ACKNOWLEDGEMENTS

I wish to express my thankfulness to my internal guide, Prof. Govind M.P. Department of Planning for his able supervision and useful suggestions, which helped me in finishing the thesis work, in time. I take enormous pleasure in thanking Professor Nikhil Ranjan Mandal, Head of Department, Planning, SPA-Bhopal and our Thesis Coordinator Rama U. Pandey Department of Planning, for having permitted me to carry out master's degree thesis as per my choice.

Words are inadequate in offering my thanks to my friends Jugal, Bijay Gaurab and Abhilash and to my best friend Tanvi Katre and also my fellow classmates for their encouragement and support in carrying out the thesis work. Finally, yet importantly, I would like to express my beloved parents for their blessing, my younger brother for his encouragement for the successful completion of this thesis. Lastly I would like to thank the almighty who gave me strength and rigor to carry out my thesis enthusiastically.

Arunava Bhattacharya
Masters of Planning
May 2017

Copyright@SPA Bhopal

Abstract

The future is urban and it is projected that by 2030, fifty-six per cent of the population of the developing countries would be living in cities. To satisfy the overgrowing demand of development natural capital like forests, land and water are being converted into man made capital which must be conserved. This study is of Urban Heat Island Effect (UHI) in Guwahati city that is established within the North East region of India. The study area consists of the area underneath Guwahati Metropolitan Development Authority. Guwahati has a population increase of 8394 in 1891 to of 968549 in 2011.This advanced urbanization, has altered the land surface characteristics within the city and have increased the land surface temperature and thereby the urban hat island effect.

Analysis of satellite imageries were carried out in this study that has disclosed instant decrease of land cover with a definite increase of land surface temperature and thereby the urban heat island effect from 2001 to 2016. Due to inadequacy of vegetation, some hot spots on encompassing hillocks were known, the surface temperature of which is as high as the valley portion of the city.Thus, in this study an attempt has been made to correlate variation in temperature for the selected temporal years. The results of this study are taken into account as a helpful analysis to develop step to thermal environmental strategy for Guwahati Metropolitan Area. The study additionally focuses on the impact of the expansion of the town on the forest areas within it. To do so, secondary information of concerning a hundred years (from 1911 to 2015) of forests and also the urban growth are analysed.

The main target of the study is on the Urban Forest of Guwahati, since these forests on the hills play a twin role by providing rich biodiversity and play an important role in balancing the microclimate of a place by sequestering greenhouse emission gas emissions, thereby acting as a sink and subjugate the UHI effect upon the hillocks. It has been seen from literature review that growth of city typically takes place with the conversion of accessible forests areas, leading to loss of ecological services that the forests give. This study is an attempt to know urbanization from the ecological footprint (forestry) perspective. The study shows that enormous forest areas were degraded in urbanization method,

Copyright@SPA Bhopal

leading to baring of hills among the Guwahati Municipal Corporation Area, high surface break out and concrete flooding. The city needs to reduce its UHI effect as well as enhance its carbon sequestration potential many times to become an eco-city.

For the study, Vegetation type, Land Surface Temperature and Urban Heat Island map of Guwahati City has been prepared for three years i.e., 2001, 2011 and 2016 using Landsat 5 ETM+ and Landsat 7ETM+ satellite data with a spatial resolution of 30m. Among various strategies to reduce UHI, effect “Trees and Vegetation Strategy” has been given more importance in this study.

Geomatics has been used for mapping the classification of vegetation type and land use classes. The remote sensing of land surface temperature, has been used for retrieving land surface temperature map from Landsat thermal band data. Based on the analysis it absolutely was seen that the city of Guwahati had the formation of heat Islands and to adapt and scale back these effects proper green adaptation and mitigation methods has been prepared at the regional level and site level.

Copyright@SPA Bhopal

सार

भविष्य शहरी है और यह अनुमान है कि 2030 तक, विकासशील देशों की जनसंख्या का पचास प्रतिशत हिस्सा शहरों में रह जाएगा। विकास की बढ़ती मांग को पूरा करने के लिए वन, भूमि और पानी जैसे प्राकृतिक पूंजी को मानव निर्मित पूंजी में परिवर्तित किया जा रहा है जिसे संरक्षित किया जाना चाहिए। यह अध्ययन गुवाहाटी शहर में शहरी हीट द्वीप प्रभाव (यूएचआई) है जो भारत के पूर्वोत्तर क्षेत्र में स्थापित है। अध्ययन क्षेत्र में गुवाहाटी मेट्रोपॉलिटन डेवलपमेंट अथॉरिटी के नीचे स्थित क्षेत्र शामिल हैं। गुवाहाटी की आबादी में 8 9 4 में 18 9 1 से बढ़कर 9 68549 हो गया है। इस उन्नत शहरीकरण ने शहर के भीतर भूमि की सतह की विशेषताओं को बदल दिया है और भूमि की सतह के तापमान में वृद्धि की है और शहरी टोपी द्वीप प्रभाव को बढ़ा दिया है।

इस अध्ययन में उपग्रह इमेजेरिज़ का विश्लेषण किया गया है जिसमें भूमि की सतह के निश्चित निश्चित वृद्धि और 2001 से 2016 तक शहरी गर्मी द्वीप प्रभाव के साथ भूमि कवर की तुरंत कमी का खुलासा किया गया है। वनस्पति की अपर्याप्तता के कारण, पहाड़ी पर स्थित कुछ गर्म स्थान ज्ञात थे, जिसकी सतह का तापमान शहर के घाटी भाग के बराबर है। इसलिए, इस अध्ययन में चयनित अस्थायी वर्षों के लिए तापमान में अंतर को सहसंबंधित करने का प्रयास किया गया है। गुवाहाटी मेट्रोपॉलिटन एरिया के लिए थर्मल पर्यावरणीय रणनीति के लिए कदम विकसित करने के लिए इस अध्ययन के परिणाम एक उपयोगी विश्लेषण के रूप में ध्यान में रखते हैं। अध्ययन इसके अतिरिक्त, इसके भीतर के वन क्षेत्रों पर शहर के विस्तार के प्रभाव पर केंद्रित है। ऐसा करने के लिए, वनों और शहरी विकास का सौ साल से (1 911 से 2015 तक) की माध्यमिक जानकारी का विश्लेषण किया जाता है।

अध्ययन का मुख्य लक्ष्य गुवाहाटी के शहरी वन पर है, क्योंकि पहाड़ियों पर इन वनों को समृद्ध जैव विविधता प्रदान करके और ग्रीनहाउस उत्सर्जन गैस उत्सर्जन को क्रमशः करके एक स्थान के सूक्ष्म-संतुलन को संतुलित करने में एक महत्वपूर्ण भूमिका निभाते हैं, इसलिए इस तरह अभिनय एक सिंक और पहाड़ी पर UHI प्रभाव subjugate। साहित्य की समीक्षा से यह देखा गया है कि शहर की वृद्धि आम तौर पर सुलभ जंगलों के क्षेत्रों के रूपांतरण के साथ होती है, जिससे वनों को देने वाली पारिस्थितिक सेवाओं की हानि हो जाती है। यह अध्ययन पारिस्थितिक पदचिह्न (वानिकी) के परिप्रेक्ष्य से शहरीकरण को जानने का एक प्रयास है अध्ययन से पता चलता है कि विशाल वन क्षेत्र को शहरीकरण पद्धति में अपमानित किया गया था, जिससे गुवाहाटी नगर निगम क्षेत्र, उच्च सतह के बाहर तोड़कर और ठोस बाढ़ के बीच पहाड़ियों को रोकना पड़ा। शहर को अपने यूईई प्रभाव को कम करने और इसके साथ-साथ अपने कार्बन जब्ती क्षमता को भी कई बार पारिस्थितिकी-शहर बनने की आवश्यकता है।

Copyright@SPA Bhopal

अध्ययन के लिए, 30 एम के स्थानिक रिज़ॉल्यूशन के साथ लैंडसैट 5 ईटीएम + और लैंडसेट 7 एटीएम + उपग्रह डेटा का उपयोग करते हुए तीन साल के लिए गुवाहाटी सिटी के वनस्पति के प्रकार, भूमि सतह तापमान और शहरी गर्मी द्वीप के मानचित्र को तैयार किया गया है। यूएआई को कम करने के लिए विभिन्न रणनीतियों में, इस अध्ययन में "पेड़ और वनस्पति रणनीति" को अधिक महत्व दिया गया है।

जैमेटिक्स का उपयोग वनस्पति के प्रकार और जमीन उपयोग कक्षाओं के वर्गीकरण के मानचित्रण के लिए किया गया है। भूमि की सतह के तापमान का रिमोट सेंसिंग, लैंडैट थर्मल बैंड डेटा से भूमि सतह के तापमान के नक्शे को पुनः प्राप्त करने के लिए इस्तेमाल किया गया है। विश्लेषण के आधार पर यह पूरी तरह से देखा गया कि गुवाहाटी शहर में गर्मी आइलैंड्स का गठन किया गया था और इन प्रभावों को अनुकूलन और पैमाने पर करने के लिए क्षेत्रीय स्तर और साइट स्तर पर उचित हरे रंग की अनुकूलन और शमन पद्धतियां तैयार की गई हैं।

Copyright@SPA Bhopal

List of Abbreviations

ASTER	:	Advanced Space borne Thermal Emission and Reflection Radiometer
ATLAS	:	Airborne Terrestrial Applications Sensor
AVHRR	:	Advanced Very High Resolution Radiometer
BLUHI	:	Boundary Layer Urban Heat Island
CLUHI	:	Canopy Layer Urban Heat Island
DN	:	Digital Number
EPA	:	Environmental Protection Agency
ETM	:	Enhanced Thematic Mapper
ETM+	:	Enhanced Thematic Mapper Plus
LEED	:	Leadership in Energy and Environmental Design
LST	:	Land Surface Temperature
LULC	:	Land Use/Land Cover
NDVI	:	Normalized Difference Vegetation Index
NIR	:	Near Infrared
PSP	:	Public and Semi Public
ROIs	:	Region of Interest
RSPM	:	Respirable Suspended Particulate Matter
SPM	:	Suspended Particulate Matter
TIR	:	Thermal Infrared
TM	:	Thematic Mapper
UHI	:	Urban Heat Islands
UNDP	:	United Nations Development Programme
UTFVI	:	Urban Thermal Field Variance Index
GMDA		Guwahati Metropolitan Development Authority
GMCA		Guwahati Municipal Corporation Area

Copyright@SPA Bhopal

Contents

Copyright@SPA Bhopal

Copyright@SPA Bhopal

Copyright@SPA Bhopal

1. Introduction

1.1 Background

The year 2007 has been described as the tipping point in human history with half of the world's population living in urban areas for the first time. Urbanization in India has been closely following this world trend. [1]Cities square measure thought-about as growth engines. Economic process in urban areas represent near 1/2 India's gross domestic product. While proving to be propellers of economic process on one hand these urban areas show a parasitic character on the opposite hand. Although cities cowl solely two of the earth's surface, they consume 75% of its resources. [2]Quality infrastructure in the form of transportation networks, power supply, telecommunication networks, housing infrastructure, modernized medical facilities, Industrial centres and educational centres are a pre-requisite for economic growth in cities.

Physical infrastructure development draw heavily from the natural resources from within the city limits as well as areas far from cities. Urban dwellers play only a minor functional role within many 'in city' urban ecosystems, but they are virtually the sole macro consumers in vast areas of cropland, pasture, and forest outside the city, scattered all over the world. Similarly, many wastes generated by people in the city are injected into the global commons – the atmosphere, rivers, and ultimately the oceans – for processing and possible recycling.

The growing method of urbanization puts pressure on natural plant cover and increases the greenhouse gas emisions (GHG) in the region through vehicles and businesses. As a result of heat storage capacities and construction, also the temperature of automotive waste heat and distinct enterprises (ΔTu-r) between urban areas and in a geographic area outside the urban core is greater. So most areas of human settlements such as cities are characterized by closed isotherms indicate a surface area that is relatively hot. This method is accepted as an urban heat island (UHI). The size of ΔTu-r is greater at midnight, under a clear sky and very limited wind. The distinction between urban and rural sites grows over time as the sunset and reaches a greater distinction when it comes to four hours (Mills 2004).

In India, many metropolitan cities have also experienced UHI in this decade *(Deosthali, 2000, Amirtham et al., 2005 and Badrinath et al., 2005*). Recently,

Copyright@SPA Bhopal

estimation showed that Kolkata has lived its hottest on December 17th in 2009 with 19.4 ° C of minimum temperature *(Bhattacharyya, 2009).* Like Kolkata, **Guwahati,** the largest city in northeast India, has also experienced its hottest year in 2009 ("the hottest year in cities since 1950", 2009). Guwahati as a gateway to northeast India, characterized by a modification of the existing modification in the previous two years. Guwahati population increased from 809,895 in 2001 to 963,429 in 2011 with an increase in population density of 3736 inhabitants per km2. To 4445 per square kilometer. (Census of India, 2011). The rapid pace of urbanization has its impact on plant cover and therefore the atmosphere within the city.

During the last decade, the economic activities inside the town were accelerated. Industrial institution and concentration of recent corporations had modified the economic state of affairs of the town within the starting of the twenty first century. The development of recent highway from Jalukbari to Khanapara brought major land use amendment within the areas non-adjacent to the standard downtown centers. The high-speed transit invited many industries, establishment to line up their buildings aboard the highway, most of that were earlier inexperienced belt or wetlands. Thus, the urbanization method inside the town has accelerated at a high rate than ever before. The pressure of human settlement is felt over the reserve forest, hills and urban forests, therefore the inexperienced belt areas of the town.

In this paper, an effort has been made to analyse the impact of Urban heat island effects on the thermal setting of Guwahati City over the past fifteen years. Quantitative remote sensing techniques are adopted to analyse the results of urban heat island effect and its possible reduction strategies using vegetation i.e conservation of the urban forests within the hills of Guwahati City.

Copyright@SPA Bhopal

Various definitions:

Urban heat islands are umbellate domes of comparatively warm air emanating from the urban material of concrete and steel (Ford, 1979).

Urban heat island (UHI) could be a reverse oasis: wherever cities' air and surface temperatures are hotter than their rural surroundings (Gartland, 2008).

Temperatures area unit usually considerably higher in cities than in rural settings, creating these seasonal changes significantly dangerous for today's Urban populations. Referred to as the Urban Heat Island impact (Akbari, 2000).

The urban engineered atmosphere contributes to native will increase in air temperature in urban regions relative to the encompassing rural regions, referred to as the urban heat island (Howard, 1833). Although heat islands could kind on any rural or geographic area, and at any spatial scale, urbanised cities area unit favoured, since their surfaces area unit at risk of unleash giant quantities of warmth.

The UHI negatively affects not solely residents of urban-related surround, however conjointly humans and their associated ecosystems set secluded from cities. Small urban heat islands: They sit down with urban hot spots as poorly vegetated parking heaps, non-reflective roofs and asphalt roads.

Micro urban heat islands: area unit powerfully plagued by small climate factors, so remotely detected knowledge area unit a lot of appropriate than part knowledge for distinctive heat spots.

Urban heat sink: conjointly known as negative heat island. It's the expression of a town colder than their country sides. There are a unit few references concerning this development. Heat sinks are discovered in cities with temperate, tropical, semi-arid and arid climates, and principally throughout the daytime.

UHIs are indirectly associated with global climate change thanks to their contribution to the atmospheric phenomenon, and thus, to warming.

Copyright@SPA Bhopal

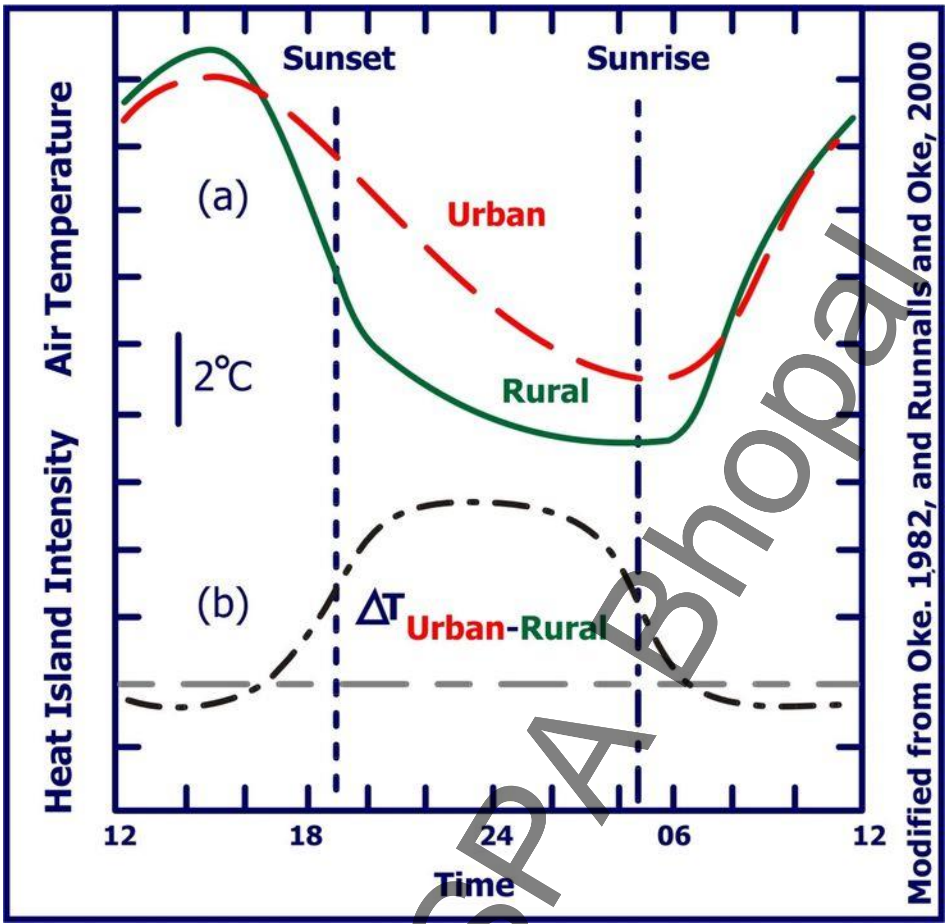


Figure 1 : Urban Heat Island Profile
Source: Oke.1982, and Runnalls and Oke, 2000

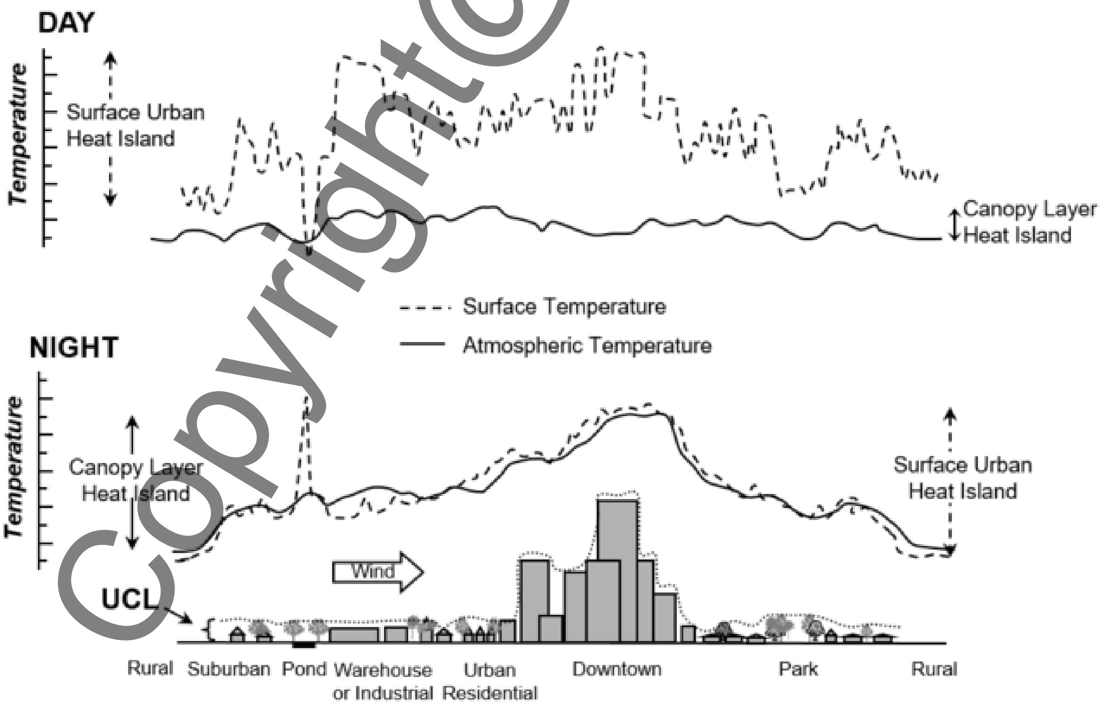


Figure 2 : Temperature variation in day and night
Source: EPA

Copyright@SPA Bhopal

1.2 Facts and Assertions

Urban heat islands are generated by factors which may be classified as controllable and uncontrollable (Rizwan et al., 2008). It's unattainable to mention that of these controls is the most significant in UHI formation as every city is exclusive and therefore the controls can differ in contribution in each case.

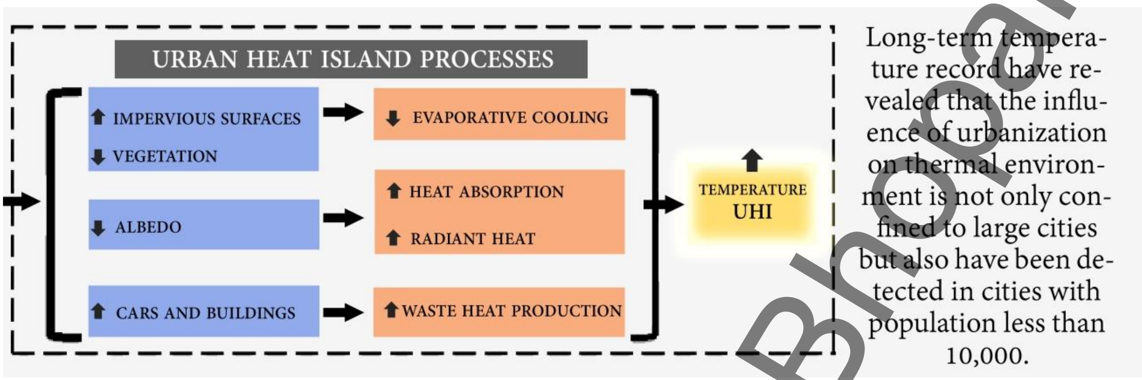


Figure 3: Model of the processes driving the enlarged temperatures leading to the UHI effect

Copyright@SPA Bhopal

1.2.1 Causes of Urban Heat Island Effect

Over the past decade UHI presence has been studied and documented in several cities around the world. As the name suggests, the cause of this phenomenon is an urban landscape in general, there are several bio-physical factors that contribute to its presence and spread.

Weather:

Weather systems UHI effects have a strong relationship with weather parameters such as wind and cloud.

Size and spread of urban sprawl:

City forms such as size, geometry and materials used in construction of urban spaces define UHI effects characteristics.

Geography:

The physical, human and environmental geography of a city including topography, rural surroundings and climate are some of the parameters considered.

1.2.2 Impacts of Urban Heat Island

Increased energy consumption:

Elevated summertime temperatures in cities increase energy demand for cooling. Research shows that electricity demand for cooling increases from 1.5–2.0% for every 1°F (0.6°C) increase in air temperatures, starting from 68 to 77°F (20 to

25°C), suggesting that 5–10% of community-wide demand for electricity is used to compensate for the heat island effect.

Urban heat islands increase overall electricity demand, as well as peak demand, which generally occurs on hot summer weekday afternoons, when offices and homes are running cooling systems, lights, and appliances. During extreme heat events, which are exacerbated by urban heat islands, the resulting demand for cooling can overload systems and require a utility to institute controlled, rolling brownouts or blackouts to avoid power outages.

1.2.2.1 Elevated Emissions of Air Pollutants and Greenhouse Gases

As described on top of, urban heat islands raise demand for electricity in summer. corporations that offer electricity usually consider fuel power plants to satisfy a lot of of this demand, that successively results in a rise in air pollutant and gas emissions. the first pollutants from power plants include:

- sulfur oxide (SO2)
- nitrogen oxides (NOx)
- particulate matter (PM)
- carbon oxide (CO) and
- mercury (Hg).

These pollutants are harmful to human health and conjointly contribute to complicated air quality issues like the formation of ground-level gas (smog), fine particulate, and acid precipitation. exaggerated use of fossil-fuel-powered plants additionally will increase emissions of greenhouse gases, like CO2 (CO2), that contribute to world global climate change.

In addition to their impact on energy-related emissions, elevated temperatures will directly increase the speed of ground-level gas formation. Ground-level gas is created when nox and volatile organic compounds (VOCs) react within the presence of daylight and weather condition. If all different variables are equal, like the extent of precursor emissions within the air and wind speed and direction, additional ground-level gas can form because the atmosphere becomes sunnier and warmer.

1.2.2.2 Compromised Human Health and Comfort

Increased daytime temperatures, reduced nighttime cooling, and higher pollution levels related to urban heat islands will have an effect on human health by

Copyright@SPA Bhopal

conducive to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.

Heat islands may exacerbate the impact of heat waves, that square measure periods of abnormally hot, and sometimes wet, weather. Sensitive populations, like youngsters, older adults, and people with existing health conditions, square measure at specific risk from these events.

Excessive heat events, or abrupt and dramatic temperature will increase, are significantly dangerous and might lead to above-average rates of mortality. The Centers for sickness control and interference estimates that from 1979–2003, excessive heat exposure contributed to quite eight,000 premature deaths within the u. s..3 This figure exceeds the amount of mortalities ensuing from hurricanes, lightning, tornadoes, floods, and earthquakes combined.

1.2.2.3 Impaired Water Quality

High pavement and rooftop surface temperatures will heat stormwater runoff. Tests have shown that pavements that area unit 100ºF (38°C) will elevate initial rain temperature from roughly 70ºF (21ºC) to over 95ºF (35ºC).4 This heated storm water usually becomes runoff, that drains into storm sewers and raises water temperatures because it is free into streams, rivers, ponds, and lakes.

Water temperature affects all aspects of aquatic life, particularly the metabolism and reproduction of the many aquatic species. rapid temperature changes in aquatic ecosystems ensuing from heat stormwater runoff may be significantly disagreeable, even fatal to aquatic life.

1.3 Significances

Increase of land surface temperature could be a prolonged period of overly hot weather that is in the midst of high humidness, particularly in oceanic climate countries. The term is applied both to routine weather variations and to extraordinary spells of heat, which can occur just one occasion a century. Severe heat waves have caused harmful crop failures, thousands of deaths from physiological state, and widespread power outages because of enlarged use of air conditioning. A heat wave is taken into account extreme weather and a danger because of heat and sunlight might overheat the human body.

Copyright@SPA Bhopal

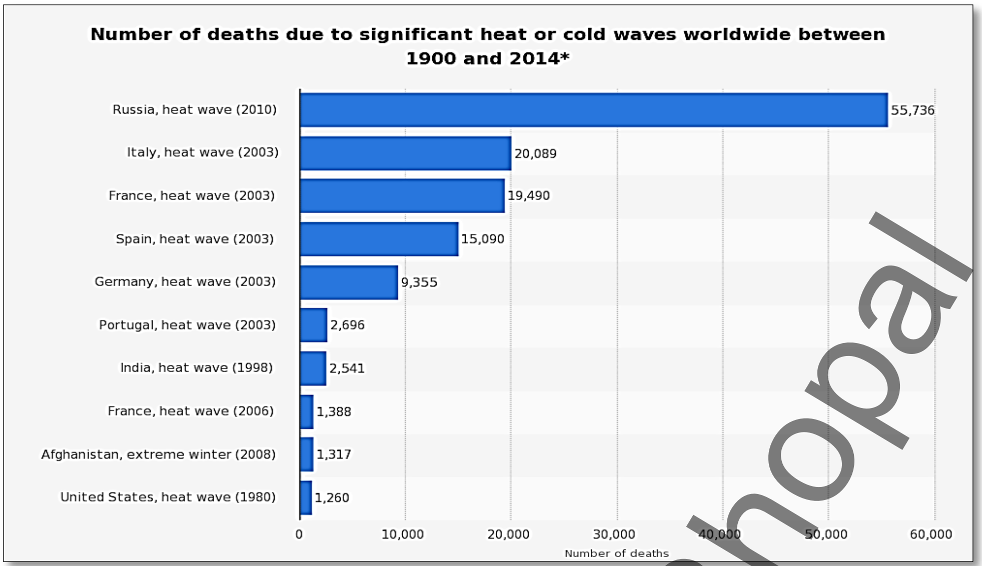


Figure 4: Deaths due to heat waves

Source: National Disaster Management Authority

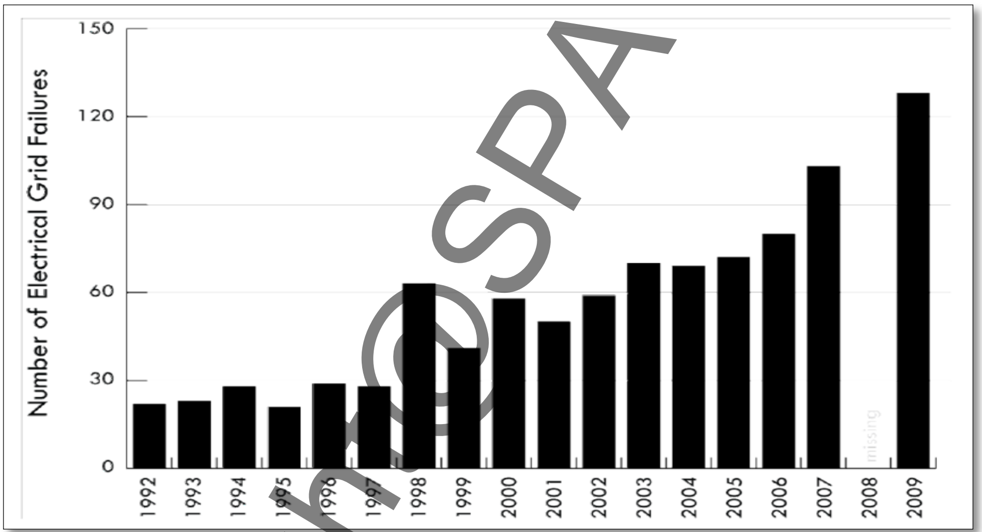


Figure 5: Electricity failure in summer

Source: North American Electric Reliability Corporation

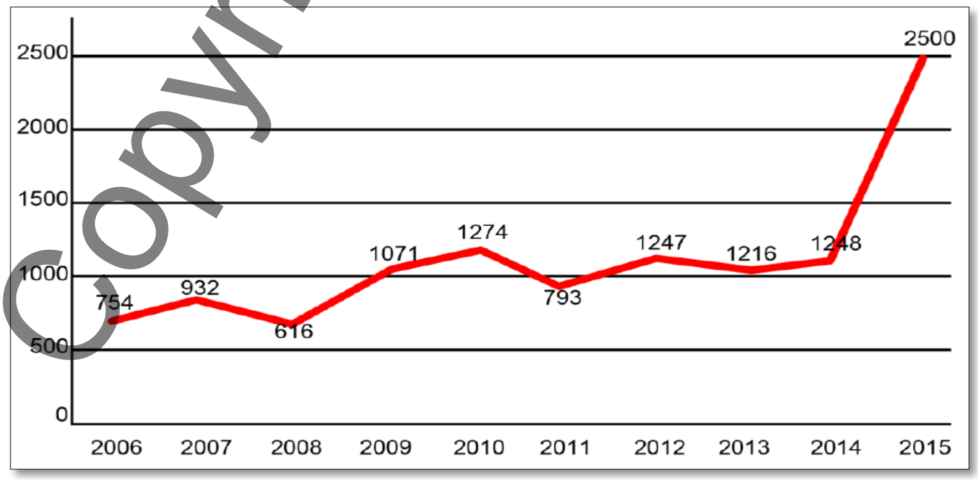


Figure 6: Deaths due to heat wave in India, 2001

Source: National Disaster Management Authority

Copyright@SPA Bhopal

1.4 Study Area

The proposed study incorporates the Guwahati Municipal Corporation Area of Assam as the study area. The hills and forests within this boundary have been taken into consideration for the present study. GMC covers an area of 216 km² under its jurisdiction and it is divided into 31 municipal wards.

