four random years 2003, 2007, 2011 and 2015 for summer, monsoon and winter season during day and night by aqua and terra. These images are randomly selected for different years for the present study. LST image corresponding to one 8 day period of each month of the year from January to December has been shown in these figures. The pattern of LST for the entire study area, as a whole, does not change significantly throughout the year. It can be seen from the images that LST of urban area is higher than the LST of rural area as maximum red pixels lies within the urban boundary for all the seasons both for aqua and terra data. From the images it can be clearly inferred that eastern part of Jaipur city encounters maximum LST during all the months especially in night time. As we put an emphasis over four images terra day(10.30am), aqua day(01.30pm),terra night(10.30pm) and aqua night(01.30am) for a particular season, it can be clearly visible that urban area remains cool during day time but as time passes urban area gets heated up at night time. During day time rural area is hotter than urban area. The difference between mean temperature between rural and urban area is 1Kelvin for day time both for Aqua & Terra LST but during night time the temperature difference is -3.1Kelvin which shows urban area is slightly warmer than rural areas both for Aqua and Terra LST.

4.3. Seasonal LST variation results for Jaipur City

4.3.1. SUMMER

The temperature ranges approximately from 309-323K for summer season for day time and 290-300K for night time both for Aqua and Terra. The mean diurnal temperature difference is 23.5K for Aqua LST and 18.7K for Terra LST for 2003-15 for summer season. The maximum difference is 4.6K between Aqua and Terra for day temperature and 2.4K for night temperature in summers. The average UHI intensity is 9K, 7.5K, 8K &7.6K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.1.

4.3.2. MONSOON

The temperature ranges approximately from 302-320K for monsoon season for day time and 291-301K for night time both for Aqua and Terra. The mean diurnal temperature difference is 18K for Aqua LST and 14K for Terra LST for 2003-15 for monsoon season which is less than summer. The maximum difference is 4.5K between Aqua and Terra for day temperature and 2.4K for night temperature in monsoons which is similar as summer. The average UHI intensity is 10K, 6K, 9K &5.6K is observed for Aqua day,

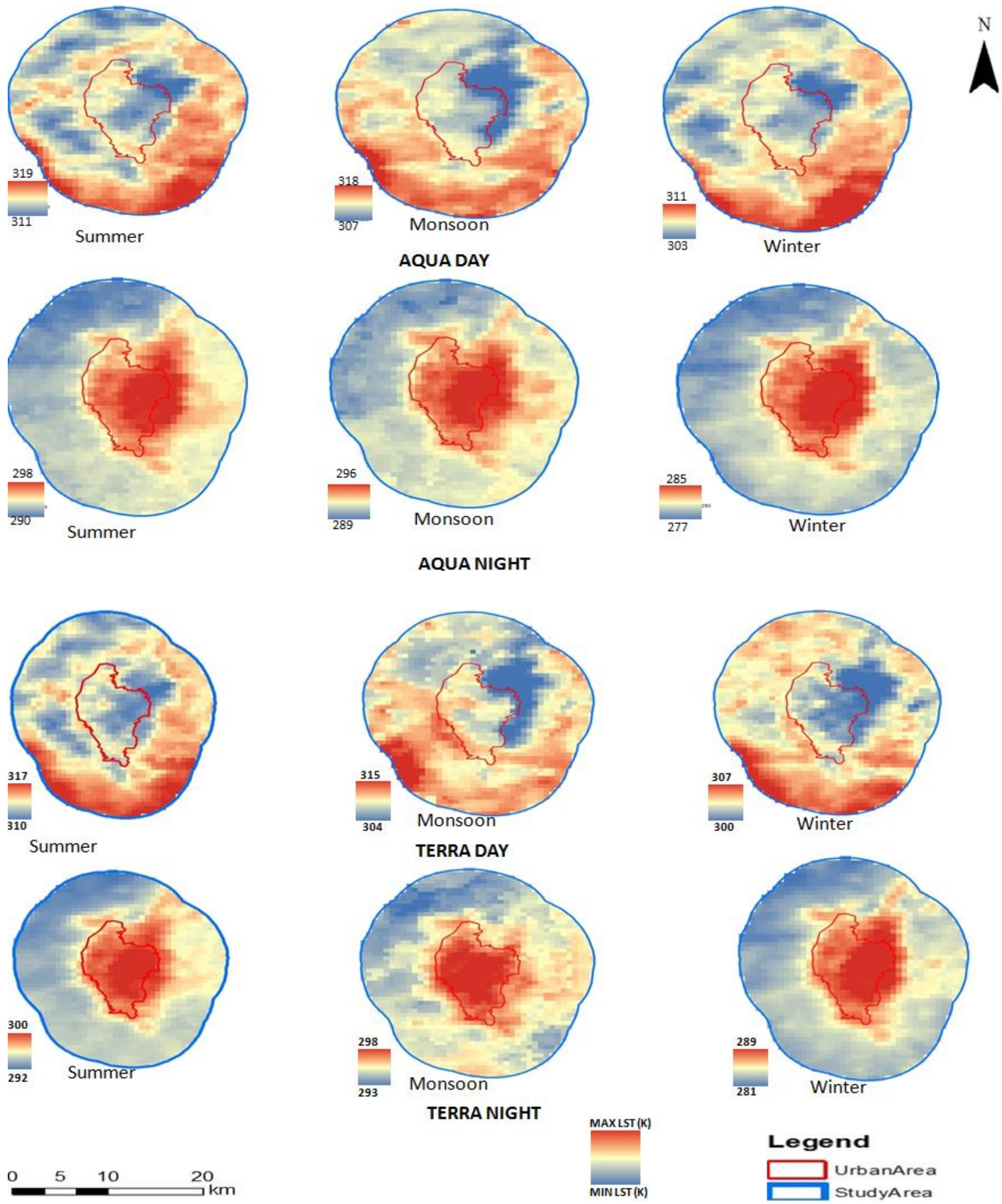


Figure4.1: LST image for study area for summer, monsoon & winter season for day -night by Aqua & Terra for 2003

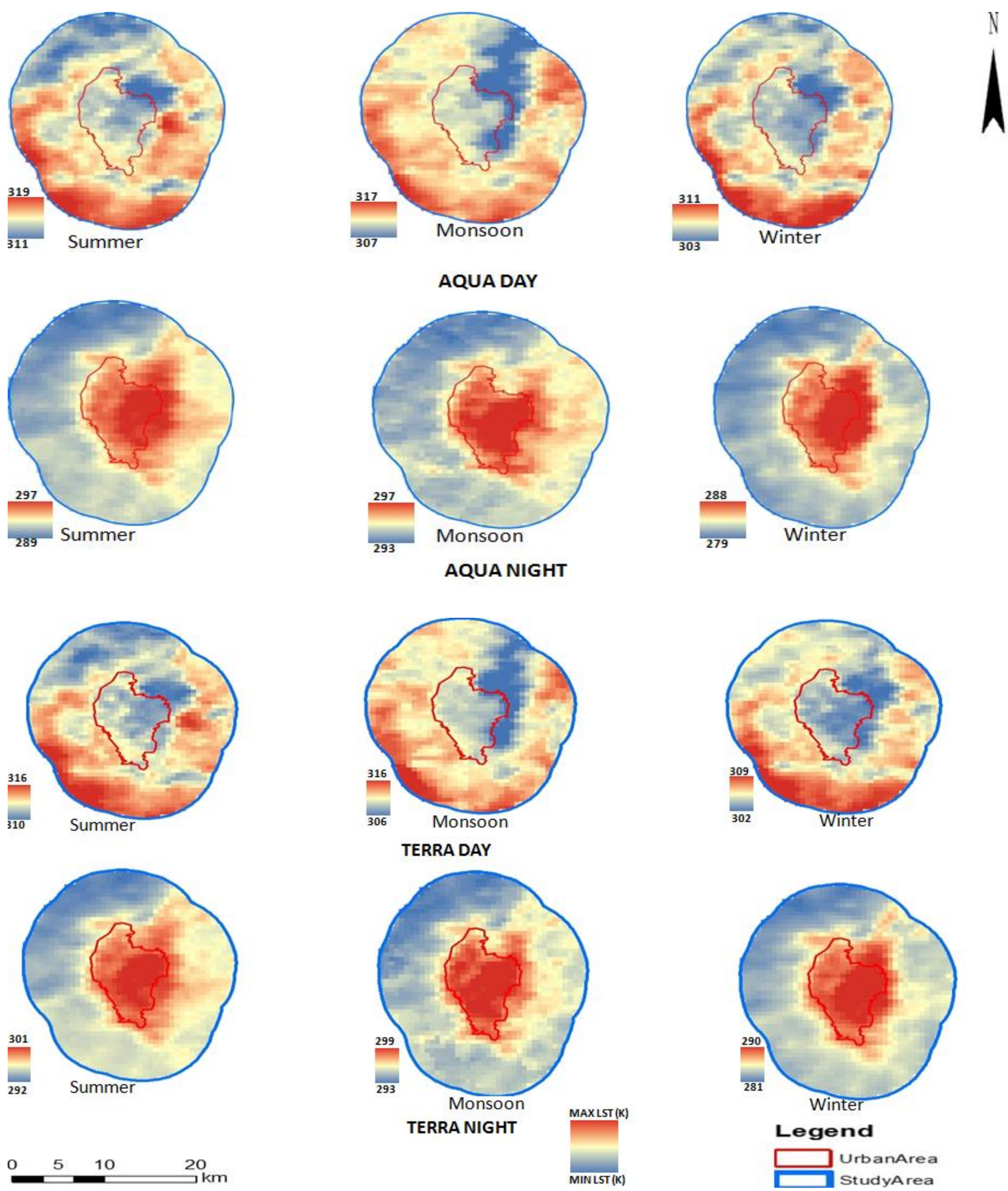


Figure4.2: LST image for Jaipur for summer, monsoon & winter season for day - night by Aqua & Terra for 2007

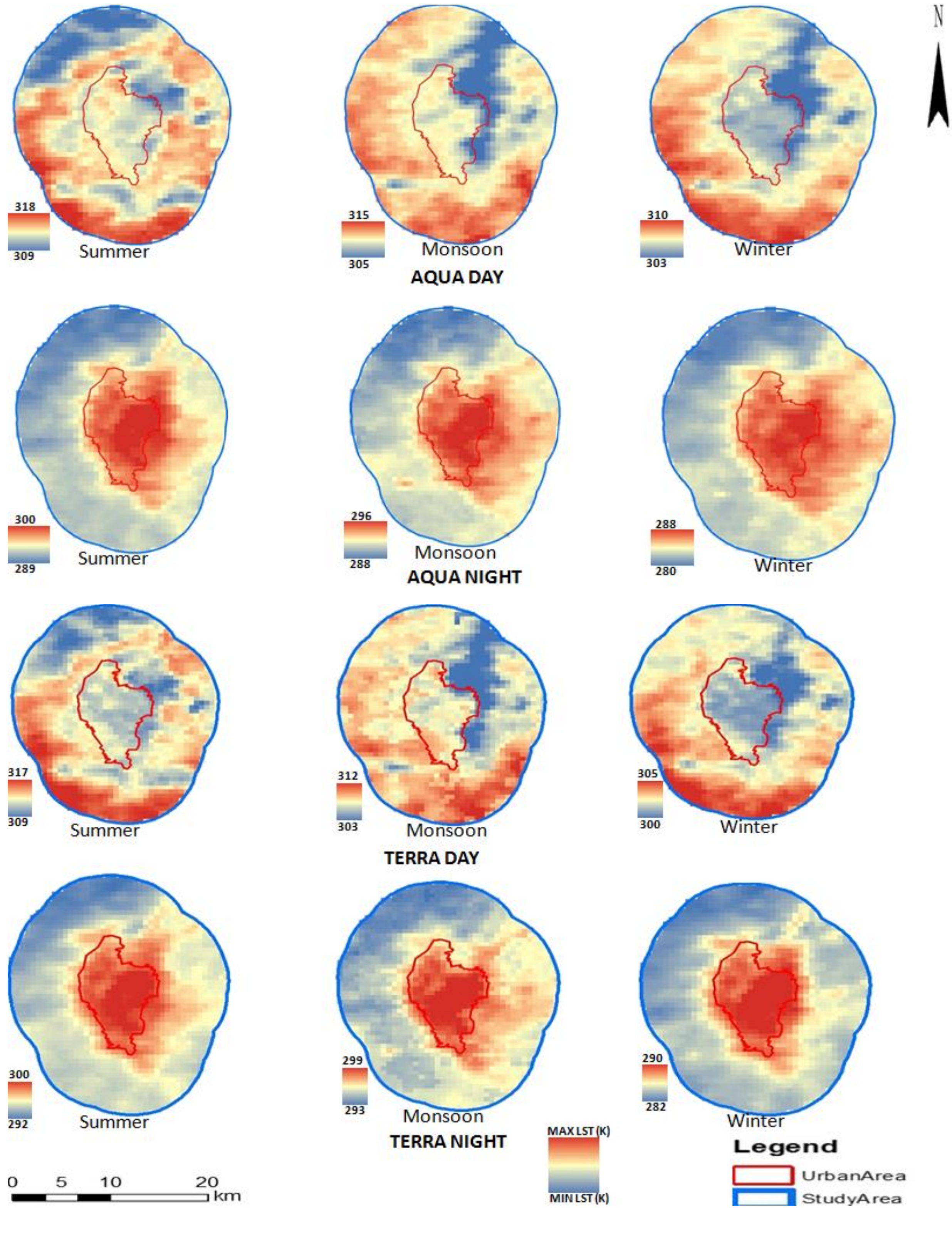


Figure4.3: LST image for Jaipur for summer, monsoon & winter season for day - night by Aqua & Terra for 2011

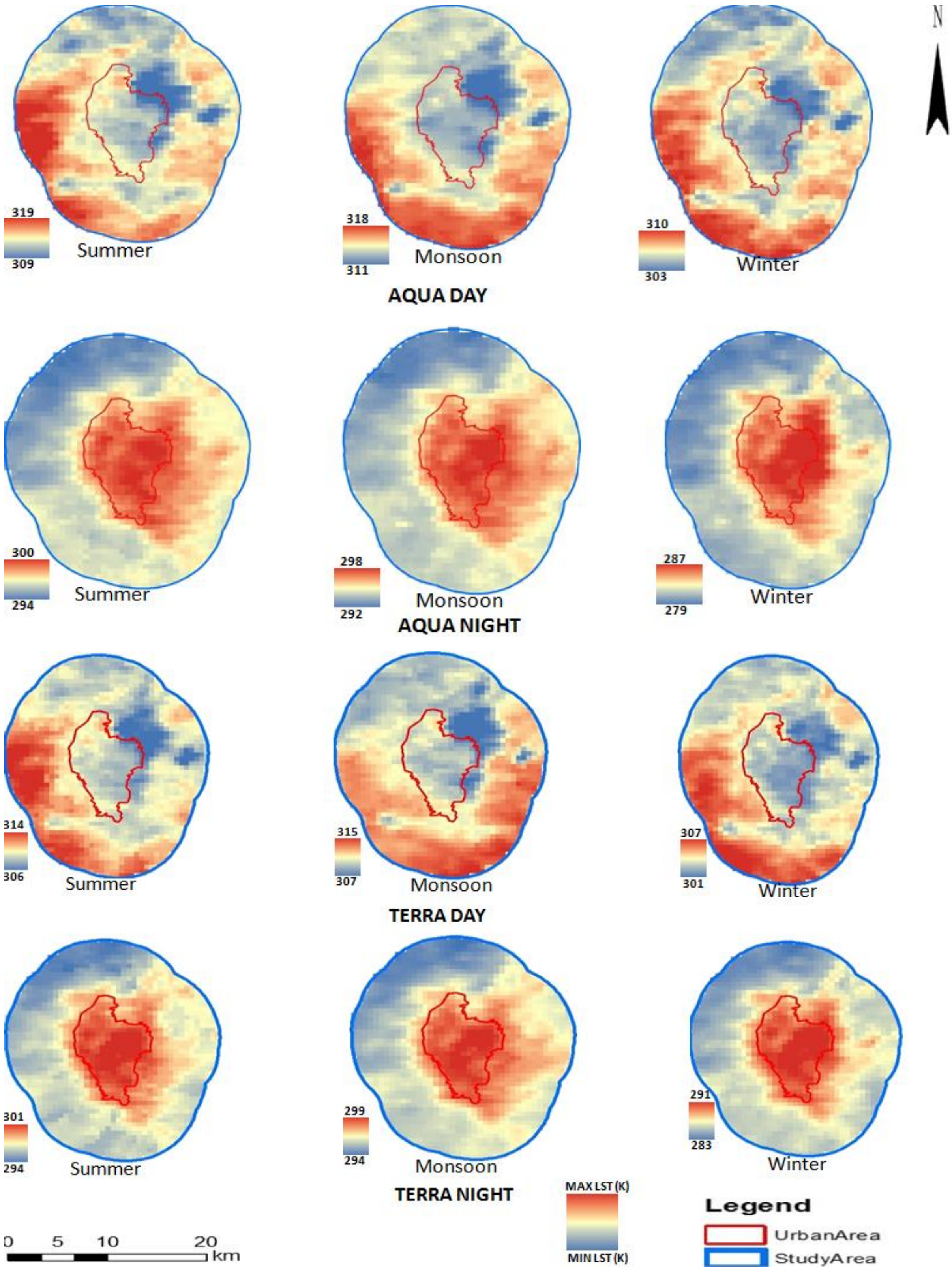


Figure4.4: LST image for Jaipur for summer, monsoon & winter season for day - night by Aqua & Terra for 2015

Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.2.

4.3.3. WINTER

The temperature ranges approximately from 276-312K for winter season for day time and 280-310K for night time both for Aqua and Terra. The mean diurnal temperature difference is 24.7K for Aqua LST and 18.9K for Terra LST for 2003-15 for winter season which is similar to summer but greater than monsoon. The maximum difference is 4.8K between Aqua and Terra for day temperature and 3.1K for night temperature in winters. The average UHI intensity is 9K, 7.5K, 8K &7.6K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.3.

4.3.4. ANNUAL

The temperature ranges approximately from 303-313K for day time and 284-296K for night time both for Aqua and Terra. The mean diurnal temperature difference is 22.5K for Aqua LST and 18.0K for Terra LST. The maximum difference is 5.3K between Aqua and Terra for day temperature and 2.3K for night temperature. The average UHI intensity is 7.8K, 7.5K, 6.8K &7.4K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.4.

Table 4.1: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Jaipur

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	311.3	319.0	315.6	1.4	7.7	290.2	297.4	292.9	1.5	7.2	309.8	317.3	313.5	1.5	7.5	292.3	299.9	295.3	1.7	7.6
2004	313.4	323.1	318.9	1.7	9.7	290.4	298.2	293.4	1.7	7.8	310.4	318.5	314.3	1.5	8.0	292.5	300.2	295.7	1.7	7.6
2005	312.1	322.0	317.7	1.6	10.0	288.7	297.1	291.8	1.9	8.5	310.4	318.7	314.5	1.5	8.3	290.9	298.4	293.9	1.6	7.5
2006	311.9	320.6	317.0	1.3	8.7	290.6	297.3	293.3	1.4	6.7	309.0	315.8	312.4	1.3	6.8	292.1	298.5	294.7	1.4	6.4
2007	311.6	319.6	315.6	1.6	8.0	290.0	297.5	293.0	1.7	7.6	309.8	316.5	312.9	1.4	6.7	291.8	299.1	294.8	1.6	7.4
2008	311.8	321.5	316.8	1.8	9.7	289.0	296.6	291.9	1.7	7.6	309.1	317.6	313.1	1.8	8.5	290.3	298.2	293.4	1.7	7.9
2009	313.3	322.6	318.8	1.7	9.3	289.7	297.7	293.0	1.8	8.0	310.1	318.6	314.3	1.7	8.5	290.8	298.7	294.3	1.8	7.9
2010	314.1	322.8	319.0	1.7	8.7	290.3	298.3	293.7	1.8	8.0	312.3	320.5	316.5	1.7	8.3	292.3	300.6	295.8	1.8	8.3
2011	309.9	318.5	314.4	1.7	8.6	289.8	297.5	292.9	1.7	7.7	309.4	317.5	313.4	1.5	8.0	291.8	300.0	295.3	1.8	8.2
2012	310.4	319.3	315.0	1.7	8.9	289.0	296.8	292.3	1.8	7.8	308.6	316.9	312.6	1.7	8.3	290.6	298.9	294.3	1.8	8.4
2013	312.4	320.1	316.5	1.6	7.7	290.6	298.2	293.6	1.7	7.6	309.9	317.4	314.2	1.5	7.5	292.2	299.8	295.3	1.7	7.7
2014	309.7	319.3	314.3	1.7	9.6	290.6	297.5	293.5	1.6	6.9	308.6	317.2	313.1	1.7	8.6	292.2	299.2	295.2	1.5	7.0
2015	309.9	319.8	315.2	1.6	9.9	290.4	296.6	293.3	1.5	6.3	306.5	314.5	311.0	1.4	8.0	291.9	299.0	294.8	1.5	7.1

Table 4.2: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for monsoon season day-night of Jaipur

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	307.7	318.1	313.8	1.7	10.4	289.6	296.4	292.4	1.4	6.8	303.6	315.1	309.3	1.8	11.5	292.7	297.5	294.8	0.9	4.8
2004	303.3	312.9	309.2	1.5	9.6	292.7	296.9	294.3	0.9	4.2	304.8	313.7	309.2	1.5	8.9	293.2	297.7	295.2	0.9	4.6
2005	305.9	314.8	311.3	1.5	8.9	293.7	298.6	295.7	1.1	4.9	305.4	313.2	310.1	1.3	7.8	294.6	300.2	296.8	1.2	5.6
2006	310.4	320.0	315.8	1.8	9.6	293.2	298.7	295.3	1.1	5.5	308.6	317.8	313.7	1.9	9.2	293.8	300.2	296.3	1.3	6.4
2007	307.2	317.4	313.5	1.7	10.1	293.1	297.7	294.8	1.0	4.6	305.8	315.9	311.1	1.6	10.1	293.1	298.7	295.1	1.2	5.6
2008	306.2	316.4	312.5	1.7	10.2	292.4	298.0	294.6	1.2	5.7	304.2	313.4	309.8	1.6	9.2	293.7	299.6	296.0	1.2	5.9
2009	308.3	318.5	313.4	1.7	10.2	293.9	298.9	296.3	1.1	5.1	306.9	317.2	311.8	2.1	10.2	295.0	300.5	297.4	1.2	5.5
2010	305.3	314.8	310.9	1.5	9.5	291.9	297.6	294.2	1.2	5.8	303.5	310.3	307.7	1.2	6.8	293.7	299.7	296.3	1.2	6.0
2011	305.8	316.0	312.0	1.8	10.2	291.3	298.1	294.4	1.4	6.7	303.1	312.3	308.3	1.6	9.2	293.3	298.7	295.5	1.2	5.4
2012	306.8	316.6	313.1	1.8	9.9	292.0	298.2	294.7	1.3	6.2	304.6	313.7	310.5	1.6	9.1	293.5	299.5	296.0	1.2	5.9
2013	302.0	313.2	309.2	1.6	11.2	293.0	298.4	295.4	1.0	5.4	301.9	310.4	307.4	1.4	8.5	294.4	299.2	296.2	1.0	4.9
2014	305.2	314.1	311.3	1.4	8.9	293.2	299.3	295.9	1.3	6.0	304.5	311.7	309.4	1.2	7.2	294.8	300.3	297.3	1.2	5.5
2015	311.2	319.6	316.1	1.6	8.4	292.9	298.7	295.5	1.3	5.8	307.3	315.3	312.0	1.5	8.0	293.7	300.5	296.9	1.5	6.8

Table 4.3: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) winter day-night of Jaipur

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	303.8	311.4	307.5	1.3	7.6	277.9	285.7	280.6	1.7	7.8	300.0	306.6	303.8	1.2	6.6	280.6	289.3	283.7	1.9	8.7
2004	301.2	310.1	306.0	1.4	8.9	278.8	287.9	282.1	2.0	9.1	298.5	305.7	302.2	1.3	7.2	281.1	289.9	284.2	1.9	8.8
2005	302.8	310.6	306.9	1.4	7.8	276.8	286.1	280.2	2.0	9.3	299.1	306.0	302.2	1.2	6.9	280.2	289.2	283.5	2.0	9.0
2006	304.8	311.1	307.9	1.2	6.4	278.6	288.1	282.2	2.1	9.5	303.4	309.9	306.3	1.3	6.5	280.4	289.3	283.6	2.0	8.8
2007	303.8	311.3	307.4	1.3	7.5	279.1	288.7	282.5	2.2	9.6	302.2	308.7	305.1	1.2	6.6	281.1	290.2	284.5	1.9	9.1
2008	303.8	311.3	307.8	1.4	7.5	278.3	287.9	281.7	2.2	9.6	301.4	307.9	304.5	1.3	6.6	280.8	290.0	284.2	2.0	9.2
2009	304.6	312.1	308.0	1.4	7.6	279.3	288.2	282.6	2.0	8.9	301.6	307.6	304.4	1.2	6.0	282.1	290.7	285.4	1.9	8.7
2010	301.4	306.9	304.1	1.0	5.4	279.9	287.7	282.9	1.8	7.8	298.3	303.1	300.5	0.9	4.8	281.9	289.4	284.8	1.6	7.5
2011	303.2	310.7	307.6	1.3	7.5	280.1	288.6	283.2	1.9	8.5	299.8	305.4	302.8	1.1	5.6	282.1	290.2	285.1	1.8	8.1
2012	301.9	309.4	306.5	1.4	7.5	278.4	287.3	281.5	2.1	8.9	299.9	306.2	303.4	1.3	6.3	280.6	288.9	283.8	1.9	8.4
2013	301.4	308.6	305.5	1.2	7.2	279.3	287.6	282.3	1.9	8.3	299.4	305.7	302.7	1.3	6.3	281.6	289.7	284.6	1.8	8.1
2014	300.7	309.2	305.4	1.5	8.5	279.5	287.7	282.5	1.9	8.2	299.3	305.4	302.4	1.2	6.1	282.1	289.7	285.0	1.7	7.6
2015	303.6	310.5	307.5	1.3	6.8	279.5	287.8	282.7	1.9	8.3	301.4	307.4	304.4	1.2	6.0	283.1	290.5	286.2	1.6	7.5

Table 4.4: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) annually day-night of Jaipur

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	308.6	316.0	312.7	1.3	7.4	285.6	292.7	288.2	1.5	7.1	305.3	312.9	309.1	1.4	7.7	287.5	295.0	290.3	1.7	7.5
2004	307.7	316.5	312.7	1.4	8.8	286.8	294.0	289.5	1.6	7.2	303.6	310.9	307.4	1.3	7.4	288.5	295.6	291.2	1.5	7.1
2005	307.9	316.3	312.8	1.4	8.4	285.6	293.3	288.5	1.7	7.8	304.8	312.1	308.5	1.3	7.3	287.3	294.9	290.1	1.7	7.6
2006	308.5	315.8	312.5	1.2	7.3	286.1	293.7	289.0	1.6	7.6	306.7	313.3	309.9	1.3	6.5	287.7	294.9	290.4	1.6	7.2
2007	306.8	314.5	310.8	1.3	7.7	286.2	293.9	289.1	1.7	7.7	306.0	312.8	309.3	1.3	6.7	287.6	295.2	290.5	1.6	7.6
2008	307.7	315.8	312.1	1.5	8.1	284.5	292.7	287.5	1.8	8.2	305.0	312.2	308.6	1.4	7.2	286.2	294.3	289.3	1.8	8.1
2009	309.1	317.0	313.4	1.5	7.9	287.2	294.5	290.1	1.7	7.4	306.2	313.5	309.6	1.5	7.3	289.1	296.4	292.2	1.6	7.3
2010	307.0	313.5	310.5	1.2	6.5	286.6	293.9	289.5	1.6	7.3	304.8	310.2	307.5	1.1	5.5	288.3	295.7	291.3	1.6	7.5
2011	306.0	313.3	309.9	1.3	7.3	285.3	293.2	288.4	1.8	7.9	304.8	311.3	308.2	1.2	6.5	287.7	295.3	290.7	1.7	7.6
2012	306.6	314.1	310.8	1.4	7.5	285.1	293.0	288.2	1.8	7.9	304.5	311.3	308.1	1.4	6.8	286.9	294.8	290.2	1.7	7.9
2013	306.1	313.2	310.2	1.3	7.2	285.3	292.9	288.2	1.7	7.6	305.1	311.4	308.5	1.3	6.3	287.6	294.9	290.5	1.6	7.3
2014	304.3	312.5	309.1	1.4	8.2	287.4	294.6	290.3	1.6	7.1	304.0	310.6	307.6	1.3	6.6	288.4	295.3	291.2	1.5	6.9
2015	308.0	316.6	312.7	1.5	8.5	287.3	293.8	290.0	1.6	6.6	304.7	310.9	308.2	1.3	6.2	289.3	296.4	292.3	1.5	7.1

