LANDSCAPE CONFIGURATION AND THERMAL ENVIRONMENTS OF CENTRAL NATIONAL CAPITAL REGION

(Thesis submitted to the Andhra University)

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Submitted by

AMREESH KAUR BHULLAR

Under the supervision of

Dr.Sadhana Jain – 'SE'
Urban and Regional Studies Department

INDIAN INSTITUTE OF REMOTE SENSING
INDIAN SPACE RESEARCH ORGANISATION (ISRO)
DEPARTMENT OF SPACE, GOVT. OF INDIA,
Dehradun – 248001

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DISCLAIMER

This work has been carried out in partial fulfilment of Masters in Technology program in Remote Sensing and Geographic Information System at Indian Institute of Remote Sensing, Dehradun, India. The author is solely responsible for the contents of the thesis.

CERTIFICATE

This is to certify that the research work entitled "Landscape configuration and thermal environments in Central National Capital Region" is the original record of work carried out by Amreesh Kaur Bhullar towards partial fulfilment of the requirements for award of Master of Technology in Remote Sensing and GIS by Andhra University at Urban and Regional Studies Department, Indian Institute of Remote Sensing (IIRS), Dehradun. The project contains original work carried out by her and she has duly acknowledged the sources of data and resources used.

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(Dr. Sadhana Jain)

Project Supervisor

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(Mr.Pramod Kumar)	**(Dr. S. K. Saha)**	**(Dr.Y.V.N. Krishna Murthy)**
Head, URSD, IIRS	Group Director, ERSSG and Dean (Academics), IIRS	Director, IIRS

Dedicated to My family

who have stood by me every moment. I would not be who am today without them.

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ABSTRACT

Cities are home to more than half of the world population and are complex adaptive systems maintained by the most intense form of human-nature interaction known as urban landscapes. They are growing to be the centres of economic and social developments, as well as sources of many major environmental problems. The future of humanity continues to increasingly rely on cities, and the future of landscape ecology will inevitably be controlled more by the urban component. To meet the grand challenge of the time, sustainability, cities must be made sustainable and, to this end, landscape ecology has much to offer. Understanding the effects of changing landscape pattern and ecology with spurious anthropogenic growth gives a reasonable perspective for mitigating Urban Heat Island effect, an issue for every growing city in the tropics. The presented research put forths an attempt in analyzing the correlation between the quantification of landscape configuration and the land surface temperature using LISS IV and Landsat-8 data of May 2013 for the major urban centres of CNCR ie. Ghaziabad, Noida, Faridabad and Gurgaon. They have been identified as major settlements of Delhi Metropolitan Area (DMA)/ Central National Capital Region cities of National Capital Region (NCR) based on their strong inter-linkages that they have with NCT-Delhi.

The quantification of urban form was based on four aspects of measure- Area and Edge, Shape, Core Area, and Aggregation. LST (Land Surface Temperature) data were retrieved from two thermal bands of TIRS with the application of split window algorithm model. Pixel based correlation was employed to investigate the relationship between LST and the spatial pattern of land cover configuration represented via metrics. The correlation found in the region was gentle varying from -0.4 for water bodies and 0.4 for built-up land cover as built-up contributes towards the propagation of surface temperature. Among the four indices, Area Weighted Radius of Gyration exhibited highest correlation with the thermal conditions and Gurgaon exhibiting a better arrangement of land covers in the four cities. This interlinking of urban climate and heterogeneity seems to have a role in controlling the microclimate and applicability for future urban ecological planning and design of the region.

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1. INTRODUCTION

"There has been a mismatch between the questions that planners, designers, and decision-makers are asking urban ecologists, and the questions that urban ecologists are asking to advance the science of urban ecology."- Mark J. McDonnell

1.1 BACKGROUND

Human society is transforming this planet rapidly into the home of an intriguing system wherein an intensive usage and exhaustion of resources via anthropogenic infrastructures and complex processing systemsare replacing the natural components by urban and industrial sprawling (Farina,2007) . These urban regions behave like complex coupled human-natural systems wherein humans play the predominant role of altering the environment. The dominance of human activities transforms natural landscape and leads to creation of a new set of ecological condition by transforming the dynamics of the ecosystem processes. Urbanization changes natural habitats, biodiversity and alters biogeochemical cycles including hydrological and nutrient cycles. This manifests cities into places of severe environmental problems, growing socioeconomic inequality, and political and social instabilities. Although the physical urbanized area covers merely about 3 % of the earth's land surface, the ''ecological footprints'' of cities are disproportionally large, often hundreds of times their physical sizes(Wu *et al.*,2013)**.**These footprints can be witnessed down the hierarchy of the whole ecological setup. While most of the impacts are at a large scale, there is one impact that occurs at local scale too and that undesirable thermal condition is popularly known as Urban Heat Island effect. Planners and natural scientists are posed with the challenge to fathom the details of how humans and ecosystemsimpact in bringing up this phenomena and restricting sustainable future of urban landscapes. Landscape ecology thus emerged as a subject towards the end of 70's for deeper understanding of the depleting qualitative metabolism of the ecological setup and for making attempts to mitigate it.

1.2 URBAN GROWTH STATISTICS

Globally, urban population makes it to 50% of the total amount and the proportion is increasing by 1 million every week. According to the projections by United Nations, 80 %of the global population will turn to urban areas by 2050. Even after the world population stabilizes around 2050, the urban population will continue to grow, and then most of the population increase will take place in urban areas of tropical developing countries, majorly Asia and Africa (Wu *et al.,*2013).Asia which is the largest and most populous continent of the world is also home to the highest economic growth. Though it is one of the less urbanized continents in comparison to others, it is expanding at a greater pace than other areas. According to UNDP the share of Asian population living in urban areas has grown to 42% from 32% in last 2 decades. It is adding 1,00,000 urban residents each day since last 5 years. UN has also forecasted that by 2026 half of the Asians will be city dwellers.The huge size of continent's population makes the task of managing the expanding urban areas arduous. Moreover, Asia presently has seven of the world's 10 most populous urban areas, Delhi being one of them (Boselli, 2011).

In India it was after 1950's that the growth rate of urban population witnessed a rise, hence the need of planning and redevelopment became essential. There were some regions which witnessed higher urban growth. At regional level a large city is seen as the node of its hinterland regions which is spatially linked to them. These centres grow around the node through a pattern of radial networks leading to formation of urban agglomerations. It then transforms to a continuous urban spread constituting a major town and its adjoining outgrowths arranged in a ring manner around the regional node. This kind of agglomeration is termed as conurbation when the urban rural fringe distinguishing the node from its satellite towns gets dissolved in the process of expansion.In census 2011 among the Million plus UAs/Cities, there were three very large UAs with more than 10 million persons in the country, known as Mega Cities. These are Greater Mumbai UA (18.4 million), Delhi UA (16.3 million) and Kolkata UA (14.1 million). The largest UA in the country is Greater Mumbai UA followed by Delhi UA and Kolkata UA. Kolkata UA which held the second rank in Census 2001 has been replaced by Delhi UA in 2011. The growth of population in the Mega Cities has slowed down considerably during the last decade as can be seen in figure 1.1, but the growth rate of Delhi remains higher compared to other agglomerations though Mumbai UAhas higher total population than Delhi UA(Census of India,2011).

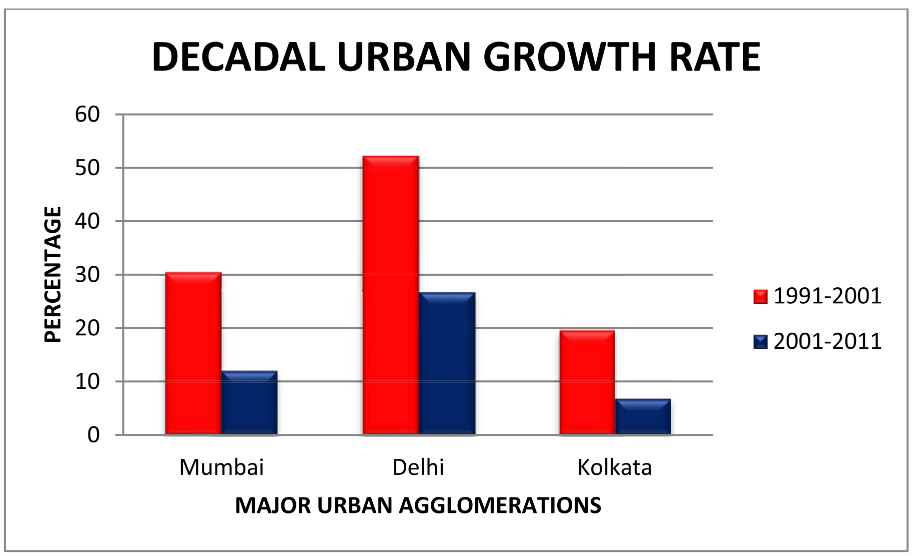


Figure 1.1: Decadal growth rate of major Urban Agglomerations in India

The high growth rate of Delhi UA called for planning of the region and thus the National Capital Regional Plan was formulated for decentralizing economic activities from National Capital Territory of Delhi to Delhi Metropolitan Area (now called CNCR) towns and other towns of NCR. The NCT with highest urban population proportion of 97.50 % is already witnessing a boom in development and with efforts of the State Governments concerned to develop Special Economic Zones, Hi-Tech Cities, Industrial Estates etc., are bound to have spread effect on the vast hinterland. This sprawl can and will alter the landscape, so it becomes highly vital that the region should be studied for landscape studies and alternatives for balanced growth (Kshirsagar, 2007).

1.3 ECOLOGICAL IMPACT OF URBAN GROWTH

According to Asian Development Bank the ongoingmigration from the countryside of cities to core areas in the regional landscapes of Asia is “unprecedented in human history” and the rise in urban population has intense environmental consequences (Boselli, 2011).Moreover, the natural and agricultural landscapes are getting converted to urban and suburban occupancies at a faster rate than the growth of population in core urban areas. Cities are not growing in compact, isodiametric form; rather, they sprawl in spider-like configurations along the radial routes engulfing the satellite towns and abutting into its wild lands too. This anthropogenic way of ecological patterning and process brings upon changes in their climate, soil, hydrology, species composition, population dynamics and flows of energy and matter; and these urban ecosystems are far different from natural ecosystems (Pickett *et al.,* 2001).

While most of these impacts are external to the urban area (i.e. global or regional impacts of urbanization), there is one impact of this massive land use change that significantly affects the urban environment locally. It is due to the complex interactions taking place between transforming urban morphology, climate, atmospheric emissions and human health (Kalnay and Cai, 2003). The rising discomfort over cities because of increasing UHI refers to the phenomenon of higher atmospheric and surface temperatures occurring in urban central areas than in the surrounding rural areas. This is very widely being observed in cities irrespective of their sizes and locations. Increased temperatures due to UHI may have adverse impacts over species composition and distribution, increase air pollution, and affect the comfort of urban dwellers, and at worse can lead to greater health risks. Hence, since first reported in 1818, UHI has become a major research focus in urban climatology and urban landscape planning and ecology.

It is reported that with one million or more people the annual mean air temperature of a city can be 1 to 3°C warmer than its surroundings. Landscape geometry has been identified to alter surface UHI as it affects the canopy layer and nothing beyond that. They are caused because of the changes in radiative and thermal properties of urban infrastructure as well as the impacts buildings can have on the local micro-climate Surface UHI is more prevalent in day and in summer than atmospheric UHI which functions otherwise (Fig 1.2). The variations of surface UHI are peak (10-15 °C in day and 5-10 °C in night) and can be measured through remote sensing unlike the atmospheric UHI. This kind of surface warming that result over small areas such as cities is an example of local climate change or local heat islands. Local climate changes resulting from urban heat islands fundamentally differ from global climate changes in that their effects are limited to the local scale and decrease with distance from their source (Akbari, *et.al* 2010)

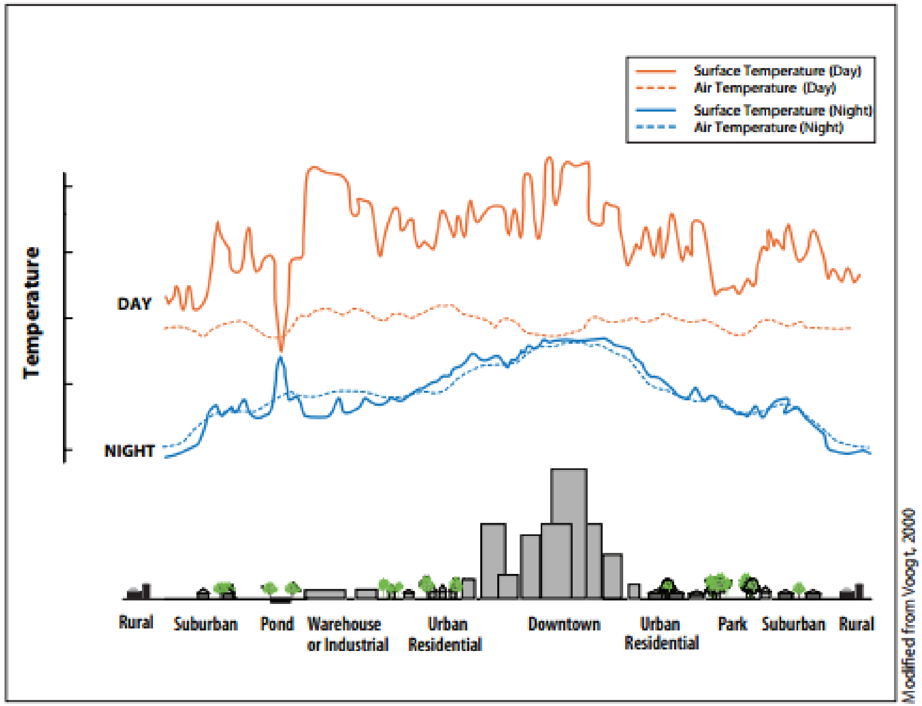


Figure 1.2: Difference between surface and air temperature (Akbari, et.al. 2010)

Major factors causing UHI:

a) Geographic location: Proximity to large water bodies and mountainous terrain can influence local wind patterns and urban heat island formation.
b) Weather: Certain conditions, such as clear skies and calm winds, can foster urban heat island formation.
c) Anthropogenic heat emissions: Contribute additional warmth to the air.
d) Reduced vegetation in urban regions: Reduces the natural cooling effect from shade and evapo-transpiration.
e) Properties of urban materials: Contribute to absorption of solar energy, causing surfaces, and the air above them, to be warmer in urban areas than those in rural surroundings.
f) Urban geometry: The height and spacing of buildings affects the amount of radiation received and emitted by urban infrastructure.

Thermal storage increases in cities in due to the lower solar reflectance of urban surfaces, but it is also influenced by the thermal properties of construction materials and urban geometry. Urban geometry can cause some short-wave radiation (Fig 1.3) particularly within urban canyons to be reflected on nearby surfaces, such as building walls, where it gets absorbed rather than escaping into the atmosphere. Urban geometry can also impede the release of long-wave, or infrared radiation into the atmosphere.

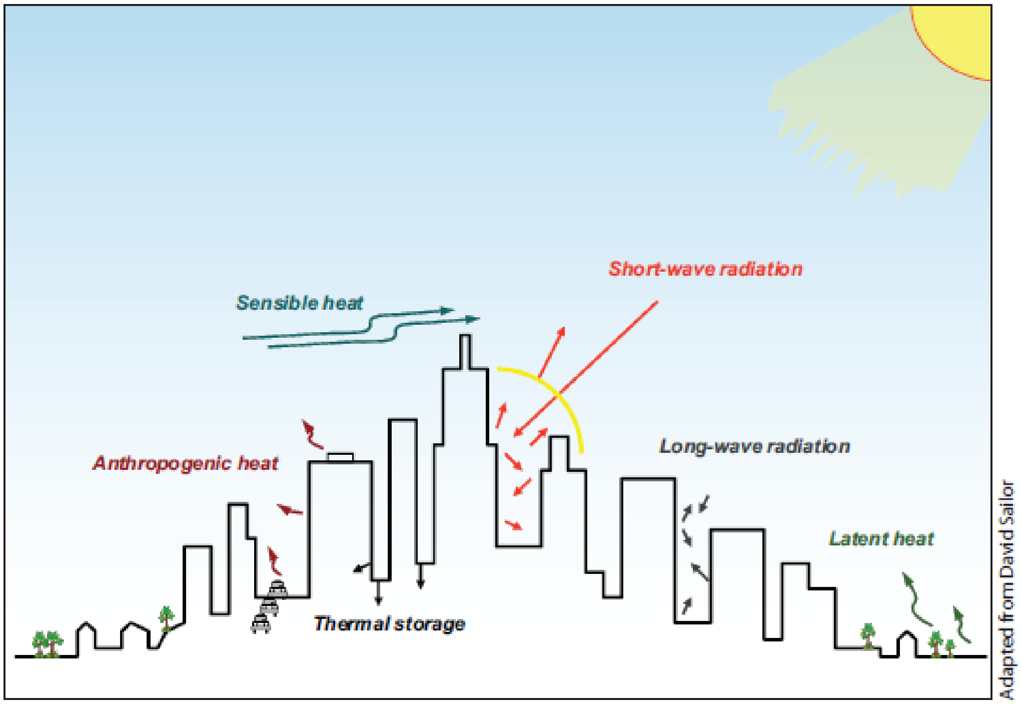


Figure 1.3 Thermal budget of urban landscape (Akbari, *et.al* 2010)

1.4 ECOLOGICAL CONDITION OF INDIA AND CNCR

In India, the temperatures start to increase all over the country in March and by April, central and northern Indian land mass becomes hot with daytime maximum temperatures reaching about 40°C at many locations. The range of the daytime maximum and night-time minimum temperatures in found to be more than 15 °C at many stations in these States. Maximum temperatures rise sharply exceeding 45 °C by the end of May and early June. Analysis of data for the period 1901-2009 suggests that annual mean temperature for the country as a whole has risen by 0.560°C over the period. It has been found that in general, there is an increasing & significant trend in the discomfort indices from the last 10 days of April to June over most of the Indian cities (Attri, 2010).

The Asian Green City Index has measured and rated the environmental performance of 22 Asian cities including Delhi. It is the third most populous city in the Asian Green City Index and an additional 2 million commuters from neighboring areas visit Delhi daily for work or school. The capital produces 5% of India's GDP with its main industries being food production, textiles, leather, energy, media, tourism and real estate which fetches it a capita income of an estimated US$2,000 that is more than twice the national average. But, on a global level the city is among the poorest cities in the Index. Also, the study has found a relation between the economic condition and greenness status of the cities wherein a capita income of US $20000 is a desirable amount for a green city. This accounts for Delhi region to be 10 times farther to reaching the milestone of a green region (Boselli, 2011).

CNCR's unprecedented rate and scale of urbanization over the last few decades has placed enormous stress on the natural resources of the cities and faced its ill effects too. In comparison to the urbanization rate in the last 50 years, the rate of environmental degradation has grown at a far higher rate. This includes the loss of green cover, loss of biodiversity and aesthetics; increasing air pollution, surface and ground water pollution; loss of water bodies, receding water table, high incidence of diseases and mortality. The transport, domestic and industrial sectors are the major contributors for this rise in ambient air pollution levels (CDP DELHI JNNURM).Also, very recentlyWHO has reported that Delhi's air is the most polluted in the world.The WHO report, which examined pollution levels in nearly 1,600 cities in 91 countries for the years 2008 to 2013, found that the annual mean for PM 2.5 concentrations in Delhi was 153 micrograms per cubic meter (NYI, 8 May, 2014). It is causing localised temperature hot spots and is one of the main reasons behind the sweltering heat in the cities as researched by Pune-based Indian Institute of Tropical Meteorology (IITM).

1.5 URBAN LANDSCAPE ECOLOGY

As discussed the complexity of growing urban landscape and its ecological effects in the CNCR, urban landscape ecology was considered to be a wise perspective for studying the ecological dynamisms of the region. Urban landscape ecology is perhaps the first sincere effort for studying how human action by transforming spatial patterns can influence fluxes of materials like thermal conditions in urbanizing environments. The spatial structure and land use patterns influence urban energy flows directly by redistributing solar radiation. Furthermore the concentration of the GHGs in the urban atmosphere is not only controlled by topography, location of polluting sources but also the pattern of artificial heat generation micro-zones. In addition, land use patterns directly & indirectly affect the local sink with water bodies and green areas that mitigate the heat island effect and absorb pollution. Connors et al. 2013 put forth that intraurban variation in temperatures can be accounted to be a result for following factors:

a) Building configuration.
b) Physical characteristics of urban structure (e.g. Height-to-width ratio of buildings and streets);
c) Urban land use cover (e.g. Proportion of built-up vs. vegetated surfaces per unit area);
d) Urban fabric (e.g. Physical properties of concrete, asphalt etc.); and
e) Urban metabolism (e.g. Waste energy from human activities)

Differentials in building configuration urban use patterns explain the variability in microclimates and thus the formation of ozone. These heat island effects and warmer temperatures during the summer affect urban air pollution directly and also increase the energy consumption demand of people in their homes and workplaces. Considering the increasing problem of UHI, cities worldwide are taking different policy measures for mitigating UHI impacts. While formulating policies for UHI mitigation, it should also be considered the temperature distribution pattern with respect to urban landscape configuration, and how the mitigation measures will contribute towards overall temperature of the urban area. Through an integrated view of landscape spatial heterogeneity and LULC composition, we can recognize not only the composition and configuration but also their impact on such physical phenomena (Stone and Norman, 2006).