Guwahati is the business hub and largest city of Assam and North East. It is also the biggest commercial, industrial, educational and health centre of the region. The urban area is around 262 sq.km and has a population of about 12 lakh (Census of India, 2011).

The city enjoys a sub-tropical with semi -dry summer & cold in winter climate. The annual rainfall ranges from 1500 mm to 2600 mm. The average humidity of the district is 75% and the maximum and minimum temperature ranges from 38.5° C during summer season and 7° C during winter season.

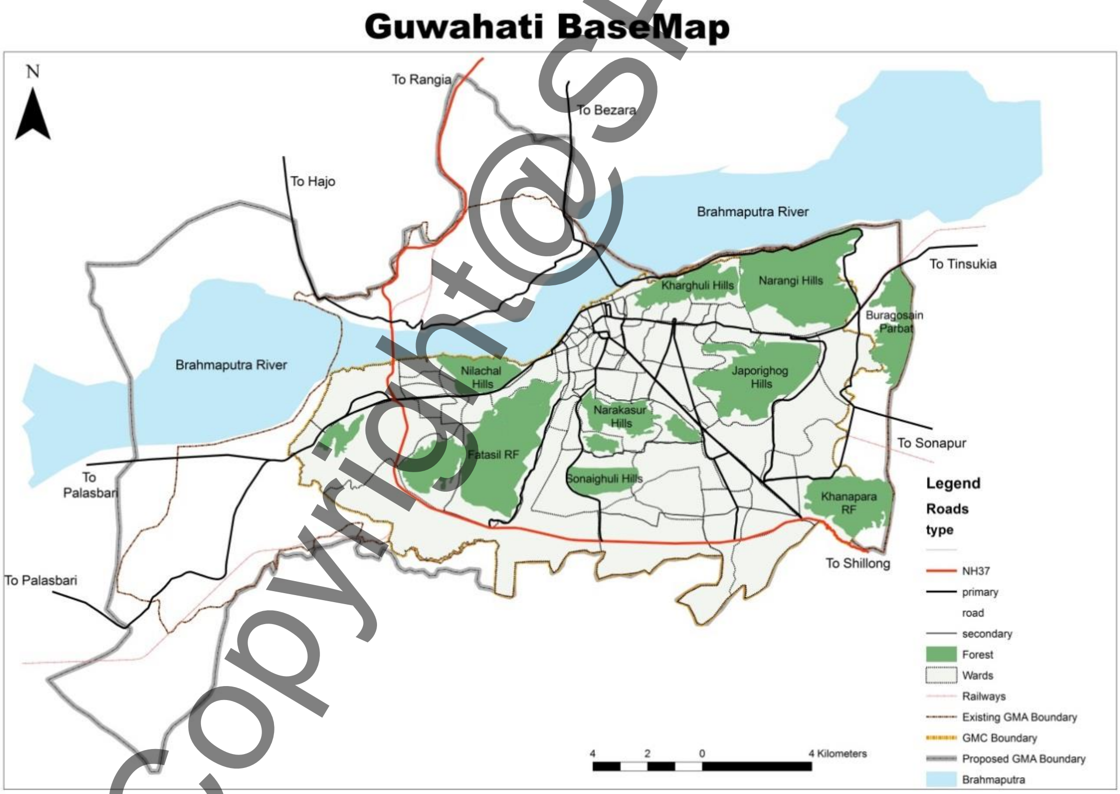


Figure 7: Guwahati Planning Area

Copyright@SPA Bhopal

1.5 Aim

Conservation of Urban Forests for reducing the impacts of heat island effect in an urban area.

1.6 Objectives

1. To explore the linkages of urban forest and UHI.
2. To analyse the existing condition of the urban forest and UHI effect in the study area
3. To identify and propose appropriate conservation measures for reducing UHI in the study area.

1.7 Outcome of the study

- Comprehension of connection amongst vegetation and to the land surface temperature and effects of urban heat island (UHI)
- Provide suitable mitigation measures to overcome the urban heat island (UHI) Impact.

1.8 Scope and limitation

- Un-accessibility of high definition pictures for mapping all the categories of UHI.
- Un-accessibility of Night-time satellite Imagery.

1.9 Study Methodology

The above objectives are achieved with the guide of a diagram, which depicts the framework of this study, so the case will be focused on the literature study which concerns with increasing temperature of Guwahati city and mapping of land surface temperature.

Study methodology is accomplished by literature review of objective 1, which relates to urban forest and UHI and analysing objective 3 for proposing strategic measures for implementation of the proposals.

Copyright@SPA Bhopal

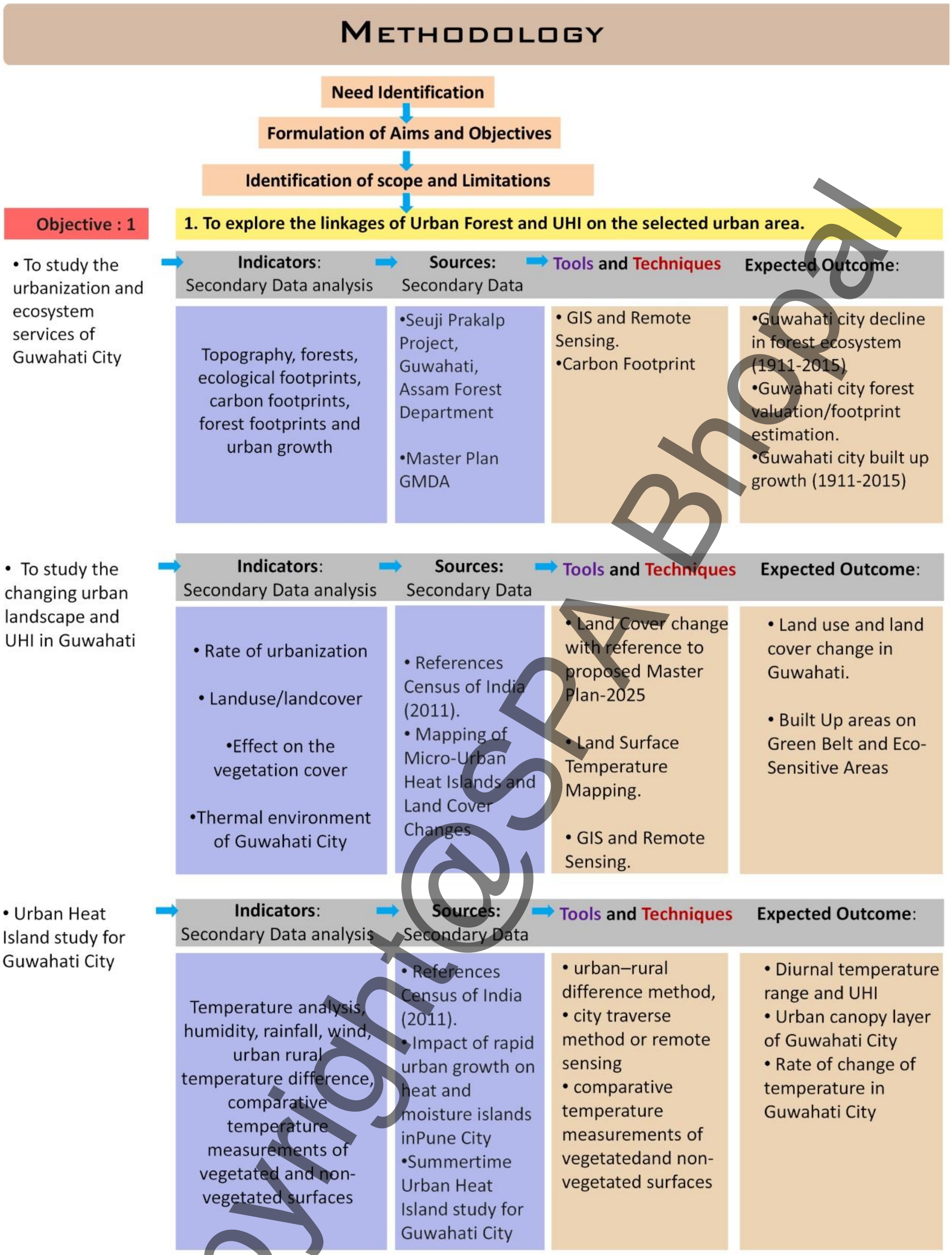


Figure 8 : Study Methodology Part 1

Copyright@SPA Bhopal

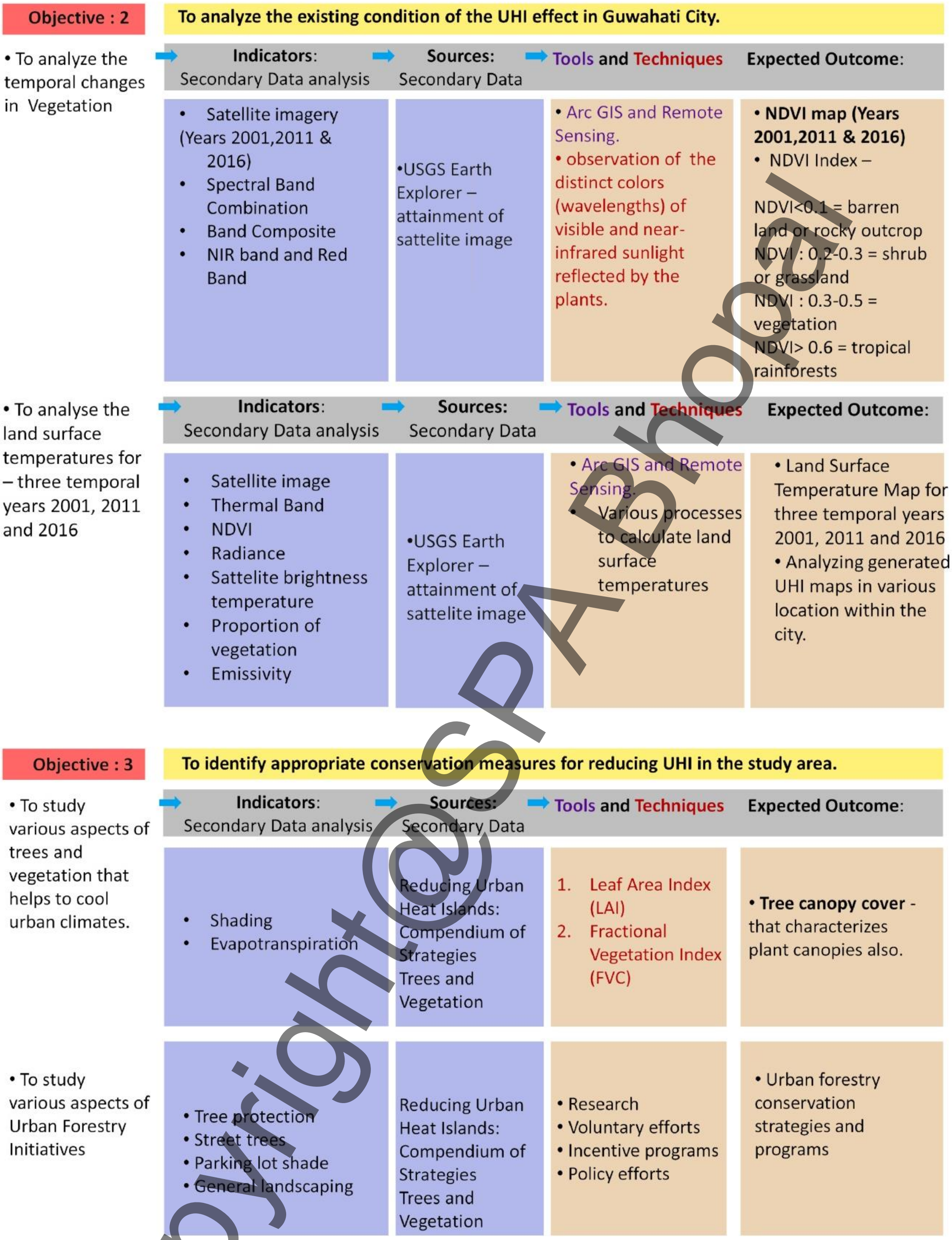


Figure 9: Study Methodology part 2

Copyright@SPA Bhopal

2. LITERATURE REVIEW

2.1 General characteristics of urban heat islands

Although there are many other factors that affect UHI, deforestation and conversion of waterproof permeable ground surfaces (which do not return water to the atmosphere and interrupt the climate cycle) are some of the major contributing factors that greatly contribute to UHI.

2.1.1 Role of Land Surfaces

Adjusting the urban atmosphere is the result of population convergence, the development of space beneath and above ground, and the alteration of Earth's surface materials, and alterations or changes in soil cover. (Skinner, 1999 and Kalnay 2003) estimated literature that in the last 50 years in the United States due to the Earth's surface coverage has increased to 0.27 ° C, which is at least twice the previously estimated temperature (Narisma, 2003). Also observed similar impacts of LULC coverage changes on Australian Earth's surface temperatures. Overall, these research studies explain that the Earth's surface temperature change of 1.67° C - 2.22 ° C in summer and LST case up to 5.7 ° C in case of winters in the urban area of the city compared with Surrounding countryside.

Similarly, other literature has also explained the impact of Urban heat islands (UHI) variations in terms of their thermal properties. For example, in northern China, the effects of garbage on soil cover (ie, conversion from arable crops and roads) to thermal capacity, local albedo and thermal conductivity of its surface, explained by (Zeng, 2002). Together, these literatures explain that building materials in cities and vegetation have a very important role in reducing surface temperature and absorption of solar radiation and again the energy-re-radiation of the atmosphere which results in an increase in the Elevation of surface temperature. Thermal, local albedo, and thermal conductivity impacts at local, national, regional and global levels.

In large cities such as London, Japan, Germany, Hong Kong and Hokkaido (Clarke 1972 Shudo 1997 Giridharan 2004 Blankenstein 2004 Chandler 1968) undergoes diversity, variety of composition, patterns and extension in the ground

Copyright@SPA Bhopal

space covers in urban areas. Revolutionary research Chandlers has been supported by work on local air change Louis-Missouri for Tucson, Arizona and in-depth research also verified Chandler's statements on the impact of soil waterproofing or the impact of paved surface and heat Residual from the heat island intensity and the heat of the urban surface, and to some extent all of the variables mentioned above contribute to increasing the Earth's surface temperature on the cities. Additionally, according to (Quattrochi 1998), the difference between urban and extra-urban environments is a function of the surface structure that randomly affects relatively different climates in these areas. Literature that isolates the impact of LC's heterogeneity on heat, energy and movement globally, regionally and locally in the climate system, which is mainly limited because about 70% of the homogeneous ocean surface. However, studies at various scales have shown collectively that cities in relation to their impact on both local and regional climates are not monolithic pavement surfaces (Quattrocchi, 1998).Therefore, the island of heat is basically the result of the variation of the surface of the earth affecting the overall thermal budget of urban space.

2.1.2 The Role of Water

Water is also another important factor for the UHI, since from its surface and surface atmosphere its movement is an important management effect of the urban heat island and as a result of that part of solar energy absorbed by the regenerator Surface in thermal energy. That is, the energy used to evaporate water or sublimate / smooth ice) cannot be used to increase the temperature as "sensitive heat". Since evaporation is only the process that is the element of each energy balance equation and therefore the water balance equation.

Many literature data on it have analysed the role of the hydrological cycle and localization balance, such as Israel, Mexico, and these studies recommend that the amount of energy involved in latent heat depends on the supply of water in that area to carry out the process Of evaporation.

2.1.3 The Role of Vegetation

The vegetation is another factor that corresponds to the thermal, humidity and surface of the radioactive soil to alter the temperature of the Earth's surface

Copyright@SPA Bhopal

(Weng, 2001) properties. While the climate has a leading management on the spatial distribution of the main vegetation varieties on a global scale, vegetation coverage affects both the regional and native, i.e. microclimate, by altering the physical characteristics of the soil and as a result plants remove water from the soil through sweating so vegetation has also proven to be economical to increase conversion of incoming energy into thermal energy and reduce heating surface, and as a result of this plant coverage may be difficult in urban development. It is recommended that cities set a target of 40% overall which is equivalent to 20 large trees per acre.

But, vegetation has its impact on native urban alternatives, such as the reduction of national requirements for heating and cooling construction, filtration of pollutants and rainwater management. For example, in the case of Atlanta, the loss of 60% of natural plant cover over the past 20 years has caused a $ 2 trillion increase in rainwater management.

In the centre, it was established that a 40% plant cover district might reduce SW outflow, considering 60% more than the neighbourhood, but not the trees. The increase in plant cover will have its positive effects on wind and rain models in urban areas that could affect their thermal properties. Very few analyses quantified these interrelations.

2.1.4 Urban Heat Islands, Climate Change, and Global Warming

Urban heat islands consult with the elevated temperatures in developed areas compared to additional rural surroundings. Urban heat islands square measure caused by development and therefore the changes in radiative and thermal properties of urban infrastructure likewise because the impacts buildings will wear the native micro-climate—for example tall buildings will slow the speed at that cities cool off in the dead of night. Heat islands square measure influenced by a city's geographic location and by native weather patterns, and their intensity changes on a daily and seasonal basis.

The warming that results from urban heat islands over little areas like cities is associate example of native temperature change. native climate changes ensuing from urban heat islands essentially disagree from international climate changes in this their effects square measure restricted to the native scale and reduce with distance from their supply. international climate changes, like those caused by will increase within the sun's intensity or gas concentrations, aren't regionally or regionally confined.

Copyright@SPA Bhopal

Climate amendment, broadly, refers to any important amendment in measures of climate (such as temperature, precipitation, or wind) lasting for associate extended amount (decades or longer). temperature change might result from:

- Natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun
- Natural processes within the climate system (e.g. changes in ocean circulation)
- Human activities that change the atmosphere's composition (e.g. burning fossil fuels) and the land surface (e.g. deforestation, reforestation, or urbanization).

The term temperature change is usually used interchangeably with the term warming, however consistent with the National Academy of Sciences, "the phrase 'climate change' is growing in most popular use to 'global warming' as a result of it helps convey that there square measure [other] changes additionally to rising temperatures."

Global warming is a median increase within the temperature of the atmosphere close to the Earth's surface and within the lowest layer of the atmosphere, which might contribute to changes in international climate patterns. Warming will occur from a range of causes, each natural and human elicited. In common usage, "global warming" typically refers to the warming which will occur as a results of exaggerated emissions of greenhouse gases from human activities. Warming may be thought of a part of international temperature change in conjunction with changes in precipitation, sea level, etc.

The impacts from urban heat islands and international temperature change (or international warming) square measure typically similar. for instance, some communities might expertise longer growing seasons attributable to either or each phenomena. Urban heat islands and international temperature change will each conjointly increase energy demand, significantly summer air-con demand, and associated pollution and gas emissions, betting on the electrical system power fuel combine.

Strategies to scale back urban heat islands—the focus of this document, Reducing Urban Heat Islands: Compendium of Strategies—produce multiple edges together with lowering surface and air temperatures, energy demand, pollution and gas emissions. Thus, advancing measures to mitigate urban heat islands conjointly helps to handle international temperature change.

Copyright@SPA Bhopal

2.2 Urban Heat Island and Urban Forests

Shade trees and smaller plants such as shrubs, vines, grasses, and ground cover, help cool the urban environment. Yet, many U.S. communities have lost trees and green space as they have grown. This change is not inevitable. Many communities can take advantage of existing space, such as grassy or barren areas, to increase their vegetative cover and reap multiple benefits. These are as per EPA Compendium of Strategies.

2.2.1 Possibilities to Expand the Use of Urban Trees and Vegetation

Most U.S. communities have opportunities to increase the use of trees and vegetation. As part of the U.S. Environmental Protection Agency's (EPA's) Urban Heat Island Pilot Project, the Lawrence Berkeley National Laboratory conducted analyses to estimate baseline land use and tree cover information for the pilot program cities. Figure 10 shows the percentage of vegetated and barren land cover in four of these urban areas. The high percentage of grass and barren land cover show the space potentially available for additional tree canopy cover. The statistics do not show the loss of dense vegetated cover as cities expand, however. For example, a 2005 report estimates that Houston lost 10 million trees per year from 1992 to 2000.

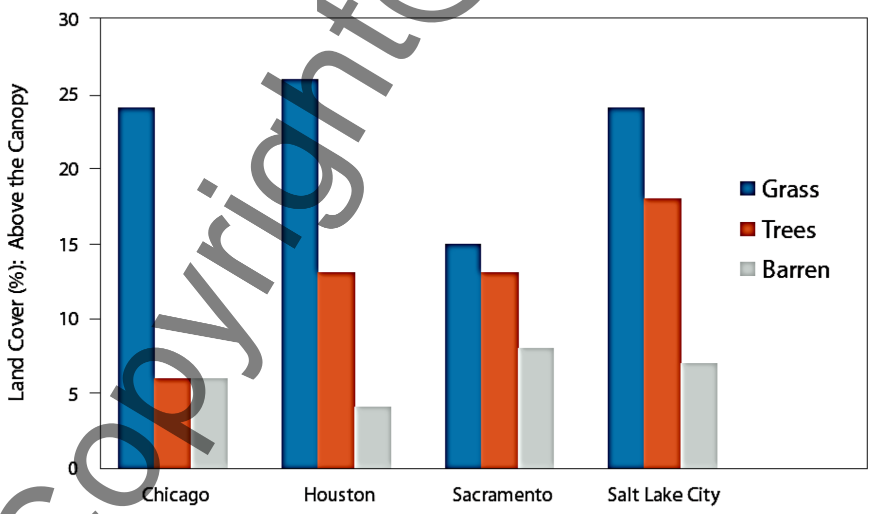


Figure 10: Land Cover Statistics for Various Cities
Source: EPA Compendium of Strategies

Copyright@SPA Bhopal

2.2.2 How It Works

Trees and all vegetative cover alleviate cooling of the urban climate through shading and evapotranspiration.

Shading:

Leaves and branches cut back the number of radiation that reaches the area below the cover of a tree or plant. the number of daylight transmitted through the cover varies based on plant species. within the time of year, usually ten to 30 % of the sun's energy reaches the area below a tree, with the rest being absorbed by leaves and used for chemical process, and a few being mirrored back to the atmosphere. In winter, the vary of daylight transmitted through a tree is far wider—10 to eighty percent—because evergreen and deciduous trees have totally different winter foliage, with deciduous trees losing their leaves and permitting additional daylight through. For Example: Chandigarh, one among the planned and trendy cities of India, has over thirty-five maximize its geographical region underneath urban forest, creating it one among the greenest cities of Indi (FSI 2009).

Copyright@SPA Bhopal

Figure 11: View of Chandigarh City
Source: RSPCB Occasional Paper

Figure 12: Tree canopies, such as the deciduous trees around this home in Virginia, can block much of the sunlight from reaching the ground or the building.
Source: EPA Compendium of Strategies

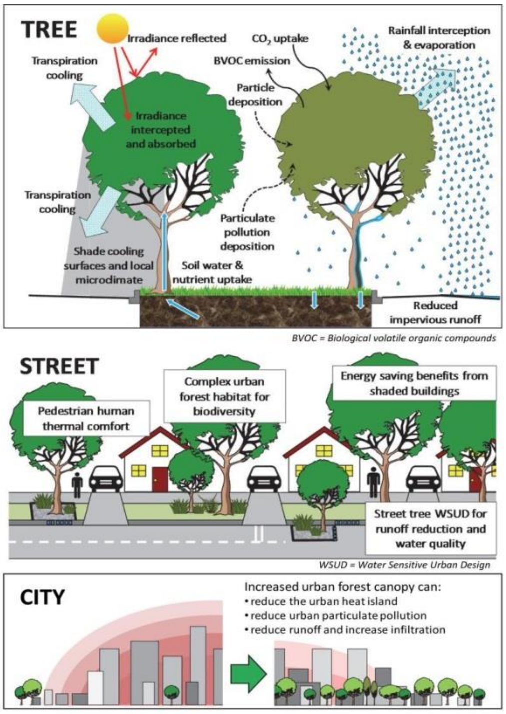
Shading reduces surface temperatures below the tree cover. These cooler surfaces, in turn, cut back the heat transmitted into buildings and also the atmosphere. as an example, a multi-month study measured most surface temperature reductions starting from 20 to 45ºF (11-25ºC) for walls and roofs at two buildings. Another study examined the results of vines on wall temperatures and located reductions of up to 36ºF (20ºC).5 a 3rd study found that tree shading reduces the temperatures inside parked cars by about 45ºF (25ºC).

Evapotranspiration:

Trees and vegetation absorb water through their roots and emit it through their leaves—this movement of water is termed "transpiration." an oversized tree, as an example, will transpire 40,000 gallons of water per year; associate degree acre of corn will transpire three,000 to 4,000 gallons every day.7 Evaporation, the conversion of water from a liquid to a gas, additionally happens from the soil around vegetation and from trees and vegetation as they intercept rain on leaves and alternative surfaces. Together, these processes square measure brought up as evapotranspiration.

Copyright@SPA Bhopal

Evapotranspiration cools the air by using heat from the air to evaporate water. Evapotranspiration, alone or in combination with shading, can help reduce peak summer air temperatures.



Trees and different massive vegetation also can serve as windbreaks or wind shields to scale back the wind speed within the neighbourhood of buildings.

Within the summer, the impacts are positive and negative. Within the time of year, reducing wind speeds, significantly cold north winds, will offer substantial energy edges.

Figure 13: Trees and Vegetation draft in context to urban heat island
Source: EPA Compendium of Strategies

Various studies have measured the following reductions:

- Peak air temperatures in tree groves that are 9ºF (5ºC) cooler than over open terrain.
- Air temperatures over irrigated agricultural
- Fields that are 6ºF (3ºC) cooler than air over bare ground.
- Suburban areas with mature trees that are 4 to 6ºF (2 to 3ºC) cooler than new suburbs without trees.
- Temperatures over grass sports fields that are 2 to 4ºF (1 to 2ºC) cooler than over bordering areas.

Copyright@SPA Bhopal

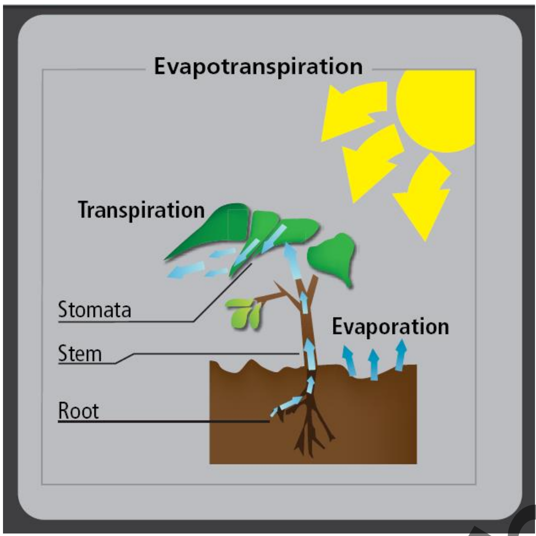


Figure 14: Plants take water from the ground through their roots and emit it through their leaves, a process known as transpiration. Water can also evaporate from tree surfaces, such as the stalk, or surrounding soil.

Source: EPA Compendium of Strategies

Copyright@SPA Bhopal

2.2.3 Trees and Vegetation in the Urban Landscape

Trees and vegetation are most helpful as a mitigation strategy once planted in strategic locations around buildings. Researchers have found that planting deciduous species to the west is often best for cooling a building, particularly if these trees shade windows and a part of the building's roof. Shading the side of a structure additionally reduces air con demand.

Planting trees to the south typically lowers season energy demand, however should be done fastidiously. reckoning on the trees, the building's height, and therefore the distance between the trees and a building, trees could also be prejudicious to associate degree energy potency strategy if they block helpful alternative energy within the winter, once the sun is low within the sky, while not providing abundant shade throughout the summer, once the sun is high within the sky.

Shading pavement in parking tons and on streets are often a good thanks to facilitate cool a community. Trees are often planted around perimeters and in medians within parking tons or on the length of streets. Strategically placed shade trees can also profit playgrounds, schoolyards, ball fields, and similar open areas.

Trees are the sole vegetation possibility. There are a unit several areas wherever trees either do not work or grow too slowly to be effective over the short term, during which case vines may match higher. Vines want less soil and area and grow terribly quickly. Vines full-grown on the side of a building, as an example, can shade the outside wall and scale back its surface temperature, so reducing heat gain within the building. The vines can give some air cooling advantages through evapotranspiration further.

Figure 15: Picking the right trees and putting them in the right location will maximize their ability to shade buildings and block winds throughout the year.
Source: EPA Compendium of Strategies

Copyright@SPA Bhopal

2.2.4 Benefits and Costs

The use of trees and vegetation within the urban setting brings several advantages, as well as lower energy use, reduced pollution and greenhouse emission emissions, protection from harmful exposure to ultraviolet (UV) rays, attenuated storm water runoff, potential reduced pavement maintenance, and different quality-of-life advantages. At the same time, communities should additionally think about the prices of associate degree urban biology program and any potential negative impacts of accelerating tree and vegetation cover. The subsequent sections address these advantages and prices in additional detail. Section half dozen of this chapter summarizes software system tools that calculate the vary of potential advantages from urban tree and vegetation initiatives.

2.2.4.1 Benefits

Reduced Energy Use - Trees and vegetation that offer direct shading scale back energy required to cool down buildings. Advantages vary supported the orientation and size of the plantings, further as their distance from a building. Giant trees planted near the side of a building can typically offer larger cooling energy savings than alternative plants.

The examples below from a variety of studies highlight cooling and year-round energy savings from trees and vegetation.