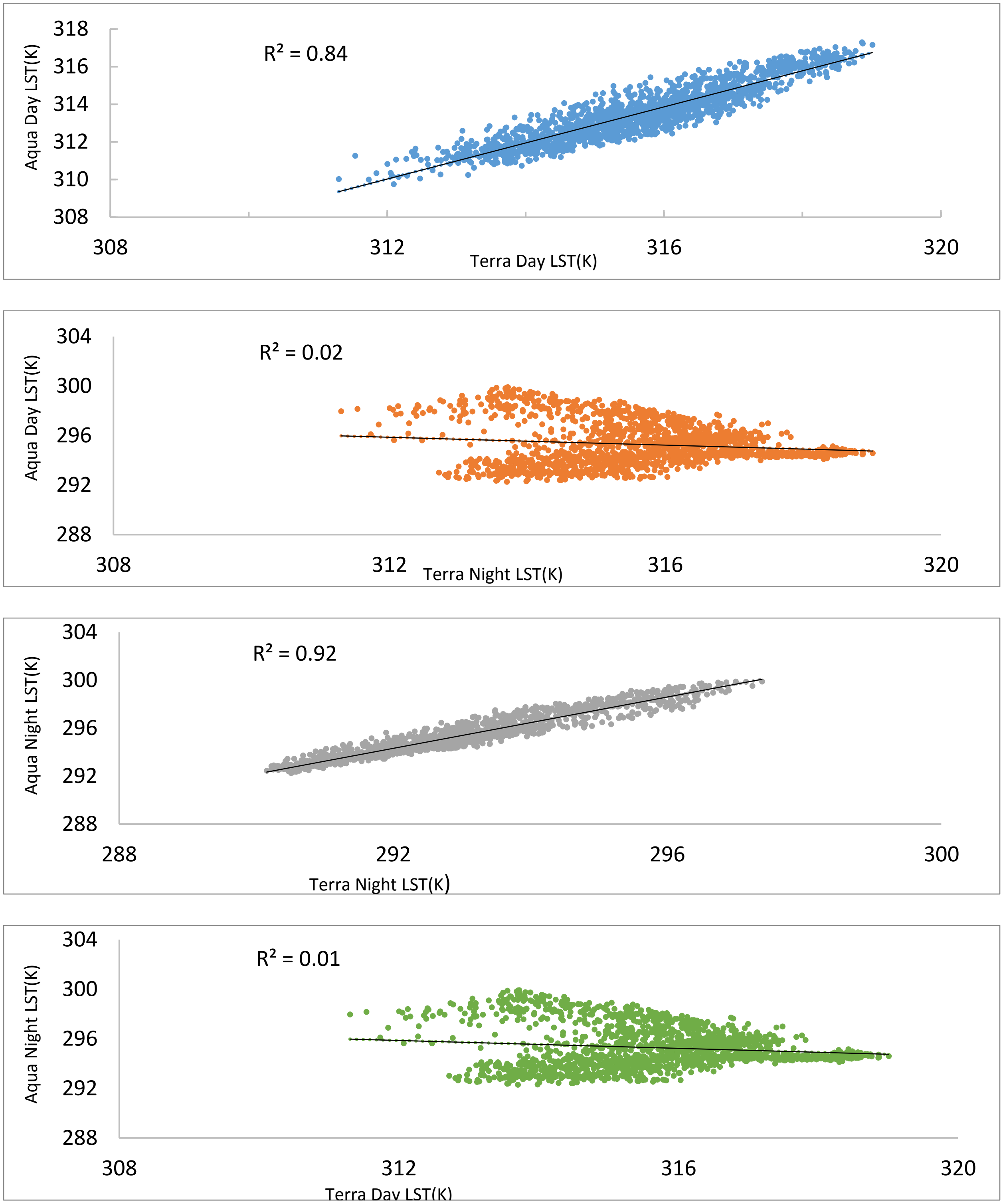


Figure 4.5: Scatter plot between Aqua and Terra LST 8-day data for summer season for Jaipur of 2003

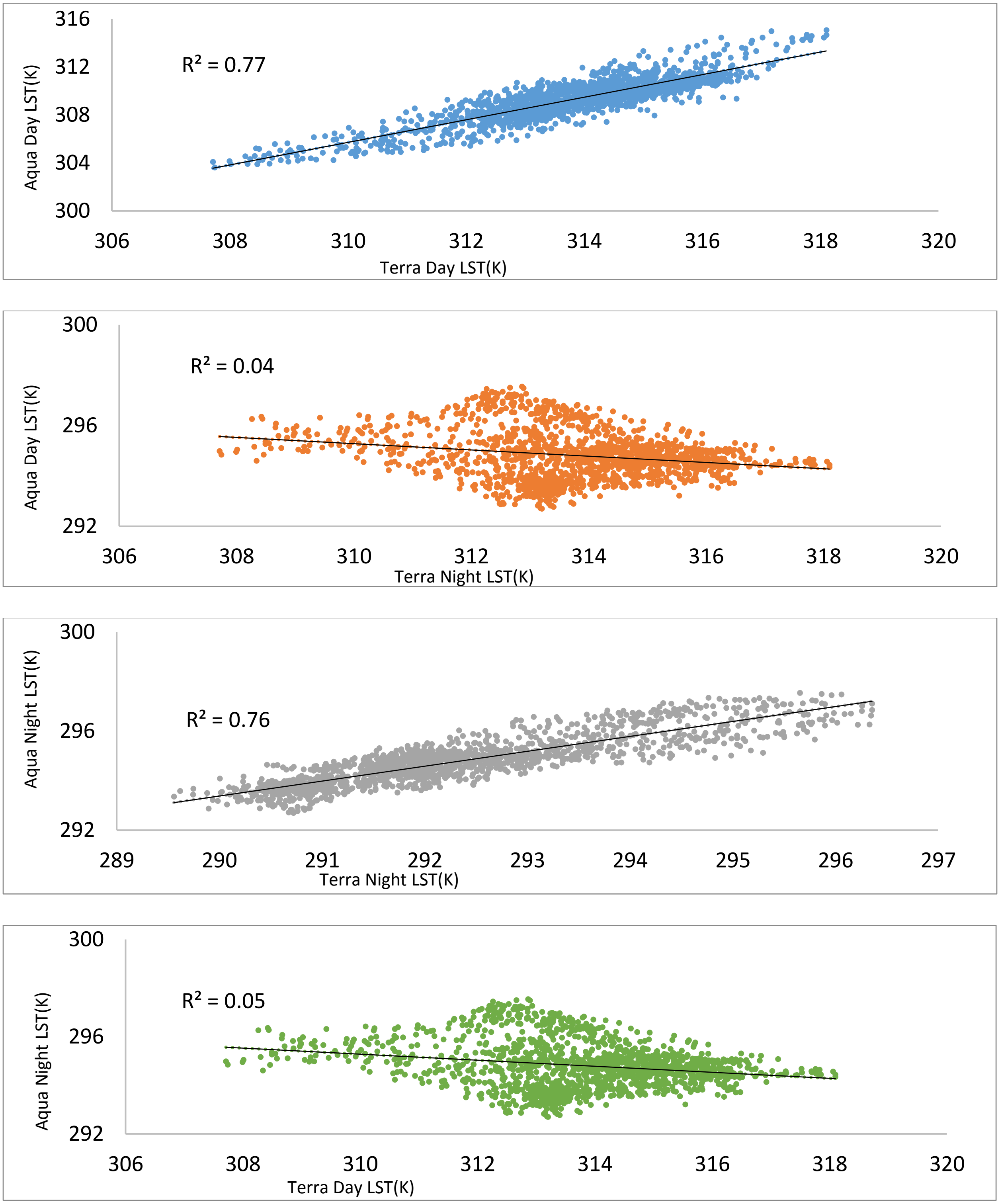


Figure 4.6: Scatter plot between Aqua and Terra LST 8-day data for monsoon season for Jaipur of 2003

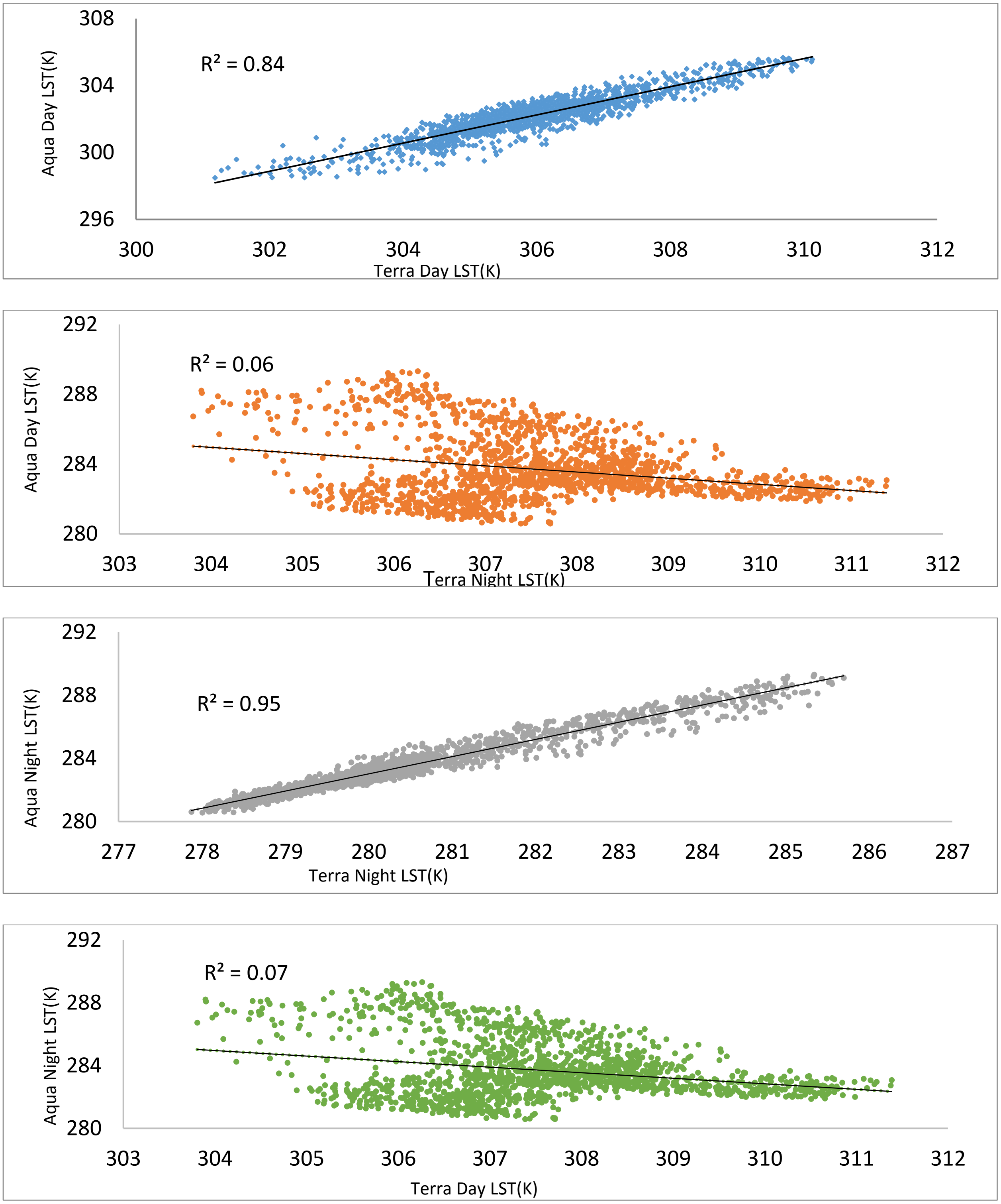


Figure 4.7: Scatter plot between Aqua and Terra LST 8-day data for winter season for Jaipur of 2003

4.4. Analysis of R^2 results for Jaipur city

The R^2 values for Aqua-Terra derived day-night LST (K) for different seasons are listed in the table 4.5. During day time the correlation range between Aqua LST & Terra LST is obtained 0.82 - 0.88 for summer season, 0.52-0.87 (highest variation) for monsoon, 0.63-0.90 for winter and 0.80-0.89 annually for 2003-2015. The highest R^2 value is achieved for winter for 2003 year, 0.95. The winter R^2 values are greater than summer and monsoon R^2 values which shows there is existence of uniform temperature (lesser variation) in winters at night time which shows the possibility of temperature uniformity is 93. The Aqua Day LST vs Terra night LST and Aqua Night LST vs Terra Day LST correlation values (R^2) almost remains same ($0.28< R^2$) for the entire seasons for 2003-15 as there is large diurnal temperature variation in day and night. It is significant that there is no temperature uniformity persists day-night. During night time the correlation range between Aqua LST & Terra LST is obtained 0.92 - 0.94 for summer season, 0.76-0.95 for monsoon, 0.72-0.95 for winter and 0.92-0.94 annually for 2003-2015. The Aqua Night LST & Terra Night LST correlation values are greater than for day values which shows there is no much temperature variation in night time during all the seasons.

The scatter plots for R^2 values are shown in figure 4.5, 4.6 & 4.7 respectively for the summer, monsoon and winter seasons. For the detailed investigational analysis we divided Jaipur study area into urban region and its surrounding rural region (12kms buffer around the city). The study involves the diurnal, seasonal and yearly analysis of day-night LST (K) for rural and urban parts separately.

4.5. Seasonal LST variation results for Jaipur Rural area

4.5.1. Summer

The temperature ranges approximately from 306-323K for summer season for day time and 288-300K for night time both for Aqua and Terra. The mean diurnal temperature difference is 24K for Aqua LST and 19K for Terra LST for 2003-15 for summer season. The maximum difference is 4.6K for 2006 between Aqua and Terra for day temperature and 2.4K for 2011for night temperature in summers.

Table 4.5: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the different seasons for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR JAIPUR CITY FOR DIFFERENT SEASON																
	SUMMER				MONSOON				WINTER				ANNUAL			
	DAY		NIGHT		DAY		NIGHT		DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.80	0.04	0.94	0.13	0.77	0.05	0.76	0.11	0.53	0.07	0.95	0.43	0.80	0.04	0.94	0.13
2004	0.86	0.03	0.94	0.08	0.52	0.02	0.85	0.02	0.84	0.00	0.72	0.29	0.86	0.03	0.94	0.08
2005	0.87	0.10	0.92	0.17	0.80	0.08	0.87	0.73	0.86	0.14	0.92	0.22	0.87	0.10	0.92	0.17
2006	0.84	0.18	0.94	0.17	0.87	0.10	0.91	0.13	0.84	0.17	0.93	0.20	0.84	0.18	0.94	0.17
2007	0.87	0.10	0.93	0.21	0.83	0.17	0.90	0.21	0.83	0.17	0.92	0.38	0.87	0.10	0.93	0.21
2008	0.88	0.10	0.92	0.21	0.84	0.08	0.90	0.17	0.89	0.29	0.92	0.41	0.88	0.10	0.92	0.21
2009	0.82	0.02	0.94	0.11	0.51	0.03	0.92	0.07	0.82	0.04	0.91	0.17	0.82	0.02	0.94	0.11
2010	0.85	0.05	0.93	0.13	0.80	0.00	0.93	0.00	0.80	0.07	0.92	0.22	0.85	0.05	0.93	0.13
2011	0.84	0.04	0.94	0.23	0.80	0.06	0.91	0.06	0.86	0.32	0.92	0.41	0.84	0.04	0.94	0.23
2012	0.89	0.12	0.94	0.22	0.84	0.10	0.93	0.07	0.90	0.35	0.93	0.48	0.89	0.12	0.94	0.22
2013	0.86	0.07	0.94	0.24	0.69	0.04	0.90	0.00	0.85	0.20	0.93	0.39	0.86	0.07	0.94	0.24
2014	0.87	0.03	0.93	0.19	0.85	0.00	0.86	0.00	0.86	0.07	0.92	0.31	0.87	0.03	0.93	0.19
2015	0.87	0.11	0.92	0.21	0.81	0.13	0.95	0.02	0.85	0.11	0.90	0.29	0.87	0.11	0.92	0.21

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

The maximum difference is 4.6K for 2006 between Aqua and Terra for day temperature and 2.4K for 2011for night temperature in summers. The average UHI intensity is 8.9K, 6.8K, 7.9K &6.6K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.6.

4.5.2. Monsoon

The temperature ranges approximately from 301-320K for monsoon season for day time and 289-299K for night time both for Aqua and Terra. The mean diurnal temperature difference is 18K for Aqua LST and 14K for Terra LST for 2003-15 for monsoon. The maximum difference is 4.7K between Aqua and Terra for day temperature and 2.4K for night temperature in monsoon both for 2003. The average UHI intensity is 9.8K, 5.1K, 8.9K & 4.6K is observed for Aqua day, Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.7.

4.5.3. Winter

The temperature ranges approximately from 298-312K for winter season for day time and 277-290K for night time both for Aqua and Terra. The mean diurnal temperature difference is 25K for Aqua LST and 20K for Terra LST for 2003-15 for winter season which is greater than summer & monsoon. The maximum difference is 4.8K for 2011 between Aqua and Terra for day temperature and 2.7K for 2009 for night temperature in winters. The average UHI intensity is 7.4K, 8.3K, 6.3K &7.3K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.8.

4.5.4. Annual

The temperature ranges approximately from 303-311K for day time and 285-296K for night time both for Aqua and Terra. The mean diurnal temperature difference is 25K for Aqua LST and 20.0K for Terra LST. The maximum difference is 3.5K between Aqua and Terra for day temperature and 2.6K for night temperature both for 2003. The average UHI intensity is 8.7K, 6.7K, 7.7K & 6.2K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.9.

Table 4.6: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Rural Jaipur

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity
2003	311.3	319.0	315.7	1.4	7.7	290.2	296.7	292.6	1.3	6.5	309.8	317.3	313.7	1.5	7.5	292.3	299.0	294.8	1.3	6.7
2004	313.4	323.1	319.0	1.7	9.7	290.4	297.1	293.0	1.5	6.8	310.4	318.5	314.5	1.6	8.0	292.5	299.2	295.2	1.3	6.7
2005	312.1	322.0	317.9	1.6	10.0	288.7	296.4	291.4	1.6	7.7	310.4	318.7	314.7	1.5	8.3	290.9	297.4	293.4	1.2	6.6
2006	312.0	320.6	317.2	1.3	8.5	290.6	296.6	293.0	1.2	6.0	309.0	315.8	312.6	1.3	6.8	292.1	297.5	294.3	1.1	5.5
2007	311.6	319.6	315.8	1.6	8.0	290.0	296.8	292.6	1.4	6.8	309.8	316.5	313.1	1.4	6.7	291.8	298.0	294.4	1.2	6.2
2008	312.0	321.5	316.9	1.9	9.5	289.0	296.0	291.5	1.4	7.0	309.1	317.6	313.3	1.8	8.5	290.3	297.2	292.9	1.3	6.9
2009	314.0	322.6	319.1	1.6	8.6	289.7	297.0	292.6	1.5	7.3	310.1	318.6	314.5	1.7	8.5	290.8	297.7	293.8	1.4	6.9
2010	314.1	322.8	319.2	1.7	8.7	290.3	297.7	293.3	1.5	7.4	312.3	320.5	316.8	1.6	8.3	292.3	299.6	295.3	1.5	7.2
2011	309.9	318.5	314.5	1.8	8.6	289.8	296.6	292.4	1.4	6.8	309.4	317.5	313.6	1.6	8.0	291.8	298.8	294.8	1.4	7.0
2012	310.4	319.3	315.2	1.8	8.9	289.0	296.2	291.9	1.5	7.2	308.6	316.9	312.8	1.8	8.3	290.6	297.9	293.8	1.4	7.3
2013	312.4	320.1	316.6	1.7	7.7	290.6	297.4	293.2	1.4	6.8	309.9	317.4	314.3	1.5	7.5	292.2	298.9	294.9	1.3	6.7
2014	309.7	319.3	314.5	1.8	9.6	290.6	296.7	293.1	1.3	6.2	308.6	317.2	313.3	1.7	8.6	292.2	298.3	294.8	1.2	6.1
2015	309.9	319.8	315.3	1.6	9.9	290.4	296.1	292.9	1.2	5.7	306.5	314.5	311.1	1.5	8.0	291.9	297.7	294.4	1.2	5.8

Table 4.7: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) for monsoon season day-night of Rural Jaipur

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	307.7	318.1	314.0	1.7	10.4	289.6	296.2	292.0	1.1	6.7	303.6	315.1	309.3	1.9	11.5	292.7	296.7	294.5	0.7	4.0
2004	303.3	312.9	309.2	1.5	9.6	292.7	296.5	294.1	0.7	3.8	304.8	313.7	309.2	1.6	8.9	293.2	296.8	294.9	0.7	3.7
2005	305.9	314.8	311.4	1.5	8.9	293.7	298.1	295.5	1.0	4.3	305.4	313.2	310.2	1.4	7.8	294.6	299.3	296.4	0.9	4.7
2006	310.4	320.0	316.0	1.8	9.6	293.2	298.1	295.1	0.9	4.9	308.6	317.8	314.0	1.8	9.2	293.8	298.8	296.0	1.0	5.0
2007	307.2	317.4	313.7	1.7	10.1	293.1	297.0	294.5	0.7	3.9	305.8	315.9	311.3	1.7	10.1	293.1	297.8	294.7	0.8	4.6
2008	306.2	316.4	312.7	1.7	10.2	292.4	297.4	294.4	0.9	5.1	304.2	313.4	310.0	1.6	9.2	293.7	298.2	295.6	0.9	4.5
2009	308.3	318.5	313.5	1.8	10.2	293.9	298.7	296.1	0.9	4.8	306.9	317.2	312.1	2.1	10.2	295.0	299.6	297.1	0.9	4.6
2010	305.3	314.8	310.9	1.6	9.5	291.9	297.0	293.9	1.0	5.1	303.5	310.3	307.6	1.2	6.8	293.7	298.5	296.0	0.8	4.8
2011	305.8	316.0	312.1	1.9	10.2	291.3	297.6	294.0	1.2	6.3	303.1	312.3	308.3	1.7	9.2	293.3	297.8	295.2	0.9	4.5
2012	306.8	316.6	313.2	1.8	9.9	292.0	297.4	294.3	1.0	5.4	304.6	313.7	310.5	1.6	9.1	293.5	298.4	295.7	0.9	4.8
2013	302.0	312.7	309.0	1.6	10.6	293.0	297.8	295.2	0.7	4.7	301.9	310.4	307.4	1.4	8.5	294.4	298.4	295.9	0.7	4.1
2014	305.2	314.1	311.3	1.4	8.9	293.2	298.8	295.5	1.1	5.6	304.5	311.7	309.3	1.2	7.2	294.8	299.8	297.0	1.0	5.0
2015	311.2	319.6	316.3	1.5	8.4	292.9	298.1	295.2	1.1	5.3	307.3	315.3	312.1	1.5	8.0	293.7	299.4	296.5	1.2	5.7

Table 4.8: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for winter season day-night of Rural Jaipur

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	303.8	311.4	307.6	1.4	7.6	277.9	285.4	280.2	1.3	7.5	300.0	306.6	303.9	1.1	6.6	280.6	288.2	283.2	1.4	7.7
2004	301.2	310.1	306.1	1.4	8.9	278.8	287.6	281.6	1.6	8.8	298.5	305.7	302.4	1.3	7.2	281.1	288.8	283.7	1.4	7.7
2005	302.8	310.6	307.0	1.4	7.8	276.8	285.9	279.7	1.6	9.1	299.1	306.0	302.4	1.3	6.9	280.2	288.2	283.0	1.5	7.9
2006	304.8	311.1	308.1	1.2	6.4	278.6	287.6	281.7	1.7	8.9	303.4	309.9	306.5	1.2	6.5	280.4	288.2	283.0	1.5	7.7
2007	303.8	311.3	307.6	1.2	7.5	279.1	288.0	282.0	1.7	8.9	302.2	308.7	305.3	1.1	6.6	281.1	289.1	284.0	1.4	8.0
2008	303.8	311.3	308.0	1.3	7.5	278.3	287.4	281.2	1.7	9.1	301.4	307.9	304.8	1.2	6.6	280.8	288.9	283.6	1.5	8.1
2009	304.6	312.1	308.2	1.5	7.5	279.3	287.5	282.1	1.6	8.2	301.6	307.6	304.6	1.2	6.0	282.1	289.6	284.8	1.4	7.5
2010	301.4	306.9	304.2	1.0	5.4	279.9	287.3	282.4	1.4	7.4	298.3	303.1	300.6	0.9	4.8	281.9	288.5	284.3	1.2	6.5
2011	303.2	310.7	307.8	1.3	7.5	280.1	288.0	282.7	1.5	8.0	299.8	305.4	303.0	1.1	5.6	282.1	289.2	284.6	1.3	7.1
2012	301.9	309.4	306.7	1.3	7.5	278.4	286.5	281.0	1.6	8.1	299.9	306.2	303.6	1.2	6.3	280.6	288.0	283.2	1.4	7.4
2013	301.4	308.6	305.6	1.3	7.2	279.3	287.2	281.8	1.5	7.9	299.4	305.7	302.9	1.3	6.3	281.6	288.5	284.1	1.3	6.9
2014	300.7	309.2	305.5	1.5	8.5	279.5	287.3	282.0	1.5	7.9	299.3	305.4	302.6	1.2	6.1	282.1	288.7	284.6	1.2	6.5
2015	303.6	310.5	307.7	1.3	6.8	279.5	287.2	282.3	1.6	7.7	301.4	307.4	304.6	1.2	6.0	283.1	289.4	285.7	1.2	6.4

Table 4.9: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) annually day-night of Rural Jaipur

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity
2003	307.6	316.2	312.5	1.5	8.6	285.9	292.8	288.3	1.2	6.9	304.5	313.0	309.0	1.5	8.5	288.5	294.6	290.9	1.1	6.1
2004	305.9	315.4	311.5	1.5	9.4	287.3	293.7	289.6	1.3	6.4	304.6	312.6	308.7	1.5	8.0	288.9	294.9	291.3	1.1	6.0
2005	306.9	315.8	312.1	1.5	8.9	286.4	293.5	288.9	1.4	7.1	305.0	312.6	309.1	1.4	7.7	288.6	295.0	291.0	1.2	6.4
2006	309.1	317.2	313.8	1.4	8.2	287.5	294.1	289.9	1.3	6.6	307.0	314.5	311.0	1.5	7.5	288.8	294.8	291.1	1.2	6.0
2007	307.5	316.1	312.3	1.5	8.6	287.4	293.9	289.7	1.3	6.5	305.9	313.7	309.9	1.4	7.8	288.7	294.9	291.0	1.2	6.3
2008	307.4	316.4	312.5	1.7	9.1	286.5	293.6	289.0	1.4	7.1	304.9	313.0	309.3	1.6	8.1	288.3	294.8	290.7	1.2	6.5
2009	309.0	317.7	313.6	1.6	8.8	287.6	294.4	290.2	1.4	6.8	306.2	314.5	310.4	1.6	8.3	289.3	295.7	291.9	1.3	6.4
2010	306.9	314.8	311.5	1.4	7.9	287.4	294.0	289.9	1.3	6.6	304.7	311.3	308.3	1.3	6.6	289.3	295.5	291.9	1.2	6.2
2011	306.3	315.1	311.5	1.7	8.8	287.1	294.1	289.7	1.4	7.0	304.1	311.8	308.3	1.4	7.6	289.1	295.3	291.5	1.2	6.2
2012	306.4	315.1	311.7	1.6	8.7	286.5	293.4	289.1	1.4	6.9	304.4	312.3	309.0	1.5	7.9	288.2	294.7	290.9	1.2	6.5
2013	305.3	313.8	310.4	1.5	8.5	287.6	294.1	290.1	1.2	6.5	303.7	311.2	308.2	1.4	7.4	289.4	295.3	291.6	1.1	5.9
2014	305.2	314.2	310.4	1.6	9.0	287.8	294.3	290.2	1.3	6.5	304.2	311.5	308.4	1.4	7.3	289.7	295.6	292.1	1.1	5.9
2015	308.2	316.6	313.1	1.5	8.4	287.6	293.8	290.1	1.3	6.2	305.0	312.4	309.3	1.4	7.3	289.6	295.5	292.2	1.2	6.0

4.6. Seasonal LST variation results for Jaipur Urban area

4.6.1. Summer

The temperature ranges approximately from 308-320K for summer season for day time and 291-300K for night time both for Aqua and Terra. The mean diurnal temperature difference is 20Kfor Aqua LST and 15Kfor Terra LST for 2003-15 for summer season. The maximum difference is 4.5K for 2009 between Aqua and Terra for day temperature and 2.7K for 2011 for night temperature in summers. The average UHI intensity is 5.8K, 4.7K, 3.3K & 4.3K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.10.

4.6.2 .Monsoon

The temperature ranges approximately from 303-316K for monsoon season for day time and 292-301K for night time both for Aqua and Terra. The mean diurnal temperature difference is 15.2Kfor Aqua LST and 11.5Kfor Terra LST for 2003-15 for monsoon season. The maximum difference is 3.7K for 2003 between Aqua and Terra for day temperature and 2.2K for2010 for night temperature in monsoons. The average UHI intensity is5.9K, 3.4K, 4.9K & 3.2K is observed for Aqua day, Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.11.

4.6.3. Winter

The temperature ranges approximately from 298-308K for winter season for day time and 279-290K for night time both for Aqua and Terra. The mean diurnal temperature difference is 20.6Kfor Aqua LST and 14.7Kfor Terra LST for 2003-15 for winter season. The maximum difference is 4.6K for 2005 & 2011 between Aqua and Terra for day temperature and 3.7K for 2005 for night temperature in winters. The average UHI intensity is 4K, 5.6K, 3K & 4.9K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.12.

4.6.4. Annual

The temperature ranges approximately from 304-314K for day time and 288-297K for night time both for Aqua and Terra. The mean diurnal temperature difference is 18.6Kfor Aqua LST and 13.7Kfor Terra LST. The maximum difference is 3.9K for 2009 between Aqua and Terra for day temperature and 2.8K for 2003 for night temperature. The average UHI intensity is 5.2K, 4.5K, 3.8K & 4.1K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.13.

4.7. Comparison of results for rural, urban and composite area

The average day and night temperature ranges remains almost same for all three areas for all three seasons. The temperature ranges 306-323K, 301-320K, 276-312K for day time and 288-300K, 291-301K, 277-300K for night time respectively for summer, monsoon and winter seasons. Aqua derived mean diurnal temperature difference is observed greater than terra derived. The diurnal temperature difference is highest for winters and lowest for summers. The rural area diurnal temperature difference is greater than urban one. The LST difference between aqua and terra derived is found highest during day time in outskirts area of Jaipur in comparison of night time and urban area. The LST difference is highest in winter and lowest in summer season for both rural and urban areas. The important term Urban Heat Island Intensity (K) is obtained greater for day time in comparison to night time. This signifies the effect of UHI over Jaipur. The UHII (K) is found highest in summer and lowest in winters. The UHII for rural areas is greater than urban areas. UHII derived from Aqua is higher than Terra one both in day and night time for rural and urban areas.