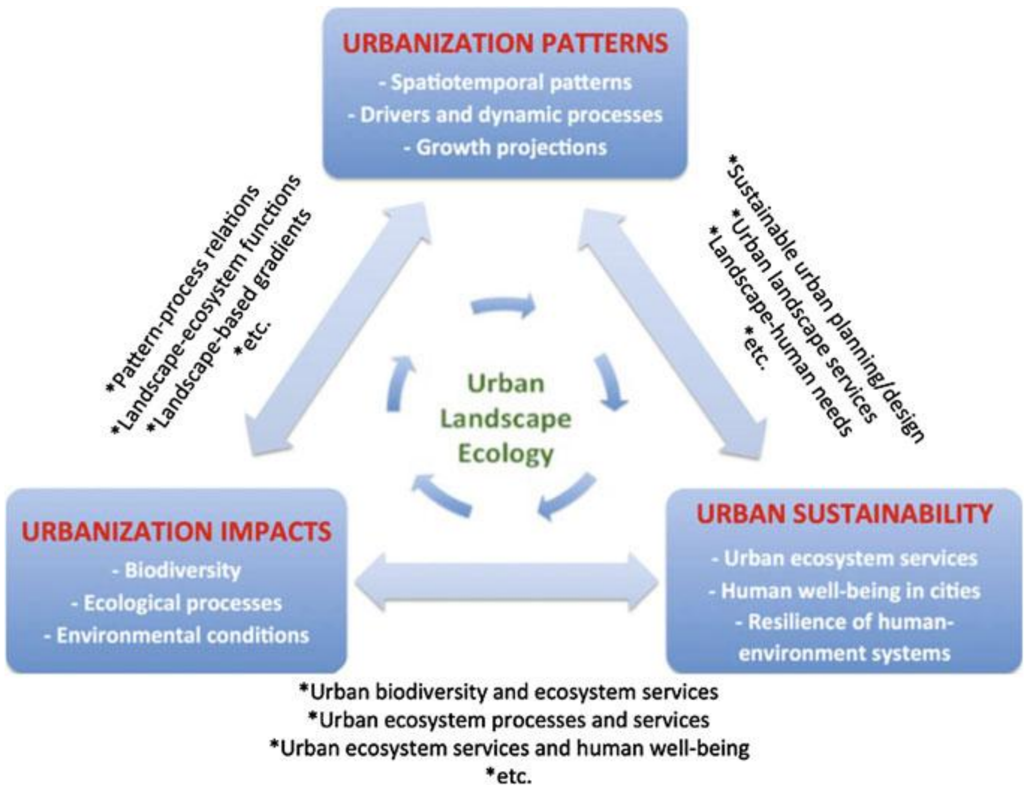


Figure 1.4: Scope of Urban Landscape Ecology (Wu et.al. 2013)

1.6 RATIONALE OF THE RESEARCH STUDY:

Delhi and its surroundings have grown as a nodal centre of economic growth, and thus attract ingression of more people into the region. A recent survey of the 4 mega cities (i.e. Mumbai, Kolkata, Chennai and Delhi) and 4 other metropolitan cities i.e. Pune, Bangalore, Hyderabad and Ahmedabad has revealed that Delhi tops the chart in job generation. Of the total jobs created in these 8 largest cities of India, Delhi is the home to one fourth thereof. This has led to rapid in-migration, shortage of housing and basic infrastructure, accompanied by a rapidly deteriorating physical environment, which is believed to have reached catastrophic proportions, causing serious concern to the Government. As a result of this concern, a compulsive need for planned development of Delhi & its surrounding counter-magnets was felt.

The problems and issues of Delhi and surroundings have always been addressed through a regional approach by planners since 1959 due to the active two way counter magnetism of the activities at the node and its associated ring towns of CNCR. The major growing towns of CNCR namely, Ghaziabad, Noida, Faridabad and Gurgaon have shared the increasing socio-economic burden of the highly urbanized Delhi but along with that are also going through the risk of inheriting the increasing problems in Delhi as discussed in the earlier sections. Delhi has been a piece of attention for researchers since long but the satellite towns have much been ignored. Furthermore, many researchers have worked in dealing with the issue of UHI problems of the region, but no study in our notice has yet attempted to associate it with land cover configuration for this region. Here an attempt is being made to cater to that problem with the perspective of landscape urban ecology in the satellite towns of DMA. This study thus primarily focuses to assess the spatial pattern and configuration of the urban land cover and its impact on the thermal environments therein.

Research Objectives:

a) To assess the urbanization pattern in major urban centres of CNCR (Central National Capital Region).
b) Computing thermal conditions and measure of the land cover classes using various spatial metric indices.
c) Analysing the effect of spatial configuration on thermal environment along with other major factors.
d) Deriving pixel based correlation among the variables and proposing solutions for the region.

Research Questions:

a) How is the municipal areas spatial land cover setup varying in the centres?
b) How is the temperature condition varying in the region among the four landscapes?
c) What is the pattern of urbanization observed from the metrics at different levels of hierarchy?
d) How are the indices of spatial configuration of land cover and thermal environments related?

1.7 POTENTIAL IMPLICATIONS OF THE RESEARCH STUDY:

Currently, there are many developed countries, mostly in North America and Europe which are already working and implementing methods for sustainable cities wherein thermal condition is one major criterion for their work. In India, the idea of sustainable cities is still at an infant stage. The rate of urbanization with the associated problems has created a sense of urgency for sustainable cities which needs to be nurtured for a safer road ahead. Organizations like, JNNURM, TERI University, CEPT University, NGOs like Jannagraha have started paving the road towards it. This study expects to put forth a small contribution to the sustainable planning studies already going on in the country.

2. LITERATURE REVIEW

In this chapter we discuss the recent developments in urban landscape ecology for analysing landscape configuration as a causation factor of UHI. The framework will integrate approaches from changing urban dynamics, urban landscape ecology, thermal remote sensing applications and sustainable planning. As put forth by Pickett *et al.* (2001), ecological studies of urban systems have been viewed along several kinds of perspectives: ecology as opposed to ecology of cities; biological versus land use planning, and disciplinary versus interdisciplinary. Urban landscape ecology is considered to consist of three interactive major components: quantifying the spatiotemporal patterns and understanding the drivers and mechanisms of urbanization (‘‘patterns/drivers studies’’), assessing the ecological and environmental impacts of urbanization (‘‘impacts studies’’), and understanding and improving urban sustainability (Fig. 2.1).Research on environment in urban systems has highlighted the dynamism and interaction of the cultural and physical environment.

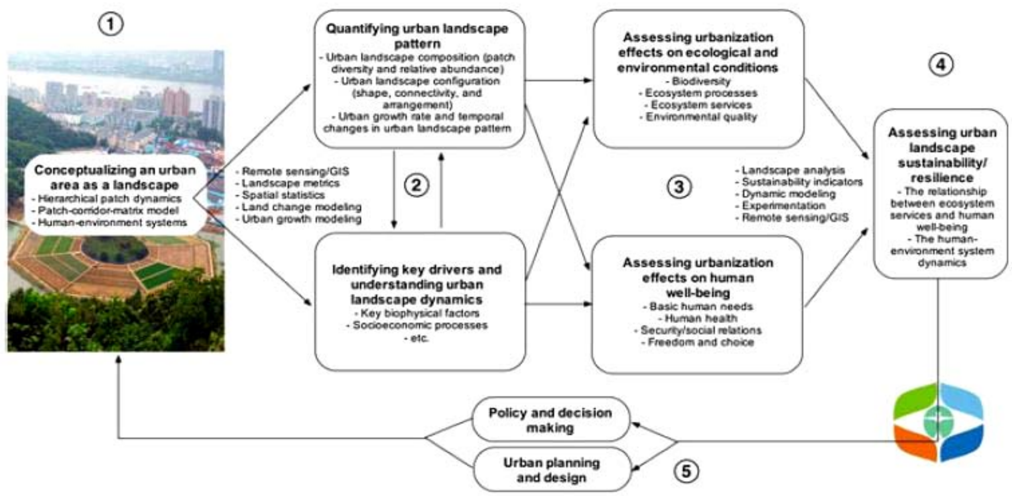


Figure 2.1: Drivers and Impacts of Urban Landscape Ecology.

Particularly relevant to this chapter is the number of research articles on urban landscape structure that have increased rapidly in the past decade. Such a growing behavior of interest in this field has reasons. Firstly, urban landscapes have highly interspersed heterogeneous patterns among all landscapes, and thus are ideal for applying spatial statistical methods and metrics analysis. Secondly, urbanization and its impact on the environment have increased and also its study has gained impetus since the last decade. Thus, the urban landscapes have emerged as a primary focus for landscape environmental studies. Given the increasingly urban nature of our landscapes and theincreasingly urban future of humanity, urban sustainability is becoming ‘‘need of the hour goal of landscape research’’ (Wu,2002).

2.1 URBAN LANDSCAPE STRUCTURE

Urban form refers to the way that a city's land use ismorphologically arranged, growsand represents the physical characteristics. It highlights the pattern of development in the city with the consideration of land use spread and the functioning of internal dynamics. Thus, it indirectly takes into account not only the physical characteristics but also the functional foot print of a city. There are classical theories on urban growth which gives important insight to this. These theories of urban morphology have defined urban patterns as concentric rings with different land use types (Burgess's Concentric Zone Theory, 1925); the concentric zone patterns modified by transportation networks to form sectors having different land use categories (Hoyt's Sector Theory, 1939) and further with the Multiple Nuclei theory (Harris and UlIman, 1945) that models an urban form with multiple centers of specialized land use. These theories explain the broader structure of a city, since l960s whereas now various modern theories have been evolved to characterize urban form at more detailed scale, such as fractals, cellular automata, spatial metrics, etc. (Aguilera *et al.,* 2011).

The urban growth form has differing characteristics at varying scales which contributes in dynamism of the whole complex system. Spatial metrics also evaluates the landscape scenario on similar terms. Scale of the growth is an important factor for urban form studies because the dynamics change at each scale and thus the analysis is also performed at various scales down the hierarchy from city, neighborhood, and street to building (Williams et al., 2000). In the previous studies metrics have been calculated on varying landscape units and scales ranging from 15-1000 m^2 depending on the spatial resolution of the application of study as well as the data available.

Spatial metrics indicators are now widely being used for quantifying urban form, exploring urban-rural gradient, or measuring the impacts of different urban forms. Quantification of urban growth on pixel level becomes vital when working with remote sensing data because all the datasets can be obtained in raster format. So, the analysis of phenomena with urban form as a parameter becomes feasible when the information is in a quantified form like other inputs. The concept of spatial metrics and its application in urban form and UHI study using remote sensing is described in the next section.

2.2 ROLE OF REMOTE SENSING AND GIS IN STUDYING THE DYNAMICS OF URBAN LANDSCAPE ECOLOGY

The dynamic nature of urban environmental as discussed above necessitates both macro and micro level analysis and the nature of digital database facilitates the multi-level processing. Until few years, maps and land survey records from archives were used for urban studies, but since the last decade trend has shifted to use digital, multispectral images acquired by the Indian and global EOS systems. The trend towards using remotely sensed data in urban studies began with first-generation satellite sensors such as Landsat MSS and was continued further by Landsat TM, ETM+ and SPOT. The advent of a third generation of high spatial resolution (5m/pixel) satellite sensors added to the remote sensing based urban studies. High resolution PAN and LISS III merged data were used together effectively for urban applications. Data from IRS P6-liss IV with 5.8 m/pixel spatial resolution is found to be very useful for intensive urban studies. In this study also LISS IV has been used. The development of Landsat TM data with 30 m/pixel spatial resolution has helped in mapping various applications like forestry, coastal management and quantifying the thermal conditions. Some of the salient features of different satellite sensors and the extractable levels of urban information are summarized in Table 2.1(Rai, and Kumar, 2011)

Table 2.1 Different Satellites providing thermal data

Sensor / Platform	Spatial resolution (m)	Spectral resolution of thermal wavelengths (μm)	Maximum temporal resolution
AVHRR / NOAA	1100	band 4: 10.3-11.3, band 5: 11.5-12.5	4 times daily
MODIS / Terra & Aqua	1000	band 31 to 36: 10.78-14.39	1-2 days
TM / Landsat 5	120	band 6: 10.4-12.5	16 days
ASTER / Terra	90	band 10 to 14: 8.125 - 11.65	16 days
ETM+ / Landsat 7	60	band 6: 10.4-12.5	16 days

Satellite-based remote sensing presently cannot provide atmospheric data at a high (i.e. < 1 km) resolution but is still very useful in describing the aspects of the climate pattern of urban areas by recording surface temperatures, soil moisture, land cover, and vegetation density. Spatially complete and time-synchronous coverage of an urban area can be obtained from thermal wavelength satellite sensors which measure Surface Temperature, thus unlike fixed stations and vehicle traverse the actual maximum and minimum temperatures over a city region can be obtained and intra-urban thermal patterns can be observed. However, because such images suffer from low temporal resolution, planners are reluctant to use the image data as representative of the UHI pattern of a city. Several studies are profusely using data from AVHRR, MODIS, PALSAR and LANDSAT data for land surface temperature estimation. It has been widely used for analyzing urban heat island effects and for planning purposes.

The evaluation of urban landscapes is often based upon different sub-functions which refer to landscape features such as land cover data, soil, groundwater and atmospheric conditions and supporting ancillary secondary data. Spatial overlaying of these parameters using GIS presents an analysis wherein the mutual functions of the parameters are more clearly understood. The characteristics of remote sensing and GIS make it feasible where the input parameters have the spatial association and represented in a digital manner. The sub-functions can thus act as monitors systems for ecological functions in urban environments and can help in guiding development along ecologically sound and sustainable paths.

2.3 SPATIAL CONFIGURATION AND SPATIAL METRICS

Spatial Metrics can be defined as, “quantitative and aggregate measurements derived from digital analysis of thematic categorical maps showing spatial heterogeneity at a specific scale and resolution” (Herold *et al.,* 2003). Developed in the late 80s, spatial metrics gives measures from both information theory and fractal geometry (Herold *et al.,* 2005). Analysis of geometric characteristics and the spatial relationships of the geographical units, spatial metrics successfully define the morphological characteristics of urban form and how the patches that form it are related. As the urban form has various levels, accordingly spatial metrics quantify the spatial heterogeneity at different levels like within individual patches, all patches in the same class, or for the entire landscape as a collection of patches (McGarigal, 1994)**.**

Landscape in the domain of metrics calculation is defined as an area of land containing a mosaic of patches (McGarigal *et al.,* 2002). Patch area has a great deal of ecological utility in its own right. Measuring the morphology,distributionandshape of land use in a hierarchy is the key feature of spatial metrics. The basic unit of the measurements is a patch. A patch is defined as a relatively homogenous area formed from some landscape property of interest such as built up, vegetation, water etc. In vector data, a patch is a polygon classified as a specific land cover type (Chakraborty, 2009) and for raster data it is ‘‘a contiguous group of cells of the same mapped category’’ (Turner *et al.*, 2001).

In this study spatial metrics were measured from LULC map derived from satellite imagery, thus patch on a raster data was considered wherein a pixel was be the basic unit and the homogeneous areas were defined from group of pixels with similar property.Patch based spatial metrics calculates a number of indices representing the geometric characteristics of the landscape units and the spatial relationship between them. While individual patches within a region or landscape possess relatively few fundamental spatial characteristics (e.g., size, perimeter, and shape), collections of patches may have a variety of aggregate properties. Based on these levels of aggregations, McGarigal (2002) defined spatial metrics at three levels corresponding to the hierarchical organization of spatial heterogeneity in patch mosaics.

1. Patch level metrics **-** Patch level metrics measures indices for individual patches, and characterize the spatial character and context of patches. Patch metrics serve primarily as the computational basis for several of the spatial metrics, for example by averaging patch attributes across all patches in the class or landscape.

2. Class level metrics **-** Class level metrics are integrated over all the patches of a given category of interest. Thus a class is a set of patches of the same land cover type. Class metrics quantify the characteristics for the entire class such as degree of aggregation and clumping and produce on unique result for each class.

3. Landscape level metrics - Landscape level metrics are integrated over all patch types or classes of interest over the full extent of the spatial unit of measurement (i.e., the entire landscape). Landscape level metrics has been widely used to measure urban form dimensions. It describes the pattern i.e. composition and configuration of the entire landscape (Leitao, 2006). Landscape patterns have been identified to originate from spatial heterogeneity like:

1) No. of patch type.
2) Proportion of each patch type.
3) Spatial arrangement of patches, namely patch aggregation level.
4) Patch shape
5) Contrast between neighboring patches.

Thermal environment of a landscape are recorded from radiative energy of surfaces, thus, pattern of land cover may influence the thermal nature of the area. It may get affected by spatial arrangement of land cover pattern due to its effect on movement and flows of material and energy exchange in a landscape. This context of landscape configuration and thermal environment can give an insight on how to mitigate impact of urbanization on UHI through urban design and vegetation management (Zhou *et al.,* 2011).

In the previous studies over various parts of the world, for evaluating dependence of LST on metrics, different combinations of indices have been used. (Dempsey *et al.,* 2010) used four spatial metrics to represent two dimensions of the urban forms: compactness and complexity whereas (Huang *et al.,* 2007) studied five dimensions of urban form: complexity, centrality, compactness, porosity anddensity. For the study in Shanghai the composition metrics used were PLAND, SHEI, SHDI and for configuration ED, PD, LSI, CI, CONTAG were used. Most of the studies have used the same indices but others have added few more like PAFRAC, PROXIMITY, GYRATE_MN, SHAPE_MN, and ENN_MN. Of these whereas area metrics are considered best representing composition, edge metrics are best at depicting configuration. In this study core area metrics have also been included as they are affected by landscape configuration and thus very helpful for the study.

In a nutshell, cell and patch level metrics represent the spatial character and context of individual patches, and class level metrics represent the amount and spatial distribution of a single patch type and can be interpreted as fragmentation indices (Leitao, 2006). Landscape level metrics, on the other hand, represent the spatial pattern of the entire landscape mosaic. Hence, it is important to interpret each metric in a manner appropriate to its level i.e. patch, class, and landscape. Particularly, for urban planning, where the extent and fragmentation of land use classes and organization of different land uses are the principle concerns, class and landscape level metrics are used. But, for analysis of parameters in raster format, cell metrics have been applied. There are studies on microclimate which deal with changes in LST over urban areas and they have shown that configuration metrics can be used for evaluating the intensity of UHI (Liu and Weng, 2009).

2.4 URBAN HEAT ISLAND

Due to rising urban air temperature and more than that the rising rural-urban gradient, UHI has become a concern for more than two decades in most of the cities of the world. UHI can be assessed in several ways: by comparing present temperature pattern to earlier conditions, by exploring the urban-to-rural temperature differences or by evaluating land surface temperature (LST) differences with respect to land cover distribution. USEPA documented that the difference between annual mean air temperatures of a city in day and night can be up to 10°C warmer than the surroundings. The measure of UHI intensity varies from city to city, but the warmest area is usually the urban core. Large amount of impervious area and lower Sky View Factor (SVF) contributes towards massive heatstorage and so areas with higher range of heat have a strong correlation with land cover pattern. Changes in the surface properties produce regions that are warmer than the surrounding natural surface (Rajasekar &Weng, 2009).

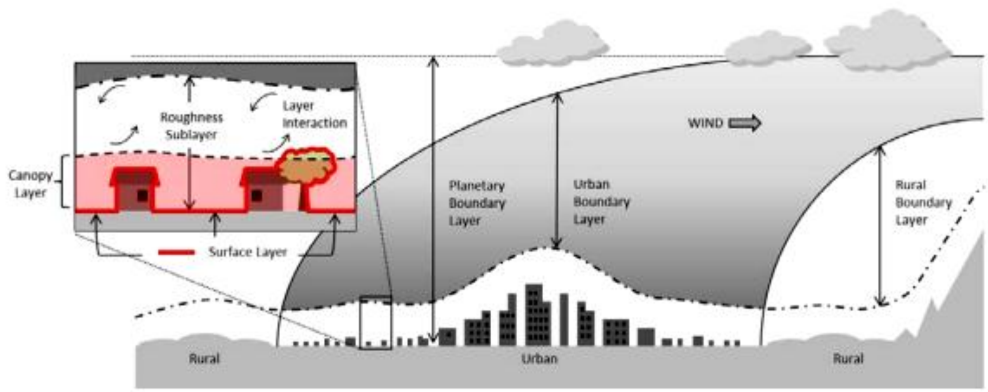


Figure2.2: Urban Layer Locations (Black, A.L. 2013)

Along with the land cover pattern there are other heat sources too like vehicles, power plants, air conditioners and other heat sources which adds to urban heat. The direct adverse impacts of UHI are deterioration of living environment, increase in energy consumption (Konopacki and Akbari, 2002), water consumption (Niizawa, 1985), elevation in ground-level ozone (Rosenfeld et al., 1998) and even an increase in mortality rates (Changnonetal, 1996). Increased temperatures not only affects the natural environment but also takes toll on resource management in the society by escalating water consumption and energy consumption of buildings with cooling systems. A USEPA study performed in New York stated that around 495 million KWh of energy could be saved for every degree reduction in UHI effect. Air temperature variations are stronger and greatest at night whereas in surface temperature variation occurs during daytime. The surface temperature can be attributed to dynamics of the surface layer because majority of the net solar radiation is absorbed at this surface and the surface properties highly influence the temperature just above the surface (Xian, 2005). In this study we thus focus on surface temperature which is directly controlled by surface properties as urban design and planning primarily deals with the surface arrangement of landscape components.

Remote sensing techniques are the most common method to analyze surface temperatures (Buyantuyev, 2010).Satellite remote sensing provides a straightforward and consistent way for determining thermal variation over surfaces. The radiance emitted by a heated object is recorded onboard sensors in the thermal infrared region of the light spectrum between 3µm and 15µm. Thermal radiation is emitted by all objects with a kinetic temperature greater than absolute zero and the distribution of wavelengths of emitted energy is directly proportional to the temperature of an object's surface layer (Planck's law) (Mather, 2004). The measured radiance in the thermal infrared spectrum is converted to surface temperature using Planck's Law at each cell of the captured image. Surface temperature maps combined with factors such as percent impervious surface area, vegetation coverage, and surface characteristics indices can give a reliable UHI scenario of the area.

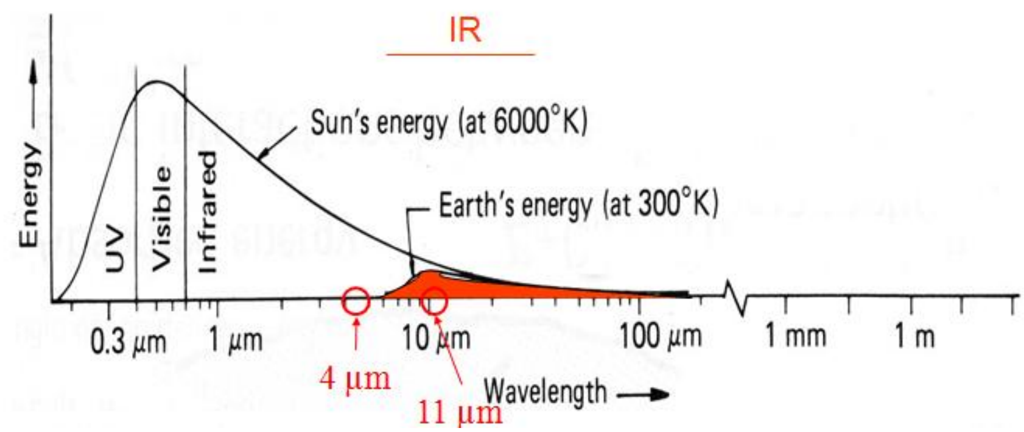


Figure 2.3 EMR region used for Thermal Remote Sensing

Since the 1980's a number of studies have demonstrated the utility of satellite Earth observed land surface temperatures as an alternative or supplementary data source for urban temperature analysis. Over this period range of sensors have been developed with thermal bands of varying spatial and spectral resolutions; from low spatial and spectral resolution sensors such as the AVHRR (1.1Km on nadir, two thermal bands) to newer higher spatial and spectral resolution thermal sensors such as ASTER (90 m at nadir and with five thermal bands). However, due to technological constraints, satellite thermal sensors are unable to capture both high spatial and high spectral resolution data with a low re-visit time (Stathopoulou and Cartalis, 2009).Many previous studies have been conducted especially using AVHRR, as Landsat TM sensor data had limited accuracy and was not employed as much prior to development of a mono-window algorithm by (Qin *et al.,* 2001). Their study found that the technique achieved accuracy within 0.4˚C between assumed and retrieved temperature levels. These results indicate that Landsat TM thermal data provides a reasonably accurate method for measuring LST with a spatial resolution adequate for urban studies.