- Joint studies by the Lawrence Berkeley National Laboratory (LBNL) and also the state capital Municipal Utility District (SMUD) placed varied numbers of trees around homes to shade windows so measured the buildings' energy use.12,13 The cooling energy savings ranged between 7 and 47 percent and were greatest once trees were planted to the west and southwest of buildings.

- A Agriculture Forest Service study investigated the energy savings ensuing from SMUD's residential tree planting program. This study enclosed over 250 program participants within the capital of California, California, area, and calculable the impact of recent shade trees planted around homes. a median of three new trees were planted among ten feet (3 m) of every house.15 Annual cooling energy savings were 1 % per tree, and annual heating energy use slashed by virtually 2 % per tree. The trees provided web winter edges as a result of the positive wind shielding impact outweighed the negative impact of superimposed shade.

- Another LBNL study simulated the results of trees on homes in numerous communities throughout the us. forward one tree was planted to the west and another to the south of a house, the model expected that a 20-percent tree cover over the house would lead to annual cooling savings of 8 to 18 percent and annual heating savings of two to 8 percent.16 though this explicit model enclosed edges from trees planted to the south of a building, consultants typically recommend planting to the west and east of buildings, taking care once planting to the south to avoid block desired star heat gain within the winter.

Copyright@SPA Bhopal

Reduced Air Pollution and Greenhouse Gas Emissions –

In addition to saving energy, the use of trees and vegetation as a mitigation strategy can provide air quality and greenhouse gas benefits:

- Leaves remove various pollutants from the air, referred to as “dry deposition”
- Shade trees reduce evaporative emissions from parked vehicles
- Trees and vegetation remove and store carbon
- Trees and vegetation reduce greenhouse Gas emissions from power plants by reducing energy demand.

Researchers have investigated the potential for expanding urban tree and vegetative cover to address air quality concerns, such as ground-level ozone. One study predicted that increasing the urban canopy of New York City by 10 percent could lower ground-level ozone by about 3 percent, which is significant, particularly in places needing to decrease emissions to meet air quality standards for this pollutant.

Pollutant Removal through Dry Deposition.

Plants usually take up aerosolised pollutants, primarily through leaf stomata, that then react with water within the plant to create acids and different chemicals Plants may intercept material as wind currents blow particulates into contact with the plants’ surfaces. Some particulates are absorbed into the plant whereas others adhere to the surface, wherever they will be suspended into the atmosphere by winds or washed off by rain to the soil below. These processes will scale back numerous pollutants found within the urban atmosphere, together with material (PM), N oxides (NOX), gas (SO2), carbon monoxide gas (CO), and ground-level gas (O3).

Various studies have documented however, urban trees will scale back pollutants. A 2006 study estimated total annual air waste product removal by urban trees within the United States at 784,000 tons, with a price of $3.8 billion. The study targeted solely on deposition of ground-level ozone, PM less than 10 microns in diameter (PM10), nitrogen dioxide (NO2), SO2, and CO. Although the estimated changes in local ambient air quality were modest, typically less than 1 percent, the study noted that additional benefits would be gained if urban temperature and energy impacts from trees and vegetation were also included.

Copyright@SPA Bhopal

Reduced Evaporative Emissions. Tree shade will keep parked cars—particularly their gas tanks—cooler, that lower evaporative emissions of volatile organic compounds (VOCs), a vital precursor pollutant within the formation of ground level gas. Most massive urban areas have a good range of management programs to scale back these emissions, and tree-shading programs may be a part of those ways. as an example, one analysis expected that light vehicle evaporative VOC emission rates throughout state capital County can be reduced by 2 percent per day if the community accumulated the tree cover over parking tons from 8 to 50 percent.

Carbon Storage and Sequestration. As trees grow, they take away carbon from the atmosphere and store, or sequester, it. As trees die or deposit litter and dust on the bottom, carbon is discharged to the atmosphere or transferred to the soil. The net result of this carbon cycle could be a substantial level of carbon storage in trees, vegetation, and soils. The net rate of carbon sequestered by urban trees within the continental United States in 2005 is estimated to be around twenty four million tons per annum (88.5 million tons).

Improved Human Health. By reducing air pollution, trees and vegetation lower the negative health consequences of poor air quality. In addition, similar to the benefits of cool roofs, shade trees can reduce heat gain in buildings, which can help lower indoor air temperatures and minimize the health impacts from summertime heat waves.

A third health benefit from trees and vegetation involves, reducing direct exposure to UV rays. The sun's UV rays can have adverse health effects on the skin and eyes. High levels of long-term exposure to UV rays are linked to skin cancer. The shade provided by dense tree canopies can help to lower UV exposure, although this should not be considered a primary preventive measure.

Enhanced Stormwater Management and Water Quality. Urban forests, vegetation, and soils will cut back stormwater runoff and adverse impacts to water resources. Trees and vegetation intercept precipitation, and therefore the exposed soils related to plants absorb water that may be returned to water systems or employed by plants. Precipitation interception works best throughout tiny rain events, that account for many precipitation. With massive rainfalls that

Copyright@SPA Bhopal

continue on the far side an explicit threshold, vegetation begins to lose its ability to intercept water. Further retention of rainwater varies the extent and nature of the urban forest community. Throughout the summer, with leafy trees, evergreens and conifers in places have been found to intercept over 35% of the precipitations that hit them.

Reduced Pavement Maintenance Costs.

Tree shade can cut back the deterioration of street pavement. One field study compared pavement condition knowledge supported completely different amounts of tree shade.30 The study found that slurry resurfacing prices on a residential street can be reduced by about 15 to 60 %, counting on the sort of shade trees used. though the particular prices and advantages can vary based on native conditions and paving practices, the study suggests that pavement maintenance advantages are another area to think about in evaluating the potential advantages of a street tree program.

Enhanced Quality of Life. Trees and vegetation will give a variety of quality-of life advantages. Adding trees and vegetation to urban parks, streets, parking heaps, or roofs will give surroundings for birds, insects, and different living things. A well-placed row of trees and shrubs will cut back urban noise by 3 to 5 decibels, while wide, dense belts of mature trees will cut back noise by doubly that quantity, which might resemble noise reduction from effective main road barriers. Urban trees and vegetation are coupled to reduced crime,32 accrued property values, and different psychological and social advantages that facilitate decrease stress and aggressive behaviour.

2.2.4.2 Costs

The primary costs associated with planting and maintaining trees or various vegetation embrace buying materials, initial planting, and on-going maintenance like pruning, pest and welfare management, and irrigation. Various costs embrace program administration, lawsuits and liability, root harm, and stump removal. However, as the following section indicates, the benefits of urban trees nearly perpetually outweigh these costs.

Copyright@SPA Bhopal

Benefit-Cost Considerations

To help communities confirm the worth of investments in urban trees and vegetation, teams have developed tools to quantify the worth of trees (see Section 6). These tools consider the total range of urban forest advantages and prices, like energy savings in buildings, air quality enhancements, storm water retention, property worth will increase, and also the worth of mulch or hardwood recovered throughout tree pruning and removal. Some tools additionally track greenhouse emission emissions or greenhouse gas reduction. The tools weigh these advantages against the prices of planting, pruning, watering, and different maintenance throughout a tree's life. In calculating benefits, it's vital to notice that trees grow slowly, therefore it should take as long as 5 years for a few advantages from trees, like energy savings, to require impact. When 15 years, an average tree typically has matured enough to supply the total range of advantages.

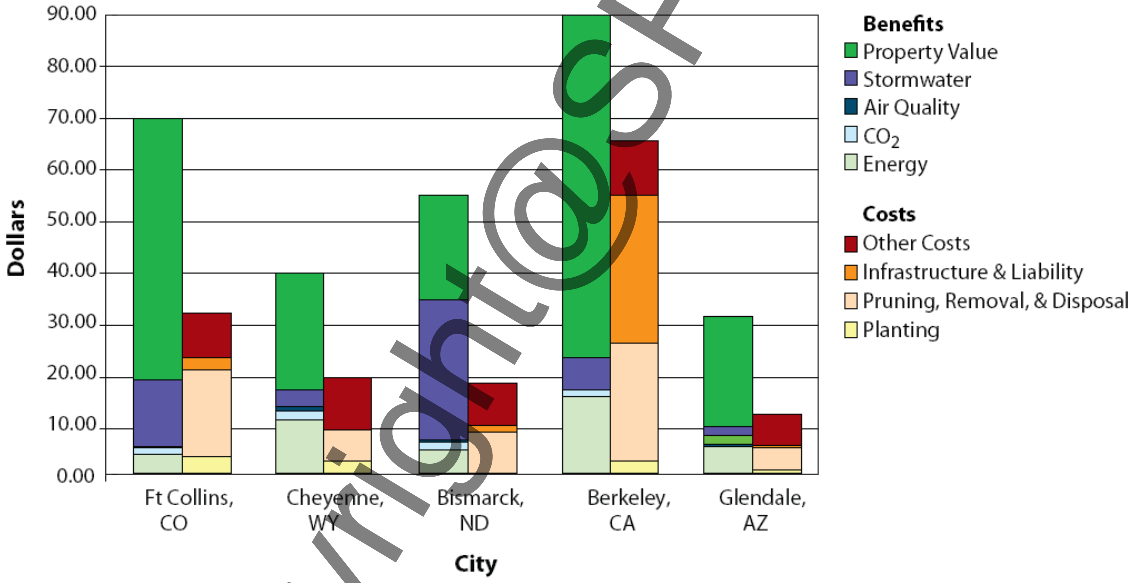


Figure 16: Total Annual Benefits versus Costs (Per Tree)
Soure: EPA Compendium of Strategies

2.3 Other Factors to Consider

2.3.1 Planting Considerations

At Buildings

To reduce temperatures and cooling energy desires, trees planted for summer shade ought to shelter western and eastern windows and walls and have branches high enough to take care of views or breezes round the windows.

Copyright@SPA Bhopal

In an urban setting, neighboring buildings, driveways, fences, and alternative options will build it difficult to follow these tips for planting trees. the subsequent are the most effective use of trees and vegetation:

- Optimize the shade coverage from trees planted in less favorable locations by pruning tree branches to a height that blocks the summer sun, however lets the winter sun through.
- Use bushes, shrubs, or vines to shade windows and walls in places wherever trees will not match. Shrubs and bushes will shade windows or walls without growing large or tall. Vines grow terribly quickly on vertical or overhead trellises and might be utilized in places with very little accessible area or soil.
- Consider a green or garden roof additionally to landscaping around a building

Paved Surfaces

Trees and huge shrubbery can also shade pavements to cut back their surface temperatures.

Planting trees at regular intervals of twenty to forty feet (6 to twelve meters) on either side of a street (see Figure 10), likewise as on medians may be a common way to offer valuable shading. Trees may shade the perimeter and interior area of parking heaps. though end islands are usually used for planting trees inside parking heaps, planting strips that run the length of a parking bay will offer larger ton shading.

Some communities have ordinances that need a particular share of tree shade in parking lots. as an example, Davis, California, and capital of California each need 50 % of the {parking area|parking ton|car park|park|lot} to be shaded inside fifteen years once the lot is made.

Permeable grass pavers may offer a number of the heat reduction advantages of larger plantings without absorbing area. Grass pavers will replace ancient pavements in low-traffic parking areas, pedestrian walkways, driveways, patios, fire lanes, and alternative paved areas that are rarely used for vehicu- lar traffic. Pavers are sometimes prefab lattice structures fabricated from concrete, plastic, or metal that's specifically designed to let water drain to the soil below whereas they support pedestrians and lightweight traffic masses.

Copyright@SPA Bhopal

2.3.2 Maintenance

Education, skill, and commitment are necessary for planting and maintaining an aesthetically, environmentally, and structurally effective urban landscape. By adhering to sensible landscape style and maintenance practices, several common issues could also be avoided. Native cooperative extension offices will offer further data on soil conditions and different necessary concerns. Also, native planting guides are typically obtainable from urban biological science agencies, utility firms, arboriculture organizations, and plant nurseries. the subsequent are steps to think about once maintaining trees in associate geographic region, serving to vegetation grow quicker and live a extended, healthier, and a lot of productive life.

- Choose the proper plants. As a result of trees and vegetation that are hardy enough to survive in a specific climate need very little maintenance, communities would possibly wish to start out by considering native species. Alternative characteristics to think about include:

– The vegetation has projected height and cover spread
– Size and growth habits of the roots
– The plant's sun, soil, water, and temperature needs
– The sorts of leaves, berries, and flowers it produces
– Allergens and biogenic emissions, which will contribute to ground-level ozone formation.

2.3.3 Safety

The use of trees and vegetation around buildings will increase fireplace risks. Communities, particularly those in fireplace prone areas, will realize data on tree choice and placement that minimizes those risks:

- The National Interagency fireplace Centre offers suggestions for tree placement and landscape maintenance to avoid losses to wild land fires.
- The Agriculture Department Forest Service helps owners verify and minimize fireplace risk from landscaping via an interactive, graphical tool.

2.3.4 Urban Forestry Initiatives

Communities can use varied mechanisms to extend their vegetative cover. These efforts embody forming public-private partnerships to encourage voluntary action

Copyright@SPA Bhopal

within the personal sector to enacting ordinances. As mentioned within the chapter “Heat Island Reduction Activities,” communities have already got developed a good range of voluntary and policy approaches for mistreatment urban trees and vegetation.

Tree planting programs, used throughout several communities, usually involve collaboration with non-profit teams and electrical utilities. Some states fund urban forestry program initiatives dedicated to addressing urban heat islands and alternative community issues.

In addition, communities have enacted varied ordinances to foster the urban forest, together with those targeted on:

- Tree protection
- Street trees
- Parking lot shade
- General landscaping

2.4 Measurement Techniques of Various Forms of UHI

2.4.1 Atmospheric Urban Heat Islands

Warmer air in urban areas compared to cooler air in nearby rural surroundings defines atmospherically urban heat islands. Specialists typically divide these heat islands into two different types:

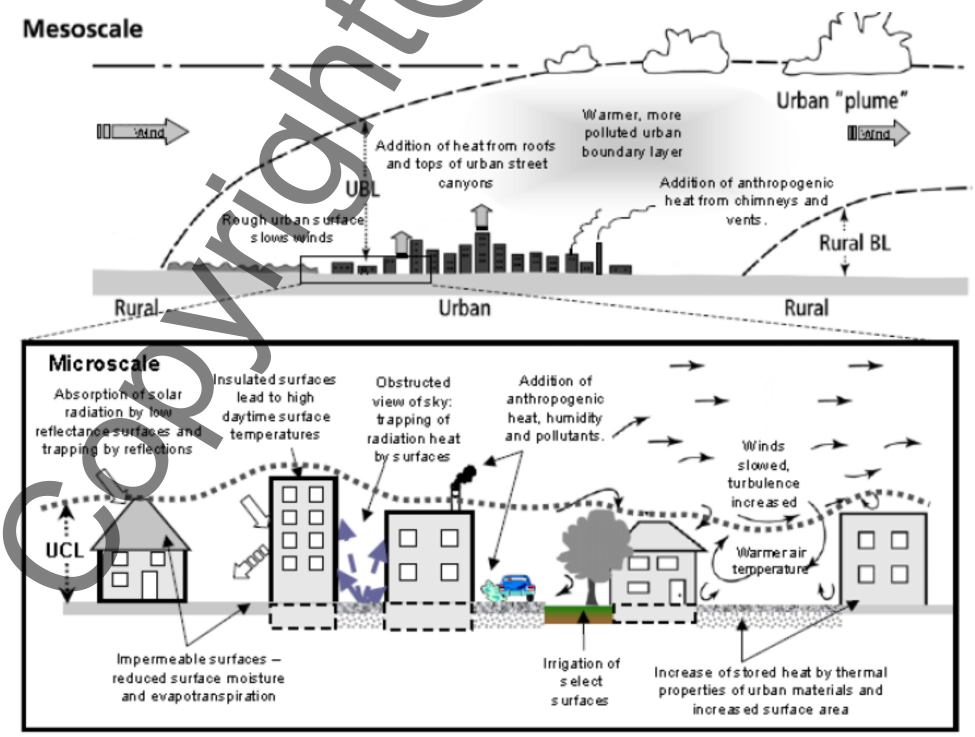


Figure 17: Different Types of UHI
Source: UETAE, IIT Mumbai

Copyright@SPA Bhopal

Canopy layer urban heat island

Canopy layer urban heat islands exist within the layer of air wherever people live, from the ground to below the tops of trees and roofs.

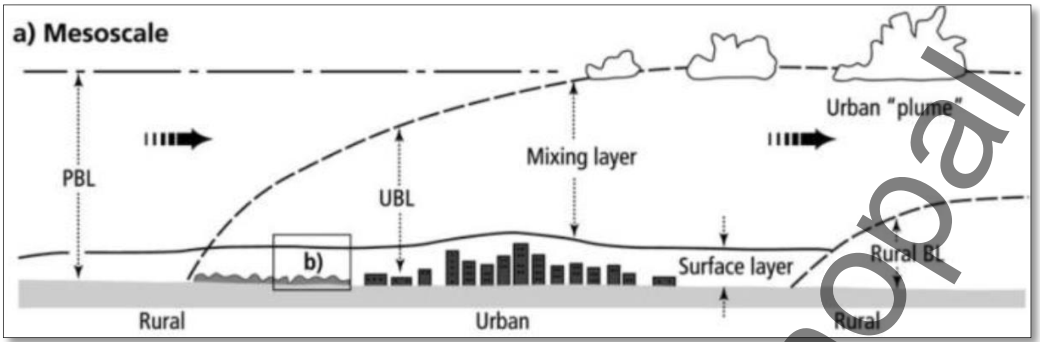


Figure 18: Different Types of UHI
Source: UETAE, IIT Mumbai

Boundary Layer Urban Heat Island

Boundary layer urban heat islands begin from the upper side and treetop level and extend up to the purpose wherever urban landscapes no longer influence the atmosphere. This region generally extends no more than one mile (1.5 km) from the surface.

2.4.2 Studying the Effect of UHI

The earlier studies used the unaltered activity using the knowledge procured by the earth science data that ground-based observations taken from are mounted Thermometer networks with the limitation that it cannot give the continual info of the surface for the regional study. With the appearance of thermal remote sensing technology, remote observation of UHIs became possible using satellite and aircraft platforms that have provided new avenues for the observation of UHIs and the study of their feet through the mix of thermal remote sensing and concrete micrometeorology. (Voogt and Oke, 2003b).

Copyright@SPA Bhopal

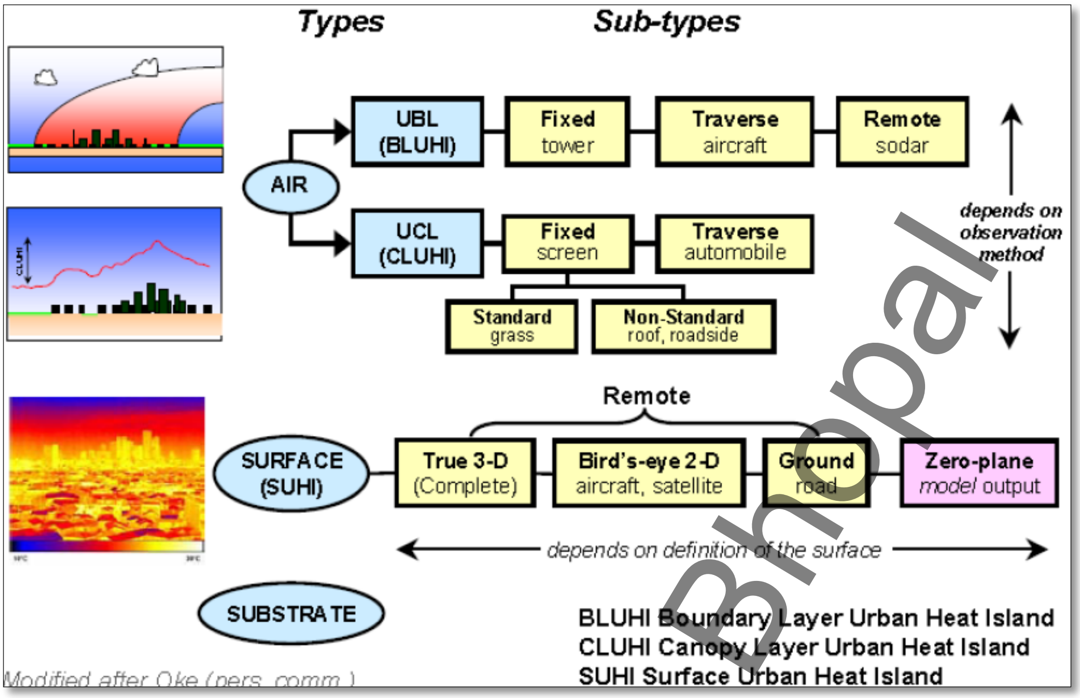


Figure 19: Measurement Techniques of different types of UHI
Source: UETAE, IIT Mumbai

2.4.2.1 Canopy Layer UHI Measurement

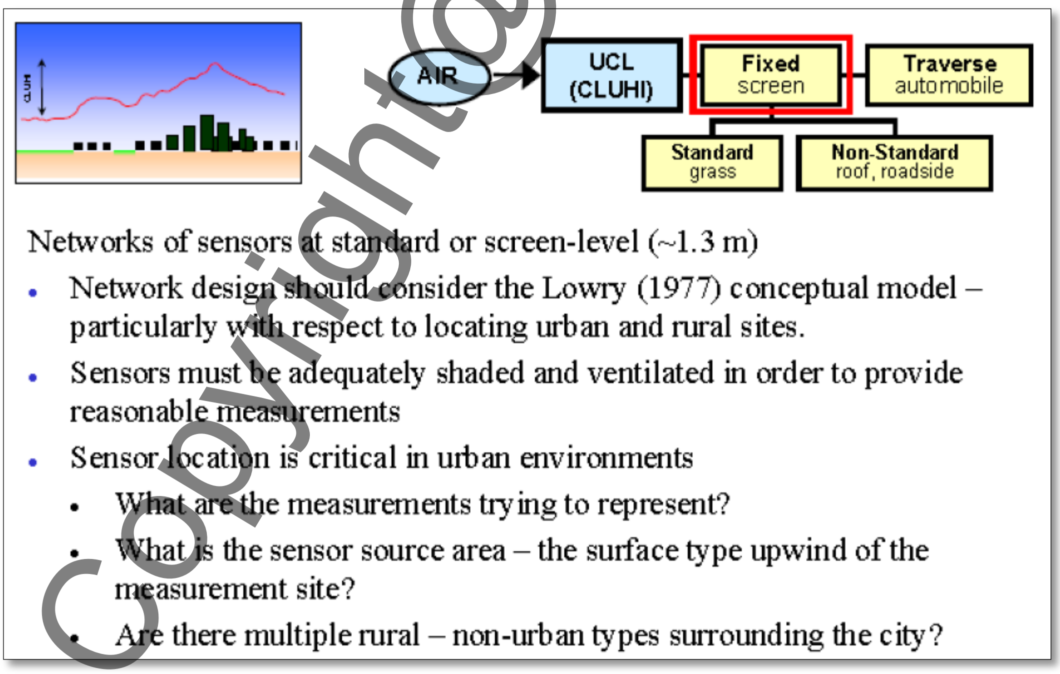


Figure 20: Process for canopy layer UHI measurement
Source: WMO / Oke (2006)

Copyright@SPA Bhopal

2.4.2.2 Surface UHI Measurements

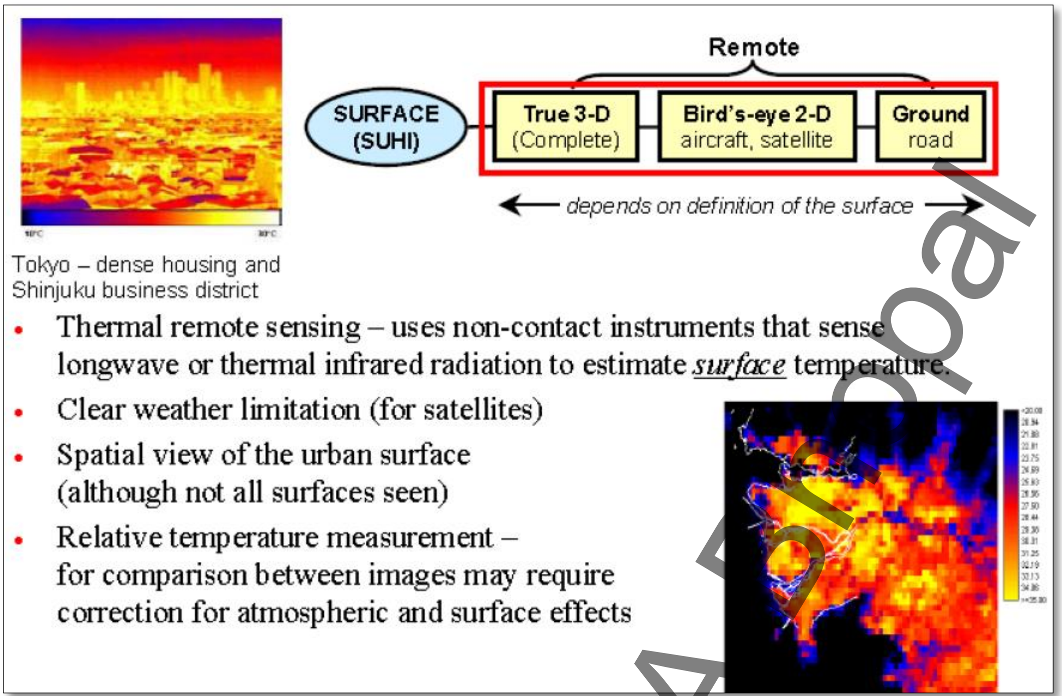


Figure 21: Process for surface UHI measurements
Source: WMO / Oke (2006)

2.4.3 Platforms for thermal remote sensing for urban areas

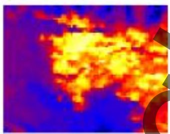
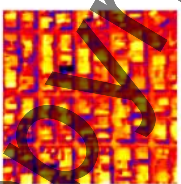
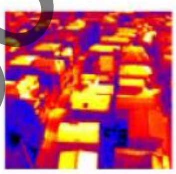
Platform	Sample Image	Comments
Satellite		Extensive spatial coverage; temporal coverage may be limited. Impacted by weather and atmosphere. Spatial resolution may be limited.
Aircraft		Higher resolution, more detail of urban features. High cost, irregular coverage. Non-standardized product.
Ground-based		May provide unique perspective of some urban features. Possibility of high temporal resolution, can avoid corrections due to atmospheric influence.

Figure 22: Platforms for thermal Remote Sensing
Source: WMO / Oke (2006)

Copyright@SPA Bhopal

2.5 Case Studies

2.5.1 International Research

The table below provides additional resources on urban heat island formation, measurement, and impacts. The key international papers and journals give the general information of the journals and publications with its web link given in table No.1

NAME	DESCRIPTION	WEBLINK
General Information		
Heat Island website of EPA	Through this web site, EPA provides background data, publications, reports, access to national webcasts, a information of urban heat island activities, and links to alternative resources to assist communities scale back urban heat islands.	<www.epa.gov/ heatisland>
International Association for Urban Climate (IAUC)	This international web site is the main forum during which urban climatologists communicate. Urban climate resources, together with a bimonthly report, and data on approaching conferences may be found here.	<www.urban-climate.org>
Lawrence Berkeley National Laborator (LBNL) He Island Grou	LBNL provides background data on urban heat islands and their impacts through this web site. It additionally presents a number of the impacts heat island reduction strategies will wear temperature, energy consumption, and air quality.	<http://eetd.lbl.gov/ HeatIslan>
National Center of Excellence - SMART Innovations for Urban Climate and Energy	Arizona State University's National Center of Excellence collaborates with industry and government to analysis and develops technologies to scale back urban heat islands, particularly in desert climates. Its web site provides background information on urban heat islands.	<www.asusmart.com urbanclimate.php>
Urban Heat Islands: Hotter Cities	Presents solution to mitigate UHI	<www.actionbioscien org/environment/voo html>

Copyright@SPA Bhopal

Measuring heat islands and their impacts		
National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey Landsat Program	The Landsat program is a series of Earth-observing satellites accustomed acquire pictures of the Earth's land surface and encompassing coastal regions. These pictures give data from which researchers can derive surface temperatures and judge urban heat islands.	<http://landsat.gsfc.nasa.gov/>
National Weather Service	The National Weather Service may be a source for air temperature measurements, climate and weather models, and past and future climate predictions. the location conjointly has links to excessive heat outlooks, fatality statistics, historic knowledge on major heat waves, drought data, and recommendation on a way to minimize the health risks of heat waves.	<www.nws.noaa.gov/>

Table 1: Urban Heat Island Resources and International Research
Source: EPA Compendium of Strategies

2.5.2 Research in India

Author	Year	Area	Methodology
S. Sundersingh et al [5]	1991	(Chennai)	Mobile Observations
Deosthali et al [6]	1999	Pune	Mobile Observations
Kiran Chand et al [7]	2005	Hyderabad	LST
M. Lei et al [8]	2008	Mumbai	Simulated System(RAMS)
Devadas et al [9]	2009	Chennai	Mobile Observations
Rose et al [10]	2010	Chennai	Thermal Comfort Index
T. Ramachandran et al [11]	2010	Bangalore	LST
M. Mohan et al [12]	2012	Delhi	Stationary measurements and Remote Sensing(LST)
Bothrakur et al [13]	2012	Guwahati	LST
Arathyram et al [14]	2012	Western Corridor	LST
D. Bajaj et al [15]	2012	Ahmedabad	LST
G. Thomas et al [16]	2014	Kochi	Local climate zone (LCZ) classification based method
R. Agarwal et al [17]	2014	Nagpur	LST
Rajeshwari et al [18]	2014	Dindigul	LST

Table 2: Summary of the UHI Case Studies Conducted In India
Source: International Journal of Multidisciplinary and Scientific Emerging Research

Copyright@SPA Bhopal

3. CITY PROFILE

3.1 Overview

The study area comprises of Guwahati City whivh is located in the northeastern region of India and situated between 26°5' to 26°13' N latitude and 91°35' to 91°52' E longitude, on the banks of the river Brahmaputra. For the study, area under Guwahati Municipal Corporation(GMC) was considered which comes under the jurisdiction of Guwahati Metropolitan Development Authority (GMDA).
GMDA extends over an area of 262 sq.km and the area within GMC comes at an area of 216 sq.km.

3.2 Topography

The topography of the city is undulating variable in elevation from 49.5 m to 55.5 m higher than Mean sea level (MSL). The land is interspersed with an oversized range of hills. The central a part of the city has little hillocks specifically Sarania hill (193 m), Nabagrah hill (217 m), Nilanchal hill (193 m) and Chunsali hill (293 m). The Buragosain Parbat within the East and the hills of Rani and Garbhanga within the south form the most important hill formations of the city. These hills create contiguous formations with the hills of Meghalaya. There are total of eighteen hills within the town. The total reported area covered by hills in GMDA area is 68.81 sq.km. The existence of forests within the city is essentially confined to the Hill areas.