4.8. Distinct R^2 seasonal comparative analysis for rural and urban Jaipur

4.8.1. Summer Season

The R^2 values for summer season for different day-night times are reported in the table 4.14. The R^2 values for rural areas for day and night time is greater than urban areas which signify that urban areas have more temperature anomalies. The night R^2 values (ranges from .84-.94 for rural areas and .63-.87 for urban areas) are larger than day R^2 values (ranges from .64-.84 for rural areas and .53-.84 for urban areas). In 2005, 2006, & 2012 there exists strong correlation in day-night temperature in urban area and in 2003 for rural area which is highlighted.

Table 4.10: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Urban Jaipur

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity
2003	311.5	316.4	314.8	1.0	4.9	292.1	297.4	295.1	1.0	5.3	310.8	314.3	312.4	0.9	3.5	295.2	299.9	298.1	0.9	4.7
2004	313.5	320.0	317.9	1.1	6.6	292.5	298.2	295.8	1.1	5.7	311.8	315.0	313.6	0.7	3.2	295.5	300.2	298.3	0.9	4.7
2005	312.2	318.5	316.5	1.0	6.3	291.2	297.1	294.6	1.2	6.0	311.5	314.9	313.3	0.8	3.4	293.7	298.4	296.6	1.0	4.7
2006	311.9	318.5	315.8	1.1	6.7	293.2	297.3	295.5	0.9	4.0	310.0	313.0	311.5	0.8	3.0	294.7	298.5	297.0	0.7	3.8
2007	311.8	316.2	314.7	0.8	4.4	292.6	297.5	295.5	1.0	4.9	310.7	313.4	312.0	0.7	2.7	294.8	299.1	297.3	0.9	4.4
2008	311.8	317.7	315.9	0.8	5.9	291.7	296.6	294.5	1.0	4.9	310.2	313.9	311.9	0.8	3.7	293.7	298.2	296.3	0.9	4.4
2009	313.3	319.7	317.2	0.9	6.4	292.7	297.7	295.7	1.0	5.0	311.2	314.4	312.7	0.8	3.2	294.6	298.7	297.1	0.8	4.2
2010	314.2	319.9	317.7	0.8	5.8	293.4	298.3	296.3	1.0	4.9	313.2	316.7	314.8	0.8	3.5	296.1	300.6	298.8	0.9	4.5
2011	310.5	316.0	314.1	0.7	5.5	292.8	297.5	295.6	1.0	4.7	311.3	314.0	312.6	0.5	2.7	295.8	300.0	298.3	0.9	4.2
2012	310.7	316.3	314.1	0.8	5.5	292.3	296.8	295.1	0.9	4.5	310.2	313.3	311.4	0.7	3.1	294.6	298.9	297.3	0.8	4.4
2013	312.4	317.3	315.6	0.7	5.0	293.9	298.2	296.4	0.9	4.3	311.0	314.7	312.9	0.7	3.7	295.9	299.8	298.2	0.8	3.9
2014	310.0	315.3	313.5	0.8	5.3	293.8	297.5	296.1	0.8	3.7	310.0	313.5	311.7	0.7	3.6	295.5	299.2	297.9	0.7	3.7
2015	310.1	316.4	314.2	1.0	6.3	293.6	296.6	295.5	0.6	3.1	308.2	312.1	310.2	0.7	3.9	295.3	299.0	297.4	0.7	3.7

Table 4.11: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) for monsoon season day-night of Urban Jaipur

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	308.4	314.4	312.6	1.1	5.9	292.2	296.4	294.5	0.9	4.1	305.0	311.6	308.9	1.2	6.5	294.9	297.5	296.5	0.5	2.7
2004	304.4	311.3	309.5	1.4	6.9	294.0	296.9	295.7	0.6	2.8	306.1	310.8	309.3	0.7	4.7	295.1	297.7	296.7	0.6	2.6
2005	306.9	312.0	310.8	1.0	5.1	295.3	298.6	297.2	0.7	3.3	307.3	311.5	310.0	0.8	4.3	296.7	300.2	298.8	0.8	3.5
2006	311.0	315.2	314.0	0.7	4.2	295.0	298.7	296.9	0.8	3.8	310.1	314.5	311.8	0.7	4.4	296.2	300.2	298.5	0.8	4.0
2007	308.5	313.8	312.3	1.1	5.3	294.7	297.7	296.4	0.6	3.0	307.2	312.0	310.0	0.8	4.8	295.1	298.7	297.1	0.7	3.6
2008	307.6	313.2	311.6	1.1	5.6	294.6	298.0	296.5	0.7	3.4	305.8	310.8	308.8	0.8	4.9	296.0	299.6	298.1	0.7	3.5
2009	309.2	315.3	313.0	1.1	6.1	295.9	298.9	297.8	0.7	3.0	307.9	311.6	309.6	0.5	3.7	297.3	300.5	299.2	0.7	3.2
2010	306.7	312.6	311.0	1.2	5.9	294.2	297.6	296.2	0.7	3.4	305.0	309.4	308.2	0.8	4.4	296.4	299.7	298.4	0.7	3.4
2011	307.0	312.8	311.3	1.2	5.8	294.0	298.1	296.5	0.8	4.0	304.6	309.7	308.1	0.9	5.1	295.6	298.7	297.5	0.7	3.2
2012	307.7	314.0	312.2	1.3	6.3	294.7	298.2	296.8	0.7	3.5	306.5	311.9	310.3	0.9	5.5	296.1	299.5	298.1	0.7	3.4
2013	304.5	313.2	310.0	1.7	8.7	295.3	298.4	297.2	0.6	3.1	303.6	309.6	307.7	0.9	6.0	296.3	299.2	298.0	0.6	3.0
2014	307.0	313.2	311.6	1.2	6.1	295.9	299.3	297.9	0.7	3.4	306.4	311.4	310.0	0.8	5.1	297.6	300.3	299.2	0.6	2.7
2015	311.8	316.4	314.6	0.7	4.6	295.6	298.7	297.4	0.6	3.1	309.2	312.6	311.1	0.7	3.4	297.1	300.5	299.3	0.7	3.5

Table 4.12: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for winter season day-night of Urban Jaipur

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	303.9	308.7	306.8	0.9	4.8	280.6	285.7	283.4	1.1	5.1	300.8	304.6	302.7	0.8	3.8	283.9	289.3	286.9	1.1	5.4
2004	301.5	306.8	305.0	0.8	5.3	281.2	287.9	285.1	1.4	6.6	299.5	303.2	301.3	0.8	3.7	284.4	289.9	287.5	1.1	5.5
2005	302.8	307.7	306.0	0.9	4.9	279.9	286.1	283.3	1.3	6.2	299.7	303.1	301.4	0.8	3.4	283.9	289.2	287.0	1.1	5.3
2006	305.0	308.2	306.9	0.6	3.2	282.0	288.1	285.4	1.3	6.1	304.0	306.8	305.3	0.7	2.8	284.0	289.3	287.0	1.1	5.2
2007	304.1	307.5	306.3	0.6	3.4	282.2	288.7	285.9	1.4	6.5	302.7	305.4	303.9	0.6	2.7	285.0	290.2	287.9	1.1	5.2
2008	304.0	307.6	306.3	0.6	3.6	281.6	287.9	285.1	1.4	6.3	301.9	304.9	303.1	0.7	3.1	284.8	290.0	287.7	1.1	5.2
2009	304.6	308.7	307.0	0.7	4.1	282.5	288.2	285.8	1.2	5.7	302.1	304.8	303.2	0.6	2.8	285.7	290.7	288.7	1.0	5.0
2010	301.6	304.8	303.5	0.5	3.2	282.6	287.7	285.6	1.1	5.1	298.7	301.1	299.8	0.5	2.4	285.1	289.4	287.7	0.9	4.4
2011	303.9	307.6	306.4	0.6	3.7	283.5	288.6	286.3	1.1	5.1	300.6	303.3	301.8	0.5	2.7	285.5	290.2	288.4	1.0	4.8
2012	302.7	306.7	305.1	0.7	4.0	281.7	287.3	284.8	1.2	5.6	300.7	303.7	302.1	0.6	3.0	284.1	288.9	287.1	0.9	4.8
2013	302.5	306.1	304.7	0.6	3.6	282.6	287.6	285.3	1.0	5.0	300.1	303.4	301.6	0.6	3.2	285.1	289.7	287.8	0.9	4.6
2014	302.0	306.3	304.7	0.8	4.3	283.1	287.7	285.7	1.0	4.6	300.2	303.0	301.6	0.5	2.8	285.5	289.7	288.0	0.9	4.2
2015	304.2	308.5	306.4	0.7	4.3	283.4	287.8	285.7	0.9	4.4	302.3	304.9	303.4	0.6	2.6	286.5	290.5	288.9	0.7	4.1

Table 4.13: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) annually day-night of Urban Jaipur

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	308.0	313.2	311.4	1.0	5.2	288.3	293.1	291.0	1.0	4.8	305.6	310.2	308.0	2.9	4.6	291.4	295.6	293.8	2.6	4.2
2004	306.5	312.7	310.8	1.1	6.3	289.3	294.3	292.2	1.0	5.1	305.8	309.7	308.1	2.3	3.9	291.7	295.9	294.2	2.7	4.3
2005	307.3	312.7	311.1	1.0	5.4	288.8	293.9	291.7	1.1	5.1	306.1	309.8	308.3	2.5	3.7	291.5	296.0	294.1	2.9	4.5
2006	309.3	314.0	312.3	0.8	4.7	290.1	294.7	292.6	1.0	4.6	308.0	311.4	309.5	2.2	3.4	291.7	296.0	294.2	2.6	4.3
2007	308.2	312.5	311.1	0.8	4.4	289.8	294.6	292.6	1.0	4.8	306.9	310.2	308.6	2.1	3.4	291.6	296.0	294.1	2.7	4.4
2008	307.8	312.8	311.3	0.9	5.1	289.3	294.2	292.0	1.0	4.9	305.9	309.8	307.9	2.3	3.9	291.5	295.9	294.0	2.7	4.4
2009	309.0	314.6	312.4	0.9	5.5	290.4	295.0	293.1	1.0	4.6	307.1	310.3	308.5	2.0	3.2	292.5	296.6	295.0	2.5	4.1
2010	307.5	312.5	310.7	0.9	5.0	290.1	294.5	292.7	0.9	4.5	305.6	309.1	307.6	2.0	3.4	292.5	296.6	294.9	2.5	4.1
2011	307.1	312.1	310.6	0.8	5.0	290.1	294.7	292.8	1.0	4.6	305.5	309.0	307.5	2.0	3.5	292.3	296.3	294.7	2.5	4.0
2012	307.1	312.3	310.5	0.9	5.2	289.6	294.1	292.2	0.9	4.5	305.8	309.7	307.9	2.3	3.9	291.6	295.8	294.1	2.4	4.2
2013	306.4	312.2	310.1	1.0	5.7	290.6	294.7	292.9	0.8	4.1	304.9	309.2	307.4	2.2	4.3	292.4	296.3	294.7	2.4	3.8
2014	306.3	311.6	309.9	0.9	5.3	290.9	294.8	293.2	0.8	3.9	305.5	309.3	307.8	2.1	3.8	292.9	296.4	295.0	2.1	3.6
2015	308.7	313.8	311.7	0.8	5.0	290.9	294.4	292.9	0.7	3.5	306.6	309.9	308.2	1.9	3.3	292.9	296.7	295.2	2.0	3.8

4.8.2. Monsoon Season

The R^2 values for monsoon season for different day-night times are reported in the table 4.15. The R^2 values for rural areas for day and night time is greater than urban areas which signifies that urban areas have more temperature anomalies like summer season. The night R^2 values (ranges from .64-.93 for rural areas and .53-.77 for urban areas) are larger than day R^2 values (ranges from .53-.87 for rural areas and .51-.84 for urban areas. There is no existence of day-night temperature correlation in both areas.

Table 4.14: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the summer season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR JAIPUR CITY FOR SUMMER SEASON								
	RURAL				URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.64	0.42	0.86	0.60	0.84	0.01	0.89	0.00
2004	0.87	0.03	0.94	0.06	0.69	0.47	0.87	0.30
2005	0.82	0.02	0.91	0.00	0.65	0.45	0.77	0.71
2006	0.73	0.03	0.89	0.01	0.64	0.50	0.80	0.70
2007	0.84	0.04	0.92	0.00	0.59	0.12	0.78	0.44
2008	0.87	0.04	0.88	0.00	0.48	0.18	0.76	0.54
2009	0.83	0.03	0.93	0.04	0.55	0.37	0.78	0.35
2010	0.84	0.04	0.93	0.00	0.47	0.32	0.78	0.61
2011	0.83	0.01	0.91	0.00	0.36	0.01	0.79	0.29
2012	0.85	0.03	0.92	0.01	0.59	0.35	0.76	0.61
2013	0.85	0.01	0.93	0.02	0.60	0.14	0.81	0.56
2014	0.86	0.00	0.91	0.07	0.53	0.02	0.73	0.33
2015	0.84	0.03	0.84	0.15	0.74	0.08	0.63	0.33

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

Table 4.15: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the monsoon season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR JAIPUR CITY FOR MONSOON SEASON								
	RURAL				URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	**ADVTD**	**ADVTN**	**ANVTN**	**ANVTD**	**ADVTD**	**ADVTN**	**ANVTN**	**ANVTD**
2003	0.80	0.00	0.64	0.12	0.74	0.01	0.33	0.20
2004	0.53	0.01	0.78	0.02	0.59	0.08	0.59	0.00
2005	0.81	0.09	0.84	0.09	0.76	0.00	0.77	0.10
2006	0.86	0.01	0.89	0.03	0.59	0.07	0.69	0.36
2007	0.83	0.11	0.84	0.15	0.69	0.00	0.72	0.20
2008	0.84	0.05	0.86	0.12	0.74	0.03	0.64	0.16
2009	0.58	0.08	0.90	0.00	0.21	0.10	0.65	0.18
2010	0.48	0.03	0.90	0.00	0.78	0.21	0.75	0.02
2011	0.84	0.11	0.87	0.09	0.61	0.04	0.75	0.00
2012	0.87	0.08	0.91	0.10	0.76	0.02	0.64	0.04
2013	0.73	0.00	0.82	0.02	0.55	0.18	0.64	0.04
2014	0.87	0.00	0.82	0.06	0.84	0.22	0.19	0.00
2015	0.81	0.03	0.93	0.00	0.76	0.04	0.70	0.15

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

4.8.3. Winter Season

The R^2 values for winter season for different day-night times are reported in the table 4.16. The winter R^2 values is greater than summer and monsoon values for both rural and urban areas. The R^2 values for rural areas for day and night time is greater than urban areas which signifies that urban areas have more temperature anomalies like above two seasons. The night R^2 values (ranges from .86-.92 for rural areas and .63-.84 for urban areas) is larger than day R^2 values (ranges from .80-.88 for rural areas and .54-.77 for urban areas). The main difference from previous two seasons occur in winter that there is comparatively good correlation between Aqua Day LST and Terra Night LST in urban area.

Table 4.16: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the winter season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR JAIPUR CITY FOR WINTER SEASON								
RURAL					URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.80	0.01	0.92	0.31	0.68	0.38	0.91	0.70
2004	0.83	0.10	0.90	0.21	0.75	0.35	0.85	0.64
2005	0.81	0.01	0.90	0.14	0.76	0.49	0.83	0.71
2006	0.83	0.06	0.90	0.09	0.66	0.43	0.84	0.66
2007	0.82	0.05	0.88	0.24	0.62	0.42	0.80	0.64
2008	0.87	0.13	0.88	0.26	0.70	0.48	0.80	0.72
2009	0.82	0.00	0.87	0.04	0.54	0.43	0.77	0.65
2010	0.80	0.01	0.88	0.12	0.60	0.17	0.77	0.47
2011	0.87	0.31	0.89	0.32	0.60	0.19	0.73	0.51
2012	0.88	0.24	0.89	0.38	0.77	0.24	0.79	0.55
2013	0.85	0.16	0.90	0.32	0.59	0.12	0.75	0.49
2014	0.87	0.04	0.86	0.26	0.63	0.09	0.74	0.46
2015	0.83	0.02	0.86	0.18	0.72	0.34	0.64	0.62

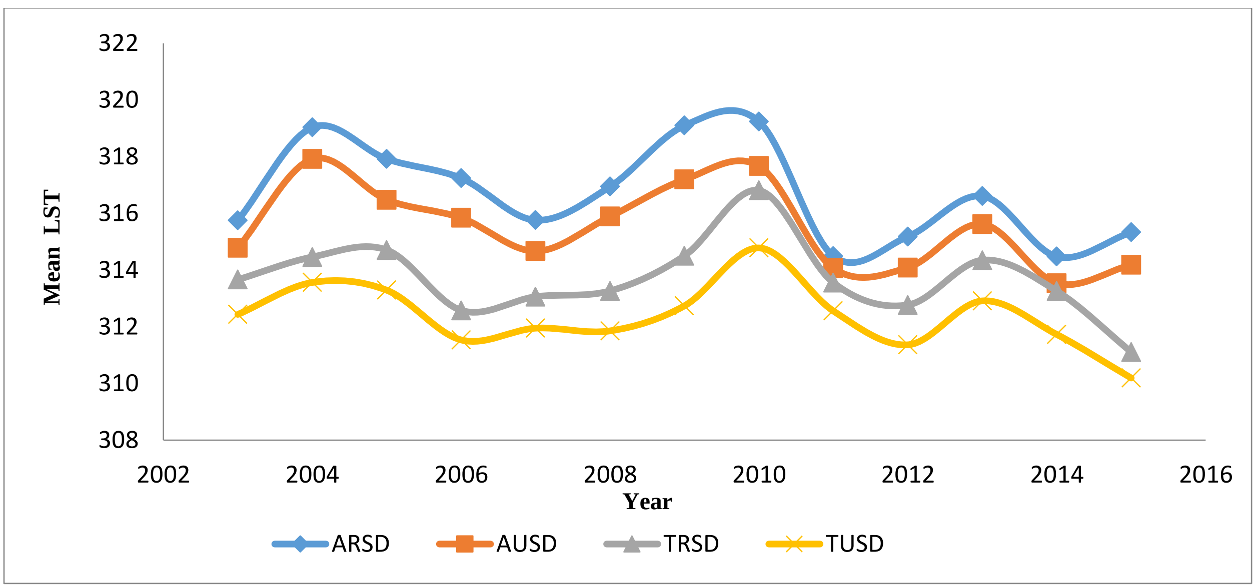
ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

4.9. Analysis of Aqua and Terra LST variation between rural and urban area for day time

This analysis includes same day LST variation comparison over a years (2003-2015) for day time for rural and urban areas of Jaipur for different season. It is very difficult to find a common day in a year to give complete LST data after Quality Check. The day should be common for each year in each season throughout 2003-15 to derive correct LST. After selecting a day and deriving LST from MODIS image, it is observed that rural area day temperature attains a higher value than an urban area during all three seasons. The detailed LST values is tabulated in table 4.17 and typical scatter plots are shown in figures 4.8, 4.10, 4.12 & 4.14 for summer ,monsoon, winter and annual respectively.

4.10. Analysis of Aqua and Terra LST variation between rural and urban area for night time

It is observed that urban area night temperature attains a higher value than a rural area during all three seasons. The possible reason is that the urban area has different composite material. Due to different material composition each surface has their unique emissivity characteristic which emits differently intensified heat into the atmosphere. On the other side rural area has almost same material composition including vegetation which emits same heat. The detailed LST values is tabulated in table 4.18 and typical scatter plots are shown in figures 4.9, 4.11, 4.13 & 4.15 for summer ,monsoon, winter and annual respectively.



ARSD-Aqua Rural Summer Day LST (K); AUSD-Aqua Urban Summer Day LST (K); TRSD-Terra Rural Summer Day LST (K); TUSD-Terra Urban Summer Day LST (K);

Figure 4.8: Graph of Mean LST (K) in Rural-Urban area for summer season during day time for Jaipur

Table 4.17: Seasonal LST (K) variation comparison between Rural-Urban over a year for Day time for study area

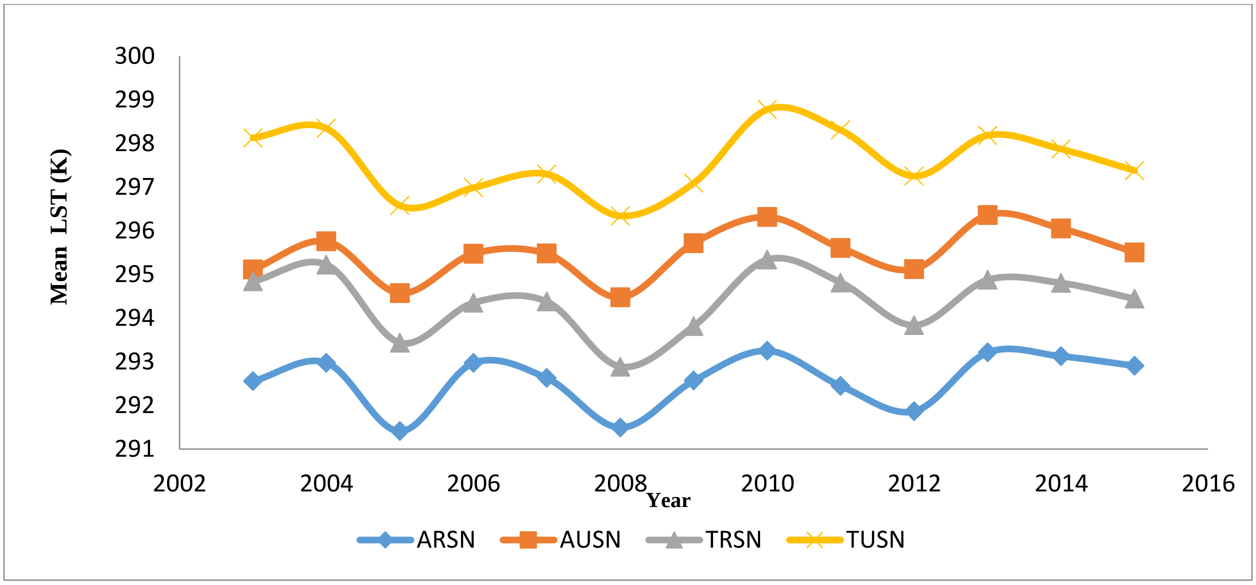
Year	ARSD	AUSD	TRSD	TUSD	ARMD	AUMD	TRMD	TUMD	ARWD	AUWD	TRWD	TUWD	ARAD	AUAD	TRAD	TUAD
2003	316	315	314	312	314	313	309	308	308	307	304	303	312	311	309	308
2004	319	318	314	314	309	308	309	308	306	305	302	301	311	311	309	308
2005	318	316	315	313	311	310	310	309	307	306	302	301	312	311	309	308
2006	317	316	313	312	316	315	314	313	308	307	306	305	314	312	311	310
2007	316	315	313	312	314	313	311	310	308	306	305	304	312	311	310	309
2008	317	316	313	312	313	312	310	309	308	306	305	303	313	311	309	308
2009	319	317	315	313	313	312	312	311	308	307	305	303	314	312	310	308
2010	319	318	317	315	311	310	308	307	304	303	301	300	311	311	308	308
2011	314	314	314	313	312	311	308	307	308	306	303	302	311	311	308	307
2012	315	314	313	311	313	312	311	310	307	305	304	302	312	310	309	308
2013	317	316	314	313	309	308	307	306	306	305	303	302	310	310	308	307
2014	314	314	313	312	311	310	309	308	305	305	303	302	310	310	308	308
2015	315	314	311	310	316	315	312	311	308	306	305	303	313	312	309	308

ARSD-Aqua Rural Winter Day LST(K) ; AUSD-Aqua Urban Winter Day LST(K); TRSD-Terra Rural Winter Day LST(K); TUSD- Terra Urban Winter Day LST(K)
ARSD-Aqua Rural Monsoon Day LST(K); AUSD-Aqua Urban Monsoon Day LST(K); TRSD-Terra Rural Monsoon Day LST(K); TUSD- Terra Urban Monsoon Day LST(K)
ARSD-Aqua Rural Winter Day LST(K); AUSD-Aqua Urban Winter Day LST(K); TRSD-Terra Rural Winter Day LST(K); TUSD- Terra Urban Winter Day LST(K)

Table 4.18: Seasonal LST (K) variation comparison between Rural-Urban over a year for Night time for study area

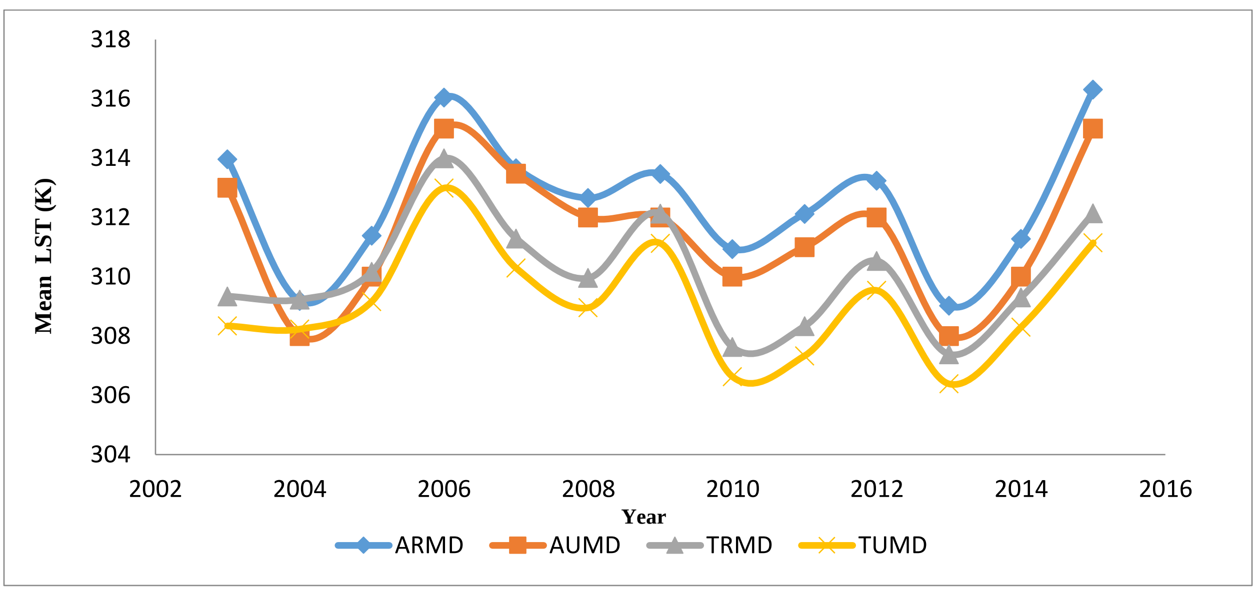
Year	ARSN	AUSN	TRSN	TUSN	ARMN	AUMN	TRMN	TUMN	ARWN	AUWN	TRWN	TUWN	ARAN	AUAN	TRAN	TUAN
2003	293	295	295	298	292	294	295	296	280	283	283	287	288	291	291	294
2004	293	296	295	298	294	296	295	297	282	285	284	288	290	292	291	294
2005	291	295	293	297	295	297	296	299	280	283	283	287	289	292	291	294
2006	293	295	294	297	295	297	296	298	282	285	283	287	290	293	291	294
2007	293	295	294	297	295	296	295	297	282	286	284	288	290	293	291	294
2008	291	294	293	296	294	296	296	298	281	285	284	288	289	292	291	294
2009	293	296	294	297	296	298	297	299	282	286	285	289	290	293	292	295
2010	293	296	295	299	294	296	296	298	282	286	284	288	290	293	292	295
2011	292	296	295	298	294	297	295	297	283	286	285	288	290	293	292	295
2012	292	295	294	297	294	297	296	298	281	285	283	287	289	292	291	294
2013	293	296	295	298	295	297	296	298	282	285	284	288	290	293	292	295
2014	293	296	295	298	296	298	297	299	282	286	285	288	290	293	292	295
2015	293	296	294	297	295	297	296	299	282	286	286	289	290	293	292	295

ARSN-Aqua Rural Winter Night LST(K); AUSN-Aqua Urban Winter Night LST(K); TRSN-Terra Rural Winter Night LST(K); TUSN- Terra Urban Winter Night LST(K) ARSN-Aqua Rural Monsoon Night LST(K); AUSN-Aqua Urban Monsoon Night LST(K); TRSN-Terra Rural Monsoon Night LST(K); TUSN- Terra Urban Monsoon Night LST(K); ARSN-Aqua Rural Winter Night LST(K); AUSN-Aqua Urban Winter Night LST(K); TRSN-Terra Rural Winter Night LST(K); TUSN- Terra Urban Winter Night LST(K)