2.5 SPATIAL METRICS AND UHI RELATION

Landscape structural patterns are related to ecological processes and the ultimate goal of analyzing spatial patterns is to get to the underlying processes or functions. Pattern analysis is a ‘‘means’’ not an “end”.Considering the evident interaction of land surface with ambient temperature, most of the previous research studies have focused on landscape composition and less on the impacts of urban structure, or spatial configuration, i.e. the spatial arrangement and structural characteristics of land cover patches within a city (Gustafson, 1998).

Some recent work has considered spatial pattern of land cover patches as a factorinfluencing urban heat island. Connors *et al.* (2013) used high-resolution (2.4 m) land cover data and an ASTER temperature product to examine 90 randomly selected sample sites of 240 m^2.They found significant relationships between several measures of spatial configuration and LST, but with differing patterns among the land uses. Zhang *et al.* (2009b) used Landsat ETM data to derive urban LST from Nanjing, China, and noted that the spatial characteristics and configurations of vegetation patches within cities have varied impacts on the distribution ofLST. Like Connors *et al.* (2013), ASTER data was also used by Cao *et al.* (2010) for analyzing park spaces and LST in Nagoya, Japan. They found that park shape influences LSTpattern. Weng *et al.* (2008), in their study on Indianapolis, found an interestingrelationship between LST in residential areas and its spatial configuration, with more complex residential zonal polygons resulting in greater variations of LST. Using fine resolution data of Baltimore, Zhou *et al.* (2011) demonstrated that configuration of land cover patches has a significant influence on urban LST.

While understanding the various effects of urbanization is important and necessary, the ‘‘impacts studies’’ need to address how these effects can be eliminated, mitigated, or adapted through urban design and planning actions. This requires the integration among the three major components mentioned here. The prior studies on spatial metric and UHI, as discussed above, have shown the influence of land use configuration on temperature, but none of the studies have explored how the metrics of landscape configuration interacts with UHI at pixel level. This study aims to fill in the void and evaluate temperature pattern with the changing land cover dynamics at micro scale in relation to the pattern measured by spatial metrics.

3. STUDY AREA

3.1 AN OVERVIEW

National Capital Region is the biggest cultural region delineated in the country based on its socio-economic linkages and growth perspective with its center placed at NCT Delhi. In the shadow of National Capital Territory of Delhi, CNCR has assumed its significance. CNCR is the belt surrounding NCT consisting of six DMA cities which are the highest order settlements in the NCR after the capital city according to NCR plan 2001. As per NCR Plan - 2021, the Delhi Metropolitan Area has been redesignated as Central National Capital Region (CNCR).The concept of CNCR was well recognized in the first Master Plan of Delhi (MPD-1962), which had defined CNCR as an area of 800 sq. km comprising the entire Union Territory of Delhi and the Ring Towns of Loni and Ghaziabad in Uttar Pradesh, Faridabad, Ballabhgarh and Gurgaon of erstwhile State of Punjab and Narelain Delhi. It was also stated that the 'Ring Towns' must be developed not only to deflect some of the population that would otherwise come into Delhi and jeopardize the planned growth of Delhi but also to help these towns to grow in a planned manner.These towns delineated in NCR Plan 2001 are Ghaziabad and Noida in Uttar Pradesh Sub Region of NCRand Faridabad, Gurgaon, Bahadurgarh-Kondli in Haryana Sub Region of NCR.

NCT Delhi with an area of1483 sq. km cannot foresee massive development in terms of infrastructure / services and residential development and so the burden had to be shared by the CNCR cities when beyond a saturation point the capital city's carrying capacity may not be able to sustain population growth. As a result of implementation of NCR plan 2001 the population growth of NCT slowed down in eighties and nineties because of the planned development of peripheral towns which contributed in accommodating the population growth and eventually these areas caught up with the speed of Delhi's population growth. The core of the agglomeration is connected to the peripheral centers along the radial routes, now on a verge of dissolving the boundaries and forming a conurbation.Among the CNCR Towns, Faridabad and Ghaziabad have already attained the status of million plus cities. These towns were slated to grow to 37 lakh against which they actually grew to 30.33 lakh as per 2001 Census. Of these six cities/towns, Ghaziabad and Faridabad have reached their targeted population, while the rest of CNCR towns could not achieve their target.

These cities have become more attractive for development of industries mainly due to proximity to Delhi with marketing and other support facilities and policies of the State Governments. The development has become intensive particularly among the major transport corridors, which has led to a form of ribbon development all along transport routes, lacking in adequate infrastructure / facilities and also shelter. Besides India, this concept of decentralization has been found to be popular in other countries too like UK, China, USA and Turkey wherein for decentralization of infrastructure, traffic overload, or introduction of garden city concept, growth of satellite towns was initiated. Now the question arises if the decentralization of NCT to CNCR has taken place in a sustainable manner or not

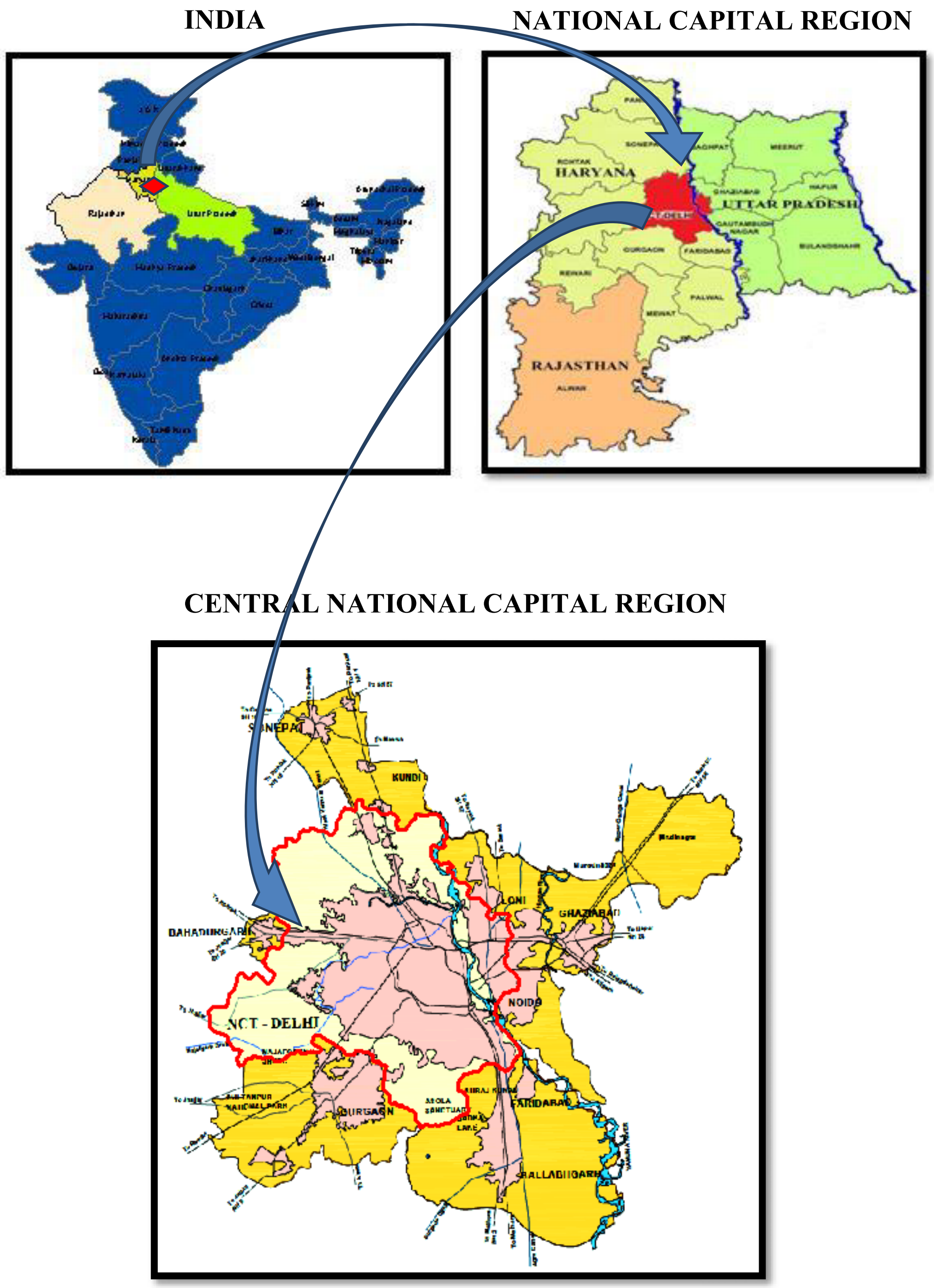


Figure 3.1 Location of the study area

3.2 CRITERIA FOR THE SELECTION OF MAJOR CENTRES OF CNCR

The region of interesti.e. CNCR discussed above doesnot experience a uniformly high growth in all of its urban centers because of various social, political and economic reasons. Whereas the objective of this research strictly concerns with a phenomena that is a result of high growth rates of population, urban area and other ancillary factors too. Thus, for meeting the primary needs of the research the centers of the region were put through a selection criterion for restricting the study area centers to be highly relevant to the research objectives. For selection, two main criteria were adopted, which have a direct and strong relation with the prevalence of any anthropogenic activity in the urban areas. First among them was the recent most decadal growth rate of population (2001-2011) which showed the current potential scenario of population growth in the region. And second was the level of urbanization which very clearly gives a glimpse of the dominant urban areas in the region. In the below diagrams we can see the results of both the criteria. In decadal growth rate Gurgaon, Noida and Ghaziabad show higher values than other 3, but Faridabad was an exception as its 2011total population was higher than Gurgaon and Noida which itself delineated it as a major urban center. The level of urbanization clearly demarcates the 4 eastern and southern centers having high urbanization whereas Sonepat and Bahadurgarh have almost negligible level of urbanization.

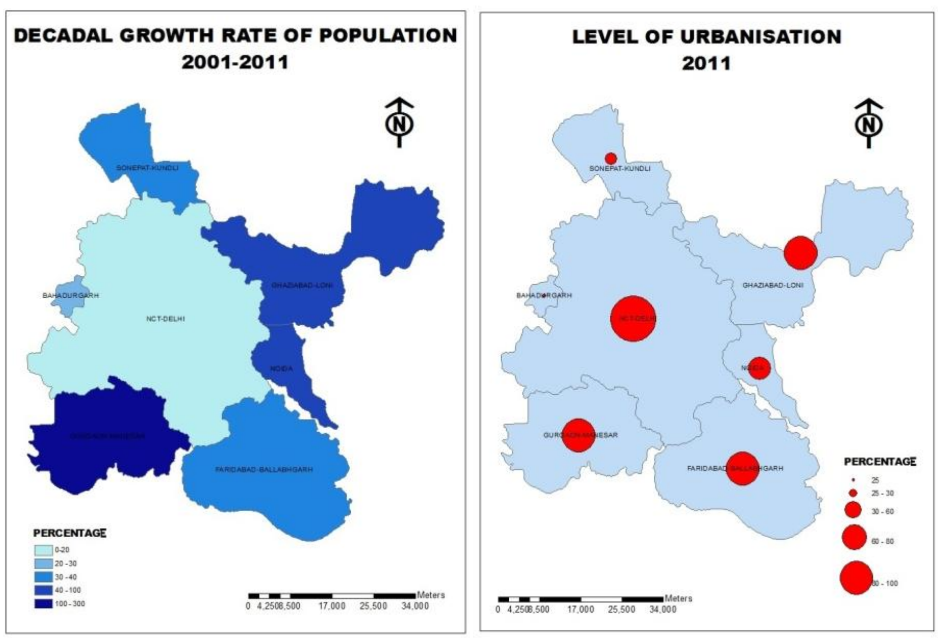


Figure3.2: a) Growth Rate of Population 2001-11; b) Level of Urbanization in 2011.

Based on the two criteria, Sonepat and Bahadurgarh were found lagging far behind than the others which seems to be two steps higher in hierarchy as put forth in the Primate City rule of Mark Jefferson. Thus, the two cities Sonepat and Bahadurgarh were abandoned from the region of interest and was narrowed down to the spuriously urbanizing cities of Ghaziabad, Noida, Faridabad and Gurgaon.

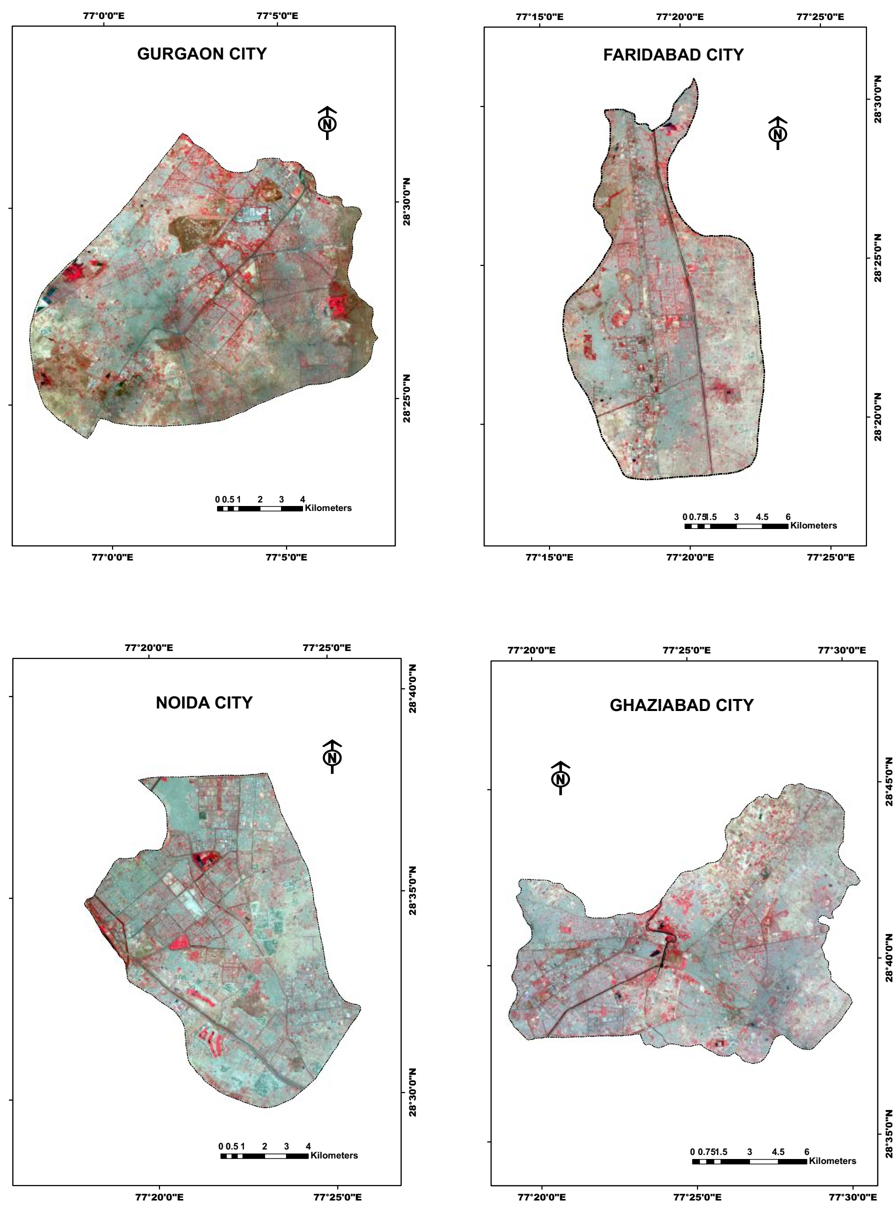


Fig 3.3: Major Cities of the study Area

3.3 CHARACTERISTICS OF STUDY AREA

3.3.1 Ghaziabad: Placed in eastern part of CNCR belt it is one of the most important cities of UP NCR sub-region, termed as Gateway of UP. It is an important industrial and trading center in the CNCR area as well as the primary commercial, industrial and educational center of western Uttar Pradesh.

a) Location: The city is located at 28.67°N latitude and 77.42°E longitude about22 km from NCT Delhi and is on NH 24 connecting the city with Delhi-Moradabad-Lucknow. The city is bounded by the NCT Delhi in the west and NOIDAin south.Situated in the Upper Gangetic Plains, the city has two major divisions separated by the Hindon River, namely: Trans-Hindon on the west and Cis-Hindon on the east side.

b) Climate and Rainfall: As it is in close proximity to the national capital, its temperature and rainfall are similar to Delhi. The Annual rainfall of the district has been reported to be 731 mm based on data from 1901 to 1970. The climate is extreme type with average temperature shooting up to 40ºC or more during peak summer and dips to less than 5ºC in the month of January. Rajasthan's dust storms and snowfall in the Himalayas, Kumaon and Garhwal hills have their impact in the weather regularly.

c) Socio-Economic Profile: In the last 3 decades i.e.1971-2001 the population of the city increased by 6.5 times.In 2001-2011 it showed a decadal growth rate of 97.2%. Census 2011 shows that it has a population of 1.6 million of which males are 8.6 lakhs and females are 7.6 lakhs and the total literacy rate is 100.54%. Ghaziabad is a subcategory B1 district of category B i.e. having socioeconomic parameters below the national average.

3.3.2 NOIDA: This city gets its name from an acronym coined for 'New Okhla Industrial Development Authority. It was primarily established not only to attract industries but also to provide residential accommodation at cheaper prices in comparison to NCT Delhi.

a) Location: The city is located at 28.57ºN and 77.32º E. It is located in close proximity to the metropolitan city of Delhi and lies along the eastern and southeastern boundaries of the National Capital Territory of Delhi. It is bounded by the river Yamuna and the city of Delhi in the Westand the South-West, National Highway 24 and the city of Ghaziabad in the North, river Hindon and Greater Noida Area in the East, and the confluence of rivers Yamuna and Hindon in the South.

b) Climate and Rainfall: In summer from March to June, the weather remains hot and temperature ranges from minimum of 28°C to maximum of 48°C.Monsoon season prevails during mid-June to mid-September.The cold waves from the Himalayan region makes the winters in Noida chilly and harsh. Temperatures fall down to as low as 3 to 4°C at the peak of winters. In January, a dense fog envelopes the city, reducing visibility on the streets.

c) Socio-Economic Profile: The population of NOIDA grew by nearly 300% during 1981- 91and has been one of the fastest growing towns in the country. The 1991-2001 decade was 108.21% and 2001-2011 was 110%. Total population is 6.4 lakh in which males are 3.5 lakhs and females are 2.8 lakhs. Total literacy rate is 88.58%. Lastly 20% of the population in NOIDA lives in slums and 48% in the urban villages. Both areas are unplanned andsuffer from serious deficiencies in terms of basic infrastructure likesewerage, piped water, drainage and power.

3.3.3 Faridabad: Faridabad, the largest city & first metropolitan city in the Delhi Metropolitan Area. The economic base of the city is its industrial character and it has been retained, as20% of the land is under the industrial use while nearly half has been envisaged under the residential use.

a) Location: The city is located at 28.42ºN and 77.30ºE. Faridabad enjoys a prime location both geographically and politically. The river Yamuna forms the eastern district boundary with Uttar Pradesh. The Delhi-Agra National Highway No.2 passes through the center of the district. The presence of Aravalli hills on the western side and Agra Canal on the eastern side has been responsible for the linear development of the city.

b) Climate and Rainfall: Faridabad town experiences a semi-arid climate characterized by wide temperature variations and scanty rainfall. During summer, temperature may reach up to 45ºC in June while in winter it drops to 1.9º C in February. May and June are the hottest and driest months, when dust storms from the west prevail with high speed. The average annual rainfall recorded at the Faridabad rain gauge station is 845 mm as computed from the data of 1978 to 1997. The number of actual rainy days varies between 7 and 22 in a year.

c) Socio-Economic Profile: The period 1981-2001 witnessed a slow growth rate but it successfully attained105.59% of the assigned population as per NCR Plan - 2001. In 2011 census Faridabad had a population of 1.4 million out of which males were 7.5 lakhs and females were 6.5 lakhs. The literacy rate is 84.88 per cent. Although being part of CNCR the quality of infrastructure in NCT and Faridabad are at opposite ends with Faridabad on the poorer side.

3.3.4 Gurgaon : Once a non-descript land, the impact of economic liberalization and State Government's policies on industrial development enabled the city to attract large number of MNCsand Automobile Industries which acquired it the image of an industrial/ commercial town and assumed significance in CNCR.

a) Location: The city is located at 28.47ºN and 77.03ºE at a distance of 32 km from Delhi. Its boundary touches Rajasthan and south Delhi and it makes Gurgaon to be a strategically important place. On its north, it is bounded by the District of Jhajjar & the union territory of Delhi; Faridabad District lies to its east. On south it shares boundaries with Mewat whereas Rewari lies on its west. The city is on a rolling plain dominated by the extensions of Aravalli.

b) Climate and Rainfall: Summers, from early April to mid-October, are typically very hot and humid, with an average daily June high temperature of 40 °C with heat indices easily breaking 43 °C. Winters are cold and foggy with few sunny days, and with a December daytime average of 33 °C. The Western Disturbance brings some rain in winters that further add to the chill. The monsoon season usually starts in the first week of July and continues till August. Thunderstorms are not uncommon during the Monsoon. The average annual rainfall is approximately 714 mm.

c) Socio-Economic Profile: Population growth rate was very high during 1941-51and 1951-61 registering more than 70% growth, however, the decades1971-81 and 1981-91 experienced slower growth rate of 50.92% and34.70% respectively while during 1991-2001, the city has witnessed upsurge in the growth. But in 2001-2011 it has shown an exponentially high growth rate of 300%. In census 2011 the population was recorded as 8.7 lakhs of which males are 4.7 lakhs and females 4 lakhs. The overall literacy rate was found to be 86.3%.

3.4 DIFFERENT FUNCTIONAL ROLE OF THE CITIES

The establishment of each of the four cities has been based on different conditions but each of them have evolved with some overlapping aspect due to one common ground lying amongst them all i.e. linkage to NCT Delhi. Up to some extent all the towns around Delhi were planned for decentralizing the overtly industrial and residential activities which were congesting the capital city and keeping it away from a balanced growth. Ghaziabad started as a center for shifting the industrial activities, and as a result it attracted many industrial estates to it. But, then growth of the other three towns also attracted the industries, and Ghaziabad started replacing industrial areas with educational activities and soon the industrial and agricultural lands started getting converted to tertiary sector lands. Noida was planned for mainly decentralizing the growing residential needs and so planned residential colonies came up in the city. Also, some small scale industries were encouraged as medium and large scale industries could not be accommodated in the midst of residential spreads.

In the last decade upcoming of DMIC (Delhi Mumbai Industrial Corridor) also affected the dynamics of the region. Faridabad had many residential cooperative societies, but gradually due to availablecheap labor, it became a hub for investors and a lot of industries came up in there. The development of DMIC has played a role in shifting the industries from Ghaziabad to Faridabad for its direct linkage with NH1. Furthermore the recent functional activity of Gurgaon also has DMIC as one of the contributing factors. With rest of the major functions dissipated to other centers, the tertiary and quaterny services ended up concentrating in Gurgaon. This has also led to changing urban morphology of the city in the form of posh residential colonies and a planned industrial development. In this manner, with decentralization process, each of the cities evolved in their own manner with a dominant function that defines each of them, where Ghaziabad has evolved as educational hub, Noida as the cheaper residential alternative, Faridabad an industrial town, and Gurgaon the cosmopolitan city.