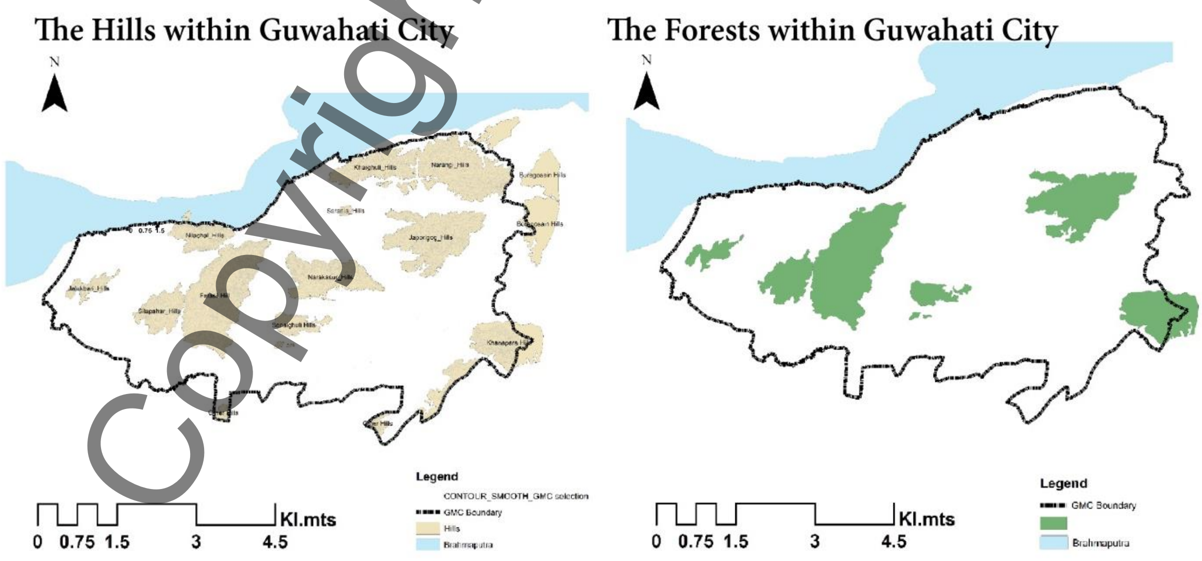


Figure 23: The Hills and Forests within the GMCA area
Source: Yadav and Barua, J Ecosys Ecograph

Copyright@SPA Bhopal

3.3 The Forests of Guwahati

The hills are mostly covered, barring the rocky outcrops, with forests of various formations ranging from Sal forests, mixed moist deciduous Forests, Evergreen Forest, Bamboo Brakes and Secondary Scrub Forests. The forests in and round the city fall within the jurisdiction of the Kamrup (East) Forest Division. The management of the forest tracts is carried out as per prescriptions of the operating Plans. As per the working plans, there are a complete of 14 Reserved Forests (RF) among and on the immediate bound of the city area. the overall RF area involves 33342.55 Ha comprising of Rani RF, Maliata RF, Agiathuri Hill RF, Garbhanga RF, Garbhanga first Addition, Fatasil RF, Amchang RF, SouthAmchang RF, Hengrabari RF, Gotanagar RF, Sarania RF, South Kalapahar RF, and Jalukbari RF. The forests on the southern fringe of the city have Sal formations mixed with patches of Evergreen and bamboo formations. The forests within the city show moist Mixed Deciduous forest formations. Where soil is shallow and poor, scrubby growth of bamboo and scrub occur.

The operating set up records over the years show that the density of the forests has more and more declined. Existing Unclassed State Forests are being jhumed extensively, are and being rapidly preoccupied for cultivation by immigrants from Bengal as well because the indigenous folks and are deteriorating rapidly underneath uncontrolled exploitation of forest turn out given liberal to settlement holders and by grazing.

It is, therefore, only a matter of time before this type of forest is drained." Increase in population is one among the most important parameters resulting in forest depletion.The current analysis has known nine landscape elements that are out there inside the notified forest boundaries of GMC area.

In addition, the current analysis has additionally known the distribution of those landscape elements in several notified areas of the district. These are:

a) Moist mixed deciduous forest (dense)
b) Moist mixed deciduous forest (open)
c) Sal forest
d) Scrub Forest
e) Degraded Forest
f) Grassland
g) Shifting Cultivation

Copyright@SPA Bhopal

h) Water Bodies
i) Non-forest areas.

Moist mixed deciduous forest (dense)

The current researchThe distribution of this class of forest is a lot of or less found in all the notified forest areas of the study area. In Rani R.F. this class of forest covers 22.63% of the whole geographic region. In Garbhanga R.F. the share of this class is 17.56%. Among all the notified forest areas the maximum concentration of moist mixed deciduous forest (dense) is found in Motapahar R.F. Out of the whole geographic region, 365 days area is covered with this class of forest in Motapahar R.F. very cheap concentration of moist mixed deciduous forest (dense) is found in Gotanagar R.F. Here solely six.13% of the whole geographic region is coved with moist mixed deciduous forest (dense). Besides these a major share of this class of forest is additionally found in Hengerabari R.F. (20.85%), Apricola East (18.83%), Amchang WLS (16.55%), South Amchang R.F. (15.80%). The table three shows the percentage of distribution of moist mixed deciduous forest (dense) all told the notified forest areas of Kamrup Metropolitan district of Assam. has conjointly known the distribution of those landscape components in numerous notified areas of the district.

Moist mixed deciduous forest (open)

This class of forest in found altogether the notified forest areas of the study area. the most concentration of this class of forest is found in Apricola East. Here 38.33% of the overall geographical area is covered with moist mixed deciduous forest (open) class. In Rani R.F. 28.15% of the overall geographical region is covered with this class of forest. In Garbhanga R.F. 25.67% is covered with this class of forest. the bottom concentration of this class of forest is found in Sarania R.F. Here solely 6.8% of the overall geographical region is roofed with this category of forest.

Sal forest

The distribution of Sal forest is just found in 5 notified forest areas. These areas South Amchange R.F., Khanapara R.F., Apricola East PRF and Apricola West R.F. and Marakdola R.F. The maximum concentration of Sal forest is found in Marakdola R.F. Here 13.24% of the whole geographical area is covered with Sal

Copyright@SPA Bhopal

forest. In Khanapara R.F, 9.52% of the whole space is covered with Sal forest. similarly the concentration of Sal forest in South Amchang, Apricola West R.F. and Apricola East PRF are 7.80%, 6.19% and 4.79% respectively.

Scrub Forest

The scrub forest is found in all the notified forest areas of the study area. Maximum concentration of this forest is found in South Kalapahar R.F. Out of the entire geographic area of the R.F 35.06% is covered with scrub forest. In Gotanagar R.F 21.23% of the entire geographical area is covered with scrub forest similarly in Motapahar R.F. 200th of the entire geographic area is covered with scrub forest. The distribution and concentration of scrub forest is additionally high in Hengrabari R.F., Amchang wildlife Sanctuary, Fatasil R.F., Khanapara R.F.

Degraded Forest

The degraded forest is conspicuously found in Garowani R.F. Here 25.8% of the overall geographical area is covered with degraded forest. the other notified forest areas wherever degraded forest is prominently found are Chamata R.F. (13.33%), Marakdola R.F. (10.43%), Hohora PRF (12.82%). In rani and Garbhanga R.F. the share of degraded forest is 4.85% and 4.37% respectively.

Grassland

Grassland is found in largely in Gotanager R.F. Here 30.66% of the entire region is covered with piece of ground. Equally in Amchang wildlife Sanctuary 14.36% space is covered with grassland. In Fatasil R.F about 24.63% of the entire space is covered with piece of ground.

Shifting Cultivation

In Kamrup Metropolitan district the most shifting cultivation is found in Apricola West R.F. Here 11.96% of the overall region is covered with shifting cultivation. Besides this shifting cultivation is additionally found in Marakdola R.F. (9.8%), Rani R.F. (6.27%), Garbhanga R.F. (8.12%), Khanapara R.F., (4.36%) Apricola East PRF (3.83%).

Copyright@SPA Bhopal

Water Bodies

Water bodies are found altogether the notified forest areas. This includes all the rivers, wetlands, ponds, etc among the notified forest areas. most water body is found in Teteliguri R.F. Here 55% of the entire geographic region is covered with water body. This forest area is usually lined with wetlands.

Non-forest areas

A non-forest area among the forest boundary is additionally found in most of the notified forest areas.

Maximum non-forest areas are found in Jalukbari R.F and Sarania R.F. These non-forest areas are in the main consisting of barren (rocky and stony waste) and settled areas (mainly encroached areas)

3.4 Demographic Profile

3.4.1 Guwahati City Population Growth

The Guwahati city population was calculable at 8394 in 1891 (GMDA, 2005). The population of the city at different periods of time is given in Table

Guwahati city population growth		
Year	**Population**	**Decadal growth rate (%)**
1891	8394	
1921	16480	25.21
1961	199482	86.52
1971	293219	46.99
1991	646169	48.45
2001	890773	37.85
2011	968549	8.73

Table 3: Population of the city at different periods
Source: Yadav and Barua, J Ecosys Ecograph

The decadenal growth rates shown in column 3 of the Table 3 are based on the previous row entries within the table, and should disagree from the official dedadenal growth rates revealed supported Decadenal census.

Since the population census unit for the city was different completely different at different times as municipality, Guwahati Municipal Corporation (GMC) and Guwahati Metropolitan space (GMA) beneath the GMDA, the figures are not precisely comparable. City rate of growth for future projections was taken to be

Copyright@SPA Bhopal

3.81% every year supported all india urban rate of growth. Based on the above growth rates, the subsequent population estimates have been fell upon for the Guwahati city for additional analysis.

Population Projection of Guwahati City	
Year	**Population**
1911	13785
1967	255724
1986	557932
2010	963255
2015	1097751

Table 4: Population estimates of Guwahati City
Source: Yadav and Barua, J Ecosys Ecograph

3.4.2 Guwahati city Built-up growth

Built up area of the Guwahati city was calculated for the years 1911, 1967, 1986 and 2010. The year wise built up area, the expansion in built up from 1911-1967, 1967-1986, 1986-2010 and 2010-2015 and therefore the corresponding growth rates are tabulated in Table seven.

Guwahati city built up growth				
Year	**Built up area (sq.km)**	**Growth (sq.km)**	**Growth rate (sq.km per year)**	**Growth rate 1911 (sq.km per year)**
1911	8.59			
1967	54.48	45.89	0.82	0.82
1986	90.65	36.17	1.9	1.09
2010	142.75	52.09	2.17	1.36
2015	176.19	33.44	6.69	1.61

Table 5: Built up Area of Guwahati City
Source: Yadav and Barua, J Ecosys Ecograph

Copyright@SPA Bhopal

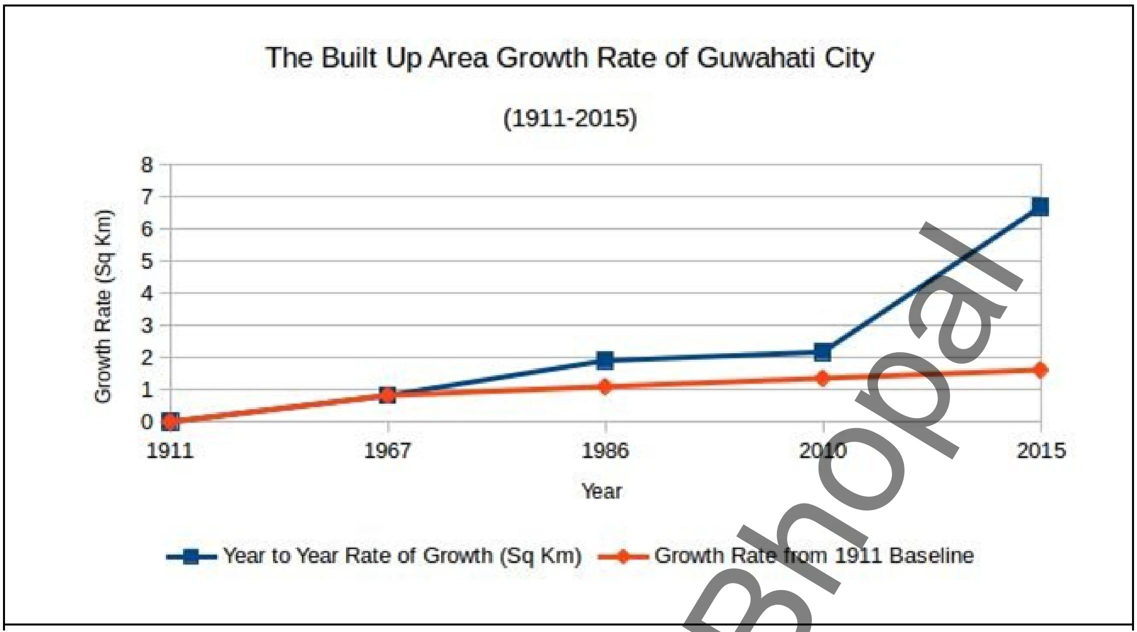


Figure 24: The growth rate of the built area of the city from the 1911 baseline
Source: Yadav and Barua, J Ecosys Ecograph

The built up area within the Guwahati city has mature among the span of 100 years ranging from 1911 to 2015 from modest 8.59 sq.km to 176.19 sq.km at a rate of about 1.61 sq.km each year. The map of the expansion of the city throughout the amount is shown in Figure. No. 27

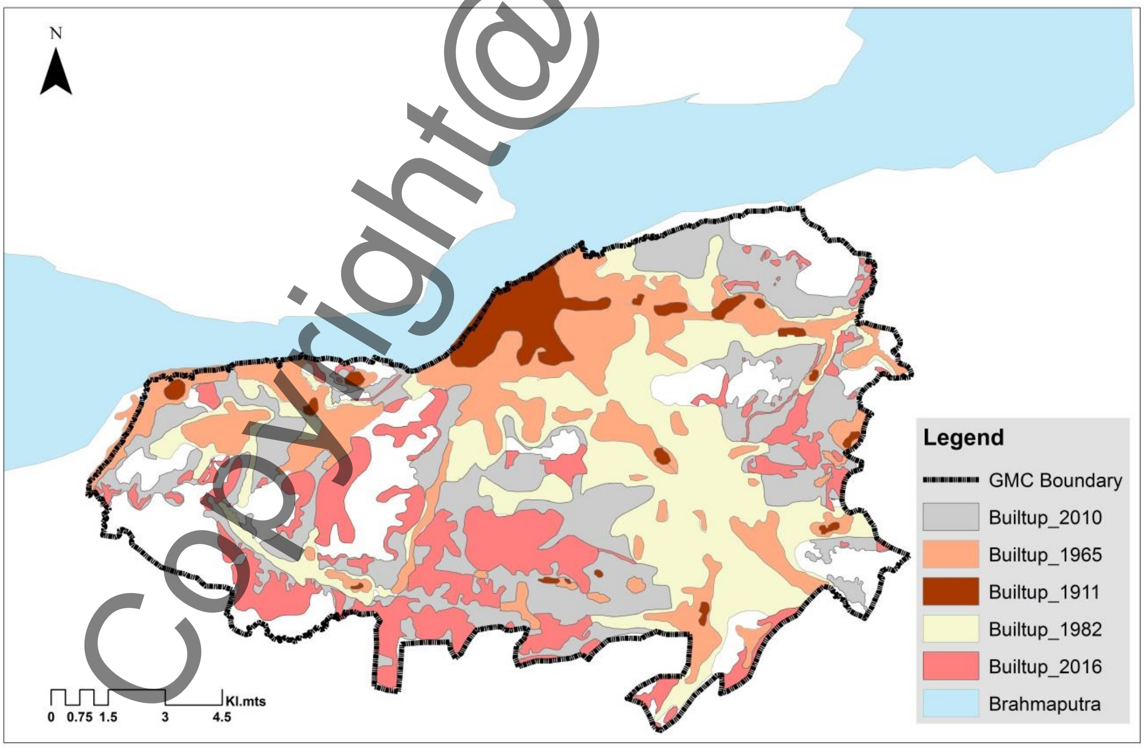


Figure 25: Map showing growth of the Guwahati City

Copyright@SPA Bhopal

3.5 Guwahati city decline in forest ecosystem (1911-2015)

The changes in land use from forestry to settlements over a amount of a hundred years have been studied to gain the degradation of the city forests, with an attempt to know the forest footprint. Prior to independence the Forest Department, Government of province didn't reserve any of hill areas among the town limits. the primary Reserved Forest to be established was Khanapara RF within the year 1953, with a notified area of 994 HA, followed by Fatasil RF in 1996 with a locality of 669.02 HA and Hengrabari RF in 1972 with a locality of 579 HA, totalling to a locality of 2242.02 ha.

The Amchang RF (part of that falls among the GMDA area) was conjointly notified in 1972 with a locality of 5318 HA As per the assam Forest Regulation 1891, all forest areas that aren't reserved area unit to be thought of as Unclassed State Forests (USF) wherever in virtually each activity is permissible unless specifically prohibited by an order by the government that is in distinction to the standing of a Reserved Forest wherever each activity by public is prohibited unless specifically permissible.

Therefore, before 1953, all the hilly/ forested tracts of the Guwahati city area were falling underneath the class of USF. The USF areas may be simply diverted for any non-forestry functions. Human habitation started changing these tracts into permanent habitation since the first part of the century. The trends of occupancy of the hilly-forested tracts continuing. the expansion of settlements in these tracts from 1911 to 2015 is sort of exponential. Supported the settlements at completely different periods within the forested hill tracts at intervals the city limits, the rate of loss of the forest areas was acquired.

Copyright@SPA Bhopal

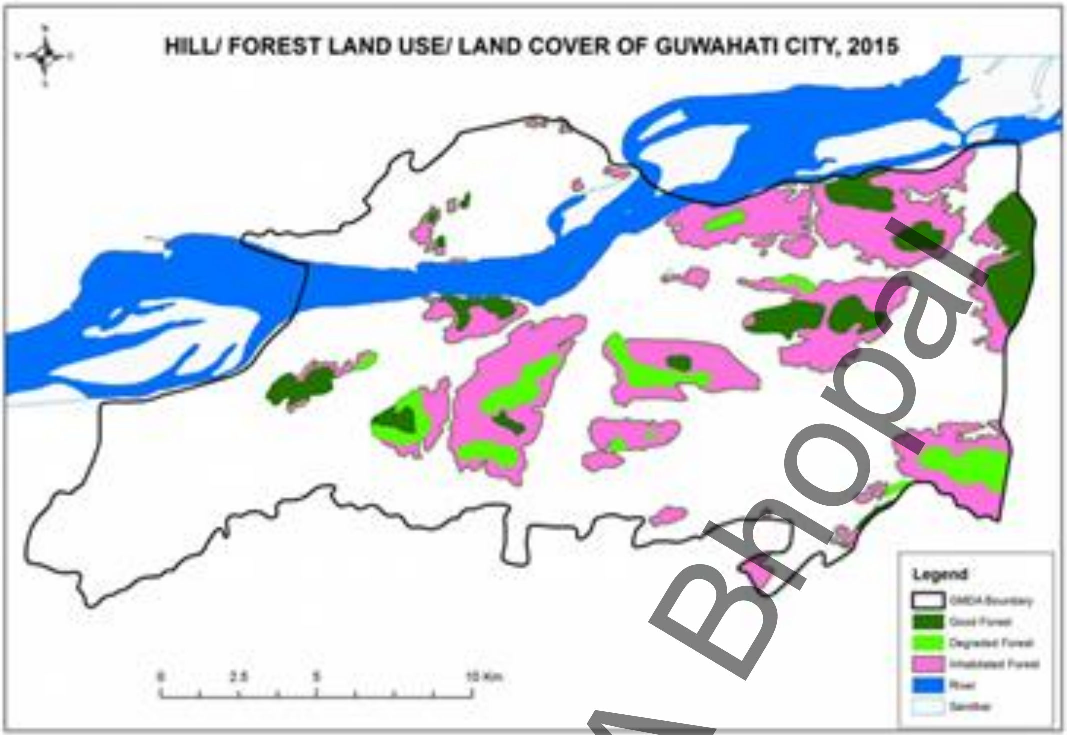


Figure 26: Composite land use / land cover for the hilly tracts of Guwahati
Source: Yadav and Barua, J Ecosys Ecograph

Copyright@SPA Bhopal

The rate of forest loss is diagrammatically represented in Figure 21. The loss in forest area and cumulative loss in forest area are acquired after totaling the dense and degraded forest cover. The analysis of dense and degraded forest couldn't be disbursed for 1911, 1967 and 1986 because the primary data used for the purpose was geography sheets. The total area of the hills falling inside the GMDA boundary involves 68.8126 sq.km of which, as of 2015, 44.5950 sq.km is occupied by human habitation. This amounts to 64.42% of the hills presently being below the scope of human occupation. Clubbing the great forest areas on With degraded forest areas, the per capita forest area was calculated. The drastic reduction within the per capita availability of forests within the Guwahati city seems to purpose within the direction of adverse supply and sink relationship of the forestry scheme services. The contribution of forest area in urbanization (built up area) just in case of Guwahati city in 2015 involves 25.31%.

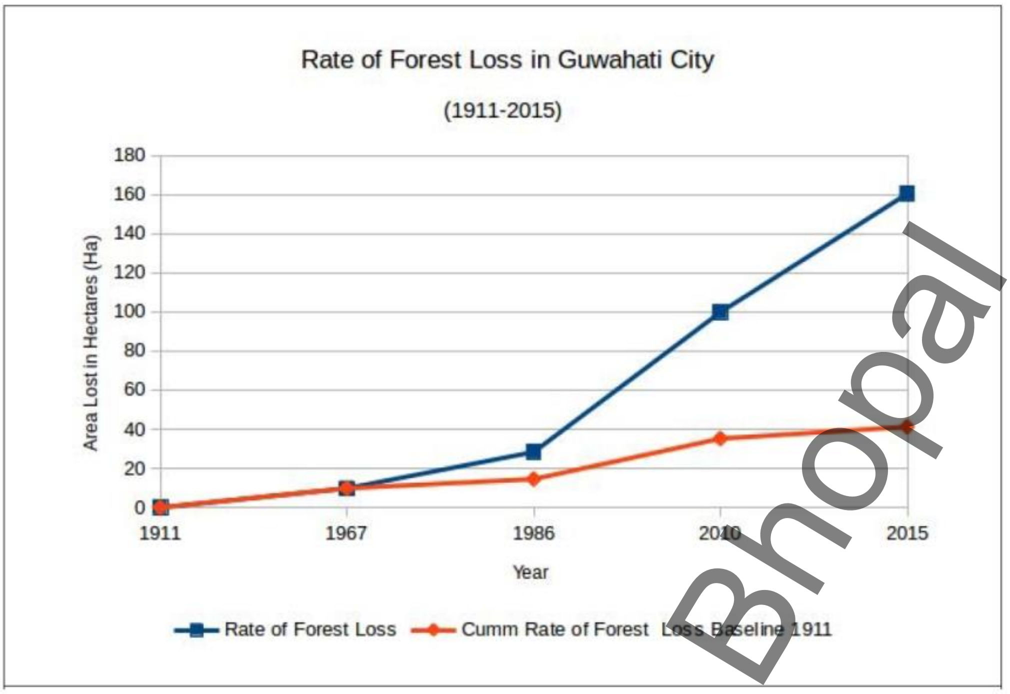


Figure 27: Rate of forest loss in Guwahati city
Source: Yadav and Barua, J Ecosys Ecograph

Copyright@SPA Bhopal

Year	Dense forest (Ha)	Degraded forest (Ha)	In habited areas (Ha)	Rate of forest loss (Ha yr -1)	Cummulative rate of loss of forest (Ha yr-1)
1911	6708.63	0	172.63	0	0
1967	6158.44	0	722.82	9.82	9.82
1986	5619.44	0	1261.82	28.37	14.52
2010	1722.84	1500.62	3657.80	99.83	35.20
2015	1438.49	983.27	4459.50	160.34	41.22

Table 6: Loss of forest in Guwahati city
Source: Yadav and Barua, J Ecosys Ecograph

Year	Built up area (Ha) (Ha)	Inhabited forest area (Ha)	% Share of forest in built up	Per capita built up area (sq.m)	Per capita inhabited forest area (sq.m)
1911	859	172.63	20.10	623.14	12 5.23
1967	5448	722.82	13.27	213.04	28.27
1986	9065	1261.82	13.92	162.47	22.62
2010	14275	3651.80	25.58	148.20	37.97
2015	17619	4459.50	25.31	160.50	40.62

Table 7: Share of forest area in built up area of the Guwahati city
Source: Yadav and Barua, J Ecosys Ecograph

4. Data Collection and Methodology

The estimation of Urban Heat Island of Guwahati City and its analysis is done by analysing Landsat Imageries for the temporal years 2001, 2011 and 2016 at summertime for the month of April. The analysis consists of the calculation of Normalized Differential Vegetation Index, (NDVI) and Land Surface Temperature, (LST) and thereby the Urban Heat Island (UHI) map has been created.

Acquisition Date	2001-04-03	2011-04-07	2016-04-12
Satellite	"LANDSAT_7"	"LANDSAT_5"	"LANDSAT_8"
Sensor	"ETM"	"TM"	"OLI_TIRS"
Resolution in meter	30 M	30 M	30 M
Path	137	137	137
Row	042	042	042
Projection and Datum	"UTM" and "WGS84"	"UTM" and "WGS84"	"UTM" and "WGS84"
Cloud Cover	1.00	4.00	2.00

Table 8: Landsat Data Specifications

Source: Image courtesy of the U.S. Geological Survey

Copyright@SPA Bhopal

4.1 Methodology Adopted

For the estimation of land surface temperatures and urban heat island maps of the study area, we need to have a particular methodology amongst the various techniques mentioned in the previous content of “Measurement Techniques” in 2.4. The following are the detailed steps of the methodology adopted in the research.

4.1.1 Assembling Satellite Imageries

Landsat data for 2001, 2011 and 2016 for the month of April has been utilized in this study and is downloaded from the relevant web site of United State geological Survey (USGS).

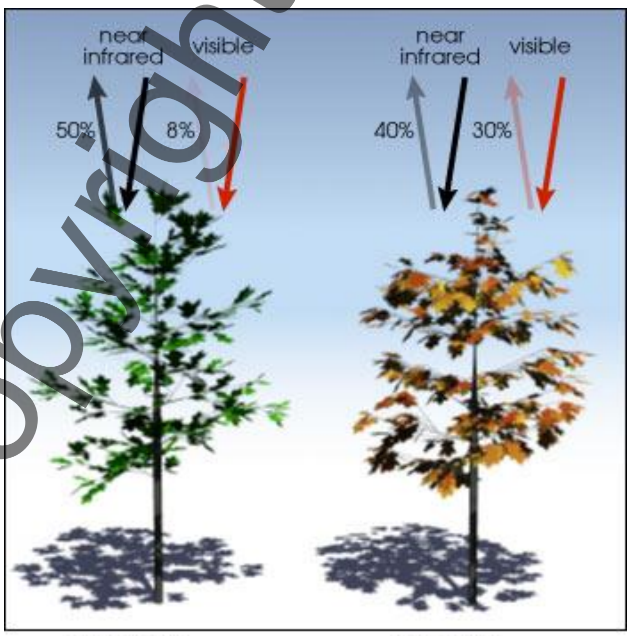
4.1.2 Image Classification

Image classification denotes to the piece of work of extracting information classes from a multi-band raster image. The ensuing raster image classification can be used to produce thematic maps. Depending on the interaction between the expert and the computer during the attributions, there are two types of classification: supervised and unsupervised. Using these classifications, the area of the classes from generated NDVI could be computed.

In this study Image, classification has been executed on combination of Band 4 (NIR), Band 3(Red) and Band 2 (Green) for all the images to classify Normalized Difference Vegetation Index (NDVI) map for 2001, 2011 and 2016.

4.1.3 Normalized Differential Vegetation Index (NDVI) Estimation

NDVI is estimated by the visible and near infrared light reflected by the vegetation. Healthy vegetation absorbs most of the visible light that strikes it and reflects much of the light in the near infrared. Unhealthy vegetation or radiance reflects the most visible light and less light in the near infrared. The figures below are representative of the actual values, but the actual vegetation is much more varied. (Illustration by Robert Simmon, earthobservatory, NASA)



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Figure 28: Illustration of NDVI

Source: Earthobservatory, NASA

Copyright@SPA Bhopal

Almost all indices of vegetation use this formula difference to quantify plant growth density on Earth - near infrared radiation less visible radiation divided by radiations of near infrared radiation more visible. The result of this formula is called - Normalized Difference Vegetation (NDVI).

Mathematically, the formula is:

NDVI = (NIR-R) / (NIR + R)

NDVI calculations for pixel data are always in a number ranging from less than one (-1) plus one (+1)

However, any green leaf gives a near zero. A zero means no vegetation and close to +1 (0.8 to 0.9) indicates the maximum density of green leaves.

4.1.4 Land Surface Temperature Estimation

Step 1: Calculation of Normalized Differential Vegetation Index (NDVI) and Proportional Vegetation (Pv)

Normalized Differential Vegetation Index (NDVI) is calculated as –

NDVI = (NIR-R) / (NIR + R)

Where, NIR - near infrared band and R – Red band

NDVI calculations for pixel data are always in a number ranging from less than one (-1) plus one (+1)

However, any green leaf gives a near zero. A zero means no vegetation and close to +1 (0.8 to 0.9) indicates the maximum density of green leaves.

Proportional Vegetation (Pv) deals with the relationship between the amount of vegetation present within a pixel and the pixel's emissivity.

$$\mathbf{P_V} = \left[\frac{\mathbf{NDVI} - \mathbf{NDVI_{min}}}{\mathbf{NDVI_{max}} - \mathbf{NDVI_{min}}}\right]^2$$

Step 2: Calculation of Emissivity

Sobrino et al., (2004) has derived a formula for calculating emissivity using NDVI and Pv as inputs. The final expression ws given by:

$$\varepsilon_{TM6} = \mathbf{0.004P_v} + \mathbf{0.986}$$

Copyright@SPA Bhopal

Step 3: Conversion of DN to Radiance

The third step is to convert the DNs to radiance, the method depends on the scene calibration data available in the header file. One method uses the Grain and Bias (or offset) value from the header file and the longer method uses the L_{min} and L_{max} spectral radiance scaling factors.

$$L_\lambda = \frac{L_{max} - L_{min}}{Qcal_{max} - Qcal_{min}} * (Qcal - Qcal_{min}) + L_{min}$$

Where,

L_λ : Spectral radiance.

$Qcal$: Quantized calibrated pixel value in DN

L_{min} :Spectral radiance scaled to $Qcal_{min}$

L_{max} : Spectral radiance scaled to $Qcal_{max}$

$Qcal_{min}$: The minimum Quantized calibrated pixel value in DN = 1

$Qcal_{max}$: The minimum Quantized calibrated pixel value in DN = 255

Calculate brightness temperature

Step 4: Calculation of Land Surface Temperature (LST)

Computation of Land Surface Temperature (LST) including brightness temperature and emissivity is as follows:

$$T_{sat} = \frac{K_2}{\ln\left[\frac{\varepsilon K_1}{L_\lambda} + 1\right]} - 273$$

Where,

T_{sat} is the brightness temperature. The coefficients K1 and K2 are the constants of calibration given by the manufacturer of the sensor, for Landsat 7 TM sensors K1 and K2 are respectively equal to 666.09 watts/(m2 * ster* m) and 1282.71 Kelvin(-273 to convert Kelvin to Celsius).