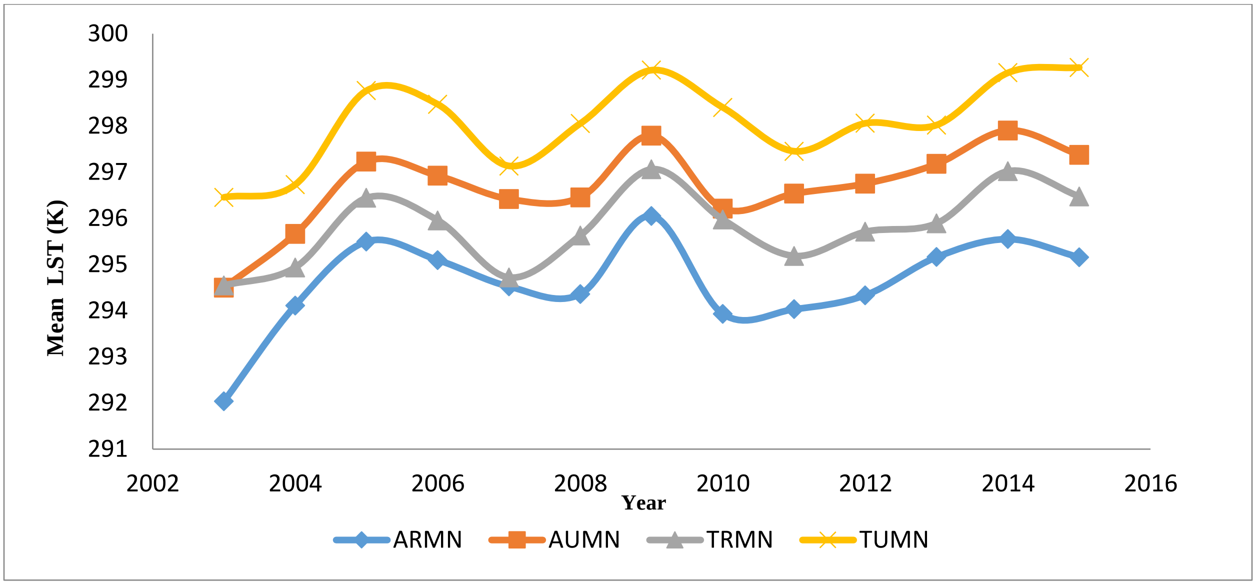
ARSN-Aqua Rural Summer Night LST (K); AUSN-Aqua Urban Summer Night LST (K); TRSN-Terra Rural Summer Night LST (K); TUSN-Terra Urban Summer Night LST (K);

Figure 4.9: Graph of Mean LST (K) in Rural-Urban area for summer season during night time for Jaipur



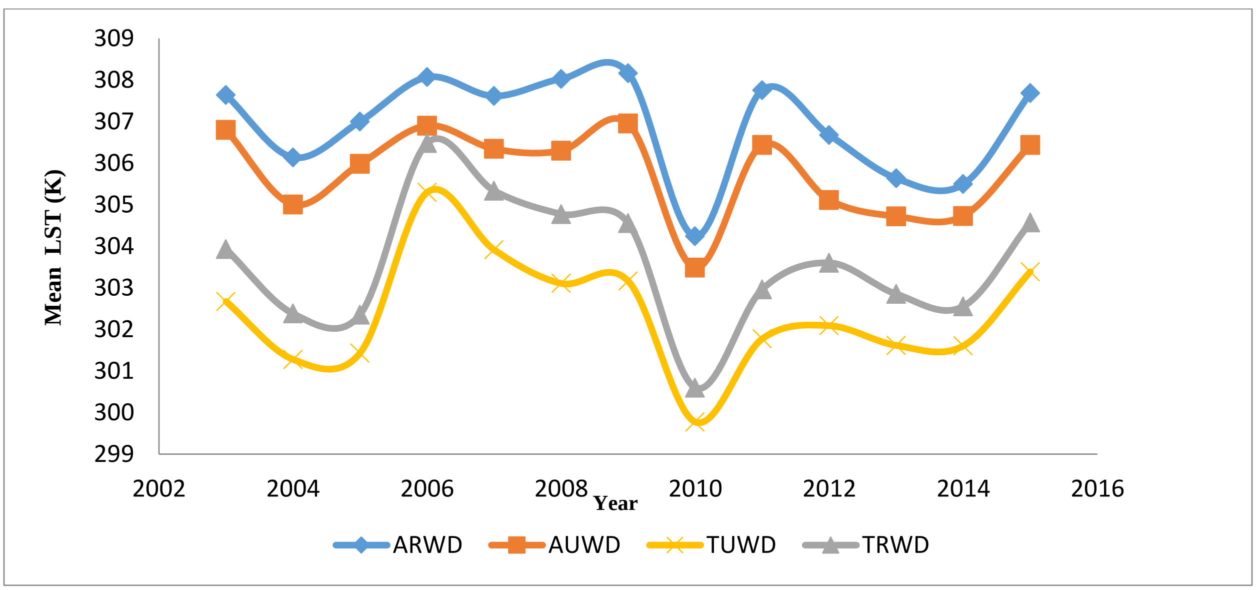
ARMD-Aqua Rural Monsoon Day LST (K); AUMD-Aqua Urban Monsoon Day LST (K); TRMD-Terra Rural Monsoon Day LST (K); TUMD-Terra Urban Monsoon Day LST (K);

Figure 4.10: Graph of Mean LST (K) in Rural-Urban area for monsoon season during day time for Jaipur



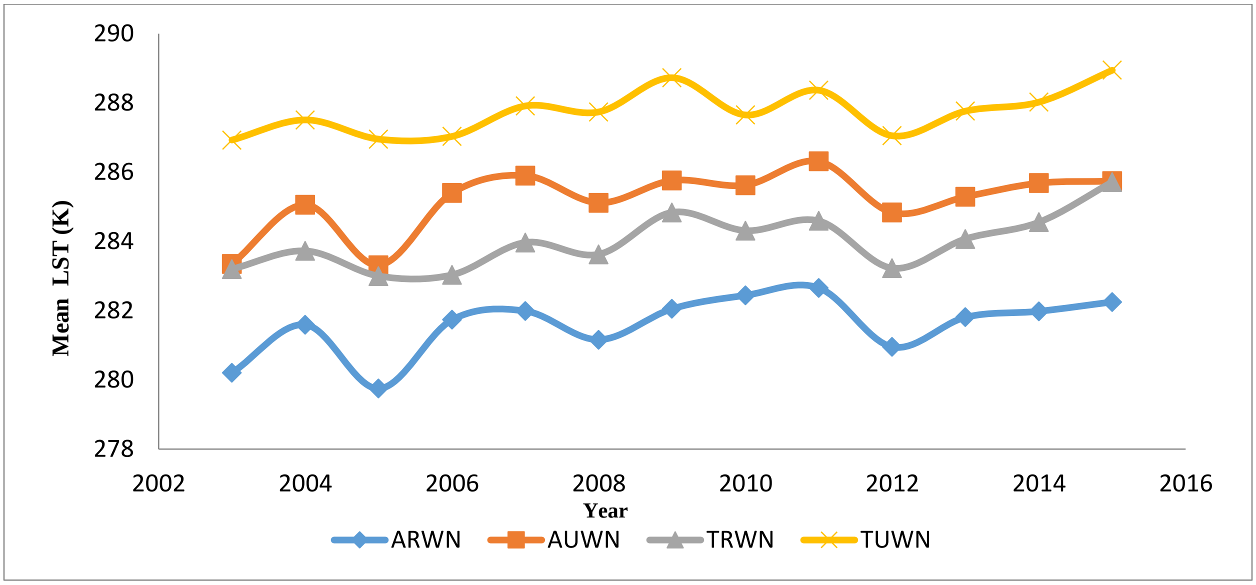
ARMN-Aqua Rural Monsoon Night LST (K); AUMN-Aqua Urban Monsoon Night LST (K); TRMN-Terra Rural Monsoon Night LST (K); TUMN-Terra Urban Monsoon Night LST (K);

Figure4.11: Graph of Mean LST (K) in Rural-Urban area for monsoon season during night time for Jaipur



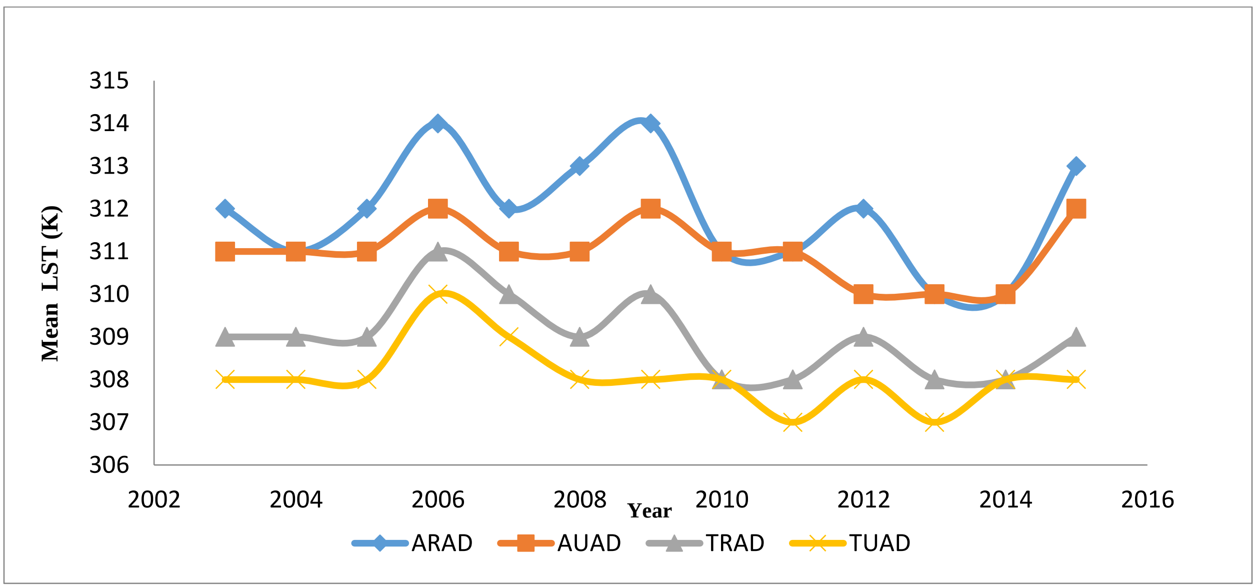
ARWD-Aqua Rural Winter Day LST (K); AUWD-Aqua Urban Winter Day LST (K); TRWD-Terra Rural Winter Day LST (K); TUWD-Terra Urban Winter Day LST (K);

Figure4.12: Graph of Mean LST (K) in Rural-Urban area for winter season during day time for Jaipur



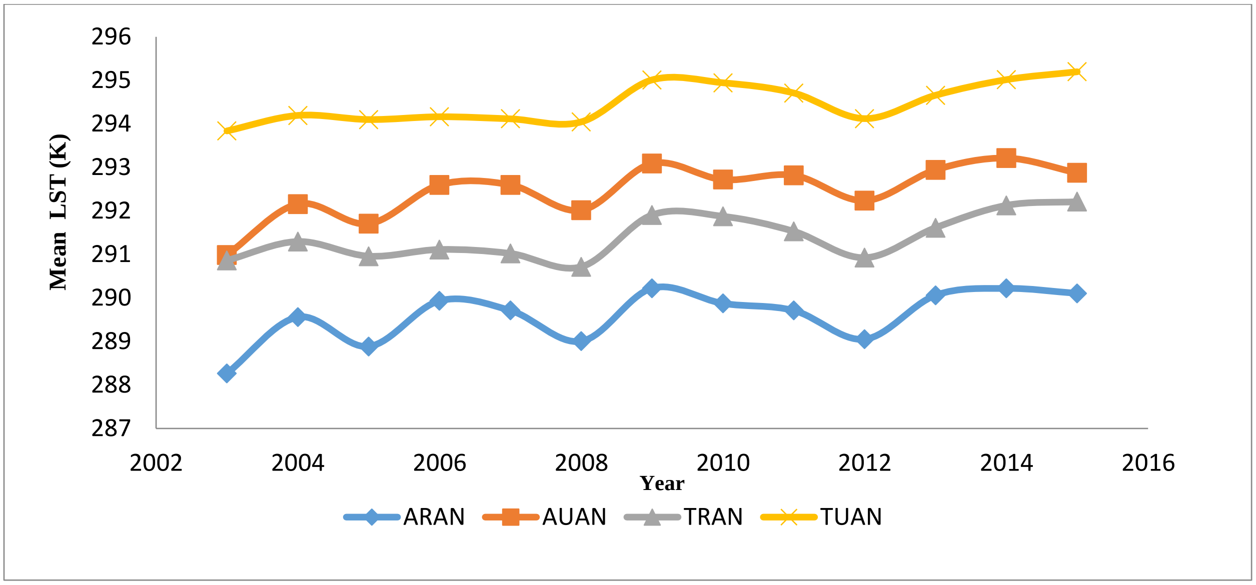
ARWN-Aqua Rural Winter Night LST (K); AUWN-Aqua Urban Winter Night LST (K); TRWN-Terra Rural Winter Night LST (K); TUWN-Terra Urban Winter Night LST (K);

Figure 4.13: Graph of Mean LST (K) in Rural-Urban area for winter season during night time for Jaipur



ARAD-Aqua Rural Annual Day LST (K); AUAD-Aqua Urban Annual Day LST (K); TRAD-Terra Rural Annual Day LST (K);TUAD-Terra Urban Annual Day LST (K);

Figure 4.14: Graph of Mean LST (K) in Rural-Urban area annually during day time for Jaipur



ARAN-Aqua Rural Annual Night LST (K); AUAN-Aqua Urban Annual Night LST (K); TRAN-Terra Rural Annual Night LST (K); TUAN-Terra Urban Annual Night LST (K);

Figure 4.15: Graph of Mean LST (K) in Rural-Urban area annually during night time for Jaipur

4.11. Comparisons for Ahmadabad city

The study area for Ahmedabad city is divided into two zones mainly rural (9 km buffer around Ahmedabad city) and urban area. The comparison for Ahmedabad city clearly states the rural temperature during day time is slightly **less** (1K-4K) than urban temperature during all seasons for all the years from 2003 to 2015 for both aqua and terra. This result is just opposite to Jaipur city. The comparison results for night time depict a just opposite scenario as the urban night time temperature is slightly lesser (3K-4K) than rural temperature for the same season and years. The above phenomenon is justified by the LST pictures for four random years 2003, 2007, 2011 and 2015 for summer, monsoon and winter season during day and night by aqua and terra.

4.12. Seasonal LST variation results for Ahmedabad City

4.12.1. Summer

The temperature ranges approximately from 299-324K for summer season for day time and 292-300K for night time both for Aqua and Terra. The mean diurnal temperature difference is 22.4K for Aqua LST and 17.1K for Terra LST for 2003-15 for summer season. The maximum difference is 7.2K for 2007 for between Aqua and Terra for day temperature and 303K for 2004 for night temperature in summers. The average UHI intensity is 10.5K, 5.7K, 9.9K & 5.7K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.1.

4.12.2. Monsoon

The temperature ranges approximately from 300-317K for monsoon season for day time and 292-301K for night time both for Aqua and Terra. The mean diurnal temperature difference is 15K for Aqua LST and 11K for Terra LST for 2003-15 for monsoon season. The maximum difference is 5.1K for 2008 between Aqua and Terra for day temperature and 1.1K for 2004 for night temperature in monsoon. The average UHI intensity is 11.4K, 4.5K, 9.7K & 5.3K is observed for Aqua day, Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.2.

4.12.3. Winter

The temperature ranges approximately from 296-312K for winter season for day time and 283-295K for night time both for Aqua and Terra. The mean diurnal temperature difference is 20K for Aqua LST and 15.1K for Terra LST for 2003-15 for winter season. The maximum difference is 4.8K for 2007 between Aqua and Terra for day temperature and 3.4K for 2015 for night temperature in winters. The average UHI intensity is 7K, 7.1K, 6.1K & 6.9K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.3.

4.12.4. Annual

The temperature ranges approximately from 299-317K for day time and 289-298K for night time both for Aqua and Terra. The mean diurnal temperature difference is 19.2K for Aqua LST and 15.1K for Terra LST. The maximum difference is 5.1K for 2003 between Aqua and Terra for day temperature and 2.5K for 2010 for night temperature. The average UHI intensity is 7.9K, 5.4K, 7.2K & 5.8K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.4.

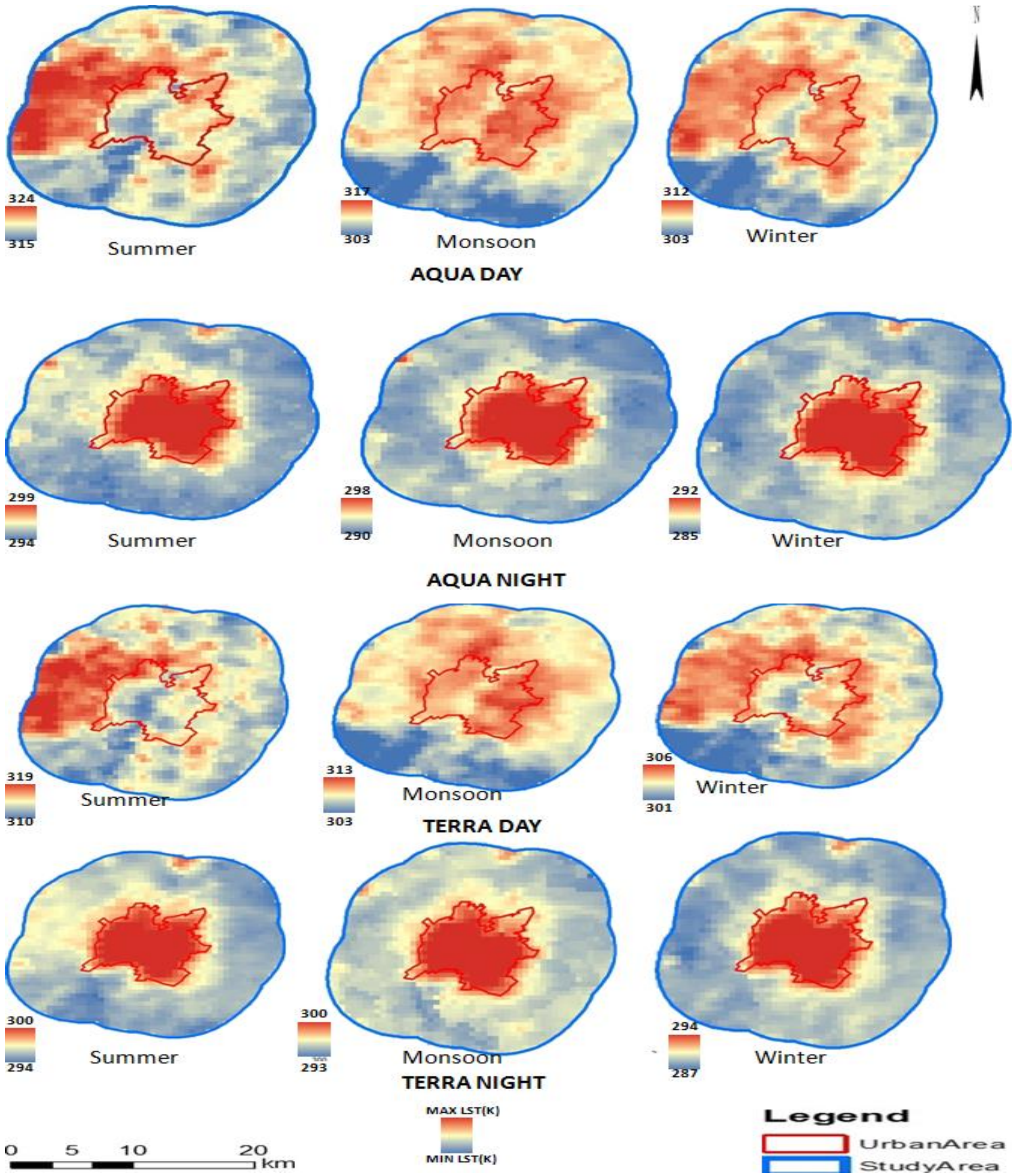


Figure4.16: LST image for study area for winter, monsoon & winter season for day - night by Aqua & Terra for 2003

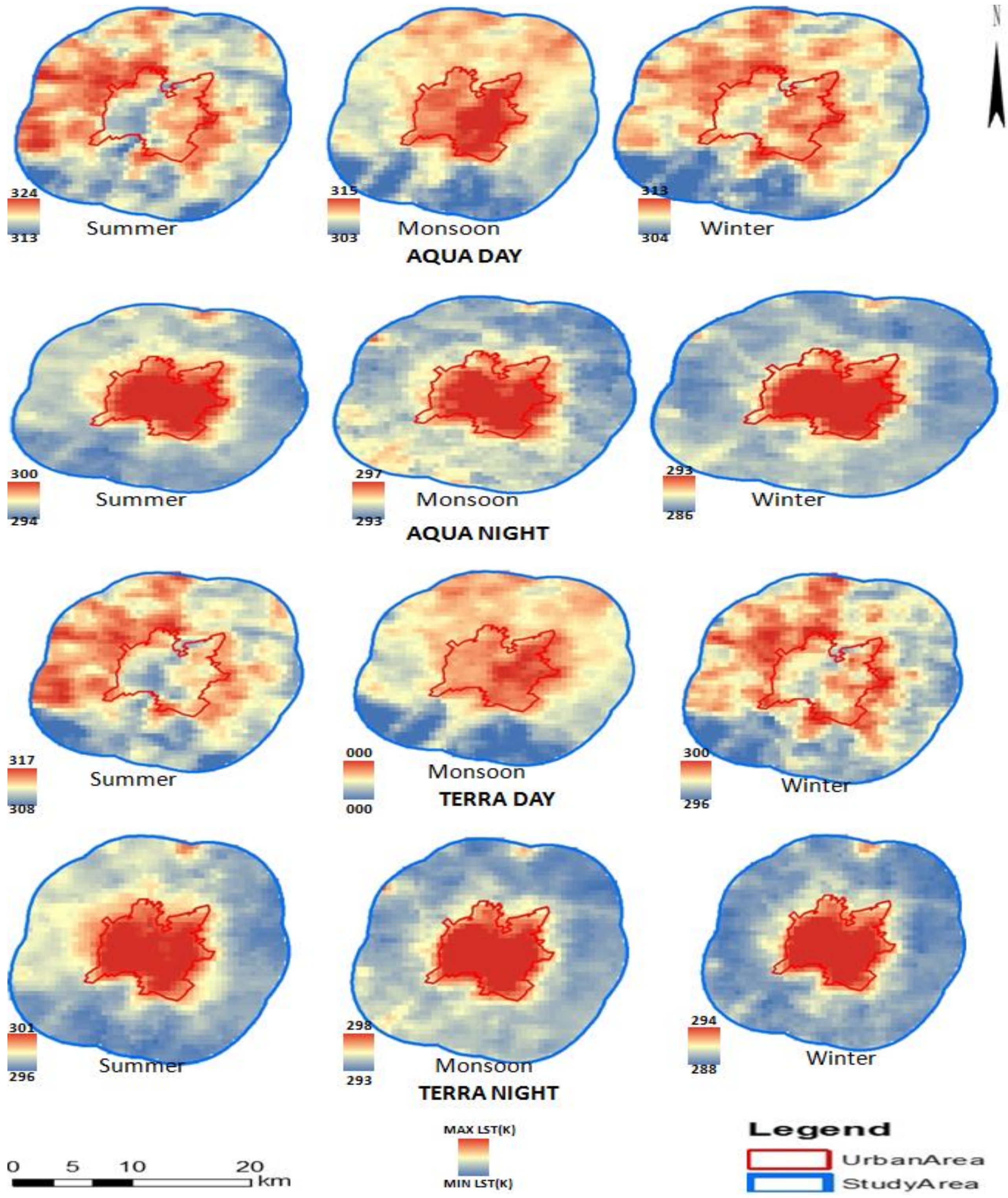


Figure4.17: LST image for study area for winter, monsoon & winter season for day - night by Aqua & Terra for 2007

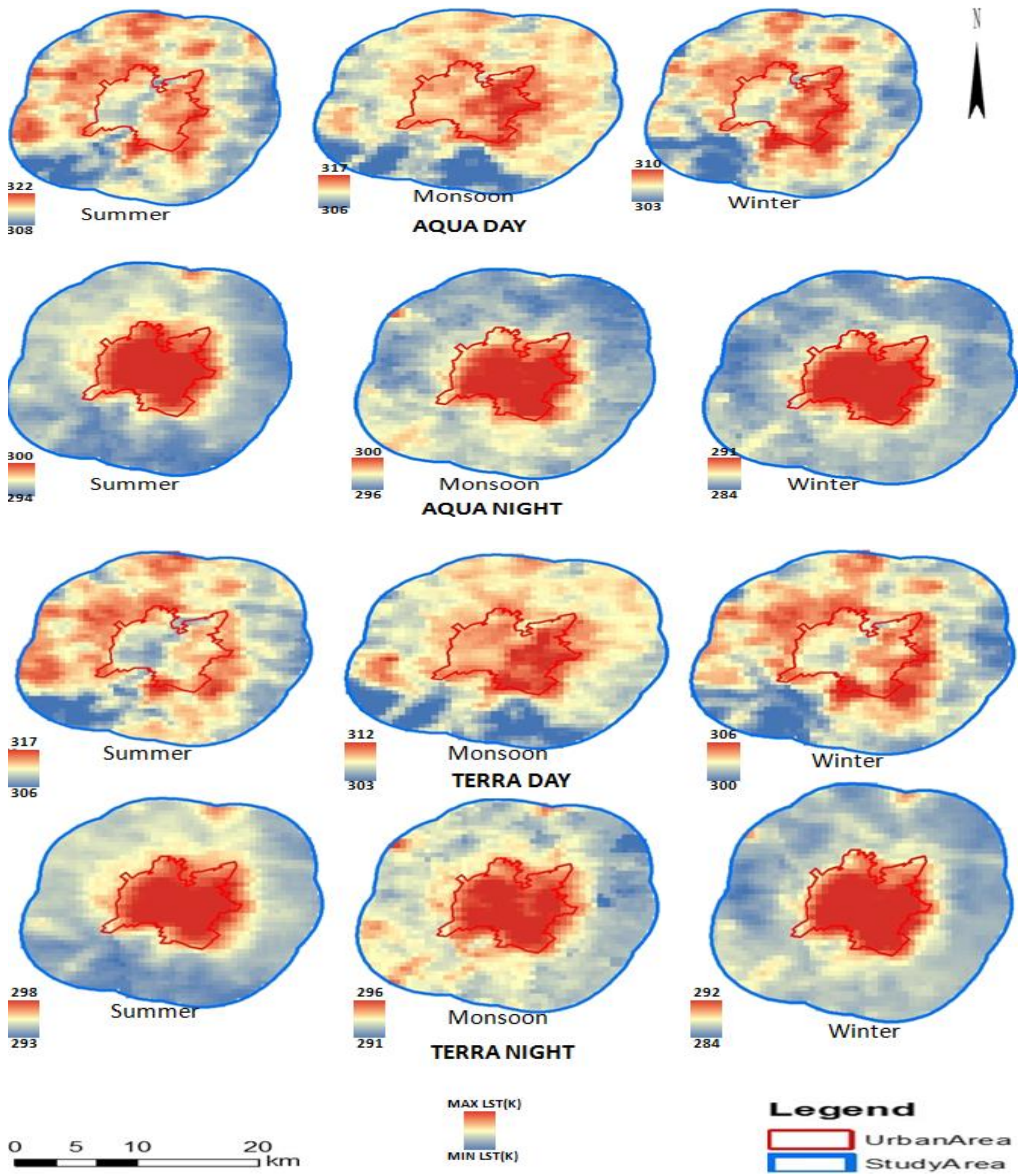


Figure4.18: LST image for study area for winter, monsoon & winter season for day - night by Aqua & Terra for 2011

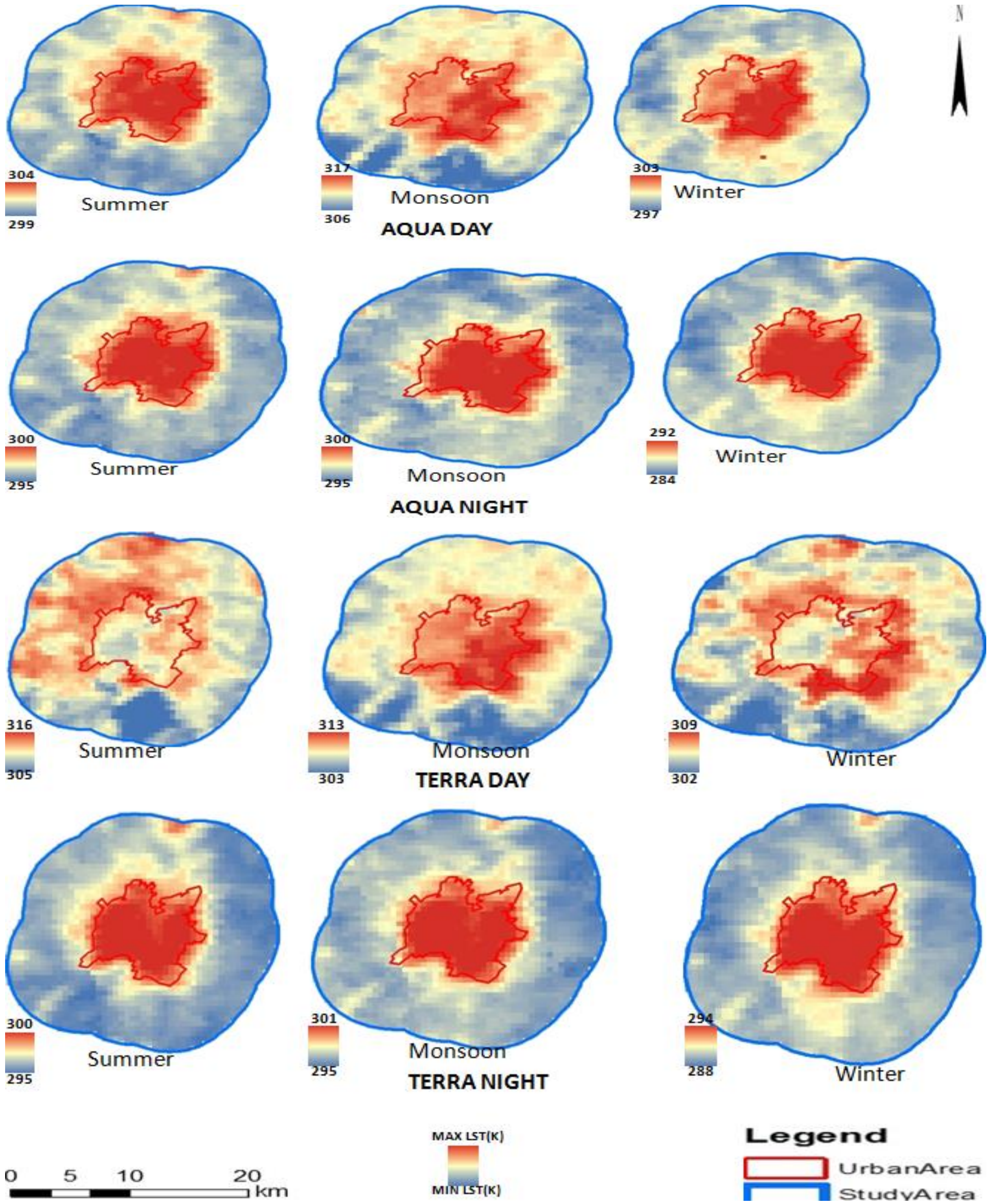


Figure4.19: LST image for study area for winter, monsoon & winter season for day - night by Aqua & Terra for 2015