3.5 MATERIALS AND DATA USED

3.5.1 Satellite data

Satellite data gives exact information about the spatial information on the surface of the earth that is changing with time. Spatial information depends on the four types of resolution i.e. spatial resolution, temporal resolution, radiometric resolution and spectral resolution. Spatial resolution depends on the sensor of the satellite; the finer is the resolution the more detailed information is obtained. Remotely sensed data is the primary data used in the study is for deriving two main components of this research i.e. land cover and thermal data. LISS-1V imagery was used for land cover and Landsat-8 TIRS bands 10 and 11 were employed for retrieving temperature respectively. The choice of period of study was chosen based on the prevalence of thermal micro-climatic conditions, which was found to be intense in summer months i.e. May and June. Furthermore, the time of data observed for both the satellites was kept closer for higher accuracy in analyses.

3.5.1.1 RESOURCESAT-2 LISS-IV

A moderately detailed land cover map was required for the study, so data retrieved from LISS-IV sensor onboard the Resourcesat-2 satellite was brought to use. Resourcesat-2 is a follow on mission to Resourcesat-1 and is intended to continue the remote sensing data services to global users provided by Resourcesat-1. In Resourcesat-2 swath of LISS-4 has been increased from 23 km to 70 km and also the radiometric accuracy has improved from 7 bits to 10 bits. The georeferenced and orthorectified product has accuracy better than 5 m.

Table 3.1 Specification of LISS IV data

SPECIFICATIONS OF SENSOR	
Number of Bands	**1-Mono , 3- Multispectral**
Spectral bands (µm)	**B2 0.52-0.59 ; B3 0.62-0.68 ; B4 0.77-0.86**
Resolution (m)	**5.8**
Swath (Km)	**70/23**
Revisit (Days)	**5**
Quantization	**10-bit**

SPECIFICATIONS OF DATA	
Path ; Row ; Sub scene	**96 ; 51 ; A,B,C,D**
Date of Pass	**24 April 2013 (B,D) ; 18 May 2013 (A,C)**
Time of Pass	**05:40**
Data Type	**GEOREF**
Data Format	**GeoTIFF**
Projection & Datum	**UTM and WGS84**

3.5.1.2 LANDSAT-8 OLI& TIRS :

The Landsat program is a corroborative effort between the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to gather satellite remote sensed spectral images of the Earth’s surface. The first of seven satellites was launched on July 23, 1972. Thermal infrared (TIR) imaging was included for the first time with the MSS for the Landsat 3 and with Thematic Mapper (TM) for the Landsat 5. OLI onboard Landsat-8 has advancement over earlier Landsat sensors. Instruments on earlier Landsat satellites employed scan mirrors to sweep the instrument fields of view across the surface swath width and transmit light to a few detectors. The OLI instead uses long detector arrays, with over 7,000 detectors per spectral band, aligned across its focal plane to view across the swath. This “push-broom” design results in a more sensitive instrument providing improved land surface information with fewer moving parts. With an improved signal-to-noise ratio compared to past Landsat instruments, engineers expect this new OLI design to be more reliable and to provide improved performance.

TIRS uses Quantum Well Infrared Photo detectors (QWIPs) to detect long wavelengths of light emitted by the Earth whose intensity depends on surface temperature. These wavelengths, called thermal infrared, are well beyond the range of human vision. The QWIPs TIRS uses are sensitive to two thermal infrared wavelength bands, helping it separate the temperature of the Earth's surface from that of the atmosphere. Their design operates on the complex principles of quantum mechanics. Gallium arsenide semiconductor chips trap electrons in an energy state well until the electrons are elevated to a higher state by thermal infrared light of a certain wavelength. The elevated electrons create an electrical signal that can be read out and recorded to create a digital image.USGS provides Landsat data product after Standard Terrain Correction (Level 1T). Standard Terrain Correction (Level 1T) provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy (Landsat Product Information, USGS).

The specifications of the sensor characteristics and data acquired are given in the table that follows.

Table 3.2 Specification of LANDSAT 8

SPECIFICATIONS OF SENSOR	
Number of Bands	**9-OLI , 2-TIRS**
TIRS Spectral bands (µm)	**B10 10.3-11.3 ; B11 11.5-12.5**
Resolution (m)	**15m (PAN), 30m (MX), 100m (Thermal)**
Swath (Km)	**185 km**
Revisit (Days)	**16**
Quantization	**16 unsigned bit**
SPECIFICATIONS OF DATA	
Path ; Row	**146 ; 40**
Date of Pass	**13 May 2013**
Time of Pass	**10: 50 IST**
Data Type	**L1T**
Data Format	**GeoTIFF**
Projection & Datum	**UTM and WGS84**

3.5.2 Secondary Data:

For preparation of spatial digital database both spatial and aspatial data is required. Thus, both existing spatial and aspatial data was used for supplementing the remote sensing data with ground reality.

a. CNCR does not have an administrative boundary, thus the boundaries of CNCR region along with other ancillary spatial data were obtained from NCRPB (National Capital Region Planning Board) through internet.

b. Regional and master plans for the cities were also downloaded for the year 2011 from different sources on internet.

c. Census data wherever used was obtained from Census of India website providing not only primary but also derived variables.

4. METHODOLOGY

4.1 APPROACH OF THE STUDY

This chapter presents the analytical approach followed to evaluate the relation between land surface temperature and urban land form configuration in the four major urban centers of CNCR. The methodology can be assumed to be broadly divided into 4 major steps. Firstly, classification of images for land cover information, secondly, land surface temperature derivation for UHI scenario, thirdly metrics calculation for the land cover varying patterns and fourthly correlation analyses of the datasets. Land use/land cover (LULC) data were derived from the LISS IV and Land surface temperature (LST) was derived from Landsat 8satellite image. From the LULC data, spatial metrics were derived to evaluate the geometrical dimensions and various distribution aspects of urban form for the four centers of the region. The spatial metrics were calculated at different levels i.e.landscape, class and pixel level. LST distribution for the four cities was evaluated to understand the differences in local temperature distribution. Finally, linear regression technique was applied to identify the dominant spatial patterns of urban form that are significantly contributing towards land surface temperature. Figure 4.1 presents a flow chart of the methodology that schematically represents the entire process.

4.2 IMAGE CLASSIFICATION

Land cover map depicting the physical material over the earth is used for several applications and decision making purposes. The main objective of this research lies with analyzing the fragmentation of the land cover and so land cover is a primary dataset in this study. Thematic maps are very much useful for management of natural resources and developmental planning, and forms the basis for every study that concerns with spatial studies, thus it becomes necessary to prepare thematic maps. These maps were prepared using satellite imageries and secondary spatial data using visual interpretation and digital interpretation techniques.

4.2.1 Acquisition and pre-processing of data

The temporal resolution of the LISS IV sensor is 5 days; as a result, for each month 5 or 6 images for a location were available. For avoiding misclassification, cloud free images were selected to avoid loss of information. For minimizing seasonal variation, images were selected within short time interval of the same season. Before the primary image processing, pre-processingwas donefor the raw satellite data in case the data had any distortion. Geometric correction of the raw data is performed to remove the geometric distortion of the image. The received image was geometrically corrected so this step was avoided. The four images were then mosaicked and the study area was subset from it. Due to unfavorable weather condition satellite data requires image enhancements for improving the basic quality of the image to be interpreted. Thus, atmospheric correction of the LISS IV image was done using QUAC model of ENVI software.

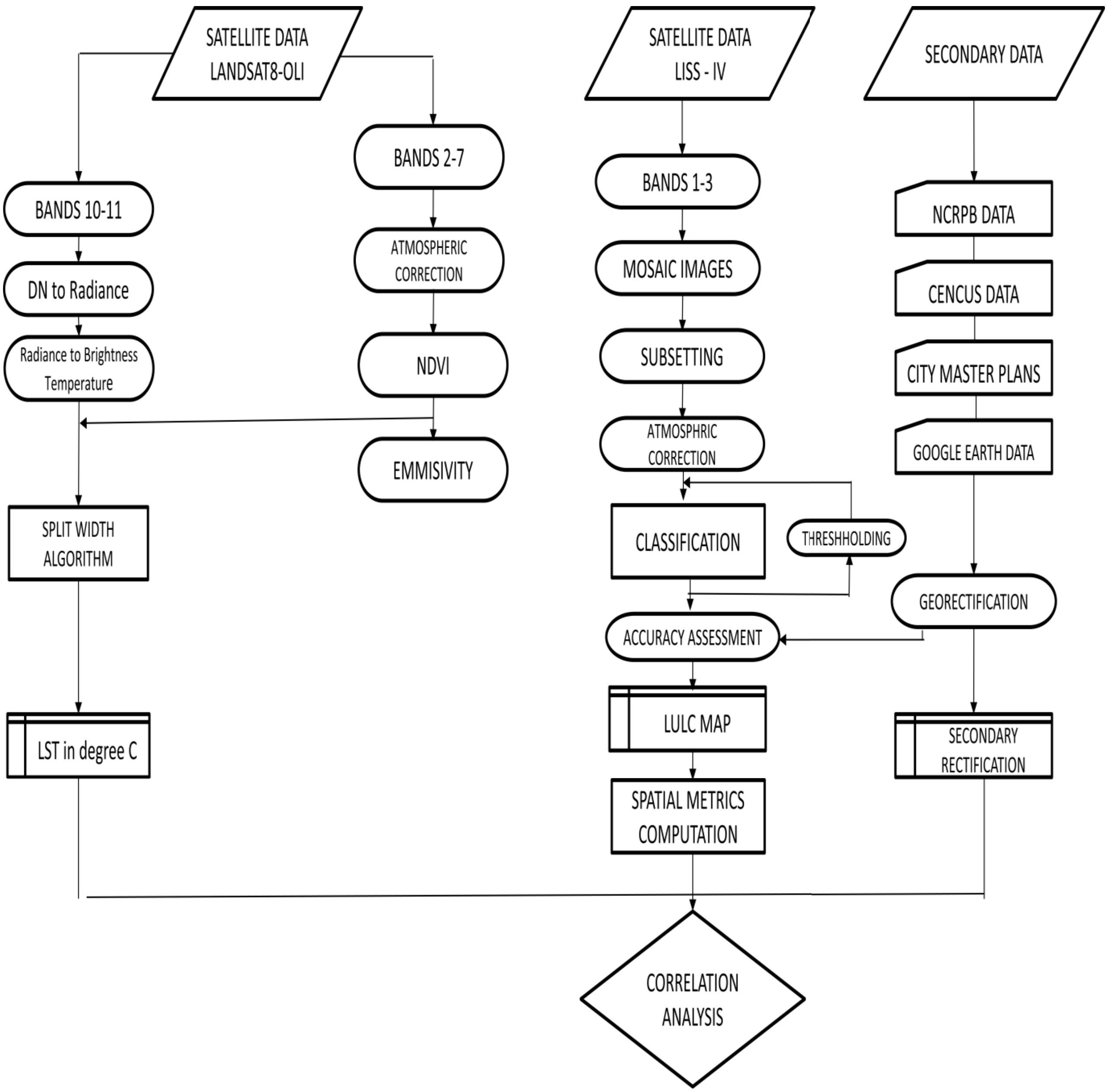


Figure 4.1 Methodology Chart

4.2.2 Training data sampling

The first step in selecting the training data involves the decision for number of classes an image has to be classified into. The demand of the research depends on the major land cover components of an urban landscape so level-1 classification of image into the major components of a urban landscape i.e. built-up, vegetation, water, bare ground would suffice but for other analyses the land uses were also included. Thus, five major classes were delineated through the digital classification process and later on the classification was reorganized to add land use information too. A division was made to the vegetation class depending on its density because of the variation visible in the images and also its role as a factor in urban microclimate.The training samples were taken by seed growing method. It uses spectral Euclidean distance as the delineating factor for the class signatures. The process gave very little overlap between the training signatures and that added to the accuracy of the classification results.

4.2.3 Digital Classification

It is the sorting of pixels into a finite number of classes or categories.During visual image interpretation pixels are sorted into homogeneous areas that can be associated with land cover features of interest. But digital image classification techniques use radiance measured by a remote sensor in one or more wavebands to sort pixels into information classes or themes. MLC classification is the most commonly used classification for remotely sensed data which is based on the Baye's theorem. The classification process was performed individually for each city of the study area. The MLC algorithm assumes C = (C1, C2... Cnc) which denotes a set of classes, where nc is the total number of classes. For a given pixel with a grey-level vector x, the probability that x belongs to class ci is P (Ci|x), i = 1, 2...nc. When (Ci|x) is known for every class, it can be determined into which class x should be classified. This is done by comparing P (Ci|x)'s, i = 1, 2...nc.x => ci, if P (Ci|x) >P (Cj|x) for all j # i.

However, P (Ci|x) is not known directly. Thus, the algorithm uses Baye's theorem:

$$P(Ci|x) = p(x|Ci) ï P(Ci)/P(x)$$

Where (Ci) is the probability that Ci occurs in the image. It is called apriori probability.P(x) is the probability of x occurring in each class ci. The classification was found to be quite satisfactory for most of the classes except for barren land due to mixed pixels. Thus barren land was delineated with visual interpretation and then the identified areas were incorporated into the classified image, which added to the information rendered by the results.

4.2.4 Accuracy Assessment

The accuracy assessment of classification is often required to determine the "fitness of use" or suitability of a data set for a particular application. Failure to identify the magnitude of inaccuracies in classified data can result in errors cascading into subsequent exploitation and eventually result in false conclusions. For accuracy assessment of images average 30 samples per class which counts to 150 for each thematic classification were taken. Minimum number of samples for each class was set to 20. These points were generated using random sampling method and laid on the images. The sampled points were exported from Erdas and the ground truthing for the points was done using the Google earth imagery of the same time period as that of LISS IV image used for classification. The ground recordings were then input in Erdas and verified with the land cover of original image using visual interpretation. In the report confusion matrix, kappa coefficient and overall accuracy were generated wherein kappa coefficient gives more precise result than the class wise accuracies

4.3 DERIVATION OF LAND SURFACE TEMPERATURE

Land surface temperature has realized several application domains over the years in which Landsat has proven to be an equal counterpart to MODIS and ASTER datasets for its higher spatial resolution than others. The recent satellite of LDCM i.e. Landsat-8 has two thermal bands which have been used to enable the atmospheric correction of the thermal data using a split window algorithm (SWA). The use of two separate, relatively narrow, thermal bands has been shown to minimize the error in the retrieval of LST. No literature has been yet published for usage of SWA for landsat-8 except for one very recently by Rozenstein *et al*. (2014) where the algorithm used is given by (Qin *et al.*, 2001) that involves other inputs along with emissivity. The transmittance values required in that algorithm applied to an area in USA were obtained from AERONET database which are not available for Asia and Africa.

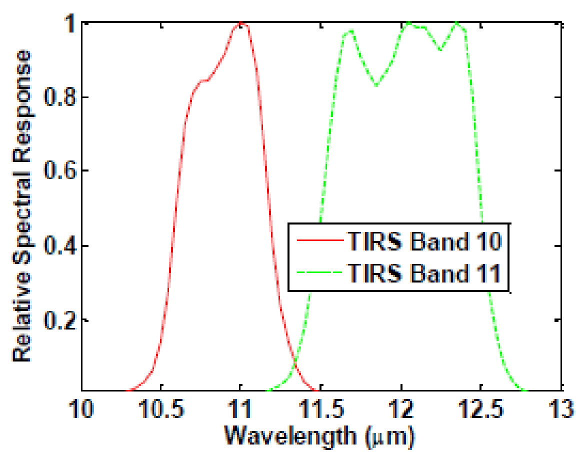


Figure 4.2 Relative spectral responses of TIRS bands

Some SWAs were developed for wide swath sensors (e.g., NOAA-AVHRR, MODIS), and consequently emphasize the correction for zenith view angle effects on the atmospheric transmittance. However, in the case of the Landsat-8 TIRS at an altitude of 705 km with a swath of 185 km, the maximum zenith view angle is about 7.5°. At that angle, the effect on the atmospheric transmittance in both LWIR bands is negligible. Thus, transmittance can be avoided for the purpose of implementing SWA for TIRS. Absorption in the 10.5–12.5 μm atmospheric windows is mainly affected by water vapor that has a high spatial variability, since other atmospheric gases are well-mixed, and their effect can be considered constant throughout an image for the purpose. Also it is not feasible to calculate transmittance for each pixel unlike emissivity. Thus, the SWA selected was such that it did not include transmittance as an input.

Furthermore the data for water vapor content required in many SWAs is not available easily, except in MODIS data, which is at a much coarser scale compared to TIRS. Also the time of overpass of MODIS and TIRS varies and thus obtaining their data representing the thermal conditions of the same moment is quite a challenge.When multiple sources of data are available, temporal proximity to the TIRS image acquisition and spatial proximity of the water vapour measurement site to the study area have to be considered for applying most of the SWAs. Thus emissivity based Becker and Li algorithm published in 1994 was preferred here. It is an emissivity dependent model and a very frequently cited method. It is primarily parameterized for locality measurements. After the radiative transfer and transmittance models, this model is one which is emissivity based, easy to compute and has an RMS error of less than 3-4 ºC. Thus, it can suffice to overcome the complications that can be faced with other methods.

Method applied here for derivation of land surface temperature can be divided into 4 major steps.

1) Conversion of DN to Radiance
2) Radiance to Brightness Temperature
3) Calculation of Emissivity
4) SWA for derivation of LST.

4.3.1 Conversion of DN to Radiance

The Landsat TIRS sensor acquires temperature data and stores this information as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to ToA Reflectance using a two-step process. The first step is to convert the DNs to radiance values. There are two ways which can be used to convert DNs to radiance; the method depends on the scene calibration data available in the header file. One method uses theGain andBias (or Offset) values from the header file and the longer method uses the L_{Min} and L_{Max} spectral radiance scaling factors. Here, the spectral radiance scaling method was used as the radiance values are directly available from the header file.

$$L_\lambda = \frac{L_{MAX} - L_{MIN}}{QCAL_{MAX} - QCAL_{MIN}} * (QCAL - QCAL_{MIN}) + L_{MIN}$$

Where: L_λ = Spectral Radiance at the sensor (watts /(m^2 *sr*μm))

$QCAL$ = Quantized calibrated pixel value in DN

L_{MAX} = Spectral radiance scaled to $QCAL_{MAX}$ (watts /(m^2 *sr*μm))

L_{MIN} = Spectral radiance scaled to $QCAL_{MIN}$ (watts /(m^2 *sr*μm))

$QCAL_{MIN}$ = the minimum quantized calibrated pixel value in DN=1

$QCAL_{MAX}$ = the maximum quantized calibrated pixel value in DN=65535

This conversion is in simple terms converting the received image back to its raw format i.e. radiance data which is captured by the sensors at the time of data acquisition. Thus, thermal bands don't require any atmospheric correction.

4.3.2 Radiance to Brightness Temperature

A satellite-borne radiometer observing the Earth is sensitive to radiance which may emanate from both the surface and the atmosphere. Usually, a radiometer observation is expressed as a brightness temperature in kelvin. Were the surface a perfect blackbody viewed by the radiometer through a perfectly transparent atmosphere, the brightness temperature would equal the surface temperature (SST). Radiance observed by radiometers is described by the Planck's function. Once the DNs for the thermal bands have been converted to radiance values, it is simply a matter of applying the inverse of the Planck function to derive temperature values. For comparing different emissive channels we need to convert observed radiance into a target physical property.

$$T = \frac{k_2}{\ln\left[\left(\frac{k_1}{L_\lambda}\right) + 1\right]}$$

Where:

T = At-satellite brightness temperature (K

L_λ = TOA spectral radiance (Watts/ (m^2 * sr * μm))

K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the band number, 10 or 11)

K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the band number, 10 or 11)

4.3.3 Determination of Land Surface Emissivity

Properties of urban materials, in particular solar reflectance, thermal emissivity, and heat capacity, also influence thermal conditions, as they determine how the sun's energy is reflected, emitted, and absorbed (Akbari *et al.,* 2010). The emissivity of land is significantly different than unity, and varies with the heterogeneity of vegetation, surface moisture, roughness, and viewing angle. Since LSE can change substantially over short distances, it is important to estimate its value for every pixel prior to applying the SWA. Several methods have been suggested to estimate the emissivity for other sensors and can also be applied to TIRS. Assuming emissivity from classified image method is generally used for MODIS LST. As every pixel has a fraction cover by vegetation and other fraction cover by soil or rocks, the pixel emissivity could be obtained as a mix of the emissivity of different surfaces. Emissivity was calculated in 3 steps, calculation of NDVI, from NDVI vegetation proportion was calculated, and then proportional vegetation was used as an input to the algorithm for finding emissivity (Sobrino *et al.,* 2004).

4.3.3.1 Calculation of NDVI

A possible method for obtaining emissivity could be to obtain an LSE image from a classification image, in which an emissivity value for each class is assumed. However, this is not very operative because for that the composition of the surface materials in the region of interest is required and emissivity measurements on the surfaces representatives of the different classes. An alternative and operative procedure is to obtain the LSE image from the NDVI. It is computed as,

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where, *NDVI*: Normalized Difference Vegetation Index

NIR: Near Infra-Red

NDVI gives the live green vegetation presence in each pixel of raster image and thus gives some measure of surface composition which can be applied for obtaining emissivity values.

4.3.3.2 Calculation of proportional vegetation

Pv is the vegetation proportion and it deals with the relationship between the amount of vegetation present within a pixel and the pixel's emissivity. There have been studies that have attempted to relate NDVI with percent vegetation cover (Valor and Caselles, 1996). A scaled version of NDVI to represent the percentage of vegetation present within a pixel was given, where $NDVI_{min}$ is the NDVI value corresponding to bare soil, and $NDVI_{max}$ is the value corresponding to full vegetation. It is computed as,

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2$$

Where, *Pv* : Vegetation Proportion

NDVI : Normalized Difference Vegetation Index

$NDVI_{max}$: Maximum value of NDVI

$NDVI_{min}$: Minimum value of NDVI

Thus, lower values of P_v indicates built up or bare land and higher values indicate vegetation, whereas water and soil lies at the median of the range.

4.3.3.3 Calculation of Emissivity

Sobrino *et al.,* (2004) has derived a formula for calculating emissivity using NDVI and Pv as inputs. In the study a possible solution was to use the mean value for the emissivity of soils included in the ASTER spectral library andfilter according to band TM6 filter function. In this way considering a total of 49 soils spectra, a mean value of 0.973(with a standard deviation of 0.004) was obtained. Using that data (TM6 soil and vegetation emissivity of 0.97 and 0.99, respectively), the final expression for LSE was given by,

$$\varepsilon = 0.004 * P_v + 0.986$$

It thus gives the potential of surface materials to emit radiation. This measure contribute in reducing the error of land surface temperature computation and assures the values to be closer to ground truth.