Copyright@SPA Bhopal

Land Surface Temperature (LST) is again given by:

BT/1 + w * (BT / p) * ln(e)

Where,

BT = satellite temperature

W = wavelength of emitted radiance

P = h* c/s

Here **p** is taken as value - 14380

H = Planck's constant

C = velocity of light

e = emissivity

Step 5: Urban Thermal Field Variance Index

Urban thermal Field Variance Index (UTFVI) is used to quantitatively describe the urban heat island effect. UTFVI can be calculated using the equation as below:

$$\mathbf{UTFVI} = \frac{\mathbf{TS} - \mathbf{T_{MEAN}}}{\mathbf{T_{MEAN}}}$$

Where,

UTFVI is the Urban Thermal Field Variance Index, $\mathbf{T_s}$ is the LST of certain point in Kelvin and $\mathbf{T_{mean}}$ is the mean LST temperature of the whole study area in Kelvin. To reflect the changes of urban thermal field reflectivity directly, UTFVI can be further divided into six levels in accordance with six different ecologicalk evaluation indices. Table - 9 gives the specific thresholds in the six UTFVI levels.

Urban Thermal Field Variance Index	UHI Phenomenon	Ecological Evaluation Index
<0	None	Excellent
0 – 0.05	Weak	Good
0.05 – 0.1	Middle	Normal
0.1 – 0.15	Strong	Bad
0.15 – 0.2	Stronger	Worst
>0.2	Strongest	Worst

Table 9: Urban Thermal Field Variance Index
Source: Urban Heat Island Analysis – Lin Liu

Copyright@SPA Bhopal

5. Analysis and Results

This chapter demonstrates about the analysis and results drawn from the study. At the first section, it presents the analysis of Normalized Difference Vegetation Index (NDVI) variation for the temporal years 2001, 2011 and 2016 and variation of Land Surface Temperature (LST) in Guwahati City.

In the next section, it presents about the behaviour of modification in land use/land cover and land surface temperature and relation between them.

Finally, it has been demonstrated about the variations of urban heat island effect in Guwahati on the same temporal years and selection criteria of a micro area where UHI effect is severe.

In addition, these three factors namely NDVI, LST and UHI have also been calculated for all the notified forest within the Guwahati City to know the present scenario of the urban forests, which is on the degraded hilly areas of the city.

5.1 Normalized Difference Vegetation Index (NDVI)

In order to review the spatial-temporal changes in Land Surface Temperature (LST) and the Urban Heat Island (UHI) effect, study of vegetation as a parameter becomes important. It permits deciding the density of green on a patch of land.

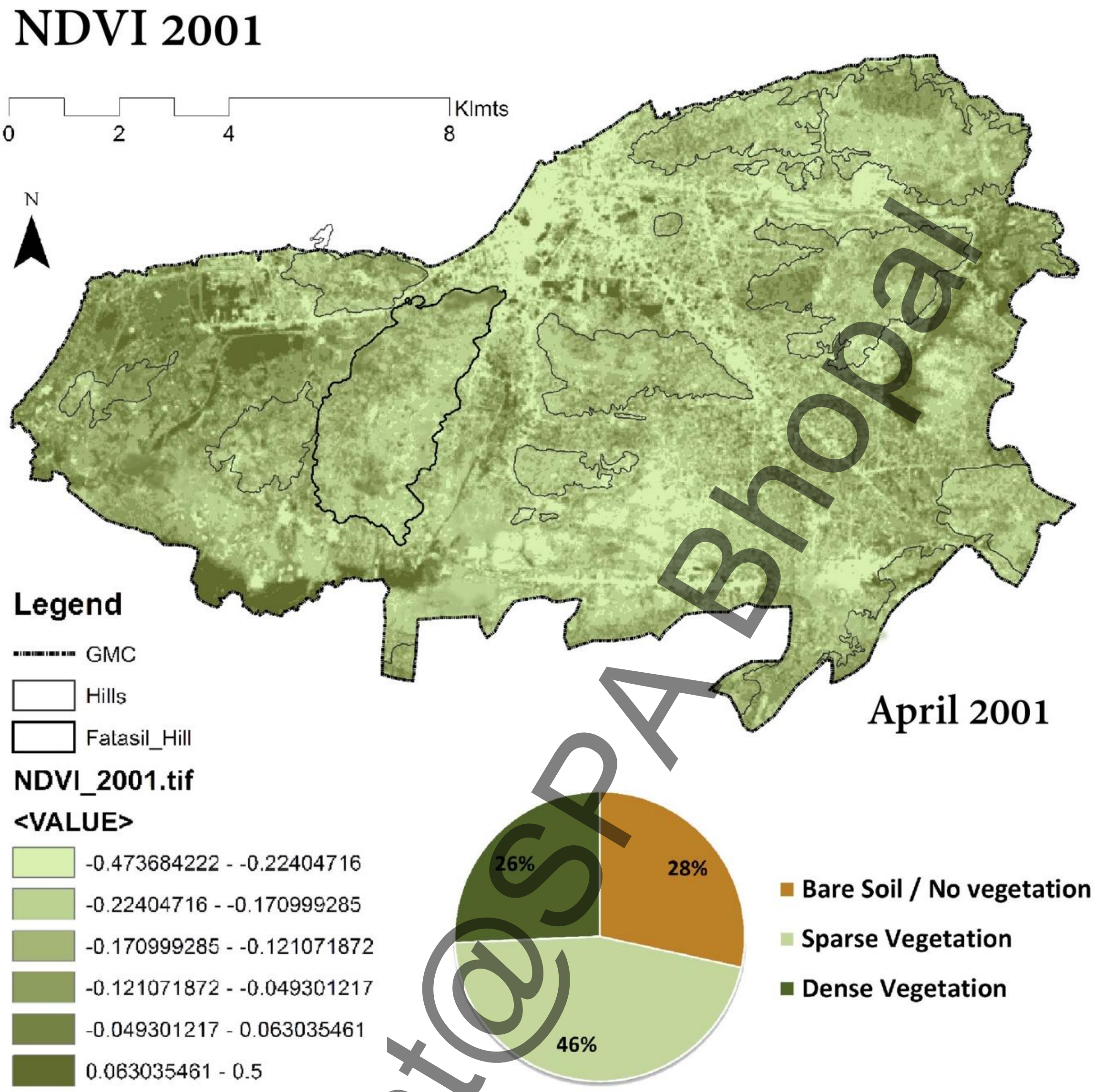
The NDVI map has been classified in three distinct classes, those are - Sparse Vegetation, Dense Vegetation and Bare Soil.

Through the analysis of NDVI, it has been estimated and observed that the quantity of Dense Vegetation has decreased and Bare Soil has increased over the temporal years from 2001 to 2016. Thus, there is loss of vegetation due to various human induced activities.

Year	April	
	Max.	Min.
2001	0.60	- 0.47
2011	0.56	- 0.18
2016	0.55	- 0.05

Table 10: NDVI values from 2001 – 2016
Source: Generated from Landsat image

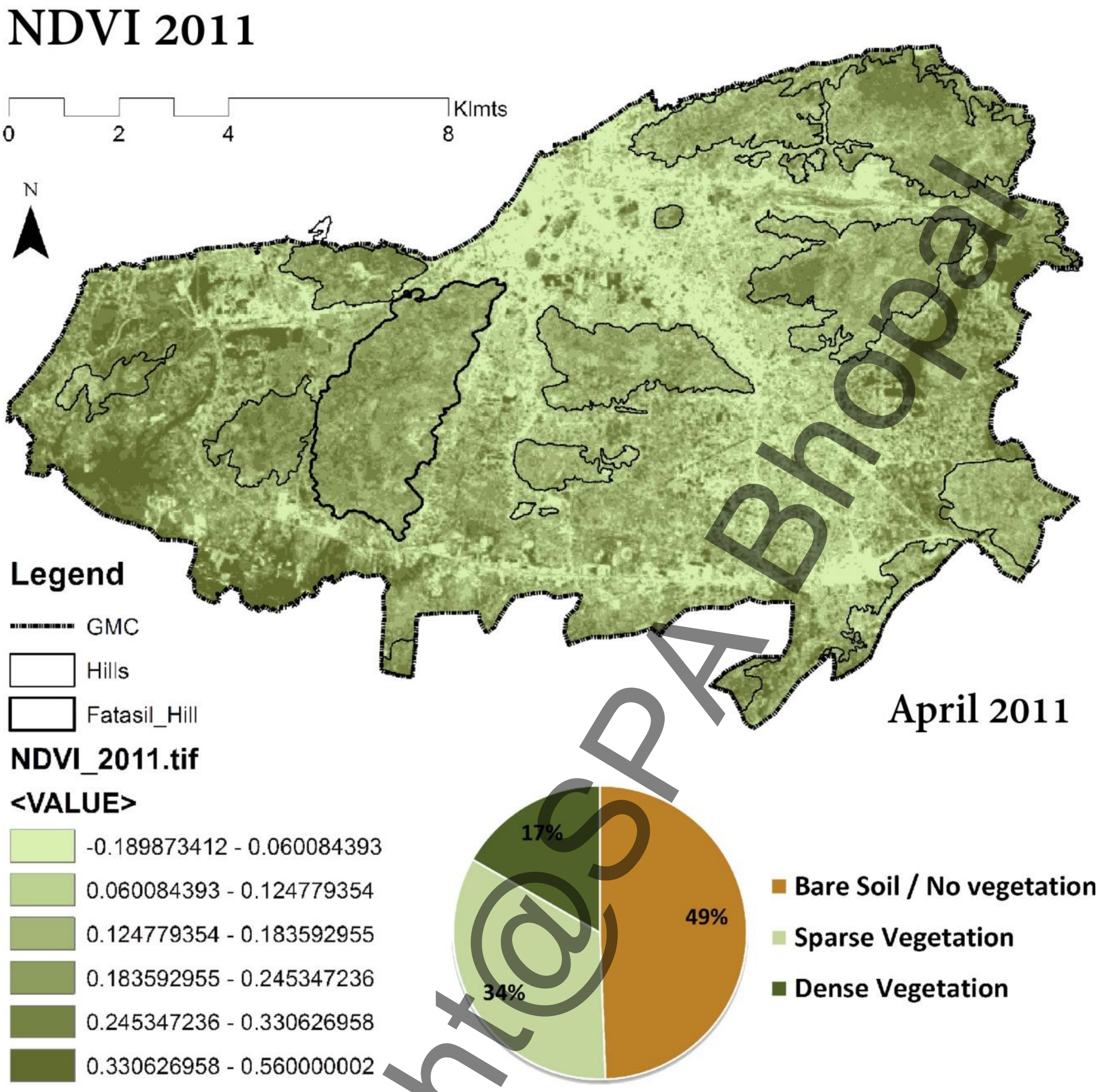
Copyright@SPA Bhopal



2001 Classification of Vegetation of GMC Area (216 sq.klm)	
	Area
Bare Soil / No vegetation	33.907
Sparse Vegetation	54.723
Dense Vegetation	30.612

Figure 29: NDVI of April 2001
Source: Generated from Landsat image

Copyright@SPA Bhopal

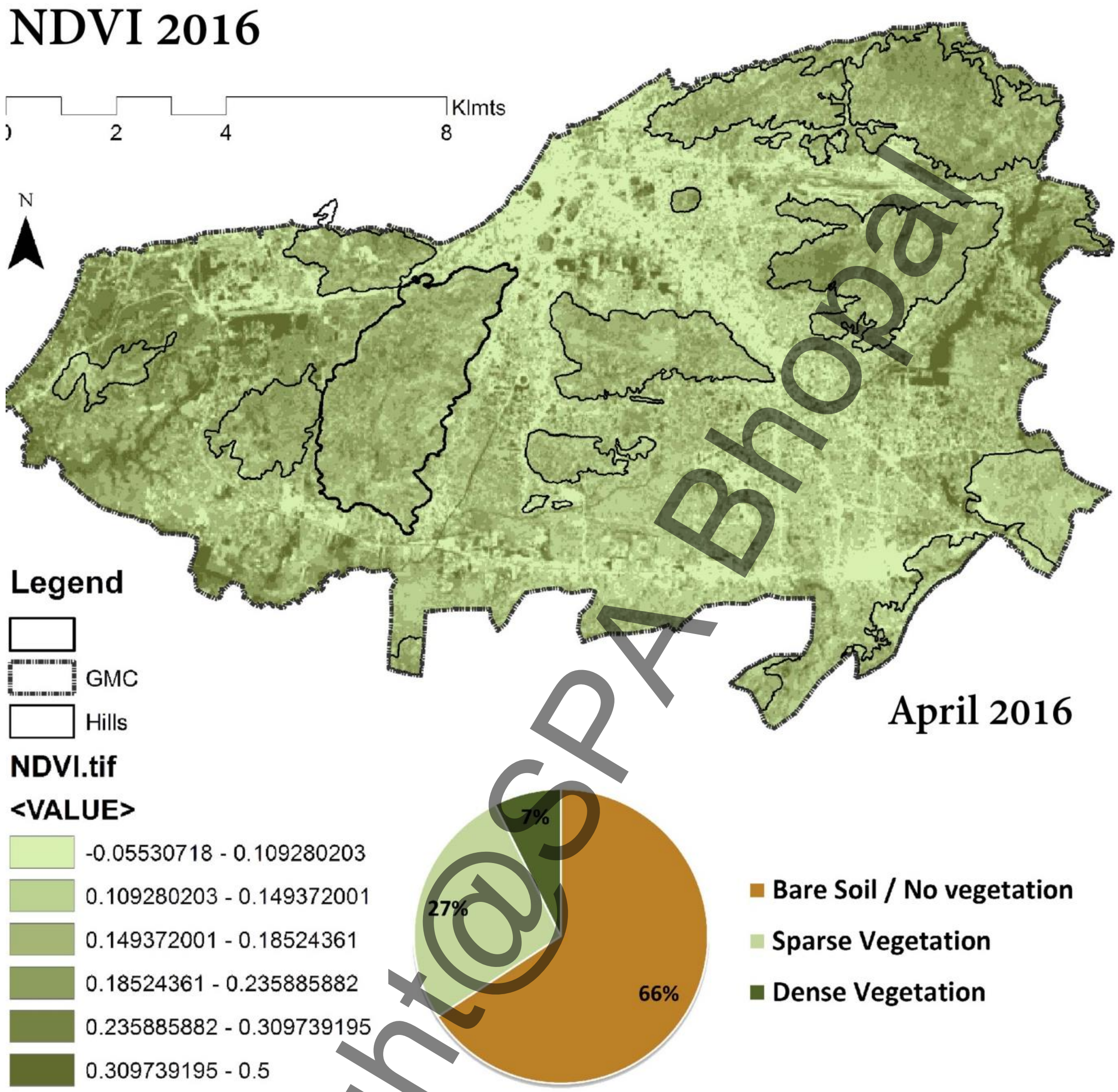


2011 Classification of Vegetation of GMC Area (216 sq.klm)	
	Area
Bare Soil / No vegetation	63.907
Sparse Vegetation	43.872
Dense Vegetation	21.612

Figure 30: NDVI of April 2011

Source: Generated from Landsat image

Copyright@SPA Bhopal



2016 Classification of Vegetation of GMC Area (216 sq.klm)	
	Area
Bare Soil / No vegetation	76.907
Sparse Vegetation	31.379
Dense Vegetation	8.612

Figure 31: NDVI of April 2016
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.2 Spatial Variation of Land Surface Temperature

The April 2001, Land Surface Temperature varied from 23.29°C to 33.17°C. Mean Land Surface Temperature for the same period is 28.23°C.

The April 2011, Land Surface Temperature varied from 22.49°C to 34.65°C. Mean Land Surface Temperature for the same period is 28.57°C.

The April 2016, Land Surface Temperature varied from 24.27 °C to 36.76°C. Mean Land Surface Temperature for the same period is 30.51°C.

The table below show the land surface temperature of Guwahati Municipal Corporation for 2001, 2011 and 2016 for the temporal years at the month of April.

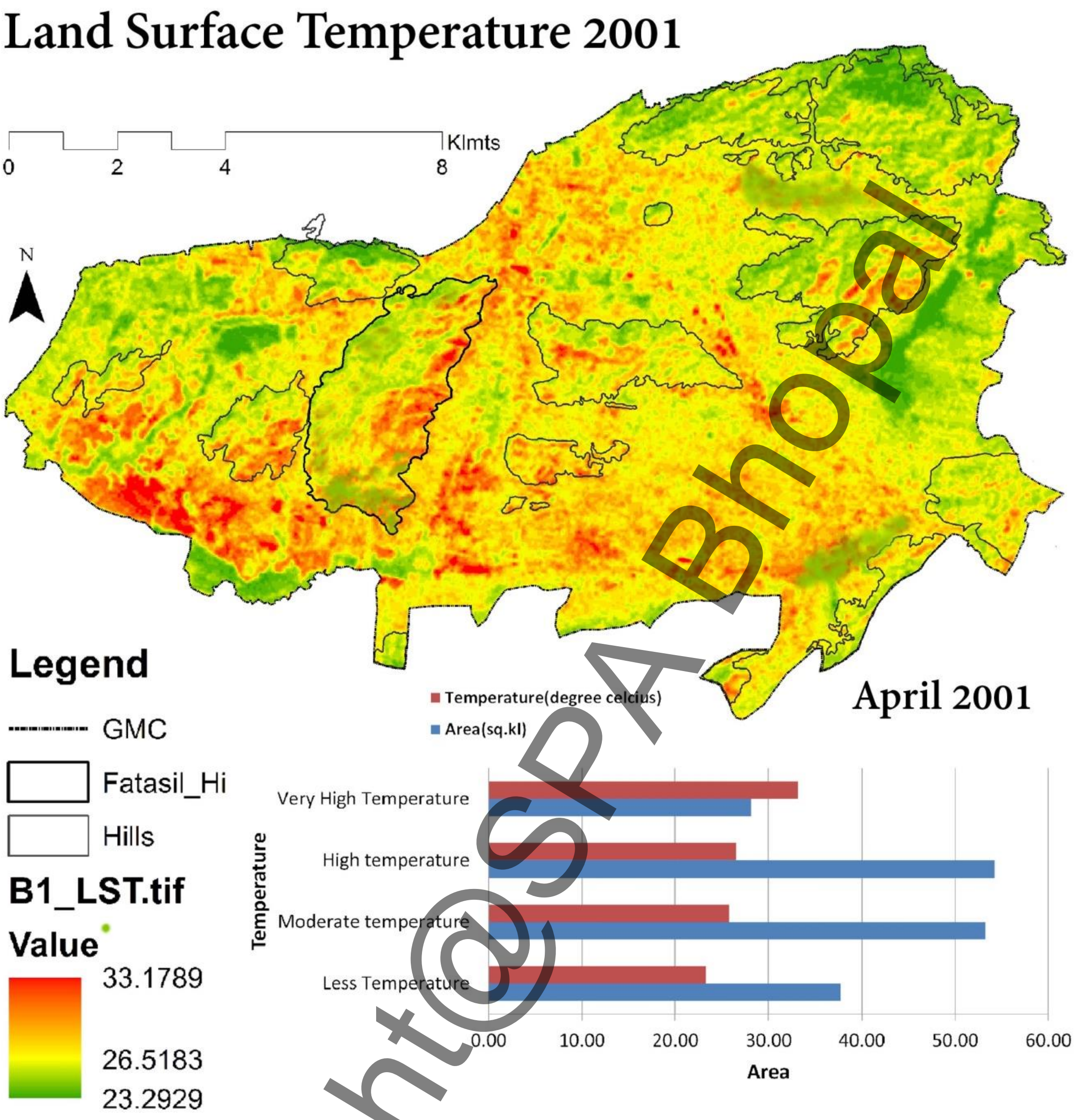
Date	Minimum LST (°C)	Maximum LST (°C)	Mean LST (°C)
April 2001	23.29°	33.17	28.23
April 2011	22.49	34.65	28.57
April 2016	24.27	36.76	30.51

Table 11: Land Surface Temperature for the years 2001, 2011 and 2016
Source: Generated from Landsat image

It has been observed that the average temperature has exaggerated from 2001 to 2016 for all the three temporal years and therefore the hottest month is April with an average temperature of 28.23°C in 2001 and 30.51°C in 2016.

The Classified Land Surface Temperature of Guwahati for the years 2001, 2011 and 2016 is shown as below:

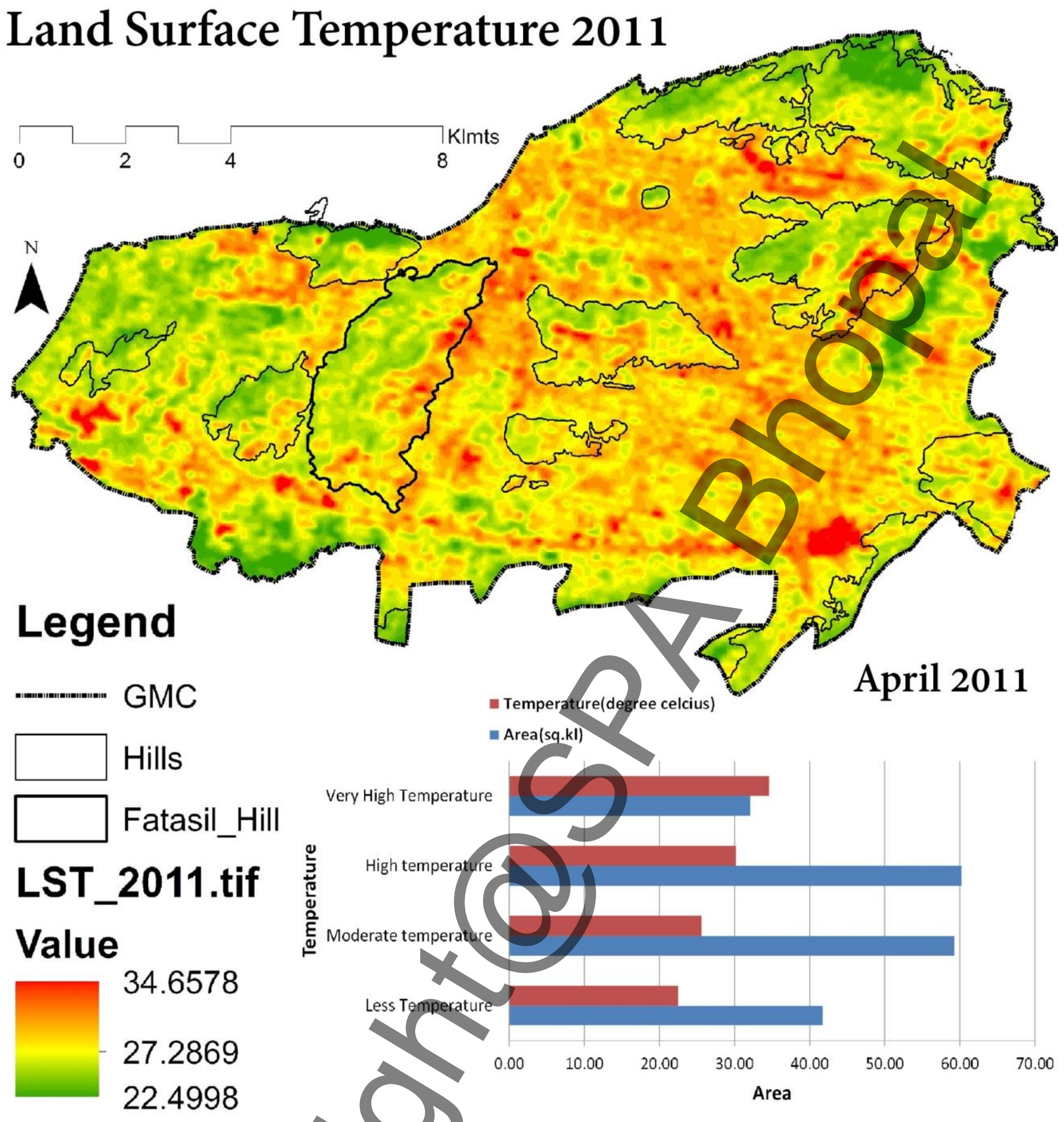
Copyright@SPA Bhopal



2001 Guwahati Land Surface Temperature		
Type	**Area(sq.kl)**	**Temperature(degree celcius)**
Less Temperature	37.74	23.29
Moderate temperature	53.25	25.81
High temperature	54.26	26.51
Very High Temperature	28.15	33.17

Figure 32: Land Surface Temperature of Guwahati Municipal Corporation Area, April 2001
Source: Generated from Landsat image

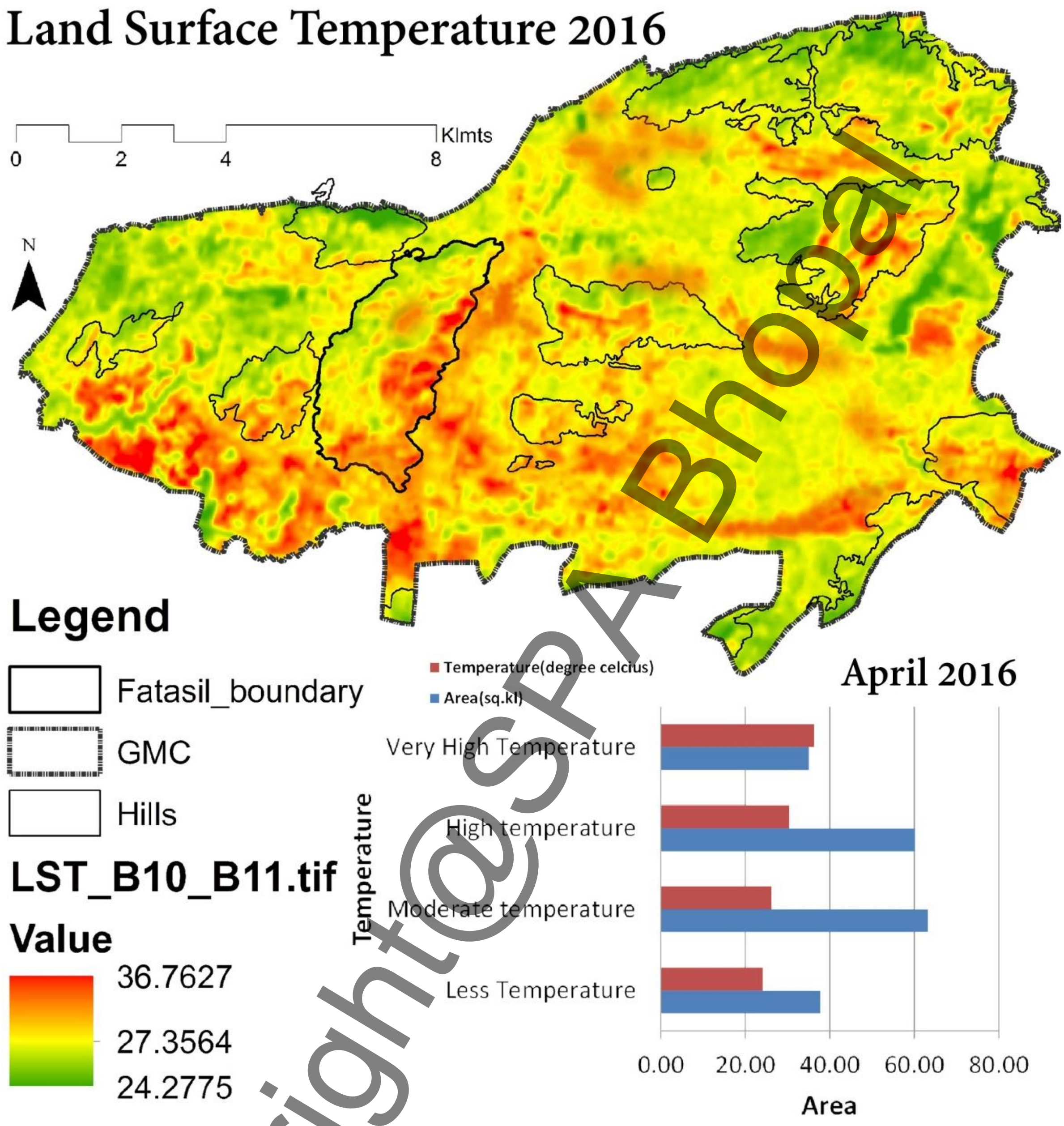
Copyright@SPA Bhopal



2011 Guwahati Land Surface Temperature		
Type	**Area(sq.kl)**	**Temperature(degree celcius)**
Less Temperature	41.74	22.49
Moderate temperature	59.25	25.61
High temperature	60.26	30.21
Very High Temperature	32.15	34.65

Figure 33: Land Surface Temperature of Guwahati Municipal Corporation Area, April 2011
Source: Generated from Landsat image

Copyright@SPA Bhopal



2016 Guwahati Land Surface Temperature		
Type	Area(sq.kl)	Temperature(degree celcius)
Less Temperature	37.74	24.27
Moderate temperature	63.25	26.21
High temperature	60.26	30.56
Very High Temperature	35.15	36.33

Figure 34: Land Surface Temperature of Guwahati Municipal Corporation Area, April 2016
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.2.1 Estimation of Land Surface Temperature of Forest Areas of Guwahati Municipal Corporation Area (GMCA)

Overall topography of the GMCA area varies from plain to undulating. The fringe area of the Meghalaya is steep undulating joining to flat terrain towards the river Brahmaputra River. The terrain is dotted with tiny hills to residual hillocks.

Here, in this study, the notified forest areas were considered to assess the current pattern forest cover in the district. There are as many as eighteen notified forest areas covering 25.34 km² within GMCA. The names of the notified forest areas with their area of extent are mentioned in the Table 12. The figure 29 shows the location of all the notified forest areas within Guwahati Municipal Corporation Area (GMCA).