Table 4.19: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Ahmedabad

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	315.0	324.1	319.9	1.5	9.1	293.6	298.7	295.2	1.2	5.1	309.6	319.0	314.8	1.4	9.5	294.2	299.6	296.2	1.3	5.4
2004	314.8	323.9	319.7	1.7	9.1	292.5	299.1	294.7	1.4	6.6	310.3	318.9	315.2	1.7	8.6	296.3	301.2	298.0	1.1	4.9
2005	316.7	324.4	320.8	1.6	7.7	294.1	300.2	296.2	1.4	6.2	315.1	321.7	318.4	1.2	6.6	293.9	300.4	296.2	1.5	6.5
2006	313.3	321.6	318.1	1.6	8.3	293.4	299.3	295.4	1.4	6.0	311.9	318.4	315.3	1.2	6.6	295.2	300.0	296.8	1.1	4.8
2007	313.4	324.2	320.6	1.5	10.8	294.4	299.7	296.2	1.3	5.3	306.7	316.2	313.4	1.4	9.5	296.2	301.5	298.1	1.2	5.2
2008	307.3	320.9	317.0	2.1	13.6	293.1	299.0	295.1	1.3	5.8	305.4	316.4	313.4	1.6	11.0	296.0	301.0	297.8	1.2	5.1
2009	311.6	324.5	321.0	1.5	12.8	293.4	299.4	295.5	1.4	6.0	308.2	319.6	316.2	1.4	11.3	295.0	301.2	297.1	1.5	6.1
2010	310.9	324.8	320.8	1.9	13.9	294.1	300.1	296.1	1.4	6.0	304.3	319.0	314.8	2.1	14.7	296.3	302.6	298.4	1.6	6.3
2011	308.6	322.3	318.5	1.6	13.7	293.0	298.9	295.2	1.4	5.8	306.0	317.5	314.4	1.3	11.5	294.1	300.7	296.4	1.6	6.5
2012	308.8	322.1	318.4	1.8	13.4	293.7	299.2	295.6	1.4	5.5	304.8	316.5	313.0	1.6	11.7	294.6	300.6	296.7	1.5	6.0
2013	315.3	323.8	319.5	1.5	8.4	294.5	300.2	296.6	1.4	5.7	308.2	316.2	312.3	1.3	8.0	295.8	302.1	298.1	1.6	6.4
2014	312.9	322.9	319.2	1.5	9.9	293.3	298.6	295.1	1.4	5.4	308.4	317.0	313.4	1.3	8.6	295.7	301.6	297.6	1.5	5.8
2015	299.4	304.8	301.6	1.3	5.4	295.0	300.0	296.7	1.2	5.0	305.8	316.0	312.8	1.6	10.3	295.3	300.4	297.0	1.4	5.1

Table 4.20: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) for Monsoon season day-night of Ahmedabad

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	303.3	316.8	311.4	2.6	13.5	292.3	298.8	295.2	1.1	6.5	302.5	313.4	309.2	2.0	10.9	292.6	300.1	295.3	1.5	7.5
2004	302.3	312.5	308.7	1.8	10.2	293.8	297.6	295.1	0.8	3.8	300.3	309.6	306.1	1.5	9.3	293.7	299.0	296.2	0.9	5.3
2005	303.7	315.1	309.6	2.1	11.4	294.0	298.2	295.6	0.8	4.1	302.3	312.0	307.5	1.9	9.7	294.9	299.6	296.3	1.0	4.7
2006	304.5	315.9	311.0	2.0	11.4	295.3	299.0	296.7	0.7	3.7	303.6	313.3	309.3	1.8	9.7	296.1	301.1	297.5	1.1	5.0
2007	303.7	315.2	309.7	2.2	11.5	293.1	297.4	294.6	1.0	4.3	301.3	310.9	306.5	1.9	9.6	293.3	298.9	295.0	1.3	5.6
2008	305.8	317.0	311.9	2.2	11.2	294.4	298.9	295.9	1.0	4.5	302.6	311.3	306.8	1.6	8.7	295.3	300.2	296.8	1.1	5.0
2009	305.0	317.5	313.4	2.1	12.5	294.8	299.2	296.4	1.0	4.4	302.4	312.3	308.5	1.9	9.9	295.3	300.4	296.9	1.2	5.1
2010	303.5	317.1	311.0	2.7	13.6	295.2	299.9	296.8	1.1	4.7	302.0	312.6	307.3	2.1	10.6	295.7	300.7	297.2	1.1	5.0
2011	306.2	316.7	312.1	1.7	10.5	293.5	298.8	295.9	1.1	5.4	303.2	312.5	308.0	1.6	9.4	295.4	300.1	296.9	1.1	4.7
2012	304.9	315.3	310.9	1.9	10.4	294.1	298.7	295.5	1.1	4.6	302.8	311.5	307.3	1.7	8.8	295.2	300.4	296.8	1.3	5.2
2013	304.7	314.6	308.9	1.7	9.9	294.7	298.9	296.1	0.9	4.1	300.1	309.6	304.5	1.6	9.5	295.8	300.8	297.4	1.1	5.0
2014	305.3	316.7	311.0	2.1	11.5	295.1	299.0	296.7	0.8	3.9	302.9	312.7	308.1	1.8	9.8	295.9	301.6	297.7	1.3	5.7
2015	306.1	317.1	311.8	2.2	11.0	295.4	299.6	296.8	1.0	4.2	303.3	313.4	307.8	1.9	10.1	296.0	301.2	297.7	1.3	5.2

Table 4.21: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for winter season day-night of Ahmedabad

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	302.9	311.5	308.0	1.7	8.6	284.9	291.9	287.0	1.5	7.0	300.6	306.5	304.0	1.1	5.8	287.1	293.8	289.1	1.5	6.7
2004	304.7	311.0	308.3	1.2	6.4	284.6	291.7	286.6	1.4	7.1	301.4	307.0	304.4	1.1	5.6	286.8	294.2	289.1	1.5	7.4
2005	303.1	309.8	306.9	1.2	6.7	283.5	290.9	285.5	1.5	7.4	299.9	305.7	303.4	1.1	5.7	285.3	292.1	287.0	1.5	6.8
2006	304.7	311.4	308.3	1.2	6.7	285.0	291.9	286.8	1.4	7.0	301.5	307.1	304.7	1.1	5.6	287.6	294.3	289.6	1.5	6.7
2007	304.4	311.8	308.8	1.4	7.4	286.1	292.8	288.0	1.5	6.8	301.1	306.6	304.0	1.0	5.5	288.6	295.1	290.3	1.6	6.5
2008	304.2	311.0	307.4	1.2	6.7	285.0	292.3	287.2	1.6	7.3	299.9	305.9	302.7	1.0	6.0	286.2	293.4	288.3	1.7	7.2
2009	304.7	312.3	308.6	1.3	7.6	285.7	292.7	287.6	1.6	7.0	300.7	307.5	304.5	1.3	6.8	287.7	294.6	289.6	1.6	6.9
2010	304.4	310.8	307.5	1.1	6.4	284.5	291.1	286.5	1.5	6.6	301.0	307.1	304.1	1.1	6.1	287.3	293.4	289.2	1.4	6.1
2011	302.9	310.0	306.8	1.1	7.1	284.9	292.1	287.3	1.6	7.1	300.9	307.0	304.1	1.0	6.1	287.6	294.3	289.8	1.5	6.8
2012	304.2	311.1	308.3	0.9	6.8	285.4	292.6	287.7	1.6	7.2	301.2	307.9	305.3	0.7	6.7	286.2	293.4	288.6	1.7	7.2
2013	303.3	310.4	307.1	1.0	7.1	285.0	291.9	287.2	1.6	6.9	299.7	305.7	303.2	0.6	6.0	286.5	293.4	288.7	1.6	6.9
2014	303.9	311.2	308.6	1.0	7.4	285.2	292.1	287.6	1.6	6.9	300.7	307.0	304.3	0.7	6.4	286.9	293.7	289.1	1.6	6.8
2015	296.7	302.3	299.4	1.0	5.6	284.5	291.9	287.0	1.7	7.5	302.4	309.2	306.0	1.0	6.8	288.1	295.0	290.4	1.6	6.8

Table 4.22: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) annually day-night of Ahmedabad

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity	Min	Max	Mean	SD	Intensity
2003	309.4	317.2	313.7	1.6	7.8	290.1	296.1	292.1	1.2	5.9	304.6	311.4	308.6	1.2	6.8	290.9	296.7	292.6	1.3	5.8
2004	308.2	315.4	312.5	1.3	7.2	291.1	296.3	292.4	1.1	5.2	305.2	311.5	308.8	1.3	6.3	292.0	297.5	293.6	1.2	5.5
2005	308.9	315.3	312.4	1.3	6.4	291.2	296.3	292.6	1.2	5.1	306.6	312.2	309.6	1.1	5.6	291.0	296.5	292.5	1.3	5.6
2006	307.4	314.7	311.5	1.3	7.3	290.9	296.3	292.4	1.2	5.4	305.8	311.8	309.1	1.1	6.0	292.2	297.5	293.5	1.2	5.3
2007	308.0	316.4	313.1	1.4	8.4	291.2	296.4	292.7	1.2	5.2	303.3	310.2	307.6	1.2	7.0	292.6	298.2	294.1	1.3	5.7
2008	305.9	315.1	311.5	1.6	9.1	290.1	295.9	291.7	1.3	5.7	302.9	310.8	307.8	1.2	7.8	291.3	297.2	293.1	1.4	5.9
2009	307.7	317.4	313.7	1.3	9.7	291.2	296.7	292.8	1.3	5.5	304.1	312.8	309.7	1.3	8.7	291.7	297.8	293.5	1.5	6.1
2010	306.8	316.0	312.4	1.4	9.3	290.4	295.9	292.0	1.3	5.5	302.6	311.6	308.3	1.4	9.0	292.8	298.4	294.5	1.4	5.6
2011	306.4	314.3	311.0	1.2	7.8	289.6	295.4	291.4	1.4	5.8	303.6	311.3	308.3	1.1	7.6	291.9	297.9	293.8	1.5	6.0
2012	306.2	315.2	311.9	1.4	9.0	290.8	296.4	292.4	1.4	5.6	304.2	311.7	308.8	1.1	7.5	291.3	297.2	293.1	1.5	5.9
2013	308.0	315.2	311.9	1.0	7.2	291.3	296.5	292.9	1.3	5.3	303.4	310.4	307.3	0.9	7.1	291.2	297.1	293.0	1.5	6.0
2014	308.3	316.0	312.7	1.2	7.7	291.0	296.1	292.6	1.2	5.1	304.2	311.3	308.2	0.9	7.1	291.9	297.9	293.8	1.5	6.0
2015	299.9	305.5	302.2	1.2	5.6	291.5	296.7	293.1	1.3	5.2	304.4	312.0	308.5	1.2		292.1	297.9	294.0	1.5	5.8

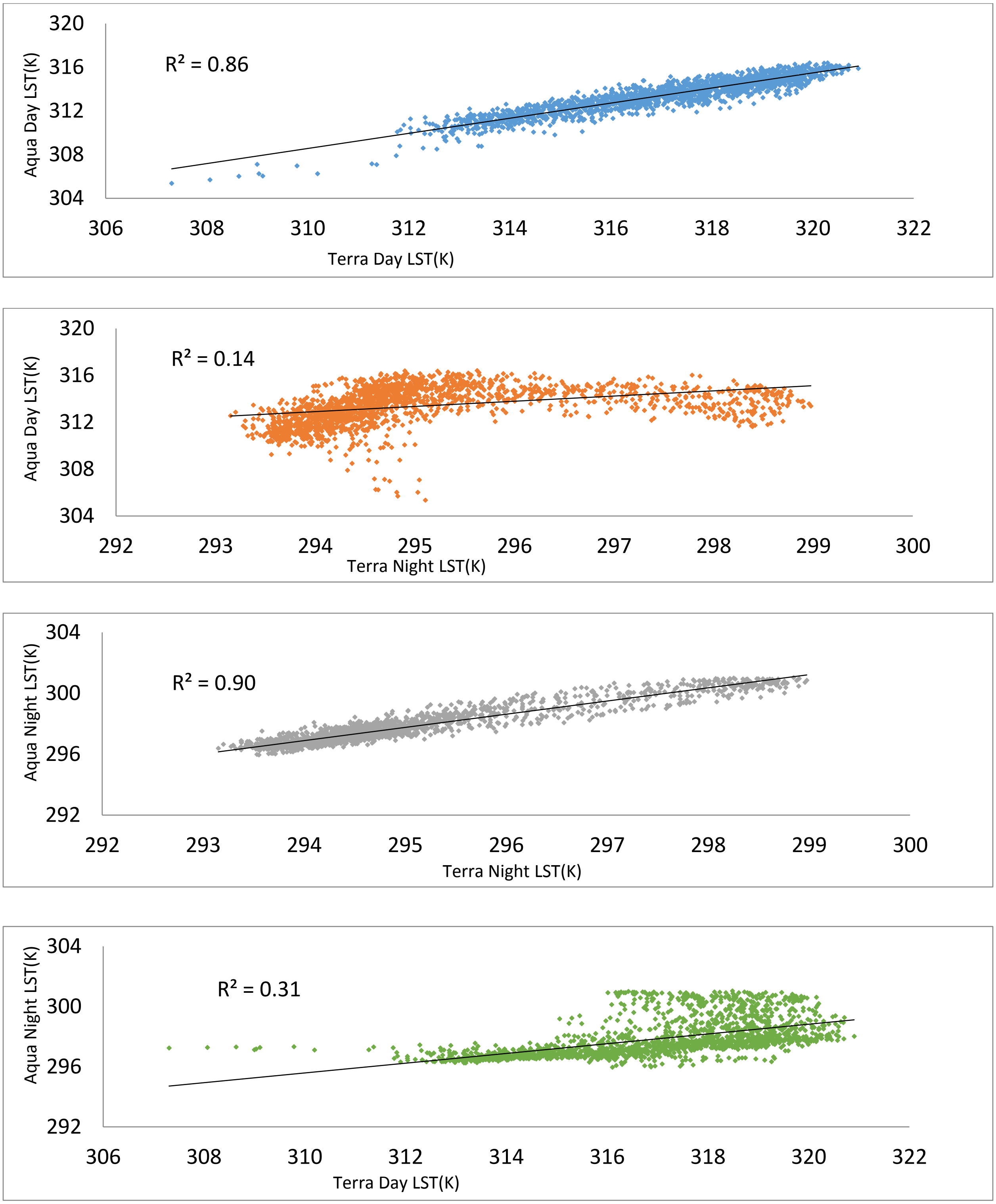


Figure 4.20: Scatter plot between Aqua and Terra LST 8-day data for summer season for Ahmedabad of 2003

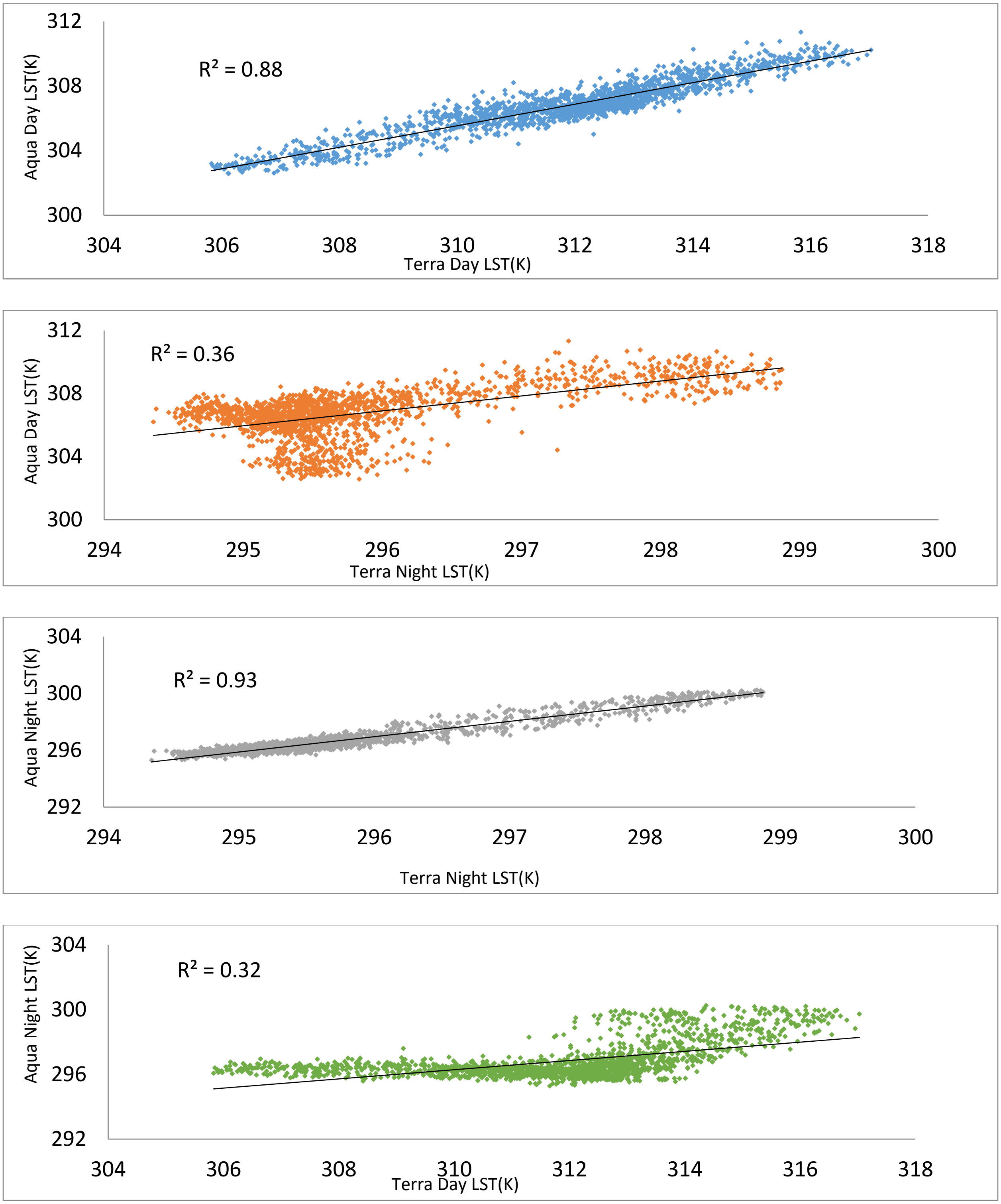


Figure 4.21: Scatter plot between Aqua and Terra LST 8-day data for monsoon season for Ahmedabad of 2003

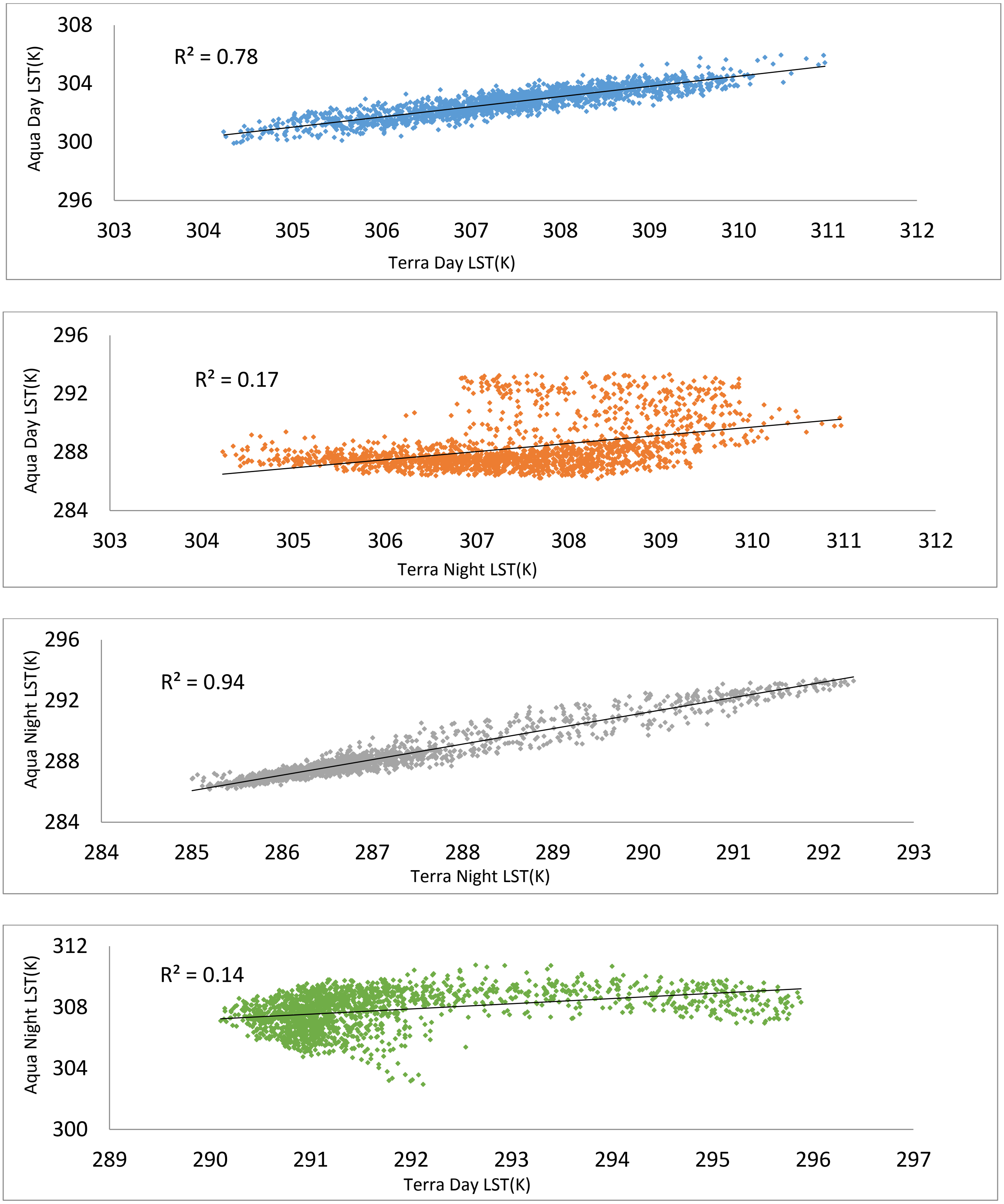


Figure 4.22: Scatterplot between Aqua and Terra LST 8-day data for winter season for Ahmedabad of 2003

4.13. Analysis of R^2 results for Ahmedabad city

The R^2 value for Aqua-Terra derived day-night LST (K) for different seasons is listed in the table 4.23. During day time the correlation range between Aqua LST & Terra LST is obtained 0.68 - 0.85 for summer season, 0.86-0.97 for monsoon, 0.69-0.83 for winter and 0.65-0.88 annually for 2003-2015. The highest R^2 value is achieved for monsoon for 2015year 0.97 which is greater than summer and winter day values as well as night values. These R^2 values are simultaneously affected by lots of variables such as external energy source (Sun light), composition of land surface, and emissivity property of surface and thermal properties of sensor. The summer day R^2 values are comparatively greater than winter which is contrary as winter season has less temperature variation and hence the winter R^2 values should be larger. The possible reason for this contradiction may be cooling effect of Sabarmati River in day time in Ahmedabad city.

The Aqua Day LST vs Terra night LST and Aqua Night LST vs Terra Day LST correlation values (R^2) almost remains same ($0.3< R^2$) for the entire seasons for 2003-15 as there is large diurnal temperature variation in day and night. It is significant that there is no temperature uniformity persists day-night. During night time the correlation range between Aqua LST & Terra LST is obtained 0.90 - 0.93 for summer season, 0.73-0.91 for monsoon, 0.89-0.97 for winter and 0.92-0.94 annually for 2003-2015. The Aqua Night LST & Terra Night LST correlation values are greater than for day values which shows there is no much temperature variation in night time during all the seasons. The highest R^2 value (0.97) for night time is obtained for winter season for 2003 which shows the possibility of temperature uniformity is 97%.

The scatter plots for R^2 values are shown in figure 4.20, 4.21 & 4.22 respectively for the summer, monsoon and winter seasons. For the detailed investigational analysis we divided Ahmedabad study area into urban region and its surrounding rural region (8kms buffer around the city). The study involves the diurnal, seasonal and yearly analysis of day-night LST (K) for rural and urban parts separately.

Table 4.23: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the different seasons for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR AHMEDABAD CITY FOR DIFFERENT SEASON																
	WINTER				MONSOON				WINTER				ANNUAL			
	DAY		NIGHT		DAY		NIGHT		DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.68	0.23	0.93	0.02	0.92	0.22	0.81	0.11	0.83	0.05	0.97	0.00	0.65	0.00	0.95	0.04
2004	0.85	0.17	0.90	0.17	0.86	0.25	0.77	0.11	0.84	0.07	0.89	0.01	0.88	0.13	0.92	0.09
2005	0.64	0.42	0.92	0.00	0.92	0.27	0.73	0.27	0.81	0.07	0.92	0.00	0.84	0.20	0.93	0.06
2006	0.72	0.08	0.92	0.00	0.76	0.34	0.79	0.01	0.85	0.16	0.93	0.02	0.85	0.17	0.94	0.07
2007	0.77	0.07	0.92	0.00	0.87	0.39	0.88	0.26	0.78	0.07	0.93	0.03	0.89	0.17	0.93	0.14
2008	0.86	0.31	0.90	0.14	0.88	0.32	0.93	0.34	0.78	0.17	0.96	0.05	0.89	0.23	0.94	0.14
2009	0.78	0.05	0.91	0.01	0.85	0.22	0.91	0.21	0.77	0.10	0.94	0.02	0.82	0.11	0.94	0.06
2010	0.87	0.20	0.93	0.09	0.93	0.36	0.87	0.27	0.81	0.12	0.92	0.03	0.89	0.22	0.94	0.10
2011	0.82	0.14	0.92	0.05	0.80	0.20	0.82	0.20	0.83	0.13	0.92	0.08	0.85	0.17	0.93	0.14
2012	0.87	0.17	0.94	0.06	0.91	0.50	0.92	0.25	0.59	0.10	0.95	0.02	0.88	0.20	0.96	0.10
2013	0.75	0.15	0.94	0.22	0.64	0.66	0.85	0.41	0.63	0.33	0.96	0.08	0.81	0.30	0.96	0.21
2014	0.77	0.09	0.95	0.03	0.92	0.27	0.88	0.91	0.71	0.03	0.96	0.04	0.83	0.17	0.96	0.13
2015	0.85	0.24	0.93	0.09	0.97	0.46	0.90	0.47	0.69	0.24	0.94	0.14	0.77	0.55	0.94	0.20

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

4.14. Seasonal LST variation results for Ahmedabad Rural area

4.14.1. Summer

The temperature ranges approximately from 306-323K for summer season for day time and 307-325K for night time both for Aqua and Terra. The mean diurnal temperature difference is 23.9K for Aqua LST and 17.8K for Terra LST for 2003-15 for summer season. The maximum difference is 5.7K for 2014 between Aqua and Terra for day temperature and 3.3K for 2004for night temperature in summers. The average UHI intensity is 10.8K, 5.2K, 9.8K & 4.9K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.24.

4.14.2. Monsoon

The temperature ranges approximately from 302-317K for monsoon season for day time and 292-300K for night time both for Aqua and Terra. The mean diurnal temperature difference is 14.8K for Aqua LST and 10.8K for Terra LST for 2003-15 for monsoon. The maximum difference is 4.9K for 2009 between Aqua and Terra for day temperature and 1.1K for 2013for night temperature. The average UHI intensity is 11K, 3.9K, 9.2K & 4.6K is observed for Aqua day, Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.25.

4.14.3. Winter

The temperature ranges approximately from 297-313K for winter season for day time and 283-294K for night time both for Aqua and Terra. The mean diurnal temperature difference is 21.3K for Aqua LST and 15.7K for Terra LST for 2003-15 for winter season which is greater than summer & monsoon. The maximum difference is 5.2K for 2007 between Aqua and Terra for day temperature and 3.2K for 2006 for night temperature in winters. The average UHI intensity is 7.2K, 6.1K, 6.1K & 6.0K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.26.

4.14.4. Annual

The temperature ranges approximately from 302-314K for day time and 290-298K for night time both for Aqua and Terra. The mean diurnal temperature difference is 20.0K for Aqua LST and 15.0K for Terra LST. The maximum difference is 5.1K for 2013 between Aqua and Terra for day temperature and 2.3K for 2004 for night temperature. The average UHI intensity is 6.0K, 5.1K, 8.3K & 5.2K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.27.

4.15. Seasonal LST variation results for Ahmedabad Urban area

4.15.1. Summer

The temperature ranges approximately from 310-325K for summer season for day time and 294-302K for night time both for Aqua and Terra. The mean diurnal temperature difference is 15.6K for Aqua LST and 10.6K for Terra LST for 2003-15 for summer season. The maximum difference is 7.1K for 2013 between Aqua and Terra for day temperature and 2.8K for 2014 for night temperature in summers. The average UHI intensity is 5.9K, 4.2K, 5.1K & 3.6K is observed for Aqua day, Aqua night, Terra day and Terra night in summer. The detailed analysis is tabulated in table 4.10.