4.3.4 Land Surface Temperature using Split Window Algorithm

Based on radiative transfer theory and numerical simulations, Becker and Li (1990) proposed a local split-window algorithm for channels 4 and 5 of AVHRR. And it was applied here to Landsat-8 TIRS band 10 and 11. The general form of the split window algorithm can be written as,

$$T_s = 1.274 + \frac{M(T_{10} + T_{11})}{2} + \frac{N(T_{10} - T_{11})}{2}$$

Where temperatures are in Kelvin and the coefficients *M* and *N* are given by,

$$M = 1 + \frac{0.15616(1-\varepsilon)}{\varepsilon} - \frac{0.482(\Delta\varepsilon)}{\varepsilon^2}$$

$$N = 6.26 + \frac{3.98(1-\varepsilon)}{\varepsilon} - \frac{38.33(\Delta\varepsilon)}{\varepsilon^2}$$

Where, Ts represents the land surface temperature, T_{10} and T_{11} represent the brightness temperature for channels 10 and 11respectively, M and N are the coefficients determined by the impact of atmospheric conditions and other related factors on the thermal spectral radiance, and itstransmissionin channels 10 and 11. Emissivity for both the bands is assumed to be same as it is a factor of surface materials which were same for both the bands while image acquisition. The value of delta emissivity is given as .004 by Vidal (1994).

4.4 COMPUTATION OF SPATIAL METRICS

Prior studies on urban form and urban form relation with UHI explored a broad range of indicators using spatial metrics. As discussed in earlier sections how geometry of urban form pattern can impact the thermal conditions, thus this computation forms the other major component of the study. The indices computed here thus gives the measure of various geometry based aspects of quantification. Specific metrics were selected based on the objective, purpose of the research, data availability, and unit of analysis. Schwarz (2010) provides a comprehensive summary of frequently used spatial metrics indicators to define urban form as used in different studies. Ritters *et al.* (1995) calculated fifty-five metricsof landscape patterns (for 85 maps of LULC) and applied multivariate factor analysis to identifythe common dimensions within these metrics. They got a reduced set of 26 metrics and found sixdominating factors that can explain about 87% of the variations of these metrics. For landscape, class and pixel level, metrics were chosen on some grounds that are listed below,

1) Metrics were chosen based on the frequency with which they have been used in previous studies. Many studies have used landscape and class studies mostly in the western world. It were thus chosen from there.
2) The applicability to the study was also looked for. As mentioned earlier too, there are recent studies which related the spatial configuration with LST. From those studies too, the list of metrics was derived.
3) Metrics were carefully chosen to represent each hierarchy level for a deeper insight into the complexity and pattern of urban form. The three levels include, coarse (landscape), moderate (class), fine (cell).
4) Also, the metrics were chosen representing all the aspects of measure, so that each aspect can be understood and unbiased results can be obtained for each landscape.
5) Finally, a thorough understanding of working of all the metrics was understood from the manual of the computing software, FRAGSTATS, and then the metrics to be computed were listed.

The chosen metrics in each hierarchy and aspect of measure have been depicted below in a comprehensive manner (Table 4.1).

Table 4.1 Selected Metrics for computation

S.No.	ASPECT	CELL	CLASS	LANDSCAPE
1	Area and Edge	GYRATE_AM	CA , PLAND, NP ,LPI , ED, AREA_MN , AREA_SD	NP, LPI, AREA_MN , AREA_SD, ED
2	Shape	-	SHAPE_MN, SHAPE_SD	SHAPE_MN, SHAPE_SD
3	Core Area	CAI_MN	-	
4	Contrast	CONTIG_MN	-	-
5	Aggregation	AI	PD , ENN_MN , ENN_SD, CONTAG, AI	PD , ENN_MN , ENN_SD,CONTAG
6	Diversity	-	-	SHDI

4.4.1 Landscape metrics

Landscape metrics that gives measure for the whole landscape are computed for entire patch mosaic; the resulting landscape output file contains a single row (observation vector) for the landscape, where the columns (fields) represent the individual metrics. There are two basic types of metrics at the landscape level (1) Indices of the composition and spatial configuration of the landscape, and (2) Distribution statistics that provide first and second order statistical summaries like the mean, area-weighted mean, median, range etc. in the patch attributes across all patches in the landscape. The 12 landscape metrics used in this study are described below (Table 4.2).

Table 4.2: Characteristics of Selected Landscape Metrics

Metric Acronym	Metric Name	Unit	Description
NP	No. of Patches	None	Total number of patches in the landscape excluding the background cells.
PD	Patch Density	No./100 ha	Number of Patches per total landscape area.
LPI	Largest Patch Index	Percent	Area of largest patch divided by total landscape area.
ED	Edge Density	Meters per ha	Sum of all edge segments divided by total landscape area.
AREA_MN	Mean Patch Area	m^2	Sum of area of all patches divided by total no. of patches.
AREA_SD	Std. Dev. of Patch Area	m^2	Deviation of patch area from mean of population.
SHAPE_MN	Mean Patch Shape Index	None	Sum of area of shape indices of all patches divided by total no. of patches.
SHAPE_SD	Std. Dev. of Patch Shape	None	Deviation of shape indices from mean of population.
ENN_MN	Mean Euclidean Neighbor Dist.	Meters	Mean distance between patches and their nearest neighbors of landscape.
ENN_SD	Std. Dev. Euclidean Dist.	Meters	Std. dev. of distance between patches and their nearest neighbors of landscape.
CONTAG	Contagion Index	Percent	It indicates the level of interspersion of patches in the landscape.
SHDI	Shannon's Diversity Index	None	Proportional abundance across all patches.

4.4.2 Class Metrics

Class metrics lower in hierarchy to landscape are computed for every patch type or class in the landscape; the resulting class output file contains a row (observation vector) for every class. Like landscape, there are two basic types of metrics at the class level also: (1) indices of the amount and spatial configuration of the class, and (2) distribution statistics that provide first and second-order statistical summaries of the patch metrics for the focal class. The latter are used to summarize the mean, area-weighted mean, median, range, standard deviation, and coefficient of variation in the patch attributes across all patches in the focal class. The class metrics were chosen with care which can well document the pattern of each class.

Table 4.3: Characteristics of Selected Class Metrics

Metric Acronym	Metric Name	Unit	Description
CA	Class Area	Hectares	It gives measure of the landscape composition.
PLAND	Percentage of Land	Percent	Proportional abundance of each patch type in the landscape.
NP	No. of Patches	None	Total number of patches in the focal class excluding the background cells.
PD	Patch Density	No./100 ha	Number of Patches per total class area.
LPI	Largest Patch Index	Percent	Area of largest patch divided by total class area.
ED	Edge Density	Meters per ha	Sum of all edge segments divided by total class area.
AREA_MN	Mean Patch Area	m^2	Sum of area of all patches in the focal class divided by total no. of patches.
AREA_SD	Std. Dev. of Patch Area	m^2	Deviation of mean patch area in focal class from mean of population pixels.
SHAPE_MN	Mean Patch Shape Index	None	Sum of area of shape indices of all patches in focal class divided by total no. of patches.
SHAPE_SD	Std. Dev. of Patch Shape	None	Deviation of shape indices from mean of patch index in focal class.
ENN_MN	Mean Euclidean Neighbor Dist.	Meters	Mean distance between patches and their nearest neighbors of same class.
ENN_SD	Std. Dev. Euclidean Dist.	Meters	Std. dev. of distance between patches and their nearest neighbors of same class.
CONTAG	Contagion Index	Percent	It indicates the level of interspersion of patches in the class.
AI	Aggregation Index	Percent	Frequency of different pair types appearing side by side.

4.4.3 Cell Level Metrics

Cell metrics exhibit the index values at the finest level. Each pixel gets the index value and this character of it makes it highly advantageous for performing anlyses with raster datasets. The computation process is executed in the form of moving window analysis or local structure gradient which gives an output as a new grid for each selected metric. Before initiating the analysis all the parameters like level of heterogeneity, shape and size of the window to be used have to be defined. A window of the specified shape and size is passed over every positively valued cell in the grid. The shape of the window can be either circular or square; in this study square shape was used. Size of the neighbourhood can be either 4 cells or 8 cells; here 8 cell neighbourhood was chosen. Only cells in which the entire window is contained within the landscape are evaluated. Within each window, each selected metric at the class or landscape level is computed and the value is returned to the focal cell. For each fragmentation measurement aspect, one metric was chosen at class level which could best represent each aspect of geometry measure.

4.4.3.1 Area Weighted Radius of Gyration (GYRATE_AM):

It is a metric of 'Area and Edge' aspect of measure. It provides a measure of landscape continuity (also known as correlation length) that represents the average traversability of the landscape for a phenomenon that is confined to remain within a single patch; specifically, it gives the average distance one can move from a random starting point and travelling in a random direction without leaving the patch. It is mathematically given as:

$$GYRATE = \sum_{r=1}^{z} \frac{h_{ijr}}{z}$$

Where, h_{ijr} = distance (m) between cell ijr [located within patch ij] and the centroid of patch ij (the average location), based on cell center-to-cell center distance.

z = number of cells in patch ij.

The unit of measurement is meters. GYRATE = 0 when the patch consists of a single cell and increases without limit as the patch increases in extent. GYRATE achieves its maximum value when the patch comprises the entire landscape.

4.4.3.2 Mean Contiguity Index (CONTIG_MN)

It is a method of assessing patch shape based on spatial connectedness or contiguity of cells within a grid cell patch to provide an index on patch boundary configuration and thus patch shape. It is quantified by convolving a 3x3 pixel template with a binary digital image in which the pixels within the patch of interest are assigned a value of 1 and the background pixels are given a value of 0.This combination of integer value weights orthogonally contiguous pixels more heavily than diagonally contiguous pixels. The contiguity value for a pixel in the output image is the sum of the products, of each template value and the corresponding input image pixel value, within the nine cell neighborhood.

$$CONTIG = \frac{\left[\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}}\right] - 1}{v - 1}$$

Where, c_{ijr}= contiguity value for pixel r in patch ij.

v = sum of the values in a 3-by-3 cell template (13 in this case).

a_{ij} = area of patch ij in terms of number of cells.

It does not have any unit and the values range between 0 and 1. The value is 0 for a one pixel patch and increases to a limit of 1 as patch contiguity increases.

4.4.3.3 Mean Core Area Index (CAI_MN)

This metric was used to depict the core area aspect of the landscape. It is a metric that quantifies core area as a percentage of total area. The CAI quantifies the core area percentage of the entire class with respect to the landscape. The index is an edge to interior ratio like many of the shape indices, the main difference being that the core area index treats edge as an area of varying width and not as a line around each patch. Also, it is a relative measure; it does not reflect patch size, class area or total landscape. It is calculated as:

$$CAI = \frac{a_{ij}^{c}}{a_{ij}}(100)$$

Where, a_{ij}^{c} = core area (m^2) of patch ij based on specified edge depths (m).

a_{ij} = area (m^2) of patch ij.

The unit is percentage and range lies between $0 \leq CAI < 100$ CAI = 0 when CORE = 0 (i.e., every location within the patch is within the specified depth-of-edge distance(s) from the patch perimeter); that is, when the patch contains no core area. CAI approaches 100 when the patch, because of size, shape, and edge width, contains mostly core area.

4.4.3.4 Aggregation Index (AI)

It is a metric dealing with aggregation aspect of landscape. It is computed as a percentage based on the ratio of the observed number of like adjacencies ($e_{i,i}$) adopting the single count method, to the maximum number of like adjacencies (max_ $e_{i,i}$) given $P_{i.}$ The maximum number of like adjacencies is achieved when the class is clumped into a single compact patch, which does not have to be a square. The index ranges from 0 when there is no like adjacencies (i.e., when the class is maximally disaggregated) to 1 when ei,i reaches the maximum (i.e., when the class is maximally aggregated). It is given as:

$$AI = \left[\frac{g_{ii}}{max \to g_{ii}}\right](100)$$

Where, g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method.

Max–›gii = maximum number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method.

AI is partially confounded with Pi because the minimum value of the index varies with Pi when Pi > 0.5; specifically, the minimum value > 0 when Pi > 0.5 and asymptotically approaches 1 as Pi 61. Thus, AI does not account for the expected value under a spatially random distribution when Pi > 0.5; e.g., AI could equal 0.8 and yet the distribution could be more disaggregated than expected under a random distribution if Pi > 0.8. Thus, caution must be exercised in interpreting this metric.

4.5 ANALYSES OF DATASETS

The computation of the major components in the study was already completed at this step and the analyses were then done to carve out the aspects playing major role in propagating the thermal phenomena. The analyses was performed in four ways,

1) Analysis of the LULC and LST results by visual comparison and support of secondary sources for understanding the nature of distribution of these phenomena in the study area. That gave an insight to the dynamics of pattern existing in the region and thermal conditions thereof.
2) Identification of temperature change with respect to each LULC class by statistical means. This analysis gave a more detailed variation of thermal conditions and the dependence of temperature on land use. It reduces the biasness of landscape level analysis.
3) Comprehending the geometric pattern of development of landscapes via interpreting the three-tier metric results i.e. landscape, class and cell level. Landscape and class level results aspatial form and the cell level in spatial form. The metric results help in validating the indices among themselves.
4) Establishing a correlation between the two major datasets, metrics and land surface temperature was done. Pearson's linear correlation method was employed for deriving the relation among the datasets. The analysis gave a very valuable information about the aspect that describes the configuration in the best possible manner.

The results then led to deriving important conclusions and proposing recommendations for the study area and the problem areas recognised in the study.

5. RESULTS

This chapter discusses the results and analyses that brings out the highlight outcomes of the research. First two sections of the chapter contain a discussion on the analysis of LULC variation and distribution of land surface temperature of the four urban areas from remotely sensed data. Next section discusses the fragmentation analysis from spatial metrics for identifying areas the geometric pattern and the final section discusses the correlation analyses of the cell metrics and land surface temperature.

5.1 LULC DYNAMICS OF THE REGION

Any urban phenomena directly depend on the changing nature and characteristics of LULC. The development pattern of the cities Land use/Land cover (LULC) was analyzed to evaluate the variation in urban growth of the centers in study area as a region. The classified LULC data that depicted the 10 major LULC classes are analysed in this section. It gives the distribution of the major LULC in the region. This classified data were further also used for measuring the changing patterns of urban form by measuring spatial metrics. Prior to understanding the pattern depicted by those metrics, an initial knowledge of the dynamics scenario is vital.

5.1.1 Spatial representation of LULC

As discussed in previous chapter, five major land cover classes were used for the classification of landscapes in the study. Further, inclusion of details of land use classes (industrial, commercial, residential, roads and railways) which can’t be identified by image processing were added through the manual editing with support of recent City Development Plan of all four cities under study (Figure 5.1, 5.2, 5.3 and 5.4). From the LULC representation it can be seen that the growth of the four cities are in the same direction as travelling outwards from Delhi to its surrounding hinterland region. It typically represents the pattern of satellite cities as growing around a major urban center in a conurbation.The land use characteristics of CNCR are reported to be influenced by mainly two factors: The first has been the continuousand rapid increase of the economic activities and second has been the rapid increase in the development of industrial activities on the transport arteries radiating from Delhi.The consequences are pre-mature andspeculative sub-division of land for residential and industrial uses along the corridors originating radially outwards from Delhi. Each city has a mushrooming industrial agglomeration along the transport, the effect of which is reflected in their economic activities. The prime observation of the region says that all the cities have maximum growth at the boundary edges connected to Delhi. Gurgaon shows a dominant urban landscape and less proportion of agriculture within its boundary. Faridabad has a linear development along the major transport routes which originates from Delhi and it also shows a large area under barren land at the right side of the canal planned for future urban development. Noida being a planned city shows mixed characteristics share whereas Ghaziabad with large area under industries and agriculture has a significant secondary economic activity center.

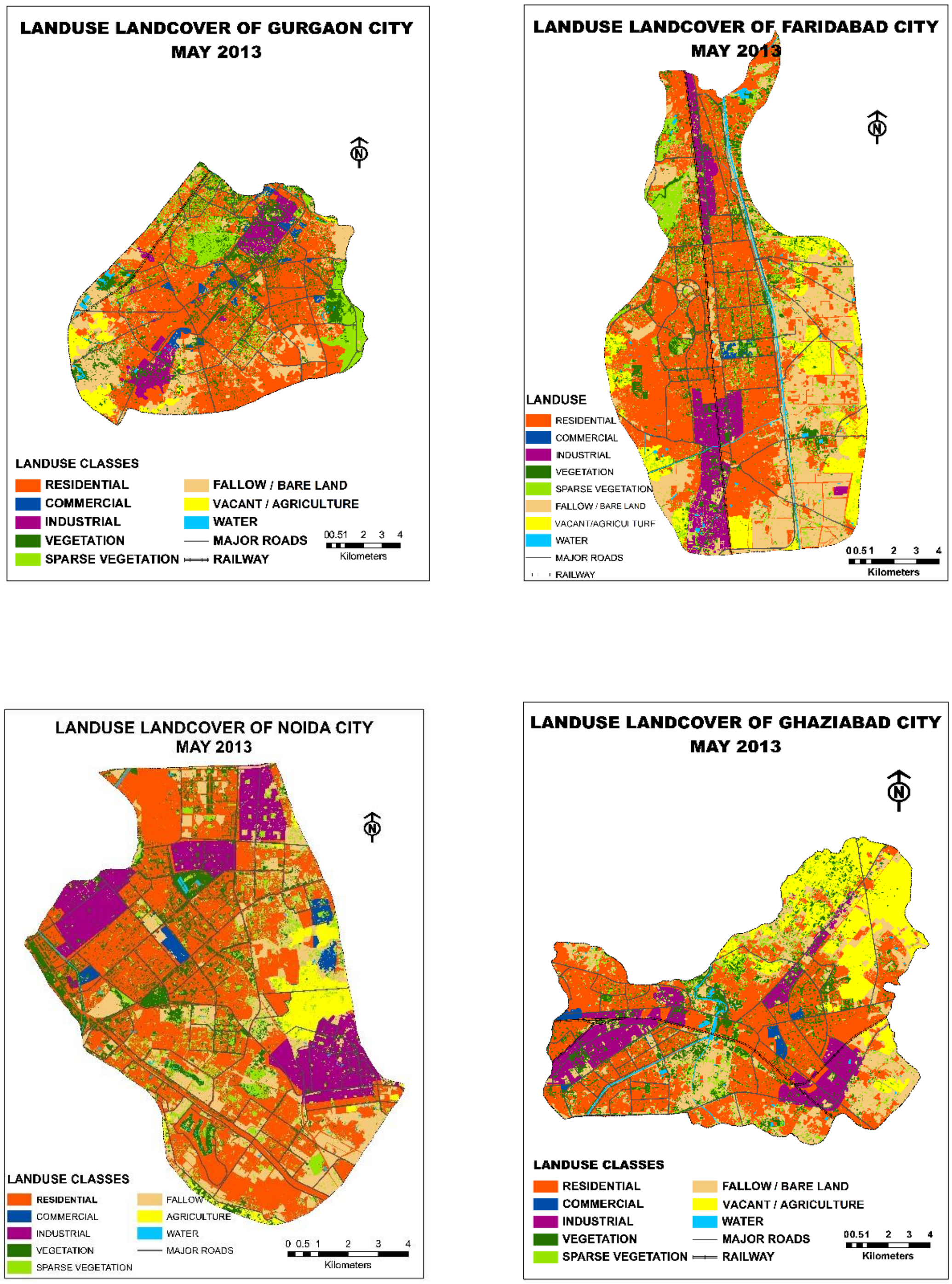


Fig 5.1: Gurgaon City; 5.2: Faridabad city; 5.3: Noida city; 5.4: Ghaziabad city

5.1.1 Accuracy assessment

The accuracy assessment value of the classified images for the four landscapes are above 88 % on average which states a good accuracy for further analyses.

Table 5.1: Accuracy assessment result of classified images.

CITY	Classification Accuracy	Kappa Statistics
Gurgaon	88.00%	0.8473
Faridabad	88.67%	0.8546
Noida	88.00%	0.8458
Ghaziabad	87.33%	0.8378

5.1.2 Land use variation of the cities

A statistic representation of the varying land use areas in km^{2}over the four cities is given in Annexure -I. It is seen that Faridabad has the largest area, whereas Noida is the smallest in terms of aerial extent. The area under residential use is highest in Noida followed by Gurgaon, Ghaziabad and Faridabad. Whereas, industrial use, assumed to be a major contributor in increasing thermal conditions, occupies maximum area in Noida followed by Ghaziabad, Faridabad and Gurgaon with 12.83%, 10.97%, 6.94% and 5.16% respectively. Distribution of vegetation cover (dense and sparse) is almost similar in Noida, Faridabad, and Ghaziabad about 17-18%, but Gurgaon covers largest percentage of area under vegetation cover (25%). In the immediate hinterlands of the city, fallow land has a dominating percentage ranging from 9.5% in Ghaziabad to 24.6% in Faridabad which has shown a dominant impact on LST whereas agriculture land use is concentrated at the periphery of towns. (Refer Annexure-I)

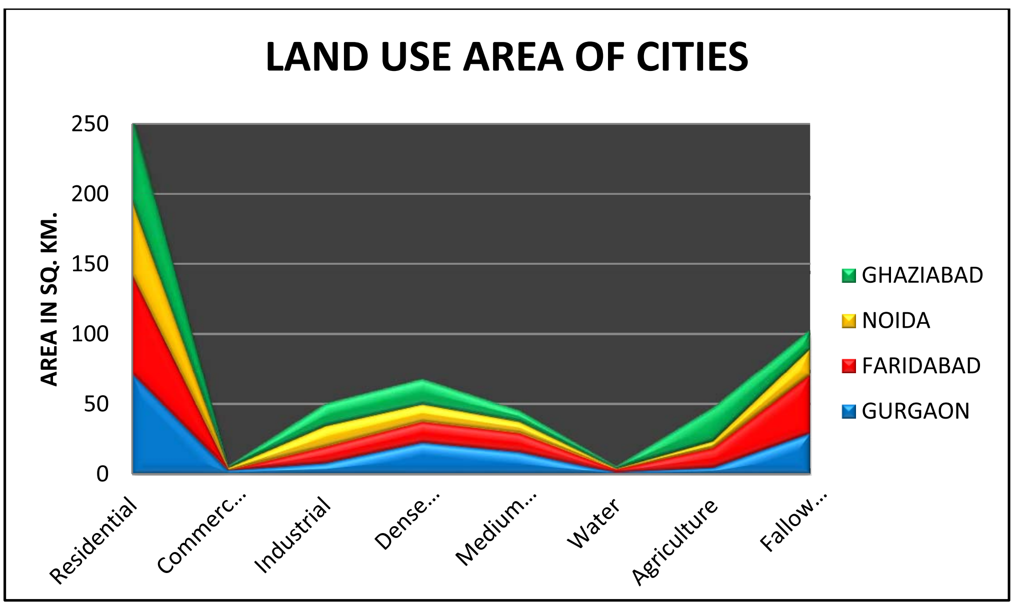


Figure 5.5: Land use area of cities in CNCR

5.2 Land surface temperature trends

The LST obtained from conputation from Landsat-8 TIRS was represented spatially for the study areas (Figure 5.6, 5.7, 5.8 and 5.9). It depicts the spatial variation of temperature over the spatial extent of cities. Distribution of land surface temperature (LST), calculated from Landsat thermal band is evaluated to identify the distribution of thermal conditions within the land use classes of the four cities and also among the cities. The temperature can be analysed with different perspectives depending on the application. Here, the primary concern is studying the variation over space in the four centres in relation to land use classes.