Copyright@SPA Bhopal

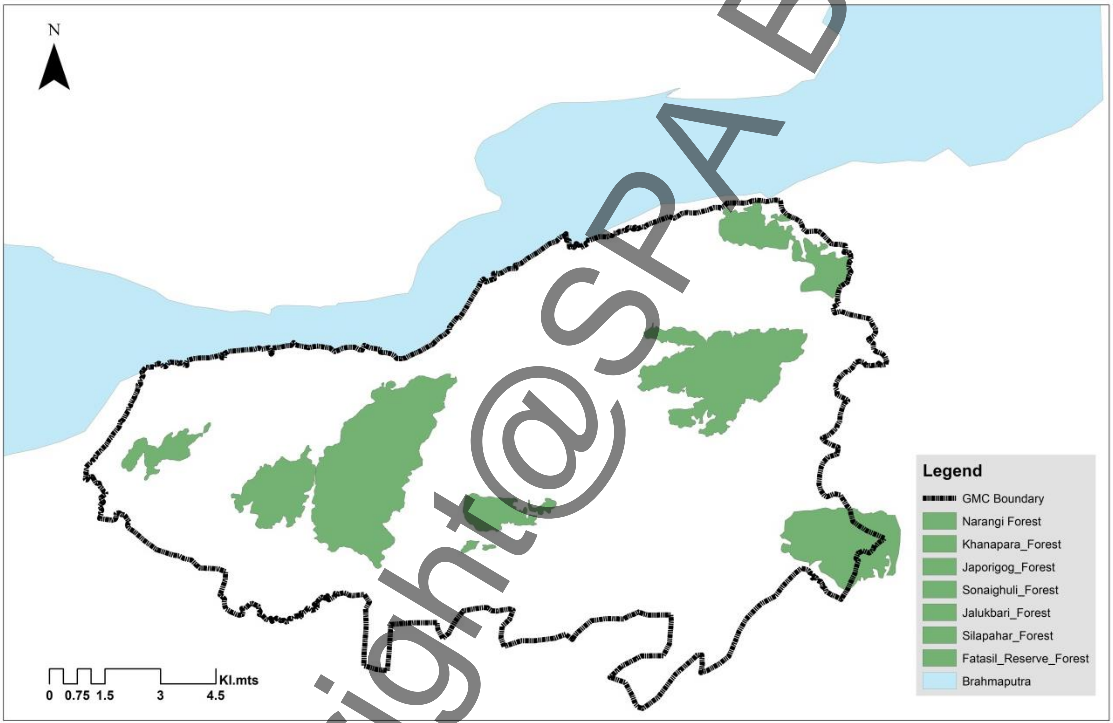


Figure 35: Notified Forest Areas within Guwahati Municipal Corporation Area (GMCA)

Sl.No	Forest Name	Area [Sq. Klmts]
1	Sonaighuli Forest	1.616
2	Hengerabari Forest	7.572
3	Fatasil Forest	7.061
4	Silapahar Forest	2.792
5	Khanapara Forest	5.085
6	Jalukbari Forest	1.223
Total		**25.349**

Table 12: Notified Forests of Guwahati City with its area

Source: Yadav and Barua, J Ecosys Ecograph

5.2.1.1 Land Surface Temperature of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2001

2001 Land Surface Temperatures Of Forest Areas Of Guwahati			
Sl. No.	**Forest Name**	**Min. Temp (°C)**	**Max. Temp (°C)**
1	Sonaighuli Forest	24.85	29.81
2	Hengerabari Forest	23.32	29.78
3	Fatasil Forest	24.34	31.21
4	Silapahar Forest	23.8	30.72
5	Khanapara Forest	23.83	29.33
6	Jalukbari Forest	24.34	29.11

Table 13: 2001 Land Surface Temperatures of Forest Areas of Guwahati
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.2.1.2 Land Surface Temperature of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2011

2011 Land Surface Temperatures Of Forest Areas Of Guwahati			
Sl. No.	**Forest Name**	**Min. Temp (°C)**	**Max. Temp (°C)**
1	Sonaighuli Forest	24.9	30.24
2	Hengerabari Forest	23.87	29.86
3	Fatasil Forest	25.22	32.72
4	Silapahar Forest	23.86	31.69
5	Khanapara Forest	23.96	29.85
6	Jalukbari Forest	25.1	29.26

Table 14: 2011 Land Surface Temperatures of Forest Areas of Guwahati
Source: Generated from Landsat image

5.2.1.3 Land Surface Temperature of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2016

2016 Land Surface Temperatures Of Forest Areas Of Guwahati			
Sl. No.	**Forest Name**	**Min. Temp (°C)**	**Max. Temp (°C)**
1	Sonaighuli Forest	25.85	32.81
2	Hengerabari Forest	24.78	30.46
3	Fatasil Forest	26.43	35.11
4	Silapahar Forest	24.31	33
5	Khanapara Forest	24.83	29.9
6	Jalukbari Forest	25.34	29.71

Table 15: 2016 Land Surface Temperatures of Forest Areas of Guwahati
Source: Generated from Landsat image

5.2.2 Change in Land Surface Temperature Over the Temporal Years in the Forest Areas of Guwahati

It has been determined that:

• Dense vegetation of GMCA has been decreased from 26% to 7% i.e. a change of 19% from 2001-2016.

• Land surface temperature of GMCA has been increased from 28.23 (°C) to 30.52 (°C) from 2001 to 2016.

• This results in increase in UHI effect in Guwahati city as well as within the forest areas

5.2.2.1 Change in Land Surface Temperature Over the Temporal Years in the Forest Areas of Guwahati from 2001 – 2011

Change in Land Surface Temperature from 2001 - 2011			
Sl. No	**Forest**	**Maximum Temperature (°C)**	**Minimum Temperature (°C)**
1	Sonaighuli Forest	0.43	0.05
2	Hengerabari Forest	0.08	0.55
3	Fatasil Forest	1.51	0.88
4	Silapahar Forest	0.97	0.06
5	Khanapara Forest	0.52	0.13
6	Jalukbari Forest	0.15	0.76

Table 16: Change in Land Surface Temperature of the Notified Forests from 2001 – 2011
Source: Generated from Landsat image

5.2.2.2 Change in Land Surface Temperature Over the Temporal Years in the Forest Areas of Guwahati from 2011 – 2016

Change in Land Surface Temperature from 2011 - 2016			
Sl. No	**Forest**	**Maximum Temperature (°C)**	**Minimum Temperature (°C)**
1	Sonaighuli Forest	2.57	0.95
2	Hengerabari Forest	0.6	0.91
3	Fatasil Forest	2.39	1.21
4	Silapahar Forest	1.31	0.45
5	Khanapara Forest	0.05	0.87
6	Jalukbari Forest	0.45	0.24

Table 17: Change in Land Surface Temperature of the Notified Forests from 2011 – 2016
Source: Generated from Landsat image

Copyright@SPA Bhopal

The highest change in land surface temperature has been found mostly in the forest of Fatasil Hills i.e. 1.51 °C from 2001 – 2011 and 2.39 °C from 2011 - 2016. Thereby probable effect of Urban Heat Island in these areas would prevail due to various factors.

5.3 Relationship between Land Surface Temperature (NDVI) and Land Surface Temperature (LST)

Vegetation cover incorporates an important influence on the Land Surface Temperature (LST) distribution. The correlation between LST and NDVI is represented in the *Figure No. 38* below by plotting the values of NDVI and LST of haphazardly selected points.

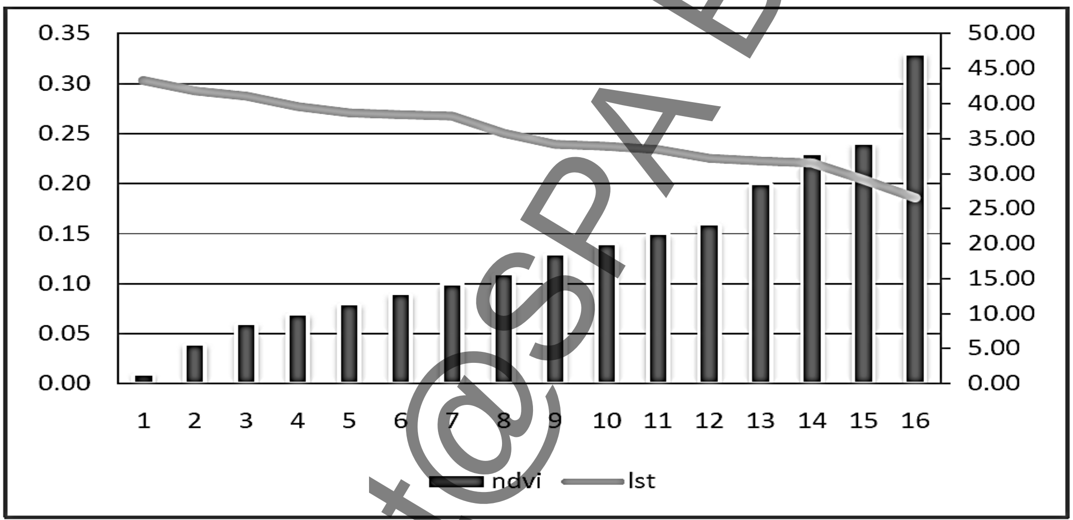


Figure 36: Relationship between NDVI and LST
Source: World Bank

Thus, this is distinctly suggesting that the LST is strongly and negatively correlative with NDVI. Thus, areas with very less vegetation are experiencing higher land surface temperatures.

5.4 Spatial Variation of Urban Heat Island (UHI)

The Guwahati metropolitan area has shown a recognized heat island from the year 2001. The high dense settlement areas have a greater effect in the heat island formation. New industrial areas came upon along the National highway 37 has conjointly exaggerated the surface temperature within the boundary of the city. A patch of high surface temperature zone can even been traced around the new modernized LGNB International field.

Copyright@SPA Bhopal

The Classified Urban Heat Island effect of Guwahati for the years 2001, 2011 and 2016 is shown as below:

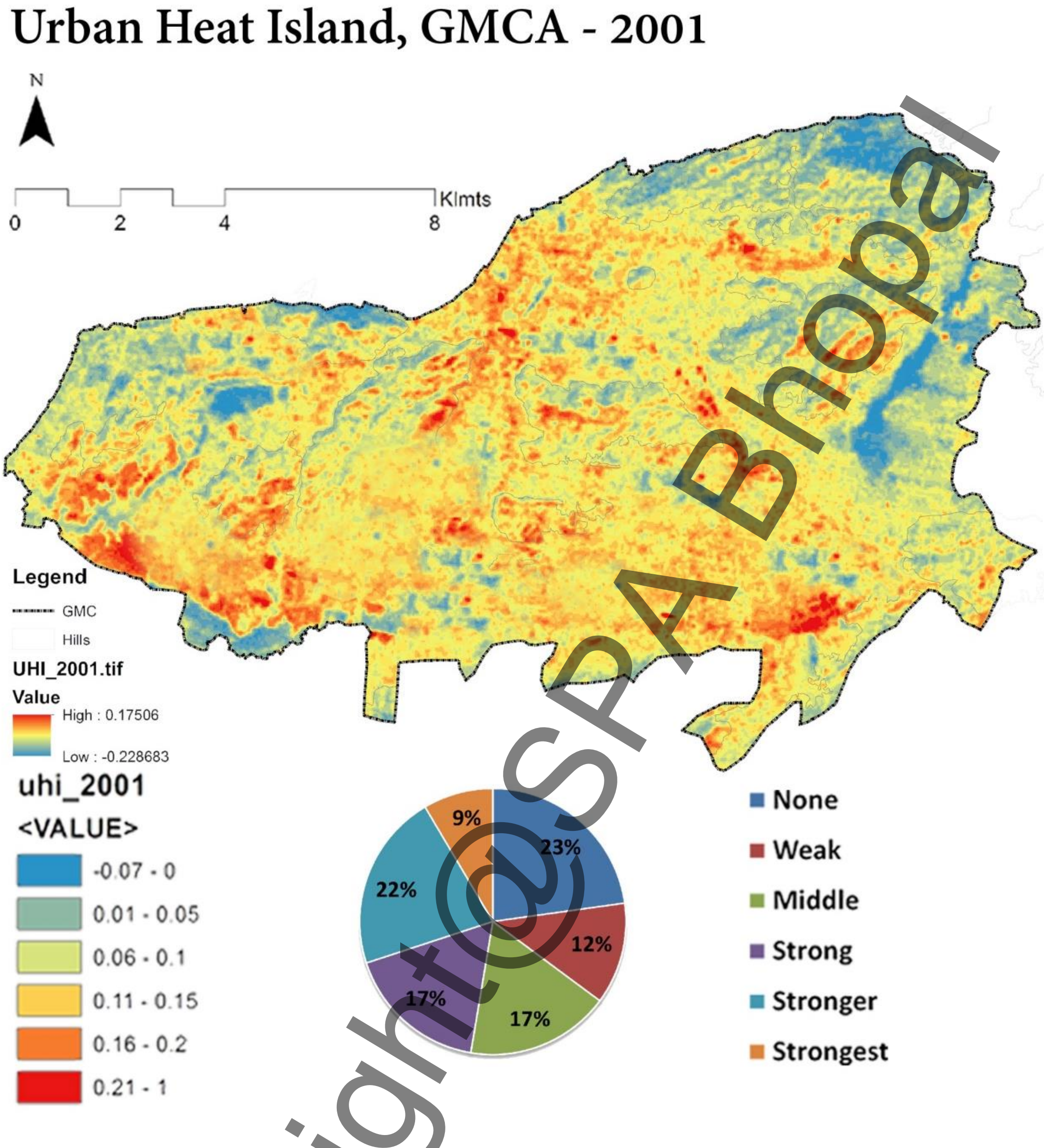
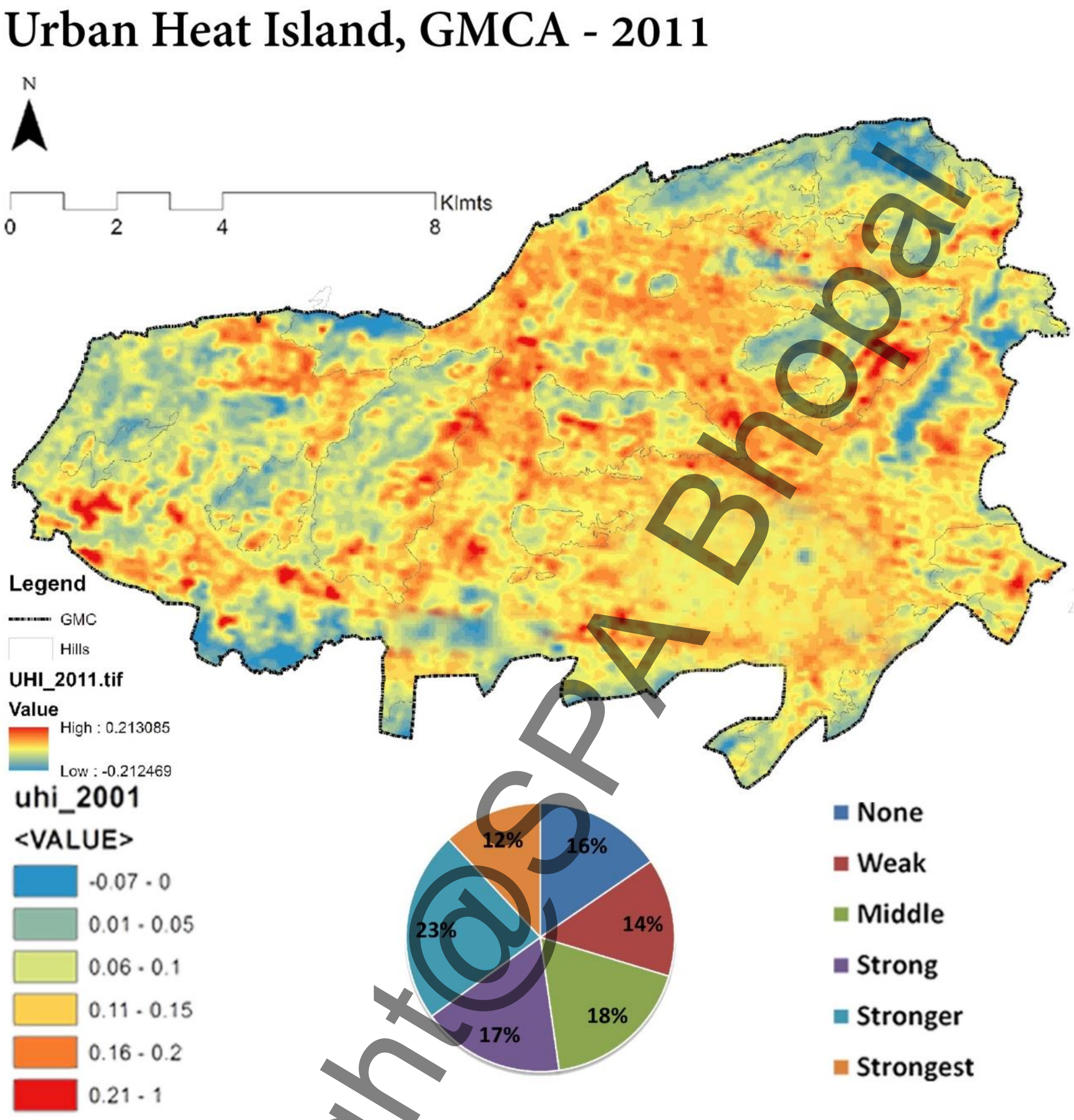


Figure 37: Urban Heat Island of Guwahati City – 2001
Source: Generated from Landsat image

2001 Guwahati UHI Classification			
Sl. No	Urban thermal field variance index	Urban heat island phenomenon	Area
1	<0	None	39.527
2	0 – 0.05	Weak	21.427
3	0.05 – 0.1	Middle	30.353
4	0.1 – 0.15	Strong	29.990
5	0.15 – 0.2	Stronger	37.350
6	0.2 - 1.00	Strongest	14.754

Table 18: Classification of Urban Heat Island of Guwahati in 2001
Source: Generated from Landsat image

Copyright@SPA Bhopal

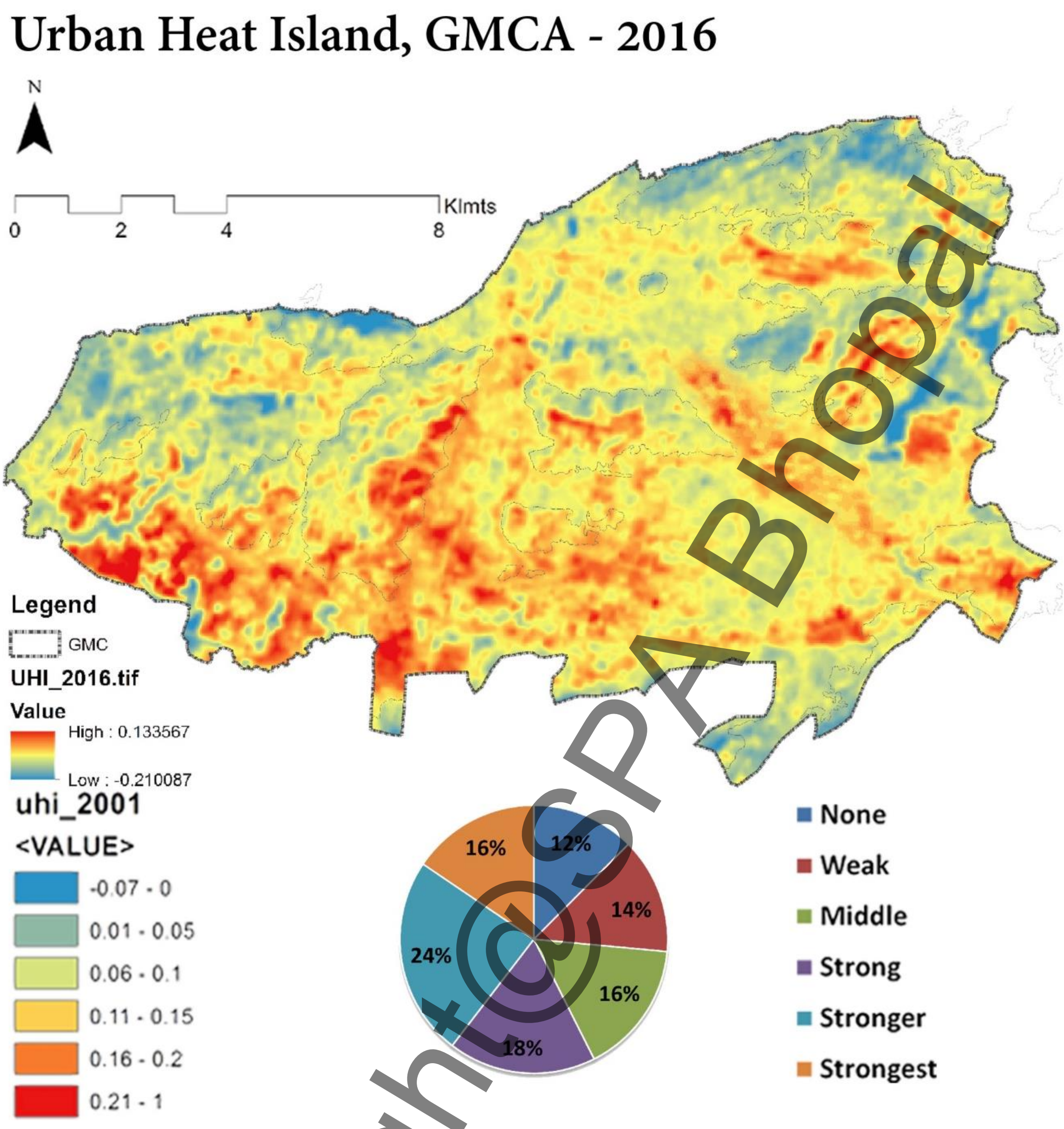


Copyright@SPA Bhopal

Figure 38: Urban Heat Island of Guwahati City – 2011
Source: Generated from Landsat image

2011 Guwahati UHI Classification			
Sl. No	Urban thermal field variance index	Urban heat island phenomenon	Area
1	<0	None	27.527
2	0 – 0.05	Weak	25.437
3	0.05 – 0.1	Middle	32.286
4	0.1 – 0.15	Strong	30.789
5	0.15 – 0.2	Stronger	41.098
6	0.2 - 1.00	Strongest	21.369

Table 19: Classification of Urban Heat Island of Guwahati in 2011
Source: Generated from Landsat image



Copyright@SPA Bhopal

Figure 39: Urban Heat Island of Guwahati City – 2016
Source: Generated from Landsat image

2016 Guwahati UHI Classification			
Sl. No	**Urban thermal field variance index**	**Urban heat island phenomenon**	**Area**
1	<0	None	23.527
2	0 – 0.05	Weak	26.396
3	0.05 – 0.1	Middle	30.353
4	0.1 – 0.15	Strong	33.683
5	0.15 – 0.2	Stronger	45.329
6	0.2 - 1.00	Strongest	29.286

Table 20: Classification of Urban Heat Island of Guwahati in 2016
Source: Generated from Landsat image

5.4.1 Estimation of Urban Heat Island of Forest Areas of Guwahati Municipal Corporation Area (GMCA)

Here, in this study, the notified forest areas were considered to assess the current pattern forest cover in the district.

5.4.1.1 Urban Heat Island of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2001

2001 Urban Heat Island Effect Of Forest Areas Of Guwahati				
Sl. No	**Forest Name**	**Urban thermal field variance index**	**Urban heat island phenomenon**	**Ecological evaluation index**
1	Sonaighuli Forest	0.044	Weak	Good
2	Hengerabari Forest	-0.064	None	Excellent
3	Fatasil Forest	0.121	Middle	Normal
4	Silapahar Forest	0.039	Weak	Good
5	Khanapara Forest	0.112	Middle	Normal
6	Jalukbari Forest	-0.062	None	Excellent

Table 21: Urban Heat Island of Forest Areas of GMCA – 2001
Source: Generated from Landsat image

UHI among all the forest within GMCA, the Fatasil Forest has found to be more with a value of UHI - 0.116 having Normal Ecological Evaluation Index.

5.4.1.2 Urban Heat Island of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2011

2011 Urban Heat Island Effect Of Forest Areas Of Guwahati				
Sl. No	**Forest Name**	**Urban thermal field variance index**	**Urban heat island phenomenon**	**Ecological evaluation index**
1	Sonaighuli Forest	0.043	Weak	Good
2	Hengerabari Forest	0.059	Weak	Good
3	Fatasil Forest	0.151	Strong	Bad
4	Silapahar Forest	0.068	Middle	Normal
5	Khanapara Forest	0.121	Middle	Normal
6	Jalukbari Forest	-0.088	None	Excellent

Table 22: Urban Heat Island of Forest Areas of GMCA – 2011
Source: Generated from Landsat image

Copyright@SPA Bhopal

Change in UHI of Fatasil Forest from 2001 - 2011 has been determined to be 0.035, increased from 0.116 to 0.151 i.e. Ecological Evaluation Index - from Normal to Bad.

5.4.1.3 Urban Heat Island of Forest Areas of Guwahati Municipal Corporation Area (GMCA) – 2016

2016 Urban Heat Island Effect Of Forest Areas Of Guwahati				
Sl. No	**Forest Name**	**Urban Thermal field Variance index**	**Urban heat Island Phenomenon**	**Ecological evaluation index**
1	Sonaighuli Forest	0.088	Weak	Good
2	Hengerabari Forest	0.124	Middle	Normal
3	Fatasil Forest	0.187	Stronger	Worst
4	Silapahar Forest	0.097	Middle	Normal
5	Khanapara Forest	0.141	Strong	Bad
6	Jalukbari Forest	0.047	Weak	Good

Table 23: Urban Heat Island of Forest Areas of GMCA – 2016
Source: Generated from Landsat image

Change in UHI of Fatasil Forest from 2011 - 2016 has been determined to be 0.036, increased from 0.151 to 0.187 i.e. Ecological Evaluation Index - from Bad to Worst.

5.5 Micro Study area Site Analysis

For further digging into the Urban Heat Island effect within the Guwahati city's urban forest, the UHI phenomenon of all the forest areas are analysed and the most affected forest area has been selected as the detailed study patch for this research.

This micro level study area is selected to study the relationship of UHI with the native parameters and context. The micro study patch will be selected on the basis of more intensified urban heat island effects on the forests of Guwahati. A buffer area will be considered along with the forest area to break down the urban heat island phenomenon in details.

Copyright@SPA Bhopal

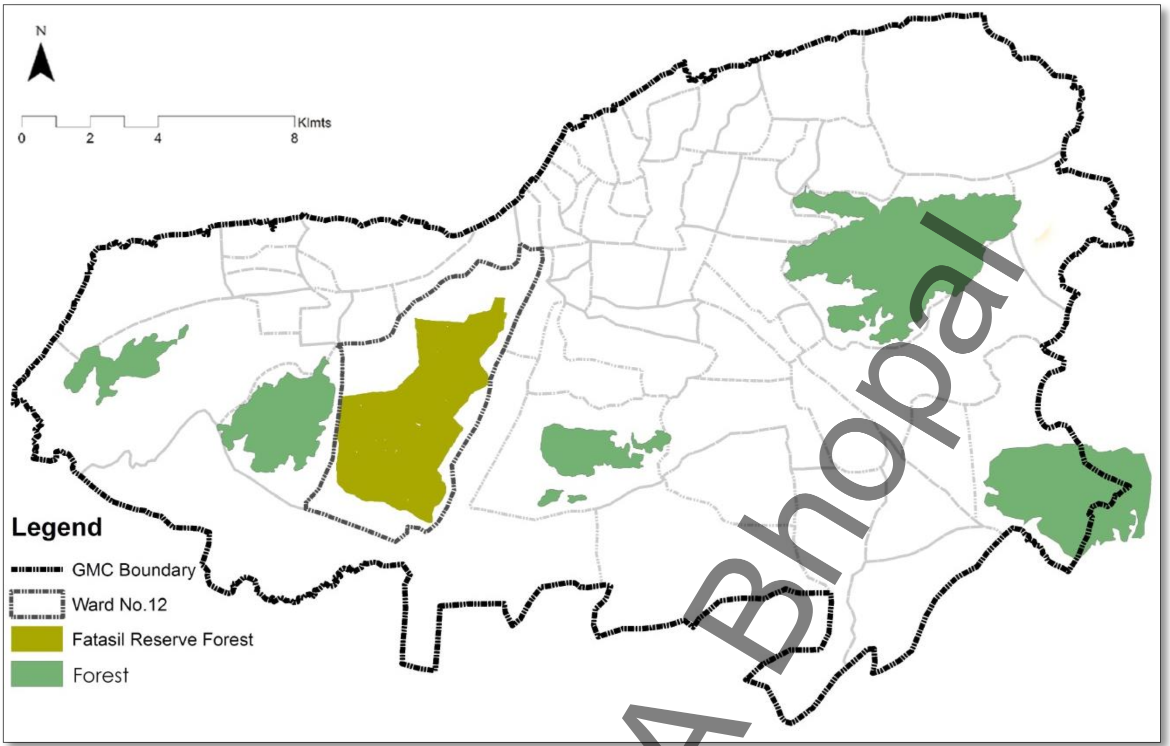


Figure 40: Micro Study Area - Fatasil Forest, Ward no. – 12

Fatasil Forest				
Year	**Vegetation (Area sq.km)**	**LST (°C)**		**UHI**
		Max.	**Min**	
2001	3.66	31.21	24.34	0.121
2011	4.6	32.72	25.22	0.151
2016	3.2	35.11	26.43	0.187

Table 24: Land Surface Temperatures and Urban Heat Island of Fatasil Forest in 2001, 2011 and 2016

The Forest area within Fatasil Hills has an increasing UHI effect and has increasing values of: [- 0.03 and 0.036]

Change in Temperature			
Sl. No	**Forest**	**2001 - 2011**	
		Max. temp	Min. temp
1	Sonaighuli Forest	0.43	0.05
2	Hengerabari Forest	0.08	0.55
3	Fatasil Forest	1.51	0.88
4	Silapahar Forest	0.97	0.06
5	Khanapara Forest	0.52	0.13
6	Jalukbari Forest	0.15	0.76

Copyright@SPA Bhopal

Change in Temperature			
Sl. No	**Forest**	**2011 - 2016**	
		Max. temp	Min. temp
1	Sonaighuli Forest	2.57	0.95
2	Hengerabari Forest	0.6	0.91
3	Fatasil Forest	2.39	1.21
4	Silapahar Forest	1.31	0.45
5	Khanapara Forest	0.05	0.87
6	Jalukbari Forest	0.45	0.24

Table 25: Highlighted rows are the LST for Fatasil Forest, which is estimated and observed to be more among the other forest area
Source: Generated from Landsat image

Thus, the Ecological Evaluation Index for Fatasil Forest area is ranging from -

Normal to Bad and then to Worst.

Thus, the Fatasil forest has been observed to be severly affected area among the other forest area in context to land surface temperature and urban heat island and hence more affects that area. This is regarded as the micro study patch for this research which falls under ward number 12 of GMCA.