4.15.2. Monsoon

The temperature ranges approximately from 302-317K for monsoon season for day time and 294-302K for night time both for Aqua and Terra. The mean diurnal temperature difference is 15.6K for Aqua LST and 10.6K for Terra LST for 2003-15 for monsoon season. The maximum difference is 5.6K for 2008 between Aqua and Terra for day temperature and 1.9K for 2006 for night temperature in monsoons. The average UHI intensity is5.7K, 3.2K, 4.4K & 3.6K is observed for Aqua day, Aqua night, Terra day and Terra night in monsoon. The detailed analysis is tabulated in table 4.11.

4.15.3. Winter

The temperature ranges approximately from 301-312K for winter season for day time and 284-295K for night time both for Aqua and Terra. The mean diurnal temperature difference is 18.8K for Aqua LST and 12.5K for Terra LST for 2003-15 for winter season. The maximum difference is 5.6K for 2007 between Aqua and Terra for day temperature and 3.5K for 2006 for night temperature in winters. The average UHI intensity is 4.8K, 5.4K, 3.9K & 5.0K is observed for Aqua day, Aqua night, Terra day and Terra night in winter. The detailed analysis is tabulated in table 4.12.

Table 4.24: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Rural Ahmedabad

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	315.0	324.1	319.9	1.6	9.1	293.6	298.1	294.8	0.7	4.5	309.6	319.0	314.8	1.4	9.5	294.2	298.5	295.8	0.7	4.3
2004	314.8	323.9	319.7	1.7	9.1	292.5	298.2	294.3	0.8	5.7	310.3	318.9	315.1	1.7	8.6	296.3	300.4	297.6	0.7	4.1
2005	316.8	324.4	320.7	1.6	7.6	294.1	299.9	295.8	0.9	5.9	315.2	321.7	318.5	1.2	6.6	293.9	299.3	295.7	0.9	5.4
2006	313.3	321.6	318.0	1.6	8.3	293.4	298.7	295.0	0.9	5.3	311.9	318.4	315.2	1.2	6.6	294.6	299.5	296.0	0.7	4.9
2007	313.3	324.1	320.2	1.6	10.8	294.4	299.2	295.8	0.8	4.8	308.2	317.4	314.7	1.3	9.1	296.5	300.8	297.9	0.8	4.3
2008	307.3	320.9	316.8	2.2	13.6	293.1	298.6	294.7	0.8	5.5	305.4	316.4	313.3	1.6	11.0	296.0	300.3	297.4	0.8	4.4
2009	311.6	324.5	321.0	1.5	12.8	293.4	298.9	295.0	0.9	5.5	308.2	319.6	316.2	1.5	11.3	295.0	300.2	296.6	0.9	5.2
2010	310.9	324.8	320.7	2.0	13.9	294.1	299.3	295.7	0.9	5.2	304.3	319.0	314.8	2.2	14.7	296.3	301.7	297.9	1.0	5.4
2011	308.6	322.3	318.4	1.6	13.7	294.1	299.3	295.7	0.9	5.2	306.0	317.5	314.4	1.4	11.5	293.0	298.4	294.8	0.9	5.4
2012	308.8	322.1	318.3	1.8	13.4	293.7	298.8	295.2	0.9	5.1	304.8	316.4	313.0	1.7	11.7	294.6	299.9	296.2	0.9	5.3
2013	315.3	323.8	319.4	1.5	8.4	294.5	299.9	296.1	1.0	5.4	308.2	316.2	312.2	1.4	8.0	295.8	301.5	297.6	1.0	5.7
2014	312.9	322.9	319.1	1.5	9.9	293.3	298.4	294.6	0.9	5.1	308.4	317.0	313.4	1.4	8.6	295.7	301.0	297.2	0.9	5.3
2015	313.8	323.5	318.7	1.4	9.7	295.0	299.4	296.4	0.8	4.5	305.8	316.0	312.7	1.6	10.3	295.3	299.9	296.5	0.9	4.7

Table 4.25: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for monsoon season day-night of Rural Ahmedabad

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	303.3	316.2	311.0	2.5	12.9	292.3	297.9	294.9	0.8	5.6	302.5	313.4	308.8	2.0	10.9	292.6	299.0	294.8	0.8	6.4
2004	302.3	312.5	308.5	1.8	10.2	293.8	296.8	294.9	0.5	3.0	300.3	309.3	305.9	1.5	9.0	293.7	298.3	295.9	0.6	4.6
2005	303.7	313.9	309.1	1.8	10.3	294.0	297.6	295.3	0.5	3.6	302.3	311.3	307.1	1.7	9.0	294.9	298.7	296.0	0.6	3.8
2006	304.5	315.5	310.7	1.9	10.9	295.3	298.6	296.5	0.4	3.2	303.6	313.3	309.1	1.8	9.7	296.1	300.1	297.1	0.6	4.0
2007	303.7	314.0	309.3	1.9	10.3	293.1	297.1	294.3	0.6	4.0	301.3	310.4	306.2	1.8	9.1	293.3	298.3	294.6	0.7	5.0
2008	305.8	317.0	311.4	2.0	11.1	294.4	298.3	295.5	0.6	4.0	302.6	310.1	306.4	1.4	7.5	295.3	299.5	296.4	0.6	4.2
2009	305.0	317.5	313.1	2.1	12.5	294.8	298.6	296.0	0.6	3.8	302.4	312.1	308.2	1.8	9.6	295.3	299.7	296.5	0.7	4.4
2010	303.5	316.7	310.4	2.4	13.2	295.2	299.6	296.4	0.7	4.4	302.0	311.6	306.8	1.8	9.6	295.7	299.9	296.9	0.6	4.3
2011	306.2	316.2	311.8	1.6	10.0	295.2	299.6	296.4	0.7	4.4	303.2	311.8	307.7	1.5	8.7	293.5	298.3	295.6	0.7	4.8
2012	304.9	315.2	310.5	1.7	10.3	294.1	298.0	295.2	0.7	4.0	302.8	310.9	307.0	1.6	8.2	295.1	299.8	296.4	0.7	4.7
2013	304.7	313.7	308.4	1.3	9.0	294.7	298.4	295.9	0.5	3.7	300.1	309.5	304.1	1.3	9.4	295.8	300.0	297.0	0.7	4.2
2014	305.3	316.7	310.5	2.0	11.5	295.1	298.4	296.4	0.6	3.3	302.9	312.3	307.8	1.7	9.4	295.9	300.8	297.3	0.7	5.0
2015	306.1	316.9	311.3	1.9	10.9	295.4	299.1	296.5	0.6	3.7	303.3	312.7	307.4	1.7	9.5	296.0	300.7	297.3	0.8	4.7

Table 4.26: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for winter season day-night of Rural Ahmedabad

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	302.9	311.5	307.8	1.7	8.6	284.9	290.6	286.5	0.7	5.6	300.6	306.5	304.0	1.2	5.8	287.1	292.9	288.7	0.7	5.8
2004	304.7	311.0	308.2	1.2	6.4	284.6	290.3	286.1	0.8	5.7	301.4	307.0	304.3	1.2	5.6	286.8	293.1	288.6	0.7	6.3
2005	303.1	309.8	306.8	1.2	6.7	283.5	289.6	285.0	0.8	6.1	299.9	305.7	303.3	1.2	5.7	285.3	291.2	286.5	0.8	5.9
2006	304.7	311.4	308.1	1.2	6.7	285.0	290.7	286.4	0.8	5.7	301.5	307.1	304.7	1.1	5.6	288.4	293.8	289.6	0.8	5.4
2007	304.5	312.5	309.2	1.5	8.1	286.1	292.0	287.5	0.8	6.0	300.9	306.8	304.0	1.1	5.9	288.3	294.3	289.5	0.8	6.0
2008	304.2	311.0	307.3	1.2	6.7	285.0	291.4	286.7	0.9	6.4	299.9	305.9	302.6	1.0	6.0	286.2	292.5	287.7	0.9	6.3
2009	304.7	312.3	308.5	1.3	7.6	285.7	291.7	287.1	0.9	6.0	300.7	307.5	304.4	1.4	6.8	287.7	293.7	289.0	0.8	6.1
2010	304.4	310.8	307.4	1.1	6.4	284.5	290.3	286.0	0.8	5.8	301.0	307.0	304.0	1.1	6.0	287.3	292.5	288.8	0.8	5.2
2011	302.9	310.0	306.7	1.1	7.1	284.5	290.3	286.0	0.8	5.8	300.9	306.8	304.0	1.0	5.9	284.9	291.4	286.8	0.9	6.5
2012	304.2	311.1	308.2	0.8	6.8	285.4	291.8	287.2	1	6.4	301.2	307.8	305.2	0.7	6.6	286.2	292.6	287.9	0.9	6.3
2013	303.3	310.4	306.9	0.9	7.1	285	291.1	286.6	0.9	6.1	299.7	305.6	303.2	0.6	5.9	286.5	292.8	288.2	0.9	6.3
2014	303.9	311.2	308.6	1	7.4	285.2	291.4	287.1	0.9	6.2	300.7	306.9	304.2	0.7	6.3	286.9	293.1	288.5	0.9	6.2
2015	304.2	311.8	308	0.8	7.6	284.5	291.3	286.5	1.1	6.9	302.4	309.2	305.9	1	6.8	288.1	294.3	289.9	1	6.2

Table 4.27: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) annually day-night of Rural Ahmedabad

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	307.1	313.0	312.9	1.9	5.9	290.3	295.5	292.1	0.7	5.3	304.2	313.0	309.2	1.5	8.7	291.3	296.8	293.1	0.7	5.5
2004	307.2	312.4	312.1	1.6	5.2	290.3	295.1	291.7	0.7	4.8	304.0	311.8	308.4	1.5	7.8	292.3	297.3	294.0	0.7	5.0
2005	307.9	312.6	312.2	1.5	4.8	290.5	295.7	292.0	0.7	5.2	305.8	312.9	309.6	1.4	7.1	291.4	296.4	292.8	0.7	5.0
2006	307.5	312.5	312.3	1.6	5.0	291.2	296.0	292.6	0.7	4.8	305.7	312.9	309.7	1.4	7.3	293.0	297.8	294.2	0.7	4.7
2007	307.1	313.4	312.9	1.6	6.3	291.2	296.1	292.5	0.7	4.9	303.5	311.5	308.3	1.4	8.1	292.7	297.8	294.0	0.8	5.1
2008	305.8	312.6	311.8	1.8	6.8	290.8	296.1	292.3	0.8	5.3	302.6	310.8	307.5	1.3	8.2	292.5	297.4	293.9	0.7	5.0
2009	307.1	313.9	314.2	1.6	6.8	291.3	296.4	292.7	0.8	5.1	303.8	313.0	309.6	1.6	9.2	292.7	297.9	294.0	0.8	5.2
2010	306.3	313.1	312.8	1.8	6.8	291.2	296.4	292.7	0.8	5.2	302.4	311.5	308.5	1.7	9.1	293.1	298.0	294.5	0.8	5.0
2011	305.9	312.8	312.3	1.5	6.9	291.2	296.4	292.7	0.8	5.2	303.4	312.1	308.7	1.3	8.7	290.5	296.0	292.4	0.9	5.6
2012	306.0	312.7	312.3	1.5	6.7	291.1	296.2	292.5	0.8	5.1	302.9	311.7	308.4	1.3	8.8	292.0	297.4	293.5	0.9	5.4
2013	307.8	312.9	311.6	1.2	5.2	291.4	296.5	292.9	0.8	5.1	302.6	310.4	306.5	1.1	7.8	292.7	298.1	294.2	0.9	5.4
2014	307.3	313.1	312.7	1.5	5.8	291.2	296.1	292.7	0.8	4.9	304.0	312.1	308.5	1.3	8.1	292.8	298.3	294.3	0.9	5.5
2015	307.6	312.8	310.2	1.3	5.2	291.6	296.6	294.1	0.8	5.0	303.8	312.6	308.6	1.4	8.8	293.1	298.3	294.6	0.9	5.2

4.15.4. Annual

The temperature ranges approximately from 305-317K for day time and 291-299K for night time both for Aqua and Terra. The mean diurnal temperature difference is 18.9Kfor Aqua LST and 12.7Kfor Terra LST. The maximum difference is 7.3K for 2015 between Aqua and Terra for day temperature and 2.3K for 2004 for night temperature. The average UHI intensity is 5.4K, 4.2K, 4.6K & 4.1K is observed for Aqua day, Aqua night, Terra day and Terra night. The detailed analysis is tabulated in table 4.13.

4.16. Comparison of results for rural, urban and composite area

The average day and night temperature ranges remains almost same for all three areas for all three seasons. The temperature ranges 299-325K, 300-317K, 297-317K for day time and 292-302K, 291-302K, 283-298K for night time respectively for summer, monsoon and winter seasons. Aqua derived mean diurnal temperature difference is observed greater than terra derived like Jaipur. The diurnal temperature difference is highest for summers and lowest for winters just opposite to Jaipur. The rural area diurnal temperature difference is greater than urban one similar to Jaipur. The LST difference between aqua and terra derived is found highest during day time in urban area of Ahmedabad in comparison of night time and rural area. The LST difference is highest in summer and lowest in winter season for both rural and urban areas. The important term Urban Heat Island Intensity (K) is obtained greater for day time in comparison to night time. The UHII (K) is found highest in summer (almost double than winter) and lowest in winters. The UHII for rural areas is greater than urban areas. UHII derived from Aqua is higher than Terra one both in day and night time for rural and urban areas.

Table 4.28: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for summer season day-night of Urban Ahmedabad

	AQUA SUMMER LST										TERRA SUMMER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	317.5	322.8	320.0	1.2	5.3	294.7	298.7	297.6	0.8	3.9	312.2	317.4	314.6	1.1	5.2	296.2	299.6	298.7	0.7	3.5
2004	316.7	323.1	320.2	1.3	6.4	294.3	299.1	297.5	1.1	4.8	313.0	318.0	315.8	1.1	4.9	298.0	301.2	300.1	0.6	3.2
2005	316.7	323.5	321.0	1.3	6.8	295.6	300.2	298.9	1.0	4.6	315.1	321.0	317.8	1.2	5.9	295.9	300.4	299.1	0.8	4.5
2006	315.0	321.5	318.6	1.3	6.5	294.8	299.3	298.0	0.9	4.5	312.3	317.6	315.1	1.1	5.3	296.5	300.2	299.0	0.7	3.7
2007	317.9	323.8	320.6	1.3	5.9	295.8	299.7	298.6	0.8	3.9	312.6	316.9	314.6	1.0	4.3	298.2	301.5	300.6	0.6	3.3
2008	315.1	320.5	318.3	1.1	5.5	294.5	299.0	297.7	0.9	4.4	311.6	316.1	314.0	1.0	4.5	298.2	301.0	300.2	0.6	2.9
2009	317.7	323.9	321.1	1.3	6.3	295.2	299.4	298.2	0.9	4.3	313.8	319.3	316.0	1.1	5.6	297.1	301.2	300.1	0.8	4.1
2010	318.3	324.3	321.5	1.2	6.0	295.8	300.1	298.8	0.8	4.3	312.8	318.8	315.1	1.2	6.0	298.8	302.6	301.5	0.8	3.8
2011	316.0	321.5	319.0	1.2	5.5	295.8	300.1	298.8	0.8	4.3	312.4	317.1	314.5	1.0	4.8	294.8	298.9	297.8	0.8	4.1
2012	315.8	321.7	319.1	1.2	5.9	295.1	299.2	298.2	0.8	4.2	310.8	316.5	313.4	1.0	5.7	296.9	300.5	299.5	0.7	3.6
2013	317.7	322.8	319.8	1.1	5.1	296.4	300.2	299.2	0.7	3.8	311.0	315.9	312.7	0.9	4.8	298.5	302.1	301.1	0.8	3.7
2014	316.6	322.1	319.5	1.1	5.5	295.1	298.6	297.7	0.7	3.6	311.3	316.6	313.5	1.0	5.3	298.1	301.6	300.5	0.7	3.5
2015	317.2	322.9	320.1	1.1	5.7	296.3	300.0	298.9	0.6	3.7	311.5	315.7	313.2	0.9	4.2	297.4	300.4	299.6	0.6	3.0

Table 4.29: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) for monsoon season day-night of Urban Ahmedabad

	AQUA MONSOON LST										TERRA MONSOON LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	310.4	316.8	313.9	1.1	6.4	295.0	298.8	297.3	0.8	3.8	308.9	312.9	311.0	0.9	4.0	295.4	300.1	298.3	1.1	4.7
2004	307.2	312.5	310.3	1.1	5.3	294.4	297.6	296.4	0.6	3.2	304.7	309.6	307.4	0.9	4.9	296.2	299.0	297.9	0.5	2.8
2005	309.3	315.1	312.7	1.2	5.7	294.8	298.2	297.1	0.6	3.4	306.8	312.0	309.9	1.0	5.2	296.2	299.6	298.3	0.7	3.4
2006	310.3	315.9	313.1	1.1	5.6	296.2	299.0	297.8	0.5	2.8	309.1	313.3	310.8	0.9	4.2	297.4	301.1	299.7	0.8	3.7
2007	309.9	315.2	312.8	1.2	5.3	294.3	297.4	296.4	0.7	3.2	306.9	310.9	308.9	0.8	4.0	294.6	298.9	297.6	0.9	4.3
2008	311.3	317.0	314.5	1.2	5.7	295.6	298.9	297.8	0.7	3.3	306.6	311.3	308.9	0.8	4.8	296.8	300.2	299.1	0.8	3.5
2009	311.5	317.3	314.9	1.1	5.8	296.3	299.2	298.3	0.6	2.9	308.2	312.3	310.2	0.9	4.1	296.9	300.4	299.4	0.7	3.5
2010	311.0	317.1	314.6	1.2	6.1	296.4	299.9	298.7	0.8	3.5	307.2	312.6	310.3	1.0	5.4	297.2	300.7	299.5	0.8	3.5
2011	310.8	316.7	313.9	1.1	5.9	296.4	299.9	298.7	0.8	3.5	307.8	312.5	310.0	1.0	4.8	295.6	298.8	297.8	0.6	3.3
2012	310.0	315.3	313.2	1.0	5.3	295.2	298.7	297.5	0.7	3.4	307.3	311.5	309.5	0.8	4.2	296.9	300.4	299.3	0.8	3.5
2013	308.6	314.6	311.8	1.2	5.9	296.0	298.9	297.7	0.6	2.9	302.5	309.6	306.5	1.6	7.1	297.5	300.8	299.6	0.7	3.3
2014	310.5	316.3	313.4	1.2	5.7	296.5	299.0	298.1	0.5	2.6	307.8	312.7	310.1	1.0	4.9	297.7	301.6	300.3	0.8	3.8
2015	311.6	317.1	314.7	1.1	5.5	296.7	299.6	298.6	0.6	3.0	308.1	313.4	310.5	1.1	5.3	297.8	301.2	300.2	0.7	3.4

Table 4.30: Minimum LST, Maximum LST, Mean LST, Standard Deviation, UHI Intensity (K) for winter season day-night of Urban Ahmedabad

	AQUA WINTER LST										TERRA WINTER LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	306.4	310.8	308.9	1.0	4.4	286.4	291.9	289.8	1.2	5.5	302.4	306.2	304.4	0.8	3.8	288.9	293.8	292.1	1.1	4.9
2004	306.5	310.8	309.0	1.0	4.3	285.6	291.7	289.3	1.3	6.0	302.9	306.5	304.8	0.8	3.5	288.9	294.2	292.1	1.2	5.3
2005	305.1	309.7	307.5	1.0	4.6	284.7	290.9	288.4	1.4	6.2	301.9	305.6	303.8	0.8	3.7	286.6	292.1	290.2	1.2	5.5
2006	307.1	311.3	309.2	0.9	4.2	286.4	291.9	289.6	1.3	5.5	303.6	306.9	305.3	0.7	3.3	289.6	294.9	293.1	1.2	5.3
2007	307.9	312.4	310.2	1.0	4.5	287.6	292.8	290.9	1.2	5.2	302.7	306.7	304.6	0.8	4.0	290.0	294.8	293.3	1.1	4.8
2008	306.2	310.5	308.5	0.9	4.2	286.8	292.3	290.2	1.3	5.6	301.8	305.9	303.2	0.7	4.2	288.1	293.4	291.7	1.2	5.3
2009	306.9	311.7	309.4	1.0	4.8	286.9	292.7	290.8	1.3	5.8	303.3	307.0	305.1	0.8	3.7	289.6	294.6	293.0	1.1	5.0
2010	306.2	310.6	308.3	0.9	4.4	286.1	291.1	289.4	1.1	5.0	302.7	307.1	304.4	0.8	4.4	289.1	293.4	292.0	1.0	4.3
2011	305.4	309.9	307.6	1.0	4.5	286.1	291.1	289.4	1.1	5.0	303.1	307.0	304.6	0.8	3.9	286.9	292.1	290.4	1.2	5.2
2012	306.2	311.0	308.9	1.0	4.8	287.2	292.6	290.8	1.1	5.4	303.7	307.9	305.3	0.8	4.2	288.3	293.1	291.7	1.0	4.9
2013	306.1	310.2	308.2	0.8	4.1	286.9	291.9	290.2	1.1	5.0	302.1	305.7	303.5	0.7	3.6	288.7	293.4	292.0	1.0	4.7
2014	306.9	311.2	308.8	1.0	4.2	287.7	292.1	290.6	1.0	4.5	303.1	307.0	304.4	0.8	3.9	288.9	293.7	292.2	1.0	4.7
2015	306.4	311.6	309.0	1.1	5.2	286.8	291.9	290.2	1.2	5.1	305.1	309.2	306.5	0.8	4.0	290.6	295.0	293.6	0.9	4.4

Table 4.31: Minimum LST, Maximum LST, Mean LST, Standard Deviation, and UHI Intensity (K) annually day-night of Urban Ahmedabad

	AQUA ANNUAL LST										TERRA ANNUAL LST									
	DAY					NIGHT					DAY					NIGHT				
Year	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**	**Min**	**Max**	**Mean**	**SD**	**Intensity**
2003	311.4	316.8	314.3	1.1	5.4	292.0	296.5	294.9	0.9	4.4	307.8	312.2	310.0	0.9	4.3	293.5	297.9	296.4	1.1	4.4
2004	310.1	315.4	313.2	1.1	5.3	291.4	296.1	294.4	1.0	4.7	306.9	311.4	309.3	0.9	4.5	294.4	298.2	296.7	0.9	3.8
2005	310.4	316.1	313.7	1.2	5.7	291.7	296.4	294.8	1.0	4.7	307.9	312.9	310.5	1.0	4.9	292.9	297.4	295.8	0.9	4.5
2006	310.8	316.2	313.6	1.1	5.4	292.5	296.8	295.2	0.9	4.3	308.3	312.6	310.4	0.9	4.3	294.5	298.7	297.3	0.9	4.2
2007	311.9	317.1	314.5	1.2	5.2	292.6	296.6	295.3	0.9	4.1	307.4	311.5	309.4	0.9	4.1	294.3	298.4	297.1	1.0	4.1
2008	310.9	316.0	313.8	1.1	5.2	292.3	296.7	295.2	1.0	4.4	306.6	311.1	308.7	0.9	4.5	294.4	298.2	297.0	0.9	3.9
2009	312.0	317.6	315.1	1.1	5.6	292.8	297.1	295.7	0.9	4.3	308.4	312.9	310.4	0.9	4.5	294.5	298.7	297.5	0.9	4.2
2010	311.8	317.4	314.8	1.1	5.5	292.8	297.0	295.6	0.9	4.3	307.6	312.8	310.0	1.0	5.2	295.0	298.9	297.6	0.9	3.9
2011	310.7	316.0	313.5	1.1	5.3	292.8	297.0	295.6	0.9	4.3	307.7	312.2	309.7	0.9	4.5	292.4	296.6	295.3	0.9	4.2
2012	310.7	316.0	313.7	1.0	5.3	292.5	296.8	295.5	0.9	4.3	307.3	312.0	309.4	0.8	4.7	294.0	298.0	296.9	0.9	4.0
2013	310.8	315.9	313.3	1.0	5.0	293.1	297.0	295.7	0.8	3.9	305.2	310.4	307.6	1.1	5.2	294.9	298.8	297.5	1.1	3.9
2014	311.4	316.5	313.9	1.1	5.2	293.1	296.6	295.4	0.8	3.5	307.4	312.1	309.3	0.9	4.7	294.9	298.9	297.7	0.9	4.0
2015	310.5	316.5	317.4	0.7	6.1	293.3	297.2	295.9	0.8	3.9	308.2	312.7	310.1	0.9	4.5	295.3	298.9	297.8	0.9	3.6

4.17. Distinct R^2 seasonal comparative analysis for rural and urban Ahmedabad

4.17.1 .Summer Season

The R^2 values for summer season for different day-night times are reported in the table 4.32. The R^2 values for rural areas for day and night time is greater than urban areas which signifies that urban areas have more temperature anomalies. The night R^2 values (ranges from .77-.93 for rural areas and .64-.91 for urban areas) is larger than day R^2 values (ranges from .69-.89 for rural areas and .60-.77 for urban areas).

4.17.2. Monsoon Season

The R^2 values for monsoon season for different day-night times are reported in the table 4.33. The R^2 values for rural areas for day and night time is greater than urban areas which signifies that urban areas have more temperature anomalies like summer season. The night R^2 values (ranges from .62-.92 for rural areas and .46-.84 for urban areas) are larger than day R^2 values (ranges from .64-.89 for rural areas and .52-.84 for urban areas. There is no existence of day-night temperature correlation in both areas.

4.17.3. Winter Season

The R^2 values for winter season for different day-night times are reported in the table 4.34. The winter R^2 values is lesser than summer values for both rural and urban areas. The R^2 values for rural areas for day and night time is greater than urban areas which signifies that urban areas have more temperature anomalies like above two seasons. The night R^2 values (ranges from .68-.95 for rural areas and .76-.88 for urban areas) is larger than day R^2 values (ranges from .52-.87 for rural areas and .51-.75 for urban areas). The main difference from previous two seasons occur in winter that there is comparatively good correlation between Aqua Day LST and Terra Night LST in urban area.

Table 4.32: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the summer season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR AHMEDABAD CITY FOR SUMMER SEASON								
RURAL					URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	**ADVTD**	**ADVTN**	**ANVTN**	**ANVTD**	**ADVTD**	**ADVTN**	**ANVTN**	**ANVTD**
2003	0.86	0.35	0.83	0.17	0.71	0.32	0.69	0.44
2004	0.86	0.44	0.77	0.40	0.72	0.23	0.64	0.38
2005	0.69	0.33	0.80	0.16	0.71	0.17	0.71	0.49
2006	0.78	0.41	0.82	0.32	0.63	0.13	0.72	0.44
2007	0.82	0.44	0.82	0.24	0.73	0.22	0.70	0.38
2008	0.88	0.42	0.78	0.29	0.60	0.05	0.65	0.19
2009	0.80	0.18	0.79	0.12	0.68	0.12	0.70	0.35
2010	0.88	0.40	0.84	0.26	0.69	0.16	0.68	0.46
2011	0.83	0.24	0.93	0.18	0.77	0.04	0.91	0.30
2012	0.89	0.24	0.86	0.12	0.73	0.12	0.74	0.36
2013	0.75	0.36	0.88	0.44	0.73	0.19	0.77	0.32
2014	0.78	0.18	0.87	0.09	0.69	0.11	0.82	0.20
2015	0.82	0.23	0.89	0.20	0.71	0.07	0.81	0.26

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

4.18. Analysis of Aqua and Terra LST variation between rural and urban area for day time

It is observed that rural area day temperature attains a lesser value than an urban area during all three seasons. The detailed LST values is tabulated in table 4.35 and typical scatter plots are shown in figures 4.23, 4.25, 4.27 & 4.29 for summer ,monsoon, winter and annual respectively.

Table 4.33: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the monsoon season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR AHMEDABAD CITY FOR MONSOON SEASON								
	RURAL				URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.76	0.11	0.92	0.01	0.52	0.01	0.71	0.01
2004	0.72	0.13	0.85	0.01	0.69	0.17	0.57	0.05
2005	0.68	0.00	0.91	0.05	0.78	0.25	0.55	0.23
2006	0.99	0.10	0.84	0.00	0.52	0.16	0.46	0.00
2007	0.72	0.01	0.90	0.00	0.76	0.20	0.67	0.25
2008	0.81	0.12	0.86	0.10	0.63	0.08	0.80	0.19
2009	0.77	0.22	0.84	0.09	0.73	0.00	0.78	0.00
2010	0.71	0.09	0.91	0.02	0.73	0.28	0.77	0.39
2011	0.66	0.01	0.77	0.01	0.59	0.01	0.83	0.16
2012	0.77	0.03	0.88	0.03	0.75	0.10	0.74	0.10
2013	0.64	0.36	0.62	0.23	0.52	0.40	0.70	0.06
2014	0.75	0.06	0.91	0.00	0.83	0.16	0.84	0.20
2015	0.75	0.23	0.89	0.23	0.70	0.10	0.65	0.19

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

Table 4.34: Coefficient of correlation between Aqua & Terra data retrieved LST (K) for the winter season for the study area

COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR AHMEDABAD CITY FOR WINTER SEASON								
RURAL					URBAN			
	DAY		NIGHT		DAY		NIGHT	
Year	ADVTD	ADVTN	ANVTN	ANVTD	ADVTD	ADVTN	ANVTN	ANVTD
2003	0.85	0.03	0.91	0.00	0.64	0.25	0.88	0.50
2004	0.86	0.06	0.68	0.01	0.66	0.17	0.76	0.39
2005	0.83	0.09	0.77	0.00	0.70	0.22	0.84	0.36
2006	0.87	0.12	0.79	0.00	0.70	0.06	0.83	0.27
2007	0.81	0.09	0.77	0.03	0.69	0.17	0.77	0.22
2008	0.80	0.11	0.84	0.05	0.59	0.08	0.83	0.15
2009	0.79	0.10	0.83	0.02	0.51	0.16	0.82	0.40
2010	0.83	0.07	0.79	0.03	0.68	0.05	0.81	0.25
2011	0.83	0.09	0.95	0.08	0.73	0.04	0.88	0.16
2012	0.62	0.08	0.87	0.10	0.61	0.04	0.84	0.10
2013	0.66	0.23	0.90	0.13	0.74	0.00	0.88	0.05
2014	0.70	0.05	0.88	0.09	0.75	0.05	0.85	0.11
2015	0.32	0.54	0.85	0.11	0.67	0.21	0.79	0.05

ADVTD-Aqua day LST VS Terra day LST correlation coefficient; ADVTN-Aqua day LST VS Terra night LST correlation coefficient; ANVTN-Aqua night LST VS Terra night LST correlation coefficient; ANVTD-Aqua night LST VS Terra day LST correlation coefficient;

4.19. Analysis of Aqua and Terra LST variation between rural and urban area for night time

It is observed that urban area night temperature attains a lesser value than a rural area night temperature during all three seasons. The possible reason is due to cooling effect of Sabarmati River. The detailed LST values is tabulated in table 4.36 and typical scatter plots are shown in figures 4.24, 4.26, 4.28 & 4.30 for summer ,monsoon, winter and annual respectively.