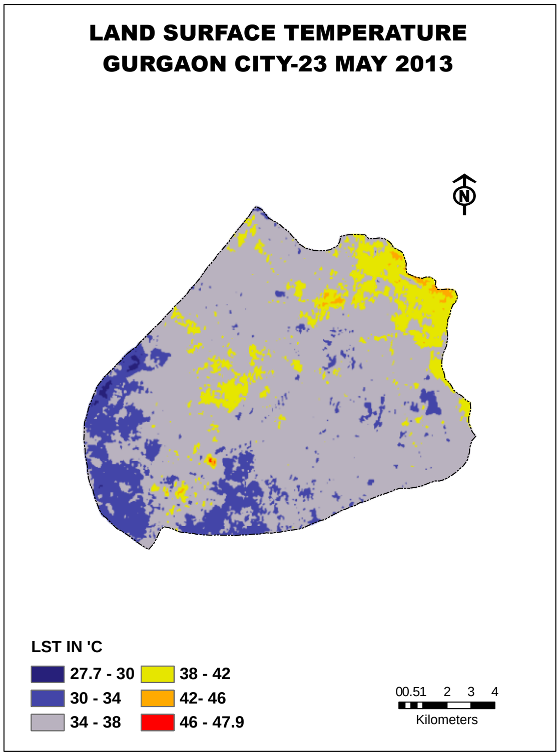
5.2.1 Spatial variation of Land Surface Temperature

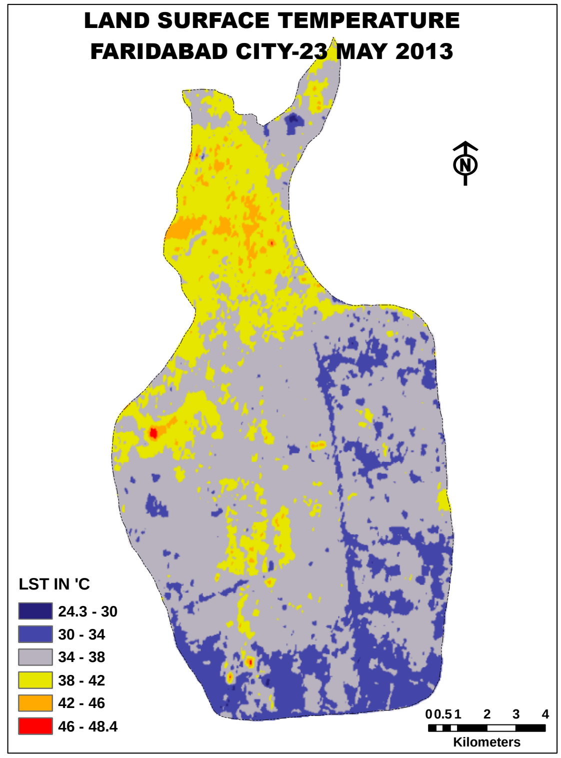
The descriptive statistics of land surface temperature of the cities retrieved from satellite image of23 May 2013 at 11 am in the morning is given below in table5.2. It shows how the range of thermal conditions is varying over the region. Minimum recordings can be seen at Faridabad over the water bodies towards the northern boundary whereas Ghaziabad exhibits the highest minimum as well as maximum range which strongly indicates to more industrial area in the city. Mean temperature is observed to be lowest in Gurgaon city which states that the thermal conditions compared to the other cities is most optimal in this city.

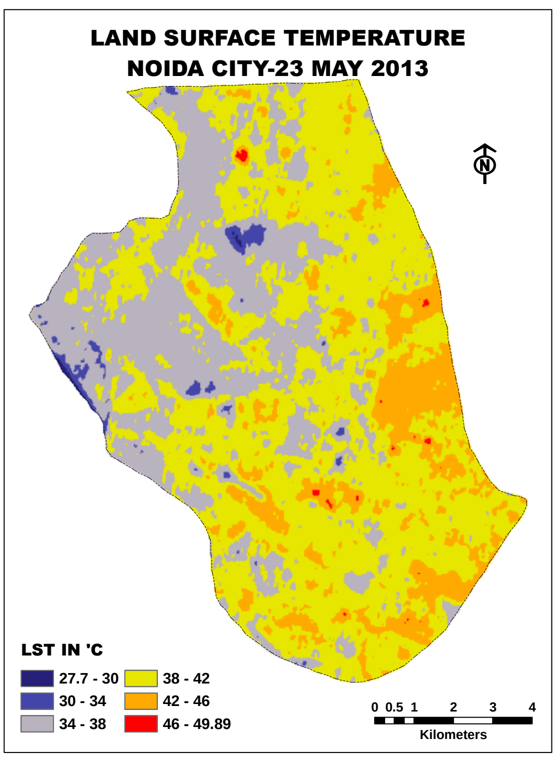
Table 5.2: Descriptive statistics of LST images

City	Minimum	Maximum	Mean	Std. Dev.
Gurgaon	27.705	47.889	35.917	1.884
Faridabad	24.279	48.411	36.362	2.455
Noida	27.672	49.855	39.253	2.387
Ghaziabad	28.944	50.903	41.027	2.531

Gurgaon and Noida show nearly the same range but Noida with higher maximum and mean temperature is pointing to some reasonable variation there. In terms of land use Noida has a high industrial percentage compared to that of Gurgaon whereas Gurgaon has 23% green cover. There is a deviation in the pattern revealed by the other two cities i.e. Ghaziabad and Noida. Ghaziabad and Noida which were showing higher temperature than other two cities, they never showed high temperature over the industrial land. One probable reason can be its close proximity to the bank of river Yamuna flowing adjacent to the western edge of the cities. This can be one factor because the temperature pattern in other two cities, Gurgaon and Faridabad has shown a higher collinear trend over the industrial land. Only very few pixels exhibit extreme values of maximum temperature above 46ºC recorded in the statistics. But, it should not be understood as representing the whole landscape. The average maximum temperature for the region is observed to be 46ºC.Thus, the representation of maps too has been done accordingly for its clear delineation and so the highest class has been decided as 46 & above. As the values of the whole landscape can sometimes be less informative, so it is needed to analyse the temperature trends further at next hierarchy to landscape i.e. LULC classes.







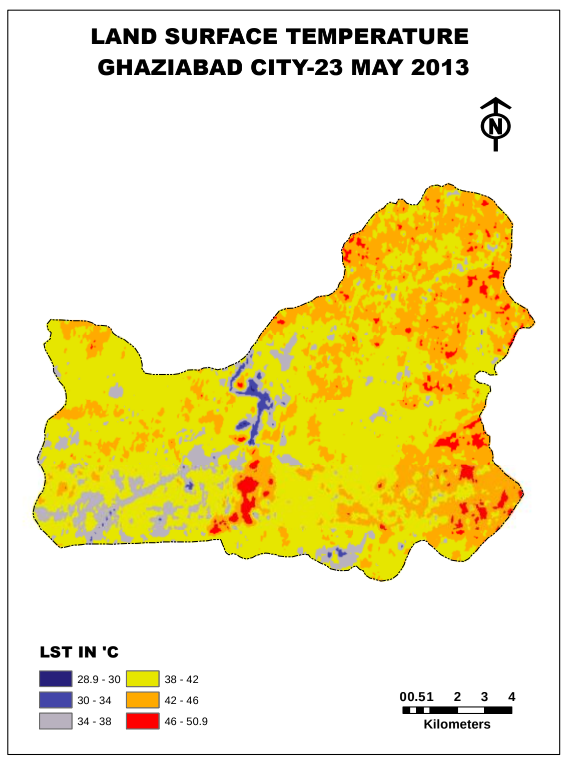


Fig 5.6: Gurgaon City; 5.7: Faridabad city; 5.8: Noida city; 5.9: Ghaziabad city

As it can be seen that maximum temperatures are very high in range, it has been supported by a document published in The Times of India (24 May 2013). The satellite image was sensed on 23rd May and on 24 May Times of India reported that Delhi and its surroundings on 23rd May recorded highest May temperature in 11 years and the CNCR towns were slightly worse off where Noida in the east recorded the highest minimum temperatures in the national capital area with 32.7 degrees Celsius respectively and a maximum of 45 degrees Celsius. The maximum temperatures in Faridabad and Gurgaon were recorded to be 46.6 degrees and 46.1 degrees Celsius respectively. Officials also said that the prolonged heat wave was a result of the absence of western disturbance activity for a long period of time, strong hot north-westerly winds and subsidence of air due to an anticyclone over Rajasthan. (24 May 2013, Times of India)

5.2.2 Variation of temperature over different land use classes

As thermal phenomena is directly associated with the land cover, thus for better understanding the role of land cover dynamics in variation of temperature spatially, next hierarchy i.e. class level variation was analysed. It indicates the influence of specific land use classes on overall LST of landscape. For the analysis the descriptive statistics of LST were extracted for each class using a series of method with geospatial tools. From previous research, urban developed areas are found to have the highest thermal signature, while forest to have lowest thermal signature (Weng *et al,.* 2004). This same pattern is observed within the land use classes of this study too. According to the table 5.4 and figure 5.10 water and vegetated areas shows the lowest temperature in all the cities, wherever they had a large proportional area. Farmland/bare lands which are devoid of any forest or grasslands experienced significantly higher temperature almost in equivalent ratio to built-up land. The highest extreme in mean temperature can be seen over built-up land covers.

Gurgaon and Faridabad show similar kind of thermal signatures of land use, whereas Noida and Ghaziabad differs from that. Gurgaon and Faridabad exhibits higher temperatures over industrial and residential areas in comparison to fallow land respectively. In Faridabad, a high mean temperature has been seen over residential areas because some of the areas are very dense and unplanned.On the other hand the industrial area of Gurgaon has large areas too under industrial activity but it has patches of vegetation. For other classes, higher heterogeneity of land cover patches can be attributed to their variation of LST (in terms of minimum, maximum, and standard deviation). Commercial area experiences higher range of temperature in Noida and Ghaziabad. There is a dominance of fallow land in Ghaziabad towards its farther eastern part which leads to higher temperatures in that area. This analysis points to the general expected trend of temperature wherein temperatures are higher over un-natural land covers and lower over natural covers. But, some anomalies can be experienced which can’t be explained only by the land use type of that area but the role of other factors are also to be looked into. Thus, the role of pattern of land cover based on many aspects of measure was considered which could give clearer scenario and also explain the anomalies observed in the results. In the forthcoming sections these temperature conditions are interpreted with metric values and that presents a more reasonable outcome.

Table 5.3: Variation of temperature over different land use classes

GURGAON

CLASS	Min	Minus 1SD	Plus 1SD	Max
Residential	29.89	34.57	37.59	44.93
Commercial	33.08	35.87	38.33	41.75
Industrial	30.65	35.26	39.38	47.89
Vegetation	30.22	34.69	37.65	44.88
Dense Vegetation	28.23	33.81	37.47	44.6
Agriculture	31.27	31.8	35.1	45.3
Fallow Land	28.04	33.43	37.67	47.2
Water	27.71	30.13	35.57	42.29

FARIDABAD

CLASS	Min	Minus 1SD	Plus 1SD	Max
Residential	30.11	44.73	48.89	46.81
Commercial	33.21	34.79	36.87	39.57
Industrial	24.29	35.02	40.78	48.19
Vegetation	24.56	33.38	39.16	47.8
Dense Vegetation	29.41	34	38.86	46.73
Agriculture	29.79	32.43	36.59	42.15
Fallow Land	29.11	33.28	38.46	48.41
Water	28.66	32.28	37.26	44.36

NOIDA

CLASS	Min	Minus 1SD	Plus 1SD	Max
Residential	27.79	36.6	40.58	46.82
Commercial	33.15	38.2	42.36	45.14
Industrial	33.27	37.96	41.56	44.27
Vegetation	31.43	37.11	41.73	46.85
Dense Vegetation	27.93	35.33	39.73	46.41
Agriculture	34.08	39.92	44.7	46.62
Fallow Land	32.24	38.17	42.67	49.9
Water	29.6	33.36	40.1	45.08

GHAZIABAD

CLASS	Min	Minus 1SD	Plus 1SD	Max
Residential	30.32	38.26	41.86	50.46
Commercial	35.64	39.56	42.5	44.19
Industrial	35.47	40.02	43.14	48.83
Vegetation	29.4	38.3	43.4	48.91
Dense Vegetation	29.4	37.12	41.92	48.34
Agriculture	34.6	40.96	45.4	48.86
Fallow Land	30.03	38.87	44.33	50.9
Water	28.94	32.9	39.98	47.33

This representation of temperature via statistics here tries to describe all the measures and shows the detailed distribution of data. Standard deviation up to 1st interval is known to cover 68% of the data. So, this analysis gives a very robust way of interpreting the variation of temperature with classes but the data needs to be assisted with other measures of size and pattern of land cover patches.

Ghaziabad and Noida show different characteristics for temperature statistics than Gurgaon and Faridabad. Values are higher for fallow and agriculture than industrial. Both the cities exhibit surprisingly high temperature over agricultural and barren land. The role of soil composition can be found as the soil consists of a high percentage sandy soil and the character of sandy soil can emit high thermal radiations. Noida has three well-maintained greenbelts along the river Yamuna and other huge green space including city forest and Golf course. This controls the rising temperature over industrial and residential areas placed nearer, unlike for fallow land which is located towards the fringe. Contrarily, Ghaziabad has grown as an industrial town. Thus, its overall temperature range is high but the privilege of two main water rivers lower downs the temperature in the vicinity land use covers.

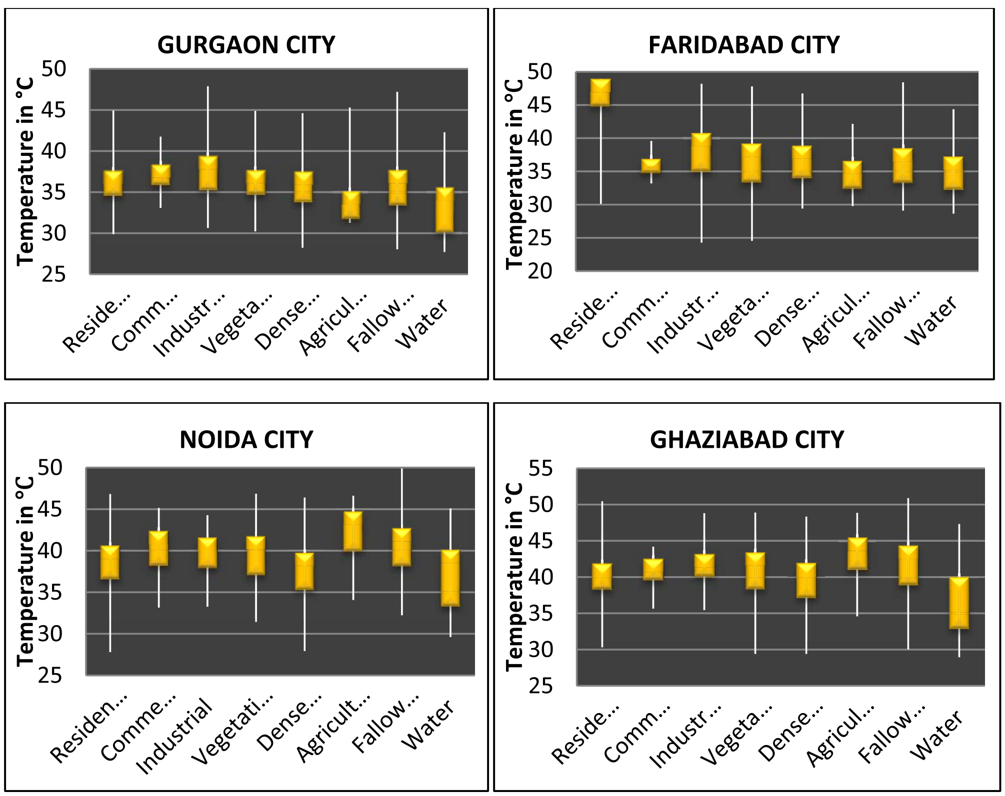


Fig5.10: Varying statistics (minimum, maximum, standard deviations from mean) of temperature over different land use classes.

According to last 5 years (10/2009-05/2014) of data recorded at Indira Gandhi International Airport for wind pattern over Delhi, in the month of May and June the winds strictly blow towards the west at an average speed of 12-15 km/h(Wind and Weather statistics, Delhi). This is also one major contributing factor for the comparatively lower temperatures over industrial areas than agriculture lands. These strong westerly winds help the heat to regulate and rather gets pushed to the western boundaries, where it adds up to the heat of fallow lands after cultivation of crop.

5.3 Result of Metrics

5.3.1 Landscape Metrics

The local spatial character of the landscape has an impact on the microclimate, and subsequently affecting the results of LST. But, the LULC when quantified only for area can describe the broad level conditions but it can't convey form of the urban structure. As it is seen the land use/ cover has a role in regulating the land surface temperature along with other factors. So, the role that land use plays has to be quantified by various metrics of the landscape at different hierarchies. This quantification gives an insight to the geometry of land use structure and how it will affect the heat circulations in the urban landscapes.

Table 5.4: Landscape metrics of the regional centres

Landscape Metrics	GURGAON	FARIDABAD	NOIDA	GHAZIABAD	Normalized values
NP	50.49	55.868	32.171	41.811	No. Count/1000
PD	21.49338	20.44557	16.5883	15.42873	PD/10
LPI	33.4334	38.089	41.2827	34.6736	Index
ED	22.6268	19.88129	17.75579	16.97022	ED/10
AREA_MN	46.53	48.91	60.28	64.81	m2*100
AREA_SD	48.8837	53.5277	58.3906	60.127	m2
SHAPE_MN	12.89	12.747	12.9	12.991	Index*10
SHAPE_SD	61.73	55.94	59.06	60.48	Index*100
ENN_MN	23.246	23.9208	25.7186	26.5407	Index
ENN_SD	30.6828	31.3414	35.1012	37.0259	Index
CONTAG	52.4774	54.4137	57.7102	56.53	Index
SHDI	14.529	14.126	13.18	13.667	Index*10

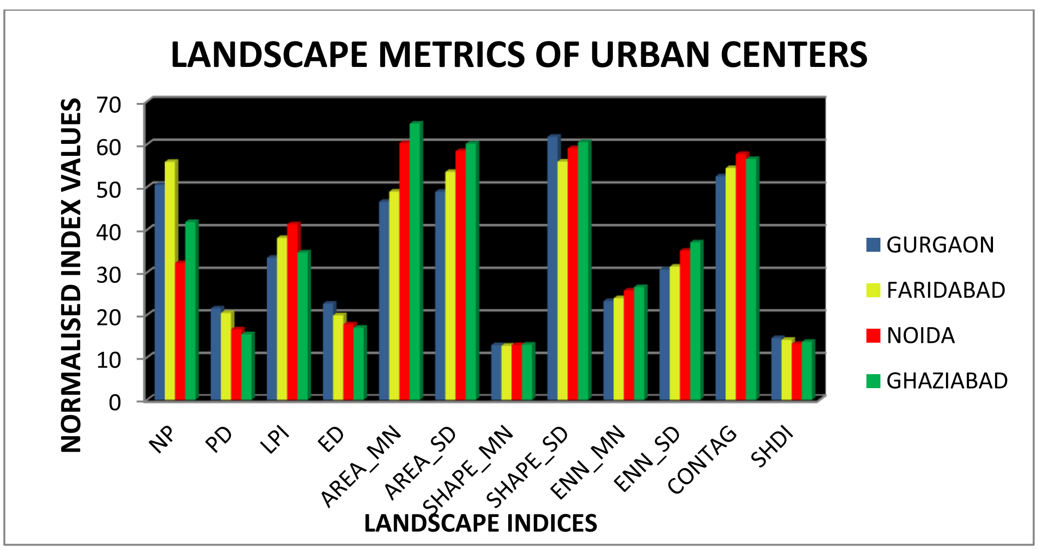


Fig 5.11: Landscape Metrics of the urban centres

In figure 5.11, NP and PD values show that Gurgaon and Faridabad have more number of patches than Noida and Ghaziabad, which depicts more fragmentation of the landscape in the earlier two and can have an effect on controlling the heat. LPI is higher for Faridabad and Noida, pointing to the areas which have dense built-up land patches. Metrics like ED and SHAPE should be high for more fragmentation and it depicts more heterogeneity and interspersion of land use classes. Gurgaon shows the best values of fragmentation whereas the fragmentation decreases when movingfrom SW of Delhi i.e. Gurgaon to East of Delhi i.e. Ghaziabad. Contrarily, the temperature values show a negatively correlated trend i.e. it increases while moving from East of Delhi to SW of Delhi. This gives a clear relation of how the fragmentation is contributing its part in the heat regulation.

5.3.2 Class Metrics

Landscape metrics give an insight into the fragmentation of landscape as a whole. And here, class metrics give us quantified results for fragmentation for each class, which can give us a next level perspective of how it can affect the UHI. Many studies till now have been finding relationship of LST with class area and percentage, which is important in its own manner.But metrics has an advantage as it adds the information manifold and validates the relationships by other measures of quantification too.