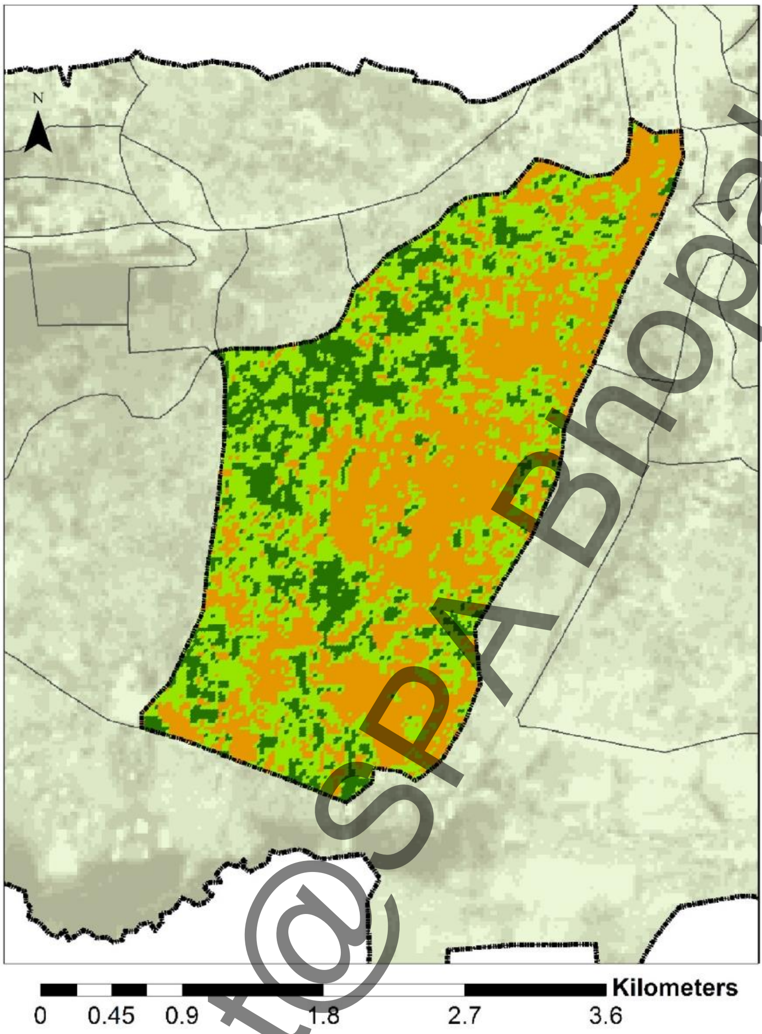
5.5.1 Micro Study Area Analysis

The study patch is located at [26°.8’36.033” N, 91°.42’31.94”E] within Guwahati Municipal Corporation Area (GMCA) Area.

For better analysis of the Forest area, the overall ward number 12 is taken into account to observe the land use of the area. The area of ward number 12 is - 7.06 sq. km.

Copyright@SPA Bhopal

5.5.1.1 Analysis of Vegetation Index of the Study Patch [Ward no. 12] - 2001

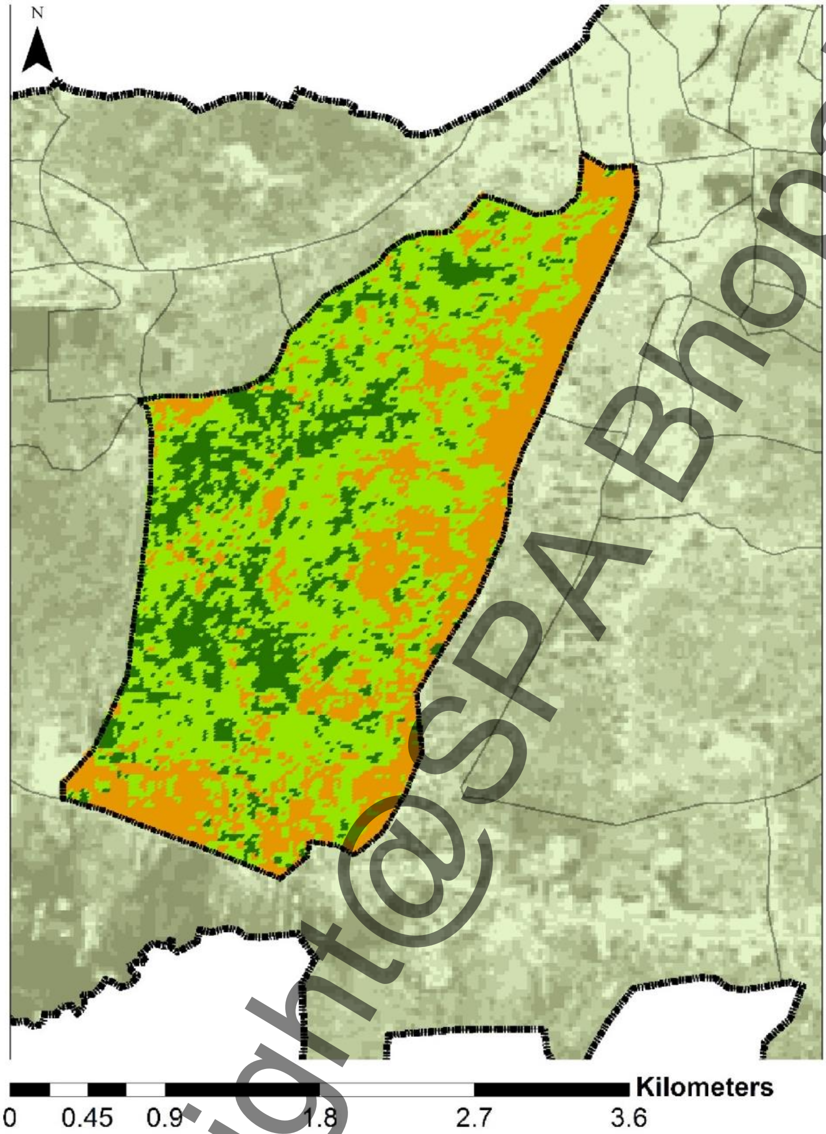


Vegetation Classification of Ward No.12 - 2001	
Type	Area(sq.km)
BareSoil	5.58
Sparse Vegetation	5.12
Dense Vegetation	2.21

Figure 41: Normalized Difference Vegetation Index (NDVI) of Ward No. 12- 2001
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.5.1.2 Analysis of Vegetation Index of the Study Patch [Ward no. 12] - 2011

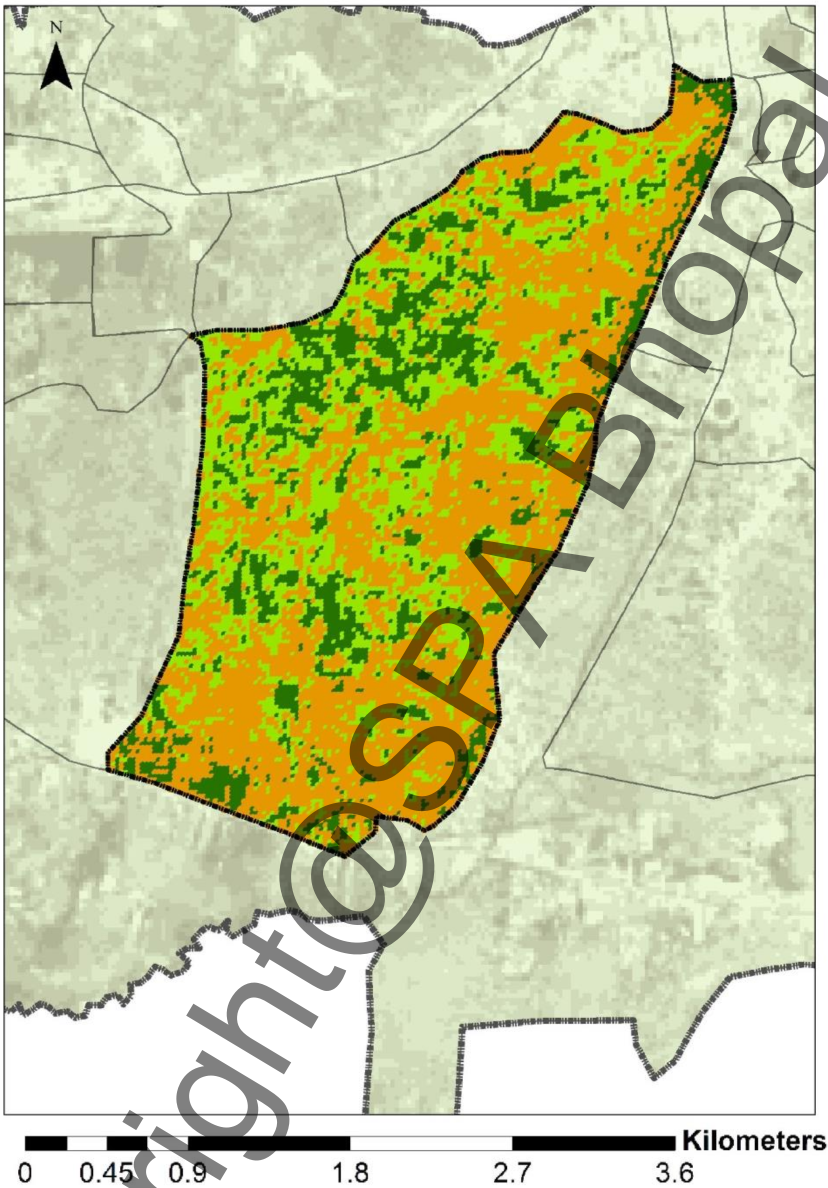


Vegetation Classification of Ward No.12 - 2011	
Type	**Area (sq.km)**
Bare soil	3.66
Sparse Vegetation	7.05
Dense Vegetation	2.16

Figure 42: Normalized Difference Vegetation Index (NDVI) of Ward No. 12- 2011
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.5.1.3 Analysis of Vegetation Index of the Study Patch [Ward no. 12] - 2016



Vegetation Classification of Ward No.12 - 2016	
Name	**Area**
Bare Soil	6.47
Sparse Vegetation	4.11
Dense Vegetation	1.32

Copyright@SPA Bhopal

Figure 43: Normalized Difference Vegetation Index (NDVI) of Ward No. 12- 2016
Source: Generated from Landsat image

5.5.1.4 Analysis of Land Surface Temperature (LST) of the Study Patch [Ward no. 12] – 2001

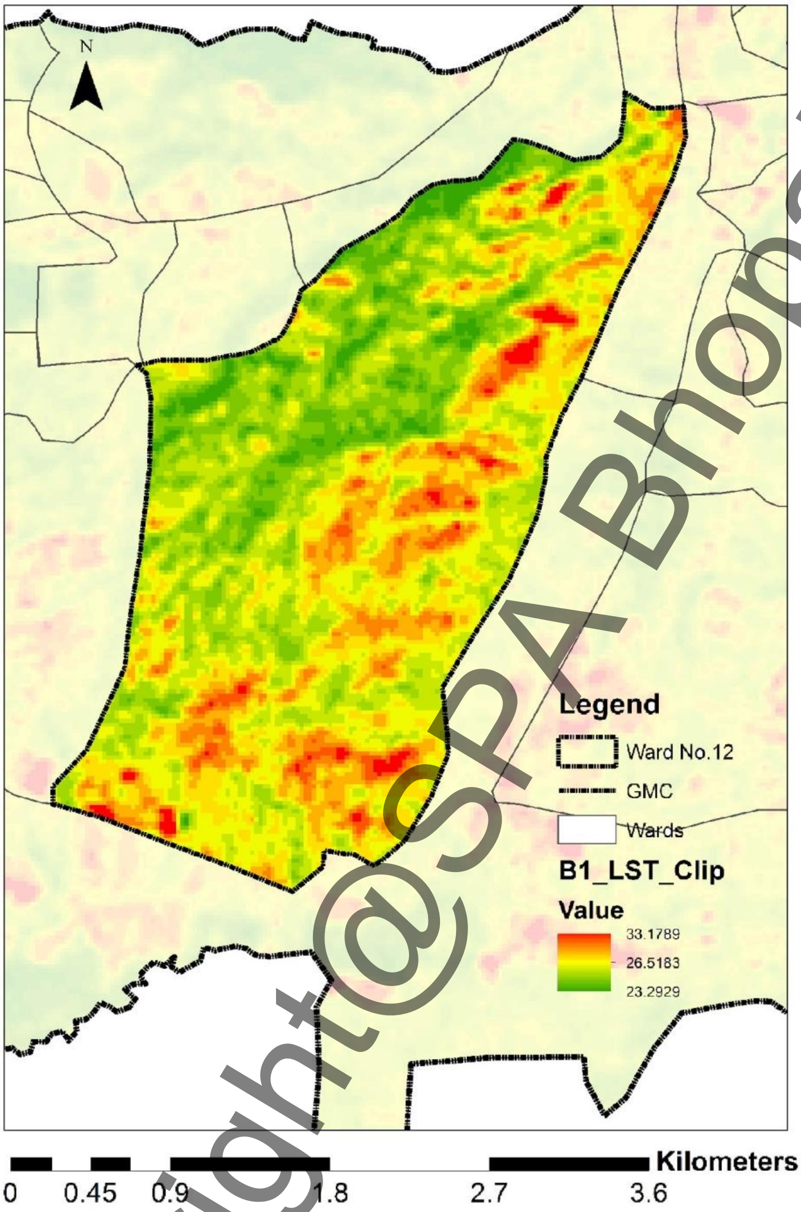
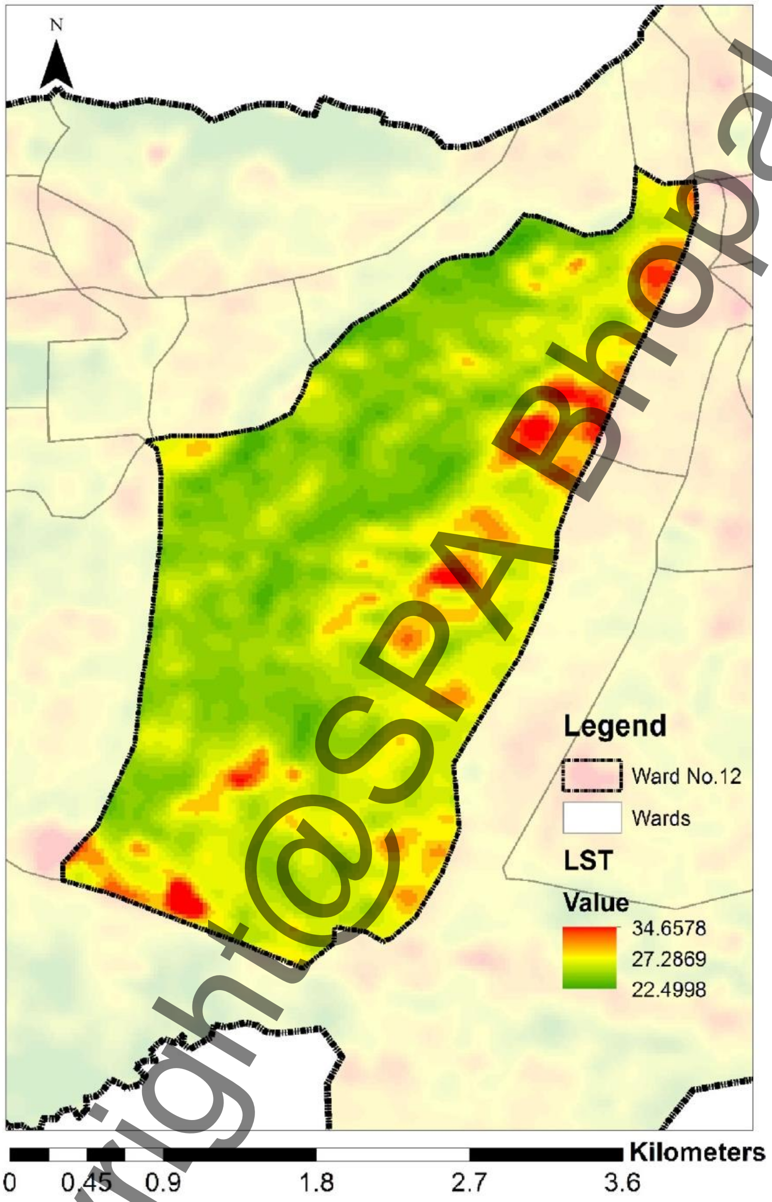


Figure 44: Land Surface Temperature (LST) of Ward No. 12- 2001
Source: Generated from Landsat image

Copyright@SPA Bhopal

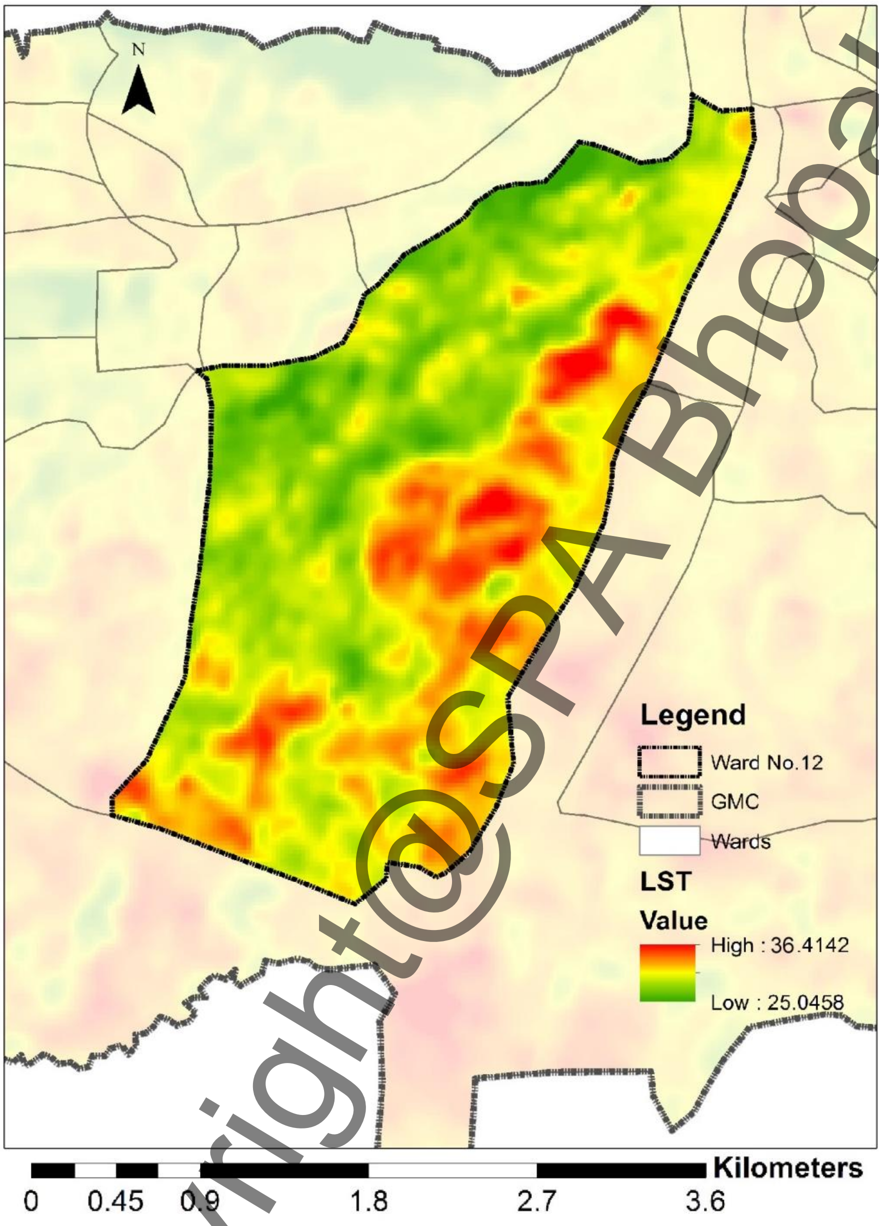
5.5.1.5 Analysis of Land Surface Temperature (LST) of the Study Patch [Ward no. 12] – 2011



Copyright@SPA Bhopal

Figure 45: Land Surface Temperature (LST) of Ward No. 12- 2011
Source: Generated from Landsat image

5.5.1.6 Analysis of Land Surface Temperature (LST) of the Study Patch [Ward no. 12] – 2016



Copyright@SPA Bhopal

Figure 46: Land Surface Temperature (LST) of Ward No. 12- 2016
Source: Generated from Landsat image

5.5.1.7 Analysis of Urban Heat Island (UHI) of the Study Patch [Ward no. 12] – 2001

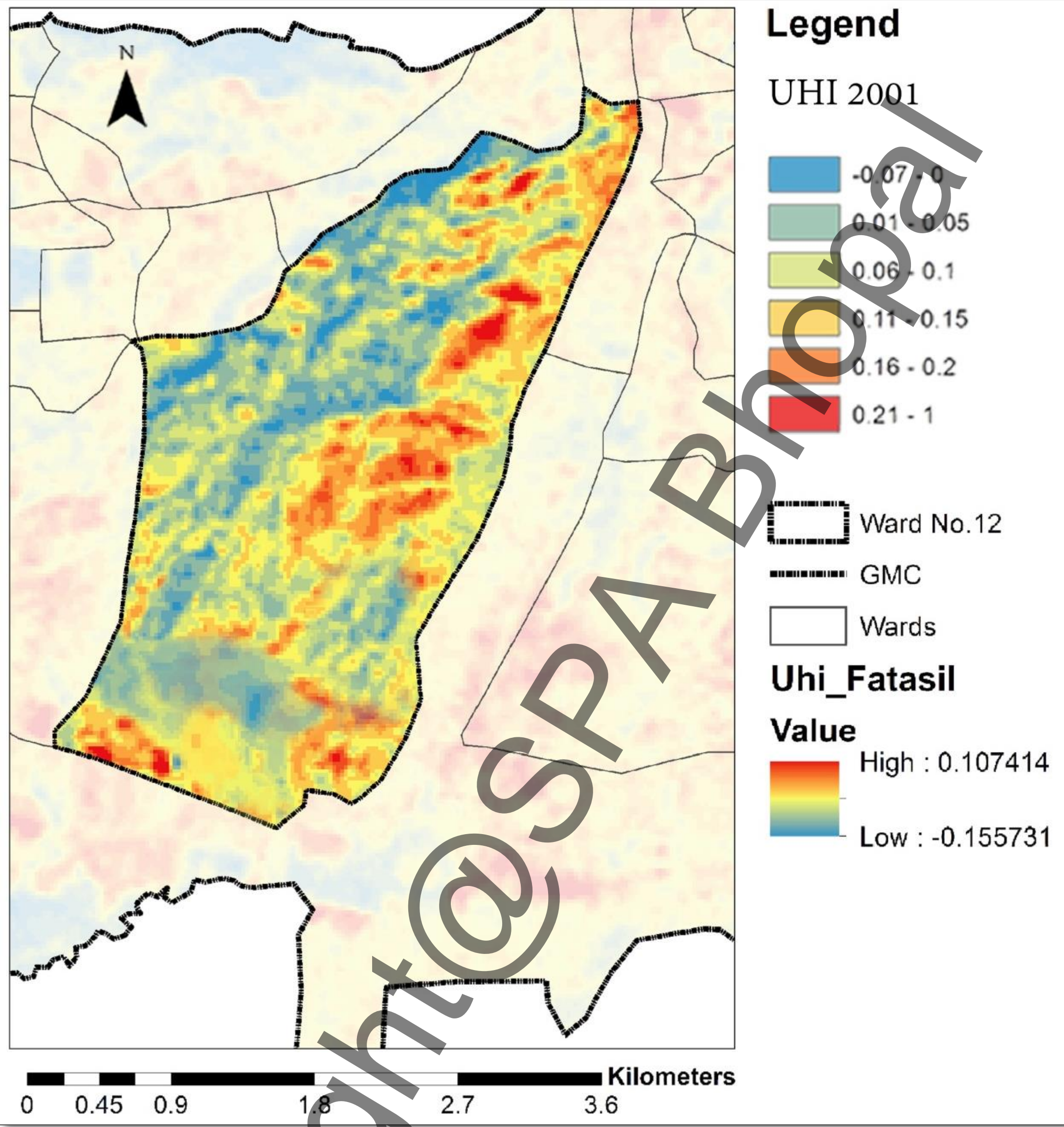
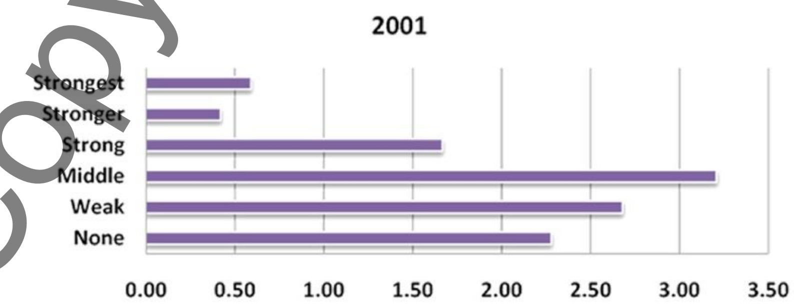


Figure 47: Urban Heat Island (UHI) Map of Ward No. 12 – 2001
Source: Generated from Landsat image



	None	Weak	Middle	Strong	Stronger	Strongest
Area[sq.kl]	2.28	2.68	3.21	1.67	0.42	0.59

Figure 48: Area estimated for UHI phenomenon at ward no. 12 in 2001
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.5.1.8 Analysis of Urban Heat Island (UHI) of the Study Patch [Ward no. 12] – 2011

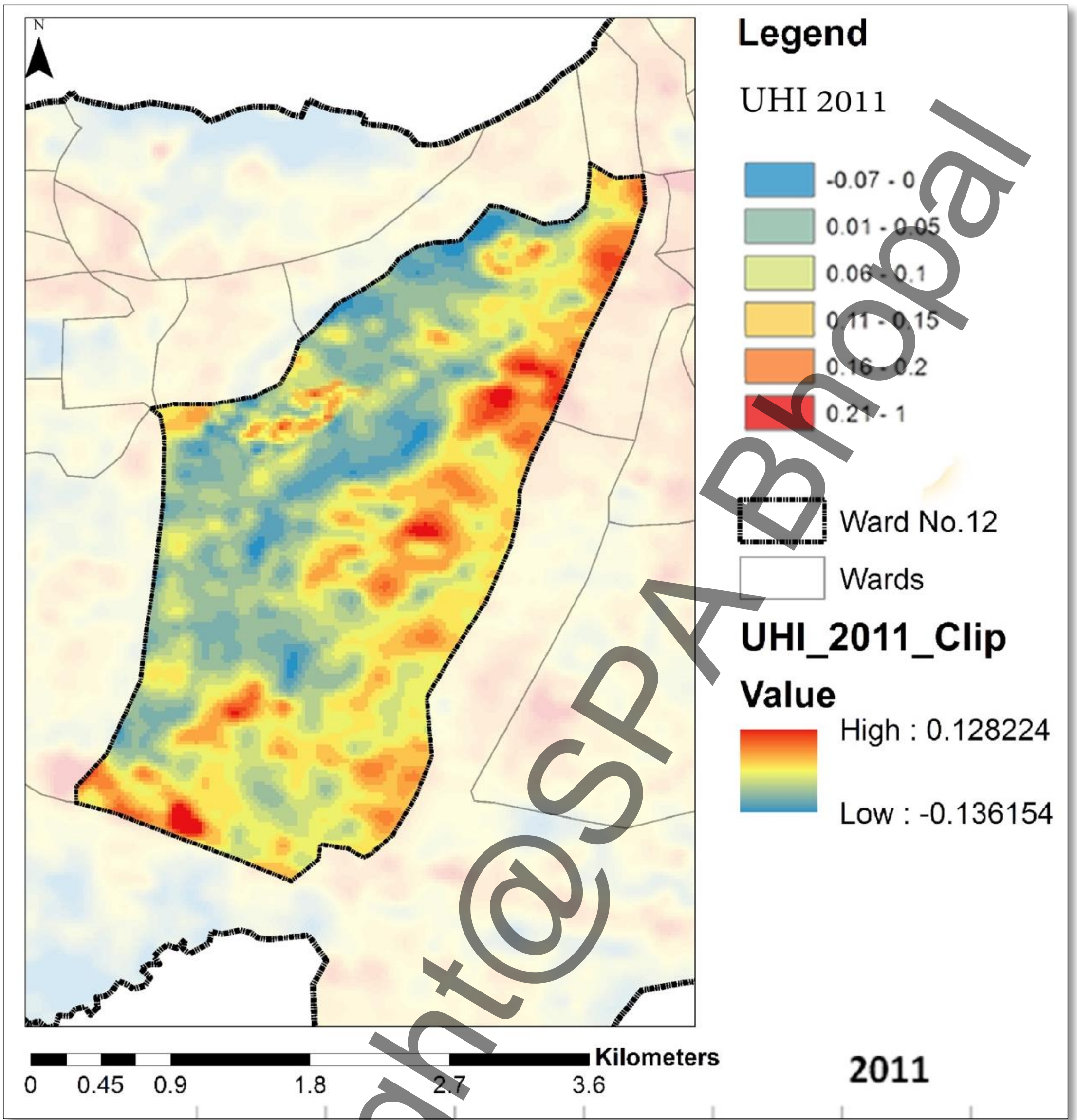
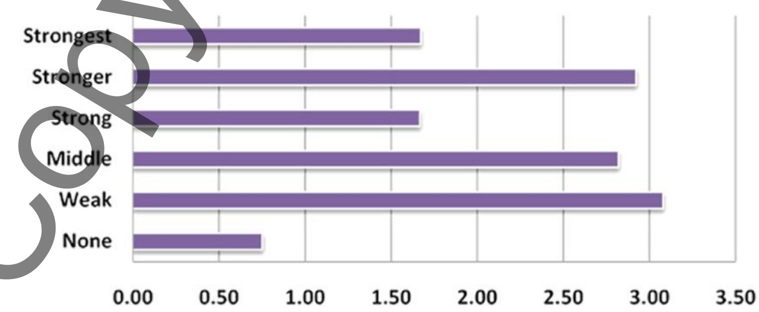


Figure 49: Urban Heat Island (UHI) Map of Ward No. 12 – 2011
Source: Generated from Landsat image



	None	Weak	Middle	Strong	Stronger	Strongest
Area[sq.kl]	0.75	3.08	2.82	1.67	2.92	1.67

Figure 50: Area estimated for UHI phenomenon at ward no. 12 in 2011
Source: Generated from Landsat image

Copyright@SPA Bhopal

5.5.1.9 Analysis of Urban Heat Island (UHI) of the Study Patch [Ward no. 12] – 2016

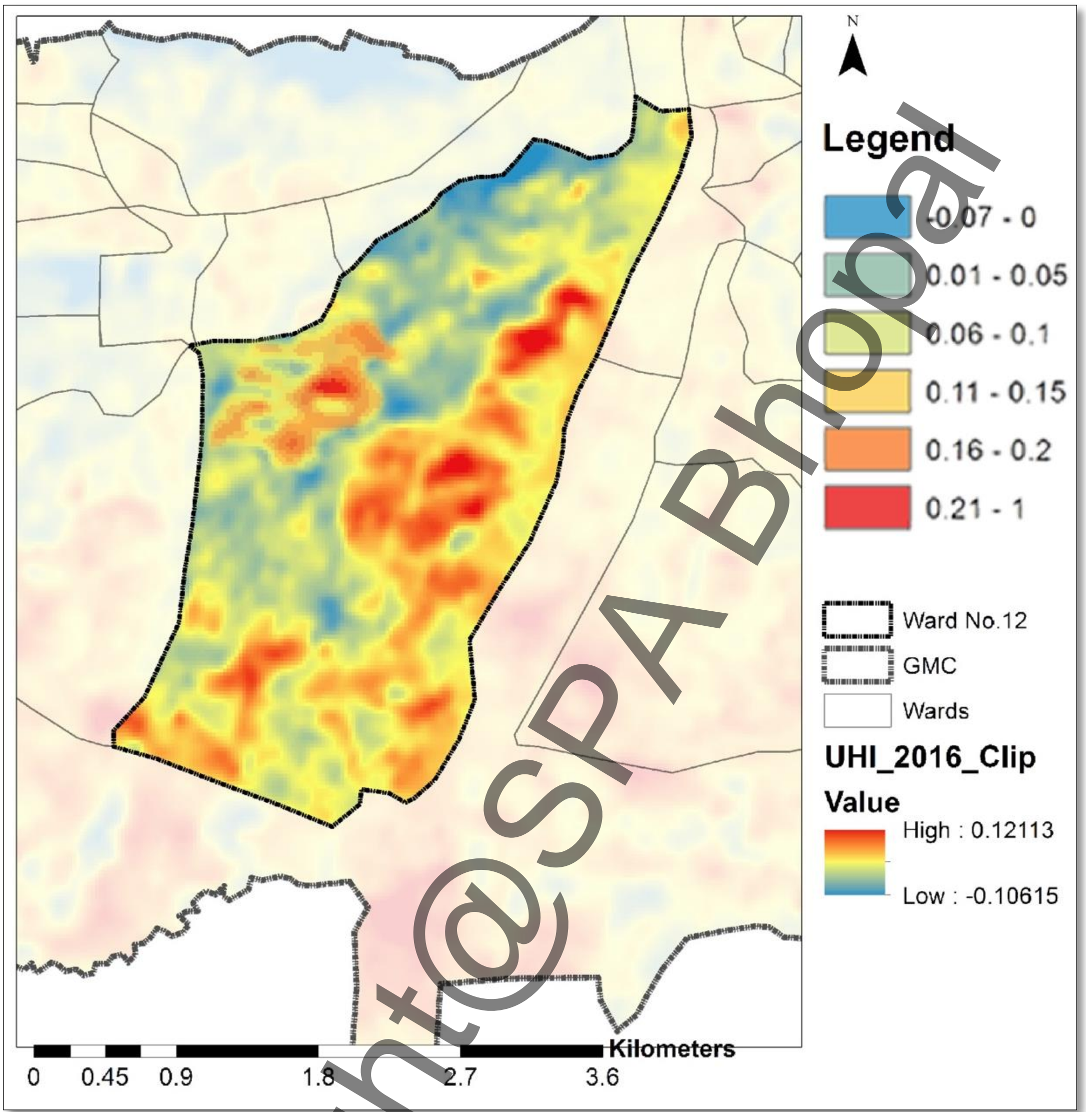
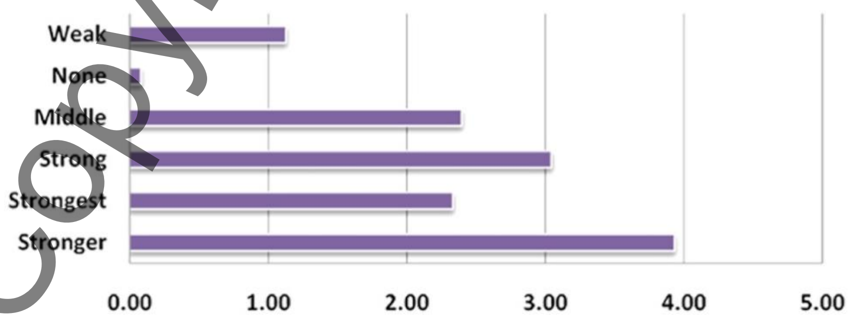


Figure 51: Urban Heat Island (UHI) Map of Ward No. 12 – 2016
Source: Generated from Landsat image



	Stronger	Strongest	Strong	Middle	None	Weak
Area	3.93	2.33	3.04	2.40	0.08	1.13

Figure 52: Area estimated for UHI phenomenon at ward no. 12 in 2016
Source: Generated from Landsat image

Copyright@SPA Bhopal

6. Proposals

In this chapter, two of the components for reducing the urban heat island through vegetation have been concentrated. Those are - Identification and Propose appropriate conservation measures for reducing UHI in the study patch.