Table 4.35: Seasonal LST (K) variation comparison between Rural-Urban over a year for Day time for study area

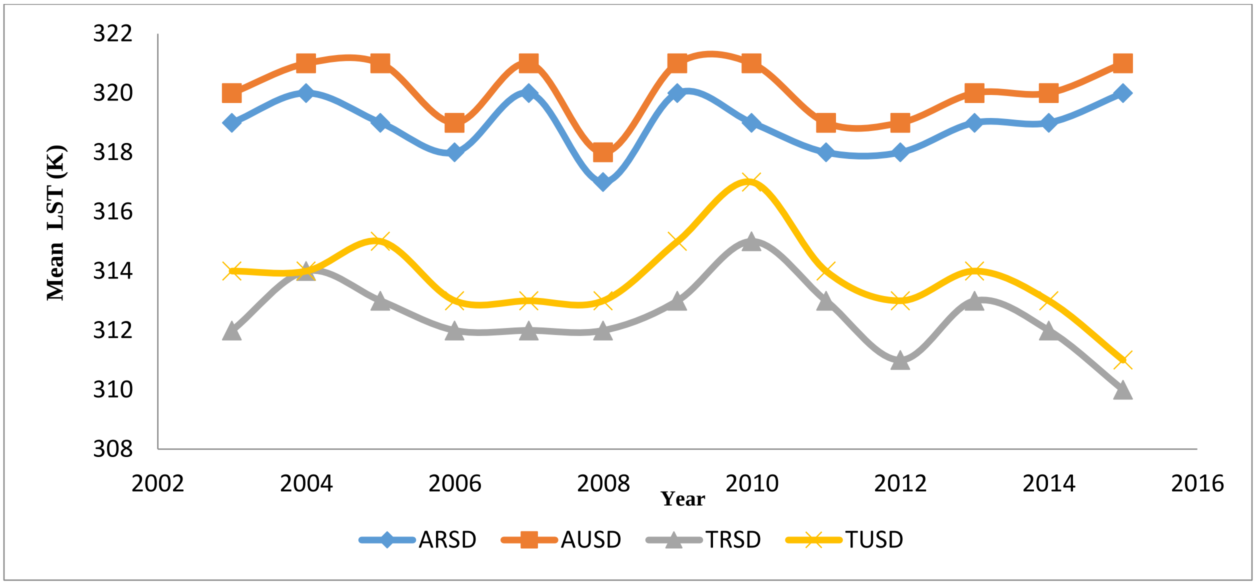
Year	ARSD	AUSD	TRSD	TUSD	ARMD	AUMD	TRMD	TUMD	ARWD	AUWD	TRWD	TUWD	ARAD	AUAD	TRAD	TUAD
2003	319	320	312	314	311	314	306	308	308	309	303	304	313	314	309	310
2004	320	321	314	314	309	313	306	307	308	309	301	302	312	313	308	309
2005	319	321	313	315	309	313	308	309	307	308	301	302	312	314	310	311
2006	318	319	312	313	311	313	307	309	308	309	305	306	312	314	310	310
2007	320	321	312	313	309	313	306	308	309	310	304	305	313	315	308	309
2008	317	318	312	313	311	315	309	310	307	308	303	305	312	314	308	309
2009	320	321	313	315	313	315	308	310	308	309	303	305	314	315	310	310
2010	319	321	315	317	310	315	307	308	307	308	300	301	313	315	309	310
2011	318	319	313	314	312	314	306	308	307	308	302	303	312	314	309	310
2012	318	319	311	313	310	313	308	310	308	309	302	304	312	314	308	309
2013	319	320	313	314	308	312	307	308	307	308	302	303	312	313	307	308
2014	319	320	312	313	311	313	309	310	308	309	302	303	313	314	309	309
2015	320	321	310	311	311	315	307	309	307	309	303	305	310	317	309	310

ARSD-Aqua Rural Winter Day LST(K) ; AUSD-Aqua Urban Winter Day LST(K); TRSD-Terra Rural Winter Day LST(K); TUSD- Terra Urban Winter Day LST(K)
ARSD-Aqua Rural Monsoon Day LST(K); AUSD-Aqua Urban Monsoon Day LST(K); TRSD-Terra Rural Monsoon Day LST(K); TUSD- Terra Urban Monsoon Day LST(K)
ARSD-Aqua Rural Winter Day LST(K); AUSD-Aqua Urban Winter Day LST(K); TRSD-Terra Rural Winter Day LST(K); TUSD- Terra Urban Winter Day LST(K)

Table 4.36: Seasonal LST (K) variation comparison between Rural-Urban over a year for Night time for study area

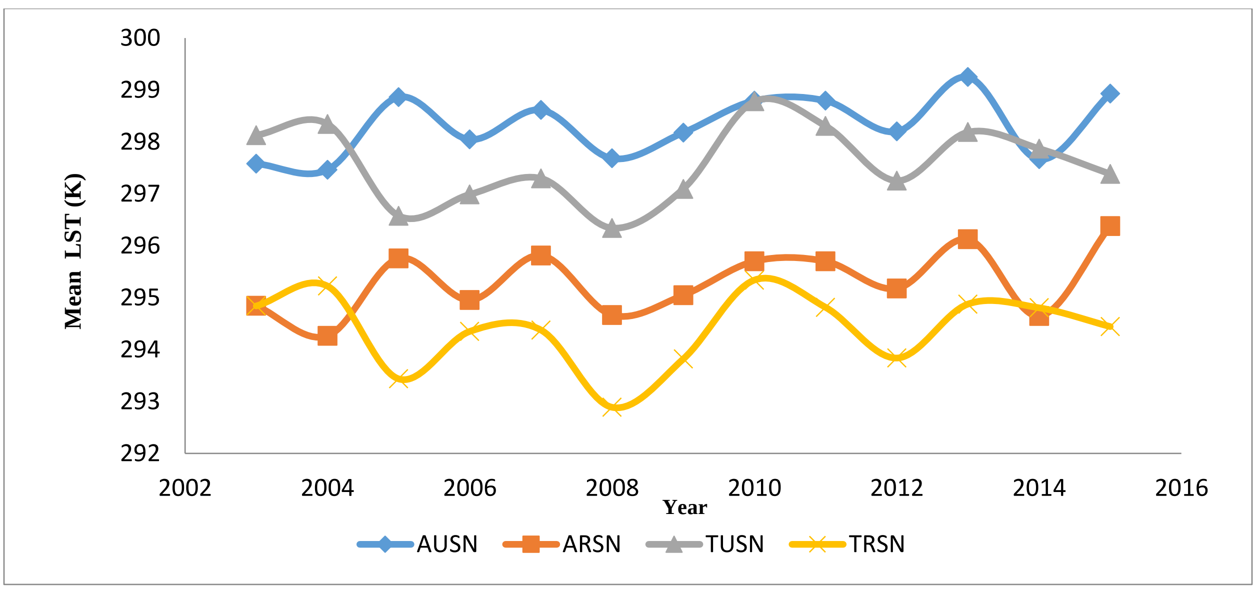
Year	ARSN	AUSN	TRSN	TUSN	ARMN	AUMN	TRMN	TUMN	ARWN	AUWN	TRWN	TUWN	ARAN	AUAN	TRAN	TUAN
2003	298	295	298	295	314	311	309	308	290	286	287	283	292	295	291	294
2004	297	294	298	295	310	308	309	307	289	286	288	284	292	294	291	293
2005	299	296	297	293	313	309	310	309	288	285	287	283	292	295	291	294
2006	298	295	297	294	313	311	309	308	290	286	287	283	293	295	291	294
2007	299	296	297	294	313	309	308	307	291	288	288	284	293	295	291	294
2008	298	295	296	293	315	311	310	308	290	287	288	284	292	295	291	294
2009	298	295	297	294	315	313	309	307	291	287	289	285	293	296	292	295
2010	299	296	299	295	315	310	308	306	289	286	288	284	293	296	292	295
2011	299	296	298	295	314	312	308	306	289	286	288	285	293	296	292	295
2012	298	295	297	294	313	310	307	306	291	287	287	283	293	296	291	294
2013	299	296	298	295	312	308	308	307	290	287	288	284	293	296	292	295
2014	298	295	298	295	313	311	310	309	291	287	288	285	293	295	292	294
2015	299	296	297	294	315	311	309	308	290	286	289	286	293	296	292	295

ARSN-Aqua Rural Winter Night LST(K) ; AUSN-Aqua Urban Winter Night LST(K); TRSN-Terra Rural Winter Night LST(K); TUSN- Terra Urban Winter Night LST(K) ARSN-Aqua Rural Monsoon Night LST(K); AUSN-Aqua Urban Monsoon Night LST(K); TRSN-Terra Rural Monsoon Night LST(K); TUSN- Terra Urban Monsoon Night LST(K) ARSN-Aqua Rural Winter Night LST(K); AUSN-Aqua Urban Winter Night LST(K); TRSN-Terra Rural Winter Night LST(K); TUSN- Terra Urban Winter Night LST(K)



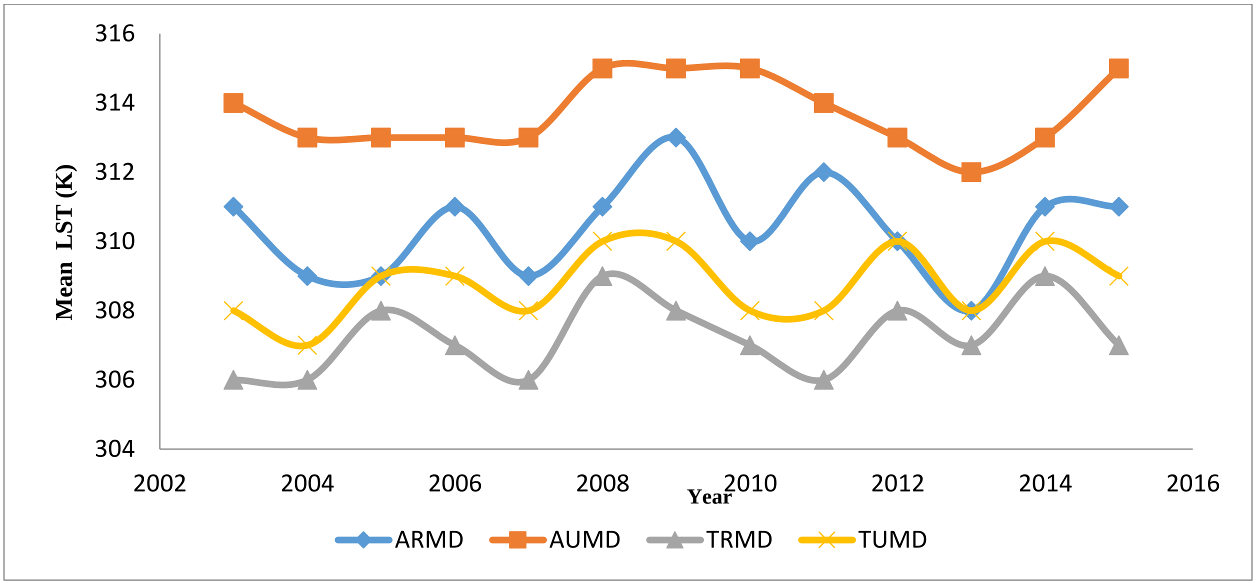
ARSD-Aqua Rural Summer Day LST (K); AUSD-Aqua Urban Summer Day LST (K); TRSD-Terra Rural Summer Day LST (K); TUSD-Terra Urban Summer Day LST (K);

Figure 4.23: Graph of Mean LST (K) in Rural-Urban area for summer season during day time for Ahmedabad



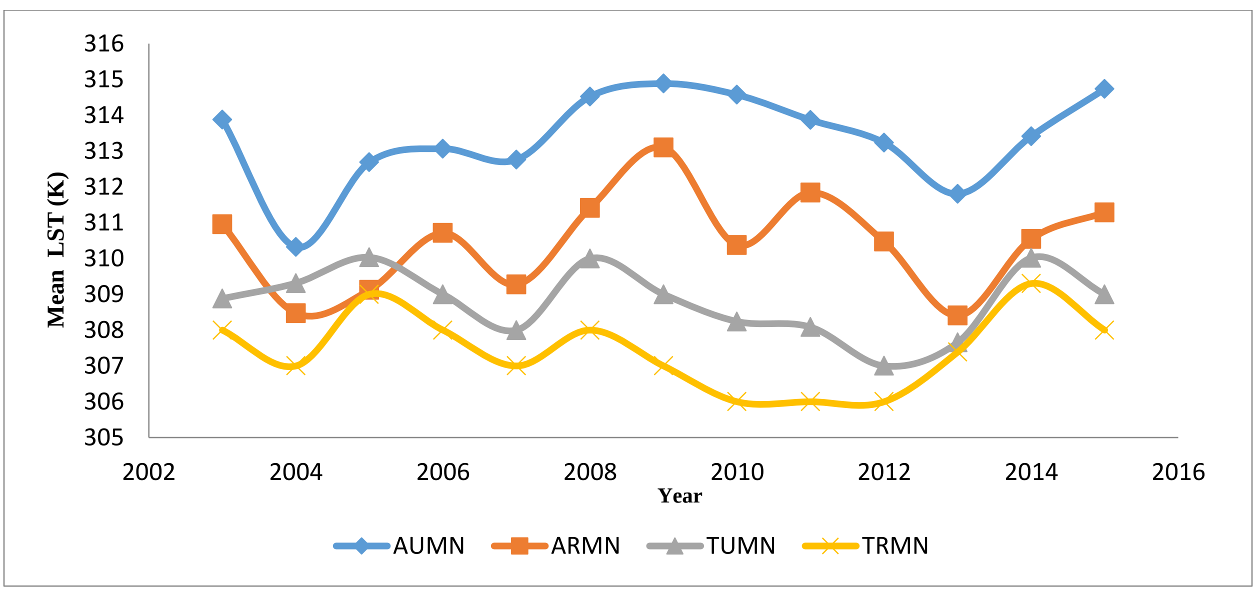
ARSN-Aqua Rural Summer Night LST (K); AUSN-Aqua Urban Summer Night LST (K); TRSN-Terra Rural Summer Night LST (K);TUSN-Terra Urban Summer Night LST (K);

Figure 4.24: Graph of Mean LST (K) in Rural-Urban area for summer season during night time for Ahmedabad



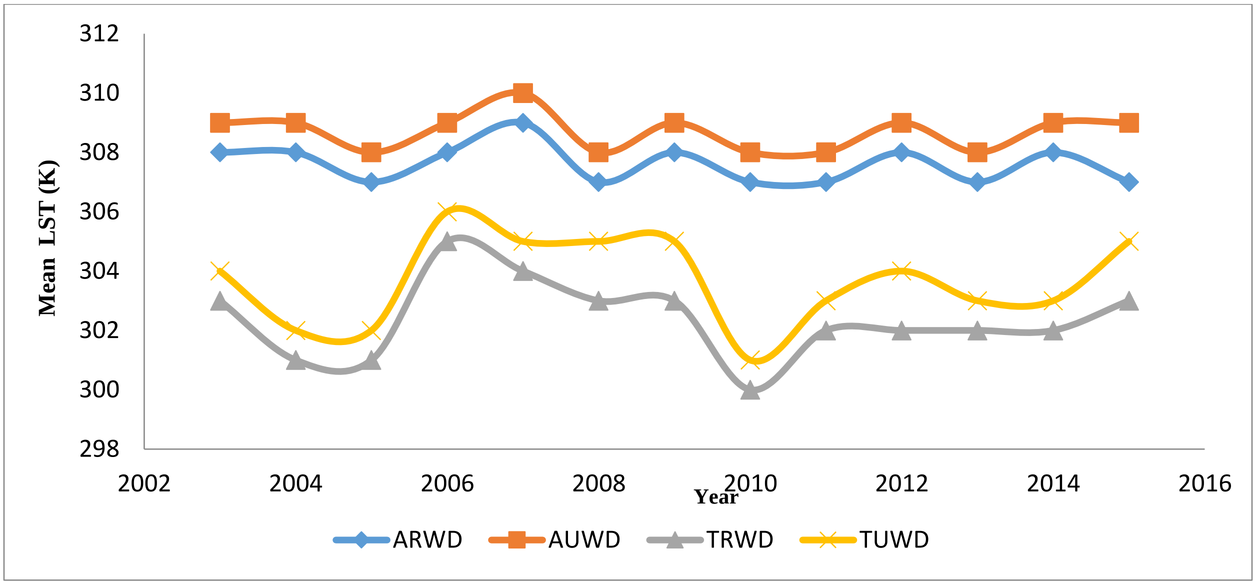
ARSD-Aqua Rural Monsoon Day LST (K); AUSD-Aqua Urban Monsoon Day LST (K); TRSD-Terra Rural Monsoon Day LST (K); TUSD-Terra Urban Monsoon Day LST (K);

Figure 4.25: Graph of Mean LST (K) in Rural-Urban area for monsoon season during day time for Ahmedabad



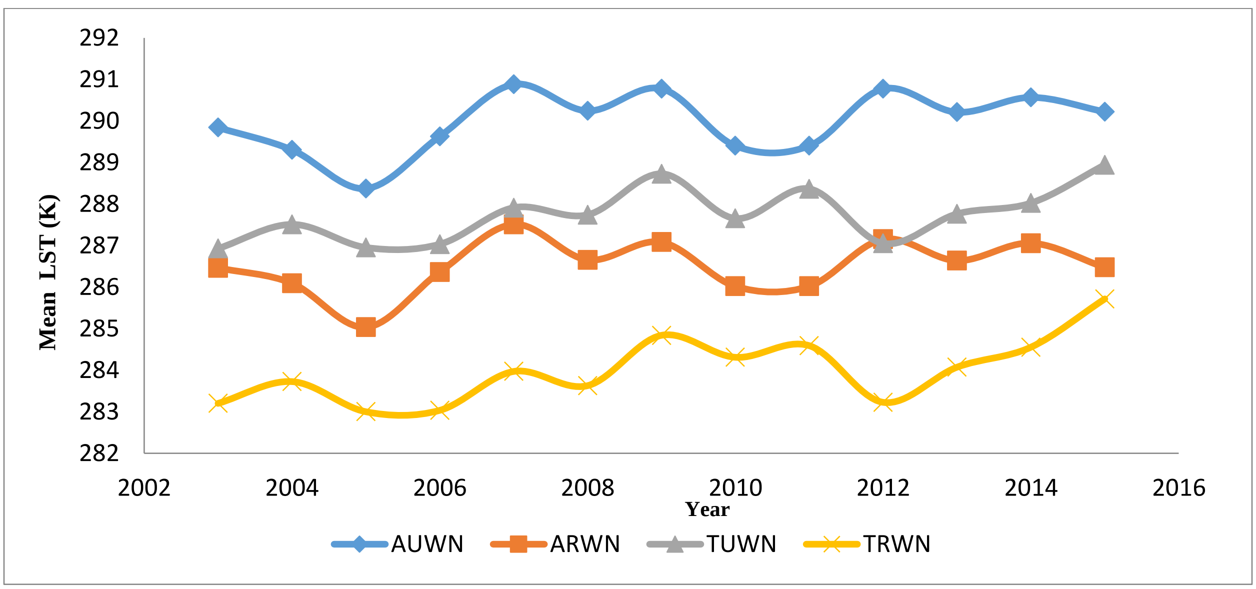
ARSN-Aqua Rural Monsoon Night LST (K); AUSN-Aqua Urban Monsoon Night LST (K); TRSN-Terra Rural Monsoon Night LST (K); TUSN-Terra Urban Monsoon Night LST (K);

Figure 4.26: Graph of Mean LST (K) in Rural-Urban area for monsoon season during night time for Ahmedabad



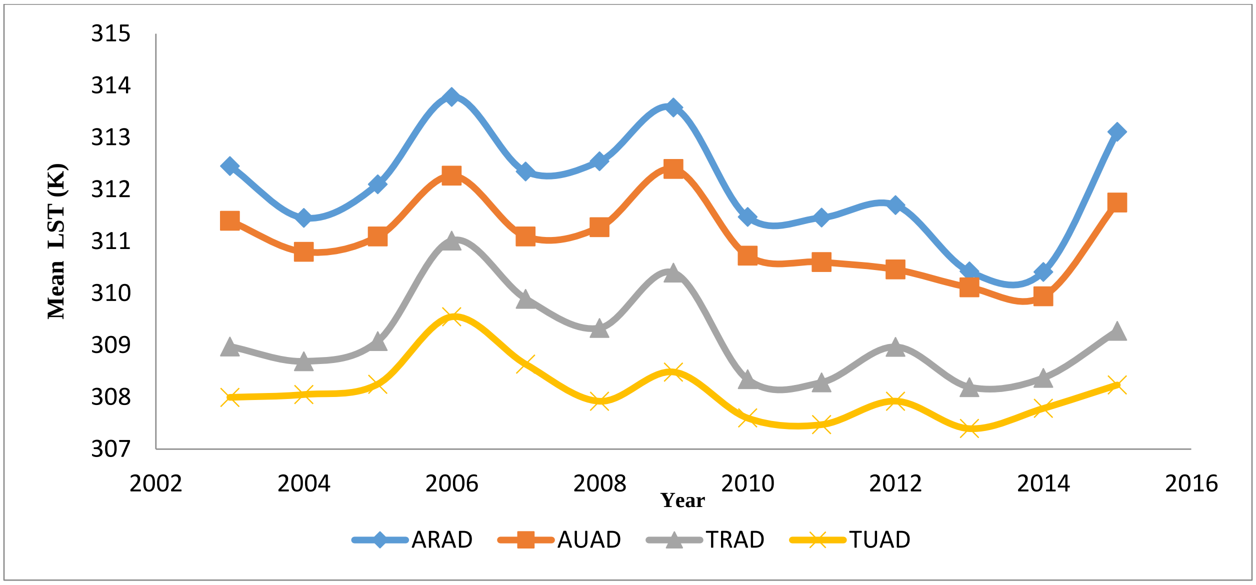
ARSD-Aqua Rural Winter Day LST (K); AUSD-Aqua Urban Winter Day LST (K); TRSD-Terra Rural Winter Day LST (K); TUSD-Terra Urban Winter Day LST (K);

Figure 4.27: Graph of Mean LST (K) in Rural-Urban area for winter season during day time for Ahmedabad



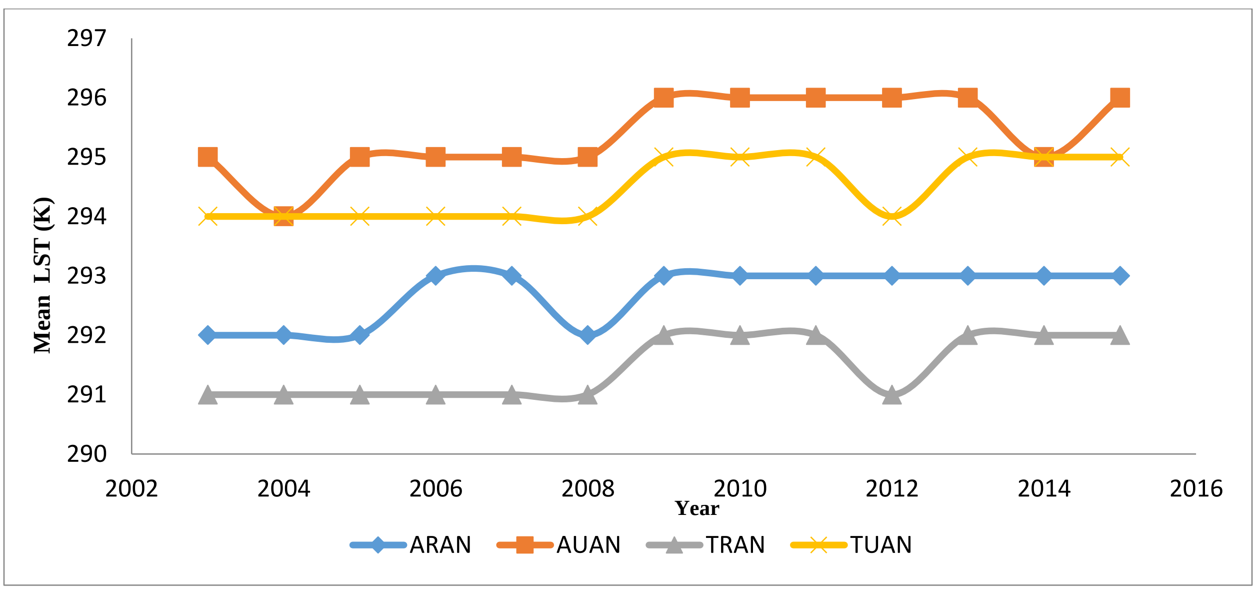
ARSN-Aqua Rural Winter Night LST (K); AUSN-Aqua Urban Winter Night LST (K); TRSN-Terra Rural Winter Night LST (K); TUSN-Terra Urban Winter Night LST (K);

Figure 4.28: Graph of Mean LST (K) in Rural-Urban area for winter season during night time for Ahmedabad



ARSD-Aqua Rural Annual Day LST (K); AUSD-Aqua Urban Annual Day LST (K); TRSD-Terra Rural Annual Day LST (K); TUSD-Terra Urban Annual Day LST (K);

Figure 4.29: Graph of Mean LST (K) in Rural-Urban area annually during day time for Ahmedabad



ARSN-Aqua Rural Annual Night LST (K); AUSN-Aqua Urban Annual Night LST (K); TRSN-Terra Rural Annual Night LST (K); TUSN-Terra Urban Annual Night LST (K);

Figure 4.30: Graph of Mean LST (K) in Rural-Urban area annually during night time for Ahmedabad

4.20. Comparison of previous results with 1-Day data

4.20.1. Jaipur City

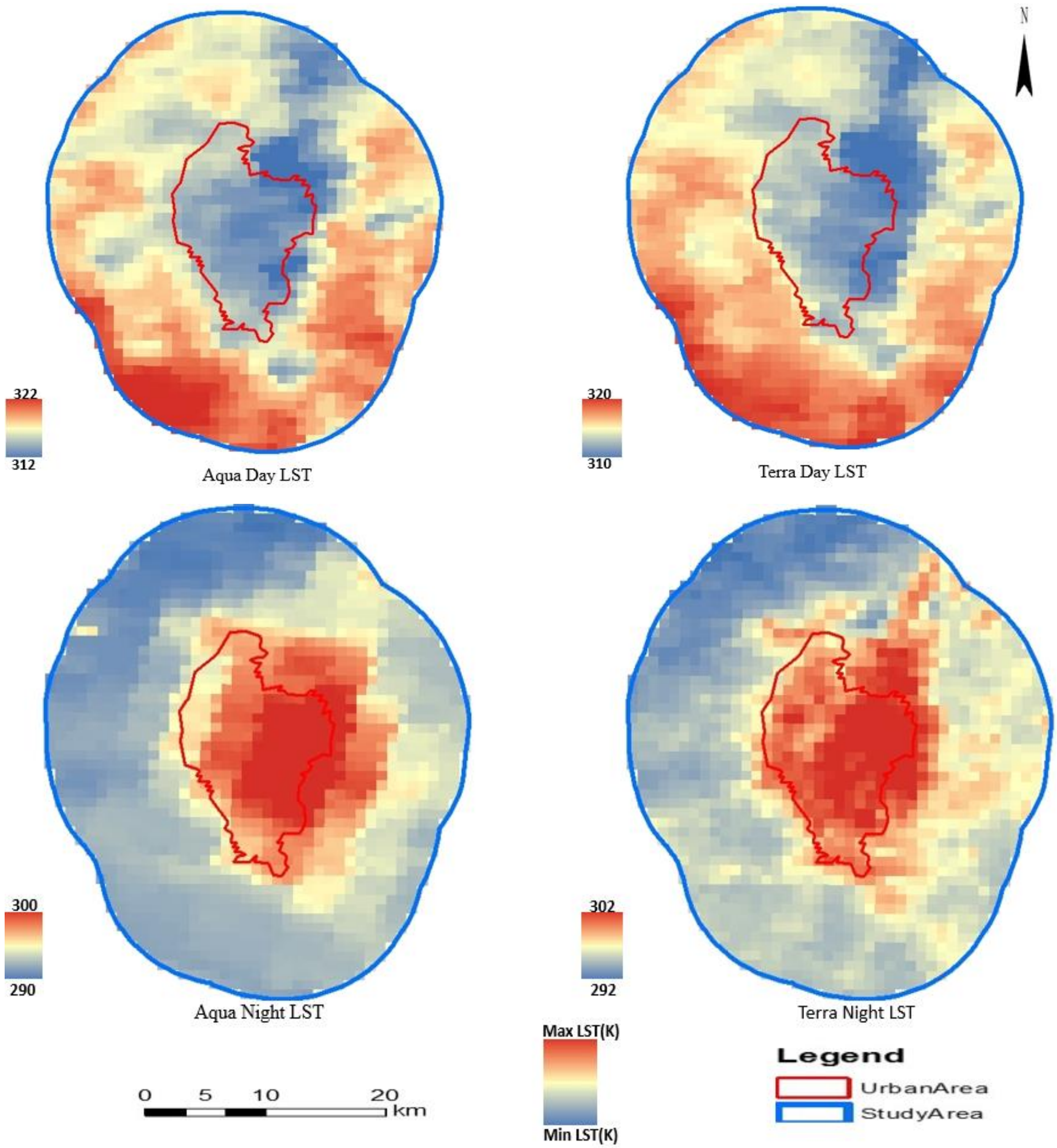


Figure4.31: Day- Night LST images of Aqua-Terra 1-Day data of Jaipur city of 2004 of 315th day