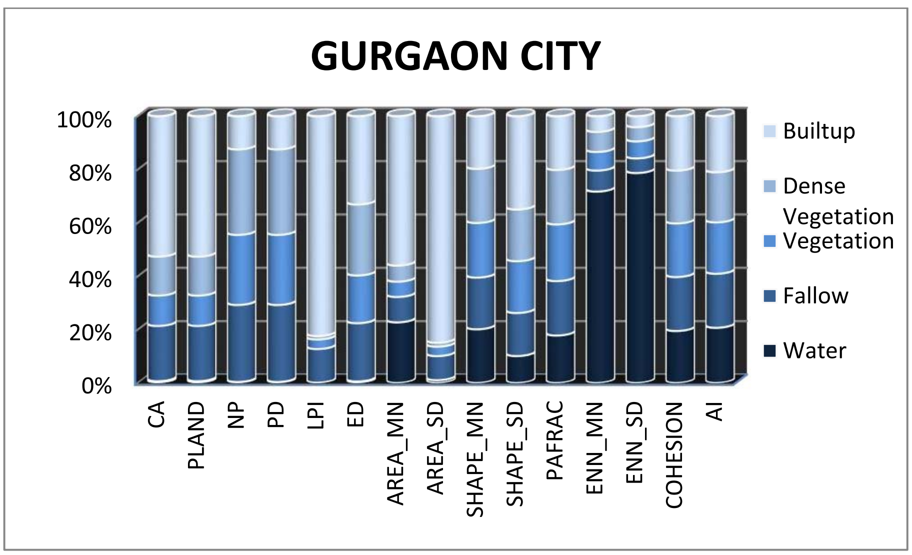


Fig 5.12: Class level metrics of Gurgaon city

The key points of the above depicted graph (figure 5.12) are that built-up is highly contiguous and very less fragmented. The LPI is extremely high compared to other classes and at the same time ENN is too less. But, it is a relief to know that dense vegetation is highly fragmented and uniformly spread as analysed by the ENN and mean patch area. Water bodies have a very negligible proportion in the landscape. Fallow land also exhibits a fragmented character with a small ENN and mean patch area value. Thus, the Gurgaon city seems to have good heterogeneity which allows the regulation of heat. (Refer Annexure II-A)

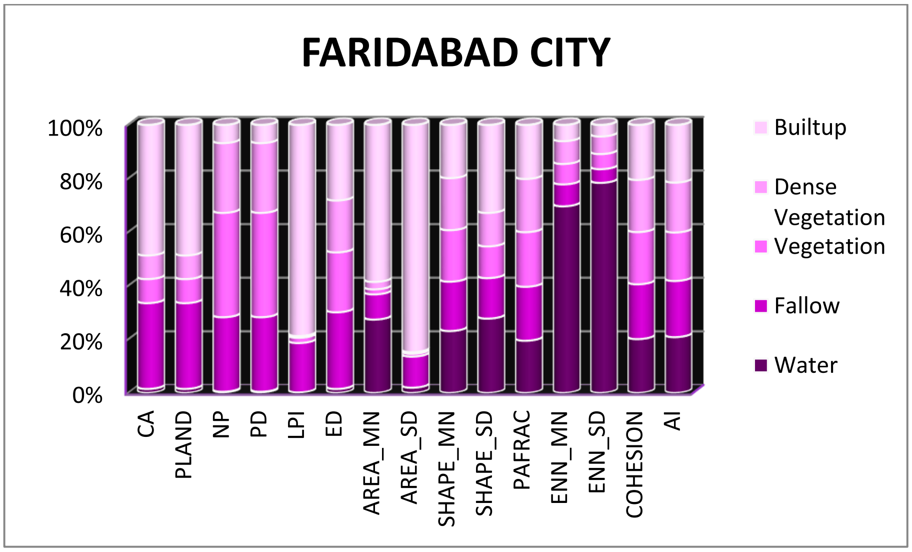


Fig 5.13: Class level metrics of Faridabad city

The analysis in Faridabad city highlights as seen in figure 5.13, the built up land characteristics varies from Gurgaon for two factors that are class area, and mean area. Class area of built-up is lesser to Gurgaon but the high mean area shows high contiguity and lesser fragmentation, a possible form that diminishes heat regulation. Furthermore, fallow land is very high here than the vegetation unlike Gurgaon where they were almost equal. Water has the same character as Gurgaon with a very less area and located at large distances. (Refer Annexure III-A)

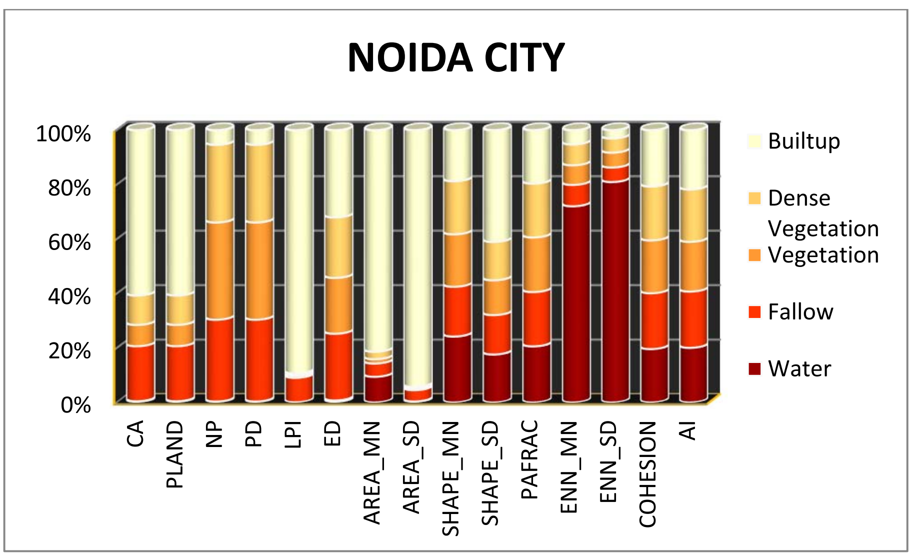


Fig 5.14: Class level metrics of Noida city

Noida city as discussed in previous chapters is a planned city but the built-up land is shows extreme contiguity with 90% higher mean area than other classes. Also, it has fragmented vegetation as given by moderately high values of NP and PD as seen in figure

5.14. Fallow land has a higher proportion to vegetation in the landscape and lesser fragmented than vegetation unlike Gurgaon which had a similar scenario for built up and vegetation, but had lesser fallow land. LPI and Area_SD values for built up are highest in Noida that tells about the extreme contiguity in builtup patches. The patch measure of vegetation and water for LPI and Area_SD are not even seen in the graph which points to very low presence of these land covers in any part of the city. (Refer Annexure IV-A)

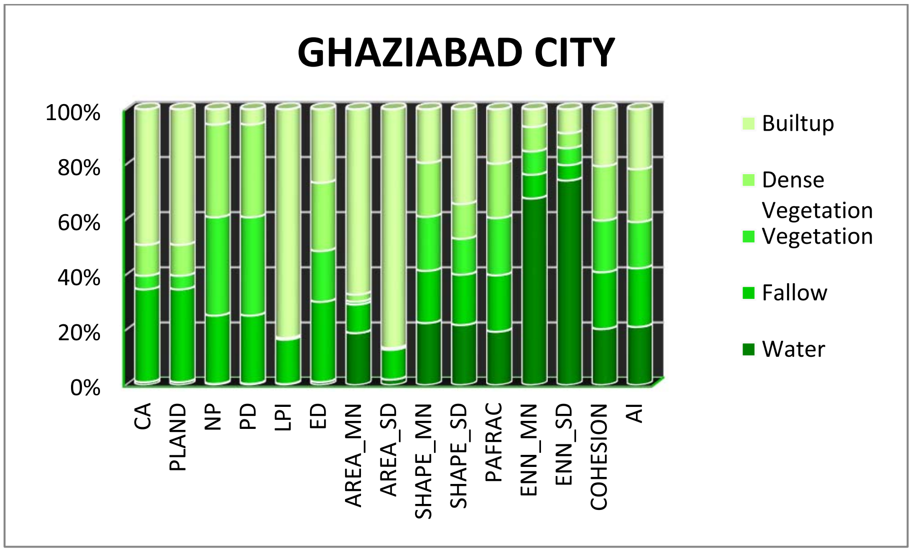


Fig 5.15: Class level metrics of Ghaziabad city

In Ghaziabad city (5.15), the fallow land has a higher ratio compared to other cities including a lot of agricultural lands in its western region. Built-up land continues to remain high with higher contiguity and aggregation whereas share of vegetation is lesser in comparison to other cities. LPI and Area_SD values for built up are very high in Ghaziabad following the trend in Noida. Also, Shape_SD is very high for builtup which shows its lesser interspersion with the natural land covers. The class level metrics for the four cities have well assisted in understanding the difference in various classes and completely supports the conclusions that were derived from landscape metrics. Wherein, Gurgaon shows more heterogeneity in land use/ covers, it degrades from Faridabad to Noida and Ghaziabad. Not only the area of built-up to non-built-up has changed but the most important function that metrics provides, fragmentation is decreasing in the order of Gurgaon, Faridabad, Noida and Ghaziabad.

5.3.3 Cell level metrics

In geospatial studies when the basic unit of raster data is a pixel, these metrics can be very efficiently used for analysis there. Above discussed metrics are spatial in nature but these cell level metrics provide spatial information too. These metrics are in grid format, wherein each pixel has a metric value. The metric data output was in the form of 20 grids for one metric and city (5 classes*4 metrics) that counts to 80 in total for all the cities. In the later section the correlation of these indices with LST has been computed and discussed. The metric information of these metrics are shown below.(Annexure II, III, IV, V-B)

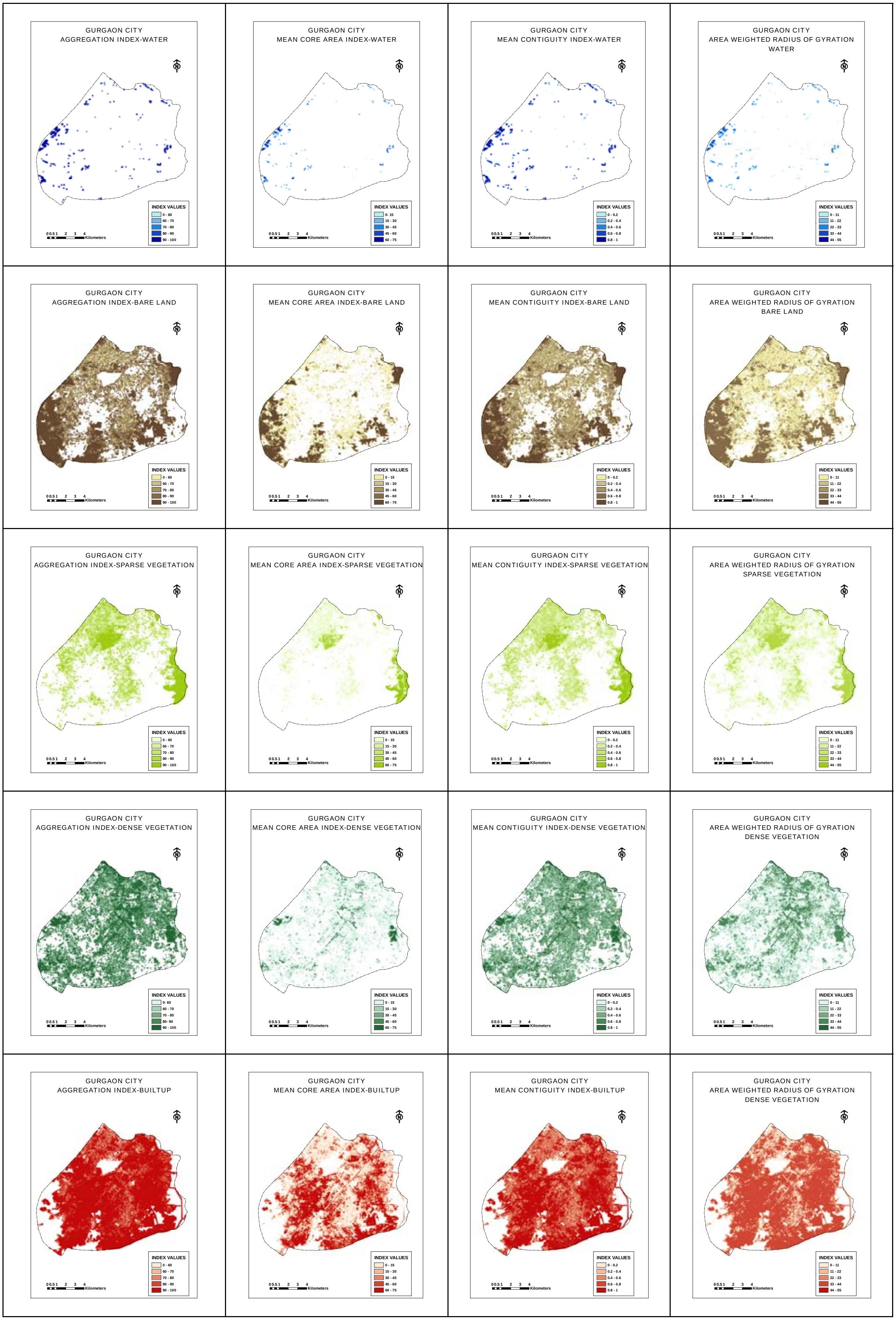


Fig 5.16 Cell Metrics of Gurgaon City

Fig 5.16 Cell Metrics of Faridabad City

Fig 5.16 Cell Metrics of Noida City

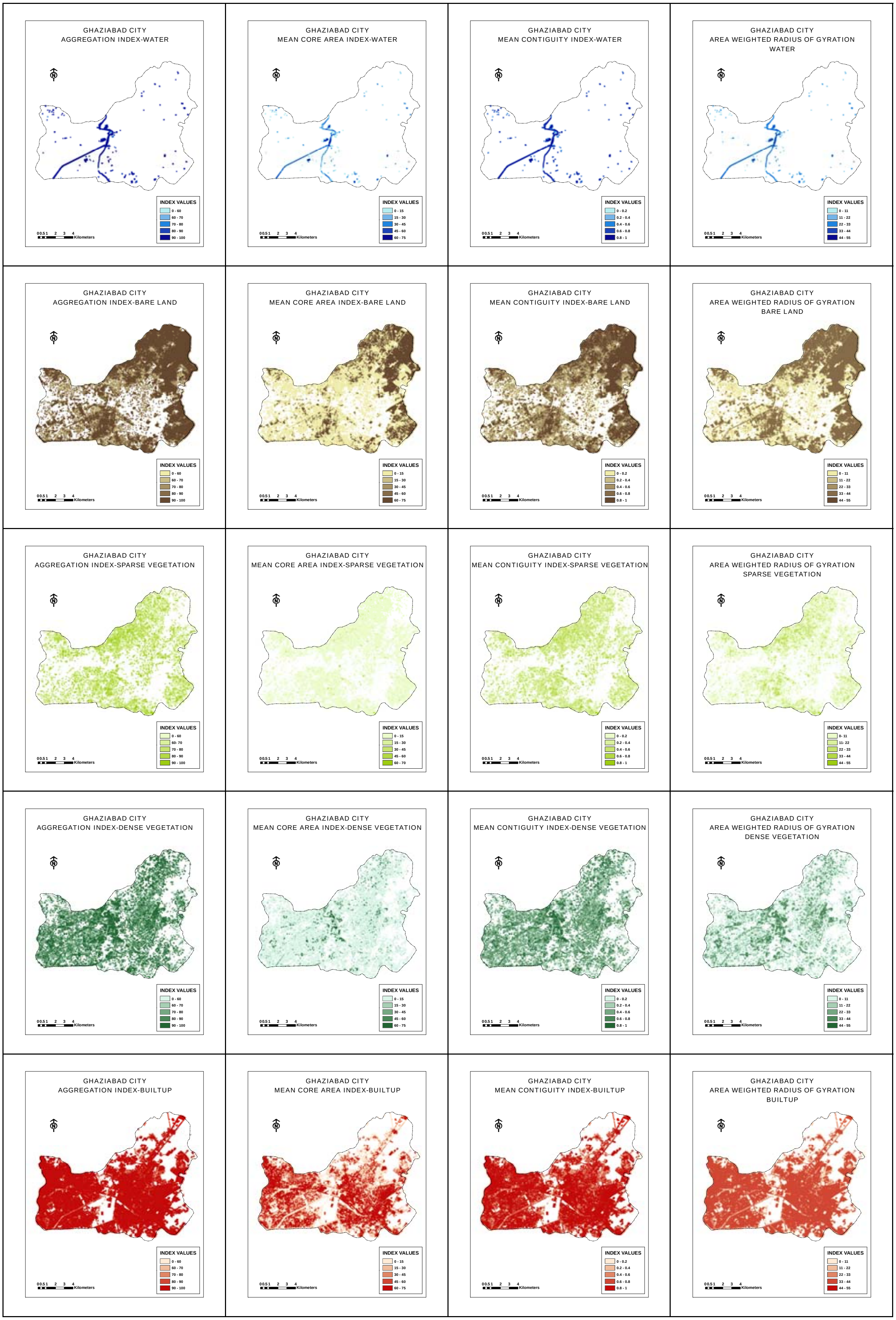


Fig 5.16 Cell Metrics of Ghaziabad City

5.4 Spatial Correlation

Spatial regression on LST explores more about which specific land use and fractal geometry as measured by metrics significantly influences temperature pattern within the study area. This analysis of metrics of LULC categories in relation to the LST will provide useful information about the urban thermal environment and how they relate with the thermal signatures. It is important to know how configuration of these LULC class metricsinfluences the thermal signatures through spatial regression. Also, which measure is the most optimal for further application in this domain of study. Spatial regression of raster datasets involves the inevitability of alignment in the two datasets, and in case it is not there, the process can be lengthy and tedious. Like here, the datasets had different spatial resolution and so their correlation was done by geospatial analyses of 100% sample points values extracted from the raster datasets of metrics and LST. The pixel based correlation to be executed was not possible by overlaying the datasets because the spatial resolution of LULC prepared from LISS-IV was different from LST derived from Landsat-TIRS. It was thus done by point extraction of the large sized datasets and the further processing for bringing it into the format where correlation analyses could be done. Depicted below are the results obtained from the correlation of datasets with LST.

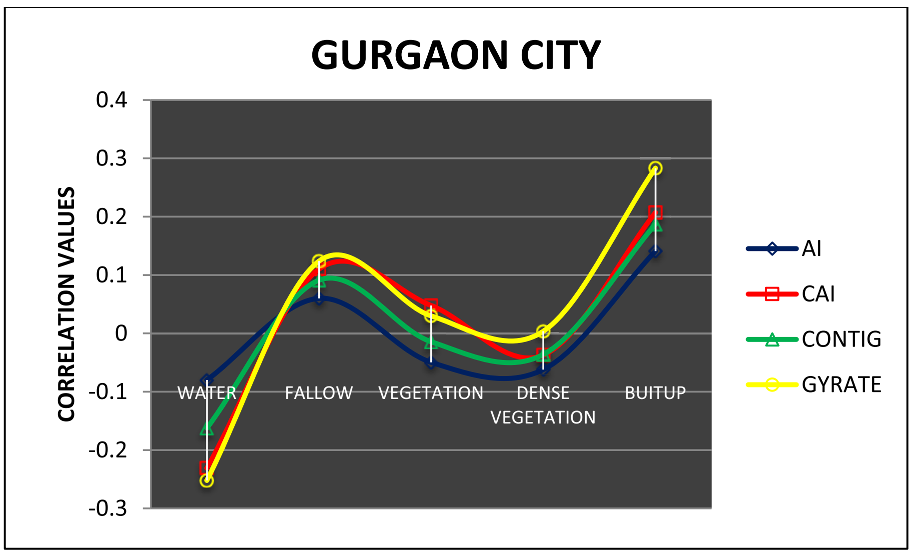


Fig5.20: Pearson Correlation of Gurgaon landscape metrics and LST

In Gurgaon the correlation values seen above in figure 5.20 conveys that the overall correlation value ranges between -0.3 to 0.3. In the above depiction radius of gyration shows higher correlation than the other indices and aggregation indices show the least correlation value among all. Core area index shows nearly equivalent value to gyration as they have the same function i.e. it refers to the interior most area measurement in a patch. Higher core areas can have different effect on thermal regulation. High core area or also high contiguity will exacerbate the thermal conditions, whereas for water or vegetation higher core areas will help to regulate them. It was also observed in class metrics that the ratio of LPI and Area_SD for built up was lesser in comparison to Noida and Ghaziabad. Similarly the number of patches of builtup is also higher which points to better fragmentation of builtup and other classes too. Thus because of heterogeneous configuration and higher fragmentation a balance is seen between the correlation value for built-up and non-built-up.

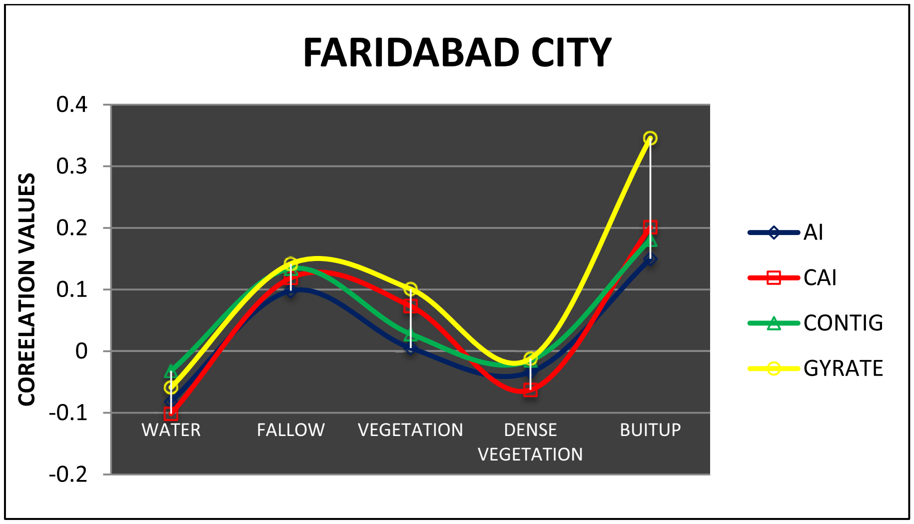


Fig 5.21: Pearson Correlation of Faridabad landscape metrics and LST

Faridabad city in figure 5.21 has a higher correlation of built-up than observed in Gurgaon. Based on the earlier landscape and class metrics it can be seen that the built up is dominating over other land use classes and its non-heterogeneous character is contributing to higher temperatures. At the same time, the proportion of water area is lesser so the index value goes down and so does the correlation values. Contiguity and aggregation fall short of the other two indices recommending more applicability of the former two in representing the phenomena. Correlation of medium density vegetation is seen to have a neutral correlation which can be improved or worsened for mitigating the thermal adversities or otherwise respectively.

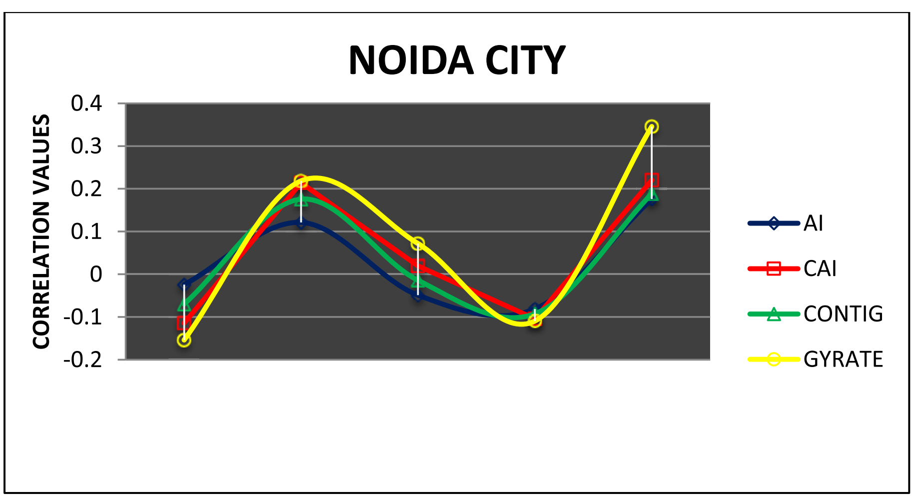


Fig 5.22: Pearson Correlation of Noida landscape metrics and LST

Except for water and dense vegetation, other land use/cover shows positive correlation (figure 5.22). This little anomaly over vegetation land cover can be because of other factors acting strongly. These values can also be attributed to the spatial configuration of the landscape as discussed in landscape and class level metrics. A major observation in the class metrics is that there is a very clear domination of built up class over other land covers. This also suppresses the role that natural land covers have as there fragmentation measures are higher and their abundance indices based on spatial extent are lower. When fragmentation and heterogeneity of natural land cover decreases then the role of man-made land use controlling the microclimatic condition increases, thus controlling the correlation results too. Also the physical phenomena can get transfered to next higher hierarchy and then it becomes a phenomenon of canopy layer and not solely of the surface and boundary layer.