6.1 Literature on Afforestation

6.1.1 Interventions on sloping lands in Asia: Selected observations

Governments and non-government agencies promote policies for reforestation, afforestation, forest management, and agroforestry on sloping lands to -

- Mitigate soil erosion, water loss, land degradation,
- Enhance specific ecosystem goods and services (often for people downstream)
- Conserve biodiversity
- Promote sustainable development

6.1.2 Examples of Interventions

- China: Conversion of Cropland to Forest Program (CCFP)
- India: dam building, cash crop production in the North and northeast, biodiversity conservation in the south and southwest
- Thailand: Water provision for lowland rice cultivation
- Indonesia: Reforestation for PES, timber production

6.1.3 Forest Legislation in India

6.1.3.1 Colonial Forest Legislation

- 1865, 1894, 1927: Indian Forest Act (IFA)- Forest control and management for timber extraction. Forests designated as Protected forests (PF) and reserve forests (RF)
- 1878: Forest Act –communities could seek concessions to use forests (for NTFPs such as fuel, fodder, etc) in Village Forests (VF)

6.1.3.2 Forest Legislation in Independent India

- 1952: National Forest Policy - Afforestation, reforestation, regulation of shifting cultivation (60% forest cover on of slopes,20% on plains)

Copyright@SPA Bhopal

- 1988: National Forest Policy, manage forests to provide fuel wood, fodder, timber and non-timber forest products to meet the needs of local people living adjacent to forests
- Also encourage community or social forestry, and “farm forestry” to meet local needs.
- 1990: Joint Forest Management (JFM) rural forest dependent communities to “partner” with Forest Department to plant, restore and manage degraded forests.
- Working Group on Forests, 11th Five Year Plan (2007-2012): emphasis on the inclusion of other natural ecosystems (including treeless areas and trees outside forests) to forest cover to achieve the targets set in 1988 National Forest Policy (increase forest cover to 33% of national area).
- It also recommended that tribal farmers should take up farm forestry; support should be provided to farmers for extension of agroforestry and farm forestry so that the fuel wood demand can be met from them
- 2014 National Agroforestry Policy

6.1.4 Interventions in upland and hilly areas in India

- Watershed Development to arrest land degradation and watershed restoration
- Hill Area Development Programme and Western Ghats Development Programme: infrastructure development for the local communities to focus on eco-restoration and eco-development.
- Farm Forestry Programmes, and later social forestry programs to grow trees to meet the fuel, fodder, food needs of rural people
- Agroforestry: multiple goals including increasing forest cover, meeting subsistence needs, and supplying commercial products.

6.1.5 North Eastern Region Community Resource Management Project for Upland Areas

- Joint Program between North East Council, International Fund for agriculture Development and ICIMOD. Designed from 1994-1997.
- Project villages selected on the criteria such as dependence on jhum, small farm acreage, rainfed cultivation and prevalence of disadvantaged families.

Copyright@SPA Bhopal

- Objective was to improve livelihoods through better management of natural resources.
- Reduction in area under jhum cultivation, development of terraced and irrigated lands and uptake of diversified cropping particularly horticultural crops have been some of the achievement of the program.

National Policies

Afforestation in Hilly Areas was recently more focused to the Indian Parliament on July, 2016. The Ministry of Environment, Forests and Climate Change (MoEF & CC) is implementing a centrally sponsored “National Afforestation Programme (NAP)” scheme for regeneration and restocking of degraded forests in the country. The scheme is implemented in participatory mode under the Joint Forest Management by State Forest Development Agency (SFDA) at the State level, Forest Development Agency (FDA) at the forest division/district level and Joint Forest Management Committee (JFMC) at the village level. The Scheme is implemented in 800 FDAs including 248 FDAs falling in hilly forest areas of the country. Under NAP, the grants are released to SFDAs and implementation is monitored at the state level.

6.2 Interventions at the study area

6.2.1 Identification of patches for Afforestation

The identification of patches for afforestation within the study area of ward No. 12 will be accomplished through different stages of exercises. These are as follows:

- The areas having the highest Land Surface Temperature (LST) and strong Urban heat island (UHI) in the present time.
- Identification of Internal Streets for avenue plantation.
- Identification of areas having Bare Soil and Sparse Vegetation.

6.2.2 Classification of the study area for estimation of areas of UHI phenomenon

Ward No. 12 has been classified under six categories of UHI from the generated UHI Map of the study area. Further, the area of these categories has been calculated in GIS and thus from the table it could be observed that the stronger category has the highest UHI.

Copyright@SPA Bhopal

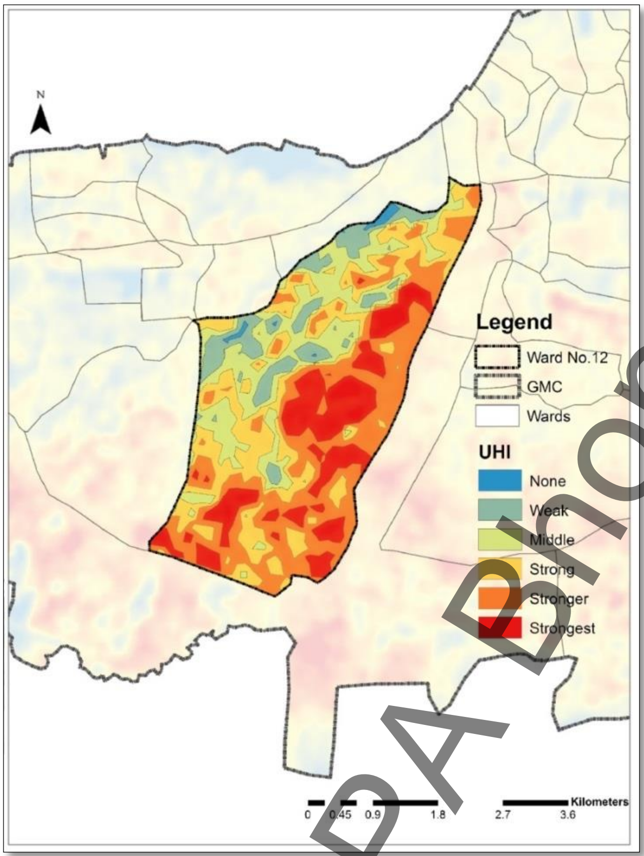


Figure 53: UHI Classification of Ward 12
Source: Generated from Landsat image

UHI Phenomenon Classification	
Name	**Area** [m²]
Stronger	3.93
Strongest	2.33
Strong	3.04
Middle	2.40
None	0.08
Weak	1.13

Table 26: Classification of UHI at ward no. 12
Source: Generated from Landsat image

Figure 54: Vacant land left for few years could be used as a forest stand and thereby used for its valuable benefits

Copyright@SPA Bhopal

6.2.3 Identification of patches in the Study Area

The afforestation should be done after the identification of certain patches of land in the study area patch i.e. in ward no. 12. The possibilities for selection of land for plantation has

6.2.3.1 Major roads and internal streets

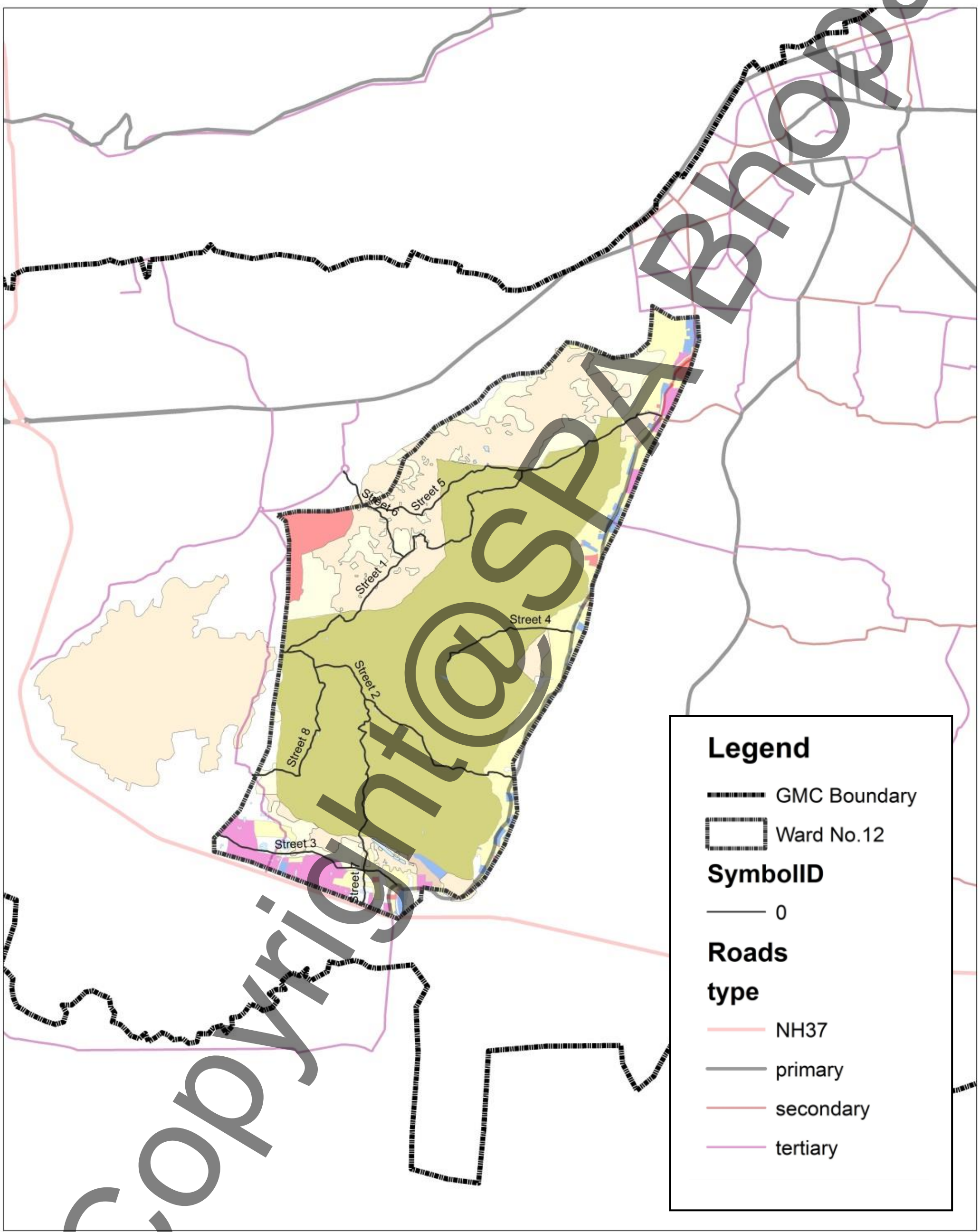


Figure 55: Blow- up of ward no. 12 with its major roads

Copyright@SPA Bhopal

6.2.4 Planting Measures

Selection of trees for afforestation in the identified patches in the study area depends on :

- **Identification of Native tree species:** The management and protection of forests and afforestation of barren and deforested lands with the purpose of helping in the environmental, social and rural development.
- **Tree species with high Leaf Area Index and Foliage Density:** Shading criteria is achieved through this parameter and thus the evapotranspiration will be improved thereby giving more cooling effect in the surrounding area.

The vegetation of Guwahati is predominantly a Tropical one and can broadly be classified as follows:

- Tropical
- Sub-tropical
- Vegetation of Aquatic and Marshy habitats
- Climbers and Thinners
- Parasites
- Epiphytes
- Hedge plants

Process

- Identification of predominate species of Guwahati
- Average Leaf Area Index [LAI] of those species
- Type [Evergreen or Deciduous] and their identification
- Use of more evergreen species

Leaf Area Index in Plant Species: Assam					
Sl.No	Dominant species	Common Name	LAI	Method	Type
1	Dendrocalamus strictus	Solid bamboo	4.08	Several direct	S-DECID
2	Hevea brasiliensis	Rubber tree	4.34	LAI-2000	EVER
3	Bamboosa arundinacea	Clumping bamboo	2.31	Hemispherical photograph	S-DECID
4	Pterocarpus marsupium et al.	Indian kino tree	3.76	Allometry	S-DECID
5	Ficus religiosa	Peepal tree	7.58	Destructive	EVER
6	Tectona grandis	Teak	5.26	Destructive	S-DECID
7	Shorea robusta	Shala tree	6.11	Destructive	EVER
8	Gmelina arborea	Gamhar tree	2.31	Hemispherical photograph	S-DECID
9	Mangifera indica	Mango Tree	6.31	Hemispherical photograph	S-DECID
10	Dillenia indica	Elephant apple	2.31	Hemispherical photograph	S-DECID
11	Terminalia arjuna	Arjun tree	4.31	Hemispherical photograph	EVER
12	Mesua ferrea	Indian rose chestnut	3.76	Allometry	S-DECID
13	Cassia fistula	Golden rain tree	3.76	Algometry	EVER
14	Bauhinia acuminata	White orchid-tree	3.76	Allometry	S-DECID

Table 27: LAI of plant species in Assam

Copyright@SPA Bhopal

Source : The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) for biogeochemical dynamics is one of the NASA Earth Observing System Data and Information.

6.2.5 Planting techniques

Two major models has been considered for detailing out planting techniques and best practices.

6.2.5.1 Assisted Natural Regeneration (ANR)

Assisted Natural Regeneration (ANR) aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest The benefits of using Assisted Natural Regeneration (ANR):

- A cost efficient way of regenerating forest
- Contribute to strengthening biodiversity
- Increase carbon sequestration and carbon sinks, which contribute to climate change mitigation.

  Assisted Natural Regeneration (ANR) Model is further sub divided into:

1. **Eco-Restoration Model**

- **Core Species**: No planting is proposed in this model. Only dibbling of seeds of native species will be taken up.

- **Planting Technique:**

  i. Protection through excavation of cattle proof trenches @ 72 RMT/ 90 CMT per ha.
  ii. Sowing of seeds of Glyrecidia, Planting of Agave suckers on the CPT mounds in open area and Duranta cuttings on the CPT mounds in partially shaded area in high forest locations.
  iii. Watch and Ward for every 50 ha.
  iv. Dibbling of seeds of Sandal, Neem, Seetaphal, Honge and other native species.
  v. Clearing unwanted growth, Climber cutting, Tending, cutting back of half cut stumps / stools to get good coppice growth and singling of coppice growth @ 400 plants/ha. The training of local community/ VFC members and sharing of biomass and its documentation shall be made in this operation.

Copyright@SPA Bhopal

2. Supplemental Planting Model

Species Proposed

1.	Bevu	Azadiracta indica
2.	Tapasi	Holoptelia integrifolia
3.	Seetaphal	Annona Squamosa
4.	Honge	Pongamia pinnata
5.	Kamara	Hardwikia binata
6.	Bage	Albezzia lebbek
7.	Ficus	Ficus bengalensis
8.	Sisso	Dalbargia Sisso
9.	Ailanthus	Ailanthus excelsa
10.	Hale	Writia tinctoria
11.	Ude	Steriospermum chelanoides
12.	Dhupa	Boswella Serrata
13.	Nelli	Emblica officinalis
14.	Honne	Pterocarpus marsupium

Moist Deciduous Forests

1.	Teak	Tectona grandis
2.	Nandi	Legarstroemia lanceolata
3.	Honne	Pterocarpus marsupium
4.	Mathi	Terminalia alata
5.	Shivane	Gmelina arboria
6.	Kindal	T.paniculata
7.	Beete	Dalbargia latifolia
8.	Tare	T.belerica
9.	Bamboo	Bambusa arundinasia
10.	Muthuga	Butea monosperma
11.	Hippe	Madhuca latifolia
12.	Sandal	Santalum album
13.	Nelli	Emblica officinalis
14.	Neral	Sizyzium cumini
15.	Dhaman	Grevia tilifolia
16.	Kaval	Careya arborea
17.	Harada	Terminatia chebula

Copyright@SPA Bhopal

Planting Technique:

1. Identified area is demarcated and surveyed and area will be closed with CPT / barbed wire fence.
2. The SMC works are taken up from ridge to valley concept. SMC trenches of 5X1X1 mts. across rills with spill ways and nala bunds are created.
3. The young regeneration is protected, the coppice growth is promoted by cutting back of stumps, singling of multiple shoots. Training of local community / VFC members for singling, pruning, cutting back, sharing of biomass and its documentation is done. This to be done by watch and ward persons.
4. Advance work is done by digging upto 200 pits of 75cm3 in dry zones, upto 400 pits of 60cm3 in other zones avoiding pitting near the existing root stock / regeneration.
5. Sowing of seeds of Prosopis, Glyrecidia in dry areas only. Planting of Agave suckers on the CPT mounds in open area and Duranta cuttings on the CPT mounds in partially shaded area in high forest locations.
6. At least 12 month old seedling in 10” X 16” polythene bags in dry zones and 10 months old 8” X 12” / 6” X 9” (for teak) polythene bags in other zones are used for planting.
7. Planting with Agave, Suckers/ bulbils and sowing of seeds of Bamboo, Sandal, Glyrecedia, Cassia, honge etc., on Mounds of SMC trenches and on Cattle Proof Trenches is done.
8. If necessary, further tending of root suckers, cutting back stumps, singling of coppice growth and soil working up to 400 plants/ha. is done during 3rd year involving local community / VFC members with documentation.

6.2.5.2 Artificial Regeneration Models (AR)

Artificial regeneration is taken up on barren, open areas, waste lands, blanks and laterate patches and forest areas where the canopy density or root stock is less than 10%. The site preparation is normally done by ripping by D-80 / D-120 dozers in dry and transitional zones and pitting is also done in the patches where ripping cannot be taken up in rocky patches, rugged nalas up to 100 pits per hectare with pit size 75 cm^3.

Copyright@SPA Bhopal

AR model for low fertility, eroded and rocky areas -

Area Description:

These are rocky eroded areas with very little or no top soil (less than 30 cm). The rainfall is scanty and ill distributed with high mean annual temperatures. The strategy for such areas is primarily to check the further degradation of sites and create a green cover using pioneer, colonizing species like Glyrecedia, C.Siamia, Agave etc., with a suitable mixture of hardy local species. The fast growing species like Glyrecedia cover up the site in 2-3 years and it is seen to compliment and facilitate the growth of inter planted local hardy species in course of time.

Core Species and Planting Pattern:

- In the locations where there is no chance of getting roots sucker and regeneration after ripping, the planting density is as follows:

1.	Glyrecedia, C.Siamia, Agave	1400 plants / ha.
2.	Honge, Seetaphal, Tapasi, Ficus	100 plants / ha.

Table 28: Plant species when root suckers is not found

- In the locations where there are chances of sufficient roots sucker and natural regeneration after ripping, the following core species-planting pattern shall be followed.

1.	Glyrecedia, C.Siamia, Agave	800 plants / ha.
2.	Honge, Seetaphal, Tapasi, Ficus	200 plants / ha.

Table 29: Plant species when root suckers is found

Copyright@SPA Bhopal

AR model for poorer sites in transitional areas –

a) Area Description:

These areas also have little or no top soil, eroded, rocky and of low fertility. However, the sites are located in "better rainfall and moderate temperature and weather conditions".

b) Core Species:

1.	Auriculiformis in >1000 mm rainfall areas	1500 plants / ha.
2a.	C.Siamia, Sisso, Sterospermum, Seemaruba, Kamara	1300 plants / ha.
	Honge, Tapasi, Ficus, Nelli, Cashew, Bevu.	200 plants / ha.
2b	In the locations where there are chances of sufficient roots sucker and regeneration after ripping the following core species planting pattern shall be followed:	
	C.Siamia, Sisso, Sterospermum, Seemaruba, Kamara	800 plants / ha.
	Honge, Tapasi, Ficus, Nelli, Cashew, Bevu	200 plants / ha.

Table 30: Coe species at moderate temperature

Copyright@SPA Bhopal

AR model for high fertile areas in transitional areas –

a) Area Description:

The sites are having better soil depth (30-60 cms) and are situated in better rainfall and moderate weather conditions, conducive for raising productive plantations of fuel and small timber. Very fertile areas in this zone are put under NTFP / Fruit Orchard Model.

b) Planting Pattern

Fast growing species like Kamara, C.Siamia, Sisso etc., in single species rows and species like Mango, Nerale, Nelli, Cashew at 10M spacing but in the ripped line only, without resorting to excavation of separate pits.

1.	A.auriculiformis in better rainfall areas and JFPM areas.	1500 plants / ha.
2a	C.Siamia, Sisso, Sterospermum, Seemaruba, Kamara	1100 plants / ha.
	Bamboo, Shivani, Nelli, Mango, Nerale, Cashew, Bage, Honge, Tapasi, Ficus	400 plants / ha.
2b.	In the locations where there are chances of sufficient roots suckers and regeneration after ripping the following core species planting pattern shall be followed.	
	C.Siamia, Sisso, Sterospermum, Seemaruba, Kamara	800 plants / ha
	Bamboo, Shivani, Nelli, Mango, Nerale, Cashew, Bage, Honge, Tapasi, Ficus	200 plants / ha.

Table 31: Coe species having better soil depth

6.3 Cost Analysis for plantation

- Trenching in ordinary soil up to a depth of 60 cm including removal and stacking of serviceable materials and then disposing of surplus soil, by spreading and neatly levelling within a lead of 50 m and making up the trenched area to proper levels by filling with earth or earth mixed with sludge or / and manure before and after flooding trench with water (excluding cost of imported earth, sludge or manure)

Copyright@SPA Bhopal

ICD No	Description	Unit	Qty	Rate	Amount (Rs.)
	LABOUR:				
0114	Beldar	day	0.71	368.00	261.28
9999	Sundries	L.S.	2.73	1.73	4.72
0115	Coolie	day	0.35	368.00	128.80
	TOTAL				394.80
	Add Water Charges @ 1%				3.95
	TOTAL				398.75
	Add C.P. & O.H. @ 15%				59.81
	Cost of 10 cum				458.56
	Cost of 1 cum				45.86
	Say				**45.85**

Source: Delhi schedule of rates, analysis of rates and specifications (horticulture & landscaping)

- Supplying and stacking of good earth at site including royalty and carriage upto 5 kms. Lead complete (earth measured in stacks will be reduced by 20% for payment).

Details of cost for one cum

ICD No	Description	Unit	Qty	Rate	Amount (Rs.)
	Excavation:				
0114	Beldar	day	0.177	368.00	65.14
0115	Coolie	day	0.167	368.00	61.46
0979	Royalty for good earth	cum	1.00	30.00	30.00
2241	Carriage of good earth by mechanical transport upto 5 km lead	cum	1.00	129.71	129.71
	TOTAL				286.30
	Add Water Charges @ 1%				2.86
	TOTAL				289.17
	Add C.P. & O.H. @ 15%				43.37
	Cost of 1 cum				332.54
	Say				**332.55**

Source: Delhi schedule of rates, analysis of rates and specifications (horticulture & landscaping)

Copyright@SPA Bhopal

7. Conclusion

During the last 15 years, the Guwahati Metropolitan Area has undergone phenomenal change in urban landscape that resulted in the loss of natural land cover. As a result, the surface temperature of the city has increased and a prominent urban heat island is formed in and around the settlement areas. All these have severe environmental and health consequences. The land use regulation plan of GMDA‟s Mater plan can be a tool for sustainability of natural land cover. But the continuous intervention of human settlement to natural land covers in Guwahati metropolitan area has revealed the failure of land use zoning and regulatory action. The metropolitan development authorities should have strict regulation in the green belt and eco sensitive areas of the city. Social forestry in the green belt areas, light colour surfaces in residential units, plantation in the roof of buildings and trees along by the roads, may be some countermeasures of the heat island effect in Guwahati.

The forest reserves within the city limits of Guwahati have declined with increase in urbanization. Almost 4287 ha of forest land use land cover have been lost to permanent habitation and cutting of hills since 1911. The forest footprint of the urban built up of Guwahati city has reached to more than 0.25. The impacts of forest depletion manifest in the form of increased flash floods in the city, landslides and air pollution which the city has been witnessing too often these days [41]. The situation could be mitigated by creating production forestry stands of high carbon sequestering varieties capable of sequestering 4-6 t eq C ha -1 yr- If such stands are created in the urban and peri-urban areas, the ecological footprint could be reduced considerably. Adopting efficient natural resource use and land use, waste recycling, efficient energy use, large scale afforestation and conservation of existing natural ecosystems in and around the city would ensure the city dwellers a better quality of life. By reducing the deficit in carbon emission and sequestration, the city of Guwahati could become an eco-city.

Copyright@SPA Bhopal

8. References

B Ostro, L. R. (2990). Estimating the mortality effect of the July 2006 California heat wave. In Environmental Research

Balling, R. (1992). The Heated Debate. Pacific Research Institute for Public Policy, San Fransisco, CA

Blankenstein, S. a. (2004). Impact of street geometry on downward longwave radiation and air temperature in an urban environment. Meteorologische Zeitschrift

Bretz, P. B. (1997). Preliminary survey of the solar reflectance of cool roofing materials. Energy and Buildings

Brovkin, V. (2002). Climate- vegetation interaction. Journal de Physique

C D Idso, S. I. (2001). An intensive two-week study of an urban CO2 dome in Phoenix, Arizon, USA. In Atmospheric Environment

Chandler, T. (1968). Urban climates. Proceedings of the Symposium on Urban Climates and Building Climatology

Cheng, L. L. (2009). Air quality influenced by urban heat island coupled with synoptic weather patterns. In Science of the Total Environment

Clarke, J. a. (1972). The effect of regio nal climate and land use on the nocturnal heat island. Conference on Urban Environment and Second Conference on Biometeorology

Comrie, A. (2000). Mapping a wind- modified urban heat island in Tucson, Arizona. Bulletin of the American Meteorological Society

Conservation and forest development in hilly/mountainous landscapes of India – Kiran Asher,Ph.D. CIFOR, Bogor, Indonesia

Copyright@SPA Bhopal

SPECIES AND PLANTING TECHNIQUE MODELS General Guidelines - Karnataka Forest Department

Reducing Urban Heat Islands: EPA Compendium of Strategies - Urban Heat Island Basics

Reducing Urban Heat Islands: EPA Compendium of Strategies Trees and Vegetation

Government of India, Central public works department, Delhi schedule of rates, analysis of rates and specifications (Horticulture & landscaping)

Handbook of Landscape, Central public works department

A Global Database of Field-observed Leaf Area Index in Woody Plant Species, 1932-2011 doi 10.3334_ORNLDAAC_1231, NASA

Tree canopy chart - Based on information from Virginia Nursery & Landscape Association, Inc., and "tree Canopy Spread and coverage in Urban Landscapes

A Study of Changing Urban Landscape and Heat Island Phenomenon in Guwahati Metropolitan Area - Monjit Borthakur and Bhrigu Kr. Nath

A Study of Urbanization and Ecosystem Services of Guwahati City from
Forest Footprint Perspective - Yadav R* and Barua - A Indian Institute of Technology Guwahati, Department of Humanties and Social Sciences, Guwahati 781039, Assam, India

Copyright@SPA Bhopal

Copyright@SPA Bhopal

Copyright@SPA Bhopal

Copyright@SPA Bhopal

Copyright@SPA Bhopal