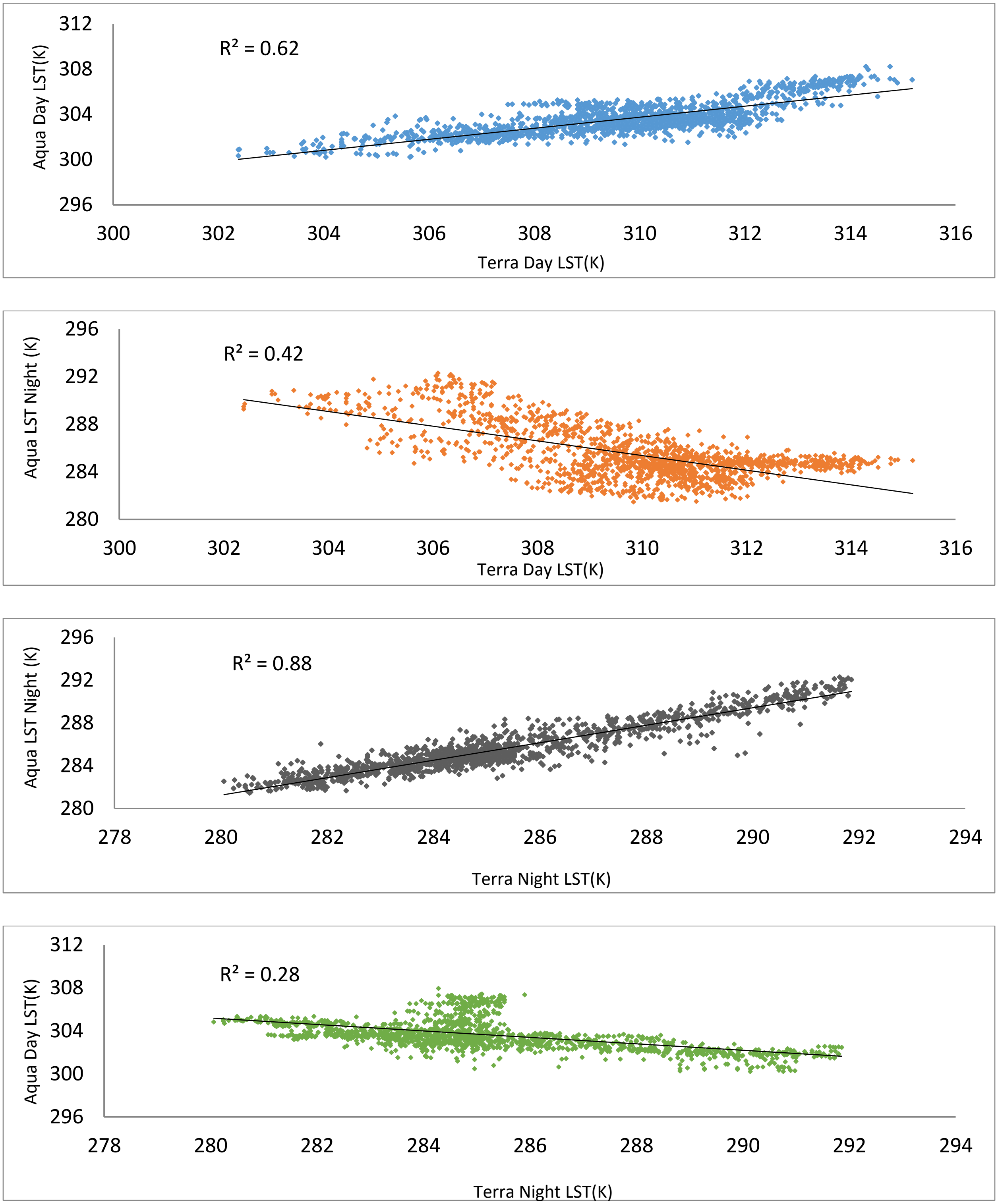


Figure4.32: Typical scatter plot between Aqua and Terra derived LST for Jaipur city for 2004 for 315th day

Table 4.37 Comparisons of NDVI values with coefficient of correlation between Aqua Vs Terra 1-Day data For Jaipur city

COMPARISON OF NDVI VALUES WITH COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR JAIPUR CITY								
		Coefficient of Correlation Between Aqua VS Terra LST Data				NDVI		
Year	Common Day	ADVTD	ADVTN	ANVTN	ANVTD	RURAL	URBAN	COMPOSITE
2003	313	0.62	0.1	0.84	0.43	0.28	0.27	0.28
2004	315	0.62	0.42	0.88	0.28	0.3	0.3	0.3
2005	276	0.74	0.17	0.92	0.06	0.4	0.34	0.39
2006	276	0.79	0.32	0.86	0.41	0.34	0.3	0.33
2007	274	0.76	0.14	0.88	0.28	0.39	0.32	0.38
2008	62	0.53	0.2	0.77	0.01	0.33	0.22	0.31
2009	60	0.78	0.05	0.8	0.01	0.28	0.2	0.27
2010	141	0.56	0.21	0.83	0.59	0.18	0.17	0.18
2011	81	0.79	0.08	0.82	0.06	0.33	0.23	0.31
2012	89	0.7	0.11	0.63	0.04	0.26	0.2	0.25
2013	65	0.76	0.06	0.89	0.25	0.35	0.23	0.33
2014	72	0.68	0.06	0.84	0	0.35	0.23	0.33
2015	120	0.02	0	0.8	0.32	0.25	0.22	0.24

The present study includes finding a common day (after quality check) for four data sets (Aqua/Terra-day/night LST) and NDVI analysis for the corresponding day for rural, urban and composite areas for all three cities. From the present study it has been observed that coefficient of correlation between 1-day and 8-day analysis are almost same. The scatterplots for correlation for 315day in 2004 shows almost similar trends as in 8-day study. The correlation analysis from 1-day shows R^2 values is not much affecting with NDVI values. Here lower NDVI values (<0.4) shows less vegetation density which are creating a non-uniformity in day-night temperatures which results in poorer correlation (almost 0) between Aqua day-Terra night LST.

4.20.2 Ahmedabad City

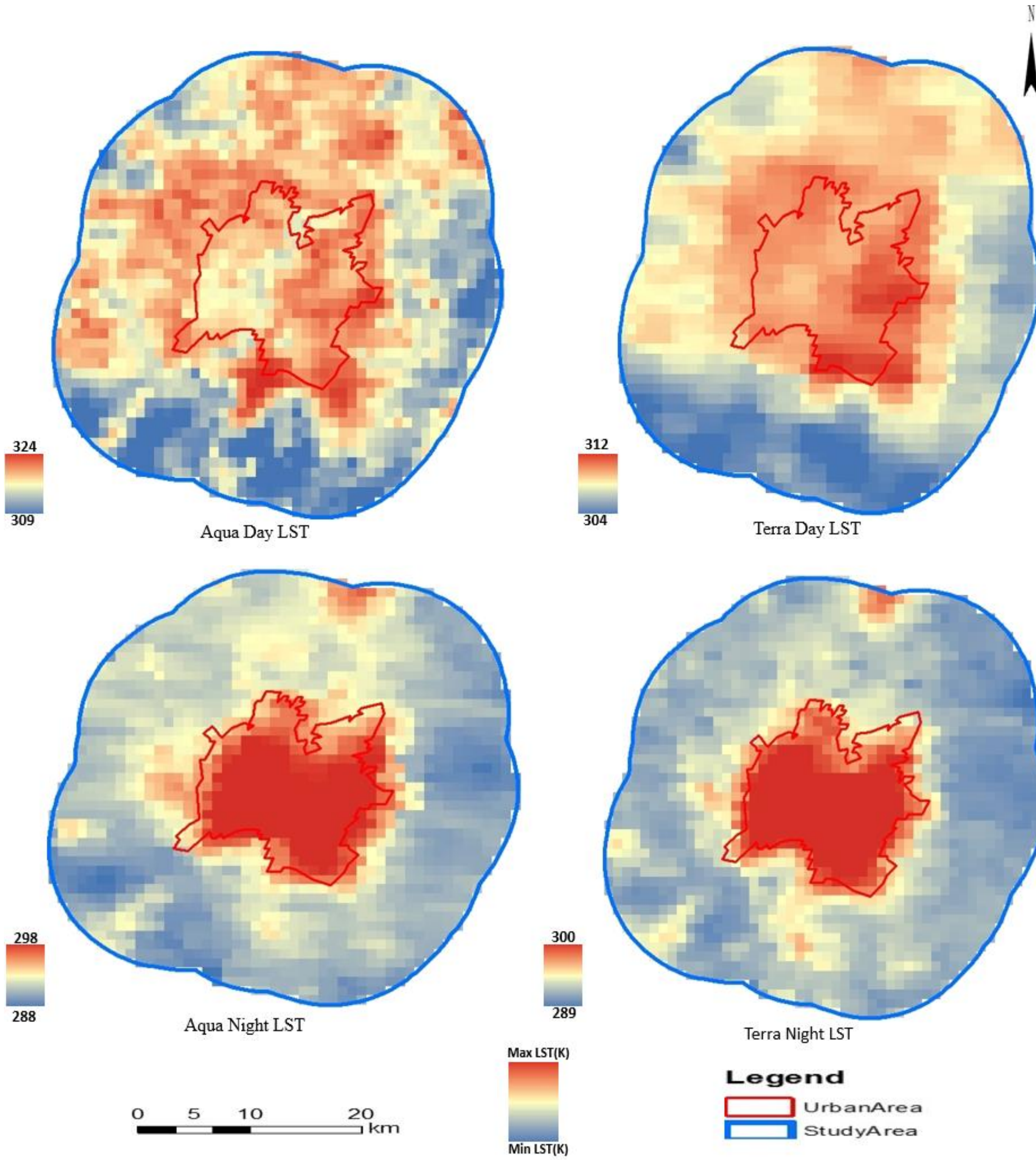


Figure4.33: Day- Night LST images of Aqua-Terra 1-Day data of Ahmedabad city of 2013 of 65th day

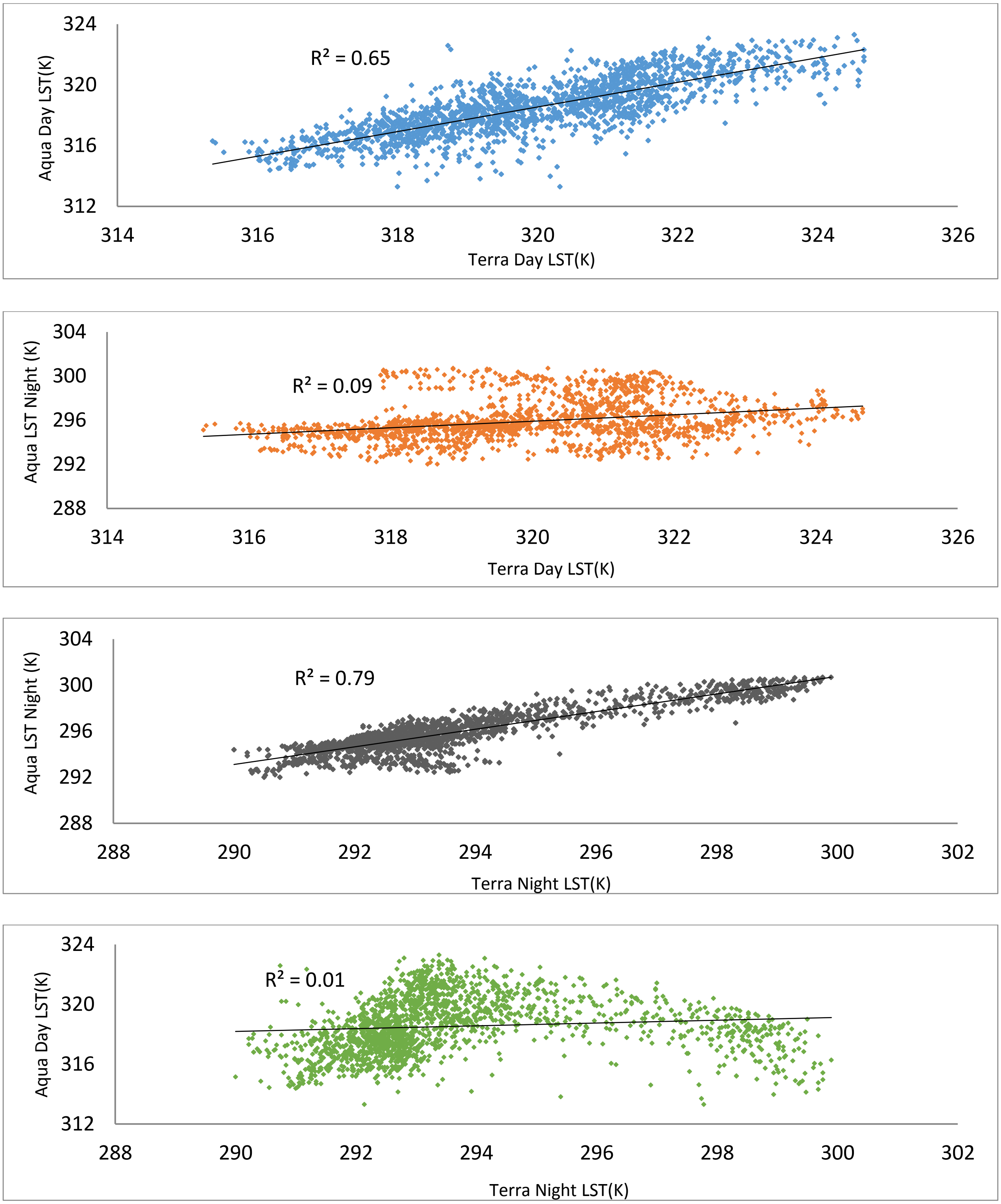


Figure4.34: Typical scatter plot between Aqua and Terra derived LST for Ahmedabad city for 2004 for 90th day

Table 4.38 Comparisons of NDVI values with coefficient of correlation between Aqua Vs Terra data For Ahmedabad city

COMPARISON OF NDVI VALUES WITH COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR AHMEDABAD CITY								
		Coefficient of Correlation Between Aqua VS Terra LST Data				NDVI		
Year	Common Day	ADVTD	ADVTN	ANVTN	ANVTD	RURAL	URBAN	COMPOSITE
2003	14	0.68	0.15	0.8	0	0.44	0.24	0.4
2004	90	0.65	0.09	0.79	0.01	0.31	0.23	0.28
2005	89	0.71	0.19	0.88	0.18	0.32	0.22	0.3
2006	88	0.66	0.07	0.88	0.05	0.33	0.24	0.31
2007	56	0.7	0.06	0.84	0.17	0.42	0.24	0.4
2008	62	0.67	0.29	0.83	0.08	0.37	0.22	0.35
2009	60	0.68	0.13	0.79	0.08	0.34	0.22	0.35
2010	87	0.82	0.14	0.71	0.1	0.33	0.21	0.36
2011	81	0.8	0.26	0.88	0.27	0.36	0.22	0.29
2012	89	0.72	0.33	0.76	0.09	0.33	0.21	0.28
2013	65	0.72	0.17	0.89	0.42	0.38	0.21	0.36
2014	70	0.58	0.01	0.77	0	0.39	0.22	0.37
2015	113	0.71	0.13	0.81	0	0.33	0.22	0.31

From the present study for Ahmedabad city it has been observed that coefficient of correlation between 1-day and 8-day analysis are almost same. The scatterplots for correlation for 90^{th} day in 2004 shows almost similar trends as in 8-day study. Various R^2 values for different day in different years along their NDVI values are tabulated in table 4.38. The correlation analysis from 1-day shows R^2 values is not much affecting with NDVI values. Here lower NDVI values (<0.4) shows less vegetation density which are creating a non-uniformity in day-night temperatures which results in poorer correlation (almost 0) between Aqua day-Terra night LST.

4.20.3. Ludhiana city

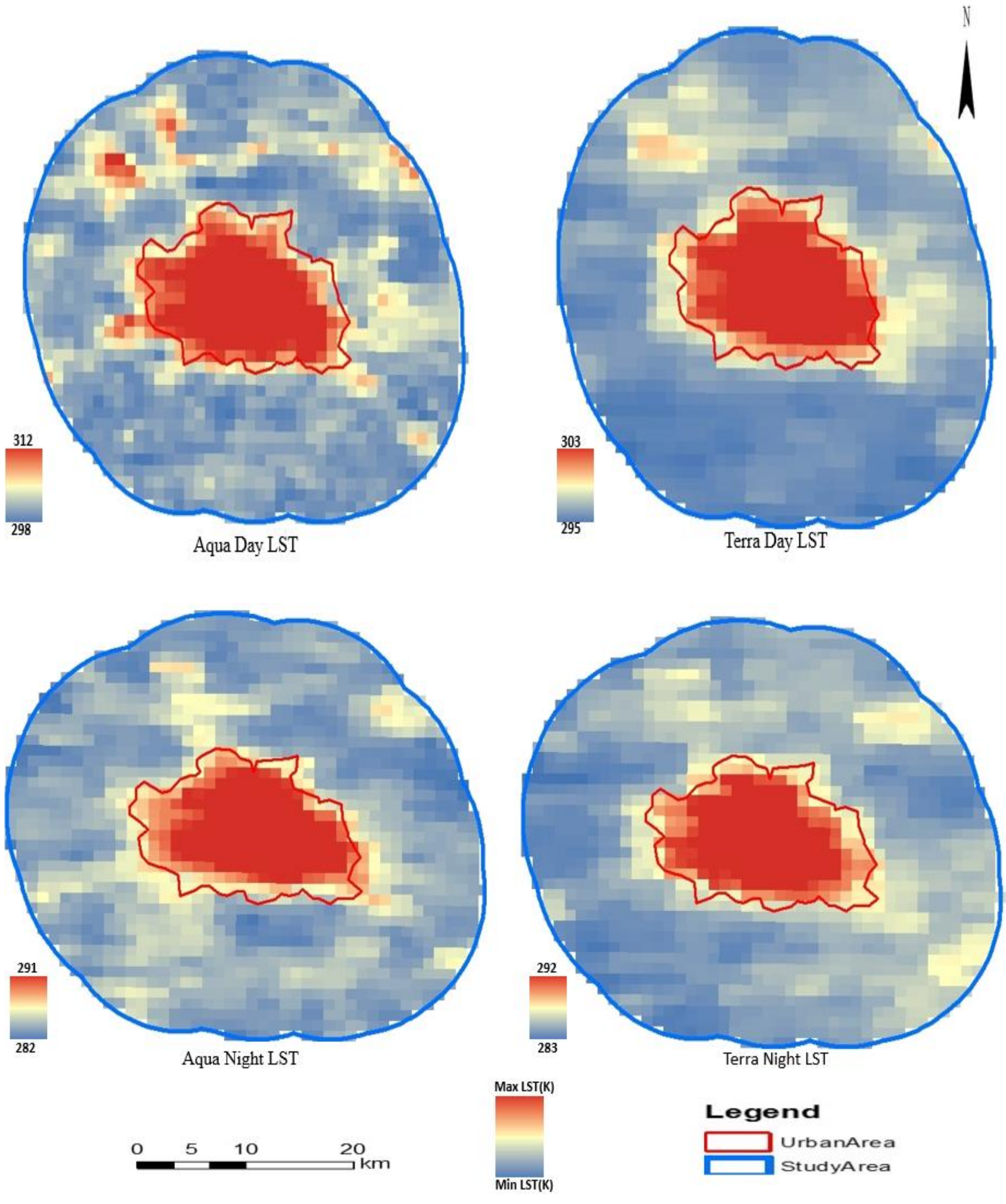


Figure4.35: Day- Night LST images of Aqua-Terra 1-Day data of Ludhiana city of 2004 of 66th day

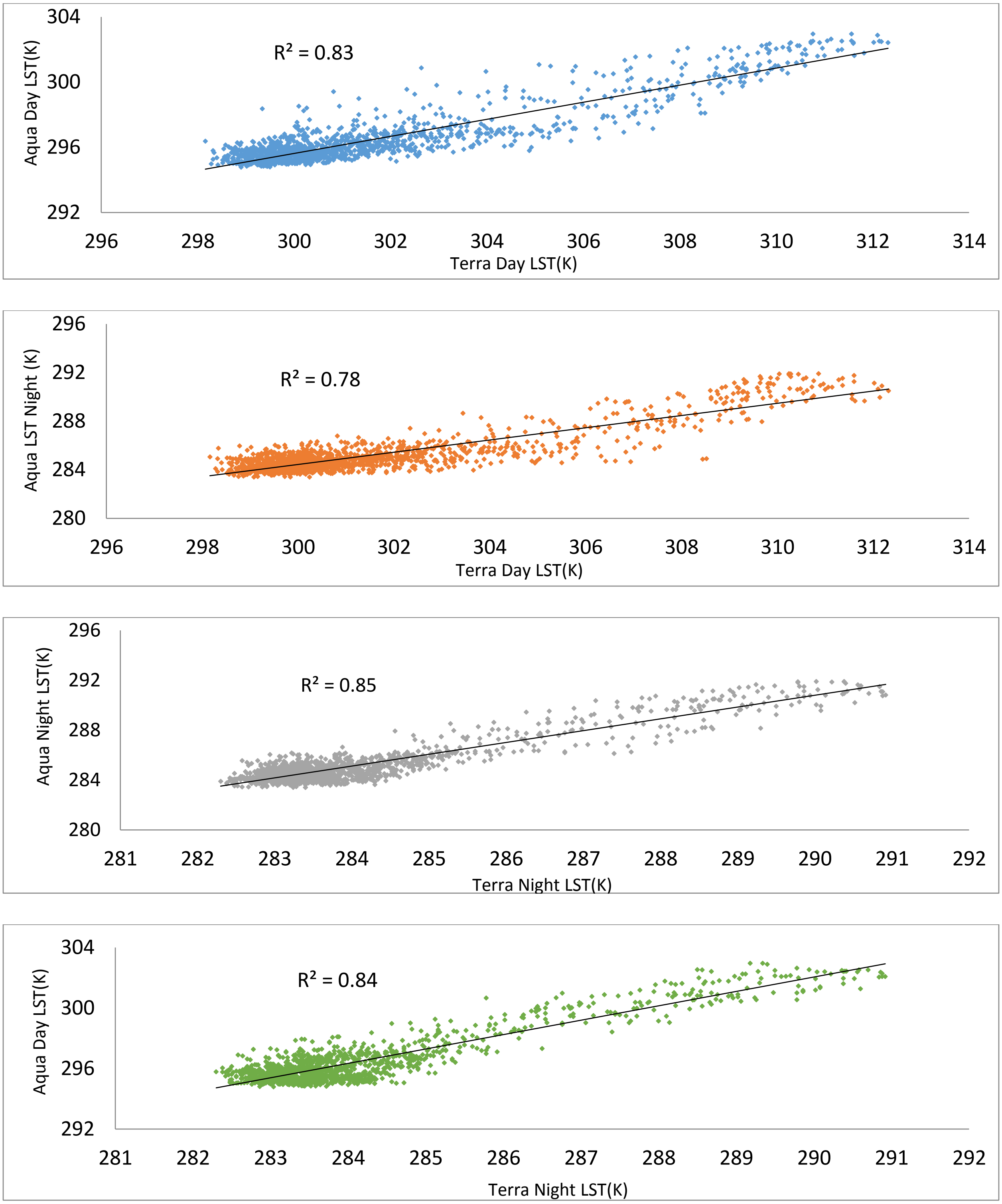


Figure4.36: Typical scatter plot between Aqua and Terra derived LST for Ludhiana city for 2004 for 66th day

Table 4.39 Comparisons of NDVI values with coefficient of correlation between Aqua Vs Terra data For Ludhiana city

COMPARISON OF NDVI VALUES WITH COFFICIENT OF CORELATION BETWEEN AQUA VS TERRA DATA FOR LUDHIANA CITY								
		Coefficient of Correlation Between Aqua VS Terra LST Data				NDVI		
Year	Common Day	ADVTD	ADVTN	ANVTN	ANVTD	RURAL	URBAN	COMPOSITE
2003	90	0.82	0.64	0.6	0.72	0.45	0.32	0.4
2004	66	0.83	0.78	0.84	0.85	0.74	0.38	0.6
2005	289	0.84	0.82	0.68	0.63	0.37	0.28	0.33
2006	288	0.59	0.57	0.46	0.79	0.38	0.29	0.34
2007	285	0.8	0.73	0.5	0.78	0.32	0.24	0.31
2008	291	0.78	0.42	0.2	0.65	0.5	0.36	0.48
2009	69	0.88	0.77	0.65	0.81	0.66	0.31	0.58
2010	288	0.68	0.71	0.6	0.87	0.37	0.31	0.35
2011	288	0.66	0.6	0.28	0.83	0.41	0.28	0.37
2012	69	0.79	0.69	0.65	0.88	0.68	0.31	0.59
2013	289	0.7	0.73	0.52	0.71	0.45	0.31	0.42
2014	292	0.81	0.63	0.49	0.84	0.37	0.28	0.29
2015	65	0.78	0.73	0.69	0.8	0.75	0.38	0.69

Here Ludhiana city is chosen as case study for inter-comparison between Ahmedabad and Jaipur cities. The similar 1-day data analysis is done for this city. Ludhiana city is having UHI effect both in day and night (refer fig 4.38). The scatterplot shows better relationship in day-night LST than other two cities. Ludhiana city is having higher NDVI values (>.37) which shows highly dense vegetation around the city. This vegetation maintains a uniformity in temperature variations. The highlighted NDVI values and associated R^2 values for the year 2004, 2009, 2012 and 2015 show the vegetation effect over the LST.

Chapter 5

Conclusions

This study documents the diurnal and seasonal LST analysis and correlation between LST retrieved from same sensor but during different times of the day. 1-Day and 8-day MODIS LST data has been used for the present study and the diurnal temperature analysis of three Indian cities Jaipur, Ahmedabad and Ludhiana has been carried out. The study investigates the seasonal analysis for summer, monsoon, and winter and annually for both day and night time. The study area includes the rural (buffer around the urban), urban and composite for the duration of 2003-2015. It is clearly visible in the high LST pixels images of all three cities that a thermal gradient lies between the remote rural area and urban central area of the city. Most of the high temperature LST pixel lies in the urban boundary and low temperature pixel lies outside the boundary. It is clearly evident from the present study during day time LST images show significantly higher temperature variations in the different parts of the study area as compared to night time images. Hence diurnal temperature variation in the different time intervals especially Aqua and Terra exists. Significant existence of SUHI is observed in Jaipur during study period. The urban eastern part of Jaipur comprises of heavy built-up and roads, includes maximum high LST pixels within it. During day time south-east rural area has highest temperature due to presence of exposed rocks in all three seasons and north western rural area has lowest temperature as it occupies mostly agricultural area. North western rural and urban area has lowest night temperature but eastern urban area attains highest LST. The comparative analysis between rural and urban for day and night temperature shows that rural area has higher day temperature than urban area during day time but during night time the temperature for urban area attains highest value. Aqua derived mean diurnal temperature difference is observed greater than terra derived it happens because of its timing of image acquiring and maximum solar radiance. Summer season has higher anthropogenic heat hence it has lower diurnal temperature difference than winter season.

LST variations in the Ahmedabad city are mainly due to the seasonal vegetation growth as vegetation has notable cooling effect. The variations are more in night time as move from urban boundary to rural area. In summer season higher LST pixels in the western part of the city both in rural and urban areas. Diurnal temperature variations significantly exists in the city in different time intervals especially for Aqua and Terra. During monsoon higher LST pixels lies within the city during day and night due to vegetation growth in rural areas. The eastern part of the urban area remains warmer than western part because eastern part has less built-up and roads.

R^2 analysis for three cities for a single common day signifies good correlation between day-day and night-night LST (K). Ludhiana city shows higher vegetation density compared to Ahmedabad and Jaipur rural areas. Hence higher values of NDVI has been experience in the Ludhiana non-urbanized areas compared to Ahmedabad and Jaipur rural areas. The R^2 values for day-night and night-day LST (K) for Jaipur and Ahmedabad cities are almost negligible as day and night temperature is entirely different for rural and urban area also but in case of green city Ludhiana these R^2 values are higher because of higher vegetation density in rural areas. The subtropical climate of the city provides favorable conditions to grow vegetation in rural areas hence less barren land is available to heat up. The overall R^2 values for all four possible LST sets remains same for Ludhiana city but in 2004, 2007, 2012 and 2015 the R^2 values for day-night and night-day exceeds with day-day and night-night R^2values as these years are having higher NDVI values (>0.65). Surface temperature characteristics and variations has been observed more uniform during night time compared to day time using Aqua-Terra data analysis. Hence these results show how higher vegetation density influence the diurnal temperature. Therefore diurnal variation of a particular city mainly depends on the topographical parameters of the particular area.

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