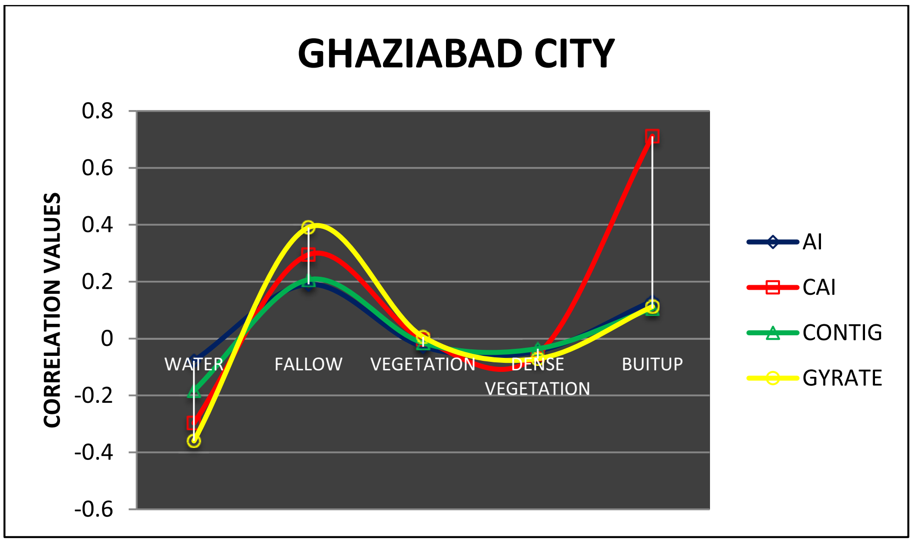


Fig 5.23: Pearson Correlation of Ghaziabad landscape metrics and LST

Ghaziabad city shows highest and very strong correlation of core area index amongst the four cities in figure 5.23. Also, it exhibits the highest range of correlation compared to other landscapes. Fallow land, which shows the highest temperature is represented to be highly correlated to LST by character of its core area. Water seems to play a much important role than the vegetation land use in this landscape. The patch area of vegetation and water is seen to be highly fragmented which prevents its effect on temperature mitigation. On the other hand built up has very high CA, LPI , Area_SD which represents contiguity and very less NP and ENN values which show fragmentation. Moreover, Core area index and gyration have shown tremendously different results which also signifies that every landscape can have its own dominant metric.

The role of cell metrics in describing the relation with LST is also dependent on some characteristics of the metrics. The characteristics can vary with landscapes and here the role of cell metrics has to be discussed for deciphering the functioning of metrics and its relation with LST thereof. The characteristics of its functioning in these landscapes have been discussed in the following section.

1) Area Weighted Radius of Gyration (GYRATE_AM): Maximum variation has been observed with GYRATE_AM metric wherein the correlation value ranges from 0.4 for built-up to -0.3 for water. Built-up has a significant positive correlation in comparison to the other land covers, as it contributes towards the propagation of surface temperature. Despite a small percentage share of land covers, water has a negative relationship with this metric and indicates its important role in the mitigation of temperature. In all four cities, dense vegetation does not show a very strong negative relationship with GYRATE_AM. High number of patches and low mean area value have a significant impact on LST as the GYRATE_AM metric.

2) Aggregation Index (AI): The value of correlation coefficient of AI for different land covers and LST depicts the least variation among all the indices computed. Despite having a compact development pattern, built-up AI does not exhibit strong relationship with LST in any of the landscape. Water shows a negative and negligible relationship with LST which is due to the small size of the water body as well as the low dependence of LST on this aspect of measure. Dense and sparse vegetation also has a negative and insignificant relationship. Due to the dispersed characteristics of these two classes, it does not have any significant influence on the LST. Aggregation index thus was not able to establish a strong relationship with LST directing to its lesser applicability in this study.

3) Mean Core Area Index (CAI_MN): Large built-up core area with high contiguity will exacerbate the thermal conditions, whereas for water and vegetation large core areas will help to mitigate the surface temperature. At the same time, the proportion of water area is lesser so the index value goes down. Still, water has considerable negative relationship with the LST. Fallow land and builtup which shows the highest temperature ranges are represented to be highly correlated to LST due to large areas and thus large core size. Water seems to play a much important role than the vegetation land use in the temperature regulation. Negative relationship indicates that increase in the area under water will help in the decrease of LST.

4) Mean Contiguity Index (CONTIG_MN): The trend of relationship between CONTIG_MN metrics of different land cover and LST follows the almost similar trend as discussed in above three metrics. Overall, this index has a very less variation in the correlation value between LST and different land covers. The correlation value with LST and CONTIG_MN of built-up is highest 0.189 in Noida and lowest0.106 in Ghaziabad. CONTIG_MN of fallow land also indicates a similar trend like built-up with LST. Vegetation cover is non-contiguous in nature and CONTIG_MN has a very low negative correlation value with LST. The index from a different aspect of measure has a similar result like aggregation index and finds little usability in this application.

6. CONCLUSIONS AND RECOMMENDATIONS

This purpose of the study was to understand the contribution of meso-level spatial configuration on thermal conditions in an urban landscape using RS & GIS of the CNCR region. After the study, the results gave a deeper insight into the subject as well as the main objective i.e. the thermal scenario over the CNCR. In other countries, spatial metrics of urban form has interested many researchers in urban ecological planning and design. Urban climate and urban setting are found to be inter-linked through spatial metrics which has been now observed through this study also. It was observed that the thermal conditions are varying in this region in an increasing trend. Major observations and based on that the conclusions can be listed down as:

- Gurgaon was found to be having the lowest maximum temperature whereas Ghaziabad exhibited the highest trend in temperature variations reaching upto 50°C in few areas.
- Built up land cover scored highly in contiguity indices and poorly in fragmentation indices and vice versa was with the natural land covers in all the four landscapes of the region.
- The trend observed in the region is that the temperature increases with least at Gurgaon, higher at Faridabad, Noida and highest recorded at Ghaziabad. Whereas the fragmentation of landscapes is exactly in the reverse order to it.
- Fragmentation indices exhibited a gentle correlation with the LST where the GYRATE_AM index showed the highest correlation and Aggregation Index showed the least correlation.
- The behavior of GYRATE_AM was similar to CAI_MN which are based on gradation of values from the center of patch to outwards whereas the behavior of AI was similar to CONTIG_MN based on the adjacency of pixels.
- The fragmentation of large core areas built-up seems to be having greater significance and impact than the aggregation of non-built-up in mitigating the LST. It is diagrammatically represented below.

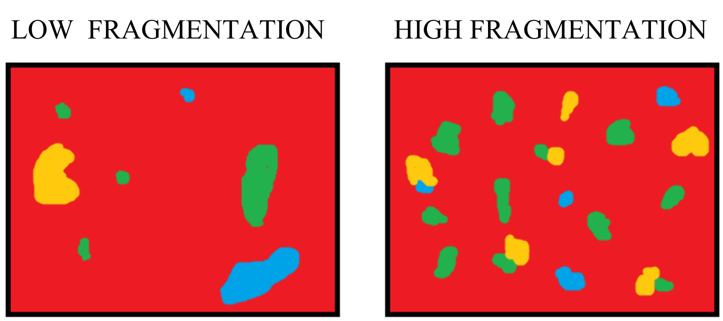


Figure 6.1 Diagrametic Representation of Hetrogeneous Fragmentation

- Gurgaon exhibits a lot of heterogeneity in its landscape pattern, which can be considered good from landscape ecology point of view, whereas Ghaziabad has large core areas for built up and fallow, which shows extreme values in results and such a landscape development doesn't favor sustainable growth.

- A relationship has been established between the metrics and it can be concluded that these metrics can be used for comparative study or can be applied to any other landscape for such studies.
- Such analyses are better to be interpreted with metrics like done in this study which gave the land use arrangement at each level and thus a comprehensive analysis of the interlinked phenomena.
- Designing landscape based on the metrics is one important future research that can be explored and implemented for sustainable development of different areas with environmental problems.

Keeping in view this rapid conversion of natural landscapes to manmade landscapes in the CNCR towns and also the rate of environmental degradation the region, the following four distinct zones have been identified by NCRPB for application of strict land use control and development. The vulnerable areas have been grouped as follows:

(a) Urbanisable area,

(b) Green belt/green wedge is often converted to urban lands,

(c) Areas along the major transport routes,

(d) Remaining rural land is a common prey to urban land expansion due to its low cost.

The governing bodies identify these regions and the likely major economic activities in thereof for proposing appropriate and viable land use conversions. With the policy of inducing development in the regional and sub-regionalcenters, the urbanization will be much more faster which implies additional land for urban expansion. In the same lines, land use policies are existing designed by the NCRPB for regulating the density of settlements in the CNCR:

(a) For urban centers upto1.0 lac population, a density of 80 persons per hectare,

(b) For urban centersof 1.0 lac of 5.0 lac population, a density of 110 persons *per* hectare, and

(c) For urban centers ofmore than 5.0 lac population, a density of 125 persons per hectare.

These policies along with the other quantified factors including spatial metrics should be used for designing the landscape with environmentalism as an important aspect in mind. Mitigating the UHI intensity wherein spatial metrics also has a role to play, increasing vegetation cover is the most widely applied measure which could achieve huge energy savings through temperature reduction of an area. But as mentioned above only the increase in quantity in few areas is not the solution but it has be uniform and heterogeneous in its spread. It was reported in a study conducted by Spronken-Smith *et al*. (2000) that parks could help control temperatures through an evaporation of morethan 300% as compared to its surrounding. Thus, areas in these cities where there is high contiguity of built up, there parks and gardens can be introduced. Some other traditional mitigation measures include lighter color of pavement and cooler roofs using spray; proper ventilation; shades;open and airy spaces; photovoltaic canopies (Golden *et al.,* 2007) etc. Fortunately, urban heat island mitigation strategies—for example, trees and vegetation and green roofs—generally provide year-round benefits, or their winter penalty, such as that from cool roofs, is much smaller than their summertime benefits.Future policy efforts may focus on encouraging strategies to modify urban geometry and anthropogenic heat in communities to reduce urban heat islands.However, most effectivemitigationmeasures for an area should be developed based on context/place specific spatiotemporalnature of UHI of an area. It is one future potential of this study where the mitigation strategies can be designed based on urban geometry.

It is critical that we develop an integrated approach at a time when urbanizing regions are facing rapid environmental change. Planners and managers worldwide face unprecedented challenges in accommodating urban populations and improving their wellbeing while simultaneously maintaining ecosystem functions. Agencies must devise policies to guide urban development and make decisions about investing in infrastructure that is both economically viable and ecologically sustainable. An integrated framework is required to assess the environmental implications of alternative urban development patterns and to develop policies to manage urban areas in the face of change. In particular, strategies for urban growth management will require such integrated knowledge to maintain ecological resilience by preventing development pressure on the urban fringe, reducing resource use and emissions of pollutants, as well as minimizing impacts on terrestrial ecosystems. The ecology of urban areas has long elicited the academic attention of ecologists, planners and social scientists and regional planners, there is much opportunity to extend and integrate knowledge of the metropolis using an ecological lens. How NCRPB and other planning and developmental authorities of the region manage urbanization and its ecology will be crucial to the health and wellbeing of billions of people in the region.It appears urgent to find solutions able to maintain the ecology and the biodiversity of conurbations with the sprawling urban areas, and contemporarily to assure a sustainable future to humanity.

"Landscape ecology needs to be more "urban;" urban ecology needs to be more landscape-realistic; both need to focus more on sustainability."- (Wu et.al. 2013)

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ANNEXURE-I

LANDUSE PATTERN IN STUDY AREA

CLASS	GURGAON		FARIDABAD		NOIDA		GHAZIABAD	
	Sq. Km.	Percentage	Sq. Km.	Percentage	Sq. Km.	Percentage	Sq. Km.	Percentage
Residential	71.875	45.97	70.6	41.73	53.276	46.79	62.835	43.12
Commercial	2.678	1.71	0.406	0.24	1.628	1.43	1.506	1.03
Industrial	8.0754	5.16	11.732	6.94	14.607	12.83	15.991	10.97
Dense Vegetation	22.677	14.50	14.794	8.75	12.221	10.73	18.062	12.39
Sparse Vegetation	15.88	10.16	13.548	8.01	7.982	7.01	7.881	5.41
Water	1.049	0.67	2.549	1.51	0.517	0.45	1.646	1.13
Agriculture	4.867	3.11	13.917	8.23	4.89	4.29	23.966	16.45
Fallow Land	29.264	18.72	41.622	24.60	18.748	16.46	13.838	9.50
Total	156.365	100	169.168	100	113.869	100	145.725	100

ANNEXURE-II

(A)-GURGAON CLASS METRICS

Class Metrics	Water	Fallow	Sparse Vegetation	Dense Vegetation	Builtup
CA	105.2475	3238.47	1777.305	2280.0375	8236.0625
PLAND	0.448	13.786	7.5659	9.706	35.0606
NP	198	14561	13256	16188	6286
PD	0.8429	61.9856	56.4302	68.9116	26.7592
LPI	0.0434	4.9328	1.3919	0.5037	32.2021
ED	2.5887	98.1978	80.4071	119.5907	148.9693
AREA_MN	0.5316	0.2224	0.1341	0.1408	1.3102
AREA_SD	1.1815	10.1477	3.9705	1.6464	95.4045
SHAPE_MN	1.2967	1.2483	1.3184	1.3078	1.2725
SHAPE_SD	0.2944	0.4704	0.5656	0.5649	1.0203
PAFRAC	1.1449	1.3122	1.3665	1.3141	1.2974
ENN_MN	221.4211	24.3222	21.5626	23.2084	18.1576
ENN_SD	297.4451	20.722	24.0964	20.1244	15.5276
COHESION	95.4773	99.0702	98.4257	97.0975	99.9548
AI	93.2328	91.1764	86.8186	84.6871	94.7411

(B)-GURGAON CELL METRICS

INDEX	CLASS	Min	Max	Mean	Std Dev.
AGGREGATION INDEX	WATER	0	99.6	93.49	8.31
	BARE LAND	0	99.6	84.67	14.27
	SPARSE VEGETATION	0	99.6	74.93	20.54
	DENSE VEGETATION	0	99.6	81.53	15.04
	BUILT-UP	0	99.6	92.19	8.9
MEAN CORE AREA INDEX	WATER	0.58	67.51	28.14	19.01
	BARE LAND	0.56	67.48	26.01	25.16
	SPARSE VEGETATION	0.07	67.14	17.62	21.78
	DENSE VEGETATION	0.09	67.33	13.11	15.1
	BUILT-UP	0.49	67.4	32.76	23.16
MEAN CONTIGUITY INDEX	WATER	0	0.94	0.64	0.27
	BARE LAND	0	0.94	0.54	0.25
	SPARSE VEGETATION	0	0.94	0.4	0.25
	DENSE VEGETATION	0	0.94	0.47	0.22
	BUILT-UP	0	0.94	0.72	0.22
AREA WEIGHTED RADIUS OF GYRATION	WATER	2.5	43.18	15.9	10.62
	BARE LAND	2.5	54.02	18.02	13.43
	SPARSE VEGETATION	2.5	50.36	14.48	12.03
	DENSE VEGETATION	2.5	52.59	14.97	10.74
	BUILT-UP	2.5	54.53	31.09	11.08

ANNEXURE-III

(A)-FARIDABAD CLASS METRICS

Class Metrics	Water	Fallow	Sparse Vegetation	Dense Vegetation	Builtup
CA	254.7	5413.43	1517.2725	1490.0725	8241.86
PLAND	0.9321	19.8111	5.5526	5.4531	30.1621
NP	251	15528	21752	14541	3795
PD	0.9186	56.8266	79.6041	53.2145	13.8883
LPI	0.0627	5.9295	0.6301	0.2066	25.3469
ED	5.8898	112.9066	88.195	76.4099	111.3344
AREA_MN	1.0147	0.3486	0.0698	0.1025	2.1718
AREA_SD	2.6133	15.3767	1.434	0.7748	112.4828
SHAPE_MN	1.542	1.2281	1.2822	1.2954	1.325
SHAPE_SD	1.0092	0.55	0.4307	0.4543	1.1951
PAFRAC	1.2732	1.3157	1.3317	1.2975	1.3183
ENN_MN	203.6601	23.909	22.3123	24.8476	17.7497
ENN_SD	292.9379	19.0881	21.0593	24.4895	16.1584
COHESION	97.8302	99.5874	94.8702	94.74	99.9446
AI	92.3912	92.9387	80.2487	82.5918	95.4385

(B)-FARIDABAD CELL METRICS

INDEX	CLASS	Min	Max	Mean	Std Dev.
AGGREGATION INDEX	WATER	0	99.6	92.85	8.46
	BARE LAND	0	99.6	86.16	14.35
	SPARSE VEGETATION	0	99.6	72.96	20.57
	DENSE VEGETATION	0	99.6	79.38	17.41
	BUILT-UP	0	99.6	93.08	8.64
MEAN CORE AREA INDEX	WATER	0	67.3	18.23	18.35
	BARE LAND	0	67.86	18.77	23.96
	SPARSE VEGETATION	0	67.83	3.2	9.31
	DENSE VEGETATION	0	66.98	4.82	10.51
	BUILT-UP	0	67.29	32.88	24.36
MEAN CONTIGUITY INDEX	WATER	0	0.94	0.63	0.24
	BARE LAND	0	0.94	0.57	0.26
	SPARSE VEGETATION	0	0.94	0.36	0.21
	DENSE VEGETATION	0	0.94	0.43	0.22
	BUILT-UP	0	0.94	0.74	0.21
AREA WEIGHTED RADIUS OF GYRATION	WATER	2.5	48.47	20.28	10.05
	BARE LAND	2.5	54.13	24.33	14.29
	SPARSE VEGETATION	2.5	51.09	10.71	8.69
	DENSE VEGETATION	2.5	51.73	12.65	9.5
	BUILT-UP	2.5	54.82	31.6	10.5

ANNEXURE-IV

(A)-NOIDA CLASS METRICS

Class Metrics	Water	Fallow	Sparse Vegetation	Dense Vegetation	Builtup
CA	51.7825	2300.808	889.3375	1230.79	6914.785
PLAND	0.267	11.8636	4.5857	6.3463	35.6546
NP	112	9660	11483	9180	1735
PD	0.5775	49.8098	59.2097	47.3347	8.9462
LPI	0.0224	3.4913	0.3178	0.2994	34.6223
ED	2.5936	86.2745	72.1411	78.1196	112.9645
AREA_MN	0.4623	0.2382	0.0774	0.1341	3.9855
AREA_SD	0.651	7.1033	0.8312	1.1722	161.1565
SHAPE_MN	1.6413	1.2383	1.3057	1.3238	1.2709
SHAPE_SD	0.6321	0.5188	0.4585	0.5051	1.4731
PAFRAC	1.3637	1.3194	1.3274	1.3083	1.3002
ENN_MN	242.4019	26.395	24.258	25.7048	17.7051
ENN_SD	372.4191	24.4999	25.1565	24.0256	13.9839
COHESION	94.7569	98.9928	93.8018	95.7563	99.9678
AI	88.4729	91.0046	80.4702	84.7334	96.0974

(B)-NOIDA CELL METRICS

INDEX	CLASS	Min	Max	Mean	Std Dev.
AGGREGATION INDEX	WATER	0	99.61	91.62	7.89
	BARE LAND	0	99.61	84.33	15.27
	SPARSE VEGETATION	0	99.61	74.94	20.34
	DENSE VEGETATION	0	99.61	80.62	17.06
	BUILT-UP	0	99.61	94.35	7.87
MEAN CORE AREA INDEX	WATER	0	66.86	12.24	15.3
	BARE LAND	0	68.16	13.72	21.32
	SPARSE VEGETATION	0	68.8	3.46	9.18
	DENSE VEGETATION	0	68.09	6.67	12.88
	BUILT-UP	0	67.61	37.59	23.28
MEAN CONTIGUITY INDEX	WATER	0	0.93	0.64	0.22
	BARE LAND	0	0.94	0.52	0.26
	SPARSE VEGETATION	0	0.94	0.38	0.22
	DENSE VEGETATION	0	0.94	0.46	0.23
	BUILT-UP	0	0.94	0.78	0.19
AREA WEIGHTED RADIUS OF GYRATION	WATER	2.5	49.66	15.38	8.85
	BARE LAND	2.5	52.91	17.74	13.59
	SPARSE VEGETATION	2.5	50.64	10.87	8.59
	DENSE VEGETATION	2.5	49.06	13.73	9.32
	BUILT-UP	2.5	54.43	33.21	9.62

ANNEXURE-V

(A)-GHAZIABAD CLASS METRICS

Class Metrics	Water	Fallow	Vegetation	Dense Vegetation	Builtup
CA	164.505	5478.733	802.93	1820.68	8006.368
PLAND	0.607	20.2171	2.9629	6.7185	29.5444
NP	171	10350	14905	14053	2330
PD	0.631	38.1927	55.0011	51.8571	8.598
LPI	0.1125	5.4059	0.0409	0.1529	27.8349
ED	3.5584	97.8856	61.9551	83.2242	89.7199
AREA_MN	0.962	0.5293	0.0539	0.1296	3.4362
AREA_SD	3.528	19.4577	0.2456	0.8815	156.2371
SHAPE_MN	1.5039	1.266	1.3119	1.3067	1.3021
SHAPE_SD	0.8084	0.6793	0.4839	0.4681	1.2791
PAFRAC	1.2597	1.3332	1.3537	1.2862	1.287
ENN_MN	204.9808	26.0798	25.6036	26.8616	19.5481
ENN_SD	343.4412	25.8281	28.5112	24.9603	40.3756
COHESION	98.1798	99.6134	90.7415	95.2618	99.9615
AI	93.0361	94.0113	73.9928	84.615	96.2578

(B)-GHAZIABAD CELL METRICS

INDEX	CLASS	Min	Max	Mean	Std Dev.
AGGREGATION INDEX	WATER	0	99.61	92.85	8.14
	BARE LAND	0	99.61	87.97	13.7
	SPARSE VEGETATION	0	99.61	71.75	21.85
	DENSE VEGETATION	0	99.61	81.96	16.42
	BUILT-UP	0	99.61	94	8.72
MEAN CORE AREA INDEX	WATER	0	67.4	20.27	20.1
	BARE LAND	0	67.83	20.51	25.43
	SPARSE VEGETATION	0	67.01	2.05	5.88
	DENSE VEGETATION	0	67.29	6.65	12.61
	BUILT-UP	0	67.67	37.29	23.93
MEAN CONTIGUITY INDEX	WATER	0	0.93	0.69	0.23
	BARE LAND	0	0.93	0.61	0.27
	SPARSE VEGETATION	0	0.93	0.34	0.21
	DENSE VEGETATION	0	0.94	0.47	0.23
	BUILT-UP	0	0.94	0.77	0.21
AREA WEIGHTED RADIUS OF GYRATION	WATER	2.5	46.71	19.22	10.89
	BARE LAND	2.5	51.87	23.29	14.38
	SPARSE VEGETATION	2.5	54.24	9.7	7.65
	DENSE VEGETATION	2.5	52.45	13.41	9.95
	BUILT-UP	2.5	55.53	33.34	10.76